CHARACTERIZATION OF ARSENIC BEARING ECAR SLUDGE AND ITS IMMOBILIZATION IN CONCRETE

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EXAMINATION ROLL NO: M4CIV1512
CLASS ROLL NO.: 001410402022
SESSION: 2015-2016

A Thesis Is Submitted For The Partial Fulfillment Of The Continuous Assessment Of The Course Of Master Of Civil Engineering Of Jadavpur University For The Session 2015-2016

UNDER THE GUIDANCE OF
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DECLARATION

This thesis titled "**Characterization of Arsenic Bearing ECAR Sludge and Its Immobilization in Concrete**" is prepared and submitted for the partial fulfillment of the continuous assessment of Master of Engineering in Environmental Engineering course of Jadavpur University for the session 2015-2016.

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RECOMMENDATION CERTIFICATE

It is hereby certified that this Thesis titled "**Characterization of Arsenic Bearing ECAR Sludge and Its Immobilization in Concrete**" is prepared and submitted for the partial fulfillment of the continuous assessment of **Master of Civil Engineering in Environmental Engineering** course of **Jadavpur University** by **Indranil Mookherjee**, a student of the said course for the session 2015-2016 under our super supervision and guidance. It is also declared that no part of thesis of said work has been presented or published elsewhere.

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This is to certify that this thesis is hereby approved as an original work conducted and presented satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is implied that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein, but approve the thesis only for the purpose for which it is submitted.

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ACKNOWLEDGEMENT

At the outset I would like to express my deep gratitude and kindest regards to Dr. Amit Dutta and Dr. Pritam Aitch for their invaluable and generous guidance rendered to me for the preparation of this Thesis report. This Thesis would have never been completed without their guidance, careful supervision and inspiration at all stages of the work.

I am sincerely thankful and indebted to Prof. S.N. Mukherjee, Dr. A. Debsarkar, Dr. T. Hazra, Prof. A.Gangopadhyay and Prof. S.K. Mukherjee for their constant encouragement and continuous valuable suggestions throughout my thesis work.

I would like to express my appreciation to Mr. Abhisek Roy, Senior Research Project Personnel, for his constant inspiration and kind supports during the work.

I sincerely acknowledge the help of Mr. Samrat Sengupta of Concrete Technology Laboratory of Civil Engineering Department, Jadavpur University.

I sincerely acknowledge the help of Mr. Robin Pal of Soil Mechanics and Foundation Engineering Laboratory of Civil Engineering Department, Jadavpur University.

I would like to thank Mr. Surajit Bhandari and Mr. Sanjib Paul, Project Staffs of Jadavpur University for their kind cooperation during the period for work.

Last, but not the least, I express my sincere gratitude to the Research Scholars of Environmental Engineering Division, Department of Civil Engineering, Jadavpur University; my classmates and my family for the encouragements and supports they provided throughout the work. This thesis would not have been possible without them.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1
Introduction

1.1Background

Water is a fundamental human need. Each person on the earth requires at least 20 to 50 litres of clean, safe water a day for drinking, cooking and for simply keeping themselves clean. Improving access to safe drinking water is a necessity and efforts should be made to achieve drinking water that is as safe as practicable. Water is indispensable for the endurance of human being on the earth. Improving access to safe drinking water can result in intangible benefits to health. In India, particularly in West Bengal, surface and subsurface water sources are utilized for drinking. Ground water use has become enormously high since 1980's solely because it is treated as safe for drinking. The welfare and development of a society are strongly dependent on a safe drinking water supply. In the 1970s and 80s, millions of tube wells accessing groundwater were installed in Bangladesh and India with the well-intentioned aim of improving the microbial quality of water supplies. Unfortunately groundwater of the Bengal delta is contaminated with naturally occurring Arsenic. Same problem has also occurred in perspective of Global scenario.

Arsenic is a chemical element with atomic number 33 and in the periodic table it is placed in group number 15 and period number 4. Arsenic is a ubiquitous element that ranks 20th in terms of abundance in the earth's crust, 14th in the seawater, and 12th in the human body. Since its isolation in 1250 A.D. by Albertus Magnus, this element has been a center of controversy in human history. It has been used in medicine. Not only medicine, it has been used in various fields i.e. agriculture, livestock, electronics, industry and metallurgy. It is now well recognized that consumption of arsenic, even at low levels, leads to carcinogenesis. It is considered as an exceptionally poisonous element. One of the important characteristics of Arsenic is that it is tasteless, odorless and colorless. From the chemical perspective it is metalloid. The element can be easily traced from the ores like Arsenopyrite ($FeAsS$), Realgar (AsS) and Orpiment (As_2S_3).

Arsenic is one of the most feared contaminants because of its high toxicity at small concentrations and ability to go undetected ***(Niemenski et al., 1995)***. Exposure to high levels of arsenic (As) can cause problems in humans ranging from gastrointestinal symptoms to arsenicosis, a chronic disease resulting from extended exposure to As, which occurs mainly via ingestion of water containing this metal. Once it is dissolved in water and ingested, arsenic accumulates in the body. Contamination of groundwater with arsenic is a major environmental and public health problem on a global scale. The World Health Organization (WHO) guideline for As in drinking water is 10 ppb (WHO, 2004). This limit also applies in the US (since January 2006), India, Taiwan, Vietnam, and Japan ***(Mondal et al., 2006; Mohan and Pittman, 2007)***. In Bangladesh, China, and most of Latin American countries the maximum contaminant level (MCL) is 50 ppb, while in Germany and Canada the limit is 25 ppb ***(Mondal et al., 2006)***. In Mexico, the MCL has been 25 ppb since 2005 ***(Swedlund et al., 1999)***.

Arsenic contamination of drinking water sources is estimated to affect over 144 million people around the world, spurring the development of numerous water treatment technologies to limit negative health impacts associated with exposure to arsenic contaminated water including skin lesions and cancers ***(Clancy et al., 2013)***. These technologies include ion exchange, adsorptive media filtration, coagulation and flocculation, electro-coagulation, and anaerobic removal with iron sulphides. It should be noted that in areas where alternative groundwater wells with low arsenic concentrations are available, well-switching can be an effective means to provide safe drinking water ***(Clancy et al., 2013)***. In areas where arsenic removal from groundwater is needed, drinking water treatment systems have been implemented in developed and developing countries, ranging in size from centralized treatment plants to smaller systems for individual households. In 1993, the World Health Organization (WHO) lowered the arsenic drinking water guideline from 50 to 10 μg/L ***(Clancy et al., 2013)***. Following this change, many countries adopted a more stringent drinking water standard for arsenic, expanding the need for incorporating arsenic removal technologies in drinking water treatment processes ***(Clancy et al., 2013)***.

Electro coagulation (EC) is a method of treating polluted water and wastewater for numerous contaminants, ***(Amrose et al., 2014)*** including arsenic. In EC using iron electrodes, electrolytic oxidation of a sacrificial iron anode produces hydrous ferric oxide (HFO; also called Fe [III] precipitates) in contaminated water. Contaminants form surface complexes on HFO, which then aggregate to form a floc that can be separated from water.

While several technologies of arsenic removal from water environment have been found to be successful, the safe disposal of the sludge arising out of its treatment still remains a challenging problem to be sorted out. Thus, finding a best practicable and cost effective technological solution to the aforesaid problem has become a dire necessity on the part of scientists and engineers, especially in a developing country like India.

Chapter 2
Arsenic in Ground Water

2.1 Arsenic in Ground Water: Occurrence and Concentrations

Groundwater of the Bengal delta is polluted with naturally occurring Arsenic. It has steadily affected people in the Bengal Basin. Triggered by the setting up of tube wells without watchful scientific investigation, arsenic dissolved into the drinking water. People did not realize that arsenic was present in the drinking water since it is colourless, tasteless and odourless.

Inorganic arsenic found in groundwater is in most cases of geological origin. Typical arsenic concentrations in groundwater are very low and in most cases below 10 μg/L. Elevated arsenic concentrations up to 5,000 μg/L are typically found in areas with active volcanism, geothermal waters, sedimentary rocks, and in soils with a high concentration of sulphides (e.g. Arsenopyrite). Arsenic can be also introduced into groundwater by mining activities. Arsenic is highly soluble and mobile in water.

WHO has set a guideline value of 10 parts per billion (ppb) (or 10 μg/L) for arsenic in drinking water. This guideline value is considered provisional, because of uncertainties about the health effects of low level exposure to arsenic, and the practical difficulties in measuring or removing arsenic to levels below 10 ppb water.

2.2 Arsenic Contamination in Ground Water- A Global Perspective

Arsenic in the drinking water of millions of people living in different parts of the world has been a focus of attention for public health scientists and engineers ***(Ng et al., 2003; Bhattacharya et al., 2007)***. The Arsenic crisis prevailing in the Gangetic delta extending over a large area of Bangladesh and India is arguably one of the worst calamities of the world in recent times. The crisis is slowly unfolding in Southeast Asia also, affecting several countries including Cambodia, Vietnam, Laos, Myanmar, etc. ***(Berg et al., 2001)***. The use of groundwater in these regions is favored by its easy availability, microbial safety and absence of proper infrastructure for treatment and distribution of surface water. Surface water is often contaminated due to the absence of proper sanitation practice. With growing populations and agricultural demand, excessive groundwater withdrawals have resulted in the dissolution of Arsenic due to the geochemical weathering of minerals within the aquifer. The consequence of drinking Arsenic contaminated water over a long period of time causes severe damages to the human body and often becomes fatal. While the best solution to the problem is to switch over to treated surface water which does not have any Arsenic contamination, development and maintenance of surface water based drinking water system is expensive, time-consuming and investment-intensive.

Table 2.1: Arsenic Contamination of Water from Different Parts of the World
(Mukherjee et al., 2006)

LOCATION	COUNTRY	SOURCE
Ghazni	Afghanistan	Natural
Cordoba, Salta, La Pampa, Santa Fe, Tucuman, Santiago del Estero, san Luis, and parts of Buenos Aires	Argentina	Natural
Victoria gold-mining region	Australia	Anthropogenic
16-18 of 64 districts	Bangladesh	Natural
Minas Gerais in south-eastern Brazil	Brazil	Anthropogenic
Srednogorie	Bulgaria	Anthropogenic
Halifax county of Nova Scoti; mainland coast of southern British Columbia, and Toronto, Ontario	Canada	Natural and anthropogenic
LowerMekongBasin	Cambodia	Natural
Antofagasta, Aracamenan settlements near Calama, and Chquicamata copper mine	Chile	Natural and anthropogenic
Xinjiang, Inner Mongolia, Shanxi, Tianshan mountainous district, Guizhou, Ningxia, Jilin, Qinghai, Anhui, certain suburbs of Beijing, Xingren county; and southern Yunan province	China	Natural and anthropogenic
-	Czech Republic	Anthropogenic
Cairo	Egypt	Natural
-	Finland	Natural
-	Germany	Anthropogenic
Obuasi area in the Ashanti region and Bolgatanga area of the Upper East region	Ghana	Natural
Lavrion	Greece	Natural
Southern part of the Great Hungarian Plain	Hungary	Natural
West Bengal, Bihar, Uttar Pradesh, Jharkhand,	**India**	**Natural and anthropogenic**
Kurdistan province	Iran	Natural
Sendai, Tkasuki, Kuamoto, Nakajo, Toroku, and Matsuo	Japan	Natural and anthropogenic
Lagunera region, State of Hidago, Torreon city, Silesia, and San Luis de Potosi	Mexico	Natural and anthropogenic
Ayeyarwady division	Myanmar	Natural
Terai region and Rupandehi district	Nepal	Natural
	New Zealand	Natural
Rawalpindi, Attock, Gujarat, Jhelum, Sargodha, and Chakwal	Pakistan	Natural
Northwestern parts of Transylvania	Romania	Natural
	Sri Lanka	Natural

	Spain	Natural
Northern Sweden	Sweden	Anthropogenic
Ticino, Grisons, and Valais cantons	Switzerland	Natural
South-West coast of Taiwan	China	Natural
Ronpibool district	Thailand	Anthropogenic
Utah, Oregon, California, Nevada, New Hampshire, Alaska, and Minnesota	USA	Natural and anthropogenic
South-West England, and Central Scotland	United Kingdom	Anthropogenic

2.3 Arsenic Contamination of Groundwater: Indian Scenario

The occurrence of high Arsenic in ground water was first reported in 1978 in West Bengal in India. In West Bengal, 79 blocks in 8 districts have Arsenic beyond the permissible limit of .05 mg/l. The most affected areas are on the eastern side of Bhagirathi River in the districts of Malda, Murshidabad, Nadia, North 24 Parganas and South 24 Parganas and western side of the districts of Howrah, Hugli and Bardhman. Arsenic in ground water is confined mainly in the aquifers up to 100 m depth. The deeper aquifers are free from Arsenic contamination. As of 2009 about 162.6 lakh people (35.48% of the total population of the state) live in the risk zone of potential threat in terms of Arsenic related diseases. Arsenic groundwater contamination in Bihar was initially detected in the year 2002 from Semariya-Ojhapatti villages of Bhojpur district. Detailed investigations in the Gangetic Plain of Bihar revealed its wide occurrence on both the banks of the river Ganga. The other parts of the country having Arsenic infested ground water include parts of U.P, Chhattisgarh, Jharkhand, Assam & Manipur. ***(Kunar et al., 2009)***

2.4 Arsenic Contamination of Groundwater: Bangladesh's Scenario

In Bangladesh, arsenic contamination of water in tube-wells was confirmed in 1993 in the Nawabganj district. In 1998, a British Geological Survey of 41 districts collected 2022 water samples — 35% were found to have arsenic concentrations above 50 mg/l and 8.4% were above 300 mg/l. Based on population density measured in 1998, this group estimated that the number of people exposed to arsenic concentrations above 50 mg/l, which is the permissible limit of Arsenic in drinking water in the country, was about 21 million. ***(Smith et al., 2000)***

Chapter 3

Arsenic-Its Sources, Remediation and Management

3.1. General Chemistry of Arsenic

Arsenic is a common, naturally occurring drinking water contaminant that originates from Arsenic-containing rocks ***(Clancy et al., 2013)*** and soil and is transported to natural waters through erosion and dissolution. Arsenic occurs in natural waters in both organic and inorganic forms. However, inorganic Arsenic is predominant in natural waters and is the most likely form of Arsenic to exist at concentrations that cause regulatory concern.

The valence and species of inorganic Arsenic are dependent on the oxidation-reduction conditions and the pH of the water. As a general rule of thumb, the reduced, trivalent from [As(III)] normally is found in ground water (assuming anaerobic conditions) and the oxidized, penta valent form [As(V)] is found in surface water (assuming aerobic conditions), although this rule does not always hold true for ground water, where both forms have been found together in the same water source.

3.2. Different Forms of Arsenic

Arsenic (As) exists in several forms, which vary in toxicity and occurrence. The metallic form of Arsenic (zero valency) is not absorbed by the stomach and intestines and does not exert adverse effects. On the other hand, a volatile compound such as AsH_3 is toxic, but is not present in water or food. Moreover, the primary organic forms (arsenobetanine and arsenocholine) found in fish and shellfish seem to have little or no toxicity. Arsenobetanine quickly passes out of the body through urine without being metabolized to other compounds. Arsenite (+3) and arsenate (+5) are the most prevalent toxic forms of inorganic Arsenic that are found in drinking water. Arsenite As (+3) in reduced state in inorganic is a toxic pollutant in natural environment and is more soluble and mobile than the oxidised state of inorganic Arsenic, arsenate As (+5).

3.3. Sources of Drinking Water Arsenic

Rural India has more than 700 million people residing in about 1.42 million habitations spread over 15 diverse ecological regions. Meeting the drinking water needs of such a large population can be a daunting task. The non-uniformity in level of awareness, socio-economic development, education, poverty, practices and rituals and water availability add to the complexity of the task.

Source of drinking water can be divided into ground water and surface water.

Ground water:

Dug well: It is the vertical pit of 1-5m depth for ground water accumulation and the traditional system for ground water collection.

Tube well: It is a type of water well in which a long 100-200 mm (5-8 inch) wide stainless steel tube or pipe is bored into an underground aquifer.

Tap water: Water supply purified in public water treatment plants. Groundwater is usually submitted to iron removal and disinfection, but not yet to Arsenic removal, although the iron removal process can also lower Arsenic levels.

Surface water:

Water body: It may be an important source of drinking water in remote areas.

Rain water: Rainwater runoff collected from the house roofs and stored in large tanks. This water is free of iron and Arsenic, is collected to cover the drinking water requirements of a family during rainy seasons.

3.4 Mechanism of Arsenic Release in Ground Water

Arsenic in released in ground water by the following three mechanisms:

Reductive dissolution: it occurs when iron oxide, in which Arsenic is absorbed, breaks down under the influence of decaying organic matter and dissolves.

Alkali Desorption: Mainly occurs at higher pH (≥8.0) and in the process of dissolved oxygen, nitrate or sulphate, producing waters which can be termed 'alkali-oxic' and which have low concentrations of iron and manganese.

Sulphide Oxidation: It takes place when sulphide minerals, such as pyrite or arsenopyrite are exposed to oxygen- often at the water table to produce water that are typically both acid and sulphate-rich, but not necessarily high in iron.

3.5. Effects of Arsenic on Humans

A. Respiratory Effects

Effects of arsenic on the human respiratory system have been reported both from occupational exposure as well as from tube well water arsenic toxicity. Humans exposed to arsenic dust or fume inhalation are more opt to be encountered in mining and milling of ores, in industrial processing, such as smelting industry which often produces irritation of the mucous membrane, resulting in laryngitis, bronchitis, rhinitis and trachea bronchitis, causing stuffy nose, sore throat, hoarseness and chronic cough etc. Chronic asthmatic bronchitis and asthma is a common complication of ground water arsenic toxicity.

B. Cardiovascular Effects

It has been suggested by several epidemiological studies that chronic inhalation of arsenic trioxide can increase the risk of death in humans from cardiovascular disease. Long term inhalation of inorganic arsenic could injure the blood vessels or the heart. Arsenic ingestion through food or water may have serious effects on the human cardiovascular system. Low level arsenic exposure by humans may also cause vascular system damage, a classical example of which is Blackfoot disease.

C. Gastrointestinal Effects

Gastrointestinal symptoms are common in acute poisoning but not in chronic like groundwater arsenicosis. Workers exposed to high levels of arsenic dusts or fumes suffer from nausea, vomiting and diarrhoea. Clinical signs of gastrointestinal irritation from acute arsenic poisoning include burning lips, painful swallowing, thirst, nausea and several abdominal colic pains. The efficiency of absorption or inorganic arsenicals from the gastrointestinal tract is related to their water-solubility.

D. Haematological Effects

The haematopoietic system is also affected by both short-and long-term arsenic exposures. Anaemia and leucopoenia are common effects of poisoning and have been reported as resulting from acute, intermediate, and chronic oral exposures. Relatively high doses of arsenic have been reported to cause bone marrow depression in humans.

E. Hepatic Effects

Arsenic was the first chemical agent to which liver disease was attributed in humans. Since the liver tends to accumulate arsenic with repeated exposures, hepatic involvement has been reported most commonly as a complication of chronic exposures over periods of months or years.

F. Renal Effects

Like the liver, the kidneys will accumulate arsenic in the presence of repeated exposures. The kidneys are the major route of arsenic excretion, as well as major site of conversion of penta valent arsenic into the more toxic and less soluble trivalent arsenic. Sites of arsenic damage in the kidney include capillaries, tubules, and glomeruli.

G. Dermal Effects

Skin disorders have been documented in several epidemiological studies in which people consumed drinking water that contained arsenic of levels of 0.01 to 0.1 mg As/kg/day or more. Characteristic effects of arsenic ingestion included generalized hyperkeratosis, warts or corns on the palms and soles, and areas of hyper-pigmentation interspersed with small areas of hypo pigmentation on the face, neck, and back.

H. Neurological Effects

Several studies have indicated that ingestion of inorganic arsenic can result in neural injury. Like the cardiovascular system, both the peripheral and central components of the nervous system can be damaged by arsenic.

I. Developmental Effects

It is not well established whether ingestion of inorganic arsenic can cause developmental abnormalities in humans. In chronic arsenicosis from ground water, no development defect has been experienced till now.

J. Mutagenic Effects

Mutagenesis includes the induction of DNA damage and a wide variety of genetic alterations, which can range from simple gene mutations. Some of these changes may cause genetic damage transmissible to subsequent generations, and/or some may cause cancer or their problems in the exposed generation. Arsenic has long been known to cause chromosomal damage, but most investigators have been unable to induce direct gene mutation. This apparent pardon plus occasional poor correlation between arsenic exposure dose and resultant frequency of chromosomal aberrations have been explained by the concept that arsenic promotes genetic damage in large part by inhibiting DNA repair. Comparisons of chromosome aberration frequencies induced by trivalent and penta valent arsenic have indicated that the trivalent forms are far more potent and genotoxic than the penta valent forms.

K. Carcinogenic Effect

Introduction of cancer appears to be the most striking long-term effect of chronic expose to inorganic arsenic. Epidemiological studies have demonstrated an evident causal relationship between environmental, Occupational, and medical exposure of man to inorganic arsenic and cancer of the skin and lungs. Most animal experiments, however, were not able to demonstrate carcinogenicity, except for very few observations of increased incidence of leukaemia and lung cancer. There exist a clear association between skin cancer and to some extent, lung cancer and exposure of humans to water-soluble inorganic arsenic through drinking water with high natural arsenic content. Epidemiological studies in Argentina, Chile, Canada, and Taiwan Suggest correlations between drinking water that contains arsenic and black foot disease, Bowen’s disease and skin cancer.

L. Cancer of the Respiratory System

An excess of deaths due to respiratory cancer has been observed among workers exposed to inorganic arsenic in the production and use of pesticides (spray) in gold mining, in the smelting of nonferrous metals, especially copper. An increase of lung cancer with increasing duration of exposure to arsenic compounds was observed but not with non-arsenic products.

M. Cancer of the Skin

Skin cancer has been associated with inorganic arsenic exposure. The exposure occurred most frequent via the oral route, either through contaminated drinking water or medication.

N. Biochemical Effects

Arsenical compounds are known to inhibit a number of important enzymes in both animals and humans. Arsenite is rapidly and extensively accumulated in the liver.

3.6 Technologies for Arsenic Removal

Today, removal technologies implemented at community level are well-developed but often expensive. Therefore, the focus of research has been based on the development of cheap and easy-to-handle removal technologies especially for decentralized use in rural areas in developing countries. It is reported that the commonly used technologies in these countries are oxidation, coagulation-precipitation, and adsorption to activated carbon, activated alumina, and iron oxide coated materials.

The implementation model allows for a much wider array of technologies to be viable than a household filter model. Specifically, an electricity-based technology could be viable if the treatment costs were low enough to offset the maintenance, operation, and capital costs of a small scale electricity source such as Photovoltaic (PV) or battery packs.

All of the technologies for arsenic removal rely on a few basic chemical processes, which are summarized below:

- **Oxidation/Reduction:** Reactions that reduce (add electrons to) or oxidize (remove electrons from) chemicals, altering their chemical form. These reactions do not remove arsenic from solution, but are often used to optimize other processes.

- **Precipitation:** Causing dissolved arsenic to form a low-solubility solid mineral, such as calcium arsenate. This solid can then be removed through sedimentation and filtration.
When coagulants are added and form flocs, other dissolved compounds such as arsenic can become insoluble and form solids, this is known as co-precipitation. The solids formed may remain suspended, and require removal through solid/liquid separation processes, typically coagulation and filtration.

- **Adsorption and Ion Exchange:** Various solid materials, including iron and aluminium hydroxide flocs, have a strong affinity for dissolved arsenic. Arsenic is strongly attracted to sorption sites on the surfaces of these solids, and is effectively removed from solution. Ion exchange can be considered as a special form of adsorption, though it is often considered separately. Ion exchange involves the reversible displacement of an ion adsorbed onto a solid surface by a dissolved ion. Other forms of adsorption involve stronger bonds, and are less easily reversed.

- **Solid/Liquid Separation:** precipitation, co-precipitation, adsorption, and ion exchange all transfer the contaminant from the dissolved to a solid phase. In some cases the solid is large and fixed (e.g. grains of ion exchange resin), and no solid/liquid separation is required. If the solids are formed in situ (through precipitation or coagulation) they must be separated from the water. Gravity settling (also called sedimentation) can accomplish some of this, but filtration is more effective. Most commonly, sand filters are used for this purpose.

- **Physical Exclusion:** some synthetic membranes are permeable to certain dissolved compounds but exclude others. These membranes can act as a molecular filter to remove dissolved arsenic, along with many other dissolved and particulate compounds.

- **Biological Removal Processes:** bacteria can play an important role in catalysing many of the above processes. Relatively little is known about the potential for biological removal of arsenic from water.

Most of the established technologies for arsenic removal make use of several of these processes, either at the same time or in sequence. All of the removal technologies have the added benefit of removing other undesirable compounds along with arsenic – depending on the technology, bacteria, turbidity, colour, odour, hardness, phosphate, fluoride, nitrate, iron, manganese, and other metals can be removed.

3.7 Electro Chemical Arsenic Remediation (ECAR)

3.7.1 Introduction

In light of the repeated problems with the continuing prevalence of arsenic in drinking water in Bangladesh, researchers at Lawrence Berkeley National Laboratory have recognized the need to be innovative in both technology and implementation. This interdisciplinary approach has led to the development of an efficient, effective, and low cost electricity-based technology known as Electro Chemical Arsenic Remediation (ECAR) for rural Bangladesh. This technology has a number of advantages over chemical adsorbents along with some additional challenges, such as the need for electricity. Electricity-based technologies are less appropriate for household filters in rural areas with limited electricity access. However, when partnered with an appropriate community scale implementation scheme, electricity-based technologies such as ECAR can be viable and beneficial to rural areas. ***(Addy et al., 2009)***

In Electro Chemical Arsenic Remediation (ECAR), electricity is used to continuously dissolve iron, forming a combination of corrosion products such as ferric hydroxides, oxy hydroxides, and oxides (i.e. rust). These products together form an electrochemically-generated adsorbent, or EGA, with a high affinity for arsenic. EGA is manufactured at the time of use, eliminating the need for a costly supply chain. In addition, electrochemical processes greatly enhance the arsenic removal capacity (i.e. arsenic removed per unit iron input) of ECAR relative to the chemical addition of ferric salts or metallic iron. This is due to (i) an increase in the rate of rust production (by factors of 10 to 100 over natural rust ingrate of metallic iron), and (ii) the rapid electrochemical oxidation of As(III) to the more favourable As(V),which binds much more readily to iron-based adsorbents. Thus employing a small amount of electricity allows for a large increase in efficiency, lower operating costs and production of far less arsenic-laden waste than most chemical adsorbents. In addition, the electrodes are self-cleaning if current is alternated, reducing maintenance and eliminating the need to handle strong alkalis and corrosive acids for regeneration (required of activated alumina and other regenerative adsorbents). ***(Addy et al., 2009)***

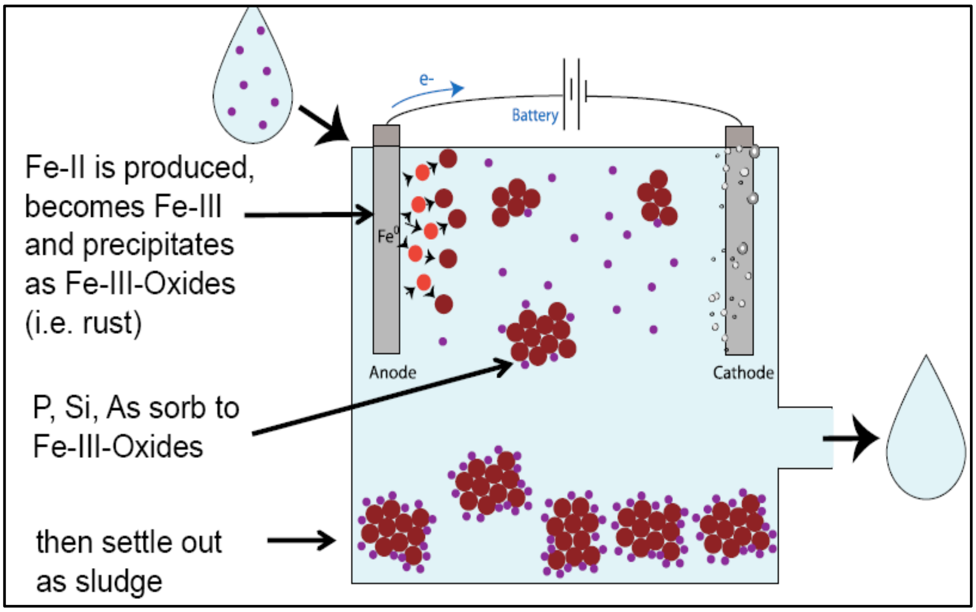

Figure 3.1 - Working of ECAR

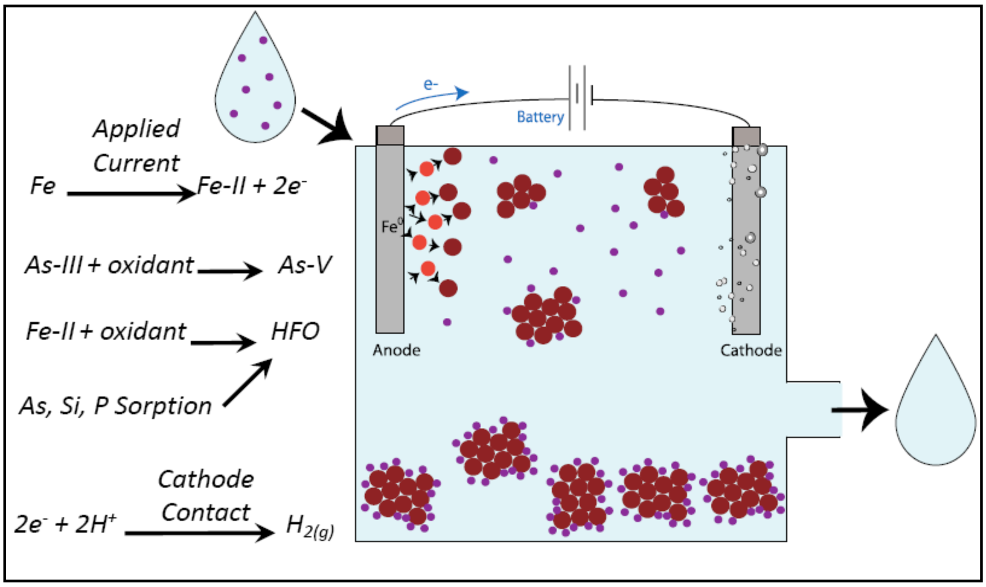

Figure 3.2 – Processes Involved in ECAR

3.7.2 Operating Parameters in ECAR

ECAR treatment is controlled by several operating parameters that could potentially be tuned to local water conditions to maximize Arsenic removal capacity. These parameters include current density and charge density. The parameters controlling ECAR treatment include the current density, j (mA/cm²), the charge density, q (C/L), and the duration of post-electrolysis mixing, t_M. Other parameters include the duration of filtration, t_{filt} and the current processing time, t_{CP} . t_{filt} is set by the filtration method and t_{CP} is determined by j and q according to the following:

$$\boldsymbol{t_{CP}} = \frac{\boldsymbol{q}}{\boldsymbol{j}(\frac{\boldsymbol{A}}{\boldsymbol{V}})}$$

Where,
t_{CP} is the current processing time,
q is the charge density,
j is the current density, and
A/V is the ratio of electrode surface area to treatment volume.

Each of the controlling parameters influences Arsenic removal in different, but intertwined ways ***(Addy et al., 2009)***.

3.7.3 Sludge Generation from ECAR

All arsenic removal technologies produce arsenic-laden sludge or waste that must be disposed of properly. In the 600L prototype model installed at the Division of Environmental

Engineering, Department of Civil Engineering, Jadavpur University, the following parameters are maintained:

i) Charge Density (q) = 440-500 C/L
ii) Current Density (j) = 0.704-0.800 mA/cm^2
iii) Current Processing Time (t_{cp}) = 100 min

The arsenic bearing sludge produced from this reactor had been used in this study.

3.7.4 Advantages of ECAR technology

ECAR has been successfully lab tested and undergone a promising first round of field trials. It was found to be highly effective (final arsenic concentrations routinely reaching < 5 μg/L), robust, require little maintenance, and produce small quantities of sludge that can be successfully stabilized. These qualities combined with an extremely low operating cost make ECAR a promising candidate technology to operate in community scale micro utilities offering clean water at a locally affordable price. In addition, ECAR does not need an adsorbent to be imported, manufactured, or regenerated. This reduces large upfront capital investment and the need to set up and maintain chemical supply chains or handle hazardous chemicals, making the technology amenable to rapid scale-up.

3.8 Stabilization of Arsenic Laden ECAR Sludge

Sustainable development is concerned with ensuring that design is made with the intention of avoiding unnecessary social, economic or environmental loss that will have consequences for future generations. In this respect methods of As waste disposal must be effective and reliable or the problem will not be dealt with in the long-term and water supplies may become unsustainable. Disposal of any hazardous waste requires effective management, so wherever As waste is generated there is a need to establish a well-defined protocol for the disposal of the As sludge ***(Mudgal, 2001)***.

Incorporation of As sludge into construction materials is common in urban areas of Bangladesh and India. Typical products include cement blocks and cement plinths for latrines. ***Sanchez et al. (2000)*** conducted experiments to show how drying and carbonation can influence the release of inorganic from cement based materials during cyclic wetting and storage. Carbonation, occurring during periods of storage, was seen to reduce the release of hydroxide whilst releasing carbonate into solution.

Sludge has also been mixed with clay for bricks or cement to produce construction blocks for housing. The structural integrity and leaching of As from clay bricks made using As removal waste with high Fe content have been investigated by ***Rouf and Hossain (2003)***. It was concluded that the firing temperature is a key factor that determines the quality of the bricks and As leaching characteristics. In addition significant health issues are also related to the amount of As containing dust generated during manufacture and construction.

When arsenic is co-precipitated with iron hydroxide in an arsenic-removal water plant, a large quantity of sludge is generated which contains a good amount (an average of 6.1 kg As/m^3 of sludge) ***(Banerjee & Chakraborty, 2005)*** of arsenic. The main objective is the, attempts to find some suitable solutions to disposal of this arsenic-bearing sludge. As a safe means of disposal, stabilization processes such as briquette production, cement mortar and concrete making have been attempted in the present investigation. It has been found that in the preparation of briquette, cement–sand mortar and concrete, mixing up to 10, 18 and 40%) ***(Banerjee & Chakraborty, 2005)*** of arsenic-bearing sludge by volume, respectively with the other common ingredients did not produce a TCLP leachate beyond its permissible direct inland water discharge standards of 0.2 g/m^3 as stipulated by the Ministry of Environment & Forest, Government of India. Also, it was noted that 25% (by volume) of cement could be replaced by fly ash to stabilize arsenic-laden sludge to the tune of 11% by volume of cement–sand (1: 3) mortar ***(Banerjee & Chakraborty, 2005)***.

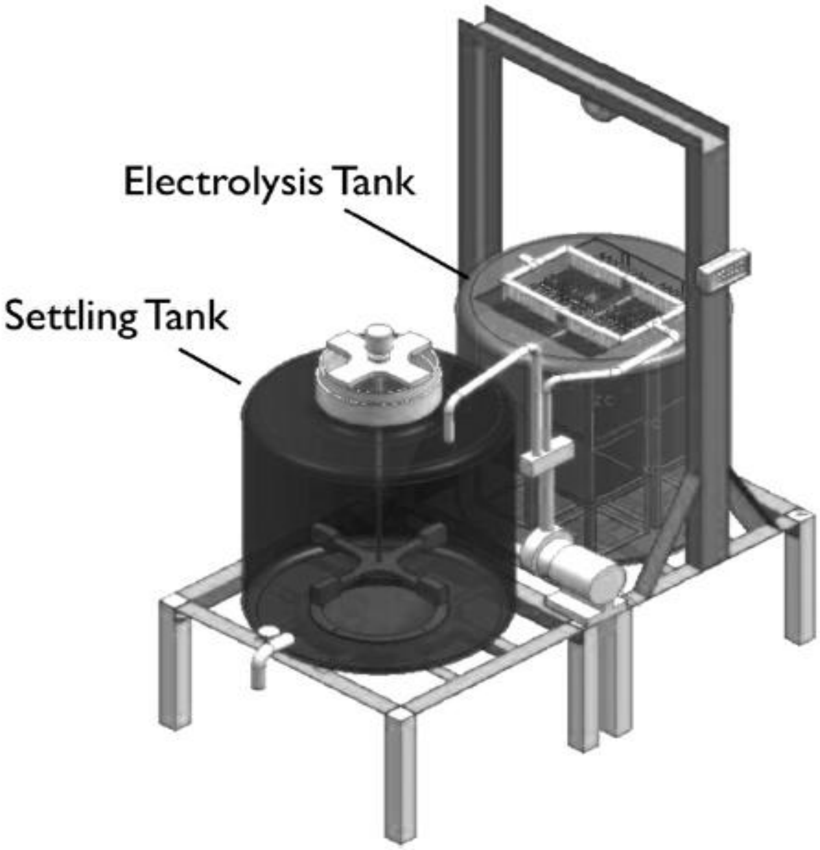

Figure 3.3 Schematic Sketch of the 600 L ECAR Reactor Assembly

Chapter 4
Review of Literature

- In a study by ***Hasan et al., 2014***, attempts were made to use the arsenic–iron sludge in making bricks and to analyse the corresponding effects on brick properties. The water treatment plant sludge is extremely close to brick clay in chemical composition. So, the sludge could be a potential substitute for brick clay. This study involved the addition of sludge with ratios 3%, 6%, 9% and 12% of the total weight of sludge–clay mixture. The physical and chemical properties of the produced bricks were then determined and evaluated and compared to control brick made entirely from clay. Results of different tests indicated that the sludge proportion and firing temperature were the two key factors in determining the quality of bricks.

  The arsenic–iron sludge waste used for this study was collected from arsenic–iron removal plant (AIRP) at Manikganj in Bangladesh. The collected sludge samples were brought to laboratory and oven dried for 24 h at 105 °C. Then, the sludge sample and collected brick clay were crushed and sieved. After drying and crushing, the moisture content, arsenic and iron content of the sludge were determined in the laboratory. For the manufacture of bricks, a specific dimension of mould was utilized. In this study, the specific dimension of brick was 250 mm x 125 mm x 75 mm. A total of 4 brick samples for each sludge–clay mixture proportion of 3%, 6%, 9% and 12% were prepared in the laboratory. For the preparation of bricks, the sludge–clay mixture was placed into the mould and then compacted well to get the desired strength. Drying and burning of the brick sample was done in three stages. At first, the sample was oven dried at a temperature of 105 °C for 2 days. Secondly, the oven dried brick was burnt into a laboratory furnace at 500 °C for 12 h. Finally, the temperature was increased to about 1000 °C and in this stage the sample was burnt for 12 h. The prepared bricks were then taken to laboratory for the determination of various physical and chemical properties. Various laboratory tests such as moisture content, specific gravity, water absorption capacity and compressive strength of bricks were performed to investigate the physical properties of the prepared sludge–clay bricks. In this study, leaching characteristics of sludge–clay bricks were investigated with the variation in sludge concentration and pH at a constant temperature.

  This study found that the arsenic and iron content of the sludge sample were very high (arsenic 0.5 mg/L and iron 7.5 mg/L). The sludge had a pH value of 6.5, indicating that the sludge can be treated as neutral material.

  The Leachability Results were as follows:

Table 4.1: Leachability Results of TCLP Carried out on Samples
(Hasan et al., 2014)

	Time	Proportion of sludge in bricks (%)				Standard Limits (mg/l) (Drinking Purpose)	
		3 %	6 %	9 %	12 %	Bangladesh	WHO
Amount of Arsenic Leaching (mg/L)	24 hrs	0.001	0.001	0.025	0.025	0.05 mg/L	0.01mg/L
	72 hrs	0.025	0.025	0.075	0.100		
	120 hrs	0.050	0.050	0.100	0.250		
	168 hrs	0.025	0.075	0.250	0.500		
	216 hrs	0.025	0.075	0.500	0.500		
Amount of Iron Leaching (mg/L)	24 hrs	0.177	0.175	0.218	0.280	0.3-1.0 mg/L	0.3 mg/L
	72 hrs	0.000	0.355	0.315	0.384		
	120 hrs	0.000	0.025	0.183	0.284		
	168 hrs	0.000	0.190	0.177	0.159		
	216 hrs	0.000	0.080	0.127	0.082		

The results of leaching tests at acidic medium indicate that leaching of arsenic and iron from burnt bricks increases with the increase in sludge proportion. In alkaline medium, the leached arsenic and iron contents from burnt brick samples were found to be within the allowable limit at the initial time period. In case of arsenic, rate of leaching increases as time passes and finally it exceeded the allowable limit. It was observed that in alkaline medium the rate of leaching was remarkably less than that in acidic medium.

Based on the laboratory test results of this study, it can be concluded that arsenic-laden sludge could be effectively used as a component of raw materials for brick making. The optimum amount of sludge that could be mixed with clay to produce good bonding of clay–sludge bricks was found to be 6% (safely maximum) by weight. Furthermore, the amount of leaching in 6% sludge content brick was less in comparison to higher sludge-mix bricks. Thus, the arsenic–iron sludge from the groundwater treatment plant would be cautiously blended with clay materials for brick manufacturing and hence be recycled as construction materials.

Remarks: In this study instead of bricks, the iron based arsenic bearing sludge had been embedded in concrete cubes of size 100mm×100mm×100mm and the effect of this mixing of sludge on the compressive strength of concrete and also on its workability had been observed. Leaching test had also been done with this concrete cubes. Moreover the sludge to be mixed had been characterized in terms of pertinent physical and chemical parameters.

- A study conducted by ***Shafiquzzaman et al., (2010)*** examines the arsenic (As) leaching from iron rich sludge. The sludge samples were taken from laboratory scale Arsenic removal columns and were tested by sequential extraction procedure, toxicity characteristic leaching procedure (TCLP) and pH leaching test. The sludge samples were observed to have 1270 mg/kg, 705 mg/kg and 313 mg/kg of As for three samples, respectively. About 50–60% of the total As in the sludge was strongly bound with amorphous iron hydroxides. TCLP extraction results showed that concentrations of As leached were below the TCLP limit. At high alkaline conditions (pH 11) the dissolved As concentrations were as much as 35–45 times higher than at lower pH (pH 3) indicating that strongly bounded As would be released in the environment at high alkaline and low redox conditions. These laboratory experiments suggested maintaining non-alkaline and high redox conditions for minimum As solubility and mobilization from the sludge.

  Remarks: In this study, the arsenic leaching had been studied after the iron based arsenic bearing sludge had been embedded in concrete. The TCLP had been performed on this sludge mixed concrete after the concrete cube had been pulverized to three size ranges viz. (i) <9.5mm; (ii) <1mm and (iii) 5-50 mm.

- Stabilisation/solidification (S/S) includes a range of processes that are normally used as a pre-landfill waste treatment technology that aim to make hazardous wastes safe for disposal. The process involves mixing the waste, either in the form of sludge, liquid or solid, into a cementitious binder system. S/S is most suitable for treating wastes that are predominantly inorganic, as these are considered more compatible with the cementitious binders used. However, a wide range of wastes, including many mixed inorganic/organic materials have been treated using S/S technologies. The aim is to encapsulate and incorporate the waste into the binder system, and produce a monolithic solid with improved structural integrity that exhibits long-term stability and minimal leaching ***(Sullivan et al., 2010)***.

- Recently in another study by ***Banerjee and Chakraborty, 2005***, concrete cubes were made in which the arsenic-bearing sludge was mixed in different proportions, (0.001, 0.01, 0.05, 10, 25, 40 and 50% by volume of total mixed slurry) with the concrete ingredients, i.e., cement, sand and stone chips and the mixture was used to prepare concrete cubes of standard dimension, i.e., 150x150x150 mm. After curing the cubes for 14–21 days, the compressive strength of the cubes was tested to check the influence of arsenic sludge on the concrete strength. Subsequent to the crushing of the cubes, leachate was generated and tested 28 by the TCLP procedure (USEPA 1986), during this part of the experimentation, a blank cube sample was also prepared without adding any arsenic sludge. For curing, the cubes were immersed for 28 days in a small vat, and at the end of curing, the water in the vat was also tested for arsenic to check leaching of any arsenic from the cubes during curing. The details of the concrete cube preparation are number of cubes: 5; size of each cube: 150x150x150 mm; weight of each cube: 8.10 kg; concrete grade: 1:2:4 (1 cement: 2 sand: 4 stone chips 20 mm down); period of curing: 28 days.

The TCLP test for generation of leachate was carried out as outlined in USEPA. In this method, the stabilized material was crushed to a particular size smaller than 9.5 mm.

Remarks: In this study the dried arsenic bearing sludge had been mixed with the concrete ingredients in different proportions by weight of cement (0%, 5%, 10%, 12.5%, 15%, 20%, 25%, 30%, 32.5%, 35%, 37.5%, 40%, 60%, 80% and 100%) and that amount of sludge had been added by replacing equivalent amount of sand. The compressive strength at the end of both 7 days and 28 days curing had been measured. The workability of the freshly prepared concrete mix had been also measured. For leaching of arsenic, TCLP had been performed on both the 7 days and 28 days cured cubes. The TCLP had been performed on this sludge mixed concrete after the concrete cube had been pulverized to three size ranges viz. (i) <9.5mm; (ii) <1mm and (iii) 5-50 mm.

- ***Rouf and Hossain (2003)*** conducted a study on using arsenic iron sludge as raw material for manufacturing bricks. Leaching of arsenic from brick manufactured from arsenic and iron sludge has been investigated in this study. TCLP result shows that leached metal concentrations are far below the regulated TCLP limits and the quantities of metal leached from sludge are less than those from dried sludge. The results of Atterberg limits tests of moulded sludge-clay mixtures indicated that both plastic index and dry shrinkage decrease with an increasing amount of sludge in the mixture. Results of tests indicated that the sludge proportion and firing temperature were the two key factors determining the quality of brick. Increasing the firing temperature and decreasing the amount of sludge in the brick resulted in a decrease of water absorption. The appropriate percentage of sludge content for producing quality bricks was in the range of 15 to 25% by weight with a 15 to 18% optimum moisture content prepared in the moulded mixture and firing at 1000°C for 6 hours. This study showed that arsenic and iron sludge could be used as brick material.

  Remarks: In this study, the arsenic leaching had been studied after the iron based arsenic bearing sludge had been embedded in concrete. The TCLP had been performed on this sludge mixed concrete after the concrete cube had been pulverized to three size ranges viz. (i) <9.5mm; (ii) <1mm and (iii) 5-50 mm.

- ***Dutre and Vandecasteele (1998)*** studied arsenical waste stabilization using cement and lime. The material under study was waste fly ash from a metallurgical industry, which contained toxic element arsenic in high concentration, ranging from 23 to 47% (by weight). Besides arsenic, antimony and lead were also present in the waste material. The waste was solidified with cement and pozzolanic materials in order to reduce the leachability of the contaminants of the waste. This solidification lowered the arsenic concentration in the leachate (evaluated using extraction test DIN 38 414 s4) ***(Chu et al., 1991)*** from 5 kg/m^3 to 5 gm/m^3. It was shown that the enormous reduction of arsenic concentration was owing to the formation of calcium bi-arsenate ($CaHAsO_3$), which possesses a binding/cementing property, in the presence of $Ca(OH)_2$.

- In another study by ***Vondruska et al., (1998)***, a laboratory procedure was developed and verified for neutralizing (detoxifying) highly toxic ash from incinerators that contain extreme quantities of soluble hexa valent chromium (Cr^{+6}) by means of stabilization-cum-solidification with the help of an asphalt binder. The volume of processed waste noticeably shrunk on stabilization. The mechanism of stabilization, by virtue of its fixation/ immobilization into the binder, consisted in creating a perfect impermeable barrier against leaching on exposure to water.

- In another study by ***Vipulanandan and Wang (1998)*** on Cr^{+6} contaminated soil, the soil samples were treated with cement in the presence as well as absence of the reducing agent ferrous chloride ($FeCl_2$). The cement to soil ratio was varied from 0.2 to 1. Subsequently, the treated soil was cured for 28 days before testing its strength. Contamination to the tune of 500 mg of $K_2Cr_2O_7$ per kg of soil could effectively be treated with cement (cement to soil ratio of 0.2) to meet the toxicity characteristics leaching procedure (TCLP) limit of 5 g/m^3. Any further increase of cement to soil ratio reduced the leaching of chromium and also improved the compressive strength. However, similar treatment was not successful with a Cr^{+6} contaminations of 25 gm $K_2Cr_2O_7$/kg of soil. Addition of ferrous chloride ($FeCl_2$) as an additive in the cement-based solidification/stabilization further reduced the leaching, but had a deleterious effect on cement setting and strength. In all cases, the leaching was rapid during the first 20 h indicating possible wash-out followed by more of diffusion-controlled leaching.

- Attempts were made to study the influence of specimen size on leachability by ***Samsonek et al., (1998)***. The specimen size was observed to influence the leachability results as well as leaching kinetics.

- ***Lange et al. (1997)*** investigated the solidified (cement–sand–pozzolona) waste specimens to assess the effect of curing in different environments of nitrogen, carbon dioxide and atmosphere for 28 days. They noted that the type of binder has a crucial role in the immobilization of contaminants in water, irrespective of the curing environment, which should be taken into account to improve the efficacy of solidification or fixation.

- ***Akhter et al. (1997)*** studied the effect of long cure times on solidification/stabilization of arsenic salts. The leachability of As (III) and As (V) (the actual salt of arsenate was not 27 mentioned in the paper) from various solidification–stabilization binders was noted over a period of 4 years. Type-1 Ordinary Portland cement (OPC), both isolated and in combination with a number of additives, resulted in the TCLP (USEPA, 1996) leachability limit below 3 g/m^3 for arsenite and less than 2 g/m^3 for arsenate. There was no appreciable change in the leachability after 3 years of curing. However, the combination of OPC and Class A fly ash as a binder resulted in substantially degraded performance as measured by the TCLP test. Furthermore, the cement-fly ash–arsenic mixture showed increased leachability with time.

To make mortar with the arsenic rich sludge, one part of cement and three parts of standard blended sand of grades I, II, III were mixed thoroughly. The clean water was then added to the cement–sand mixture (1:3 by volume) at a water–cement ratio of 0.4. The green mortar thus formed was poured into six 50 mm cube molds and vibrated for 1.5–2 min for proper compaction. After 24 h, the green mortar cubes were taken out of the molds and cured for 3, 7 and 28 days under adequate water for complete immersion. The maximum period of curing was set at 28 days as the variation of leachability of arsenic for longer duration of curing is insignificant as per the study of ***Akhter et al., (1997)***. The arsenic-laden sludge and/or fly ash were/was mixed homogeneously with the dry form of cement–sand mortar (1:3) before water was added. Duplicate cubes were also cast for each combination.

As a result,

i. The arsenic concentration did not exceed its maximum permissible limit in the water of curing of concrete or mortar.
ii. Activated Return Sludge Process (ARP) sludge can also be stabilized with standard cement concrete ingredients up to a proportion of 40% (by volume) with respect to the total volume of the concrete mixture, and the leachate formed in the TCLP test contains arsenic below its safe discharge limit, i.e., 0.2 g/ m^3.
iii. Increased leaching is observed for concrete or clay mortar richer in arsenic-laden sludge.
iv. In the preparation of cement mortar, the arsenic laden sludge could be blended (keeping a factor of safety of 1.80) up to a proportion of around 10% (v/v) with respect to cement content.

- ***Chu et al. (1991)*** made a comparison of different fixation techniques. Bench-scale studies were performed on soil samples with arsenic concentrations ranging from 1200 to 2100 mg/kg. The fixation agents tested in their study were Portland cement, fly ash, silicates and metal (ferrous and aluminum) hydroxides. The untreated and treated samples were extracted according to the federal Extraction Procedure Toxicity (EPTOX) test and TCLP as well as the California Waste Extraction test (WET). The parameters that appeared to affect leaching included dosage and capacity fixation reagents, and the final pH of the leaching test. In general, treatment using silicates reduced arsenic leaching most effectively with greater than 99% decrease for TCLP leachate and greater than 90% for WET leachate. The final pH of the leachate appeared to be an important factor.

Chapter 5
Research Objective and Scope of Work

5.1 Research Objectives

Main objective of performing this topic is to provide a cost effective robust stabilization options to get rid of the issues of Arsenic bearing water plant waste stabilization. We are thinking to stabilize the highly As content sludge coming from E.C.A.R As removal option, in Concrete. We are trying to find out the maximum limit of Arsenic laden sludge that can be mixed safely with satisfying leachability limit and desirable strength effecting issues.

5.2 Scope of Work

- Detailed characterization of arsenic bearing sludge from ECAR in terms of pertinent physical parameters, including Specific Gravity, Bulk Density, Maximum Dry Density, Optimum Moisture Content, Void Ratio, Porosity, Free Swell Index, Atterberg Limits, Permeability, Grain Size Distribution and Shear Strength Parameters; and chemical parameters including Arsenic, Iron, Aluminum, Silver, Barium, Cadmium, Chromium, Lead, Mercury, Calcium and Magnesium; anions such as Chloride, Sulfate, Phosphate, Nitrate; and Silica content.

- Embedment of ECAR sludge in variable proportions (till the point of substantial deterioration of compressive strength) in concrete and the strength and workability of the concrete to be measured.

- Determination of arsenic in the leachate generated from ECAR sludge embedded concrete after it has been pulverized to (i) <9.5mm; (ii) <1mm and (ii) 5-50 mm particles.

Chapter 6
Methodology

6.1 Sludge Collection and Sampling

The arsenic bearing sludge was collected from the 600L prototype ECAR installed at Environmental Engineering Division of Department of Civil Engineering, Jadavpur University. This prototype ECAR is designed to operate at a highest columbic dose of 450 C/L and it produces 245mg/L of dried sludge. This dose was sufficient to consistently produce product water with below 5µg/L arsenic.

The groundwater which was treated in this 600L prototype ECAR was spiked with arsenic having concentration of 300ppb. The groundwater had also been characterized with the following parameters: pH = 7.2; Alkalinity = 390 mg/L as $CaCO_3$; Acidity = 32 mg/L as $CaCO_3$; Total Hardness = 660 mg/L as $CaCO_3$; Chloride = 970 mg/L as Cl^-; Sulfate = 47 mg/L as $SO_4^=$; Iron = Below Detectable Limit; Arsenic = Below Detectable Limit; TDS = 2250 mg/L; TSS = 17 mg/L; Phosphate = Below Detectable Limit; Nitrate = 0.05 mg/L as NO_3^-; Fluoride = 0.6 mg/L as F^-.

6.2 Physical Characterization

The physical characterizations that had been done on the sludge sample coming from E.C.A.R are

i. Determination of Atterberg Limit

ii. Determination of Specific Gravity

iii. Determination of Free Swell Index

iv. Determination of Permeability (Hydraulic Conductivity)

v. Determination of Optimum Moisture Content (OMC) and Maximum Dry Density

vi. Determination of Shear Strength Parameters

vii. Determination of Grain Size Distribution

NOTE: The arsenic laden sludge had been characterized using IS code protocols for soils.

6.2.1 Method for Determining Atterberg Limit

Reference: IS 2720 (Part V):1985

6.2.1.1 Liquid Limit by Mechanical Method

- **Apparatus Required**

1. Mechanical Liquid Limit Device conforming to IS: 9259:1979

2. Grooving tool conforming to 1S: 9259:1979

3. Porcelain Evaporating Dish - about 12 to 15 cm in diameter.

4. Flat Glass Plate - 10 mm thick and about 45 cm square or larger (alternative to porcelain evaporating dish for mixing sludge with water).

5. Spatula - flexible, with the blade about 8 cm long and 2 cm wide (for mixing sludge and water in the porcelain evaporating dish).

6. Palette Knives - two, with the blade about 20 cm long and 3 cm wide (for mixing sludge and water on the flat glass plate).

7. Balance - sensitive to 0.01 g.

8. Oven - thermostatically controlled with interior of non-corrodible material to maintain the temperature between 105° and 110°C.

9. Wash Bottle or Beaker - containing distilled water.

10. Containers - air-tight and non-corrodible for determination of moisture content.

Sludge Sample - A sample weighing about 120 g had been taken from the thoroughly mixed portion of material passing 425 micron IS Sieve which was obtained in accordance with IS: 2720 (Part I):1983.

- **Adjustment of the Mechanical Device**

1. The liquid limit device had been inspected to determine that it was clean, dry and in good working order, that the cup fell freely and it did not have too much side play at its hinge. The grooving tool had been also inspected to determine that it was clean and dry.

2. Using the gauge on the handle of the grooving tool or a separate gauge and by means of the adjustment plate of the mechanical liquid limit device, the height through which the cup had to be lifted and dropped has been adjusted so that the point on the cup which came in contact with the base fell through exactly one centimeter for one revolution of the handle. The adjustment plate has been then secured by tightening the screw.

- **Procedure**

1. About 120 g of the sludge sample passing 425-micron IS Sieve had been mixed thoroughly with distilled water in the evaporating dish or on the flat glass plate to form a uniform paste. The paste should have a consistency that would require 30 to 35 drops of the cup to cause the required closure of the standard groove.

2. The sludge had then been re-mixed thoroughly before the test. A portion of the paste should be placed in the cup above the spot where the cup rested on the base, was squeezed down and was spread into position with as few strokes of the spatula as possible and at the same time was trimmed to a depth of one centimeter at the point of maximum thickness and the excess sludge was returned to the dish. The sludge in the cup had been decided by firm strokes of the grooving tool along the diameter through the centre line of the cam follower so that a clean, sharp groove of the proper dimensions was formed (see Note 1). The cup had been fitted and dropped by turning the crank at the rate of two revolutions per second until the two halves of the soil cake came in contact with bottom of the groove along a distance of about 12 mm (see Note 2). This length had been measured with the end of the grooving tool or a ruler. The number of drops that had been required to cause the groove close for the length of 12mm had been recorded.

NOTE 1 - To avoid tearing of the sides of the groove or slipping of the sludge cake on the cup, up to six strokes, from front to back or from back to front counting as one stroke, shall be permitted. Each stroke penetrates a little deeper until the last stroke from back to front scrapes the bottom of the cup clean. The groove shall be made with as few strokes as possible.

NOTE 2 - Some samples tend to slide on the surface of the cup instead of the sample flowing. If this occurs, the results should be discarded and the test repeated until flowing does occur. If sliding still occurs, the test is not applicable and a note should be made that the liquid limit could not be obtained.

3. A little extra of the sludge mixture had been added to the cup and had been mixed with the sludge in the cup. The pat had been made in the cup and the test had been repeated as in 2. In no case dried sludge had been added to the thoroughly mixed sludge that was being tested. The procedure given in 2 and in this clause had been repeated until two consecutive runs gave the same under of drops for closure of the groove (see Notes 2 and 3).

NOTE 3 - Care shall be taken to see that the sludge paste does not dry out too rapidly between repeat tests as the number of blows for closure will increase gradually as the sample dries out.

4. A representative slice of sludge approximately the width of the spatula, extending from about edge to edge of the sludge cake at right angle to the groove and including that portion of the groove in which the sludge flowed together had been taken in a suitable container and its moisture content expressed as a percentage of the oven dry weight otherwise had been determined as described in IS: 2720(Part II):1973. The remaining sludge in the cup had been transferred to the evaporating dish and the cup and the grooving tool had been cleaned thoroughly.

5. The operations specified in 2 to 4 had been repeated for at least three more additional trails (minimum of four in all), for the sludge that had been collected in the evaporating dish or flat glass plate, to with sufficient water had been added to bring the sludge to a more fluid condition. In each case the number of blows had been recorded and the moisture content had been determined as before. The specimens should be of such consistency that the number of drops required to close the groove should be not less than 15 or more than 35 and the points on the flow curve were evenly distributed in this range. The test had been performed from the drier (more drops) to the wetter (less drops) condition of the sludge. The test might had also been conducted from the wetter to the drier condition provided drying was achieved by kneading the wet sludge and not by adding dry sludge.

Determination of Liquid Limit

Liquid Limit (W_L) – 'A flow curve' had been plotted on a semi logarithmic graph representing water content on the arithmetical scale and the number of drops on the logarithmic scale. The flow curve was a straight line drawn as nearly as possible through the four or more plotted points. The moisture content corresponding to 25 drops was read from the curve and had been rounded off to the nearest whole number and had been reported as the liquid limit of the sludge.

6.2.1.2. Plastic Limit

- **Apparatus Required**

1. Porcelain Evaporating Dish - about 12 cm in diameter.
Or
Flat Glass Plate - 10 mm thick and about 45 cm square or larger.

2. Spatula - flexible, with the blade about 8 cm long and 2 cm wide.
Or
Palette Knives - two, with the blade about 20 cm long and 3 cm wide (for use with flat glass plate for mixing sludge and water).

3. Surface for Rolling - ground-glass plate about 20 x 15 cm.

4. Containers - air-tight to determine moisture content

5. Balance - sensitive to 0.01 g.

6. Oven - thermostatically controlled with interior of non-corroding material to maintain the temperature between 105°C and 110°C.

7. Rod - 3 mm in diameter and about 10 cm long.

- **Sludge Sample**

A sample weighing about 20 g from the thoroughly mixed portion of the material passing 425-micron IS Sieve, obtained in accordance with IS: 2720(Part I):1983 had been taken.

- **Procedure**

The sludge sample had been mixed thoroughly with distilled water in an evaporating dish or on the flat glass plate till the sludge mass became plastic enough to be easily moulded with fingers. A ball had been formed with about 8 g of this plastic sludge mass and rolled between the fingers and the glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length. The rate of rolling had been between 80 and 90 strokes/min counting a stroke as one complete motion of the hand forward and back to the starting position again. The rolling had been done till the threads are of 3 mm diameter. The sludge had then been kneaded together to a uniform mass and had been rolled again. This process of alternate rolling and kneading had been continued until the thread crumbles under the pressure required for rolling and the sludge could no longer be rolled into a thread. The crumbling might occur when the thread had a diameter greater than 3 mm. This had been considered a satisfactory end point, provided the sludge sample had been rolled into a thread 3 mm in diameter immediately before. At no time had an attempt been made to produce failure at exactly 3 mm diameter by allowing the thread to reach 3 mm, then reducing the rate of rolling or pressure or both, and continuing the rolling without further deformation until the thread falls apart. The pieces of crumbled sludge thread had been collected in an air-tight container and the moisture content had been determined as described in IS: 2720(Part II):1973.

6.2.2 Method for Determining Specific Gravity

Reference: IS 2720(Part III/sec-i):1980

- **Apparatus**

1. Two density bottles (pycnometers) of approximately 50 ml capacity with stoppers.

2. A water-bath maintained at a constant temperature to within ±2°C. (If standard density bottles are used this constant temperature is 27°C.)

3. Desiccators (a convenient size is one about 200 mm to 250 mm in diameter) containing anhydrous silica gel.

4. A thermostatically controlled drying oven, capable of maintaining a temperature of 105 to 110°C.

5. A balance readable and accurate to 0.00l g.

6. A spatula (a convenient size is one having a blade 150 mm long and 3 mm wide; the blade has to be small enough to go through the neck of the density bottle), or a piece of glass rod about 150 mm long and 3 mm diameter.

7. A wash bottle preferably made of plastics, containing air-free distilled water.

8. A sample divider of the multiple slot type with 7 mm width of opening.

- **Procedure**

1. The complete density bottle with stopper had been dried at 105 to 110°C and had been cooled in the desiccators and had been weighed to the nearest 0.001 g (m_1).

2. A 5 to 10 g sludge sample had been obtained by riffling, and had been oven dried at 105 to 110°C. This sample had been transferred to the density bottle direct from the desiccators in which it had been cooled. The bottle and contents together with the stopper had been weighed to the nearest 0.001 g (m_2).

3. Sufficient air-free distilled water had been added so that the sludge sample in the bottle is just covered.

4. The entrapped air had been removed by heating the pycnometer placed on a water-bath or sand-bath.

5. The stopper had then been inserted. The stoppered bottle had been immersed up to the neck in the constant-temperature bath for approximately 1 hour or until it had attained the constant temperature of the bath. If there was an apparent decrease in volume of the liquid the stopper should have been removed and further liquid had been added to fill the bottle and the stopper had been replaced. The bottle had then been returned to the bath and sufficient time had been allowed to elapse after this operation to ensure that the bottle and its contents again attained the constant temperature of the bath. If the bottle was still not completely full this process should have been repeated.

6. The stoppered bottle had then been taken out of the bath, wiped dry and the whole had been weighed to the nearest 0.00l g (m_3).

7. The bottle had then been cleaned out and filled completely with air free liquid, the stopper had been inserted and then the whole had been immersed in the constant temperature bath for 1 hour or until it had attained the constant temperature of the bath. If there was an apparent decrease in the volume of the liquid, the stopper should have been removed and further liquid had to be added to fill the bottle and the stopper replaced. The stoppered bottle had then been returned to the batch and sufficient time had been allowed to elapse after this operation to ensure that the bottle and its contents again attained the constant temperature. If the bottle was still not completely full this bottle had then been taken out of the bath, had been wiped dry and the whole had been weighed to the nearest 0.001 g (m_4).

- **Calculation**

The specific gravity of the sludge sample G shall be measured at room temperature if water has been used as the air-free liquid, then the following equation shall be used:

$$\boldsymbol{G = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}}$$

Where
m_1 = mass of density bottle in g;
m_2 =mass of bottle and dry sludge in g;
m_3 = mass of bottle, sludge and water in g; and
m_4 = mass of bottle when full of water only in g.

The specific gravity shall be calculated at 27°C. If the room temperature is different than 27°C, the following correction shall be done:

$$\mathbf{G' = KG}$$

Where
G´ = Corrected specific gravity at 27°C, and
K = (Relative density of water at room temperature)/ (Relative density of water at 27°C)

6.2.3 Method for Determining Free Swell Index

Reference: IS 2720 (Part XL):1977

- **Apparatus Required**

1. Sieve - 425-micron IS Sieve.

2. Glass Graduated Cylinders - Two, 100 ml capacity

- **Procedure**

1. Take two 10 g sludge specimens of oven dry sludge sample passing through 425 micron IS Sieve.

2. Each sludge specimen shall be poured in each of the two glass graduated cylinders of 100 ml capacity. One cylinder shall then be filled with kerosene oil and the other with distilled water up to the 100 ml mark. After removal of entrapped air (by gentle shaking or stirring with a glass rod), the sludge samples in both the cylinders shall be allowed to settle. Sufficient time (not less than 24 h) shall be allowed for the sludge sample to attain equilibrium state of volume without any further change in the volume of the sludges. The final volume of sludges in each of the cylinders shall be read out.

- **Calculation**

The level of the sludge in the kerosene graduated cylinder shall be read as the original volume of the sludge samples, kerosene being a non-polar liquid does not cause swelling of the sludge. The level of the sludge in the distilled water cylinder shall be read as the free swell level. The free swell index of the sludge shall be calculated as follows:

$$\boldsymbol{Free\ Swell\ Index, percent} = \frac{\boldsymbol{V_d - V_k}}{\boldsymbol{V_k}} \times \mathbf{100}$$

Where
V_d = the volume of sludge specimen read from the graduated cylinder containing distilled water, and
V_k = the volume of sludge specimen read from the graduated cylinder containing kerosene.

6.2.4 Method for Determining Permeability (Hydraulic Conductivity)

Reference: IS 2720(Part XVII):1986

Falling Head Test

- **Apparatus Required**

1. The mould assembly (including drainage base and drainage cap) shall conform to IS: 11209:1985.

2. The compaction rammer shall conform to IS: 9198:1979.

3. Set of Stand Pipes - Glass stand pipes for falling head (variable head test arrangement, varying in diameter from 5 to 20 mm, suitably mounted on stand or otherwise fixed on wall).

4. Miscellaneous Apparatus - Such as IS sieves, mixing pan, graduated cylinder, meter scale, stop watch, 75micron wire gauge, thermometer, and a source of de-aired water.

- **Preparation of Test Specimen**

1. A 2.5 kg sample had been taken from a thoroughly mixed air-dried or oven-dried material which had been obtained in accordance with IS: 2720(Part I):1983.

2. The moisture content of the 2.5 kg sample had been determined as described in IS: 2720(Part II):1973. The sample had been placed in an airtight container. The quantity of water to be added to the stored sample to give the desired moisture content had been computed and spread evenly over the sample, and after thoroughly mixing, the material had again been placed in the storage container. The moisture content of the sample had again been determined and the entire process had been repeated until the actual moisture content was within 0.5 percent of that desired.

3. The permeameter mould had been weighed empty to the nearest gram. After greasing lightly the inside of the mould it had been clamped between the compaction base plate and the extension collar. The assembly had been kept on a solid base.

4. The dry density for remoulding of sludge samples should be either the field density or the value of the maximum dry density estimated by the compaction tests [IS: 2720 (Part VII):1980] or any other density at which the permeability was desired. The moisture content used for compaction should be the optimum moisture content or the field moisture as the case may be. The compactive effort may be varied to simulate field conditions. Static compaction may also be used where necessary. After completion of compaction the collar, if attached, had been removed and excess sludge had been trimmed level with the top of the mould. The base had been detached and the mould full of the compacted specimen had been weighed.

5. The mould with the specimen inside had been assembled to the drainage base and cap having porous discs. The porous discs had been saturated before assembling the mould.

- **Procedure**

1. For a falling head test arrangement the specimen had been connected through the top inlet to selected stand-pipe. The bottom outlet had been opened and the time interval required for the water level to fall from a known initial head to a known final head as measured above the centre of the outlet had been recorded. The stand-pipe had been refilled with water and the test had been repeated till three successive observations give nearly same

time interval; the time intervals being recorded for the drop in head from the same initial to final values, as in the first determination. Alternatively, after selecting the suitable initial and final heads, h_1 and h_2 respectively, time intervals shall be noted for the head to fall from h_1 to $(h_1h_2)^{0.5}$ and similarly from $(h_1h_2)^{0.5}$ to h_2. The time intervals had been the same; otherwise the observation had been repeated after refilling the stand-pipe.

2. The dimensions of specimen, length 'L' and diameter 'D' had been measured. Area 'a' of stand-pipe had been recorded. The temperature T, of water was also measured.

3. During the test, observations were made of initial time t_i final time t_f, initial head h_1, final head h_2, in stand-pipe.

- **Calculations**

At temperature T of water, the permeability k_T is calculated as

$$\boldsymbol{k_T = \frac{2.303aL}{(t_f - t_i)} \times \log_{10}\left(\frac{h_1}{h_2}\right)}$$

And the permeability at 27°C is given by

$$\boldsymbol{k_{27} = k_T \times \frac{\Upsilon_T}{\Upsilon_{27}}}$$

Where
k_{27} = permeability at 27°C
γ_T = coefficient of viscosity at T°C
γ_{27} = coefficient of viscosity at 27°C

6.2.5 Method for Determining Water Content-Dry Density Relation Using Light Compaction

Reference: IS 2720(Part VII):1980

- **Apparatus Required**

1. **Cylindrical Metal Mould** - It shall be in accordance with relevant Indian standards on specification of compaction mould.

2. **Sample Extruder (Optional)** - It consists of a jack, lever frame or other device adopted for the purpose of extruding compacted specimens from the mould.

3. **Balances** - one, of capacity 10 kg sensitive to 1g and other of capacity 200 g sensitive to 0·01 g.

4. **Oven** - thermostatically controlled with interior of non-corroding material to maintain temperature between 105°C and 110°C.

5. **Container** - any suitable non-corrodible airtight container to determine the water content for tests conducted in the laboratory.

6. **Steel Straight edge** - a steel straightedge about 30 cm in length and having one beveled edge.

7. **Sieve** – 4.75 mm and 20 mm IS sieves conforming to the requirements of IS: 460 (Part I):1978.

8. **Mixing Tool** - miscellaneous tools, such astray or pan, spoon, trowel and spatula or a suitable mechanical device for thoroughly mixing the sample of sludge with additions of water.

9. **Metal Rammer** - It shall conform to IS: 9198:1979.

- **Procedure**

1. A 5kg sample of air dried sludge sample passing the 20 mm IS test sieve had been taken. The sample had been mixed thoroughly with a suitable amount of water depending on the soil type.

2. The mould with base plate attached had been weighed to the nearest 1 g (m_1). The mould had been placed on a solid base such as a concrete floor or plinth and the moist sludge sample had been compacted into the mould, with the extension attached, in three layers of approximately equal mass, each layer being given 25 blows from the 2.6 kg rammer dropped from a height of 310 mm above the sludge sample. The blows had been distributed uniformly over the surface of each layer. It had been ensured that the tube of the rammer is kept clear of sludge so that the rammer always fell freely. The amount of sludge used had been sufficient to fill the mould, leaving not more than about 6 mm to be struck off when the extension was removed. The extension had been removed and the compacted sludge had been leveled off carefully to the top of the mould by means of the straightedge. The mould and sludge had then been weighed to 1 gm (m_2).

3. The compacted sludge specimen had been removed from the mould and had been placed on the mixing tray. The water content of a representative sample of the specimen had been determined as in IS: 2720(Part II):1973.

4. The remainder of the sludge specimen had been broken up, rubbed through the 20 mm IS test sieve, and then mixed with the remainder of the original sample. Suitable increments of water had been added successively and mixed into the sample, and the above procedure from operations 2 to 4 had been repeated for each increment of water added. The total number of determinations made had been at least five and the range of moisture content had been such that the optimum moisture content, at which the maximum dry density occurred, is within that range.

- **Calculations**

1. Bulk Density - γ_m in g/ml, of each compacted specimen shall be calculated from the equation:

$$\gamma_m = \frac{m_2 - m_1}{V_m}$$

Where
m_1 = mass in g of mould and base;
m_2 = mass in g of mould, base and sludge;
V_m = volume in ml of mould.

2. **The dry density** - γ_d in g/ml, shall be calculated from the equation:

$$\gamma_d = \frac{100\gamma_m}{100 + w}$$

Where
w = moisture content of sludge specimens in percent.

6.2.6 Method for Determining Shear Strength Parameters of a Specimen Tested In Unconsolidated Undrained Triaxial Compression without the Measurement of Pore Water Pressure

Reference: IS 2720 (Part XI): 1993

- **Apparatus Required**

1. Apparatus required for the preparation of a test specimen are listed in 2 and 3 to cover the three following procedures:

   a. Procedure 1 - For obtaining a specimen from a sampler tube of the same internal diameter as the required specimen.

b. Procedure 2 - For obtaining a specimen from a sampler tube of larger diameter than the required specimen.

c. Procedure 3 - For obtaining a specimen from a block sample.

2. Articles Common to a Sample Preparation by all Three Procedures

2.1 Split mould of diameter and length to suit the test specimen.

2.2 Trimming Knife Sharp-bladed for example a spatula or pallet knife.

2.3 Piano Wire Saw

2.4 Metal Straightedge

2.5 Metal Scale

2.6 Non-Corrodible Metal or Plastic End-Caps Of the same diameter as the test specimen. The upper end cap is to have a central spherical seating to receive the loading ram (see Note).

NOTE - A plastic upper end cap, 20 mm thick, is normally satisfactory for use on soft or very soft soils. Metal end caps are considered preferable for use on stiff soils. A metal upper end cap 12 to 20 mm thick is normally satisfactory.

2.7 Seamless Rubber Membrane In the form of a tube, open at both ends of internal diameter equal to the specimen diameter and of length 50 mm greater than the height of the specimen. The membrane thickness should be selected having regard to the size, strength and nature of the sample to be tested. A thickness of 0.2 to 0.3 mm is normally satisfactory.

2.8 Membrane Stretcher to suit the size of the specimen.

2.9 Rubber Rings of circular cross section to suit the diameter of the end caps.

2.10 Apparatus for Moisture Content Determination as described in section 1 of IS 2720 (Part II):1973.

2.11 Balance Readable and accurate to 0.5 g.

3. Additional Items for the Specific Procedures

3.1 Extruders [For Procedures (a) and (b) of 1 Extruders]

3.2 Thin-walled Tubes [For Procedure (b) of 1] (for obtaining test specimens)

The tubes shall be smooth inside and out and turned at one end to form a cutting edge at the inner surface of the tube. The area ratio (see Note) shall be kept as low as possible consistent with the strength requirements of the specimen tubes and its value shall not exceed 10 percent. The length of the tubes shall be at least 50 mm more than the required length of the specimens.

NOTE - The area ratio is defined as the volume of soil displaced by the sampler in proportion to the volume of the sample and is defined as:

$$\boldsymbol{Area\ ratio = \frac{D_0^2 - D_c^2}{D_c^2} \times 100\ percent}$$

Where

D_o = outside diameter of the tube, and

D_c = inside diameter of the cutting edge

3.3 Sludge Lathe [For Procedure (c) of 1] for preparing test specimens.

3.4 Meter Box [For Procedure (c) of 1] for cutting the ends of the specimen perpendicular to their axes.

4. Apparatus Required for Triaxial Test

4.1 Triaxial Test Cell

A triaxial test cell of dimensions appropriate to the size of the specimen capable of being opened for the insertion of the specimen, suitable for use with the fluid selected for use at internal pressures up to 1 MPa and provided with a means of applying additional axial compressive load to the specimen by means of a loading ram. A transparent chamber is recommended. The base of the cell shall be provided with a suitable central pedestal with drainage outlets with valves

4.2 An Apparatus for Applying and Maintaining the Desired Pressure on the Fluid Within the Cell - To an accuracy of 10 kPa (preferably 5 kPa) with a gauge for measuring the pressure. The gauge shall be regularly calibrated.

4.3 Machine Capable of Applying Axial Compression to the specimen - At convenient speeds to cover the range 0.05 to 5 mm per minute. The machine should have a capacity of 50 KN. A means of measuring the axial compression of the specimen to an accuracy of 0.01 mm shall be provided and the machine shall be capable of applying an axial compression of about one third the height of the specimen tested.

NOTE - In case the travel of the dial gauges is not sufficient a magnetic spacer of known thickness may be used.

4.4 Provision shall be made for measuring the additional axial load on the specimen.

- **Preparation of specimens**

1. Undisturbed Specimens

1.1 The object of the specimen preparation is to produce cylindrical specimens of height twice the specimen diameter with plane ends normal to the axis and with the minimum change of the specimen structure and moisture content. The method of preparation will depend on whether the sample is received in the laboratory in a tube or as a block sample and any one of the procedures given in 1.1.1, 1.1.2 or 1.1.3 may be used.

1.1.1 A specimen from a sampler tube of the same internal diameter as the required specimen

May be obtained as given in (a) to (e):

a. When the ends of the sampling tube are not flat and normal to the axis of the tube, a length of the sample sufficient to form a specimen shall be extruded from the tube and cut off. This specimen shall then be placed in the split mould and the ends trimmed flat and normal to its axis.

b. As an alternative to (a) when the tube enclosing the sample is in good condition and the ends are plane and normal to the axis of the tube, the specimen may be prepared in the tube and extracted.

c. Any wax used for sealing, shall be removed and the cutting edge end of the sample smoothed so that it is approximately normal to the axis of the tube. The extruder shall then be used to push the sample through the tube so that the other end may be cut normal to the axis and finally smoothed with the metal straight edge. The sample should be extruded from the tube pushing from the cutting edge side and cut to the required length. During this operation the sample tube shall be held vertical. Precautions shall be taken to prevent adhesion between the sludge and the extruder, for example, by interposing oiled paper discs or lightly oiling the face of the extruder.

d. The length, diameter and mass of the specimen shall be measured to an accuracy enabling the bulk density to be calculated to an accuracy of ±1.0 percent.

e. The specimen shall be placed on one of the end caps and the other end cap shall be put on top of the specimen. The rubber membrane shall then be placed around the specimen using the membrane stretcher and the membrane sealed to the end caps by means of rubber rings.
The specimen is then ready to be placed on the pedestal in the triaxial cell. The pedestal should be either covered with a solid end cap or the drainage valve should be kept closed.

1.1.2 For obtaining a specimen from a sample tube of larger diameter than the required specimen- Two methods are available, either the specimen may be cut to size by means of thin walled tubes or by hand trimming on a sludge lathe. The preparation of specimens on the soil lathe is dealt with in 1.1.3. To prepare specimens by means of thin-walled tubes the sample shall be extruded from the sample tube directly into a number of thin-walled specimen tubes rigidly clamped with their cutting ends a short distance from the end of the sampling tube. Test specimens shall be prepared from the thin walled specimens tubes in the manner described in 1.1.1.

1.1.3 A specimen from a block sample

May be obtained as given in (a) to (c):

a. A rectangular prism slightly larger than the required final dimension of the specimen shall be cut from the block sample. The rectangular prism shall be cut either on a required orientation or an orientation as best suited to the sample. The ends of the prism shall be made plane and parallel using the meter box and the prism shall be placed in the sludge lathe. The excess sludge shall be cut off in this layer. The trimming operation, rotating, the sample between each cutting operation, shall be continued until a cylindrica1 specimen results.

b. The specimen shall be removed from the sludge lathe, placed in the split mould and cut to the correct length and the ends made plane and normal to the axis of the specimen.

c. The remainder of the preparation shall be as described in 1.1.1.

- **Testing**

1. The specimen prepared as described and shall be placed centrally on the pedestal of the triaxial cell. The cell shall be assembled with the loading ram initially clear of the top cap of the specimen and the cell containing the specimen shall be placed in the loading machine. The operating fluid shall be admitted to the cell and the pressure rose to the desired value.

2. The loading machine shall be adjusted to bring the loading ram a short distance away from the seat on the top cap of the specimen and the initial reading of the load measuring gauge shall be recorded. The loading machine shall then be further adjusted to bring the loading ram just in contact with the seat on the top cap of the specimen and the initial reading of the gauge measuring the axial compression of the specimen shall be recorded.

A rate of axial compression shall be selected such that failure is produced within a period of approximately 5 to 15 minutes. The test shall be commenced, a sufficient number of simultaneous readings of the load and compression measuring gauges being taken to define the stress strain curve (see Note). The test shall be continued until the maximum value of the stress has been passed or until an axial strain of 20 percent has been reached. The specimen shall then be unloaded and the final reading of the load measuring gauge shall be recorded as a check on the initial reading.

NOTE - It is often convenient to make a plot of load versus compression as the rest proceeds, to enable the point of failure to be determined.

3. The cell shall be drained of fluid and dismantled, and the specimen taken out. The rubber membrane shall be removed from the specimen and the mode of failure shall be noted (see Note 1). The specimen shall be weighed (see Note 2) and samples for the determination of the moisture content of the specimen shall be taken [see IS 2720 (Part II): 1973]. If there is a moisture change in the specimen it should be recorded and discretion used with regard to acceptability of the test.

NOTES

1. The most convenient method of recording the mode of failure is by means of sketch indicating the position of the failure planes. The angle of the failure plan (s) to the horizontal may be recorded, if required. These records should be completed without undue delay to avoid loss of moisture from specimen.

2. Comparison with the recorded mass of the specimen before testing provides a check on the impermeability of the rubber membrane if water has been used as the operating fluid in the cell.

- **Calculations**

1. According to the procedure the difference between the initial reading and any subsequent reading of the loading measuring device is the axial load applied to the specimen in addition to that due to cell pressure.

1.1 The area of the specimen normal to its axis at any stage of the test shall be computed on the assumption that the sample deforms as a right cylinder. This area at any strain is given by:

$$\boldsymbol{A = \frac{A_0}{1 - e}}$$

Where, A_0 = initial area of the specimen normal to the axis,
And $\boldsymbol{e = \frac{L_0 - L}{L_0}}$
Where,
L_0 = initial length of the specimen, and
L = length of the specimen at the stage of test at which area is to be determined.

1.2. The principal stress difference ($\sigma_1 - \sigma_2$) for any stage of the test shall be determined by dividing the additional axial load by the corresponding area A.

1.3 A correction to allow for the restraining effect of the rubber membrane shall be made as given below:

$$\boldsymbol{Correction = \frac{4M(1-\epsilon)}{D}}$$

Where,
M= the compression modulus of the rubber membrane in kg/cm of width
ε = the axial strain at the maximum principal stress different, and
D = initial diameter of the sample in cm.

1.4 The value of the correction calculated as given in 1.3 shall be deducted from the measured maximum principal stress difference to give the corrected value of the maximum principal stress different.

1.5 The compression modulus of the rubber membrane cannot be measured directly but may be assumed to be equal to the modulus measured in extension. The extension modulus of a circumferential strip 25mm wide cut from the membrane may be determined. The contact faces between the rubber and the glass rods should be dusted with talc powder to reduce friction.

6.2.7 Method for Determining Grain Size Distribution of Fine Grained Soil by Pipette Method

Reference: IS 2720(Part IV):1985

This method is not applicable if less than 10 percent of the material passes 75-micron IS Sieve.

- **Apparatus**

1. Sampling pipette - fitted with a pressure and suction inlet and having a capacity of approximately 10 ml. The pipette shall be so arranged that it can be inserted to a fixed depth into a sedimentation tube when the latter is immersed in a constant temperature bath.

2. Glass sedimentation tubes - a minimum of two of 50 mm diameter and approximately 350 mm long marked at 500mml volume with rubber bungs to fit.

3. Weighing bottles - required number, fitted with round stoppers or crucibles with suitable lids approximately 25 mm in diameter and 50 mm high. The bottles or crucibles shall be weighed to the nearest 0.001 gram.

4. Water-bath or constant temperature room (optional) - for maintaining the sludge suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature.

5. Stirring apparatus - a mechanical stirring device in which a suitable mounted electric motor turns a vertical shaft at a speed of 8000 to 10000 rev/min when loaded. The shaft shall be equipped with a replaceable stirring paddle and made of metal, plastic or hard rubber. The shaft shall be of such length that the stirring paddle will operate neither less than 20 mm nor more than 35 mm above the bottom of the dispersion cup. A special dispersion cup shall be provided to hold the sample while it is being dispersed. The container and baffles shall be of such material as will not be attacked by the reagents placed in the container. The motion of the sludge suspension shall be sufficient to mix the contents thoroughly but it shall not be so vigorous that the particles will be crushed or lost through splashing; neither shall it be so sluggish as to leave unmixed material in the bottom of the container.

6. Sieves - 2-mm, 425-micron, 75-micron IS Sieves and receiver.

7. Balance - accurate to 0.01 g.

8. Oven- thermostatically controlled to maintain a temperature of 105° to 110°C, with interior of non-corroding material.

9. Stop watch

10. Desiccator

11. Centimeter Scale

12. Porcelain evaporating dishes - four, about 15 cm in diameter.

13. Wide-mouth -conical flask or conical beaker - of 1000 ml capacity

14. Buchner or Hisch funnel - about 10 cm in diameter.

15. Filter flask - to take the funnel.

16. Measuring cylinder - of 100 ml capacity.

17. Wash bottle - containing distilled water.

18. Filter papers

19. Blue litmus paper

20. Glass rod - about 15 to 20 cm long and 4 to 5 mm in diameter.

21. Reagent- The reagents shall be of analytical quality.

21.1 Sodium hexametaphosphate solution - Dissolve 33 g of sodium hexametaphosphate and seven grams of sodium carbonate in distilled water to make one liter of solution.

- **PROCEDURE**

1. The sludge fraction passing 75-micron IS Sieve during wet sieving had been collected, that was oven-dried and had been used for pipette analysis. Where necessary, the oven-dried fraction had been powdered in a mortar with a rubber covered pestle taking care that the individual grains were not crushed. 25 to 50 g of the sludge had been used for the analysis.

2. **Calibration of sampling Pipette** - The sampling pipette had been thoroughly cleaned and dried and the nozzle had been immersed in distilled water. By means of a sucker, water had been sucked up in the pipette until the required volume (10 ml). The pipette shad been removed from the water. The water contained in the pipette had been discharged into a glass weighing bottle or sample can of known mass and the mass had been determined. The volume of sample had then been determined. This had been done three times and the average had been taken.

3. **Pre-treatment of sludge** - The percentage of soluble salts had been determined. In case it was more than one percent, the sludge had been washed with water before further treatment, taking care to see the sludge particles were not lost.

4. **Dispersion of sludge** - To the sludge sample in the evaporating dish 100 ml of sodium hexametaphosphate solution had been added and the mixture had then been warmed gently for about 10 minutes and then transferred to the cup of the mechanical mixer using a jet of distilled water to wash all traces of the sludge out of the evaporating dish. The amount of water used may be about 150 ml. The sludge suspension had then been stirred well for 15 minutes. The suspension had then been transferred to the 75micron IS Sieve placed on a receiver and the sludge had been washed on this sieve using a jet of distilled water from a wash bottle. Particular care had been taken to wash off all traces of suspension adhering to the dispersion cup. The amount of distilled water during this operation had been about 200ml.

The suspension that had been passed through the sieve had been transferred to the 500 ml measuring cylinder and made up to exactly 500 ml with distilled water. This suspension had then been used for the sedimentation analysis. The material retained on the 75micron IS Sieve might be over-dried and analyzed and the cumulative percentages of the sludge fraction retained on each sieve could be calculated.

5. Sedimentation

a) 25 ml of sodium hexa-meta-phosphate solution had been added from a pipette to a graduated 500-ml sedimentation tube (comparison tube) and had been diluted with distilled water to exactly 500 ml. This sedimentation tube together with the tube containing the sludge suspension had been immersed in the constant temperature bath (where used), the temperature of the bath had been noted, the rubber bungs had been inserted and the tubes had been allowed to stand until they have reached the temperature of the bath. The tubes with their contents had then been thoroughly shaken by inverting the tubes several times. They had then been replaced in the apparatus, simultaneously starting the stop watch. The rubber bungs had then been carefully removed without agitating the tubes.

b) The pipette had been lowered vertically into the sludge suspension until the end was 100mm below the surface of the suspension. It had been lowered with great care some 15 seconds before the sample is due to be taken. Approximately 10 seconds had been taken to complete this operation. A sample (10 ml) had been drawn up into the pipette. This operation had taken 10 seconds to complete. After each sampling operation the pipette had been withdrawn from the suspension, taking approximately 10 seconds to complete the operation.

c) A tared weighing can had been placed under the end of the pipette and the contents of the pipette had been delivered into the bottle. Any suspension left on the inner walls of the pipette had been washed into the weighing bottle by allowing distilled water to flow into the pipette.

d) This procedure had been repeated at the end of each time intervals 15 secs, 30 secs, 1 min, 2 min, 4 min, 8 min, 15 min, 30 min, 1 hr and 24 hrs calculated on the basis of equation given below.

e) The weighing bottles and contents had been placed in the oven maintained at 105° to 110°C and the sample evaporated to dryness. After cooling in a desiccator the weighing bottle and contents had been weighed to the nearest 0.001 g and the mass of the solid material in the sample had been determined. Other suitable time intervals might be used, provided they gave nearly equally spaced points on the grain size distribution curve.

f) Between any of the times in which the above sampling was taking place, a sample (V_p ml) had been taken from the tube containing the sodium hexametaphosphate solution. The mass of solid material in the sample had been determined (W_s).

- **Calculations**

1. Loss in mass in pre-treatment - The loss in mass in pre-treatment of the sludge shall be calculated using the formula:

$$P = 100 - \frac{W_b(100 + \omega)}{W_a}$$

Where

P = loss in mass in percentage,

W_b = mass of sludge after pre-treatment,

w = air dry moisture content of the sludge taken for analysis,

W_a = mass of air dry sludge used.

2. Sieving - The percent of sludge sample passing each of the sieve used in the analysis shall be calculated using the mass of the pre-treated sludge and as percentages of the total sludge sample taken for analysis.

3. Sedimentation

a) Diameter of the particles - The diameter of the particle in suspension at any sampling time t shall be calculated from the formula:

$$D = \sqrt{\frac{30\mu}{980(G - G_1)} \times \frac{H}{H_t}}$$

Where

D = diameter of particle in suspension, in mm;

μ = coefficient of viscosity of water at the temperature of the suspension at the time of taking the pipette reading, in poises;

G = specific gravity of the sludge fraction used in the sedimentation analysis;

G_1 = specific gravity of water;

H = height of fall of the particles or sampling depth, in cm.

t = time elapsed before sampling, in minutes.

b) Percentage finer than D - The mass of solid material in 500 ml of suspension for each respective sampling time shall be calculated from the formula:

$$M_i = \frac{W_i}{V_p} \times 500$$

Where

M_i= mass in V_p sample volume.

W_i= weight in V_p sample volume.

V_p= volume pipetted

Percentage by mass of particles finer than diameter can be calculated by,

$$W = \frac{M_i - M_s}{W_b} \times 100$$

Where

M_s = mass of sodium hexametaphosphate in 500 ml of solution

W_b = mass of sludge after pre-treatment

The values of W shall be calculated for all the values of D obtained and shall be expressed as percentages of particles finer than the corresponding value of D. These percentages shall then be expressed as combined percentages of the total soil sample taken for analysis.

6.3 Chemical Characterization

The chemical characterizations that are to be done on the sludge sample coming from E.C.A.R are

i. Determination of pH

ii. Determination of Arsenic, Iron, Aluminum, Silver, Barium, Cadmium, Chromium, Lead, Mercury, Calcium and Magnesium

iii. Determination of Chloride

iv. Determination of Nitrate

v. Determination of Phosphate

vi. Determination of Sulfate

vii. Determination of Silica

6.3.1 Method for Determining pH

Reference: IS 2720 (Part XXVI):1987 (Reaffirmed 2002)

- **Extraction:** The aqueous extraction method was used to prepare the soil sample for pH measurement. The soil sample does not need to be filtered to determine pH – measurement can directly be made in the suspension. Before extraction the soil sample is dried and then screened to a fineness of 0.2 mm using Hach Soil Sieve.

- **Procedure:**

  1. Using a 5 g scoop, measure 4 scoops of the prepared soil sample into a 50 ml plastic beaker.

  2. Using a 25 ml graduated cylinder, accurately measure 20 ml of de-ionized water and transfer it to the 50 ml beaker.

3. Repeat steps 1-2 for each soil sample undergoing extraction.

   Note: To prevent confusion when working with several samples, label each beaker with the sample or test name.

4. Using the spatula, stir the contents of the beaker for 1 min at 10 min intervals over a period of 30 min
   Note: Rinse the spatula with de-ionized water before stirring each sample.

5. After 30 min use the prepared sample for pH determination.

6.3.2 Method for Determining Arsenic, Iron, Aluminum, Lead, Mercury, Calcium, Magnesium, Silver, Barium, Cadmium and Chromium

Reference: USEPA Method 3050B

- **Scope and application:** This method has been written to provide two separate digestion procedures, one for the preparation of sediments, sludges, and soil samples for analysis by flame atomic absorption spectrometry (FLAA) or inductively coupled plasma atomic emission spectrometry (ICP-AES) and one for the preparation of sediments, sludges, and soil samples for analysis of samples by Graphite Furnace AA (GFAA) or inductively coupled plasma mass spectrometry (ICP-MS). The extracts from these two procedures are not interchangeable and should only be used with the analytical determinations outlined in this section. Samples prepared by this method may be analyzed by FLAA/ICP-AES or GFAA/ICP-MS for all the listed metals as long as the detection limits are adequate for the required end-use of the data. Alternative determinative techniques may be used if they are scientifically valid and the QC criteria of the method, including those dealing with interferences, can be achieved. The recommended determinative techniques for each element are listed below.

FLAA/ICP-AES	**GFAA/ICP-MS**
Aluminum	Arsenic
Barium	Cadmium
Cadmium	Chromium
Chromium	Iron
Iron	Lead
Lead	Mercury
Silver	

- **Apparatus and materials**

1. Digestion Vessels - 250-mL

2. Vapor recovery device (e.g., ribbed watch glasses, appropriate refluxing device, and appropriate solvent handling system)

3. Drying ovens - able to maintain 30°C ± 4°C

4. Temperature measurement device capable of measuring to at least 125°C with suitable precision and accuracy (e.g., thermometer, IR sensor, thermocouple, thermister, etc.)

5. Filter paper - Whatman No. 41 or equivalent

6. Centrifuge and centrifuge tubes

7. Analytical balance - capable of accurate weighing to 0.01 g

8. Heating source - Adjustable and able to maintain a temperature of 90-95°C. (e.g., hotplate, block digester, microwave, etc.)

9. Funnel or equivalent

10. Graduated cylinder or equivalent volume measuring device

11. Volumetric Flasks - 100mL

- **Reagents**

1. Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specific cations of the Committee on Analytical Reagents of the American Chemical Society, where such specific cations are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination. If the purity of a reagent is questionable, analyze the reagent to determine the level of impurities. The reagent blank must be less than the method detection limits (MDL) in order to be used.

2. Reagent Water will be interference free. All references to water in the method refer to reagent water unless otherwise specified.

3. Nitric acid (concentrated), HNO_3. Acid should be analyzed to determine level of impurities. If method blank is < MDL, the acid can be used.

4. Hydrochloric acid (concentrated), HCl. Acid should be analyzed to determine level of impurities. If method blank is < MDL, the acid can be used.

5. Hydrogen peroxide (30%), H_2O_2 oxidant should be analyzed to determine level of impurities. If method blank is < MDL, the peroxide can be used.

- **Procedure**

1. Mix the sample thoroughly to achieve homogeneity and sieve, if appropriate and necessary, using a USS #10 sieve. All equipment used for homogenization should be cleaned to minimize the potential of cross-contamination. For each digestion procedure, weigh to the nearest 0.01 g and transfer a 1-2 g sample (wet weight) or 1 g sample (dry weight) to a digestion vessel. For samples with high liquid content, a larger sample size may be used as long as digestion is completed.

NOTE: All steps requiring the use of acids should be conducted under a fume hood by properly trained personnel using appropriate laboratory safety equipment. The use of an acid vapor scrubber system for waste minimization is encouraged.

2. For the digestion of samples for analysis by GFAA or ICP-MS, add 10 mL of 1:1HNO_3, mix the slurry, and cover with a watch glass or vapor recovery device. Heat the sample to 95°C ± 5°C and reflux for 10 to 15 minutes without boiling. Allow the sample to cool, add 5 mL of concentrated HNO_3, replace the cover, and reflux for 30 minutes. If brown fumes are generated, indicating oxidation of the sample by HNO_3, repeat this step (addition of 5 mL of conc. HNO_3) over and over until no brown fumes are given off by the sample indicating the complete reaction with HNO_3. Using a ribbed watch glass or vapor recovery system, either allows the solution to evaporate to approximately 5 mL without boiling or heat at 95°C ± 5°C without boiling for two hours. Maintain a covering of solution over the bottom of the vessel at all times.

NOTE: Alternatively, for direct energy coupling devices, such as a microwave, digest samples for analysis by GFAA or ICP-MS by adding 10 mL of 1:1 HNO_3, mixing the slurry and then covering with a vapor recovery device. Heat the sample to 95°C ± 5°C and reflux for 5 minutes at 95°C ± 5°C without boiling. Allow the sample to cool for 5 minutes, add 5 mL of concentrated HNO_3, and heat the sample to 95°C ± 5°C and reflux for 5 minutes at 95°C ± 5°C. If brown fumes are generated, indicating oxidation of the sample by HNO_3, repeat this step (addition of 5 mL concentrated HNO_3) until no brown fumes are given off by the sample indicating the complete reaction with HNO_3. Using a vapor recovery system, heat the sample to 95°C ± 5°C and reflux for 10 minutes at 95°C ± 5°C without boiling.

2.1. After the step 2 has been completed and the sample has cooled, add 2 mL of water and 3 mL of 30% H_2O_2. Cover the vessel with a watch glass or vapor recovery device and return the covered vessel to the heat source for warming and to start the peroxide reaction. Care must be taken to ensure that losses do not occur due to excessively vigorous effervescence. Heat until effervescence subsides and cools the vessel.

NOTE: Alternatively, for direct energy coupled devices: After the Step 2 “NOTE” has been completed and the sample has cooled for 5 minutes, add slowly 10 mL of 30% H_2O_2. Care must be taken to ensure that losses do not occur due to excessive vigorous effervescence. Go to Step 2.3.

2.2. Continue to add 30% H_2O_2 in 1mL aliquots with warming until the effervescence is minimal or until the general sample appearance is unchanged.

NOTE: Do not add more than a total of 10 mL 30% $H_2 O_2$.

2.3. Cover the sample with a ribbed watch glass or vapor recovery device and continue heating the acid-peroxide digestate until the volume has been reduced to approximately 5 mL or heat at 95°C ± 5°C without boiling for two hours. Maintain a covering of solution over the bottom of the vessel at all times.

NOTE: Alternatively, for direct energy coupled devices: Heat the acid-peroxide digestate to 95°C ± 5°C in 6 minutes and remain at 95°C ± 5°C without boiling for10 minutes.

2.4. After cooling, dilute to 100 mL with water. Particulates in the digestate should then be removed by filtration, by centrifugation, or by allowing the sample to settle. The sample is now ready for analysis by GFAA or ICP-MS.

2.4.1. Filtration - Filter through Whatman No. 41 filter paper (or equivalent).

2.4.2. Centrifugation - Centrifugation at 2,000-3,000 rpm for 10 minutes is usually sufficient to clear the supernatant.

2.4.3. The diluted digestate solution contains approximately 5% (v/v) HNO_3. For analysis, withdraw aliquots of appropriate volume and add any required reagent or matrix modifier.

3. For the analysis of samples for FLAA or ICP-AES, add 10 mL conc. HCl to the sample digest from 2.3 and cover with a watch glass or vapor recovery device. Place the sample on/in the heating source and reflux at 95°C ± 5°C for 15 minutes.

NOTE: Alternatively, for direct energy coupling devices, such as a microwave, digest samples for analysis by FLAA and ICP-AES by adding 5 mL HCl and 10 mL $H_2 O_2$ to the sample digest from 2.3 and heat the sample to 95°C ± 5°C, reflux at 95°C ± 5°C without boiling for 5 minutes.

4. Filter the digestate through Whatman No. 41 filter paper (or equivalent) and collect filtrate in a 100-mL volumetric flask. Make to volume and analyze by FLAA or ICP-AES.

NOTE: Step 5 may be used to improve the solubility and recoveries of barium, lead, and silver when necessary. These steps are optional and are not required on a routine basis.

5. Add 2.5 mL conc. HNO_3 and 10 mL conc. HCl to a 1-2 g sample (wet weight) or 1 g sample (dry weight) and cover with a watch glass or vapor recovery device. Place the sample on/in the heating source and reflux for 15 minutes.

5.1. Filter the digestate through Whatman No. 41 filter paper (or equivalent) and collect filtrate in a 100mL volumetric flask. Wash the filter paper, while still in the funnel, with no more than 5 mL of hot (~95°C) HCl, then with 20 mL of hot (~95°C) reagent water. Collect washings in the same 100-mL volumetric flask.

5.2. Remove the filter and residue from the funnel, and place them back in the vessel. Add 5 mL of conc. HCl, place the vessel back on the heating sources and heat at 95°C ± 5°C until the filter paper dissolves. Remove the vessel from the heating source and wash the cover and sides with reagent water. Filter the residue and collect the filtrate in the same 100-mL volumetric flask. Allow filtrate to cool, then dilute to volume.

NOTE: High concentrations of metal salts with temperature-sensitive solubility can result in the formation of precipitates upon cooling of primary and/or secondary filtrates. If precipitation occurs in the flask upon cooling, do not dilute to volume.

5.3. If a precipitate forms on the bottom of a flask, add up to 10 mL of concentrated HCl to dissolve the precipitate. After precipitate is dissolved, dilute to volume with reagent water. Analyze by FLAA or ICP-AES.

- **Calculations**

1. The concentrations determined are to be reported on the basis of the actual weight of the sample. If a dry weight analysis is desired, then the percent solids of the sample must also be provided.

2. If percent solids are desired, a separate determination of percent solids must be performed on a homogeneous aliquot of the sample.

6.3.3 Method for Determining Chloride

Reference: USEPA Method 9212

- **Apparatus and Materials**

1. pH/mV meter capable of reading to 0.1 mV or an ISE meter.

2. Combination chloride ISE (Orion 9617 or equivalent), or separate chloride ISE (Orion 9417 or equivalent) and double-junction reference electrode (Orion 9002 or equivalent).

3. Thermally isolated magnetic stirrer, polytetrafluoroethylene (PTFE)-coated stir bar, and stopwatch.

4. Volumetric flask, 100 ml.

- **Reagents**

1. Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

2. Reagent water. All references to water in this method refer to reagent water.

3. ISA solution (5M $NaNO_3$): Dissolve 42.5 g of sodium nitrate in sufficient reagent water to make 100 ml of solution. It should be stored in a clean glass or plastic container.

4. Ethylenediaminetetraacetate (EDTA), disodium salt (2% $C_{10}H_{12}N_2O_8Na_2$).

5. Dilute sulfuric acid (0.01 M H SO_4)

6. Potassium bromate (1%, $KBrO_3$)

7. Chloride calibration stock solution (1,000 mg/L Cl^-): Dissolve 0.1649 g of sodium chloride (dried two hours at 110°C and stored in a desiccator) in reagent water and dilute to 100 ml in a volumetric flask. It should be stored in a clean bottle.

8. Chloride calibration standards: Prepare a series of calibration standards by diluting the 1,000 mg/L chloride standard. A suitable series is given in the table below.

ml of 1,000 mg/L Cl^- solution	**Concentration when Diluted to 50.0 ml (mg/L Cl^-)**
0.050	1.000
0.150	3.000
0.500	10.00
1.500	30.00
5.000	100.0

- **Procedure**

Calibration

1. If using a chloride combination ISE, ensure that the ISE is filled with the solution recommended by the manufacturer. Change the solution if the ISE has not been used for a week. If using a chloride ISE and a separate double-junction reference electrode ensure that reference electrode inner and outer chambers are filled with solutions recommended by the manufacturer. In either case, equilibrate the electrode(s) for at least one hour in a 30.0 mg/L chloride standard before use.

2. Calibrate the chloride ISE using standards that narrowly bracket the expected sample concentration. If the sample concentration is unknown, calibrate with 10.0 mg/L and 100 mg/L chloride standards. Add 50.0 mL of standard and 1.00 mL of ISA to a 100 mL beaker. Add a PTFE-coated magnetic stir bar, place the beaker on a magnetic stir plate, and stir at slow speed (no visible vortex). Immerse the electrode tips to just above the rotating stir bar. If using an ISE meter, calibrate the meter in terms of chloride concentration following the manufacturer's instructions. If using a pH/mV meter, record the meter reading (mV) as soon as the reading is stable, but in no case should the time exceed five minutes after immersing the electrode tips. Prepare a calibration curve by plotting measured potential (mV) as a function of the logarithm of chloride concentration. The slope must be 54-60 mV per decade of chloride concentration. If the slope is not acceptable, the ISE may not be working properly. For corrective action, consult the ISE operating manual.

3. Allow samples and standards to equilibrate to room temperature.

4. Prior to and between analyses, rinse the electrodes thoroughly with reagent water and gently shake off excess water. Low-level measurements are faster if the electrode tips are first immersed for five minutes in reagent water.

5. Add 50.0 mL of sample and 1.00 mL of ISA to a 100 mL beaker. Add a PTFE-coated magnetic stir bar. Place the beaker on a magnetic stir plate and stir at a slow speed (no visible vortex). Immerse the electrode tip(s) to just above the rotating stir bar. Record the meter reading (mV or concentration) as soon as the reading is stable, but in no case should the time exceed five minutes after immersing the electrode tips. If reading mV, determine chloride concentration from the calibration curve.

6. When analyses have been completed, rinse the electrodes thoroughly and store them in a 30.0 mg/L chloride standard solution. If the electrodes will not be used more than one day, drain the internal filling solutions, rinse with reagent water, and store dry.

6.3.4 Method for Determining Nitrate

Reference: APHA Method 4500-NO_3^-B

- **Apparatus**

Spectrophotometer, for use at 220 nm and 275 nm with matched silica cells of 1 cm or longer light path.

- **Reagents**

a. Nitrate free water: Use redistilled or distilled deionized water of highest purity to prepare all solutions and dilutions.

b. Stock nitrate solution: Dry potassium nitrate (KNO_3) in an oven at 105°C for 24h. Dissolve 0.7218 g in water and dilute to 1000 ml; 1,00 ml=100µg NO_3^--N. Preserve with 2 ml $CHCl_3$/L. This solution is stable for at least 6 months.

c. Nitrate solution: Dilute 100 ml stock nitrate solution to 1000 ml with water: 100 ml=10.0µg NO_3^--N. Preserve with 2 ml $CHCL_3$/L. This solution is stable for 6 months.

d. Hydrochloric acid solution, HCL , 1N

- **Procedure**

a. Treatment of sample: To 50 ml clear sample, filtered if necessary, add 1 ml HCl solution and mix thoroughly.

b. Preparation of standard curve: Prepare NO_3 calibration standards in the range 0 to 7 mg NO_3^- –N/L by diluting to 50 ml the following volumes of intermediate nitrate solution: 0, 1.00, 2.00, 4.00, 7.00…..35.0 ml. Treat NO_3 standards in same manner as samples.

c. Spectrophotometric measurement: Read absorbance or transmittance against redistilled water set at zero absorbance or 100% transmittance. Use a wavelength of 220 nm to obtain NO_3^- reading and wavelength of 275 nm to determine interference due to dissolved organic matter.

- **Calculation**

For samples and standards subtract two times the absorbance reading at 275 nm from the reading at 220 nm to obtain absorbance due to NO_3^-. Construct a standard curve by plotting absorbance due to NO_3^- against NO_3^--N concentration of standard. Using corrected sample absorbance, obtain sample concentrations directly from standard curve. NOTE: If correction value is more than 10% of the reading at 220 nm, do not use this method.

6.3.5 Method for Determining Phosphate

Reference: Olsen's Method

- **Apparatus**

1. Analytical balance, capable up to 0.001 g.
2. Reciprocal shaker, Everbach Model Cat. No. 6000-26.

3. Polyethylene bottles with good fitting tops (125 mL and 1L capacity).

4. Polypropylene funnels, 65 mm.

5. No. 40 Whattman filter paper, 11 cm.

6. 20 ml test tubes

7. Dispenser or repipet 50 ml or equivalent (calibrated at 50.00 ±0.20g).

8. Technicon Auto Analyzer II unit or any other equivalent continuous flow, segmented stream auto analyzer system.

9. Auto sampler sample cups.

10. Volumetric flasks.

11. Erlenmeyer flasks.

- **Reagents and Standards**

1. 0.05 % Polyacrylamide. Weigh 0.25 g polyacrylamide to 450 ml of double RO water and stir overnight with a magnetic stirrer. Make up to 500 ml (Do not try to add the double RO water to the polyacrylamide.)

2. 1N Sodium hydroxide for pH adjustment. Weigh 20 g of sodium hydroxide, dissolve and dilute with double RO water to 500 ml.

3. 0.5 M sodium bicarbonate, pH 8.5 with polyacrylamide (extracting solution). Weigh 168 g of sodium bicarbonate and place in a 4L Erlenmeyer flask. Dissolve in about 3,900 ml double RO water. Add 20 ml of 0.05% polyacrylamide. Adjust pH to 8.50 with 1N sodium hydroxide (approximately 60-80ml). Add enough double RO water to make to 4 L if necessary.

4. Auto Analyzer Reagents:

4.1 Wash solution - 0.5 M sodium bicarbonate, pH 8.5 with polyacrylamide (extracting solution).

4.2 2.5 N sulfuric acid - Add slowly 70 ml concentrated sulfuric acid to about 500 ml double RO water in a 1 L volumetric flask. Cool down and dilute to mark.

4.3 Acid molybdate - Dissolve 4.3 g ammonium molybdate tetrahydrate $(NH_4)_6Mo_7O_{24}.4H_2O)$ in about 200 ml of double RO water in a 1-liter volumetric flask. Add carefully 52 ml concentrated sulfuric acid. Make to volume with double RO water and shake well to mix.

4.4 1 %(w/v) Ascorbic acid solution (with SDS). Prepare this solution fresh each time before use. Dissolve 5g of ascorbic acid in 500 ml of double RO water. Add 10 -15 drops of 5% w/v sodium dodecyl sulfate (SDS) as a wetting agent to improve the auto analyzer bubble pattern.

5. Stock solution A (2000 ppm P) - Dry reagent grade potassium dihydrogen phosphate (KH_2PO_4) at 105OC for 2 hr. Cool in a dessicator. Accurately weigh out 4.394 g KH_2PO_4, dissolve in double RO water and dilute to 500 ml. Shake well to mix.

6. Intermediate standard solution B (100 ppm P) - Pipet 5.00 ml of the stock solution A containing 2000 ppm P and dilute to 100 ml with the extracting solution (0.5 M sodium bicarbonate, pH 8.5 with polyacrylamide). Shake well to mix.

7. Working standard solutions (0.5, 1, 2, 3, 4 and 5 ppm P) - Pipet 0.5, 1, 2, 3, 4, and 5 ml of the intermediate standard solution B containing 100 ppm P and dilute to 100 ml with the extracting solution (0.5 M sodium bicarbonate, pH 8.5 with polyacrylamide).

Concentration Of Working Std(ppm P)	**Intermediate Standard Soln, B(ml)**	**Final Volume(ml)**
0.5	0.5	100
1.0	1.0	100
2.0	2.0	100
3.0	3.0	100
4.0	4.0	100
5.0	5.0	100

8. Calibration blank – extracting solution (0.5 M sodium bicarbonate, pH 8.5 with polyacrylamide).

- **Procedure**

1. Sample Extraction

1.1 Weigh 2.50 g of 2 mm air-dried soil sample and place in a clean dry 125 ml polyethylene bottle. Run 2 blanks in the same way. Weigh also reference materials and sample repeats.

Note: Perform moisture determination by weighing another test portion according to QM-AD002-AP26 (Moisture Determination of Soil Samples) and incorporate results in the calculation of P when results are reported in oven-dry basis.

1.2 Add 50 ml of the extracting solution (0.5 M sodium bicarbonate, pH 8.5 with polyacrylamide) from a dispenser.

1.3 Place bottles in a reciprocating shaker and shake for 30 min.

1.4 Filter through no. 40 Whattman filter paper (11 cm) into a clean, dry 20 ml test tube.

1.5 Determine available phosphorus in the clear filtrate by colorimetry using Technicon II Autoanalyzer.

2. Colorimetric Determination of Phosphorus Using the Technicon AutoAnalyzer II. Refer to the Technicon AutoAnalyzer II Operations Manual for a complete and detailed operating procedure for the autoanalyzer. When determining phosphorus, ensure that the Olsen Phosphorus manifold is set-up for analysis.
AutoAnalyzer Settings:
Filter: 630 nm and Heating bath: 90°C

Function	Color	Block Position	Flow rate ml/min
Wash	Purple/orange	3U	3.40
Sample(from up)	Purple/purple	4U	2.50
H2SO4	Red/red	5L	0.80
Acid molybdate	Putple/purple	3L	2.50
Ascorbic acid	Red/red	6U	0.80
Air	Black/black	7U	0.32
Pull thro cell	Red/red	5U	0.80
Resample(from debubbler)	Blue/blue	2L	1.60

2.1 Set up autoanalyzer and analyze the samples.

2.2 Transfer adequate amount of the standards and samples into the auto sampler cups and start the sequence run.

2.3 After the last sample in the sequence has been taken for colorimetric analysis, turn OFF the auto sampler and timer.

2.4 Flush the system with deionized RO water for a minimum of 15 minutes (or as long as the dead time) before turning off the autoanalyzer.

- **Calculations**

Calculate soil P (mg/ kg) follows:

Soil P (mg/kg) = [(A x B x C x M)/E]
(Oven-dry basis)
Where:
A = Sample extract reading (mg/L)
B = Extract volume (ml)
C = Dilution, if performed
M = Moisture correction factor
E = Sample weight (g)

6.3.6 Method for Determining Sulfate

Reference: APHA Method 4500-$SO_4^{=}$E (Turbidimetric Method)

- **Apparatus**

1. Magnetic stirrer: Use a constant stirring speed. It is convenient to incorporate a fixed resistance in series with the motor operating the magnetic stirrer to regulate stirring speed. Use magnets of identical shape and size. The exact speed of stirring is not critical, but keeps it constant for each run of samples and standards and adjusts it to prevent splashing.

2. Photometer: One of the following is required, with preference in the order given:

a) Nephelometer.
b) Spectrometer, for use at 420nm, was providing a light path of 2.5 to 10 cm.
c) Filter photometer, equipped with a violet filter having maximum transmittance near 420 nm and providing a light path of 2.5 to 10 cm.

I. Stopwatch or electric timer.
II. Measuring spoon, capacity 0.2 to 0.3 ml.

- **Reagents**

a) **Buffer solution A:** Dissolve 30 g magnesium chloride, $MgCl_2.6H_2O$, 5 g sodium acetate, $CH_3COONa.3H_2O$, 1.0 g potassium nitrate, KNO_3, and 20 ml acetic acid, CH_3COOH (99%), in 500 ml distilled water and make up to 1000 ml.

b) **Buffer solution B (required when the sample SO_4 concentration is less than 10 mg/l):** Dissolve 30 g $MgCl_2.6H_2O$, 5 g $CH_3COONa.3H_2O$, 1.0 g KNO_3, 0.111 g sodium sulfate, Na_2SO_4, and 20 ml acetic acid (99%) in 500 ml distilled water and make up to 100 ml.

c) **Barium chloride, $BaCl_2$,** crystals, 20 to 30 mesh in standardization, uniform turbidity is produced with this mesh range and the appropriate buffer.

d) **Standard sulfate solution:** Prepare a standard sulfate solution as described in 1) or 2) below; 1.00 ml= 100µg SO4
  1) Dilute 10.4 ml standard 0.200*N* H_2SO_4 titrant to 100 ml with distilled water.
  2) Dissolve 0.1479 g anhydrous Na_2SO_4 in distilled water and dilute to 100ml.

- **Procedure**

1. **Formation of barium sulfate turbidity:** Measure 100 ml sample or a suitable portion made up to 100 ml, into a 250 ml Erlenmeyer flask. Add 20 ml 20 ml buffer solution and mix in stirring apparatus. While stirring, add a spoonful of $BaCl_2$ crystals and begin timing immediately. Stir for 60±2s at constant speed.

2. **Measurement of barium sulfate turbidity:** After stirring period has ended, pour solution into absorption cell of photometer and measure turbidity at 5± 0.5 min.

3. **Preparation of calibration curve:** Estimation SO_4 concentration in sample by comparing turbidity reading with a calibration curve prepared by carrying SO_4 standards through the entire procedure. Space standards at 5 mg/l increments in the 0 to 40mg/l SO_4 range. Above 40 mg/l accuracy decreases and $BaSO_4$ suspensions loss stability. Check reliability of calibration curve by running a standard with every three or four samples.

4. **Correction for sample color and turbidity:** Correct for sample color and turbidity by running blanks to which $BaCl_2$ is not added.

- **Calculations:**

$$\mathbf{mg\,SO_4^{=}\;/L\;=\frac{mg\,SO_4^{=}\times 1000}{mL\ sample}}$$

If buffer solution A was used, determine SO_4 concentration directly from the calibration curve after subtracting sample absorbance before adding $BaCl_2$. If buffer solution B was used subtract SO_4 concentration of blank from apparent SO_4 concentration as determined above: because the calibration curve is not a straight line, this is not equivalent to subtracting blank absorbance from sample absorbance.

6.3.7 Method for Determining Silica

Reference: IS 1727:1967(Reaffirmed 1999)

- Fuse one gram of the air dried, finely ground sample with about 7 g of anhydrous sodium carbonate in a covered platinum crucible. Raise the temperature slowly until frothing ceases, then complete the fusion at 1000°C for 30 minutes, occasionally swirling the melt to ensure thorough mixing. Quench the melt by immersing the bottom half of the crucible in cold water, then place the crucible and lid in about 100 ml of hot water contained in a platinum or porcelain evaporating basin. Cover the basin with a clock glass and add a few drops of absolute alcohol. Then gradually add 30 ml of hydrochloric acid (sp gr 1.16). Warm until the melt is completely disintegrated and remove the crucible and lid, washing them thoroughly and scrubbing them with a rubber- tipped rod. Crush any lumps remaining in the solution.

- Evaporate the solution, obtained from the fusion to dryness breaking up from time to time the crust that forms and hinder evaporation. When the residue is completely dry, cover the basin with a clock glass and drench the residue with about 20 ml of hydrochloric acid (sp gr 1.16). Allow to stand for a few minutes, and then add about 75 ml of hot water to dissolve the salts. Digest on a steam-bath for 5 minutes, and then filter through an ashless filter paper (No. 40 Whatman paper or equivalent). Transfer the silica to the filter with a jet of hot water; it is necessary to scrub the basin. Wash the residue five times with hot dilute hydrochloric acid (one percent) followed by hot water until it is free from chlorides. Reserve the residue and paper for the subsequent ignition, and transfer the filtrate and washings back to the evaporating basin.

- Again evaporate completely to dryness, cover the basin with a clock glass and bake in an air-oven for one hour at 110°C. Allow to cool, and then drench the residue with about 20 ml of hydrochloric acid (sp gr. 1.16). Allow to stand for a few minutes, add about 75 ml of hot water and digest for 5 minutes on a steam bath. Filter through another ash less filter paper (No. 40 Whitman paper or equivalent) transferring the residue to the rod. Wash five times with hot dilute hydrochloric acid (one percent), followed by hot water until the residue is free from chlorides. Reserve the filtrate and washings for the determination of ferric oxide and alumina.

- Place the two residues and papers, without drying, in a weighed platinum crucible and heat cautiously to dry the residue and char the papers. Then burn off the carbon and finally ignite at 1100 to 1200°C for 30 minutes and then to constant weight. Cool and weigh to obtain the weight of impure silica.

- Moisten the weighed residue with a few drops of dilute sulfuric acid (50 percent) and add about 10 ml of hydrochloric acid. Evaporate slowly to dryness on a sand-bath (or under a suitable radiant heater) in a fume hood. Ignite the dry residue at1050 to 1100C for five minutes, allow the crucible to cool and weigh. Subtract the weight of this residue from the weight of impure silica to obtain the amount of silica in the sample taken. If the residue weighs more than 5 mg, repeat the treatment with hydrofluoric and sulfuric acids to ensure that all the silica is removed.

- Add 0.5 g of sodium or potassium per sulfate to the crucible and treat below red heat until the small residue or impurities are dissolved in the melt. Cool, dissolve the fused mass in water; add it to the filtrate and washings reserved for the determination of the combined alumina and ferric oxide.

6.4 Embedment of Arsenic Bearing ECAR Sludge in Concrete

Arsenic bearing ECAR sludge had been embedded in concrete in variable proportions till the point of substantial deterioration of mechanical strength. The strength and workability of the prepared concrete along with leachatibility of the ECAR sludge from the concrete had been determined.

6.4.1 Characterization of Cement

Portland cements are commonly characterized by their physical properties for quality control purposes. Their physical properties can be used to classify and compare Portland cements. The challenge in physical property characterization is to develop physical tests that can satisfactorily characterize key parameters. Here we are going to use PPC grade of cement, where testing procedures are almost same as Portland cement.

The physical properties of cement that will be tested are:

1. Consistency
2. Setting Time
3. Soundness
4. Fineness
5. Strength

6.4.1.1 Test for Consistency of Cement

Reference: IS 4031(Part IV):1988

Standard consistency of a cement paste is defined as that consistency which will permit a vicat plunger having 10 mm dia and 50 mm length to penetrate to a depth of 33-35 mm from top of the mould.

- **Apparatus**

Measuring Instruments

Table 6.1: Measuring Instruments for Consistency Test of Cement

Name	Capacity/ Range/ Size	Accuracy/Least Count
Vicat Apparatus	Should be made as per IS: 5513	-
Balance	1000g	1g
Measuring Cylinder	100 ml	1 ml

Other Apparatus

Tray and glass plate

- **Procedure**

1. Take 400 g of cement and place it in the enameled tray.

2. Mix about 25% water by weight of dry cement thoroughly to get a cement paste. Total time taken to obtain thoroughly mixed water cement paste i.e. “Gauging time” should not be more than 3 to 5 minutes.

3. Fill the vicat mould, resting upon a glass plate, with this cement paste.

4. After filling the mould completely, smoothen the surface of the paste, making it level with top of the mould.

5. Place the whole assembly (i.e. mould + cement paste + glass plate) under the rod bearing plunger.

6. Lower the plunger gently so as to touch the surface of the test block and quickly release the plunger allowing it to sink into the paste.

7. Measure the depth of penetration and record it.

8. Prepare trial pastes with varying percentages of water content and follow the steps (2 to 7) as described above, until the depth of penetration becomes 33 to 35 mm.

- **Calculation**

Calculate percentage of water (P) by weight of dry cement required to prepare cement paste of standard consistency by following formula, and express it to the first place of decimal.

$$P = \frac{W}{C} \times 100$$

Where,
W=Quantity of water added
C=Quantity of cement used

6.4.1.2 Test for Setting Time of Cement

Reference: IS 4031(Part V):1988

Initial setting time is that time period between the time water is added to cement and time at which 1 mm square section needle fails to penetrate the cement paste, placed in the Vicat's mould 5 mm to 7 mm from the bottom of the mould.

Final setting time is that time period between the time water is added to cement and the time at which 1 mm needle makes an impression on the paste in the mould but 5 mm attachment does not make any impression.

- **Apparatus**

Measuring Instruments

Table 6.2: Measuring Instruments for Setting Time Test of Cement

Name	**Capacity/ Range/ Size**	**Accuracy/ Least Count**
Vicat Apparatus	Should be made as per IS: 5513	-
Balance	1000g	1g
Measuring Cylinder	100ml	1ml
Stop Watch	30min	0.2sec

Other Apparatus
Glass plate, enamel tray, trowel

- **Procedure**

(A)Test Block Preparation

1. Before commencing setting time test, do the consistency test to obtain the water required to give the paste normal consistency (P).

2. Take 400 g of cement and prepare a neat cement paste with 0.85P of water by weight of cement.
3. Gauge time is kept between 3 to 5 minutes. Start the stop watch at the instant when the water is added to the cement. Record this time (t_1).

4. Fill the Vicat mould, resting on a glass plate, with the cement paste gauged as above. Fill the mould completely and smooth off the surface of the paste making it level with the top of the mould. The cement block thus prepared is called test block.

(B)Initial Setting Time

1. Place the test block confined in the mould and resting on the non-porous plate, under the rod bearing the needle.
2. Lower the needle gently until it comes in contact with the surface of test block and quick release, allowing it to penetrate into the test block.

3. In the beginning the needle completely pierces the test block. Repeat this procedure i.e. quickly releasing the needle after every 2 minutes till the needle fails to pierce the block for about 5 mm measured from the bottom of the mould. Note this time (t_2).

(C)Final Setting Time

1. For determining the final setting time, replace the needle of the Vicat's apparatus by the needle with an annular attachment.

2. The cement is considered finally set when upon applying the final setting needle gently to the surface of the test block; the needle makes an impression thereon, while the attachment fails to do so. Record this time (t_3).

- **Calculation**

$$\boldsymbol{Initial\ Setting\ Time = t_2 - t_1}$$

$$\boldsymbol{Final\ Setting\ Time = t_3 - t_1}$$

Where,
t_1=Time at which water is first added to cement
t_2=Time when needle fails to penetrate 5 mm to 7 mm from bottom of the mould
t_3=Time when the needle makes an impression but the attachment fails to do so.

6.4.1.3Test for Soundness of Cement

Reference: Le-Chateliers Method as per IS 4031(Part III):1988

In the soundness test a specimen of hardened cement paste is boiled for a fixed time so that any tendency to expand is speeded up and can be detected. Soundness means the ability to resist volume expansion.

- **Apparatus**

Measuring Instruments

Table 6.3: Measuring Instruments for Soundness Test of Cement

Name	Capacity/ Range/ Size	Accuracy/ Least Count
Le-Chatelier Apparatus	Should be made as per IS:5514	_
Water Bath	100ºC (min)	1ºC
Caliper	30cm	0.5mm
Measuring Cylinder	100ml	1ml
Balance	100g	1g

Other Apparatus

Glass sheets (2 nos.), Enamel tray, and trowel

- **Procedure**

1. Before commencing setting time test, do the consistency test to obtain the water required to give the paste normal consistency (P).

2. Prepare a paste by adding 0.78 times the water required to give a paste of standard consistency (i.e. 0.78P).

3. Lightly oil the Le-Chatelier mould and place it on a lightly oiled glass sheet.

4. Fill the mould with the prepared cement paste. In the process of filling the mould keep the edge of the mould gently together.
5. Cover the mould with another piece of lightly oiled glass sheet; place a small weight on this covering glass sheet.

6. Submerge the whole assembly in water at a temperature of 27 ± 2^0 C and keep there for 24 hours.

7. Remove the whole assembly from water bath and measure the distance separating the indicator points to the nearest 0.5 mm (L_1).

8. Again submerge the whole assembly in water bath and bring the temperature of water bath to boiling temperature in 25 to 30 minutes. Keep it at boiling temperature for a period of 3 hours.

9. After completion of 3 hours, allow the temperature of the water bath to cool down to room temperature and remove the whole assembly from the water bath.

10. Measure the distance between the two indicator points to the nearest 0.5 mm (L_2).

- **Calculations**

$$\boldsymbol{Soundness = L_1 - L_2}$$

Where
L_1=Measurement taken after 24 hours of immersion in water at a temp. of 27 ± 2^0 C
L_2=Measurement taken after 3 hours of immersion in water at boiling temperature.

6.4.1.4 Test for Fineness of Cement

Reference: Dry Sieving Method as per IS 4031(Part I):1996

Fineness of cement is measured by sieving it on standard sieve. The proportion of cement of which the grain sizes are larger than the specified mesh size is thus determined.

- **Apparatus**

Measuring Instruments

Table 6.4: Measuring Instruments for Fineness Test of Cement

Name	**Capacity/ range/ size**	**accuracy/ least count**
sieve	90 micron mesh	_
balance	10g (max)	10mg

Other Apparatus
Glass rod, stoppered jar, pan, and lid

- **Procedure**

1. Agitate the sample of cement to be tested by shaking for 2 minutes in a stoppered jar to disperse agglomerates. Stir the resulting powder gently using a clean dry rod in order to distribute the fines throughout the cement.

2. Attach a pan under the sieve to collect the cement passing the sieve.

3. Weigh approximately 10 g of cement to the nearest 0.01 g and place it on the sieve. Fit the lid over the sieve.

4. Agitate the sieve by swirling, planetary and linear movement until no more fine material passes through it.

5. Remove and weigh the residue. Express its mass as a percentage (R_1) of the quantity first placed in the sieve.

6. Repeat the steps 3 to 5 with a fresh sample to obtain R_2.

Note: If R_1 & R_2 differ by more than 1%, then carryout a third sieving and calculate R_3.

- **Calculation**

Calculate the residue of cement R as the mean of R_1 & R_2 (or R_1, R_2 & R_3) in %, expressed to the nearest 0.1%.

6.4.1.5 Test for Compressive Strength of Cement

Reference: IS 4301(Part VI):1988

Compressive strength of cement is determined by compressive strength test on mortar cubes compacted by means of a standard vibration machine. Standard sand (IS: 650) is used for the preparation of cement mortar. The specimen is in the form of cubes 70.6mmX70.6mmX70.6mm.

- **Apparatus**

Measuring Instruments

Table 6.5: Measuring Instruments for Compressive Strength Test of Cement

Name	**Capacity/ Range/ Size**	**Accuracy/ Least Count**
Cube Mould	70.6X70.6X70.6 mm^3 (IS 10080)	_
Vibration Machine	Should be as per IS 10080	-
Balance	1000g	1g
Measuring Cylinder	200ml	1ml

Other Apparatus

Enamel tray, Trowel, Poking rod

- **Procedure**

1. Take 200 g of cement and 600 g of standard sand and mix them dry thoroughly.

2. Add $(\frac{P}{4} + 3)\%$ of water (where P is % of water required for preparing paste of standard consistency) to the dry mix of cement and sand and mix thoroughly for a minimum of 3 minutes and maximum of 4 minutes to obtain a mix of uniform color. If even in 4 minutes uniform color of the mix is not obtained reject the mix and mix fresh quantities of cement, sand and water to obtain a mix of uniform color.

3. Place the thoroughly cleaned and oiled (on interior face) mould on the vibrating machine and hold it in position by clamps provided on the machine for the purpose.

4. Fill the mould with entire quantity of mortar using a suitable hopper attached to the top of the mould for facility of filling and vibrate it for 2 minutes at a specified speed of 12000±400 per minute to achieve full compaction.

5. Remove the mould from the machine and keep it in a place with temp of 27 ± 2^0C and relative humidity of 90% for 24 hours.

6. At the end of 24 hrs remove the cube from the mould and immediately submerge in fresh clean water. The cube is taken out of the water only at the time of testing.

7. Prepare at least 6 cubes in the manner explained above.

8. Place the test cube on the platform of a compressive testing machine without any packing between the cube and the plates of the testing machine.

9. Apply the load steadily and uniformly, starting from zero at a rate of 35 N/mm^2/minute.

- **Calculation**

$$\boldsymbol{Compressive\ Strength = \frac{P}{A}}$$

Where,
P=Maximum load applied to the cube. (N)
A=Cross sectional area (Calculated from the mean dimensions) (mm^2)
Compressive strength is reported to the nearest 0.5 N/mm^2.
NOTE: Specimens that are manifestly faulty, or that give strengths differing by more than 10% from the average value of the entire test specimen should not be considered. Test three cubes for compressive strength for each period of curing.

6.4.1.6 Arsenic Content of Cement

The arsenic content of the cement had been determined as per the guidelines outlined in 6.3.2

6.4.2 Characterization of Water

The water used during preparation of concrete mixture and also for curing has been tested for the following parameters as per the guidelines outlined in APHA-AWWA-WPCF (1999):
i. pH
ii. Alkalinity
iii. Acidity
iv. Chloride

v. Sulfate
vi. Volatile Dissolved Solid
vii. Fixed Dissolved Solid
viii. Suspended Matter
ix. Arsenic Content

6.4.3 Characterization of Sand

Mainly medium sand (zone-II) is preferable for concrete work. So, the sieve analysis as per IS 2386 (Part I):1963 of the used sand sample has been done to confirm the zone-II sand.

6.4.4 Characterization of Coarse Aggregate

Our approach is to find out a combined mixed Coarse aggregate of 20 mm Nominal size by taking individual coarse aggregate Type-I and Type-II in a ratio. To find out that ratio we need to do the sieve analysis as per IS 2386 (Part I):1963 of each type of Coarse Aggregate.

6.4.5 Mix Design of M20 Grade Concrete

Reference: IS: 10262:2009

i. Grade designation: M20
ii. Type of cement: PPC
iii. Maximum nominal size of aggregates: 20mm
iv. Workability: Low (25-75mm slump height) *[as per Clause no. 7 of IS 456:2000]*
v. Compacting Factor: 0.80-0.85 *[as per Table 22 of SP 23:1982]*
vi. Exposure condition: Mild *[as per Table 3 of IS 456:2000]*
vii. Minimum cement content: 220 Kg/m^3 for PCC and 300 Kg/m^3 for RCC *[as per Table 5 of IS 456:2000]*
viii. Maximum free water-cement ratio: 0.6 for PCC and 0.55 for RCC *[as per Table 5 of IS 456:2000]*
ix. Maximum cement content: 450 kg/m^3 *[as per Clause no. 8.2.4.2 of IS 456:2000]*
x. Specific gravity of cement: 3.15
xi. Specific gravity of coarse aggregate: 2.74
xii. Specific gravity of fine aggregate: 2.70

A) Target Strength for Concrete:

$$\mathbf{f_{ck}}' = \mathbf{f_{ck}} + \mathbf{1.65}\boldsymbol{s}$$

Where
f_{ck}' = target average compressive strength at 28 days
f_{ck} = characteristic compressive strength at 28 days
s = standard deviation

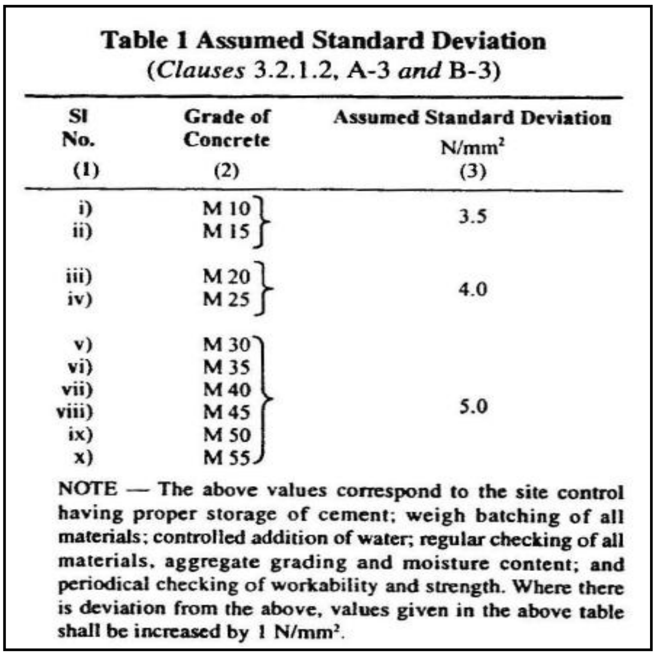

Table 1 Assumed Standard Deviation

(*Clauses* 3.2.1.2, A-3 *and* B-3)

Sl No. (1)	Grade of Concrete (2)	Assumed Standard Deviation N/mm² (3)
i)	M 10	3.5
ii)	M 15	
iii)	M 20	4.0
iv)	M 25	
v)	M 30	5.0
vi)	M 35	
vii)	M 40	
viii)	M 45	
ix)	M 50	
x)	M 55	

NOTE — The above values correspond to the site control having proper storage of cement; weigh batching of all materials; controlled addition of water; regular checking of all materials, aggregate grading and moisture content; and periodical checking of workability and strength. Where there is deviation from the above, values given in the above table shall be increased by 1 N/mm².

From Table 1 of IS 10262:2009 for M20 grade concrete, standard deviation, s = 4.0 N/mm^2

Therefore, target strength = 20 +1.65×4 = 26.6 N/mm^2

B) Selection of Water-Cement Ratio:

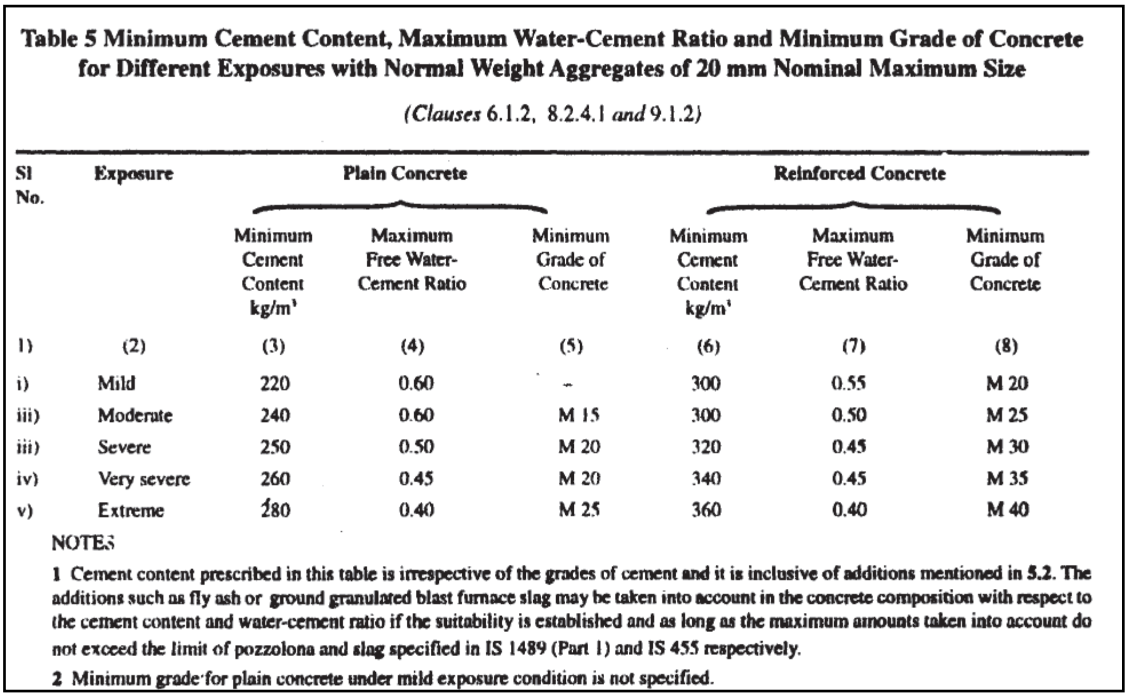

Table 5 Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum Size

(*Clauses* 6.1.2, 8.2.4.1 *and* 9.1.2)

Sl No.	Exposure	Plain Concrete			Reinforced Concrete		
		Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete	Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete
1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Mild	220	0.60	–	300	0.55	M 20
iii)	Moderate	240	0.60	M 15	300	0.50	M 25
iii)	Severe	250	0.50	M 20	320	0.45	M 30
iv)	Very severe	260	0.45	M 20	340	0.45	M 35
v)	Extreme	280	0.40	M 25	360	0.40	M 40

NOTES

1 Cement content prescribed in this table is irrespective of the grades of cement and it is inclusive of additions mentioned in 5.2. The additions such as fly ash or ground granulated blast furnace slag may be taken into account in the concrete composition with respect to the cement content and water-cement ratio if the suitability is established and as long as the maximum amounts taken into account do not exceed the limit of pozzolona and slag specified in IS 1489 (Part 1) and IS 455 respectively.

2 Minimum grade for plain concrete under mild exposure condition is not specified.

From Table 5 of IS 456:2000, maximum water-cement ratio = 0.55 for RCC
Based on experience adopted water-cement ratio is 0.50 and 0.50<0.55, hence it is OK.

C) Selection of Water Content:

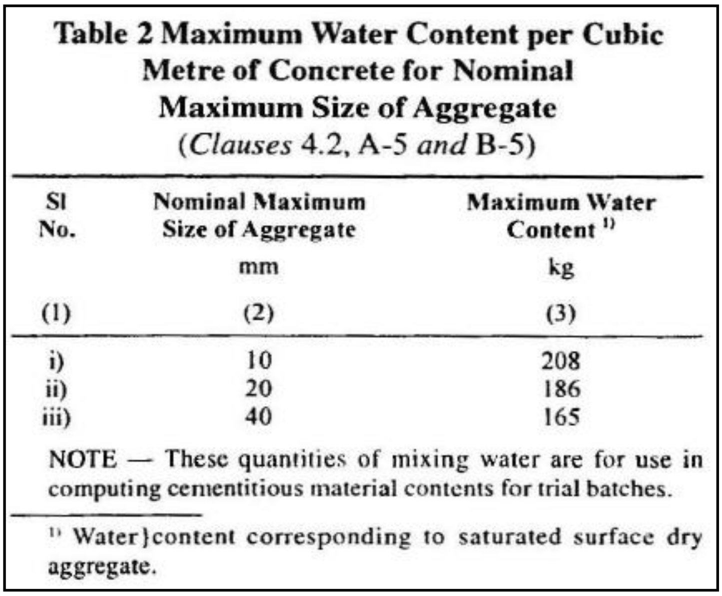

Table 2 Maximum Water Content per Cubic Metre of Concrete for Nominal Maximum Size of Aggregate
(*Clauses* 4.2, A-5 *and* B-5)

Sl No. (1)	Nominal Maximum Size of Aggregate mm (2)	Maximum Water Content [1] kg (3)
i)	10	208
ii)	20	186
iii)	40	165

NOTE — These quantities of mixing water are for use in computing cementitious material contents for trial batches.

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[1] Water}content corresponding to saturated surface dry aggregate.

From Table 2 of IS 10262:2009, maximum water content per cubic metre of concrete for 20mm nominal maximum size of aggregate and for slump of 25-50 mm range is 186 liters.

D) Calculation of Cement Content:

Water-cement ratio = 0.50

Cement content = $\frac{186}{0.50} = 372$ Kg/m^3

From Table 5 of IS 456:2000, minimum cement content for mild exposure condition = 300 Kg/m^3

As 372 Kg/m^3 > 300 Kg/m^3, hence it is OK.

E) Proportion of Volume of Coarse Aggregate and Fine Aggregate:

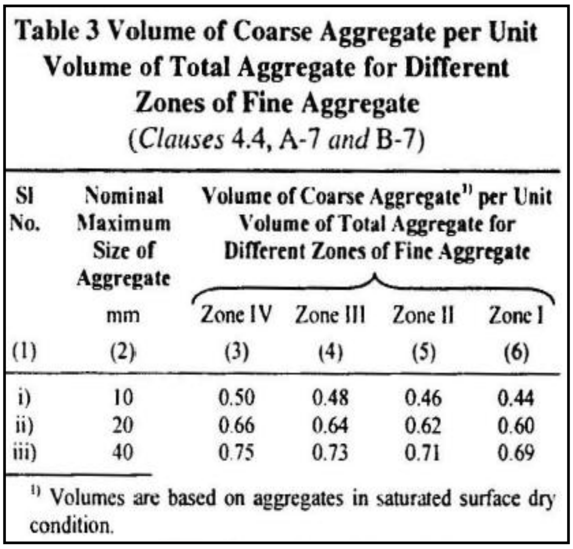


Table 3 Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate
(*Clauses* 4.4, A-7 *and* B-7)

Sl No.	Nominal Maximum Size of Aggregate	Volume of Coarse Aggregate[1] per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate			
	mm	Zone IV	Zone III	Zone II	Zone I
(1)	(2)	(3)	(4)	(5)	(6)
i)	10	0.50	0.48	0.46	0.44
ii)	20	0.66	0.64	0.62	0.60
iii)	40	0.75	0.73	0.71	0.69

---

[1] Volumes are based on aggregates in saturated surface dry condition.

From Table 3 of IS 10262:2009, volume of coarse aggregate per unit volume of total aggregate corresponding to 20 mm nominal maximum size aggregate and fine aggregate confirming to Zone II of IS 383:1970 and for water-cement ratio of 0.50 is 0.62 m^3.

Therefore volume of fine aggregates content = 1 – 0.62 = 0.38 m^3

F) Mix Calculations:

The mix calculations per unit volume of concrete shall be as follows:

i. Volume of concrete = $1m^3$

ii. Volume of cement = $\frac{\text{Mass of cement}}{\text{Specific gravity of cement}} \times \frac{1}{1000} = \frac{372}{3.15} \times \frac{1}{1000} = 0.118\ \text{m}^3$

iii. Volume of water = $\frac{\text{Mass of water}}{\text{Specific gravity of water}} \times \frac{1}{1000} = \frac{186}{1} \times \frac{1}{1000} = 0.186\ \text{m}^3$

iv. Volume of all in aggregate = [i – (ii + iii)] = 1 – (0.118+0.186) = 0.696 m^3

v. Mass of coarse aggregate =

$$(\text{iv } \times \text{Volume of coarse aggregate } \times \text{Specific gravity of coarse aggreagte} \times 1000) = 0.696 \times 0.62 \times 2.74 \times 1000 = 1182\ \text{Kg}$$

vi. Mass of fine aggregate =

$$(\text{iv } \times \text{Volume of fine aggregate } \times \text{Specific gravity of fine aggreagte} \times 1000) = 0.696 \times 0.38 \times 2.70 \times 1000 = 714\ \text{Kg}$$

So Cement: Fine Aggregate: Coarse Aggregate = 372: 714: 1182 = 1:1.92: 3.18

6.4.6 Mix Design of M15 Grade Concrete

i. Grade designation: M15
ii. Type of cement: PPC
iii. Maximum nominal size of aggregates: 20mm
iv. Workability: Low (25-75mm slump height) *[as per Clause no. 7 of IS 456:2000]*
v. Compacting Factor: 0.80-0.85 *[as per Table 22 of SP 23:1982]*
vi. Exposure condition: Moderate *[as per Table 3 of IS 456:2000]*
vii. Minimum cement content: 240 Kg/m^3 for PCC [*as per Table 5 of IS 456:2000]*
viii. Maximum free water-cement ratio: 0.6 for PCC [*as per Table 5 of IS 456:2000]*
ix. Maximum cement content: 450 kg/m^3 *[as per Clause no. 8.2.4.2 of IS 456:2000]*
x. Specific gravity of cement: 3.15

xi. Specific gravity of coarse aggregate: 2.74
xii. Specific gravity of fine aggregate: 2.70

A) Target Strength for Concrete:

$$\mathbf{f_{ck}} = \mathbf{f_{ck}} + \mathbf{1.65}\boldsymbol{s}$$

Where
f_{ck}' = target average compressive strength at 28 days
f_{ck} = characteristic compressive strength at 28 days
s = standard deviation

From Table 1 of IS 10262:2009 for M20 grade concrete, standard deviation, s = 3.5 N/mm^2

Therefore, target strength = 15 +1.65×3.5 = 20.775 N/mm^2

B) Selection of Water-Cement Ratio:

From Table 5 of IS 456:2000, maximum water-cement ratio = 0.6 for PCC
Based on experience adopted water-cement ratio is 0.55 and 0.55<0.6, hence it is OK.

C) Selection of Water Content:

From Table 2 of IS 10262:2009, maximum water content per cubic metre of concrete for 20mm nominal maximum size of aggregate and for slump of 25-50 mm range is 186 liters.

D) Calculation of Cement Content:

Water-cement ratio = 0.55
Cement content = $\frac{186}{0.55} = 338.18$ Kg/m^3
From Table 5 of IS 456:2000, minimum cement content for mild exposure condition = 240 Kg/m^3
As 338.18 Kg/m^3 > 240 Kg/m^3, hence it is OK.

E) Proportion of Volume of Coarse Aggregate and Fine Aggregate:

From Table 3 of IS 10262:2009, volume of coarse aggregate per unit volume of total aggregate corresponding to 20 mm nominal maximum size aggregate and fine aggregate confirming to Zone II of IS 383:1970 and for water-cement ratio of 0.55 is 0.61 m^3.

Therefore volume of fine aggregates content = 1 – 0.61 = 0.39 m^3

F) Mix Calculations:

The mix calculations per unit volume of concrete shall be as follows:

i. Volume of concrete = 1m^3

ii. Volume of cement = $\frac{\text{Mass of cement}}{\text{Specific gravity of cement}} \times \frac{1}{1000} = \frac{338.18}{3.15} \times \frac{1}{1000} = 0.107\text{m}^3$

iii. Volume of water = $\frac{\text{Mass of water}}{\text{Specific gravity of water}} \times \frac{1}{1000} = \frac{186}{1} \times \frac{1}{1000} = 0.186\text{ m}^3$

iv. Volume of all in aggregate = [i – (ii + iii)] = 1 – (0.107+0.186) = 0.707 m^3

v. Mass of coarse aggregate =

$$(\text{iv} \times \text{Volume of coarse aggregate} \times \text{Specific gravity of coarse aggreagte} \times 1000)$$
$$= 0.707 \times 0.61 \times 2.74 \times 1000 = 1182\text{ Kg}$$

vi. Mass of fine aggregate =

$$(\text{iv} \times \text{Volume of fine aggregate} \times \text{Specific gravity of fine aggreagte} \times 1000)$$
$$= 0.707 \times 0.39 \times 2.70 \times 1000 = 745\text{ Kg}$$

So Cement: Fine Aggregate: Coarse Aggregate = 338.18: 745: 1182 = 1:2.203: 3.495

6.4.7 Mix Design of M25 Grade Concrete

i. Grade designation: M25
ii. Type of cement: PPC
iii. Maximum nominal size of aggregates: 20mm
iv. Workability: Low (25-75mm slump height) *[as per Clause no. 7 of IS 456:2000]*
v. Compacting Factor: 0.80-0.85 *[as per Table 22 of SP 23:1982]*
vi. Exposure condition: Moderate *[as per Table 3 of IS 456:2000]*
vii. Minimum cement content: 240 Kg/m^3 for PCC and 300 Kg/m^3 for RCC [*as per Table 5 of IS 456:2000]*
viii. Maximum free water-cement ratio: 0.6 for PCC and 0.5 for RCC [*as per Table 5 of IS 456:2000]*
ix. Maximum cement content: 450 kg/m^3 *[as per Clause no. 8.2.4.2 of IS 456:2000]*
x. Specific gravity of cement: 3.15
xi. Specific gravity of coarse aggregate: 2.74
xii. Specific gravity of fine aggregate: 2.70

A) Target Strength for Concrete:

$$\mathbf{f_{ck}} = \mathbf{f_{ck}} + \mathbf{1.65s}$$

Where
f_{ck}' = target average compressive strength at 28 days
f_{ck} = characteristic compressive strength at 28 days
s = standard deviation

From Table 1 of IS 10262:2009 for M20 grade concrete, standard deviation, s = 4.0 N/mm^2

Therefore, target strength = 25 +1.65×4 = 31.6 N/mm^2

B) Selection of Water-Cement Ratio:

From Table 5 of IS 456:2000, maximum water-cement ratio = 0.5 for RCC
Based on experience adopted water-cement ratio is 0.47 and 0.47<0.5, hence it is OK.

C) Selection of Water Content:

From Table 2 of IS 10262:2009, maximum water content per cubic metre of concrete for 20mm nominal maximum size of aggregate and for slump of 25-50 mm range is 186 liters.

D) Calculation of Cement Content:

Water-cement ratio = 0.47
Cement content = $\frac{186}{0.47} = 395$ Kg/m^3
From Table 5 of IS 456:2000, minimum cement content for mild exposure condition = 240 Kg/m^3
As 395 Kg/m^3 > 240 Kg/m^3, hence it is OK.

E) Proportion of Volume of Coarse Aggregate and Fine Aggregate:

From Table 3 of IS 10262:2009, volume of coarse aggregate per unit volume of total aggregate corresponding to 20 mm nominal maximum size aggregate and fine aggregate confirming to Zone II of IS 383:1970 and for water-cement ratio of 0.47 is 0.626 m^3.

Therefore volume of fine aggregates content = 1 – 0.626 = 0.374 m^3

F) Mix Calculations:

The mix calculations per unit volume of concrete shall be as follows:

i. Volume of concrete = 1m^3

ii. Volume of cement = $\frac{\text{Mass of cement}}{\text{Specific gravity of cement}} \times \frac{1}{1000} = \frac{395}{3.15} \times \frac{1}{1000} = 0.1254\text{m}^3$

iii. Volume of water = $\frac{\text{Mass of water}}{\text{Specific gravity of water}} \times \frac{1}{1000} = \frac{186}{1} \times \frac{1}{1000} = 0.186\ \text{m}^3$

iv. Volume of all in aggregate = [i – (ii + iii)] = 1 – (0.1254+0.186) = 0.6886 m^3

v. Mass of coarse aggregate =

$$(\text{iv } \times \text{Volume of coarse aggregate } \times \text{Specific gravity of coarse aggreagte} \times 1000)$$
$$= 0.6886 \times 0.626 \times 2.74 \times 1000 = 1181\ \text{Kg}$$

vi. Mass of fine aggregate =

$$(\text{iv } \times \text{Volume of fine aggregate } \times \text{Specific gravity of fine aggreagte} \times 1000)$$
$$= 0.6886 \times 0.374 \times 2.70 \times 1000 = 695\ \text{Kg}$$

So Cement: Fine Aggregate: Coarse Aggregate = 395: 695: 1181 = 1:1.7594: 3

6.4.8 Mix Design of M30 Grade Concrete

i. Grade designation: M30
ii. Type of cement: PPC
iii. Maximum nominal size of aggregates: 20mm
iv. Workability: Low (25-75mm slump height) *[as per Clause no. 7 of IS 456:2000]*
v. Compacting Factor: 0.80-0.85 *[as per Table 22 of SP 23:1982]*
vi. Exposure condition: Moderate *[as per Table 3 of IS 456:2000]*
vii. Minimum cement content: 240 Kg/m^3 for PCC and 300 Kg/m^3 for RCC [*as per Table 5 of IS 456:2000]*
viii. Maximum free water-cement ratio: 0.6 for PCC and 0.5 for RCC [*as per Table 5 of IS 456:2000]*
ix. Maximum cement content: 450 kg/m^3 *[as per Clause no. 8.2.4.2 of IS 456:2000]*
x. Specific gravity of cement: 3.15
xi. Specific gravity of coarse aggregate: 2.74
xii. Specific gravity of fine aggregate: 2.70

A) Target Strength for Concrete:

$$\mathbf{f_{ck}} = \mathbf{f_{ck}} + \mathbf{1.65}\boldsymbol{s}$$

Where
f_{ck}' = target average compressive strength at 28 days
f_{ck} = characteristic compressive strength at 28 days
s = standard deviation

From Table 1 of IS 10262:2009 for M20 grade concrete, standard deviation, s = 5.0 N/mm^2

Therefore, target strength = 30 +1.65×5 = 38.25 N/mm^2

B) Selection of Water-Cement Ratio:

From Table 5 of IS 456:2000, maximum water-cement ratio = 0.5 for RCC
Based on experience adopted water-cement ratio is 0.43 and 0.43<0.5, hence it is OK.

C) Selection of Water Content:

From Table 2 of IS 10262:2009, maximum water content per cubic metre of concrete for 20mm nominal maximum size of aggregate and for slump of 25-50 mm range is 186 liters.

D) Calculation of Cement Content:

Water-cement ratio = 0.43
Cement content = $\frac{186}{0.43} = 433$ Kg/m^3
From Table 5 of IS 456:2000, minimum cement content for mild exposure condition = 240 Kg/m^3
As 433 Kg/m^3 > 240 Kg/m^3, hence it is OK.

E) Proportion of Volume of Coarse Aggregate and Fine Aggregate:

From Table 3 of IS 10262:2009, volume of coarse aggregate per unit volume of total aggregate corresponding to 20 mm nominal maximum size aggregate and fine aggregate confirming to Zone II of IS 383:1970 and for water-cement ratio of 0.47 is 0.634 m^3.

Therefore volume of fine aggregates content = 1 – 0.634 = 0.366 m^3

F) Mix Calculations:

The mix calculations per unit volume of concrete shall be as follows:

i. Volume of concrete = 1m^3

ii. Volume of cement = $\frac{\text{Mass of cement}}{\text{Specific gravity of cement}} \times \frac{1}{1000} = \frac{433}{3.15} \times \frac{1}{1000} = 0.1375\text{m}^3$

iii. Volume of water = $\frac{\text{Mass of water}}{\text{Specific gravity of water}} \times \frac{1}{1000} = \frac{186}{1} \times \frac{1}{1000} = 0.186 \text{ m}^3$

iv. Volume of all in aggregate = [i – (ii + iii)] = 1 – (0.1375+0.186) = 0.6765 m^3

v. Mass of coarse aggregate =

$$(\mathrm{iv}\ \times \text{Volume of coarse aggregate}\ \times \text{Specific gravity of coarse aggreagte} \times 1000)$$
$$=\ 0.6765 \times 0.634 \times 2.74 \times 1000 = 1175\ \mathrm{Kg}$$

vi. Mass of fine aggregate =

$$(\mathrm{iv}\ \times \text{Volume of fine aggregate}\ \times \text{Specific gravity of fine aggreagte} \times 1000)$$
$$=\ 0.6765 \times 0.366 \times 2.70 \times 1000 = 669\ \mathrm{Kg}$$

So Cement: Fine Aggregate: Coarse Aggregate = 433: 669: 1175 = 1:1.545: 2.714

6.4.9 Method for Determining Workability of Prepared Concrete

Reference: IS 1199:1959

Slump Cone Test of Fresh Concrete

- Equipment & Apparatus

1. Slump cone (Height = 30 cm, Base diameter = 20 cm, Top diameter = 10 cm)
2. Tamping rod (Length = 60 cm, Diameter = 16 mm)

- Procedure

1. The internal surface of the mould is thoroughly cleaned and freed from superfluous moisture before commencing the test. And if the cone is in completely dry condition then dampen it using a damp cloth.

2. The mould is then placed on a smooth, horizontally leveled rigid and non-absorbent surface such as a rigid plate. It is held firmly in place during filling by the operator by standing on the two foot pieces provided in the slump cone.
3. The mould is filled by concrete in four layers, each approximately one-quarter of height of the mould, and each layer is tamped down with 25 strokes of tamping rod with pointed end in a uniform manner.

4. After tamping the top layer, the concrete is struck off level with a trowel and any mortar leaked out between the mould and base plate is cleaned away.

5. The mould is then removed from the concrete immediately by raising it slowly and carefully in a vertical direction.

- Calculation

The slump is measured immediately by determining the difference between the height of the mould and that of the highest point of specimen and reported in terms of millimeters to the nearest 5 mm of subsidence of the specimen during the test.

6.4.10 Test for Compressive Strength of Prepared Concrete

Reference: IS 516:1959

➢ **Equipment & Apparatus**

1. Compression testing machine (2000 KN)
2. Curing tank
3. Balance (0-10 Kg)

➢ **Procedure**

1. Representative samples of concrete shall be taken and used for casting cubes 10 cm x 10 cm x 10 cm.

2. The concrete shall be filled into the moulds in layers approximately 3 cm deep. It would be distributed evenly and compacted either by vibration or by hand tamping. After the top layer has been compacted, the surface of concrete shall be finished level with the top of the mould using a trowel; and covered with a glass plate to prevent evaporation.

3. The specimen shall be stored at site for 24+ ½ h under damp matting or sack. After that, the samples shall be stored in clean water at $27+2^0$C; until the time of test. The ends of all cylindrical specimens that are not plane within 0.05 mm shall be capped.

4. Just prior to testing, the cylindrical specimen shall be capped with sulphur mixture comprising 3 parts sulphur to 1 part of inert filler such as fire clay.

5. Specimen shall be tested immediately on removal from water and while they are still in wet condition.
6. The bearing surface of the testing specimen shall be wiped clean and any loose material removed from the surface. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load cube as cast, that is, not to the top and bottom.

7. Align the axis of the specimen with the steel plates, do not use any packing.

8. The load shall be applied slowly without shock and increased continuously at a rate of approximately 140 kg/sq.cm/min until the resistance of the specimen to the increased load breaks down and no greater load can be sustained. The maximum load applied to the specimen shall then be recorded and any unusual features noted at the time of failure brought out in the report.

- **Calculation**

Compressive strength is calculate using the following formula

$$\boldsymbol{Compressive\ Strength = \frac{W_f}{A_p}}$$

Where

W_f = Maximum applied load just before load, (kg)

A_p = Plan area of cube mould, (mm^2)

6.4.11 Method for Determining Leachability

- **Toxicity Characteristic Leaching Procedure (TCLP)**

Reference: USEPA Method 1311

- **Apparatus:**

1. Agitation apparatus: The agitation apparatus must be capable of rotating the extraction vessel in an end-over-end fashion at 30 ±2 rpm.

2. Extraction vessels: Jars or bottles with sufficient capacity to hold the sample and extraction fluid. Two liter normal capacity bottles are recommended. The vessel type is determined by the analysis of interest.

3. Filtration devices

4. Filter holders: Any filter holder, which meets all of the following requirements. Capable of supporting a 0.6 to 0.8 µm glass fiber filter membranes. Has a minimum internal volume of 300 ml (1.5 L recommended) can hold a filter of minimum size 47 mm in diameter (142 mm filter diameter recommended). Positive pressure filtration units capable of exerting pressures of 350 KPa or more which are commonly called “Hazardous Waste Filtration Units”.
5. NOTE: If the leachate is to be analyzed for metals, the filter must be prewashed with 1 M nitric acid, rinsed with double distilled water (DDW) and dried before use. Acid washed filters may also be used for other non-volatile extracts.

6. pH meter: Calibrated to within ± 0.05 pH units at 25°C.

- **Reagents**

All reagents should be of recognized analytical reagent grade.

1. Nitric Acid, 1M
2. Hydrochloric Acid, 1M
3. Sodium Hydroxide, 1M
4. Glacial Acetic Acid

- **Extraction Fluid**

Extraction fluid No 1: Add 5.7 ml of glacial acetic acid to 500 ml DDW, add 64.3 ml of 1 M NaOH and dilute to 1 litre. The pH of this fluid should be 4.93±0.05

Extraction fluid No 2: Dilute 5.7 ml of glacial acetic acid to 1 litre. The pH of this fluid should be 2.88±0.05.

NOTE: The extraction fluids should be monitored frequently for impurities and the pH checked before use. Discard if impurities are found or pH is not within specifications.

- **Procedure**

A minimum of 100 g of sample is required for analysis.

1. **Crushing or Grinding**

Examine the sample. The solid has to be able to pass through a 9.5 mm sieve. Otherwise, grind or crush the solid sample to this size.

2. **Determination of Appropriate Extraction Fluid**

i. Transfer 5.0 g ± 0.1g of the sample (<9.5 mm) into a 500 ml beaker or Erlenmeyer flask.

ii. Add 96.5 ml of DDW to the beaker, cover with a watch glass and stir vigorously for 5 minutes using a magnetic stirrer.

iii. Measure and record the pH. If the pH is ≤ 5.0, use extraction fluid no 1

iv. If the pH is >5.0, add 3.5 ml 1 M HCl, slurry briefly, cover with a watch glass, heat to 50°C for 10 minutes. Let the solution cool to room temperature and record the pH. If the pH is ≤5, use extraction fluid no 1. Otherwise, use extraction fluid no 2.

3. **Extraction of Solid Waste**

Enough solid should be used for the extraction (20:1 liquid to solid ratio) such that the volume of leachate will be sufficient to support all of the analysis required. If the volume of leachate from a single extraction is insufficient, several extractions may be performed and the extracts combined for analysis.

A reagent blank with no solid sample should be included with each process batch of samples.

i. Weigh at least 100 g ± 0.1g of the field sample (<9.5 mm) into an extraction vessel.

ii. Add an amount of the appropriate extraction fluid equivalent to 20 times the weight of the sample, to the extraction vessel.

iii. Close the extraction vessel tightly (it is recommended that Teflon tape be used to ensure a tight seal), secure in the rotary agitation device and rotate at 30±2 rpm for 18±2 hours at ambient temperature (23±2°C). Note: For some types of solid sample, during the agitation, pressure may build up within the extraction vessel.

iv. Assemble the filter holder and filter following manufacturer’s instructions.

v. Place the 0.6 to 0.8 µm glass fibre filter on the support screen and secure,

vi. At the end of the extraction period, transfer the sample to the filter holder and filter the sample.

vii. Seal the filtration device and gradually apply vacuum of gentle pressure of 7-70 KPa, and if no additional liquid has passed through the filter in any 2 minute interval, slowly increase the pressure in 70 KPa increments to a maximum of 350 KPa. Repeat this until pressurizing gas begins to move through the filter or when liquid flow has ceased at 350 KPa i.e. filtration does not result in any additional filtrate within any 2 minute interval.

viii. The glass fibre filter may be changed, if necessary, to facilitate filtration. The filtrate collected is called the leachate.

4. **Analysis of Leachate**

i. Analyze the leachate as soon as possible. If the analysis cannot be carried out immediately, transfer suitable volumes of the extract into appropriate containers. If the extract is to be analyzed for organics, there should be no headspace in the container. Store all extracts at 4°C.

ii. Report the analysed concentrations of the leachate in mg/L.

iii. Determine the moisture content of the soil separately and report it together with the analytical result.

Chapter 7
Results and Discussion

7.1 Physical Characterization of ECAR Sludge

7.1.1. Determination of Atterberg Limit

M_1= weight of the empty can in gram
M_2= weight of the can plus weight of wet sludge in gram
M_3= weight of the can plus weight of dry sludge in gram

$$\text{Water Content } (\omega) = \frac{M_2 - M_3}{M_3 - M_1} \times 100\%$$

7.1.1.1 Liquid Limit

Fig-7.1: Before Application of Blows

Fig-7.2: After Application of Blows

Table-7.1: Data Table of Atterberg Liquid Limit

No of Blows	M_1	M_2	M_3	ω
15	28.794	46.536	38.583	81.240
8	28.460	48.516	39.460	82.510
36	28.386	40.255	35.230	73.420
18	28.931	46.857	39.003	77.980

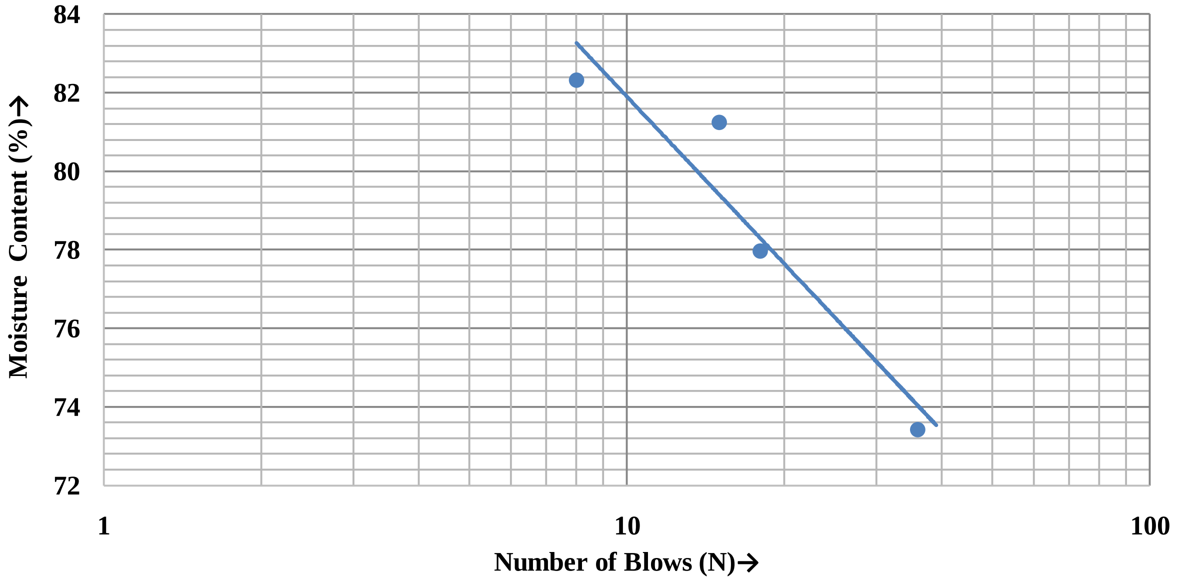


Fig-7.3: Liquid Limit Graph of Moisture Content v/s No of Blows

Liquid limit with respect to 25 no of blows obtained from graph, $y = -6.138\ln(x) + 96.023$

Or, $\omega = -6.138\ln(N) + 96.023$

Therefore, Liquid Limit (ω) = $-6.138\ln(N) + 96.023 = -6.138\ln(25) + 96.023 = 76.266\%$

7.1.1.2 Plastic Limit

Fig-7.4: Rolling Up of the Sample into Thread while Determining Plastic Limit

Table-7.2: Data Table of Atterberg Plastic Limit

M_1	M_2	M_3	ω	Mean
16.693	20.095	18.778	63.170	63.57
22.210	25.112	23.980	63.960	
20.545	23.514	22.360	63.580	

Therefore, Plastic Limit of the sample is 63.57%

Now,

Flow Index (I_f) = $\frac{(\omega_1 - \omega_2)}{\log_{10}\left(\frac{N_2}{N_1}\right)}$

Where,

ω_1 = moisture content in percent corresponding to N_1 drops, and

ω_2 = moisture content in percent corresponding to N_2 drops.

Therefore, $I_f = \frac{77.635-75.146}{\log_{10}\left(\frac{30}{20}\right)}$ =14.135

Plasticity Index (I_p) = Limit Liquid – Plastic Limit = 76.266 – 63.57 = 12.696

The magnitude of plasticity index signifies that the sludge sample is of medium plasticity as it is in between 7 and 17.

Toughness Index (I_T) = $\frac{I_p}{I_f} = \frac{12.696}{14.135} = 0.898$

As toughness index is less than 1, this sludge sample is friable at plastic limit.

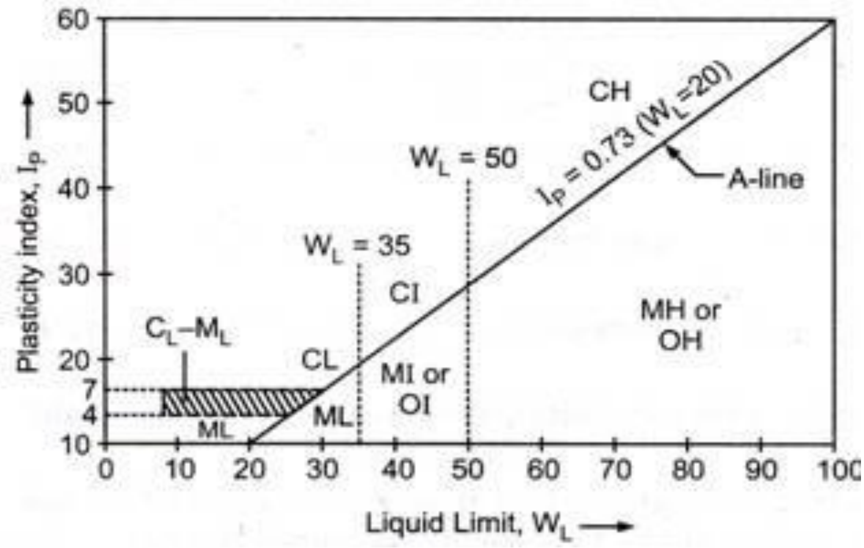
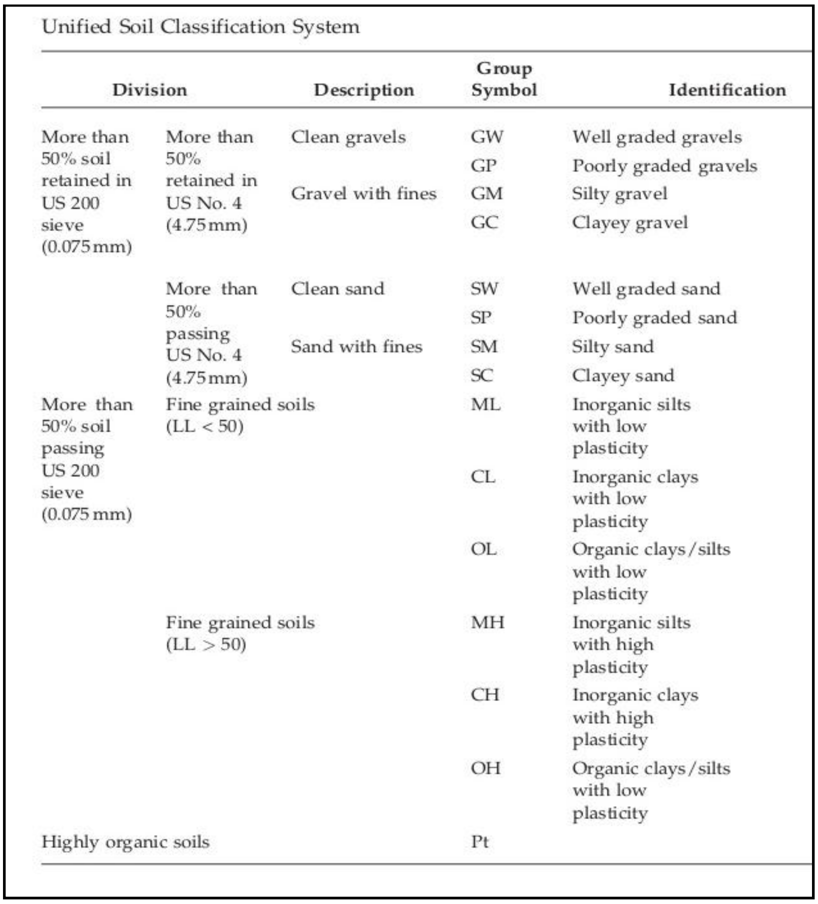


Fig-7.5: Casagrande's Plasticity Chart



Unified Soil Classification System

Division		Description	Group Symbol	Identification
More than 50% soil retained in US 200 sieve (0.075mm)	More than 50% retained in US No. 4 (4.75mm)	Clean gravels	GW	Well graded gravels
			GP	Poorly graded gravels
		Gravel with fines	GM	Silty gravel
			GC	Clayey gravel
	More than 50% passing US No. 4 (4.75mm)	Clean sand	SW	Well graded sand
			SP	Poorly graded sand
		Sand with fines	SM	Silty sand
			SC	Clayey sand
More than 50% soil passing US 200 sieve (0.075 mm)	Fine grained soils (LL < 50)		ML	Inorganic silts with low plasticity
			CL	Inorganic clays with low plasticity
			OL	Organic clays/silts with low plasticity
	Fine grained soils (LL > 50)		MH	Inorganic silts with high plasticity
			CH	Inorganic clays with high plasticity
			OH	Organic clays/silts with low plasticity
Highly organic soils			Pt	

Fig-7.6: Unified Soil Classification System

From Casagrande's Plasticity Chart it appears that the sludge will behave like high plasticity silt (MH). As it falls under this soil group, it is expected that:

i. Permeability when compacted is between semi-pervious and pervious.
ii. Shearing Strength when compacted and saturated is between fair and poor.
iii. Compressibility when compacted and saturated is high.
iv. Workability as a construction material is poor.

7.1.2. Determination of Specific Gravity

M_1= Mass of Density Bottle (Pycnometer) in gram
M_2= Mass of Density Bottle and Dry Sludge in gram
M_3= Mass of Density Bottle, Sludge and Water in gram
M_4= Mass of Density Bottle when full of Water only in gram

$$\text{Specific Gravity (G)} = \frac{M_2 - M_1}{\{(M_4 - M_1) - (M_3 - M_2)\}}$$

Volume of Density Bottle = 50 ml

Fig 7.7: Weighing of Pycnometer

Table-7.3: Data Table of Specific Gravity

Sample No	M_1	M_2	M_3	M_4	G	Mean G
1	29.45	32.95	81.22	78.96	2.823	2.897
2	28.56	31.80	80.76	78.61	2.973	
3	29.55	33.14	81.18	78.83	2.895	

Therefore, Specific Gravity (G) = 2.897

Material	Specific Gravity
ECAR Sludge	2.897
Micro Silica	2.2 – 2.3
Fly Ash	2.2 – 2.8
Metakaolin	2.4 – 2.5
Blast Furnace Slag	2.0 – 2.5

The specific gravity of the sludge sample is found to be more than that of sand and silt which is in the range of 2.65 to 2.7. This may be due to the different mineral composition of the sludge sample. Generally, heavier the minerals composing the soil, the greater is its specific gravity. As this sludge sample contains Iron, its specific gravity is high. The specific gravity of the sludge sample is higher than that of fly ash and blast furnace slag, which are used as additives to concrete.

7.1.3. Determination of Free Swell Index

Fig-7.8: Free Swell Index Experimental Setup

Free swell index = $\frac{V_d - V_k}{V_k} \times 100$

Where,

V_d= Volume of sludge specimen read from the graduated cylinder containing distilled water = 17.5 ml

V_k = Volume of sludge specimen read from the graduated cylinder containing kerosene = 16 ml

Therefore Free Swell Index= $\frac{17.5-16}{16} \times 100 = 9.375$

As the free swell index is less than 20, the degree of expansiveness is low.

7.1.4. Determination of Permeability or Hydraulic Conductivity

Fig-7.9: Falling Head Permeability Apparatus Setup used in the Experiment

7.1.4.1. At 15% moisture content

Zero of scale and water level in the trough (M) = 530mm=53 cm
Area of the cross section of the stand pipe (of diameter =20mm=2cm) =a=3.14 cm^2
Length of the sludge sample (L) =12.7 cm
Initial Head of Water = h_0
Final Head Water =h_1

$$\textbf{Hydraulic Conductivity (K)} = \frac{\mathbf{aL}}{\mathbf{At}} \mathbf{ln}\left(\frac{\boldsymbol{h_0}}{\boldsymbol{h_1}}\right)$$

Area of the cross section of the sludge sample (of diameter =100mm=10cm) =A=78.54 cm^2

Table-7.4: Data Table for Permeability at 15°C

Observation No.	**Scale Reading (cm)**		**Time Elapsed (Sec)**	**Total Head (cm)**		**Value of K (cm/sec)**	**Average K (cm/sec)**
	N_0	**N_1**		**h_0 = N_0+M**	**h_1 = N_1+M**		
1	72.2	12.0	5700	125.2	65.0	0.000058392	0.000061938 or 6.20× 10^{-5}
2	70.4	59.9	780	123.4	112.9	0.000057888	
3	59.9	26.8	2880	112.9	79.8	0.000061172	
4	75.5	62.5	840	128.5	115.5	0.000064470	
5	62.5	40.1	1740	115.5	93.1	0.000062912	
6	40.1	27.9	1140	93.1	80.9	0.000062559	
7	86.0	52.2	2160	139.0	105.2	0.000065492	
8	52.2	28.8	2040	105.2	81.8	0.000062618	

Therefore, Average Permeability, K (cm/sec) = 6.20 × 10^{-5} cm/sec

7.1.4.2 At optimum moisture content

Zero of scale and water level in the trough (M) = 474mm=47.4 cm
Area of the cross section of the stand pipe (of diameter =20mm=2cm) =a=3.14 cm^2
Length of the sludge sample (L) =12.7 cm
Initial Head of Water = h_0
Final Head Water =h_1

$$\text{Hydraulic Conductivity (K)} = \frac{\text{aL}}{\text{At}} \ln\left(\frac{h_0}{h_1}\right)$$

Area of the cross section of the sludge sample (of diameter =100mm=10cm) =A=78.54 cm^2

Table-7.5: Data Table of Permeability at OMC

Observation No.	Scale Reading (cm)		Time Elapsed (Sec)	Total Head (cm)		Value of K (cm/sec)	Average K (cm/sec)
	N_0	N_1		$h_0 = N_0+M$	$h_1 = N_1+M$		
1	87.4	79.4	88440	134.8	126.8	0.000000351	0.000000322 or 3.22×10^{-7}
2	79.4	77.9	15420	126.8	125.3	0.000000392	
3	77.9	60.8	237960	125.3	108.2	0.000000313	
4	60.8	59.8	17820	108.2	107.2	0.000000265	
5	59.8	55.2	76980	107.2	102.6	0.000000289	

Therefore, Average Permeability, K (cm/sec) = 3.22×10^{-7}cm/sec

At 15% moisture content the sludge has permeability like that of silt but at OMC its permeability is more like clay.

In case of the sludge sample, it is observed that with increase in moisture content, the permeability is decreasing. It may be due to the fact that the absorbed water surrounding the fine soil particles is not free to move, and it reduces the effective pore space available for the passage of water.

Generally, with the introduction of aggregate of low permeability into cement paste, it is expected to reduce the permeability of the system because the aggregate particles intercept the channels of flows and make it take a circuitous route.

7.1.5. Determination of Bulk Density, Maximum Dry Density, Optimum Moisture Content, Void Ratio and Porosity

M_1= weight of the empty can in gram
M_2= weight of the can plus weight of wet sludge in gram
M_3= weight of the can plus weight of dry sludge in gram

$$\text{Water Content } (\omega) = \frac{M_2 - M_3}{M_3 - M_1} \times 100\%$$

Weight of the Empty Mould = 5436 gm
Volume of the Empty Mould = 1000cc
Bulk Density = γ_t

$$\text{Dry Density}(\gamma_d) = \frac{\gamma_t}{1 + \omega}$$

Fig-7.10: Proctor Test Experimental Setup

Table-7.6: Data Table of Water Content-Dry Density Relation

M_1 (gm)	M_2 (gm)	M_3 (gm)	Water Content, ω (%)	Wt of Mould +Sludge (gm)	Wt of Sludge (gm)	Bulk Density (gm/cc)	Dry Density (gm/cc)
28.546	40.871	40.248	5.323876	6212	776	0.776	0.736775
28.931	47.510	44.714	17.71526	6316	880	0.880	0.747567
28.676	48.082	43.137	34.19542	6436	1000	1.000	0.745182
28.061	55.175	46.175	49.68533	6648	1212	1.212	0.809699
28.385	51.467	42.285	66.05755	6848	1412	1.412	0.850308
28.750	62.694	48.086	75.54820	6954	1518	1.518	0.86472
28.460	70.719	50.868	88.58890	6872	1436	1.436	0.761445

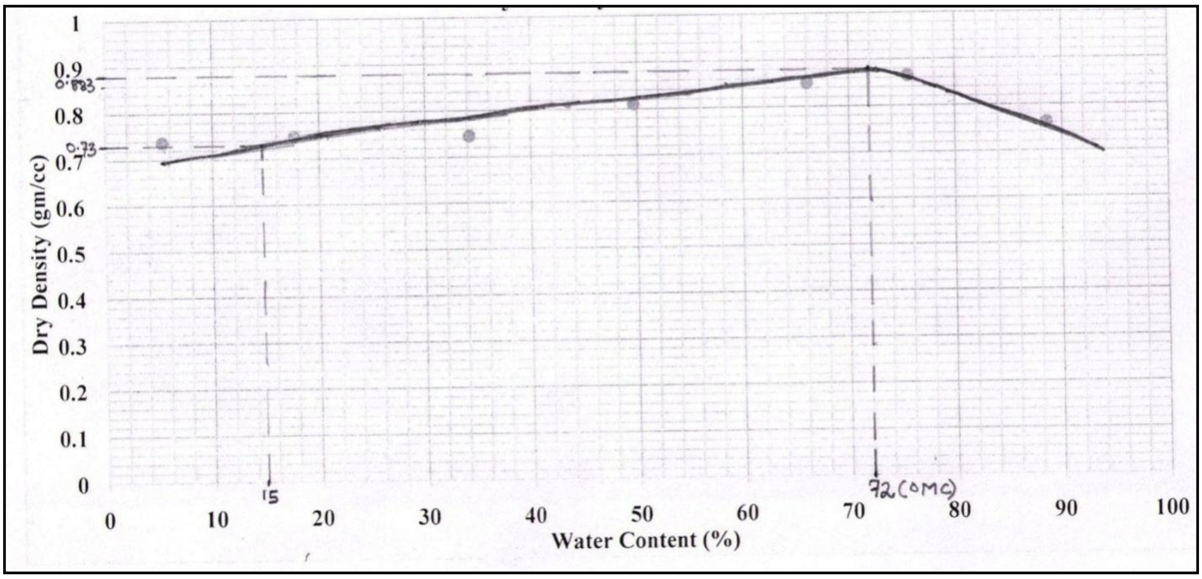


Fig-7.11: Dry Density v/s Water Content Graph

Maximum dry density was 0.883 gm/cc and the optimum moisture content (OMC) was 72%.

Bulk density at OMC = $\{\text{max dry density} \times (1 + \text{OMC})\} = 1.519\ \text{gm/cc}$

The OMC value of ECAR sludge is higher than most soil types. Higher OMC means a higher capability of holding the moisture. High OMC value will create a higher water demand in concrete if used as filler material. Additional water may have to be added to compensate that demand, which should be brought into consideration during the water-cement ratio computation in mix design of concrete.

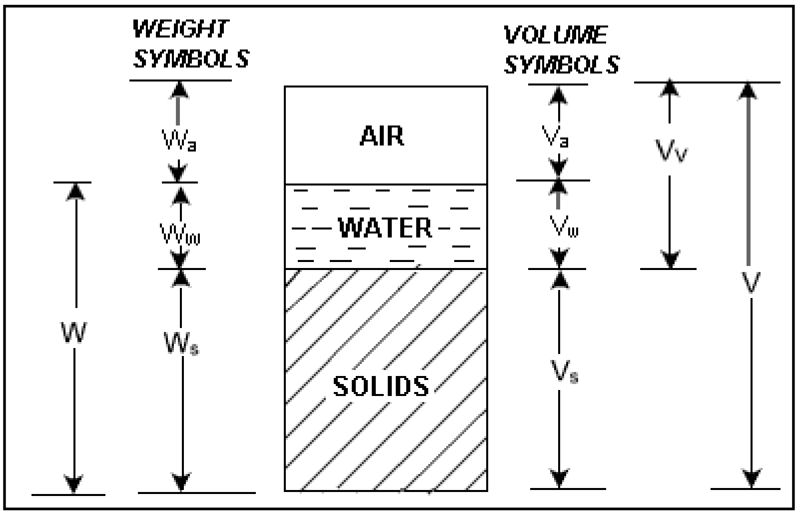


Fig-7.12: Three Phase Diagram of Soil

At 15% Moisture Content

Weight of solids in the sludge sample = W_s = 730gm
Weight of water in the sludge sample = W_w = 0.15×730 = 109.5 gm
Specific gravity of the sludge sample = 2.897
Volume of solids = $V_s = \frac{730}{2.897} = 251.985$ cc
Total Volume = V = 1000cc
Volume of voids = V_v = 1000 – 251.985 = 748.015 cc

$$\text{Void Ratio (e)} = \frac{V_v}{V_s} = \frac{748.015}{251.985} = 2.969$$

$$\text{Porosity (n)} = \frac{e}{1+e} = \frac{2.969}{1+2.969} = 0.748\ \text{i.e.}\ 74.8\%$$

At Optimum Moisture Content (72%)

Weight of solids in the sludge sample = W_s = 883gm
Weight of water in the sludge sample = W_w = 0.72×883 = 635.76 gm
Specific gravity of the sludge sample = 2.897
Volume of solids = $V_v = \frac{883}{2.897} = 304.798$ cc

Total Volume = V = 1000cc

Volume of voids = V_v = 1000 – 304.798 = 695.202 cc

$$\text{Void Ratio (e)} = \frac{V_v}{V_s} = \frac{695.202}{304.798} = 2.281$$

$$\text{Porosity (n)} = \frac{e}{1+e} = \frac{2.281}{1+2.281} = 0.695 \text{ i.e. } 69.5\%$$

Void ratio and porosity of the sludge sample are quite higher than those of sand.

7.1.6. Determination of Shear Strength Parameters by Unconsolidated Undrained Triaxial Test

Fig-7.13: Unconsolidated Undrained Triaxial Test Setup used in the Experiment

A. Sample-1

Cell Pressure σ_3 = 1 kg/cm^2

Sample Height, L = 76mm

Sample Diameter, D = 38mm

Area of sample A_0 = 11.3354 cm^2

Dial Gauge least count = 0.01 mm

Proven ring division = 1141 div=1 kN =100 kg; So, 1 Div = 0.0876 kg

Axial deformation (in mm), ΔL = Strain Dial Reading × 0.01

Axial Strain, $\varepsilon = \frac{\Delta L}{L}$

Corrected area (in cm^2), $A_c = \frac{A_0}{1-\varepsilon}$

Axial Load (in kg), P = Stress Dial Reading × 0.0876

Axial Stress (kg/cm^2) = $\frac{P}{A_c}$

Table-7.7: Data Table of Sample-1 for UU Test

Sl. No.	Strain dial Readings (Div.)	Axial deformation (mm)	Axial strain, ε	Corrected area, A_c (cm^2)	Stress dial reading (Div.) (P)	Axial load (Kg)	Axial stress (kg/cm^2)
1	0	0	0	11.3354	0	0	0
2	50	0.5	0.006579	11.410469	70	6.132	0.537401
3	100	1	0.013158	11.486539	97	8.4972	0.739753
4	150	1.5	0.019737	11.56363	124	10.8624	0.939359
5	200	2	0.026316	11.641762	147	12.8772	1.106121
6	250	2.5	0.032895	11.720958	183	16.0308	1.367704
7	300	3	0.039474	11.801238	232	20.3232	1.722124
8	400	4	0.052632	11.965144	282	24.7032	2.064597
9	500	5	0.065789	12.133668	321	28.1196	2.317486
10	600	6	0.078947	12.307006	337	29.5212	2.398731
11	700	7	0.092105	12.485368	329	28.8204	2.308334
12	800	8	0.105263	12.668976	286	25.0536	1.977555
13	900	9	0.118421	12.858066	246	21.5496	1.67596

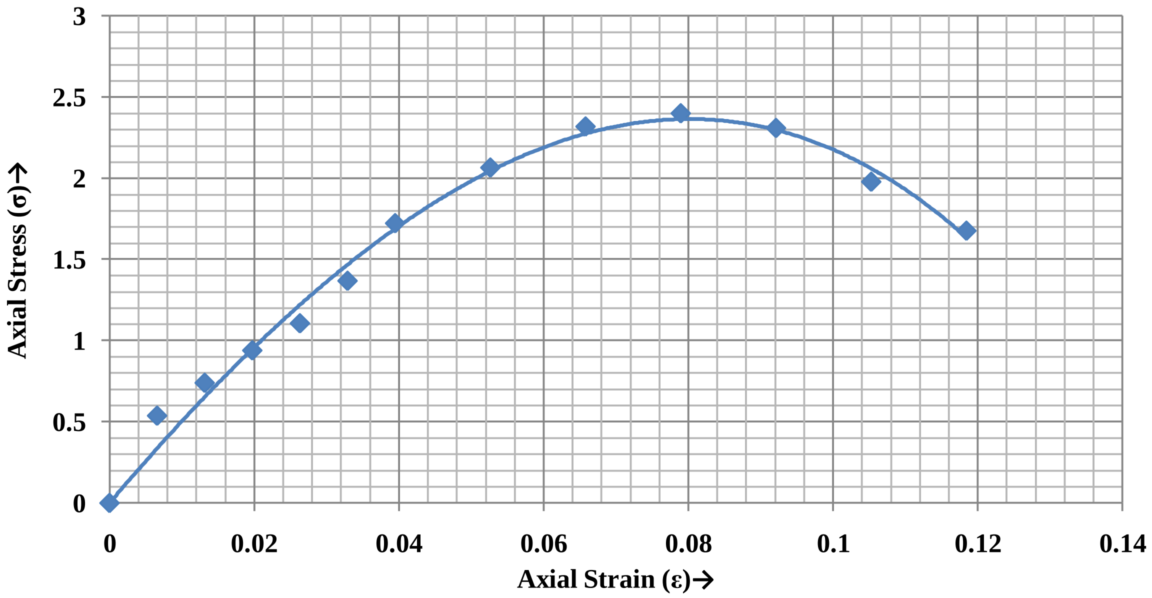


Fig-7.14: Stress Strain Curve for Sample-1 of UU Test

From the above Stress-Strain curve, we have the maximum Deviator Stress, $\sigma_d = 2.39$ kg/cm^2
From the relation, Deviator stress (σ_d) = Major Principal Stress (σ_1) –Cell Pressure (σ_3)
We get $\sigma_1 = \sigma_3 + \sigma_d = 1 + 2.39 = 3.39$ kg/cm^2
Now, $\tau = C + \sigma \tan \phi$
Where,

τ = shear stress at failure
σ = normal stress = major principal stress = 3.39 kg/cm^2
ϕ = angle of shearing resistance = 34.5°
C = cohesion = 0

Therefore Shear Stress, $\tau = 0 + 3.39\times\tan 34.5° = 2.33$ kg/cm^2

B. Sample-2

Cell Pressure σ_3 = 1.5 kg/cm^2
Sample Height, L = 76mm
Sample Diameter, D = 38mm
Area of sample A_0 = 11.3354 cm^2
Dial Gauge least count = 0.01 mm
Proven ring division = 1141 div=1 kN =100 kg; So, 1 Div = 0.0876 kg
Axial deformation (in mm), ΔL = Strain Dial Reading × 0.01
Axial Strain, $\varepsilon = \frac{\Delta L}{L}$
Corrected area (in cm^2), $A_c = \frac{A_0}{1-\varepsilon}$
Axial Load (in kg), P = Stress Dial Reading × 0.0876
Axial Stress (kg/cm^2) = $\frac{P}{A_c}$

Table-7.8: Data Table of Sample-2 for UU Test

Sl. No.	Strain dial Readings (Div.)	Axial deformation (mm)	Axial strain, ε	Corrected area, A_c (cm^2)	Stress dial reading (Div.) (P)	Axial load (Kg)	Axial stress (kg/cm^2)
1	0	0	0	11.3354	0	0	0
2	50	0.5	0.006579	11.41047	54	4.7304	0.414567
3	100	1	0.013158	11.48654	105	9.198	0.800763
4	150	1.5	0.019737	11.56363	158	13.8408	1.196925
5	200	2	0.026316	11.64176	252	22.0752	1.896208
6	250	2.5	0.032895	11.72096	291	25.4916	2.174873
7	300	3	0.039474	11.80124	335	29.346	2.486688
8	400	4	0.052632	11.96514	397	34.7772	2.906542
9	500	5	0.065789	12.13367	482	42.2232	3.479838
10	600	6	0.078947	12.30701	550	48.18	3.914843
11	700	7	0.092105	12.48537	610	53.436	4.27989
12	800	8	0.105263	12.66898	547	47.9172	3.782247
13	900	9	0.118421	12.85807	469	41.0844	3.195224
14	1000	10	0.131579	13.05288	472	41.3472	3.167668

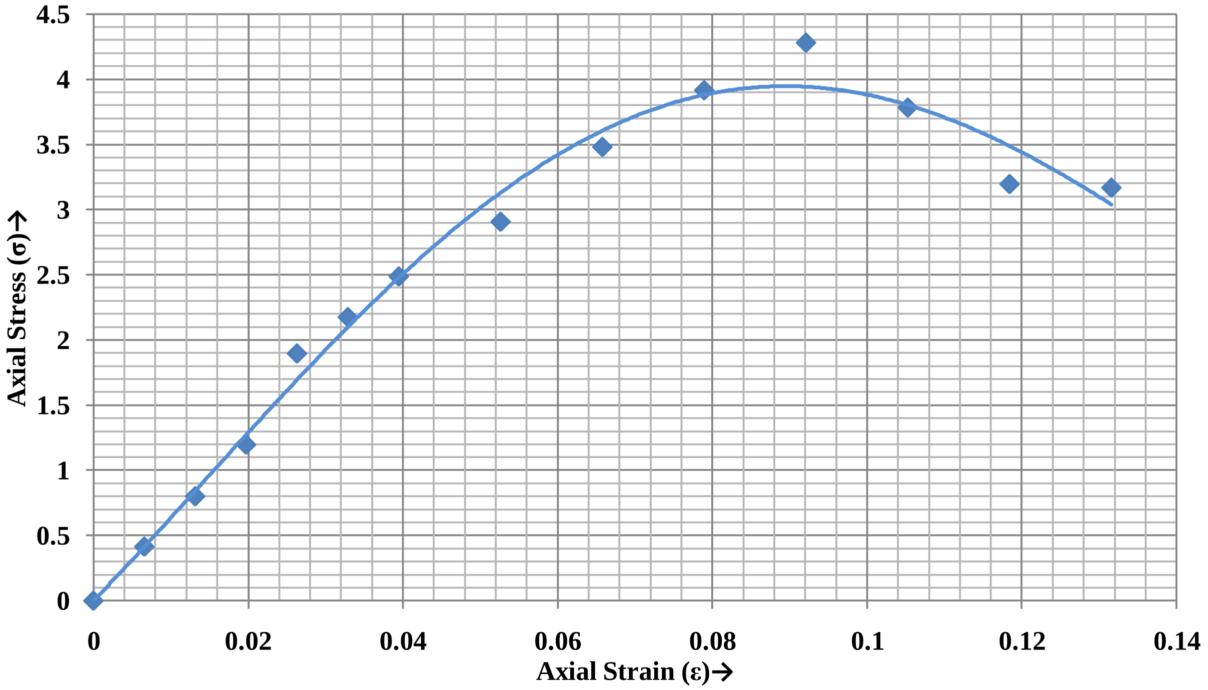


Fig-7.15: Stress-Strain Curve for Sample-2 of UU Test

From the above Stress-Strain curve, we have the maximum Deviator Stress, $\sigma_d = 3.82\ \text{kg/cm}^2$
From the relation, Deviator stress (σ_d) = Major Principal Stress (σ_1) – Cell Pressure (σ_3)
We have, $\sigma_1 = \sigma_3 + \sigma_d = 1.5 + 3.82 = 5.32\ \text{kg/cm}^2$

Now, $\tau = C + \sigma \tan \phi$
Where,
τ = shear stress at failure
σ = normal stress = the major principal stress = 5.32 kg/cm
ϕ = angle of shearing resistance = 34.5°
Therefore Shear Stress, $\tau = 0 + 5.32 \times \tan 34.5° = 3.66\ \text{kg/cm}^2$

C. Sample-3

Cell Pressure $\sigma_3 = 2\ \text{kg/cm}^2$
Sample Height, L = 76mm
Sample Diameter, D = 38mm
Area of sample $A_0 = 11.3354\ \text{cm}^2$
Dial Gauge least count = 0.01 mm
Proven ring division = 1141 div=1 kN =100 kg; So, 1 Div = 0.0876 kg
Axial deformation (in mm), ΔL = Strain Dial Reading × 0.01
Axial Strain, $\varepsilon = \frac{\Delta L}{L}$
Corrected area (in cm^2), $A_c = \frac{A_0}{1-\varepsilon}$
Axial Load (in kg), P = Stress Dial Reading × 0.0876

Axial Stress (kg/cm^2) = $\frac{P}{A_c}$

Table-7.9: Data Table of Sample-3 for UU Test

Sl. No.	Strain dial Readings (Div.)	Axial deformation (mm)	Axial strain, ε	Corrected area, A_c (cm^2)	Stress dial reading (Div.) (P)	Axial load (Kg)	Axial stress (kg/cm^2)
1	0	0	0	11.3354	0	0	0
2	50	0.5	0.006579	11.41047	68	5.9568	0.522047
3	100	1	0.013158	11.48654	132	11.5632	1.006674
4	150	1.5	0.019737	11.56363	198	17.3448	1.499944
5	200	2	0.026316	11.64176	290	25.404	2.182144
6	250	2.5	0.032895	11.72096	355	31.098	2.653196
7	300	3	0.039474	11.80124	420	36.792	3.117639
8	400	4	0.052632	11.96514	513	44.9388	3.755809
9	500	5	0.065789	12.13367	699	61.2324	5.046487
10	600	6	0.078947	12.30701	740	64.824	5.267244
11	700	7	0.092105	12.48537	744	65.1744	5.220062
12	800	8	0.105263	12.66898	712	62.3712	4.923144
13	900	9	0.118421	12.85807	695	60.882	4.734927
14	1000	10	0.131579	13.05288	687	60.1812	4.610567

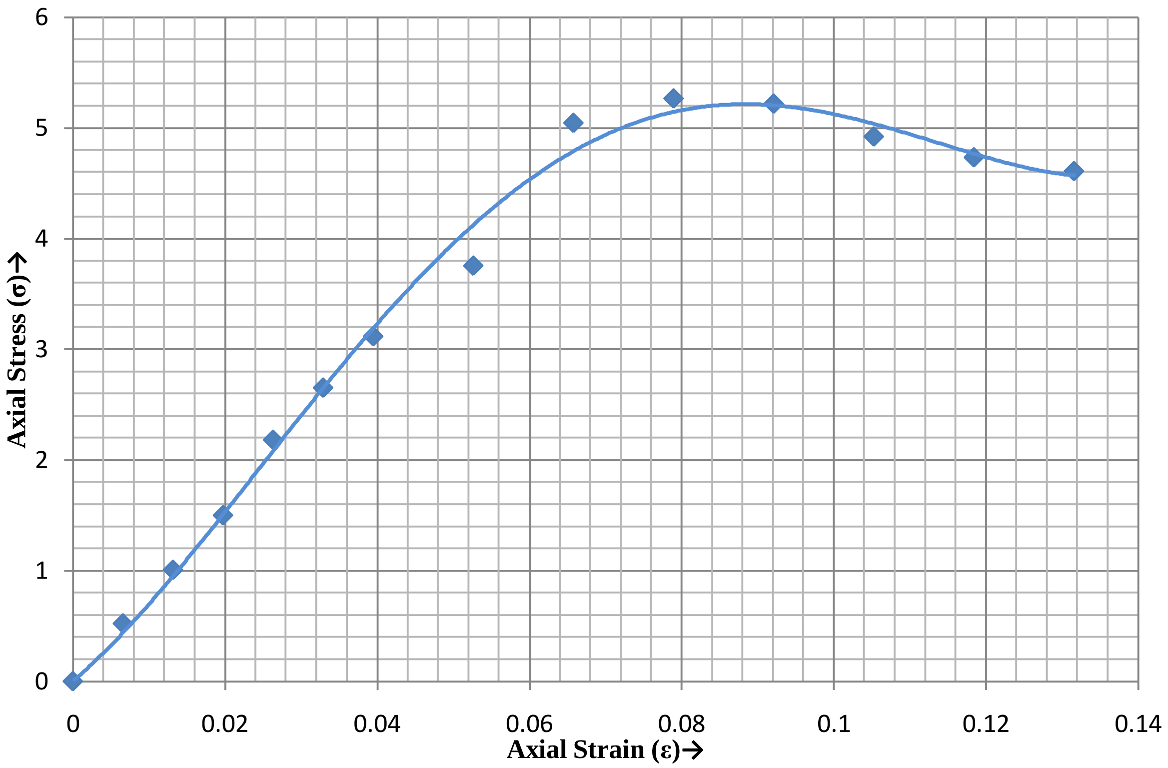


Fig-7.16: Stress-Strain Curve for Sample-3 of UU Test

From the above Stress Strain curve, we have the maximum Deviator Stress, $\sigma_d = 5.1$ kg/cm^2
From the relation, Deviator stress (σ_d) = Major Principal Stress (σ_1) – Cell Pressure (σ_3)
We have, $\sigma_1 = \sigma_3 + \sigma_d = 2 + 5.1 = 7.1$ kg/cm^2
Now, $\tau = C + \sigma \tan \phi$
Where,
τ = shear stress at failure
σ = normal stress = major principal stress = 7.1 kg/cm^2
ϕ = angle of shearing resistance = 34.5°
C = cohesion = 0

Therefore, Shear Stress, $\tau = 0 + 7.1 \times \tan 34.5° = 4.88$ kg/cm^2

Now with the values of σ_1 and σ_3 of the above three samples three Mohr's Circles are drawn as below:

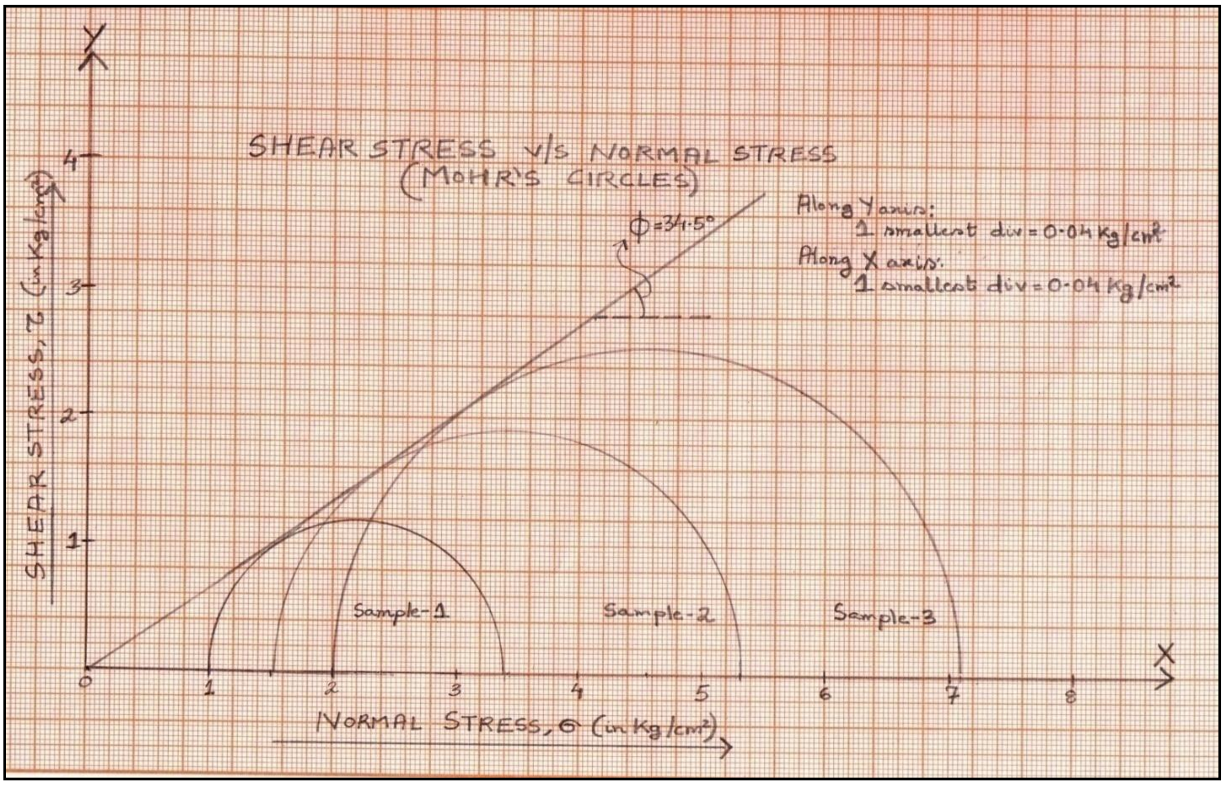


Fig-7.17: Mohr's Circles drawn with the normal stress along X-axis and shear stress along Y-axis

From the graph, it is seen that the sludge sample is cohesionless i.e. C=0 and the angle of shearing resistance ϕ= 34.5°

7.1.7. Determination of Grain Size Distribution

In this case,

μ= Coefficient of viscosity of water in poise at the temperature of this suspension (27°C) at the time of sampling=0.008

H=Height of fall of particles or sampling depth=100mm=10cm

G_1=Specific gravity of water in gm/cm^3 =1

G=Specific gravity of the sample in gm/cm^3 =2.898

t= Time elapsed before sampling in minutes

D=Diameter of particles in suspension in mm

V_p=Volume of suspension pipetted out at each sampling=10ml

M_n'=Mass of Solid Residue in nth sampling (gm)

M_n=Mass of Material in 500ml in nth sampling (gm) = $\frac{M_n'}{V_p} \times 500$

M_s=Mass of Sodium Hexametaphosphate in 500ml of suspension= 2gm

W_b= Mass of sludge in the suspension=20gm

N = Percentage Finer (in %)

$$D = \sqrt{\frac{30\mu H}{981(G - G_1)t}}$$

$$N = \frac{(M_n - M_s)}{W_b} \times 100$$

Fig-7.18: Grain Size Distribution Experimental Setup

Table-7.10: Data Table of Grain Size Distribution

Sl. No.	Time Elapsed (t) (min.)	Empty Wt. of Can (M_d) (gm.)	Empty Wt. of Can + Residue ($M_{d'}$) (gm.)	Mass of Solid residue (gm) ($M_{n'}=M_{d'} - M_d$)	Diameter (D) (mm)	Mass of Residue in 500ml sample (M_n) (gm)	Percentage Finer (N) (%)
1	0.25	15.74	16.03	0.29	0.071805	14.5	62.5
2	0.50	15.55	15.72	0.17	0.050774	8.5	32.5
3	1.00	16.41	16.58	0.17	0.035902	8.5	32.5
4	2.00	15.00	15.17	0.17	0.025387	8.5	32.5
5	4.00	16.15	16.28	0.13	0.017951	6.5	22.5
6	8.00	14.90	15.03	0.13	0.012693	6.5	22.5
7	15.00	16.67	16.78	0.11	0.009270	5.5	17.5
8	30.00	15.81	15.91	0.10	0.006555	5.0	15.0
9	60.00	21.31	21.38	0.07	0.004635	3.5	7.5
10	1440.00	14.47	14.52	0.05	0.000946	2.5	2.5

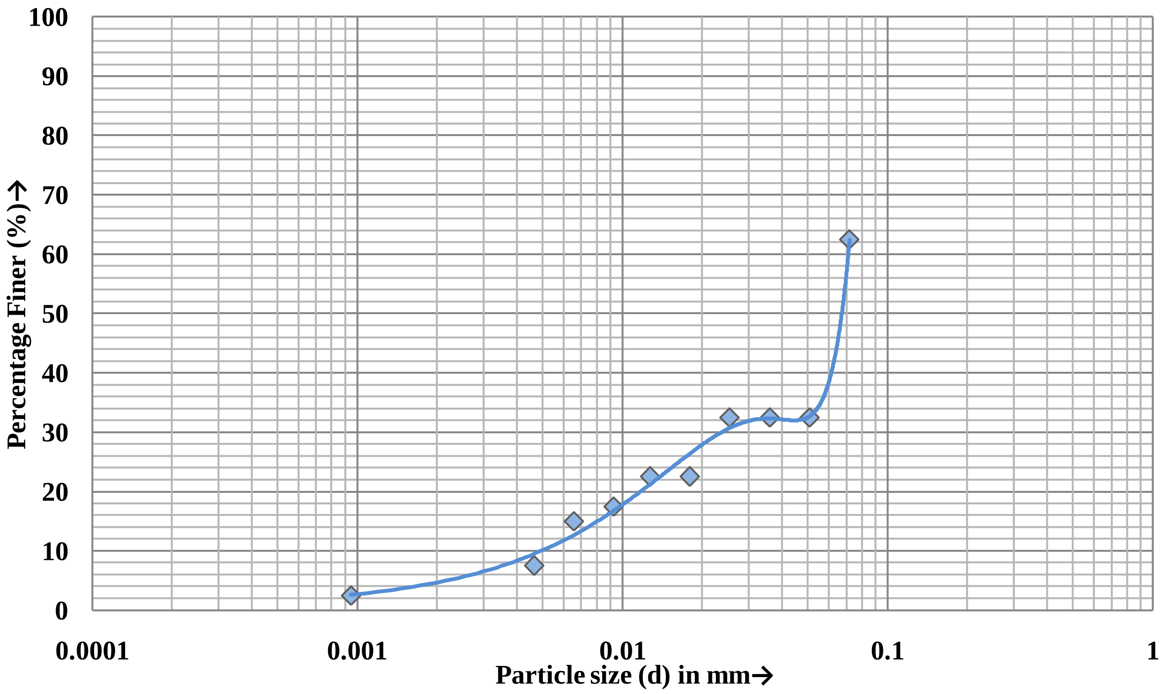


Fig-7.19: Percentage Finer v/s Particle Size Graph

From the graph it is observed that around 5% of the sludge particles has diameter less than 0.002mm (range of clay particle as per IS 1498:1970) and 57.5% of the sludge particles lies in the size range of 0.002mm to 0.075mm (range of silt particle as per IS 1498:1970). On the other hand, 37.5% of the sludge particles lies in the size range of 0.075mm and 0.425 mm (range of fine sand particle as per IS 1498:1970). The particle size range falls mainly in the silt size range.

As per IS 383:1970, percent passing through 0.6 mm sieve for Grade IV fine aggregate (sand) is 80-100 and that through 0.3 mm is 15-50. For the sludge sample, percent passing through 0.5 mm sieve is 100. So the sludge sample is finer than Grade IV sand.

7.2 Chemical Characterization of ECAR Sludge

7.2.1. Determination of pH

Before analysis, the sample solutions had been shaken for 30 mins.
Neutral Range of Water has pH ~6.5-8.3

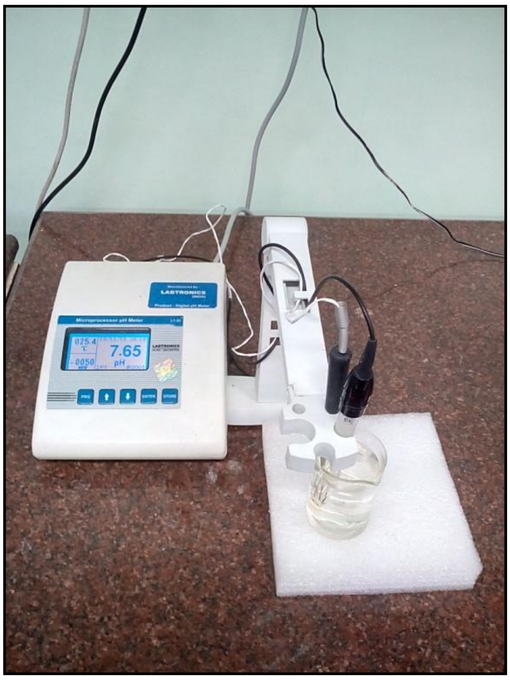


Fig-7.20: pH Meter

Table-7.11: Data Table for pH Determination

Sl. No.	Test Solution	pH Values
1	0.05 gm in 20 ml	8.27
2	0.10 gm in 20 ml	8.21
3	0.50 gm in 20 ml	8.11
4	1.00 gm in 20 ml	7.97
5	5.00 gm in 20 ml	7.83
6	10.00 gm in 20 ml	7.65

Thus, pH is in the range of 7.65 to 8.27.

7.2.2. Determination of Arsenic

Fig-7.21: Merck Millipore De-ionized (DI) Water Unit

Fig-7.22: PerkinElmer (AAnalyst400) Atomic Absorption Spectrophotometer (AAS)

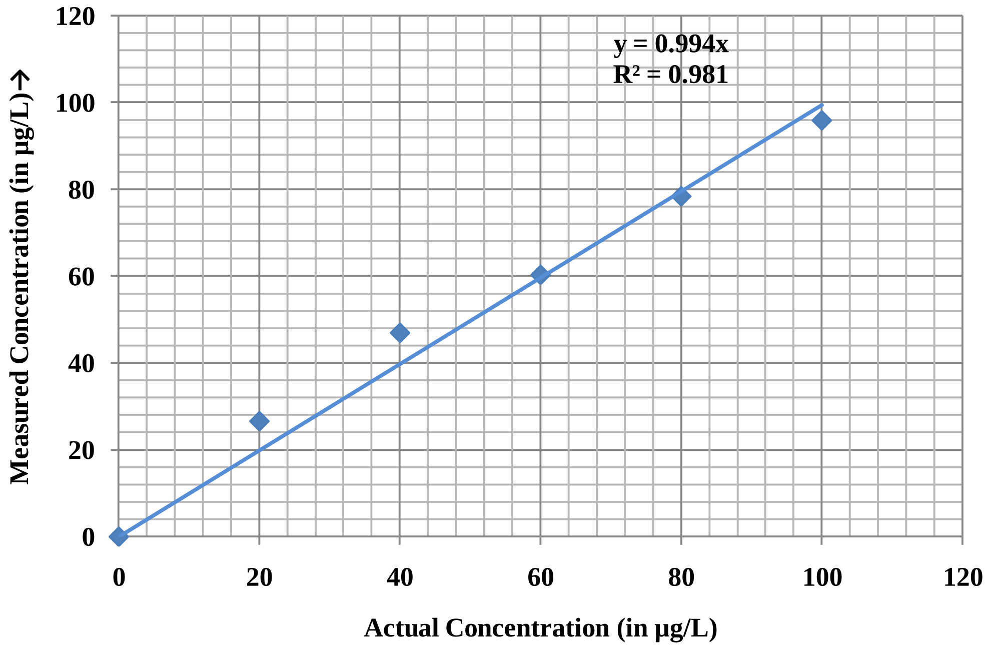


Fig-7.23: Standard curve for Arsenic Determination

Sample Calculation:

From Curve, Concentration = X µg/L
Concentration × DF = X × DF µg/L (where DF is Dilution Factor)
As Y gm of sludge is present in 100 ml (Sample Volume) or 0.1 liter
Total Arsenic present in Y gm of sludge= (X×DF×0.1) µg
Hence, Arsenic Concentration= $\frac{X\times DF\times 0.1}{Y}$µg/gm = $\frac{X\times DF\times 0.1}{Y}$mg/Kg

Arsenic Concentration in percentage = $\left(\frac{\frac{X\times DF\times 0.1}{Y}}{10^6}\times 100\right)$

Table-7.12: Data Table for Arsenic Determination

Sl No.	Arsenic percentage in the sludge sample
1	0.12
2	0.12
3	0.13
4	0.12
5	0.12

Table-7.13: Statistical Data Analysis for Arsenic Determination

No of Sample	Conc Range (in %)	Mean Conc^n (in %)	Max. Conc^n (in %)	Min. Conc^n (in %)	S.D	Variance	C.V. (%)
5	0.12-0.13	0.122	0.13	0.12	0.004324	0.0000187	3.55

Mean arsenic concentration in the sludge sample is 1220 mg/Kg, which is much higher than 50 mg/Kg {as per Indian Standard i.e. Hazardous Material (Management, Handling and Transboundary Movement) Rules, 2008}. Hence, it comes under Class-A type of Hazardous Waste.

7.2.3. Determination of Iron

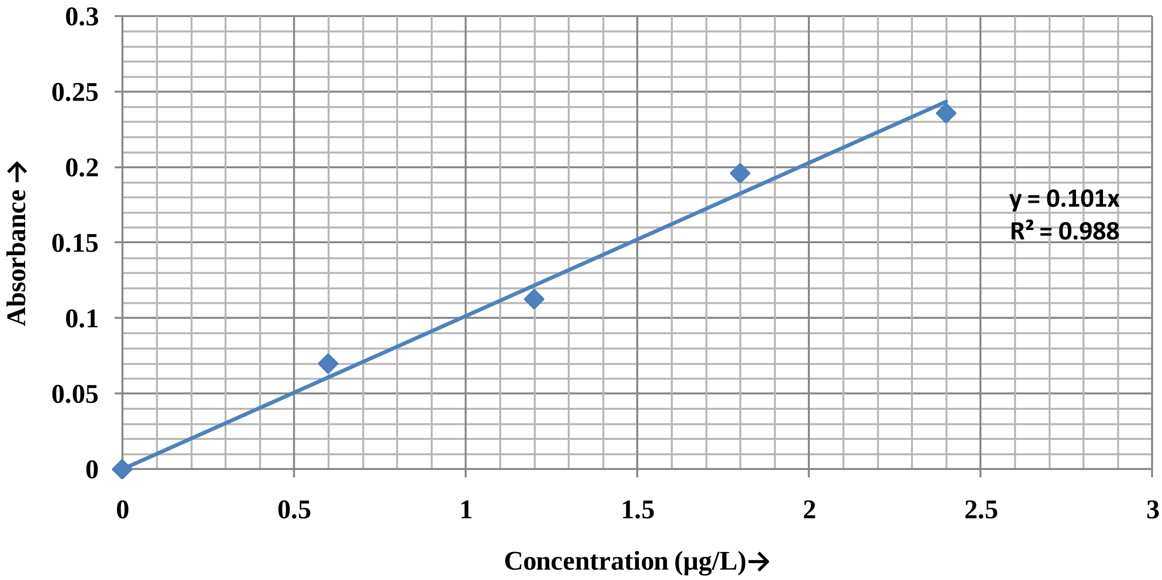


Fig-7.24: Standard curve for Iron Determination

Sample Calculation:

From Curve, Concentration = X mg/L
Concentration × DF = X × DF mg/L (where DF is Dilution Factor)
As Y gm of sludge is present in 100 ml (Sample Volume) or 0.1 liter
Total Iron present in Y gm of sludge= (X×DF×0.1) mg

Hence, Iron Concentration= $\frac{X\times DF\times 0.1}{Y}$ mg/gm = $\frac{X\times DF\times 0.1}{Y}$gm/Kg

Iron Concentration in percentage = $\left(\frac{\frac{X\times DF\times 0.1}{Y}}{1000}\times 100\right)$

Table-7.14: Data Table for Iron Determination

Sl No.	Iron percentage in the sludge sample
1	22.84
2	19.20
3	19.05
4	20.95
5	20.36
6	21.38

Table-7.15: Statistical Data Analysis for Iron Determination

No of Sample	Concentration Range (in %)	Mean Conc^n (in %)	Max. Conc^n (in %)	Min. Conc^n (in %)	S.D	Variance	C.V. (%)
6	19.05-22.84	20.63	22.84	19.05	1.4234	2.0261	6.899

Mean iron concentration in the sludge sample is 206.30gm/Kg i.e. 2,06,300 mg/Kg.

7.2.4. Determination of Aluminum

Table-7.16: Data Table for Aluminum Determination

Sl No.	Aluminum percentage in the sludge sample
1	8.07
2	9.73
3	9.92

Table-7.17: Statistical Data Analysis for Aluminum Determination

No of Sample	Conc Range (in %)	Mean Conc^n (in %)	Max. Conc^n (in %)	Min. Conc^n (in %)	S.D	Variance	C.V. (%)
3	8.07-9.92	9.24	8.07	9.92	1.018287	1.036908	11.02

Mean aluminum concentration in the sludge sample is 92.4 gm/Kg i.e. 92,400 mg/Kg.

7.2.5. Determination of Lead

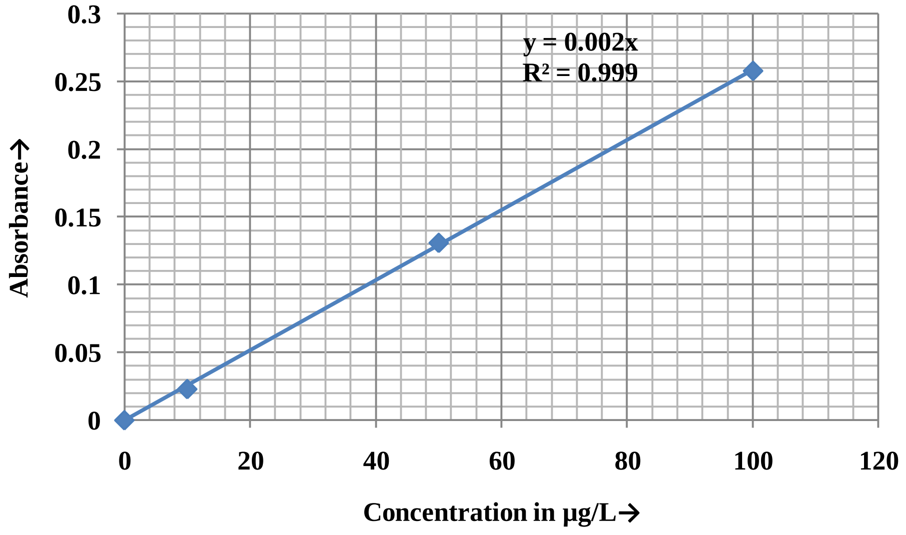


Fig- 7.25: Standard curve for Lead Determination

Table-7.18: Data Table for Lead Determination

Sl No.	Lead percentage in the sludge sample
1	0.0173
2	0.0268
3	0.0379

Table-7.19: Statistical Data Analysis for Lead Determination

No of Sample	Conc Range (in %)	Mean Conc^n (in %)	Max. Conc^n (in %)	Min Conc^n (in %)	S.D	Variance	C.V. (%)
3	0.0173-0.0379	0.0273	0.0379	0.0173	0.010309	0.000106	37.72

Mean lead concentration in the sludge sample is 273 mg/Kg which is much lower than 5,000 mg/kg {as per Indian Standard i.e. Hazardous Material (Management, Handling and Transboundary Movement) Rules, 2008}. Hence, from lead point of view the waste is not hazardous by nature.

7.2.6. Determination of Mercury

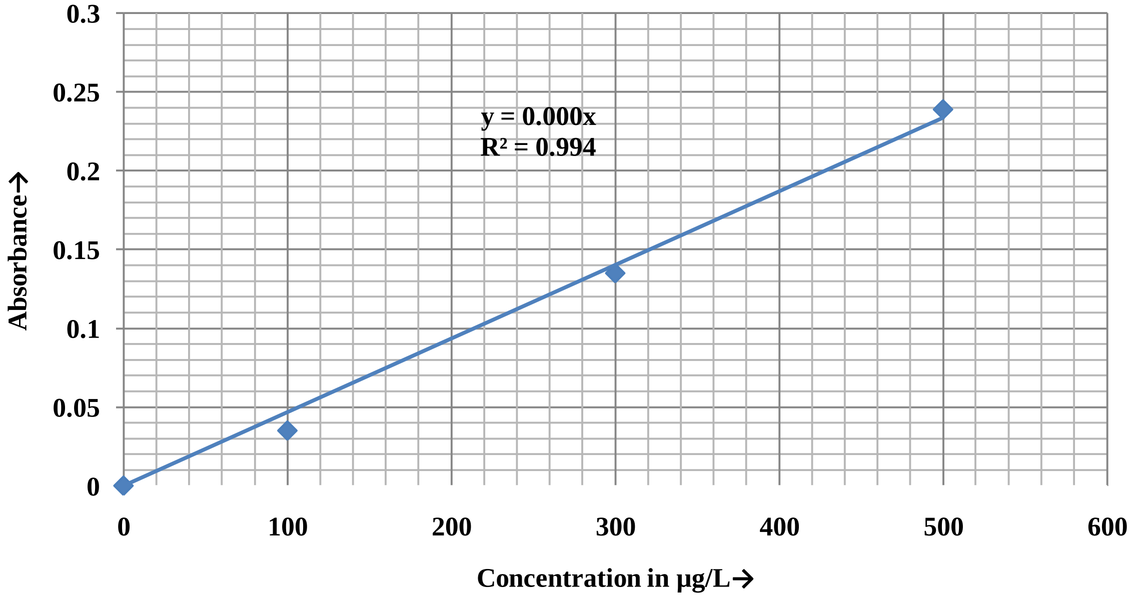


Fig-7.26: Standard curve for Mercury Determination

Table-7.20: Data Table for Mercury Determination

Sl No.	Mercury Percentage in the Sludge Sample
1	0.0019
2	0.0023
3	0.0003
4	0.0005
5	0.0000
6	0.0000

Table 7.21: Statistical Data Analysis for Mercury Determination

No of Sample	Concentration Range (in %)	Mean Conc^n (in %)	Max. Conc^n (in %)	Min. Conc^n (in %)	S.D	Variance	C.V. (%)
6	0.0000-0.0023	0.0008	0.0023	0.0000	0.001019	0.00	122.14

Mean mercury concentration in the sludge sample is 8 mg/Kg, which is much lower than 50 mg/Kg {as per Indian Standard i.e. Hazardous Material (Management, Handling and Transboundary Movement) Rules 2008}. Hence, from mercury point of view the waste is not hazardous by nature.

7.2.7. Determination of Calcium

Table-7.22: Data Table for Calcium Determination

Sl No.	Calcium percentage in the sludge sample
1	6.3600
2	6.7728
3	5.8400

Table-7.23: Statistical Data Analysis for Calcium Determination

No of Sample	Conc Range (in %)	Mean Conc^n (in %)	Max. Conc^n (in %)	Min. Conc^n (in %)	S.D	Variance	C.V. (%)
3	5.84-6.7728	6.3243	6.7728	5.8400	0.4674	0.2185	7.39

Mean calcium concentration in the sludge sample is 63.243 gm/Kg i.e. 63,243 mg/Kg.

7.2.8. Determination of Magnesium

Table-7.24: Data Table for Magnesium Determination

Sl No.	Magnesium percentage in the sludge sample
1	0.7696
2	0.7430
3	0.7500

Table-7.25: Statistical Data Analysis for Magnesium Determination

No of Sample	Concentration Range (in %)	Mean $Conc^n$ (in %)	Max. $Conc^n$ (in %)	Min $Conc^n$ (in %)	S.D	Variance	C.V. (%)
3	0.7430-0.7500	0.7542	0.7696	0.7430	0.0138	0.0002	1.83

Mean magnesium concentration in the sludge sample is 7542 mg/Kg

7.2.9. Determination of Silver

Silver concentration in % as Ag in the sludge sample is Below Detectable Limit.

7.2.10. Determination of Barium

Barium content in % as Ba in the sludge sample is 0.1020

Barium concentration in the sludge sample is 1020 mg/Kg which is much lower than 20,000 mg/Kg {as per Indian Standard i.e. Hazardous Material (Management, Handling and Transboundary Movement) Rules 2008}. Hence, from barium point of view, the waste is not hazardous by nature.

7.2.11. Determination of Cadmium

Cadmium content in % as Cd in the sludge sample is 0.003201

Cadmium concentration in the sludge sample is 32.01 mg/Kg which is lower than 50 mg/Kg {as per Indian Standard i.e. Hazardous Material (Management, Handling and Transboundary Movement) Rules 2008}. Hence, from cadmium point of view, the waste is not hazardous by nature.

7.2.12. Determination of Chromium

Chromium content in % as Cr in the sludge sample is 0.042172

Chromium is precipitated generally in the form of chromium (III). Here the chromium concentration in the sludge sample is 421.72 mg/Kg, which is much lower than 5000 mg/Kg {as per Indian Standard i.e. Hazardous Material (Management, Handling and Transboundary Movement) Rules 2008}. Hence, from chromium (III) point of view, the waste is not hazardous by nature.

7.2.13. Determination of Chloride

Chloride content in % as Cl^- in the sludge sample is 0.919

Whenever there is chloride in concrete there is an increased risk of corrosion of embedded metal. The higher the chloride content, or if subsequently exposed to warm moist conditions, the greater the risk of corrosion. All constituents may contain chlorides and concrete may be contaminated by chlorides from the external environment. To minimize the chances of deterioration of concrete from harmful chemical salts, the levels of such harmful salts in concrete coming from concrete materials, that is, cement, aggregates, water and admixtures, as well as by diffusion from the environment should be limited. The total amount of chloride content (as Cl) in the concrete at the time of placing shall be as given in Table 7 of IS-456:2000.

Table-7.26: Limits of Chloride Content of Concrete of IS-456:2000

Sl. No.	Type or Use of Concrete	Maximum Total Acid Soluble Chloride content expressed as kg/m^3 of concrete
i.	Concrete containing metal and steam cured at elevated temperature and pre-stressed concrete.	0.4
ii.	Reinforced concrete or plain concrete containing embedded metal.	0.6
iii.	Concrete not containing embedded metal or any material requiring protection from chloride.	3.0

The total acid soluble chloride content should be calculated from the mix proportions and the measured chloride contents of each of the constituents. Wherever possible, the total chloride content of the concrete should be determined.

7.2.14. Determination of Nitrate

Nitrate content in % as NO_3^- in the sludge sample is Below Detectable Limit.

7.2.15. Determination of Phosphate

Phosphate content in % as $PO_4^{=}$ in the sludge sample is Below Detectable Limit.

7.2.16. Determination of Sulfate

Fig-7.27: PerkinElmer (Lambda25) UV-Visible Spectrophotometer

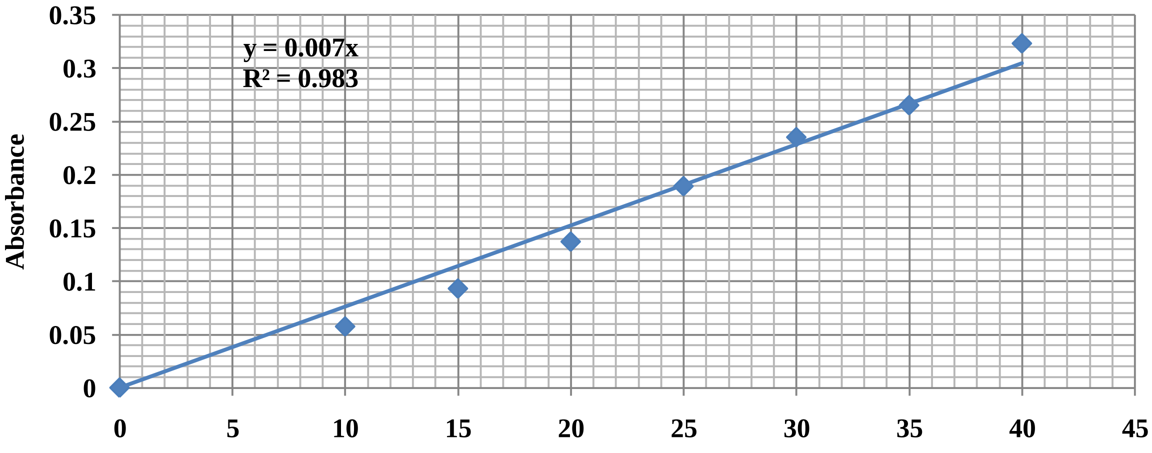


Fig-7.28: Standard curve for Sulfate Determination

Table-7.27: Data Table for Sulfate Determination

Sl No.	Sulfate percentage in the sludge sample
1	1.06
2	0.92

Table-7.28: Statistical Data Analysis for Sulfate Determination

No of Sample	Concentration Range (in %)	Mean Conc^n (in %)	Max. Conc^n (in %)	Min. Conc^n (in %)	S.D	Variance	C.V. (%)
2	0.92-1.06	0.99	1.06	0.92	0.09697	0.009404	9.81

Sulfates are present in most cement and in some aggregates; excessive amounts of water-soluble sulfate from these or other mix constituents can cause expansion and disruption of concrete. To prevent this, as per IS 456:2000 the total water-soluble sulfate content of the concrete mix expressed as SO_3 should not exceed 4% by mass of the cement in the mix. The sulfate content should be calculated as the total from the various constituents of the mix. Though sulfate content in sludge is less, the sulfate contents of the other contributing materials should also be considered during concreting.

7.2.17. Determination of Silica

Silica content in % as SiO_2 in the sludge sample is 17.51

Silica concentration in the sludge sample is 175.1 gm/Kg i.e. 1,75,100 mg/Kg.

7.3. Characterization of Cement

7.3.1 Determination of Consistency of Cement

The consistency of the cement paste was found to be 34%.

7.3.2 Determination of Setting Time of Cement

The initial setting time of the cement paste was found to be 2 hrs 30 mins and the final setting time was 5 hrs.

7.3.3 Determination of Soundness of Cement

The average expansion of the cement paste was found to be 1 mm (<10mm).

7.3.4 Determination of Fineness of Cement

The fineness of cement was found to be 2.8%.

7.3.5 Determination of Compressive Strength of Cement

The average compressive strength of cement after 7 days of curing was found to be $30N/mm^2$.

The average compressive strength of cement after 28 days of curing was found to be $44N/mm^2$.

7.3.6 Determination of Arsenic Content in Cement

The arsenic content of the cement had been found to be Below Detectable Limit.

7.4. Characterization of Water

The water used in preparation of concrete mix and also for curing had been characterized with respect to the following parameters:

Table 7.29: Composition of Water Used In the Concreting Process

Parameter	**Value**
pH	7.8
Acidity	18 mg/L as $CaCO_3$
Alkalinity	55 mg/L as $CaCO_3$
Chloride	46 mg/L as Cl^-
Sulfate	10 mg/L as $SO_4^=$
Volatile Dissolved Solids	24 mg/L
Fixed Dissolved Solids	96 mg/L
Suspended Matter	0 mg/L
Arsenic	BDL

7.5. Characterization of Sand

Weight of sample taken = 1001.2 gm

Table 7.30: Data Table for Sieve Analysis of Sand

Sl. No	Sieve Size (in mm)	Wt of Sieve (gm)	Wt of Sieve + Retained Sand (gm)	Wt of Retained Sand (gm)	Percentage Retained	Cumulative percentage retained	Percentage Finer	As per IS 383-1970 (% passing) for ZONE-II
1	10	553.5	553.5	0	0.00	0.00	100.00	100
2	4.75	545.7	555.4	9.7	0.97	0.97	99.03	90-100
3	2.36	359.2	375.2	16	1.60	2.57	97.43	75-100
4	1.18	449	568.4	119.4	11.93	14.49	85.51	55-90
5	0.6	427.7	797.2	369.5	36.91	51.40	48.60	35-59
6	0.3	202.8	590.1	387.3	38.68	90.08	9.92	8-30
7	0.15	498.8	575.4	76.6	7.65	97.73	2.27	0-10
8	PAN	416	438.7	22.7	2.27	100.00	0.00	100

So, the sand used in the concreting process falls under Zone-II Sand as per IS 383:1970.

7.6. Characterization of Coarse Aggregates

Weight of sample (CA-I) = 2000 gm

Table 7.31: Data Table for Sieve Analysis of CA-I

Sl. No	Sieve Size (in mm)	Wt of Sieve (gm)	Wt of Sieve + Retained CA-I (gm)	Wt of Retained CA-I (gm)	Percentage Retained	Cumulative percentage retained	Percentage Finer
1	40	575.6	575.6	0	0.00	0.00	100.00
2	20	492.1	492.1	0	0.00	0.00	100.00
3	16	467.7	1595.4	1127.7	56.39	56.39	43.62
4	12.5	430.3	886.9	456.6	22.83	79.22	20.79
5	10	553.2	805.7	252.5	12.63	91.84	8.16
6	4.75	545	694	149	7.45	99.29	0.71
7	2.36	359.1	363.2	4.1	0.20	99.50	0.50
8	1.18	448.3	449.6	1.3	0.07	99.56	0.44
9	0.6	417.1	422	4.9	0.24	99.81	0.19
10	0.3	202.7	203.8	1.1	0.06	99.86	0.14
11	0.15	495.7	498.5	2.8	0.14	100.00	0.00
	PAN	418.2	418.2	0	0.00	100.00	0.00

Weight of sample taken (CA-II) = 1000.9 gm

Table 7.32: Data Table for Sieve Analysis of CA-II

Sl. No	Sieve Size (in mm)	Wt of Sieve (gm)	Wt of Sieve + Retained CA-II (gm)	Wt of Retained CA-II (gm)	Percentage Retained	Cumulative percentage retained	Percentage Finer
1	40	575.6	575.6	0	0.00	0.00	100.00
2	20	492	492	0	0.00	0.00	100.00
3	16	468	468	0	0.00	0.00	100.00
4	12.5	430.6	430.6	0	0.00	0.00	100.00
5	10	553.3	718	164.7	16.46	16.46	83.54
6	4.75	545.2	1316.8	771.6	77.09	93.55	6.45
7	2.36	359.2	388.7	29.5	2.95	96.49	3.51
8	1.18	448.2	480.5	32.3	3.23	99.72	0.28
9	0.6	423.5	426.3	2.8	0.28	100.00	0.00
10	0.3	202.5	202.5	0	0.00	100.00	0.00
11	0.15	499.7	499.7	0	0.00	100.00	0.00
	PAN	415.7	415.7	0	0.00	100.00	0.00

Table 7.33: Mixing of Coarse Aggregate Samples

Sl. No	Sieve Size (in mm)	Percentage Passing for CA-I	Percentage Passing for CA-II	60% OF CA-I	40% OF CA-II	MIX	20 mm Maximum Nominal Size range as per IS 383:1970
1	40	100.00	100.00	60.00	40.00	100.00	100
2	20	100.00	100.00	60.00	40.00	100.00	95-100
3	10	8.16	83.54	4.90	33.42	38.31	25-55
4	4.75	0.71	6.45	0.43	2.58	3.01	0-10

So, after mixing CA-I and CA-II in ratio 60:40 the required combined grade of coarse aggregate i.e. 20 mm Maximum Nominal Size had been achieved.

7.7 M20 Grade Concrete Results and Discussion

The arsenic bearing sludge had been embedded in the M20 grade concrete in varying proportions viz. 0%, 5%, 10%, 12.5%, 15%, 20%, 25%, 30%, 32.5%, 35%, 37.5%, 40%, 60%, 80% and 100% by weight of cement. This amount of sludge had been added by replacing equivalent amount of sand. And water equivalent to the OMC of this sludge had also been added in the concrete mix. Seven cubes of dimension 100mm×100mm×100mm had been casted for each of the percentages from 0% to 40%. In each case the slump height and compacting factor had been determined to signify its workability. And also three cubes each for 7 days and 28 days had been cured separately in two different crates and their strengths had been determined at the end of respective curing periods. This had been done for determination of the leached Arsenic concentration in the curing water both after 7 days and 28 days of curing. And amongst these three cubes (for 7 days and 28 days), one cube had been crushed to three size ranges viz. <9.5mm, <1mm and 5-50mm and TCLP had been performed to determine the arsenic concentration in the leachate. For 60%, 80% and 100% sludge mixed concrete cubes, only three cubes had been casted in each case. Only their strength after 28 days of curing had been determined and the TCLP had been performed on them. These three percentage sludge mixed concrete had been casted for the purpose to see whether any arsenic is leaching out of the concrete even when such a high percentage like 100% by weight of cement of sludge be mixed. All the data collected for each percentage of sludge mixed concrete are tabulated below:

Table 7.34: Data Sheet for M20 Grade Concrete with 0% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**						
	Grade of concrete to be prepared :- M20 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18 Water: Cement Ratio :- 0.5 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.44 Kg Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg) Quantity of fine aggregate (sand) used :- 6.61 Kg Quantity of sludge used :- 0 Kg Quantity of water used :- (0.5×3.44) + (0.72×0) = 1.72 Kg						
2	**Workability of concrete**						
	By Slump Test the slump height is coming to be 35mm.						
3	**Compacting factor of concrete**						
	Weight of empty cylinder (W_1) = 7.215 Kg Weight of cylinder with partially compacted concrete (W_2) = 17.540 Kg Weight of cylinder with fully compacted concrete (W_3) = 19.315 Kg Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.85						
4	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	32	31.5	31.5	46	45.5	45.5
	Average Compressive	31.67			45.67		

<table>
<tr><td></td><td>Strength in N/mm^2</td><td></td><td colspan="3"></td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>5</td><td colspan="5">Arsenic concentration in curing water</td></tr>
<tr><td></td><td colspan="5">Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 0.213 ppb
Arsenic concentration in curing water after 28 days for 3 cubes :- 0.335 ppb</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>6</td><td colspan="5">Arsenic concentration in the leachate (in ppb)</td></tr>
<tr><td></td><td colspan="5">One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.</td></tr>
<tr><td></td><td colspan="2">Size Range →</td><td><1mm</td><td><9.5mm</td><td>5-50mm</td></tr>
<tr><td></td><td colspan="2">7 days</td><td>0.693</td><td>0.201</td><td>0.136</td></tr>
<tr><td></td><td colspan="2">28 days</td><td>0.369</td><td>0.334</td><td>0.990</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>7</td><td colspan="5">Observations</td></tr>
<tr><td></td><td colspan="5">▪ The slump height is 35mm which is between 25-75 mm signifying that the mix is of low workability.
▪ The compacting factor is 0.85 signifying that the mix is of low workability.
▪ The average compressive strength after 28 days of curing is 45.67 N/mm^2. So it had achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2.
▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.</td></tr>
</table>

Table 7.35: Data Sheet for M20 Grade Concrete with 5% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M20 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18 Water: Cement Ratio :- 0.5 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.44 Kg Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg) Quantity of fine aggregate (sand) used :- 6.61 Kg Quantity of sludge used :- (0.05×3.44) = 0.17 Kg Quantity of fine aggregate (sand) actually used :- (6.61 – 0.17) = 6.44 Kg Quantity of water used :- (0.5×3.44) + (0.72×0.17) = 1.845 Kg

2 Workability of concrete

By Slump Test the slump height is coming to be 25mm.

3 Compacting factor of concrete

Weight of empty cylinder (W_1) = 7.225 Kg

Weight of cylinder with partially compacted concrete (W_2) = 17.140 Kg

Weight of cylinder with fully compacted concrete (W_3) = 19.125 Kg

Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.83

4 Compressive strength of concrete

	Strength after 7 days			Strength after 28 days		
Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
Compressive Strength in N/mm^2	30	29.5	29.5	43	41.5	42.5
Average Compressive Strength in N/mm^2	29.67			42.33		

5 Arsenic concentration in curing water

Quantity of curing water taken :- 25 L

Arsenic concentration in curing water after 7 days for 3 cubes :- 0.481 ppb

Arsenic concentration in curing water after 28 days for 3 cubes :- 0.611 ppb

6 Arsenic concentration in the leachate (in ppb)

One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	1.149	1.894	0.599
28 days	0.093	0.509	1.663

7 Observations

- The slump height is 25mm which is between 25-75 mm signifying that the mix is of low workability.
- The compacting factor is 0.83 signifying that the mix is of low workability.
- The average compressive strength after 28 days of curing is 42.33 N/mm^2. So it had achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2.
- The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
- The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.36: Data Sheet for M20 Grade Concrete with 10% by weight of cement of arsenic bearing ECAR sludge

<table>
<tr><td>1</td><td colspan="7">Quantities of materials used in the concrete cube preparation</td></tr>
<tr><td></td><td colspan="7">Grade of concrete to be prepared :- M20
Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18
Water: Cement Ratio :- 0.5
No. of cubes casted :- 7
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 3.44 Kg
Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg)
Quantity of fine aggregate (sand) used :- 6.61 Kg
Quantity of sludge used :- (0.1×3.44) = 0.34 Kg
Quantity of fine aggregate (sand) actually used :- (6.61 – 0.34) = 6.27 Kg
Quantity of water used :- (0.5×3.44) + (0.72×0.34) = 1.969 Kg</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>2</td><td colspan="7">Workability of concrete</td></tr>
<tr><td></td><td colspan="7">By Slump Test the slump height is coming to be 15mm.</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>3</td><td colspan="7">Compacting factor of concrete</td></tr>
<tr><td></td><td colspan="7">Weight of empty cylinder (W_1) = 7.220 Kg
Weight of cylinder with partially compacted concrete (W_2) = 16.615 Kg
Weight of cylinder with fully compacted concrete (W_3) = 19.095 Kg
Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.79</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>4</td><td colspan="7">Compressive strength of concrete</td></tr>
<tr><td></td><td></td><td colspan="3">Strength after 7 days</td><td colspan="3">Strength after 28 days</td></tr>
<tr><td></td><td>Cube No</td><td>Cube 1</td><td>Cube 2</td><td>Cube 3</td><td>Cube 1</td><td>Cube 2</td><td>Cube 3</td></tr>
<tr><td></td><td>Compressive Strength in N/mm^2</td><td>28</td><td>29</td><td>28</td><td>38</td><td>38</td><td>39</td></tr>
<tr><td></td><td>Average Compressive Strength in N/mm^2</td><td colspan="3">28.33</td><td colspan="3">38.33</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>5</td><td colspan="7">Arsenic concentration in curing water</td></tr>
<tr><td></td><td colspan="7">Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 0.642 ppb
Arsenic concentration in curing water after 28 days for 3 cubes :- 0.634 ppb</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>6</td><td colspan="7">Arsenic concentration in the leachate (in ppb)</td></tr>
<tr><td></td><td colspan="7">One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as</td></tr>
</table>

per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	1.746	1.895	0.919
28 days	1.772	1.699	1.415

7 Observations

- The slump height is 15mm which signifies that the mix is of very low workability.
- The compacting factor is 0.79 signifying that the mix is of very low workability.
- The average compressive strength after 28 days of curing is 38.33 N/mm^2. So it had achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2.
- The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
- The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.37: Data Sheet for M20 Grade Concrete with 12.5% by weight of cement of arsenic bearing ECAR sludge

1 Quantities of materials used in the concrete cube preparation

Grade of concrete to be prepared :- M20
Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18
Water: Cement Ratio :- 0.5
No. of cubes casted :- 7
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 3.44 Kg
Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg)
Quantity of fine aggregate (sand) used :- 6.61 Kg
Quantity of sludge used :- (0.125×3.44) = 0.43 Kg
Quantity of fine aggregate (sand) actually used :- (6.61 – 0.43) = 6.18 Kg
Quantity of water used :- (0.5×3.44) + (0.72×0.43) = 2.031 Kg

2 Workability of concrete

By Slump Test the slump height is coming to be 15mm.

3 Compacting factor of concrete

Weight of empty cylinder (W_1) = 7.220 Kg
Weight of cylinder with partially compacted concrete (W_2) = 16.615 Kg
Weight of cylinder with fully compacted concrete (W_3) = 19.095 Kg
Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.79

4 Compressive strength of concrete

		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	28	27.5	27.5	32	37	35
	Average Compressive Strength in N/mm^2	27.67			34.67		

5 Arsenic concentration in curing water

Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 0.511 ppb
Arsenic concentration in curing water after 28 days for 3 cubes :- 0.605 ppb

6 Arsenic concentration in the leachate (in ppb)

One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	3.758	3.937	3.176
28 days	4.138	5.339	3.170

7 Observations

- The slump height is 15mm which signifies that the mix is of very low workability.
- The compacting factor is 0.79 signifying that the mix is of very low workability.
- The average compressive strength after 28 days of curing is 34.67 N/mm^2. So it had achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2.
- The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
- The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.38: Data Sheet for M20 Grade Concrete with 15% by weight of cement of arsenic bearing ECAR sludge

1 Quantities of materials used in the concrete cube preparation

Grade of concrete to be prepared :- M20
Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18
Water: Cement Ratio :- 0.5
No. of cubes casted :- 7
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 3.44 Kg
Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg)

Quantity of fine aggregate (sand) used :- 6.61 Kg
Quantity of sludge used :- (0.15×3.44) = 0.52 Kg
Quantity of fine aggregate (sand) actually used :- (6.61 – 0.52) = 6.09 Kg
Quantity of water used :- (0.5×3.44) + (0.72×0.52) = 2.093 Kg

2 Workability of concrete

By Slump Test the slump height is coming to be 15mm.

3 Compacting factor of concrete

Weight of empty cylinder (W_1) = 7.225 Kg
Weight of cylinder with partially compacted concrete (W_2) = 16.325 Kg
Weight of cylinder with fully compacted concrete (W_3) = 18.885 Kg
Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.78

4 Compressive strength of concrete

	Strength after 7 days			Strength after 28 days		
Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
Compressive Strength in N/mm^2	26	25	26	35	36	33
Average Compressive Strength in N/mm^2	25.67			34.67		

5 Arsenic concentration in curing water

Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 0.784 ppb
Arsenic concentration in curing water after 28 days for 3 cubes :- 0.842 ppb

6 Arsenic concentration in the leachate (in ppb)

One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	2.159	2.378	1.105
28 days	3.216	3.736	2.492

7 Observations

- The slump height is 15mm which signifies that the mix is of very low workability.
- The compacting factor is 0.78 signifying that the mix is of very low workability.
- The average compressive strength after 28 days of curing is 34.67 N/mm^2. So it had achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2.

	▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.39: Data Sheet for M20 Grade Concrete with 20% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M20 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18 Water: Cement Ratio :- 0.5 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.44 Kg Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg) Quantity of fine aggregate (sand) used :- 6.61 Kg Quantity of sludge used :- (0.2×3.44) = 0.69 Kg Quantity of fine aggregate (sand) actually used :- (6.61 – 0.69) = 5.92 Kg Quantity of water used :- (0.5×3.44) + (0.72×0.69) = 2.217 Kg
2	**Workability of concrete**
	By Slump Test the slump height is coming to be 15mm.
3	**Compacting factor of concrete**
	Weight of empty cylinder (W_1) = 7.215 Kg Weight of cylinder with partially compacted concrete (W_2) = 15.875 Kg Weight of cylinder with fully compacted concrete (W_3) = 18.415 Kg Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.77
4	**Compressive strength of concrete**

		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	25	23	24	34	34	33
	Average Compressive Strength in N/mm^2	24			33.67		

5	**Arsenic concentration in curing water**
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 0.623 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 0.793 ppb

<table>
<tr><td colspan="5"></td></tr>
<tr><td>6</td><td colspan="4">**Arsenic concentration in the leachate (in ppb)**</td></tr>
<tr><td></td><td colspan="4">One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.</td></tr>
<tr><td></td><td>Size Range →</td><td><1mm</td><td><9.5mm</td><td>5-50mm</td></tr>
<tr><td></td><td>7 days</td><td>4.574</td><td>4.441</td><td>3.926</td></tr>
<tr><td></td><td>28 days</td><td>6.285</td><td>9.476</td><td>6.335</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>7</td><td colspan="4">**Observations**</td></tr>
<tr><td></td><td colspan="4">▪ The slump height is 15mm which signifies that the mix is of very low workability.
▪ The compacting factor is 0.77 signifying that the mix is of very low workability.
▪ The average compressive strength after 28 days of curing is 33.67 N/mm^2. So it had achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2.
▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.</td></tr>
</table>

Table 7.40: Data Sheet for M20 Grade Concrete with 25% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M20 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18 Water: Cement Ratio :- 0.5 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.44 Kg Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg) Quantity of fine aggregate (sand) used :- 6.61 Kg Quantity of sludge used :- (0.25×3.44) = 0.86 Kg Quantity of fine aggregate (sand) actually used :- (6.61 – 0.86) = 5.75 Kg Quantity of water used :- (0.5×3.44) + (0.72×0.69) = 2.341 Kg
2	**Workability of concrete**
	By Slump Test the slump height is coming to be 10mm.
3	**Compacting factor of concrete**
	Weight of empty cylinder (W_1) = 7.225 Kg Weight of cylinder with partially compacted concrete (W_2) = 15.475 Kg

	Weight of cylinder with fully compacted concrete (W_3) = 18.095 Kg Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.76
4	**Compressive strength of concrete**

		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	21	22	23	31	31.5	32
	Average Compressive Strength in N/mm^2	22			31.5		

5	**Arsenic concentration in curing water**
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 0.781 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 0.918 ppb
6	**Arsenic concentration in the leachate (in ppb)**
	One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

	Size Range →	<1mm	<9.5mm	5-50mm
	7 days Cube	7.188	9.870	5.074
	28 days Cube	9.219	9.940	7.048

7	**Observations**
	▪ The slump height is 10mm which signifies that the mix is of very low workability. ▪ The compacting factor is 0.76 signifying that the mix is of very low workability. ▪ The average compressive strength after 28 days of curing is 31.5 N/mm^2. So it had achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2. ▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.41: Data Sheet for M20 Grade Concrete with 30% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M20 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18 Water: Cement Ratio :- 0.5

No. of cubes casted :- 7
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 3.44 Kg
Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg)
Quantity of fine aggregate (sand) used :- 6.61 Kg
Quantity of sludge used :- (0.3×3.44) = 1.03 Kg
Quantity of fine aggregate (sand) actually used :- (6.61 – 1.03) = 5.58 Kg
Quantity of water used :- (0.5×3.44) + (0.72×1.03) = 2.465 Kg

2 Workability of concrete

By Slump Test the slump height is coming to be 10mm.

3 Compacting factor of concrete

Weight of empty cylinder (W_1) = 7.220 Kg
Weight of cylinder with partially compacted concrete (W_2) = 15.140 Kg
Weight of cylinder with fully compacted concrete (W_3) = 17.835 Kg
Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.75

4 Compressive strength of concrete

	Strength after 7 days			Strength after 28 days		
Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
Compressive Strength in N/mm^2	20	20.5	19.5	25	27	26
Average Compressive Strength in N/mm^2	20			26		

5 Arsenic concentration in curing water

Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 1.123 ppb
Arsenic concentration in curing water after 28 days for 3 cubes :- 1.612 ppb

6 Arsenic concentration in the leachate (in ppb)

One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	2.022	3.152	1.746
28 days	2.820	7.369	1.762

7 Observations

	▪ The slump height is 10mm which signifies that the mix is of very low workability. ▪ The compacting factor is 0.75 signifying that the mix is of very low workability. ▪ The average compressive strength after 28 days of curing is 26 N/mm^2. So it had just achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2. ▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.42: Data Sheet for M20 Grade Concrete with 32.5% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**						
	Grade of concrete to be prepared :- M20 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18 Water: Cement Ratio :- 0.5 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.44 Kg Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg) Quantity of fine aggregate (sand) used :- 6.61 Kg Quantity of sludge used :- (0.325×3.44) = 1.12 Kg Quantity of fine aggregate (sand) actually used :- (6.61 – 1.12) = 5.49 Kg Quantity of water used :- (0.5×3.44) + (0.72×1.12) = 2.527 Kg						
2	**Workability of concrete**						
	By Slump Test the slump height is coming to be 5mm.						
3	**Compacting factor of concrete**						
	Weight of empty cylinder (W_1) = 7.215 Kg Weight of cylinder with partially compacted concrete (W_2) = 14.990 Kg Weight of cylinder with fully compacted concrete (W_3) = 17.685 Kg Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.74						
4	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	19	20	18	21	22	23
	Average Compressive Strength in N/mm^2	19			22		

5	**Arsenic concentration in curing water**			
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 1.016 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 1.584 ppb			
6	**Arsenic concentration in the leachate (in ppb)**			
	One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.			
	Size Range →	<1mm	<9.5mm	5-50mm
	7 days	5.296	8.133	3.000
	28 days	7.569	6.289	9.804
7	**Observations**			
	▪ The slump height is 5mm which signifies that the mix is of very low workability. ▪ The compacting factor is 0.74. ▪ The average compressive strength after 28 days of curing is 22 N/mm^2. So it had not achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2. ▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.			

Table 7.43: Data Sheet for M20 Grade Concrete with 35% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M20 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18 Water: Cement Ratio :- 0.5 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.44 Kg Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg) Quantity of fine aggregate (sand) used :- 6.61 Kg Quantity of sludge used :- (0.35×3.44) = 1.20 Kg Quantity of fine aggregate (sand) actually used :- (6.61 – 1.20) = 5.40 Kg Quantity of water used :- (0.5×3.44) + (0.72×0.86) = 2.589 Kg
2	**Workability of concrete**
	By Slump Test the slump height is coming to be 5mm.

3	**Compacting factor of concrete**
	Weight of empty cylinder (W_1) = 7.215 Kg Weight of cylinder with partially compacted concrete (W_2) = 14.990 Kg Weight of cylinder with fully compacted concrete (W_3) = 17.685 Kg Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.74

4	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	17	16.5	17.5	20.5	21	19
	Average Compressive Strength in N/mm^2	17			20.17		

5	**Arsenic concentration in curing water**
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 1.027 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 1.295 ppb

6	**Arsenic concentration in the leachate (in ppb)**			
	One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.			
	Size Range →	<1mm	<9.5mm	5-50mm
	7 days	2.654	3.122	1.742
	28 days	4.624	3.418	3.767

7	**Observations**
	▪ The slump height is 5mm which signifies that the mix is of very low workability. ▪ The compacting factor is 0.74. ▪ The average compressive strength after 28 days of curing is 20.17 N/mm^2. So it had not achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2. ▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.44: Data Sheet for M20 Grade Concrete with 37.5% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**						
	Grade of concrete to be prepared :- M20 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18 Water: Cement Ratio :- 0.5 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.44 Kg Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg) Quantity of fine aggregate (sand) used :- 6.61 Kg Quantity of sludge used :- (0.375×3.44) = 1.29Kg Quantity of fine aggregate (sand) actually used :- (6.61 – 1.29) = 5.32 Kg Quantity of water used :- (0.5×3.44) + (0.72×1.29) = 2.651 Kg						
2	**Workability of concrete**						
	By Slump Test the slump height is coming to be 5mm.						
3	**Compacting factor of concrete**						
	Weight of empty cylinder (W_1) = 7.215 Kg Weight of cylinder with partially compacted concrete (W_2) = 14.990 Kg Weight of cylinder with fully compacted concrete (W_3) = 17.685 Kg Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.74						
4	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	18.5	18	19	20	18.5	21
	Average Compressive Strength in N/mm^2	18.5			19.83		
5	**Arsenic concentration in curing water**						
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 1.153 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 1.458 ppb						
6	**Arsenic concentration in the leachate (in ppb)**						
	One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as						

per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	3.401	7.885	2.096
28 days	2.558	8.961	7.094

7 Observations

- The slump height is 5mm which signifies that the mix is of very low workability.
- The compacting factor is 0.74.
- The average compressive strength after 28 days of curing is 19.83 N/mm^2. So it had not achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2.
- The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
- The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.45: Data Sheet for M20 Grade Concrete with 40% by weight of cement of arsenic bearing ECAR sludge

1 Quantities of materials used in the concrete cube preparation

Grade of concrete to be prepared :- M20
Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18
Water: Cement Ratio :- 0.5
No. of cubes casted :- 7
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 3.44 Kg
Quantity of coarse aggregate used :- 10.95 Kg (CA-I:- 6.57 Kg and CA-II:- 4.38 Kg)
Quantity of fine aggregate (sand) used :- 6.610 Kg
Quantity of sludge used :- (0.4×3.44) = 1.38 Kg
Quantity of fine aggregate (sand) actually used :- (6.61 – 1.38) = 5.23 Kg
Quantity of water used :- (0.5×3.44) + (0.72×1.38) = 2.713 Kg

2 Workability of concrete

By Slump Test the slump height is coming to be 5mm.

3 Compacting factor of concrete

Weight of empty cylinder (W_1) = 7.215 Kg
Weight of cylinder with partially compacted concrete (W_2) = 14.890 Kg
Weight of cylinder with fully compacted concrete (W_3) = 17.685 Kg
Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.73

4 Compressive strength of concrete

		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	17.5	16.5	17	18.5	19	18
	Average Compressive Strength in N/mm^2	17			18.5		

5 Arsenic concentration in curing water

Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 1.129
Arsenic concentration in curing water after 28 days for 3 cubes :- 1.222 ppb

6 Arsenic concentration in the leachate (in ppb)

One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	3.624	7.926	2.164
28 days	4.175	4.827	2.387

7 Observations

- The slump height is 5mm which signifies that the mix is of very low workability.
- The compacting factor is 0.73.
- The average compressive strength after 28 days of curing is 18.5 N/mm^2. So it had not achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2.
- The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
- The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.46: Data Sheet for M20 Grade Concrete with 60% by weight of cement of arsenic bearing ECAR sludge

1 Quantities of materials used in the concrete cube preparation

Grade of concrete to be prepared :- M20
Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18
Water: Cement Ratio :- 0.5
No. of cubes casted :- 3
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 1.48 Kg
Quantity of coarse aggregate used :- 4.69 Kg (CA-I:- 2.82 Kg and CA-II:- 1.88 Kg)

	Quantity of fine aggregate (sand) used :- 2.833 Kg Quantity of sludge used :- (0.6×1.48) = 0.89 Kg Quantity of fine aggregate (sand) actually used :- (2.833 – 0.89) = 1.95 Kg Quantity of water used :- (0.5×1.48) + (0.72×0.89) = 1.375 Kg						
2	**Workability of concrete**						
	The concrete mix was not workable at all.						
3	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	–	–	–	21	20	22
	Average Compressive Strength in N/mm^2	–			21		
4	**Arsenic concentration in curing water**						
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 28 days for 3 cubes :- 2.862 ppb						
5	**Arsenic concentration in the leachate (in ppb)**						
	One cube for 28 days had been used in the study. The cube had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.						
	Size Range →				<1mm	<9.5mm	5-50mm
	28 days				4.866	5.11	2.778
6	**Observations**						
	▪ The concrete mix was not workable at all. ▪ The average compressive strength after 28 days of curing is 21 N/mm^2. So it had not achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2. ▪ The arsenic concentrations in curing water tested after 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.						

Table 7.47: Data Sheet for M20 Grade Concrete with 80% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M20 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18 Water: Cement Ratio :- 0.5

<table>
<tr><td></td><td colspan="7">No. of cubes casted :- 3
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 1.48 Kg
Quantity of coarse aggregate used :- 4.69 Kg (CA-I:- 2.82 Kg and CA-II:- 1.88 Kg)
Quantity of fine aggregate (sand) used :- 2.833 Kg
Quantity of sludge used :- (0.8×1.48) = 1.18 Kg
Quantity of fine aggregate (sand) actually used :- (2.833 – 1.18) = 1.65 Kg
Quantity of water used :- (0.5×1.48) + (0.72×1.18) = 1.588 Kg</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>2</td><td colspan="7">Workability of concrete</td></tr>
<tr><td></td><td colspan="7">The concrete mix was not workable at all.</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>3</td><td colspan="7">Compressive strength of concrete</td></tr>
<tr><td></td><td></td><td colspan="3">Strength after 7 days</td><td colspan="3">Strength after 28 days</td></tr>
<tr><td></td><td>Cube No</td><td>Cube 1</td><td>Cube 2</td><td>Cube 3</td><td>Cube 1</td><td>Cube 2</td><td>Cube 3</td></tr>
<tr><td></td><td>Compressive Strength in N/mm^2</td><td>_</td><td>_</td><td>_</td><td>15.5</td><td>16</td><td>15</td></tr>
<tr><td></td><td>Average Compressive Strength in N/mm^2</td><td colspan="3">_</td><td colspan="3">15.5</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>4</td><td colspan="7">Arsenic concentration in curing water</td></tr>
<tr><td></td><td colspan="7">Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 28 days for 3 cubes :- 3.046 ppb</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>5</td><td colspan="7">Arsenic concentration in the leachate (in ppb)</td></tr>
<tr><td></td><td colspan="7">One cube for 28 days had been used in the study. The cube had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.</td></tr>
<tr><td></td><td colspan="4">Size Range →</td><td><1mm</td><td><9.5mm</td><td>5-50mm</td></tr>
<tr><td></td><td colspan="4">28 days</td><td>4.858</td><td>5.376</td><td>3.456</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>6</td><td colspan="7">Observations</td></tr>
<tr><td></td><td colspan="7">▪ The concrete mix was not workable at all.
▪ The average compressive strength after 28 days of curing is 15.5 N/mm^2. So it had not achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2.
▪ The arsenic concentrations in curing water tested after 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.</td></tr>
</table>

Table 7.48: Data Sheet for M20 Grade Concrete with 100% by weight of cement of arsenic bearing ECAR sludge

1 Quantities of materials used in the concrete cube preparation

Grade of concrete to be prepared :- M20
Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.92:3.18
Water: Cement Ratio :- 0.5
No. of cubes casted :- 3
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 1.48 Kg
Quantity of coarse aggregate used :- 4.69 Kg (CA-I:- 2.82 Kg and CA-II:- 1.88 Kg)
Quantity of fine aggregate (sand) used :- 2.833 Kg
Quantity of sludge used :- (1×1.48) = 1.48 Kg
Quantity of fine aggregate (sand) actually used :- (2.833 – 1.48) = 1.36 Kg
Quantity of water used :- (0.5×1.48) + (0.72×1.48) = 1.8 Kg

2 Workability of concrete

The concrete mix was not workable at all.

3 Compressive strength of concrete

	Strength after 7 days			Strength after 28 days		
Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
Compressive Strength in N/mm^2	–	–	–	16	15.5	16.5
Average Compressive Strength in N/mm^2	–			16		

4 Arsenic concentration in curing water

Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 28 days for 3 cubes :- 3.608 ppb

5 Arsenic concentration in the leachate (in ppb)

One cube for 28 days had been used in the study. The cube had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
28 days	5.413	5.712	2.255

6 Observations

- The concrete mix was not workable at all.
- The average compressive strength after 28 days of curing is 16 N/mm^2. So it had not achieved the target mean strength for M20 grade of concrete i.e. 26.6 N/mm^2.

	▪ The arsenic concentrations in curing water tested after 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

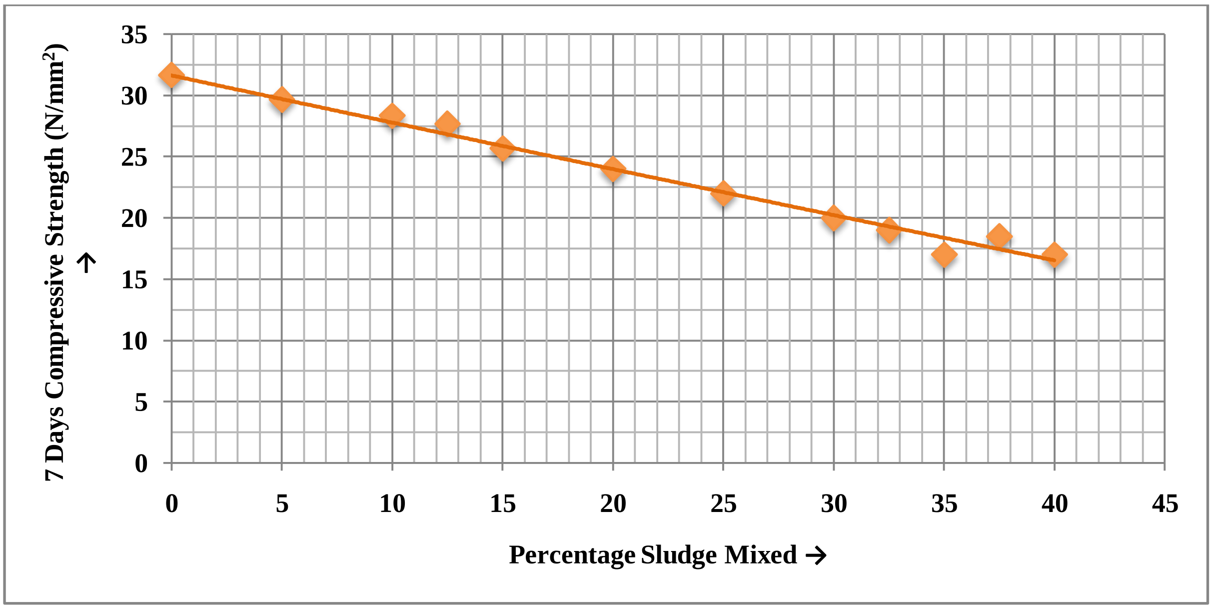


Figure 7.29: Percentage Sludge Mixed v/s 7 Days Compressive Strength Graph for M20

From Fig. 7.29 it is seen that the compressive strength of concrete cubes after 7 days of curing had been decreasing with increase in amount of sludge mixed. As per IS 456:2000, generally the strength at end of 7 days is 2/3rd of the target mean strength.

For M20 grade of concrete, the strength to be achieved at the end of 7 days is 17.8 N/mm^2. Up to 32.5% (by weight of cement) sludge mixed concrete cube had achieved this strength. But on the next increment of sludge mixed concrete i.e. 35% (by weight of cement), it had failed to achieve this strength. This 35% sludge mixed concrete cube had achieved 64% of the target mean strength after 7 days of curing.

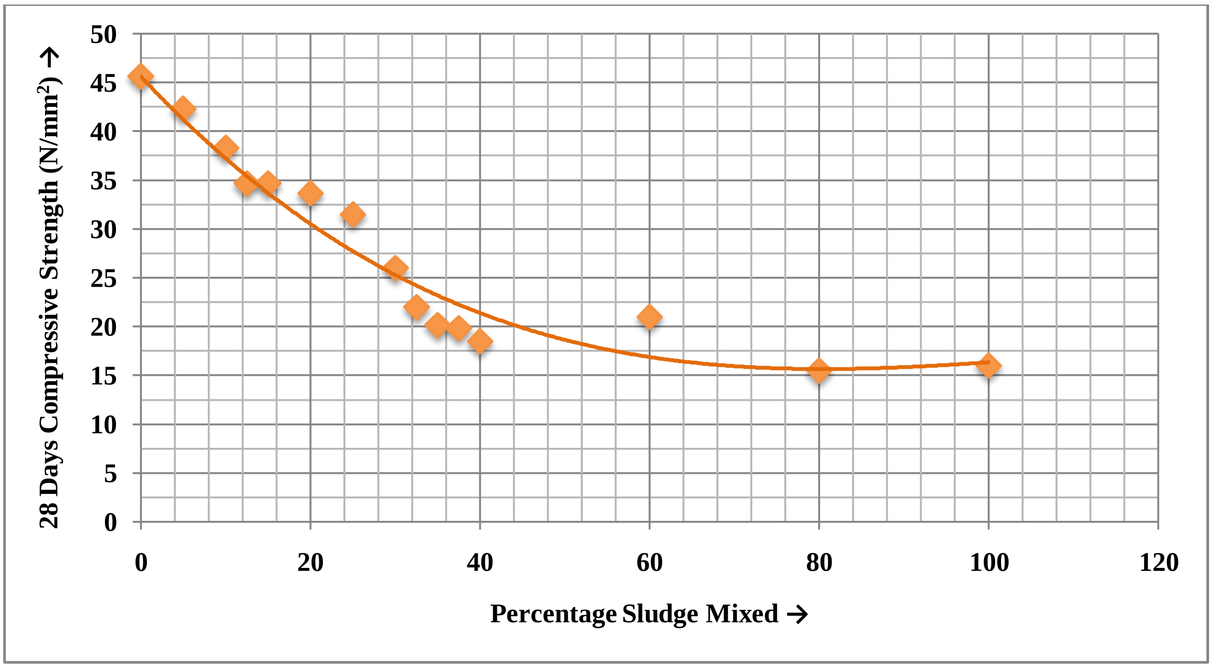


Figure 7.30: Percentage Sludge Mixed v/s 28 Days Compressive Strength Graph for M20

From Fig 7.30 it is seen that the compressive strength of concrete cubes after 28 days of curing had been decreasing with increase in amount of sludge mixed.

For M20 grade of concrete, the strength to be achieved at the end of 28 days is 26.6 N/mm^2. Up to 25% (by weight of cement) sludge mixed concrete cube had achieved this strength. But on the next increment of sludge mixed concrete i.e. 30% (by weight of cement) had just achieved this strength. So this point signifies the maximum amount of sludge that can mixed by weight of cement in M20 grade of concrete. But from practical point of view keeping a margin for safety, a factor of safety of minimum 1.5 had been prescribed. So the recommended maximum percentage of sludge (by weight of cement) that can be safely mixed with M20 grade concrete is 20%.

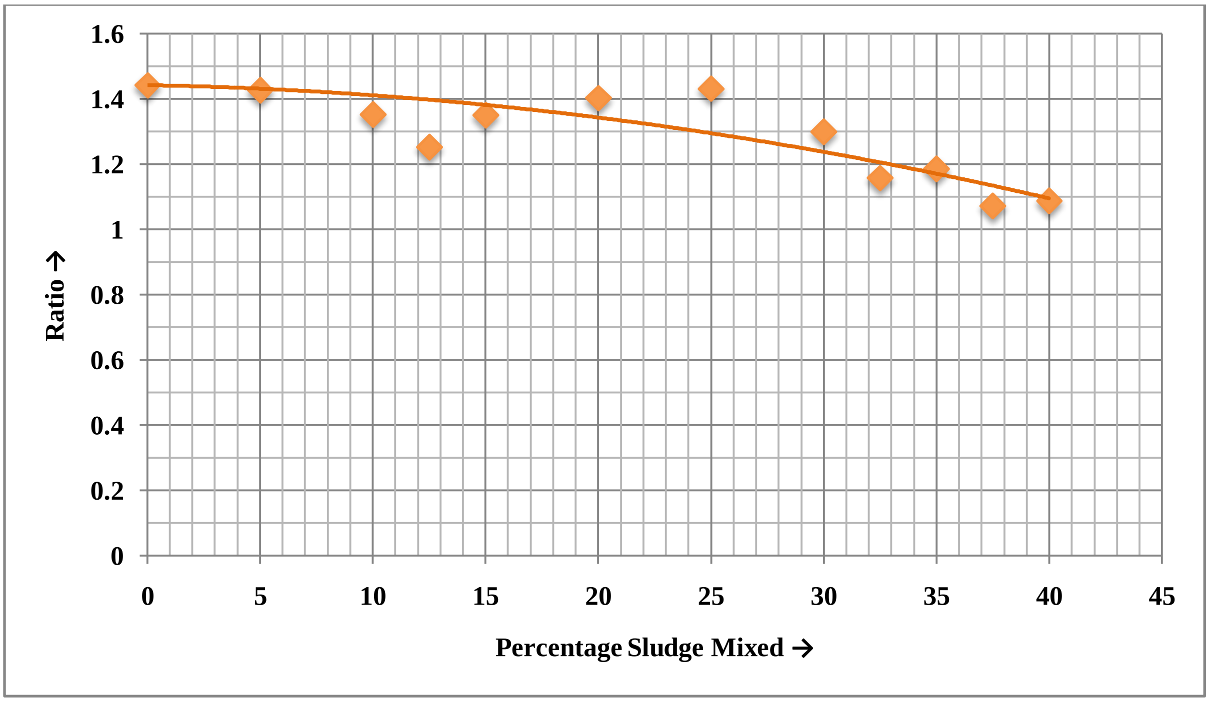


Figure 7.31: Percentage Sludge Mixed v/s Ratio of 28 days Strength to 7days Strength Graph for M20

As per IS 456:2000, the ratio of 28 days strength to 7 days strength is 1.5. And in this study it had been observed that with increase in amount of sludge mixed, the ratio had shown a decreasing trend.

For M20 the ratio was 1.44 for the 0% (by weight of cement) sludge mixed concrete. And it had decreased by 2.78% for the 20% (by weight of cement) sludge mixed concrete and by 9.72% for the 30% (by weight of cement) sludge mixed concrete.

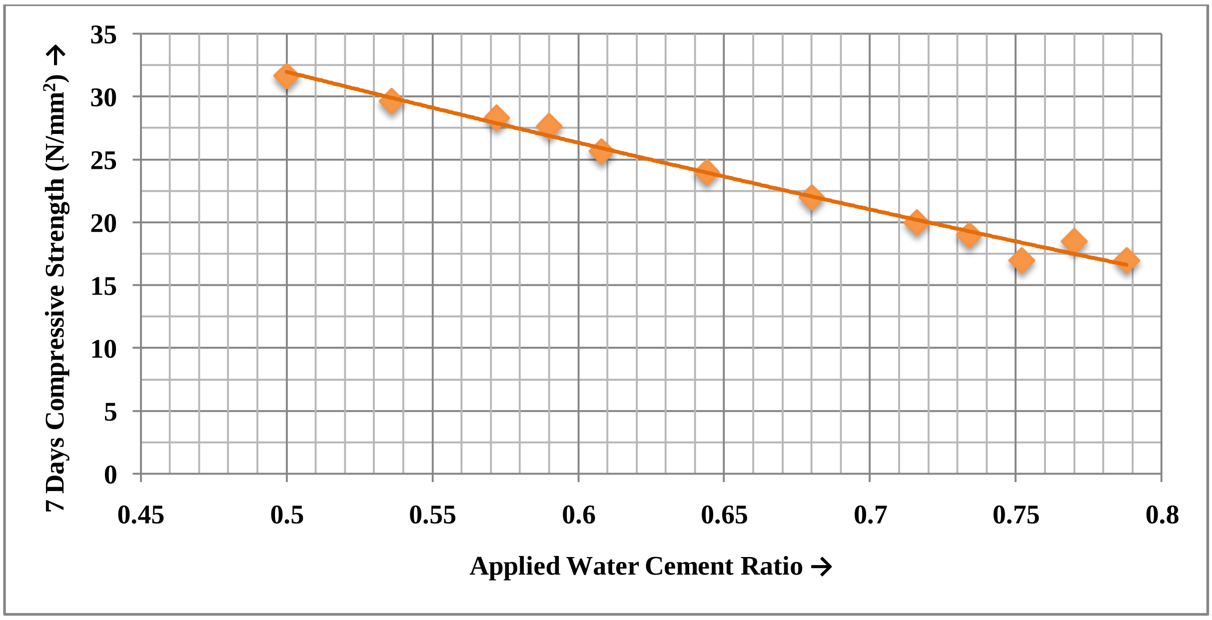


Figure 7.32: Applied WC Ratio v/s 7 days Compressive Strength Graph for M20

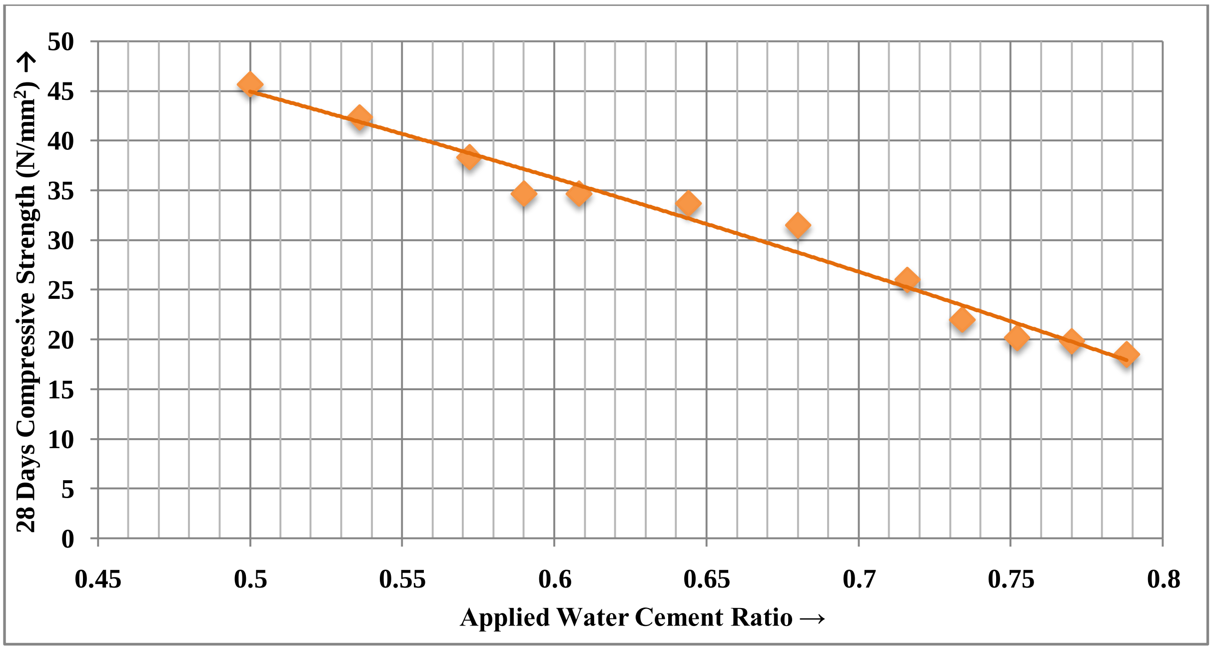


Figure 7.33: Applied WC Ratio v/s 28 days Compressive Strength Graph for M20

From Fig. 7.32 and 7.33, it had been observed that with the increase in applied water-cement ratio, the strength of the concrete had deceased. In this study, the sludge mixed had a very high OMC value which signifies that the sludge had a higher ability to hold moisture than sand. So to compensate this extra water equivalent to the OMC of the mixed sludge amount had been added in addition to mix design water requirement. So with the increase in sludge amount mixed, the water added had also increased which in turn had increased the water-cement ratio. So here the term 'Applied WC Ratio' had been used.

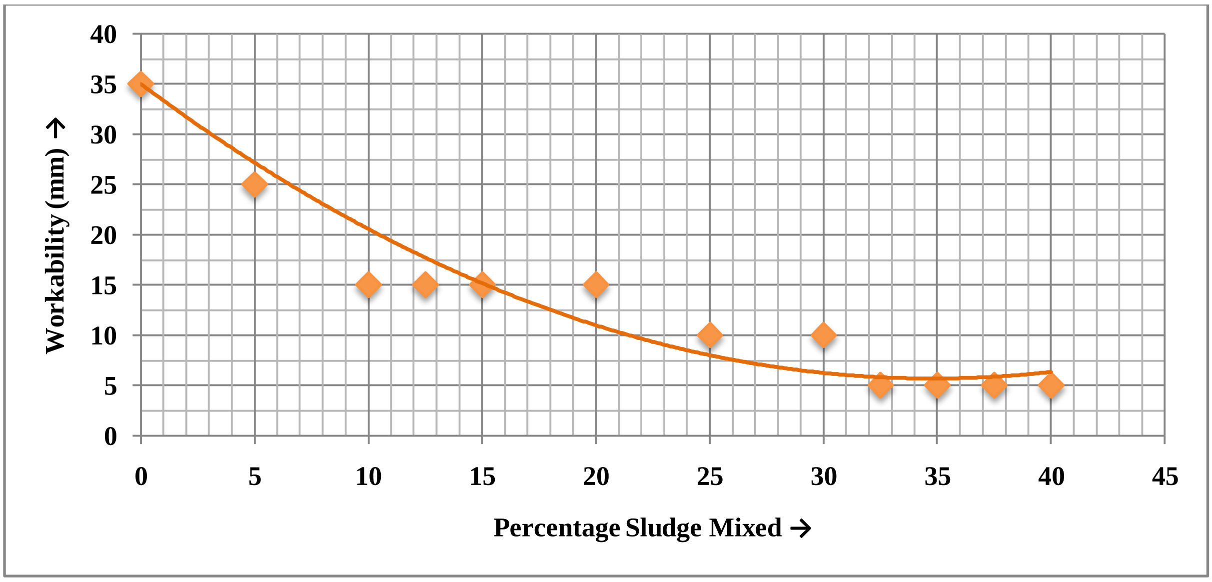


Figure 7.34: Percentage Sludge Mixed v/s Workability of Concrete Mix Graph for M20

From Fig. 7.34 it is seen that the workability determined by slump height is decreasing with increase in amount of sludge mixed. This sludge sample mixed has an exceptionally high OMC value (72%), so its moisture holding capacity is high. And although in this study extra water equivalent to the OMC of the sludge have been added, still the increase in sludge amount showed a gradual drying up of the freshly prepared concrete mix. So the workability has been decreasing significantly with addition of sludge.

For M20 grade concrete the slump height was 35 mm for 0% sludge (by weight of cement) mixed cubes. It signifies a low workability (within 25mm-75mm as per IS 456:2000). The slump height has decreased to 10mm for 30% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M20. So there had been a 71.4% decrease in workability.

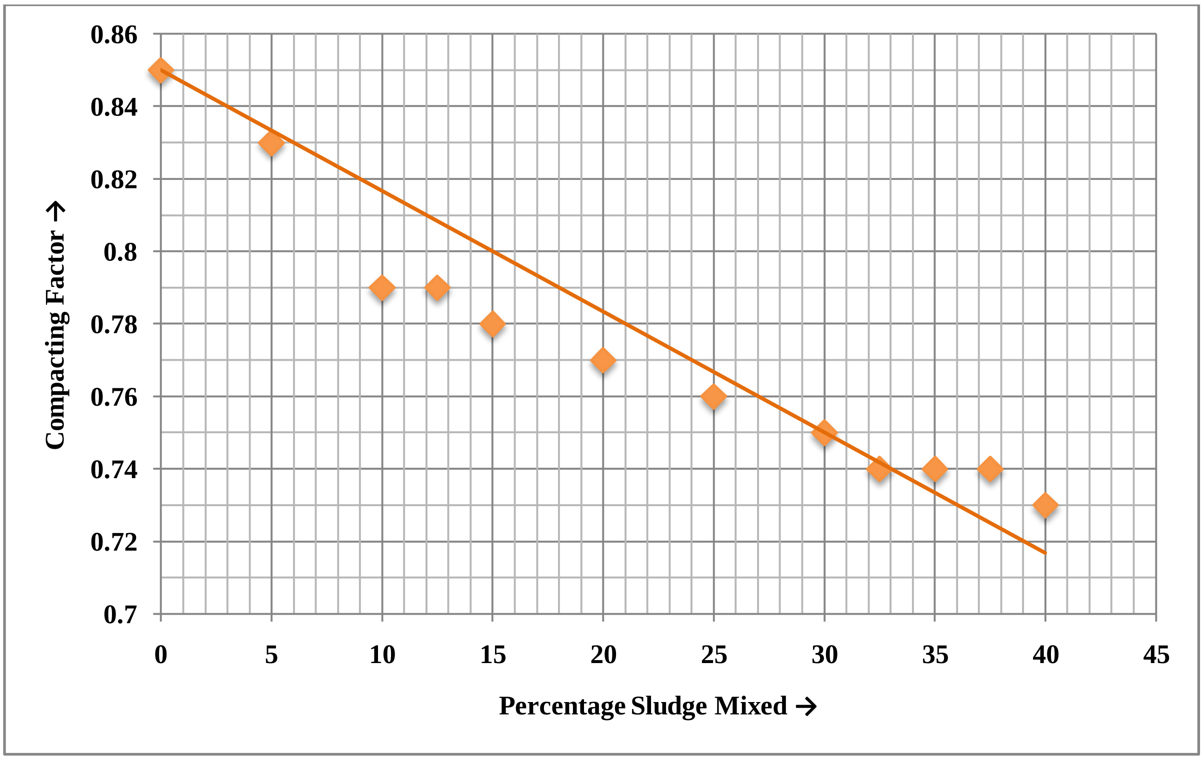


Figure 7.35: Percentage Sludge Mixed v/s Compacting Factor of Concrete Mix Graph for M20

From Fig. 7.35 it is seen that with increase in sludge percentage, the compacting factor is decreasing. Compacting factor is another measure for workability and it is decreasing because of the same reason why the slump height is decreasing.

For M20 grade concrete the compacting factor was 0.85 for 0% sludge (by weight of cement) mixed cubes. It signifies a low workability (within 0.80-0.85 as per Table No 22 of SP23:1982). The compacting factor has decreased to 0.75 for 30% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M20. It signifies a very low workability (within 0.75-0.80 as per Table No 22 of SP23:1982). So there had been an 11.8% decrease in compacting factor.

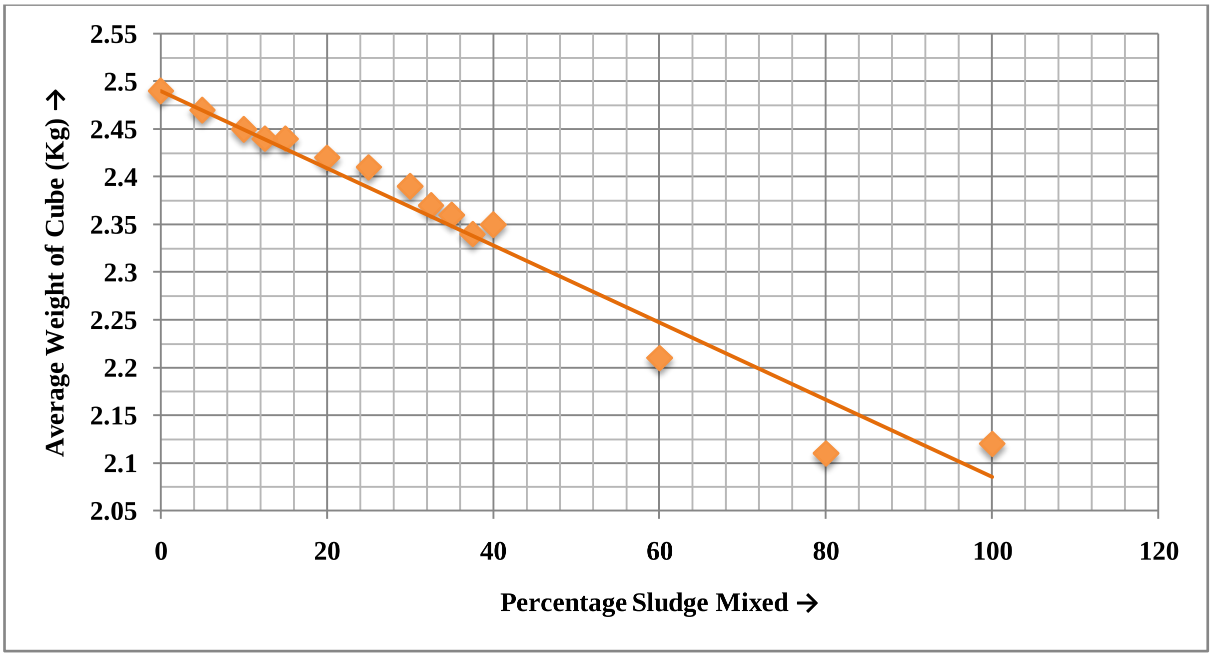


Figure 7.36: Percentage Sludge Mixed v/s Average Weight of Concrete Cubes after 28 days of Curing Graph for M20

From the above graph it is seen that with the increase in percentage of sludge mixed, the average weight of the concrete cubes is decreasing. This may be due to the fact that the maximum dry density (0.883 gm/cc) of this sludge is less than the other constituents of concrete like cement, sand and stone chips. This low density owes to the fact that the void ratio (2.281) of the sludge sample is higher than the other constituents of concrete. So the amount of voids in much higher in the sludge sample. But the design mix weight of concrete cube is fixed and with this low density it is taking up more volume. So the overall weight of the concrete cube is becoming less as we are increasing the amount of sludge mixed.

For M20 grade concrete the average weight of the concrete cubes is 2.49Kg for 0% sludge (by weight of cement) mixed cubes. It has decreased to 2.39 for 30% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M20. So there had been a 4% decrease in average weight of concrete cubes.

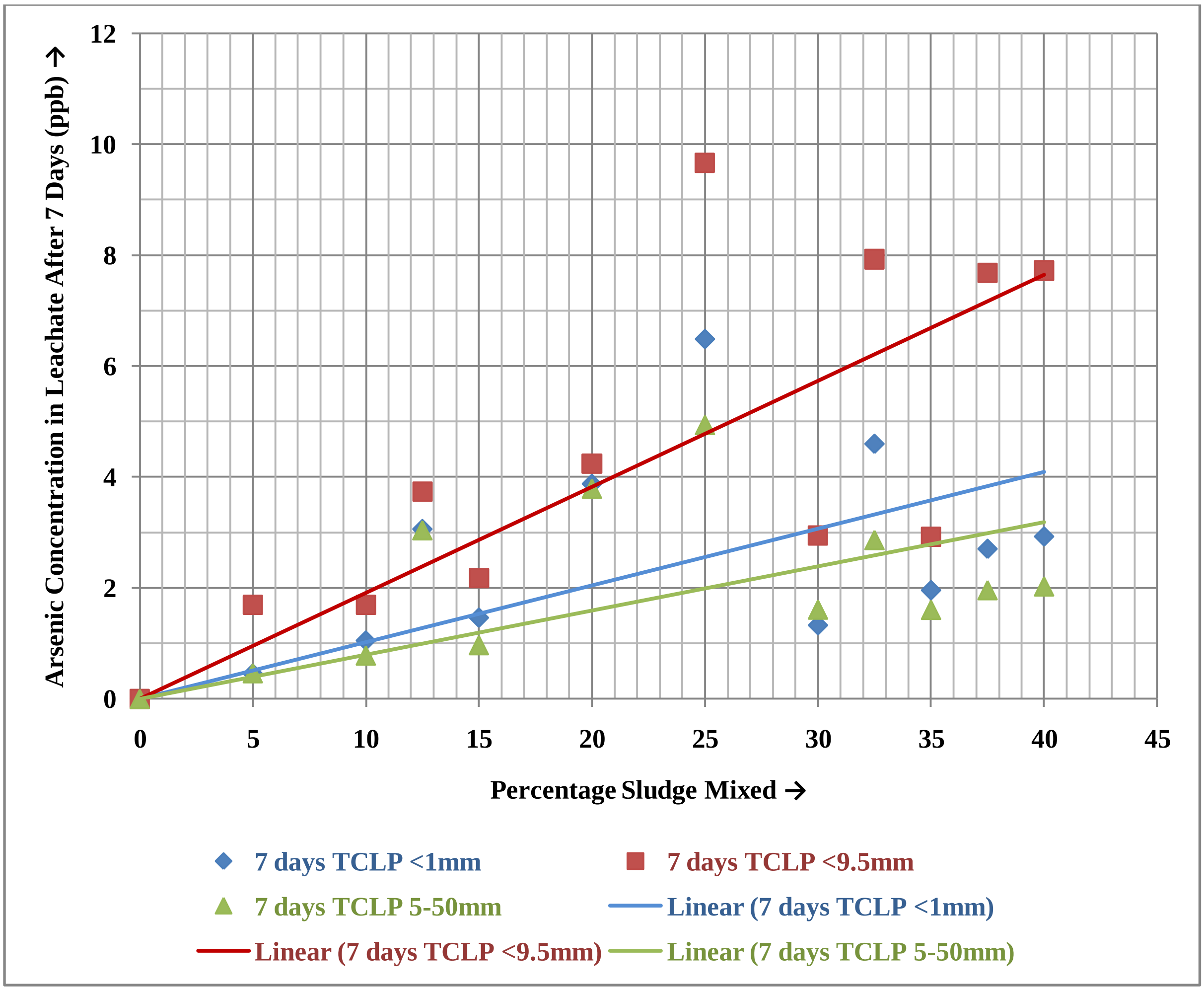


Figure 7.37: Percentage Sludge Mixed v/s 7 days As Concentration in Leachate Graph for M20

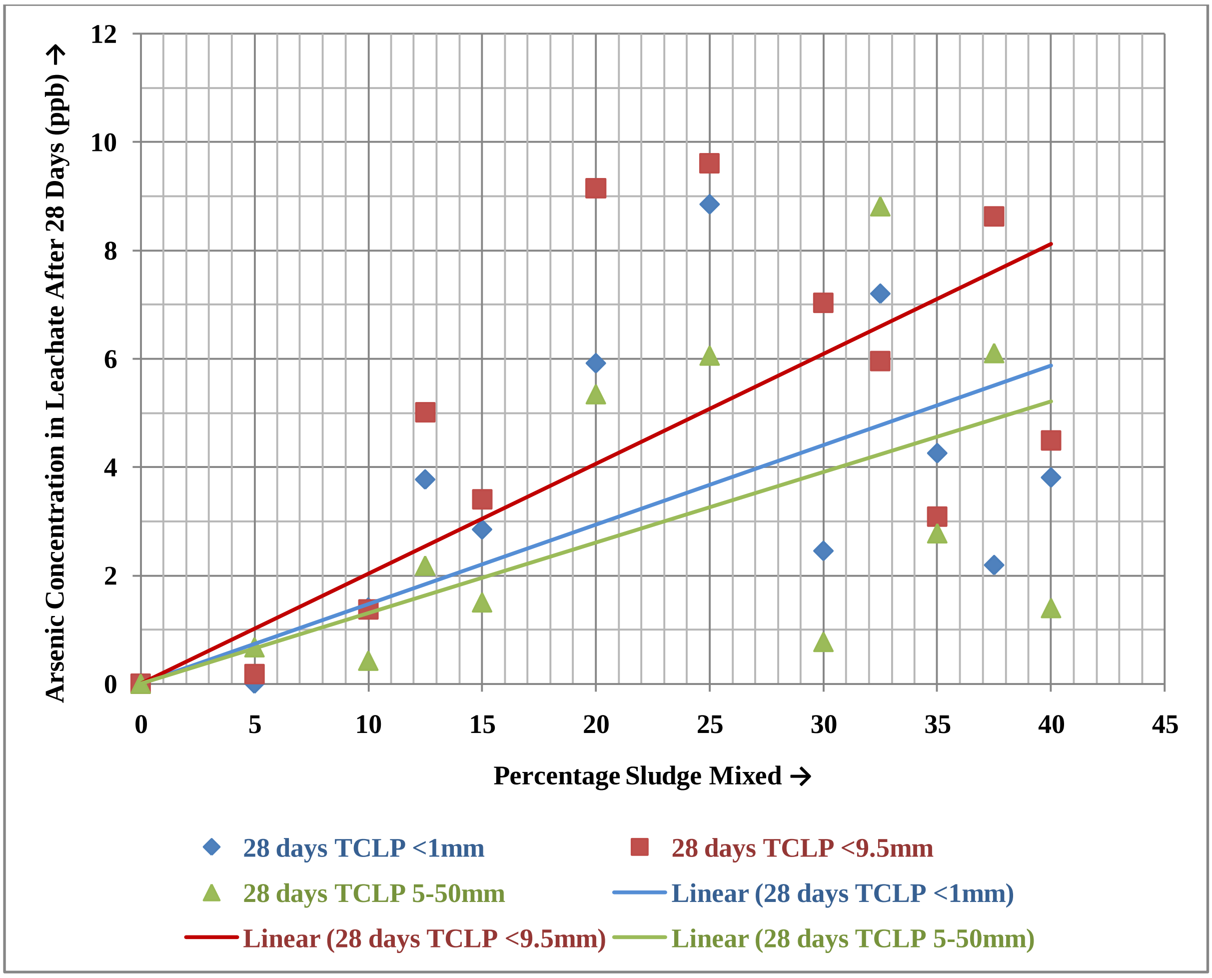


Figure 7.38: Percentage Sludge Mixed v/s 28 days As Concentration in Leachate Graph for M20

The sludge mixed concrete cubes have been checked for leachability of arsenic by TCLP. For this it had been pulverized into three size zones: i) <1mm ii) <9.5mm and iii) 5-50mm.

Figures 7.37 and 7.38 shows that for M20 grade concrete, the leached arsenic concentration in the leachate tested for the cubes after both 7 days and 28 days of curing shows an increasing trend i.e. with increase in percentage of sludge mixed the arsenic concentration in the leachate increases. But still all the arsenic concentrations are well below 200 ppb (the limit of arsenic for safe disposal of leachates) and also below 10ppb (the drinking water acceptable limit of arsenic as per IS10500:2012). The size zone <9.5mm shows the worst case scenario in terms of leached arsenic concentration and the results of this size zone can be taken as the representative one. USEPA has also recommended this size zone of <9.5mm for the determination using TCLP.

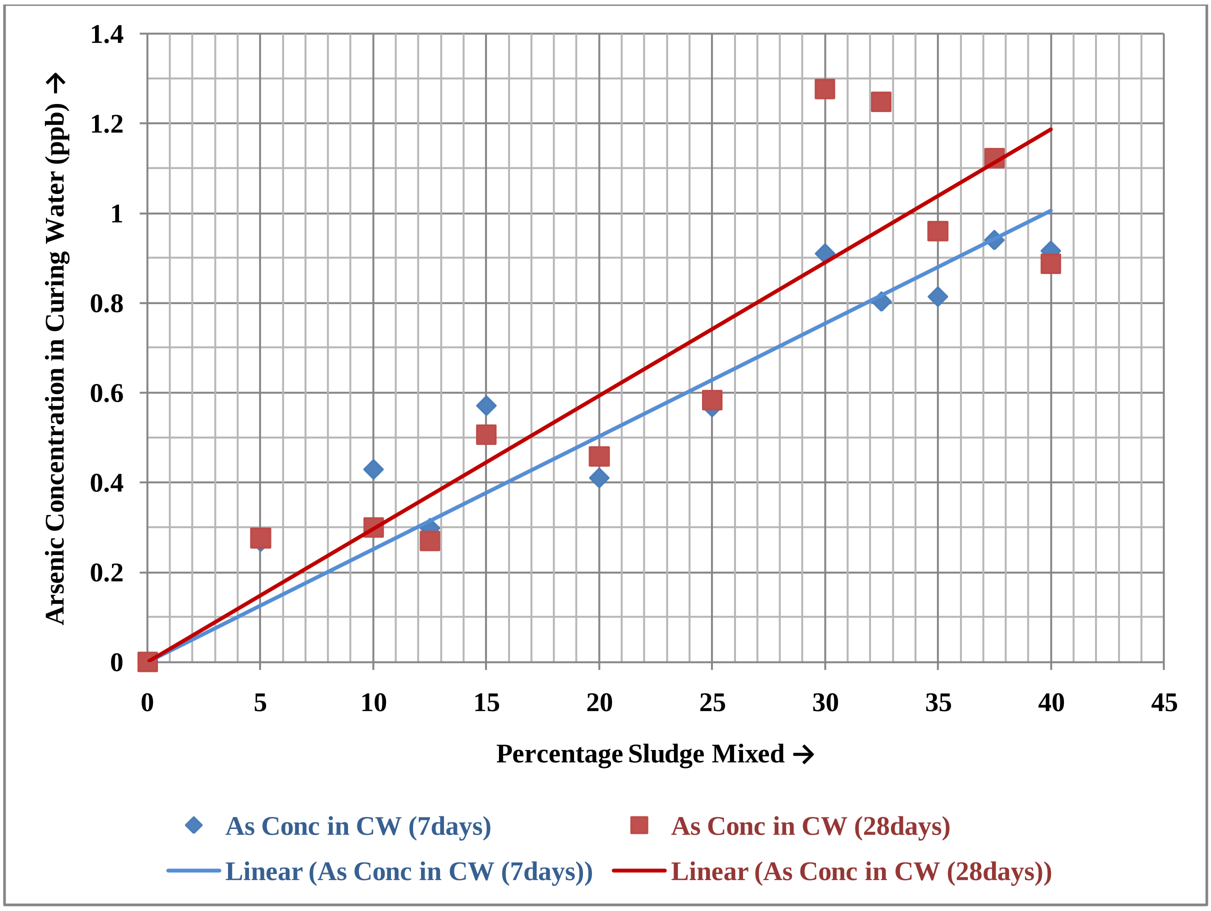


Figure 7.39: Percentage Sludge Mixed v/s As Concentration in Curing Water Graph for M20

Fig 7.39 shows the arsenic concentration in curing water tested after both 7days and 28days of curing.

For M20 grade of concrete it shows an increasing trend i.e. for increase in percentage of sludge mixed the arsenic concentration in curing increases. But still all the arsenic concentrations tested after both 7 days and 28 days of curing are well below 10ppb (the drinking water acceptable limit of arsenic as per IS10500:2012). The arsenic content in the curing water after 28 days of curing is slightly higher than that after 7 days of curing.

7.8 M15 Grade Concrete Results and Discussion

The arsenic bearing sludge had been embedded in the M15 grade concrete in varying proportions viz. 0%, 20%, 30% and 33% by weight of cement. This amount of sludge had been added by replacing equivalent amount of sand. And water equivalent to the OMC of this sludge had also been added in the concrete mix. Seven cubes of dimension 100mm×100mm×100mm had been casted for each of the percentages. In each case the slump height and compacting factor had been determined to signify its workability. And also three cubes each for 7 days and 28 days had been cured separately in two different crates and their strengths had been determined at the end of respective curing periods. This had been done for determination of the leached Arsenic concentration in the curing water both after 7 days and 28 days of curing. And amongst these three cubes (for 7 days and 28 days), one cube had been crushed to three size ranges viz. <9.5mm, <1mm and 5-50mm and TCLP had been performed to determine the arsenic concentration in the leachate.

For M20 grade the maximum percentage of sludge by weight of cement that can be mixed safely which satisfies target mean compressive strength is 30% and this percentage when expressed as the percentage of sludge by weight of (cement + sand + course aggregate) comes out to be 4.92%. For M15 grade, this 4.92% is equivalent to 33% when the percentage is expressed by weight of cement. This is the reason for casting the 33% sludge mixed concrete.

All the data collected for each percentage of sludge mixed concrete are tabulated below:

Table 7.49: Data Sheet for M15 Grade Concrete with 0% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**						
	Grade of concrete to be prepared :- M15 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:2.203: 3.495 Water: Cement Ratio :- 0.55 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.13 Kg Quantity of coarse aggregate used :- 10.97 Kg (CA-I:- 6.58Kg and CA-II:- 4.39 Kg) Quantity of fine aggregate (sand) used :- 6.90 Kg Quantity of sludge used :- 0 Kg Quantity of water used :- (0.55×3.13) + (0.72×0) = 1.724 Kg						
2	**Workability of concrete**						
	By Slump Test the slump height is coming to be 40mm.						
3	**Compacting factor of concrete**						
	Weight of empty cylinder (W_1) = 7.220 Kg Weight of cylinder with partially compacted concrete (W_2) = 15.815 Kg Weight of cylinder with fully compacted concrete (W_3) = 17.345 Kg Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.85						
4	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	24	23	25	32	34	33

	Average Compressive Strength in N/mm^2	24	33	
5	**Arsenic concentration in curing water**			
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 0.045 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 0.024 ppb			
6	**Arsenic concentration in the leachate (in ppb)**			
	One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.			
	Size Range →	<1mm	<9.5mm	5-50mm
	7 days	2.797	1.212	1.020
	28 days	1.301	1.402	0.660
7	**Observations**			
	▪ The slump height is 40mm which is between 25-75 mm signifying that the mix is of low workability. ▪ The compacting factor is 0.85 signifying that the mix is of low workability. ▪ The average compressive strength after 28 days of curing is 33 N/mm^2. So it had achieved the target mean strength for M15 grade of concrete i.e. 20.775 N/mm^2. ▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.			

Table 7.50: Data Sheet for M15 Grade Concrete with 20% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M15 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:2.203: 3.495 Water: Cement Ratio :- 0.55 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.13 Kg Quantity of coarse aggregate used :- 10.97 Kg (CA-I:- 6.58Kg and CA-II:- 4.39 Kg) Quantity of fine aggregate (sand) used :- 6.90 Kg Quantity of sludge used :- (0.2×3.13) = 0.63 Kg Quantity of fine aggregate (sand) actually used :- (36.90 – 0.63) = 6.27 Kg Quantity of water used :- (0.55×3.13) + (0.72×0.63) = 2.175 Kg

2 Workability of concrete

By Slump Test the slump height is coming to be 20mm.

3 Compacting factor of concrete

Weight of empty cylinder (W_1) = 7.210 Kg
Weight of cylinder with partially compacted concrete (W_2) = 15.315 Kg
Weight of cylinder with fully compacted concrete (W_3) = 17.335 Kg
Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.80

4 Compressive strength of concrete

	Strength after 7 days			Strength after 28 days		
Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
Compressive Strength in N/mm^2	21	22	20	28	27	27.5
Average Compressive Strength in N/mm^2	21			27.5		

5 Arsenic concentration in curing water

Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 0.751 ppb
Arsenic concentration in curing water after 28 days for 3 cubes :- 0.642 ppb

6 Arsenic concentration in the leachate (in ppb)

One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	3.437	1.681	1.126
28 days	2.875	3.442	1.590

7 Observations

- The slump height is 20mm which signifies that the mix is of very low workability.
- The compacting factor is 0.80 signifying that the mix is of very low workability.
- The average compressive strength after 28 days of curing is 27.5 N/mm^2. So it had achieved the target mean strength for M15 grade of concrete i.e. 20.775 N/mm^2.
- The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
- The arsenic concentration in the leachate obtained by TCLP test is well below the

	prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.51: Data Sheet for M15 Grade Concrete with 30% by weight of cement of arsenic bearing ECAR sludge

<table>
<tr><td>1</td><td colspan="7">Quantities of materials used in the concrete cube preparation</td></tr>
<tr><td></td><td colspan="7">Grade of concrete to be prepared :- M15
Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:2.203: 3.495
Water: Cement Ratio :- 0.55
No. of cubes casted :- 7
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 3.13 Kg
Quantity of coarse aggregate used :- 10.97 Kg (CA-I:- 6.58Kg and CA-II:- 4.39 Kg)
Quantity of fine aggregate (sand) used :- 6.90 Kg
Quantity of sludge used :- (0.3×3.13) = 0.94 Kg
Quantity of fine aggregate (sand) actually used :- (6.90 – 0.94) = 5.96 Kg
Quantity of water used :- (0.55×3.13) + (0.72×0.94) = 2.401Kg</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>2</td><td colspan="7">Workability of concrete</td></tr>
<tr><td></td><td colspan="7">By Slump Test the slump height is coming to be 15mm.</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>3</td><td colspan="7">Compacting factor of concrete</td></tr>
<tr><td></td><td colspan="7">Weight of empty cylinder (W_1) = 7.215 Kg
Weight of cylinder with partially compacted concrete (W_2) = 15.115 Kg
Weight of cylinder with fully compacted concrete (W_3) = 17.340 Kg
Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.78</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>4</td><td colspan="7">Compressive strength of concrete</td></tr>
<tr><td></td><td></td><td colspan="3">Strength after 7 days</td><td colspan="3">Strength after 28 days</td></tr>
<tr><td></td><td>Cube No</td><td>Cube 1</td><td>Cube 2</td><td>Cube 3</td><td>Cube 1</td><td>Cube 2</td><td>Cube 3</td></tr>
<tr><td></td><td>Compressive Strength in N/mm^2</td><td>19</td><td>19.5</td><td>18.5</td><td>22</td><td>23</td><td>22.5</td></tr>
<tr><td></td><td>Average Compressive Strength in N/mm^2</td><td colspan="3">19</td><td colspan="3">22.5</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>5</td><td colspan="7">Arsenic concentration in curing water</td></tr>
<tr><td></td><td colspan="7">Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 1.054 ppb
Arsenic concentration in curing water after 28 days for 3 cubes :- 1.071 ppb</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>6</td><td colspan="7">Arsenic concentration in the leachate (in ppb)</td></tr>
<tr><td></td><td colspan="7">One cubes each for 7 days and 28 days have been used in the study. The cubes had</td></tr>
</table>

been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	3.710	2.777	1.539
28 days	3.366	4.971	2.077

7 **Observations**

- The slump height is 15mm which signifies that the mix is of very low workability.
- The compacting factor is 0.78 signifying that the mix is of very low workability.
- The average compressive strength after 28 days of curing is 22.5 N/mm^2. So it had achieved the target mean strength for M15 grade of concrete i.e. 20.775 N/mm^2.
- The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
- The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.52: Data Sheet for M15 Grade Concrete with 33% by weight of cement of arsenic bearing ECAR sludge

1 **Quantities of materials used in the concrete cube preparation**

Grade of concrete to be prepared :- M15
Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:2.203: 3.495
Water: Cement Ratio :- 0.55
No. of cubes casted :- 7
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 3.13 Kg
Quantity of coarse aggregate used :- 10.97 Kg (CA-I:- 6.58Kg and CA-II:- 4.39 Kg)
Quantity of fine aggregate (sand) used :- 6.90 Kg
Quantity of sludge used :- (0.33×3.13) = 1.03 Kg
Quantity of fine aggregate (sand) actually used :- (6.90 – 1.03) = 5.86 Kg
Quantity of water used :- (0.55×3.13) + (0.72×1.03) = 2.469 Kg

2 **Workability of concrete**

By Slump Test the slump height is coming to be 15mm.

3 **Compacting factor of concrete**

Weight of empty cylinder (W_1) = 7.215 Kg
Weight of cylinder with partially compacted concrete (W_2) = 14.995 Kg
Weight of cylinder with fully compacted concrete (W_3) = 17.340 Kg

	Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.77						
4	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	14	14.5	15	18	17	17.5
	Average Compressive Strength in N/mm^2	14.5			17.5		
5	**Arsenic concentration in curing water**						
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 1.021 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 1.149 ppb						
6	**Arsenic concentration in the leachate (in ppb)**						
	One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.						
	Size Range →	<1mm	<9.5mm	5-50mm			
	7 days	3.912	2.862	1.962			
	28 days	3.984	5.376	2.145			
7	**Observations**						
	▪ The slump height is 15mm which signifies that the mix is of very low workability. ▪ The compacting factor is 0.77 signifying that the mix is of very low workability. ▪ The average compressive strength after 28 days of curing is 17.5 N/mm^2. So it had not achieved the target mean strength for M15 grade of concrete i.e. 20.775 N/mm^2. ▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.						

7.9 M25 Grade Concrete Results and Discussion

The arsenic bearing sludge had been embedded in the M25 grade concrete in varying proportions viz. 0%, 20%, 28.4% and 30% by weight of cement. This amount of sludge had been added by replacing equivalent amount of sand. And water equivalent to the OMC of this sludge had also been added in the concrete mix. Seven cubes of dimension

100mm×100mm×100mm had been casted for each of the percentages. In each case the slump height and compacting factor had been determined to signify its workability. And also three cubes each for 7 days and 28 days had been cured separately in two different crates and their strengths had been determined at the end of respective curing periods. This had been done for determination of the leached Arsenic concentration in the curing water both after 7 days and 28 days of curing. And amongst these three cubes (for 7 days and 28 days), one cube had been crushed to three size ranges viz. <9.5mm, <1mm and 5-50mm and TCLP had been performed to determine the arsenic concentration in the leachate.

For M20 grade the maximum percentage of sludge by weight of cement that can be mixed safely which satisfies target mean compressive strength is 30% and this percentage when expressed as the percentage of sludge by weight of (cement + sand + course aggregate) comes out to be 4.92%. For M25 grade, this 4.92% is equivalent to 28.4% when the percentage is expressed by weight of cement. This is the reason for casting the 28.4% sludge mixed concrete.

All the data collected for each percentage of sludge mixed concrete are tabulated below:

Table 7.53: Data Sheet for M25 Grade Concrete with 0% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M25 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.76:3.001 Water: Cement Ratio :- 0.47 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.65 Kg Quantity of coarse aggregate used :- 10.94 Kg (CA-I:- 6.56Kg and CA-II:- 4.38Kg) Quantity of fine aggregate (sand) used :- 6.42 Kg Quantity of sludge used :- 0 Kg Quantity of water used :- (0.47×3.65) + (0.72×0) = 1.714 Kg
2	**Workability of concrete**
	By Slump Test the slump height is coming to be 35mm.
3	**Compacting factor of concrete**
	Weight of empty cylinder (W_1) = 7.215 Kg Weight of cylinder with partially compacted concrete (W_2) = 15.695 Kg Weight of cylinder with fully compacted concrete (W_3) = 17.285 Kg Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.84
4	**Compressive strength of concrete**

		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	32	31	33	45	44	44.5
	Average Compressive Strength in N/mm^2	32			44.5		

5	**Arsenic concentration in curing water**
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 0.089 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 0.061 ppb
6	**Arsenic concentration in the leachate (in ppb)**
	One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

	Size Range →	<1mm	<9.5mm	5-50mm
	7 days	1.686	4.688	1.576
	28 days	1.776	3.210	1.139

7	**Observations**
	▪ The slump height is 35mm which is between 25-75 mm signifying that the mix is of low workability. ▪ The compacting factor is 0.84 signifying that the mix is of low workability. ▪ The average compressive strength after 28 days of curing is 44.5 N/mm^2. So it had achieved the target mean strength for M25 grade of concrete i.e. 31.6N/mm^2. ▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.54: Data Sheet for M25 Grade Concrete with 20% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M25 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.76:3.001 Water: Cement Ratio :- 0.47 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.65Kg Quantity of coarse aggregate used :- 10.94 Kg (CA-I:- 6.56Kg and CA-II:- 4.38Kg)

Quantity of fine aggregate (sand) used :- 6.42 Kg
Quantity of sludge used :- (0.2×3.65) = 0.73 Kg
Quantity of fine aggregate (sand) actually used :- (6.42 – 0.73) = 5.69 Kg
Quantity of water used :- (0.47×3.65) + (0.72×0.73) = 2.238 Kg

2 Workability of concrete

By Slump Test the slump height is coming to be 15mm.

3 Compacting factor of concrete

Weight of empty cylinder (W_1) = 7.220 Kg
Weight of cylinder with partially compacted concrete (W_2) = 15.095 Kg
Weight of cylinder with fully compacted concrete (W_3) = 17.290 Kg
Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.78

4 Compressive strength of concrete

	Strength after 7 days			Strength after 28 days		
Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
Compressive Strength in N/mm^2	24	23.5	24.5	31	32	31.5
Average Compressive Strength in N/mm^2	24			31.5		

5 Arsenic concentration in curing water

Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 1.265 ppb
Arsenic concentration in curing water after 28 days for 3 cubes :- 1.452 ppb

6 Arsenic concentration in the leachate (in ppb)

One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	1.973	5.712	1.663
28 days	4.169	6.360	2.972

7 Observations

- The slump height is 15mm signifying that the mix is of very low workability.
- The compacting factor is 0.78 signifying that the mix is of very low workability.
- The average compressive strength after 28 days of curing is 31.5 N/mm^2. So it had just achieved the target mean strength for M25 grade of concrete i.e. 31.6N/mm^2.

	▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.55: Data Sheet for M25 Grade Concrete with 28.4% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**						
	Grade of concrete to be prepared :- M25 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.76:3.001 Water: Cement Ratio :- 0.47 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.65Kg Quantity of coarse aggregate used :- 10.94 Kg (CA-I:- 6.56Kg and CA-II:- 4.38Kg) Quantity of fine aggregate (sand) used :- 6.42 Kg Quantity of sludge used :- (0.284×3.65) = 1.04 Kg Quantity of fine aggregate (sand) actually used :- (6.42 – 1.04) = 5.38 Kg Quantity of water used :- (0.47×3.65) + (0.72×1.04) = 2.459 Kg						
2	**Workability of concrete**						
	By Slump Test the slump height is coming to be 5mm.						
3	**Compacting factor of concrete**						
	Weight of empty cylinder (W_1) = 7.220 Kg Weight of cylinder with partially compacted concrete (W_2) = 14.795 Kg Weight of cylinder with fully compacted concrete (W_3) = 17.290 Kg Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.75						
4	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	19	19.5	18.5	22	23	22.5
	Average Compressive Strength in N/mm^2	19			22.5		
5	**Arsenic concentration in curing water**						
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 1.249 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 1.445 ppb						

<table>
<tr><td colspan="5"></td></tr>
<tr><td>6</td><td colspan="4">Arsenic concentration in the leachate (in ppb)</td></tr>
<tr><td></td><td colspan="4">One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.</td></tr>
<tr><td></td><td>Size Range →</td><td><1mm</td><td><9.5mm</td><td>5-50mm</td></tr>
<tr><td></td><td>7 days</td><td>1.981</td><td>4.734</td><td>1.662</td></tr>
<tr><td></td><td>28 days</td><td>3.458</td><td>5.189</td><td>2.037</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>7</td><td colspan="4">Observations</td></tr>
<tr><td></td><td colspan="4">▪ The slump height is 5mm signifying that the mix is of very low workability.
▪ The compacting factor is 0.75 signifying that the mix is of very low workability.
▪ The average compressive strength after 28 days of curing is 22.5 N/mm^2. So it had not achieved the target mean strength for M25 grade of concrete i.e. 31.6N/mm^2.
▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.</td></tr>
</table>

Table 7.56: Data Sheet for M25 Grade Concrete with 30% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M25 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.76:3.001 Water: Cement Ratio :- 0.47 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.65Kg Quantity of coarse aggregate used :- 10.94 Kg (CA-I:- 6.56Kg and CA-II:- 4.38Kg) Quantity of fine aggregate (sand) used :- 6.42 Kg Quantity of sludge used :- (0.3×3.65) = 1.09 Kg Quantity of fine aggregate (sand) actually used :- (6.42 – 1.09) = 5.32 Kg Quantity of water used :- (0.47×3.65) + (0.72×1.09) = 2.501 Kg
2	**Workability of concrete**
	By Slump Test the slump height is coming to be 5mm.
3	**Compacting factor of concrete**
	Weight of empty cylinder (W_1) = 7.215 Kg Weight of cylinder with partially compacted concrete (W_2) = 14.695 Kg

	Weight of cylinder with fully compacted concrete (W_3) = 17.275 Kg Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.74						
4	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	23	24	22	26	25	25.5
	Average Compressive Strength in N/mm^2	23			25.5		
5	**Arsenic concentration in curing water**						
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 1.174 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 1.394 ppb						
6	**Arsenic concentration in the leachate (in ppb)**						
	One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.						
	Size Range →	<1mm	<9.5mm	5-50mm			
	7 days	1.770	4.999	1.684			
	28 days	2.854	3.831	1.989			
7	**Observations**						
	▪ The slump height is 5mm signifying that the mix is of very low workability. ▪ The compacting factor is 0.74 ▪ The average compressive strength after 28 days of curing is 25.5 N/mm^2. So it had not achieved the target mean strength for M25 grade of concrete i.e. 31.6N/mm^2. ▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.						

7.10 M30 Grade Concrete Results and Discussion

The arsenic bearing sludge had been embedded in the M30 grade concrete in varying proportions viz. 0%, 10%, 15%, 20%, 25.9% and 30% by weight of cement. This amount of sludge had been added by replacing equivalent amount of sand. And water equivalent to the OMC of this sludge had also been added in the concrete mix. Seven cubes of dimension

100mm×100mm×100mm had been casted for each of the percentages. In each case the slump height and compacting factor had been determined to signify its workability. And also three cubes each for 7 days and 28 days had been cured separately in two different crates and their strengths had been determined at the end of respective curing periods. This had been done for determination of the leached Arsenic concentration in the curing water both after 7 days and 28 days of curing. And amongst these three cubes (for 7 days and 28 days), one cube had been crushed to three size ranges viz. <9.5mm, <1mm and 5-50mm and TCLP had been performed to determine the arsenic concentration in the leachate.

For M20 grade the maximum percentage of sludge by weight of cement that can be mixed safely which satisfies target mean compressive strength is 30% and this percentage when expressed as the percentage of sludge by weight of (cement + sand + course aggregate) comes out to be 4.92%. For M30 grade, this 4.92% is equivalent to 25.9% when the percentage is expressed by weight of cement. This is the reason for casting the 25.9% sludge mixed concrete.

All the data collected for each percentage of sludge mixed concrete are tabulated below:

Table 7.57: Data Sheet for M30 Grade Concrete with 0% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M30 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.545:2.714 Water: Cement Ratio :- 0.43 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.99Kg Quantity of coarse aggregate used :- 10.84 Kg (CA-I:- 6.50Kg and CA-II:- 4.33 Kg) Quantity of fine aggregate (sand) used :- 6.17 Kg Quantity of sludge used :- 0 Kg Quantity of water used :- (0.43×3.99) + (0.72×0) = 1.717 Kg
2	**Workability of concrete**
	By Slump Test the slump height is coming to be 35mm.
3	**Compacting factor of concrete**
	Weight of empty cylinder (W_1) = 7.215 Kg Weight of cylinder with partially compacted concrete (W_2) = 15.695 Kg Weight of cylinder with fully compacted concrete (W_3) = 17.285 Kg Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.84
4	**Compressive strength of concrete**

		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	34	34.5	33.5	47	49	48
	Average Compressive Strength in N/mm^2	34			48		

5	**Arsenic concentration in curing water**
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 0.186 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 0.199 ppb
6	**Arsenic concentration in the leachate (in ppb)**
	One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

	Size Range →	<1mm	<9.5mm	5-50mm
	7 days	0.320	0.498	0.313
	28 days	0.737	0.748	0.505

7	**Observations**
	▪ The slump height is 35mm which is between 25-75 mm signifying that the mix is of low workability. ▪ The compacting factor is 0.84 signifying that the mix is of low workability. ▪ The average compressive strength after 28 days of curing is 48 N/mm^2. So it had achieved the target mean strength for M30 grade of concrete i.e. 38.25N/mm^2. ▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.58: Data Sheet for M30 Grade Concrete with 10% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M30 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.545:2.714 Water: Cement Ratio :- 0.43 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.99Kg Quantity of coarse aggregate used :- 10.84 Kg (CA-I:- 6.50Kg and CA-II:- 4.33 Kg)

Quantity of fine aggregate (sand) used :- 6.17 Kg
Quantity of sludge used :- (0.1×3.99) = 0.40 Kg
Quantity of fine aggregate (sand) actually used :- (6.17 – 0.40) = 5.77 Kg
Quantity of water used :- (0.43×3.99) + (0.72×0.40) = 2.005 Kg

2 Workability of concrete

By Slump Test the slump height is coming to be 15mm.

3 Compacting factor of concrete

Weight of empty cylinder (W_1) = 7.215 Kg
Weight of cylinder with partially compacted concrete (W_2) = 15.295 Kg
Weight of cylinder with fully compacted concrete (W_3) = 17.285 Kg
Compacting factor = $\frac{W_2 - W_1}{W_3 - W_1}$ = 0.80

4 Compressive strength of concrete

	Strength after 7 days			Strength after 28 days		
Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
Compressive Strength in N/mm^2	30	32	31	41.5	41	41.5
Average Compressive Strength in N/mm^2	31			41.33		

5 Arsenic concentration in curing water

Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 0.492 ppb
Arsenic concentration in curing water after 28 days for 3 cubes :- 0.475 ppb

6 Arsenic concentration in the leachate (in ppb)

One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	1.983	2.459	0.971
28 days	0.816	1.891	1.843

7 Observations

- The slump height is 15mm signifying that the mix is of very low workability.
- The compacting factor is 0.80 signifying that the mix is of very low workability.
- The average compressive strength after 28 days of curing is 41.33 N/mm^2. So it had achieved the target mean strength for M30 grade of concrete i.e. 38.25N/mm^2.

	▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.59: Data Sheet for M30 Grade Concrete with 15% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**						
	Grade of concrete to be prepared :- M30 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.545:2.714 Water: Cement Ratio :- 0.43 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.99Kg Quantity of coarse aggregate used :- 10.84 Kg (CA-I:- 6.50Kg and CA-II:- 4.33 Kg) Quantity of fine aggregate (sand) used :- 6.17 Kg Quantity of sludge used :- (0.15×3.99) = 0.60 Kg Quantity of fine aggregate (sand) actually used :- (6.17 – 0.60) = 5.57 Kg Quantity of water used :- (0.43×3.99) + (0.72×0.60) = 2.148 Kg						
2	**Workability of concrete**						
	By Slump Test the slump height is coming to be 15mm.						
3	**Compacting factor of concrete**						
	Weight of empty cylinder (W_1) = 7.215 Kg Weight of cylinder with partially compacted concrete (W_2) = 15.205 Kg Weight of cylinder with fully compacted concrete (W_3) = 17.285 Kg Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.79						
4	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	29	31	30	38.5	39	38.5
	Average Compressive Strength in N/mm^2	30			38.67		
5	**Arsenic concentration in curing water**						
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 0.741 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 0.341 ppb						

<table>
<tr><td colspan="5"></td></tr>
<tr><td>6</td><td colspan="4">Arsenic concentration in the leachate (in ppb)</td></tr>
<tr><td></td><td colspan="4">One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.</td></tr>
<tr><td></td><td>Size Range →</td><td><1mm</td><td><9.5mm</td><td>5-50mm</td></tr>
<tr><td></td><td>7 days</td><td>2.072</td><td>3.972</td><td>1.972</td></tr>
<tr><td></td><td>28 days</td><td>0.942</td><td>2.216</td><td>1.295</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>7</td><td colspan="4">Observations</td></tr>
<tr><td></td><td colspan="4">▪ The slump height is 15mm signifying that the mix is of very low workability.
▪ The compacting factor is 0.79 signifying that the mix is of very low workability.
▪ The average compressive strength after 28 days of curing is 38.67 N/mm^2. So it had just achieved the target mean strength for M30 grade of concrete i.e. 38.25N/mm^2.
▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.</td></tr>
</table>

Table 7.60: Data Sheet for M30 Grade Concrete with 20% by weight of cement of arsenic bearing ECAR sludge

<table>
<tr><td>1</td><td>Quantities of materials used in the concrete cube preparation</td></tr>
<tr><td></td><td>Grade of concrete to be prepared :- M30
Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.545:2.714
Water: Cement Ratio :- 0.43
No. of cubes casted :- 7
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 3.99Kg
Quantity of coarse aggregate used :- 10.84 Kg (CA-I:- 6.50Kg and CA-II:- 4.33 Kg)
Quantity of fine aggregate (sand) used :- 6.17 Kg
Quantity of sludge used :- (0.2×3.99) = 0.80 Kg
Quantity of fine aggregate (sand) actually used :- (6.17 – 0.80) = 5.37 Kg
Quantity of water used :- (0.43×3.99) + (0.72×0.80) = 2.292 Kg</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>2</td><td>Workability of concrete</td></tr>
<tr><td></td><td>By Slump Test the slump height is coming to be 10mm.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>3</td><td>Compacting factor of concrete</td></tr>
<tr><td></td><td>Weight of empty cylinder (W_1) = 7.215 Kg
Weight of cylinder with partially compacted concrete (W_2) = 14.875 Kg</td></tr>
</table>

	Weight of cylinder with fully compacted concrete (W_3) = 17.285 Kg Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.76

4	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	26	26.5	25.5	32	33	32.5
	Average Compressive Strength in N/mm^2	26			32.5		

5	**Arsenic concentration in curing water**
	Quantity of curing water taken :- 25 L Arsenic concentration in curing water after 7 days for 3 cubes :- 1.143 ppb Arsenic concentration in curing water after 28 days for 3 cubes :- 1.846 ppb

6	**Arsenic concentration in the leachate (in ppb)**			
	One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.			
	Size Range →	<1mm	<9.5mm	5-50mm
	7 days	4.018	3.341	1.207
	28 days	0.781	2.74	1.281

7	**Observations**
	▪ The slump height is 10mm signifying that the mix is of very low workability. ▪ The compacting factor is 0.76 signifying that the mix is of very low workability. ▪ The average compressive strength after 28 days of curing is 32.5 N/mm^2. So it had not achieved the target mean strength for M30 grade of concrete i.e. 38.25N/mm^2. ▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.61: Data Sheet for M30 Grade Concrete with 25.9% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**
	Grade of concrete to be prepared :- M30 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.545:2.714 Water: Cement Ratio :- 0.43

No. of cubes casted :- 7
Size of cubes :- 100mm×100mm×100mm
Assumption :- Amount of total mix per cube is 3Kg
Quantity of cement used :- 3.99Kg
Quantity of coarse aggregate used :- 10.84 Kg (CA-I:- 6.50Kg and CA-II:- 4.33 Kg)
Quantity of fine aggregate (sand) used :- 6.17 Kg
Quantity of sludge used :- (0.259×3.99) = 1.03 Kg
Quantity of fine aggregate (sand) actually used :- (6.17 – 1.03) = 5.14 Kg
Quantity of water used :- (0.43×3.99) + (0.72×1.03) = 2.462 Kg

2 **Workability of concrete**

By Slump Test the slump height is coming to be 5mm.

3 **Compacting factor of concrete**

Weight of empty cylinder (W_1) = 7.215 Kg
Weight of cylinder with partially compacted concrete (W_2) = 14.625 Kg
Weight of cylinder with fully compacted concrete (W_3) = 17.285 Kg
Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.74

4 **Compressive strength of concrete**

	Strength after 7 days			Strength after 28 days		
Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
Compressive Strength in N/mm^2	24	26	25	30	30.5	29.5
Average Compressive Strength in N/mm^2	25			30		

5 **Arsenic concentration in curing water**

Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 1.149 ppb
Arsenic concentration in curing water after 28 days for 3 cubes :- 1.488 ppb

6 **Arsenic concentration in the leachate (in ppb)**

One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.

Size Range →	<1mm	<9.5mm	5-50mm
7 days	3.946	5.014	3.151
28 days	0.943	2.462	1.492

7 **Observations**

	▪ The slump height is 5mm signifying that the mix is of very low workability. ▪ The compacting factor is 0.74 ▪ The average compressive strength after 28 days of curing is 30 N/mm^2. So it had not achieved the target mean strength for M30 grade of concrete i.e. 38.25N/mm^2. ▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb. ▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.

Table 7.62: Data Sheet for M30 Grade Concrete with 30% by weight of cement of arsenic bearing ECAR sludge

1	**Quantities of materials used in the concrete cube preparation**						
	Grade of concrete to be prepared :- M30 Cement: Fine Aggregate : Coarse Aggregate Ratio :- 1:1.545:2.714 Water: Cement Ratio :- 0.43 No. of cubes casted :- 7 Size of cubes :- 100mm×100mm×100mm Assumption :- Amount of total mix per cube is 3Kg Quantity of cement used :- 3.99Kg Quantity of coarse aggregate used :- 10.84 Kg (CA-I:- 6.50Kg and CA-II:- 4.33 Kg) Quantity of fine aggregate (sand) used :- 6.17 Kg Quantity of sludge used :- (0.3×3.99) = 1.20 Kg Quantity of fine aggregate (sand) actually used :- (6.17 – 1.20) = 4.97 Kg Quantity of water used :- (0.43×3.99) + (0.72×1.20) = 2.580 Kg						
2	**Workability of concrete**						
	By Slump Test the slump height is coming to be 5mm.						
3	**Compacting factor of concrete**						
	Weight of empty cylinder (W_1) = 7.215 Kg Weight of cylinder with partially compacted concrete (W_2) = 15.525 Kg Weight of cylinder with fully compacted concrete (W_3) = 17.285 Kg Compacting factor = $\frac{W_2-W_1}{W_3-W_1}$ = 0.73						
4	**Compressive strength of concrete**						
		Strength after 7 days			Strength after 28 days		
	Cube No	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
	Compressive Strength in N/mm^2	25	25.5	24.5	30	29	29.5
	Average Compressive Strength in N/mm^2	25			29.5		

<table>
<tr><td>5</td><td colspan="4">Arsenic concentration in curing water</td></tr>
<tr><td></td><td colspan="4">Quantity of curing water taken :- 25 L
Arsenic concentration in curing water after 7 days for 3 cubes :- 1.105 ppb
Arsenic concentration in curing water after 28 days for 3 cubes :- 1.021 ppb</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>6</td><td colspan="4">Arsenic concentration in the leachate (in ppb)</td></tr>
<tr><td></td><td colspan="4">One cubes each for 7 days and 28 days have been used in the study. The cubes had been crushed and separated into three size ranges viz. <1mm; <9.5mm; 5-50 mm. And if any arsenic in soluble form is coming out with the leachate was measured as per the guidelines of TCLP.</td></tr>
<tr><td></td><td>Size Range →</td><td><1mm</td><td><9.5mm</td><td>5-50mm</td></tr>
<tr><td></td><td>7 days</td><td>2.822</td><td>3.922</td><td>2.641</td></tr>
<tr><td></td><td>28 days</td><td>1.141</td><td>2.556</td><td>1.003</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>7</td><td colspan="4">Observations</td></tr>
<tr><td></td><td colspan="4">▪ The slump height is 5mm signifying that the mix is of very low workability.
▪ The compacting factor is 0.73
▪ The average compressive strength after 28 days of curing is 29.5N/mm^2. So it had not achieved the target mean strength for M30 grade of concrete i.e. 38.25N/mm^2.
▪ The arsenic concentrations in curing water tested both after 7 and 28 days of curing are below the prescribed safe limit of arsenic in drinking water i.e. 10ppb.
▪ The arsenic concentration in the leachate obtained by TCLP test is well below the prescribed safe limit for disposal of arsenic i.e. 200 ppb.</td></tr>
</table>

7.11 Discussion on Results of M15, M20, M25 and M30

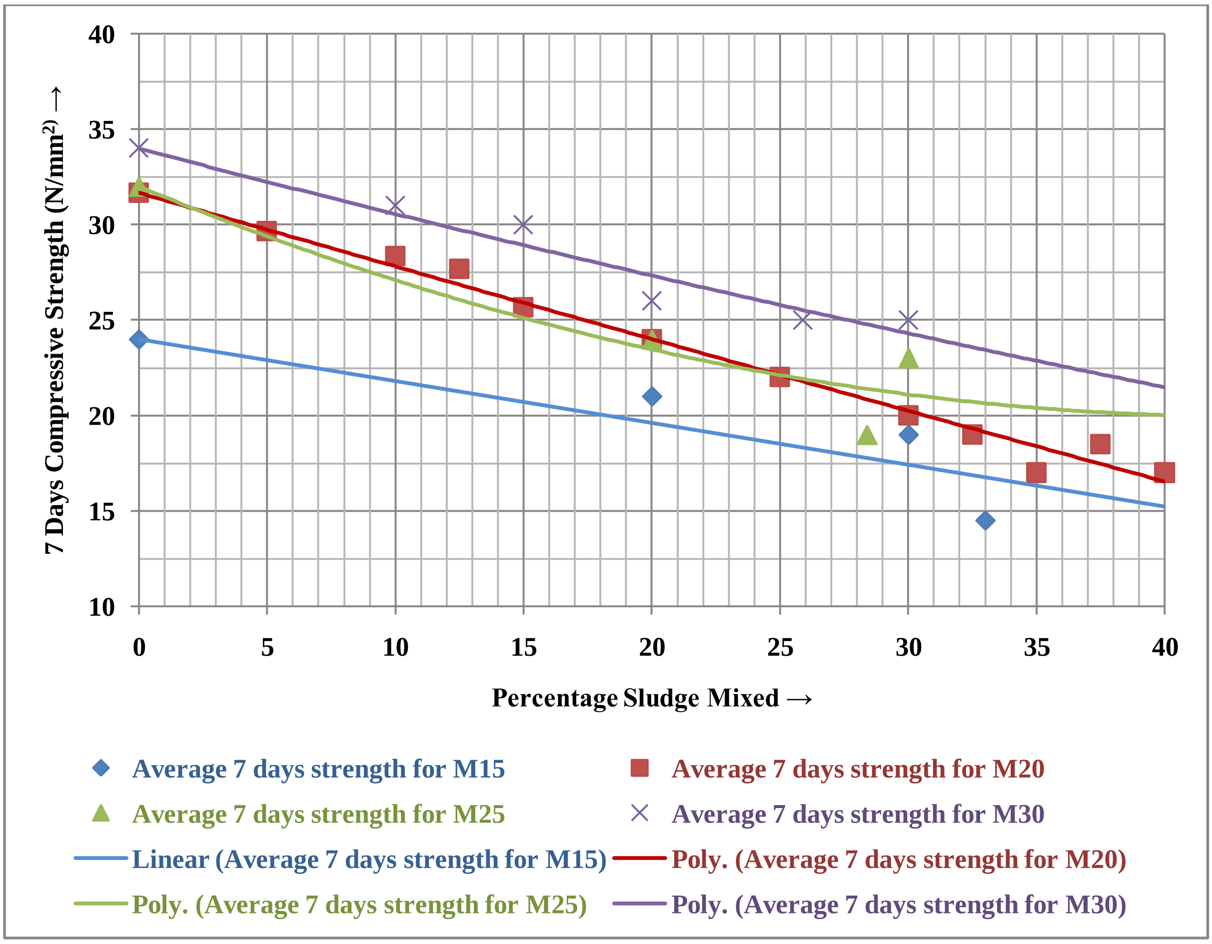


Figure 7.40: Percentage Sludge Mixed v/s 7 Days Compressive Strength Graph for All Grades of Concrete

From the above graph it is seen that the compressive strength of concrete cubes after 7 days of curing had been decreasing with increase in amount of sludge mixed. As per IS 456:2000, generally the strength at end of 7 days is 2/3rd of the target mean strength.

For M20 grade of concrete, the strength to be achieved at the end of 7 days is 17.8 N/mm^2. Up to 32.5% (by weight of cement) sludge mixed concrete cube had achieved this strength. But on the next increment of sludge mixed concrete i.e. 35% (by weight of cement), it had failed to achieve this strength. This 35% sludge mixed concrete cube had achieved 64% of the target mean strength after 7 days of curing.

For M15 grade of concrete, the strength to be achieved at the end of 7 days is 14 N/mm^2. Up to 33% (by weight of cement) sludge mixed concrete cube had achieved this strength. This 33% sludge mixed concrete cube had achieved 69.8% of the target mean strength after 7 days of curing.

For M25 grade of concrete, the strength to be achieved at the end of 7 days is 21.2 N/mm^2. Up to 30% (by weight of cement) sludge mixed concrete cube had achieved this strength. This 30% sludge mixed concrete cube had achieved 73% of the target mean strength after 7 days of curing.

For M30 grade of concrete, the strength to be achieved at the end of 7 days is 25.6 N/mm^2. Up to 20% (by weight of cement) sludge mixed concrete cube had achieved this strength. But on the next increment of sludge mixed concrete i.e. 25.9% (by weight of cement), it had failed to achieve this strength. This 25.9% sludge mixed concrete cube had achieved 65% of the target mean strength after 7 days of curing.

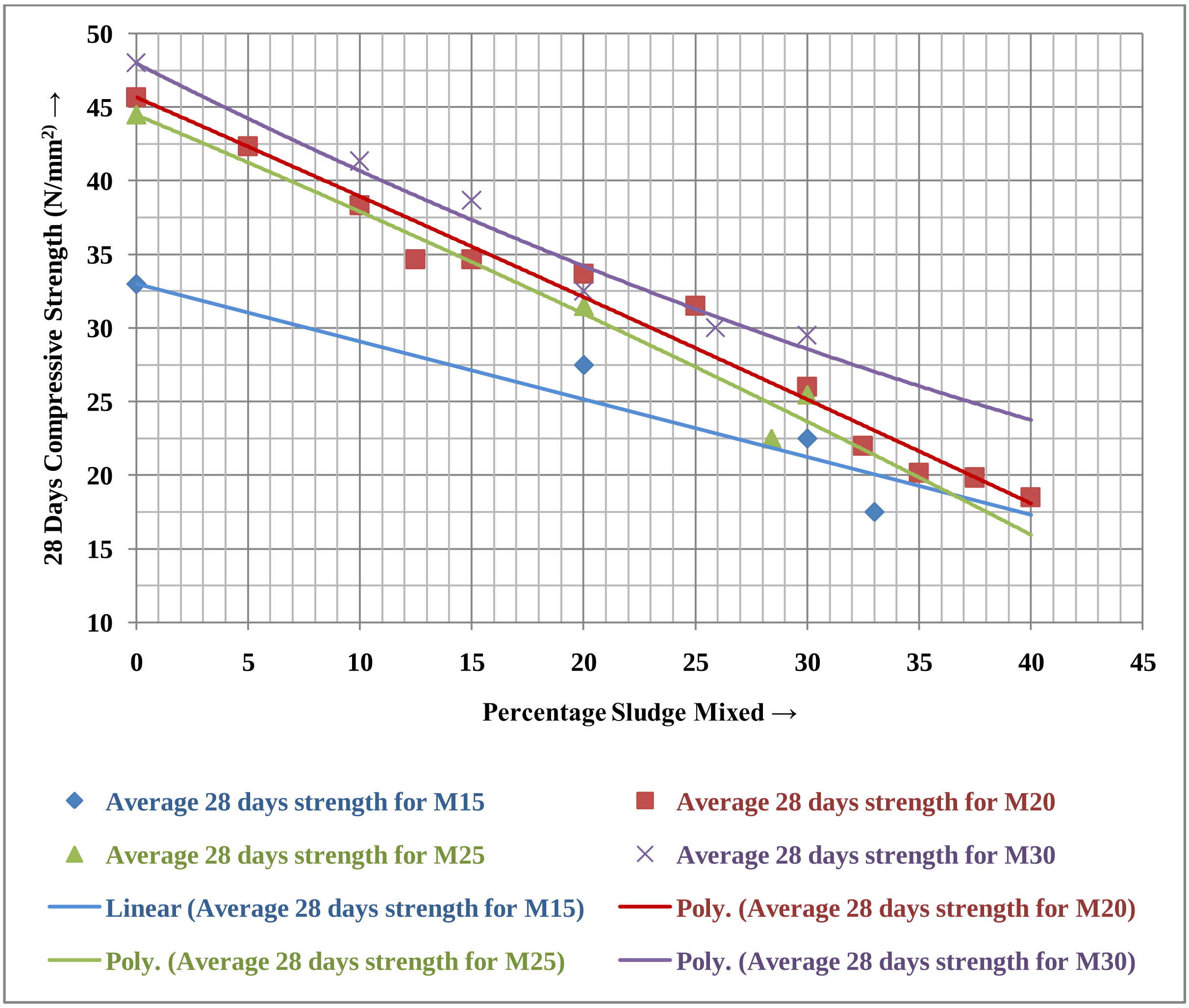


Figure 7.41: Percentage Sludge Mixed v/s 28 Days Compressive Strength Graph for All Grades of Concrete

From the above graph it is seen that the compressive strength of concrete cubes after 28 days of curing had been decreasing with increase in amount of sludge mixed.

For M20 grade of concrete, the strength to be achieved at the end of 28 days is 26.6 N/mm^2. Up to 25% (by weight of cement) sludge mixed concrete cube had achieved this strength. But on the next increment of sludge mixed concrete i.e. 30% (by weight of cement) had just achieved this strength. So this point signifies the maximum amount of sludge that can mixed by weight of cement in M20 grade of concrete. But from practical point of view keeping a margin for safety, a factor of safety of minimum 1.5 had been prescribed. So the recommended maximum percentage of sludge (by weight of cement) that can be safely mixed with M20 grade concrete is 20%.

For M15 grade of concrete, the strength to be achieved at the end of 28 days is 20.775 N/mm^2. Up to 30% (by weight of cement) sludge mixed concrete cube had achieved this strength. But on the next increment of sludge mixed concrete i.e. 33% (by weight of cement) had failed to achieve this strength. So this point i.e. 30% signifies the maximum amount of sludge that can mixed by weight of cement in M15 grade of concrete. But from practical point of view keeping a margin for safety, a factor of safety of minimum 1.5 had been prescribed. So the recommended maximum percentage of sludge (by weight of cement) that can be safely mixed with M15 grade concrete is 20%.

For M25 grade of concrete, the strength to be achieved at the end of 28 days is 31.6 N/mm^2. 20% (by weight of cement) sludge mixed concrete cube had just achieved this strength. So this point signifies the maximum amount of sludge that can mixed by weight of cement in M25 grade of concrete. But from practical point of view keeping a margin for safety, a factor of safety of minimum 2 had been prescribed. So the recommended maximum percentage of sludge (by weight of cement) that can be safely mixed with M25 grade concrete is 10%.

For M30 grade of concrete, the strength to be achieved at the end of 28 days is 38.25 N/mm^2. 15% (by weight of cement) sludge mixed concrete cube had just achieved this strength. So this point signifies the maximum amount of sludge that can mixed by weight of cement in M30 grade of concrete. But from practical point of view keeping a margin for safety, a factor of safety of minimum 3 had been prescribed. So the recommended maximum percentage of sludge (by weight of cement) that can be safely mixed with M30 grade concrete is 5%.

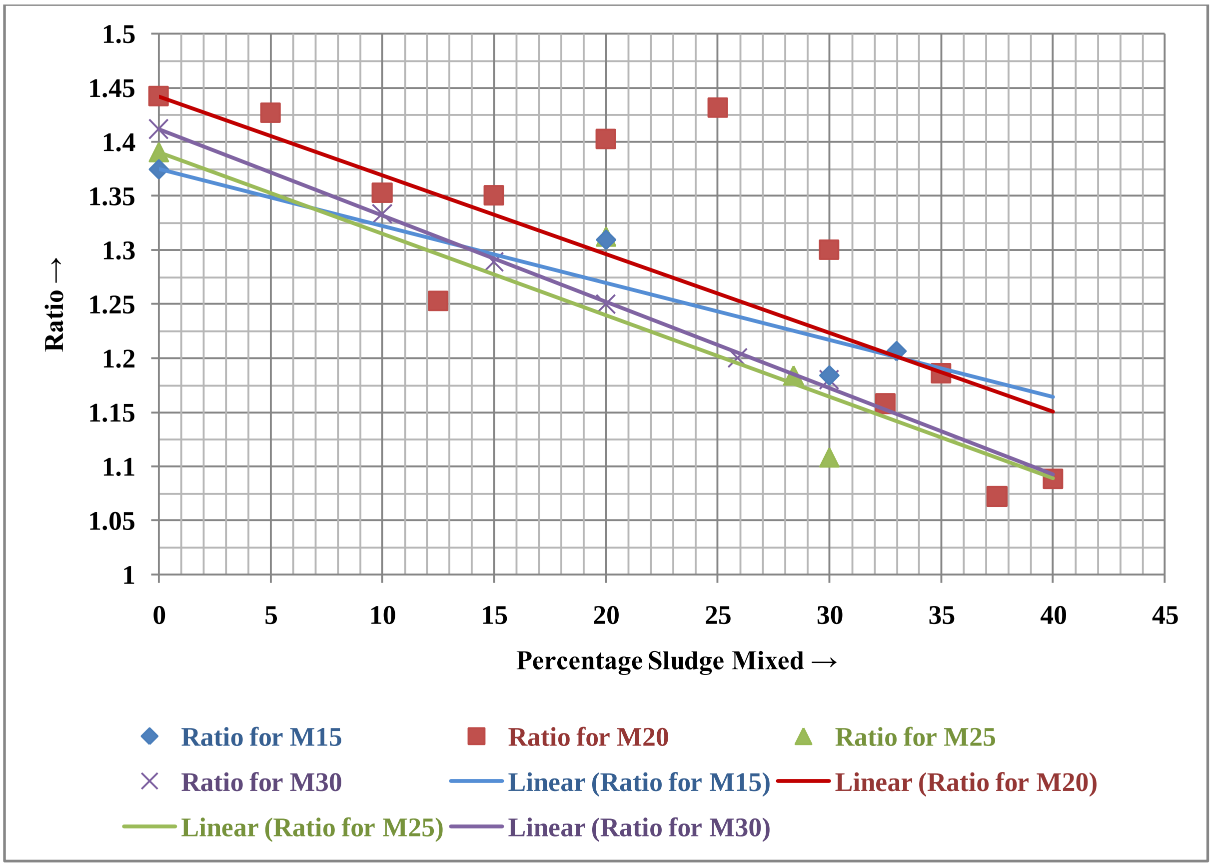


Figure 7.42: Percentage Sludge Mixed v/s Ratio of 28 Days Strength to 7 Days Strength Graph for All Grades of Concrete

As per IS 456:2000, the ratio of 28 days strength to 7 days strength is 1.5. And in this study it had been observed that with increase in amount of sludge mixed, the ratio had shown a decreasing trend.

For M20 the ratio was 1.44 for the 0% (by weight of cement) sludge mixed concrete. And it had decreased by 2.78% for the 20% (by weight of cement) sludge mixed concrete and by 9.72% for the 30% (by weight of cement) sludge mixed concrete.

For M15 the ratio was 1.375 for the 0% (by weight of cement) sludge mixed concrete. And it had decreased by 4.8% for the 20% (by weight of cement) sludge mixed concrete and by 13.9% for the 30% (by weight of cement) sludge mixed concrete.

For M25 the ratio was 1.391 for the 0% (by weight of cement) sludge mixed concrete. And it had decreased by 5.6% for the 20% (by weight of cement) sludge mixed concrete and by 20.3% for the 30% (by weight of cement) sludge mixed concrete.

For M30 the ratio was 1.412 for the 0% (by weight of cement) sludge mixed concrete. And it had decreased by 11.5% for the 20% (by weight of cement) sludge mixed concrete and by 16.4% for the 30% (by weight of cement) sludge mixed concrete.

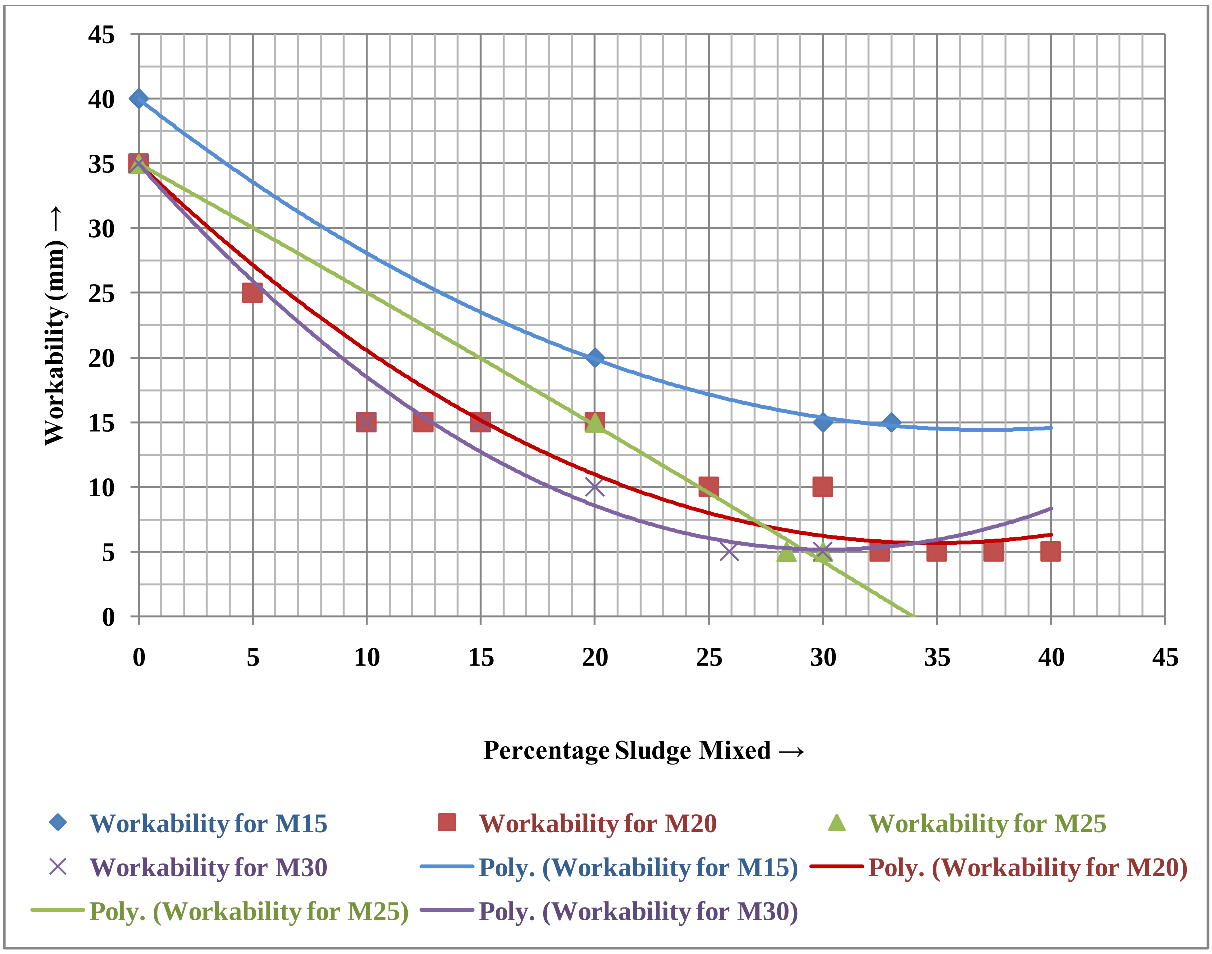


Figure 7.43: Percentage Sludge Mixed v/s Workability Graph for All Grades of Concrete

From the above graph it is seen that the workability determined by slump height is decreasing with increase in amount of sludge mixed. This sludge sample mixed has an exceptionally high OMC value (72%), so its moisture holding capacity is high. And although in this study extra water equivalent to the OMC of the sludge have been added, still the increase in sludge amount showed a gradual drying up of the freshly prepared concrete mix. So the workability has been decreasing significantly with addition of sludge.

For M20 grade concrete the slump height was 35 mm for 0% sludge (by weight of cement) mixed cubes. It signifies a low workability (within 25mm-75mm as per IS 456:2000). The slump height has decreased to 10mm for 30% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M20. So there had been a 71.4% decrease in workability.

For M15 grade concrete the slump height was 40 mm for 0% sludge (by weight of cement) mixed cubes. It signifies a low workability (within 25mm-75mm as per IS 456:2000). The slump height has decreased to 15mm for 33% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M15. So there had been a 62.5% decrease in workability.

For M25 grade concrete the slump height was 35 mm for 0% sludge (by weight of cement) mixed cubes. It signifies a low workability (within 25mm-75mm as per IS 456:2000). The slump height has decreased to 15mm for 20% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M25. So there had been a 57% decrease in workability.

For M30 grade concrete the slump height was 35 mm for 0% sludge (by weight of cement) mixed cubes. It signifies a low workability (within 25mm-75mm as per IS 456:2000). The slump height has decreased to 15mm for 15% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M30. So there had been a 57% decrease in workability.

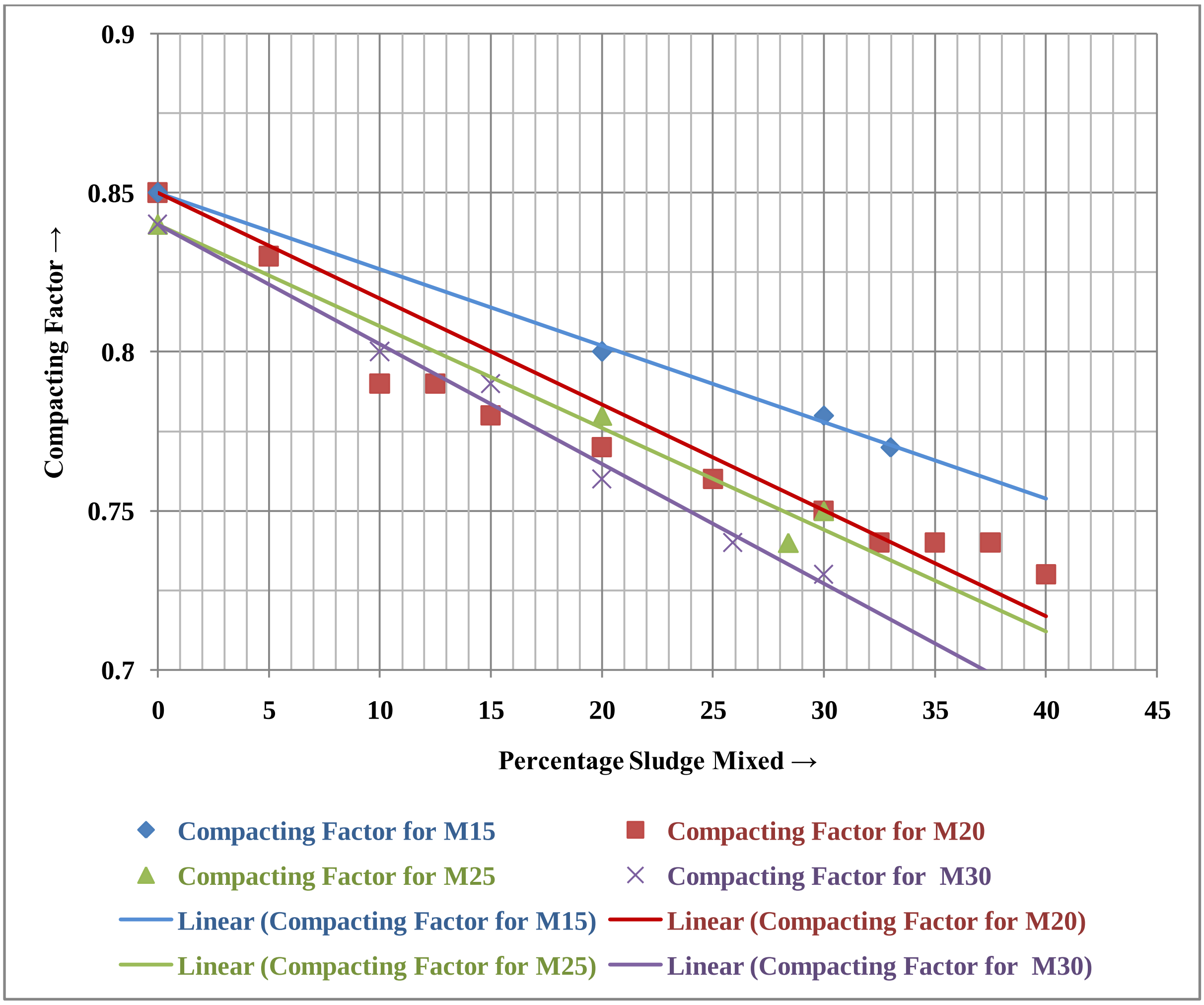


Figure 7.44: Percentage Sludge Mixed v/s Compacting Factor Graph for All Grades of Concrete

From the above graph it is seen that with increase in sludge percentage, the compacting factor is decreasing. Compacting factor is another measure for workability and it is decreasing because of the same reason why the slump height is decreasing.

For M20 grade concrete the compacting factor was 0.85 for 0% sludge (by weight of cement) mixed cubes. It signifies a low workability (within 0.80-0.85 as per Table No 22 of SP23:1982). The compacting factor has decreased to 0.75 for 30% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M20. It signifies a very low workability (within 0.75-0.80 as per Table No 22 of SP23:1982). So there had been an 11.8% decrease in compacting factor.

For M15 grade concrete the compacting factor was 0.85 for 0% sludge (by weight of cement) mixed cubes. It signifies a low workability (within 0.80-0.85 as per Table No 22 of SP23:1982). The compacting factor has decreased to 0.77 for 33% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M15. It signifies a very low workability (within 0.75-0.80 as per Table No 22 of SP23:1982). So there had been a 9.4% decrease in compacting factor.

For M25 grade concrete the compacting factor was 0.84 for 0% sludge (by weight of cement) mixed cubes. It signifies a low workability (within 0.80-0.85 as per Table No 22 of SP23:1982). The compacting factor has decreased to 0.8 for 20% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M25. It signifies a very low workability (within 0.75-0.80 as per Table No 22 of SP23:1982). So there had been a 4.8% decrease in compacting factor.

For M30 grade concrete the compacting factor was 0.84 for 0% sludge (by weight of cement) mixed cubes. It signifies a low workability (within 0.80-0.85 as per Table No 22 of SP23:1982). The compacting factor has decreased to 0.79 for 15% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M30. It signifies a very low workability (within 0.75-0.80 as per Table No 22 of SP23:1982). So there had been a 6% decrease in compacting factor.

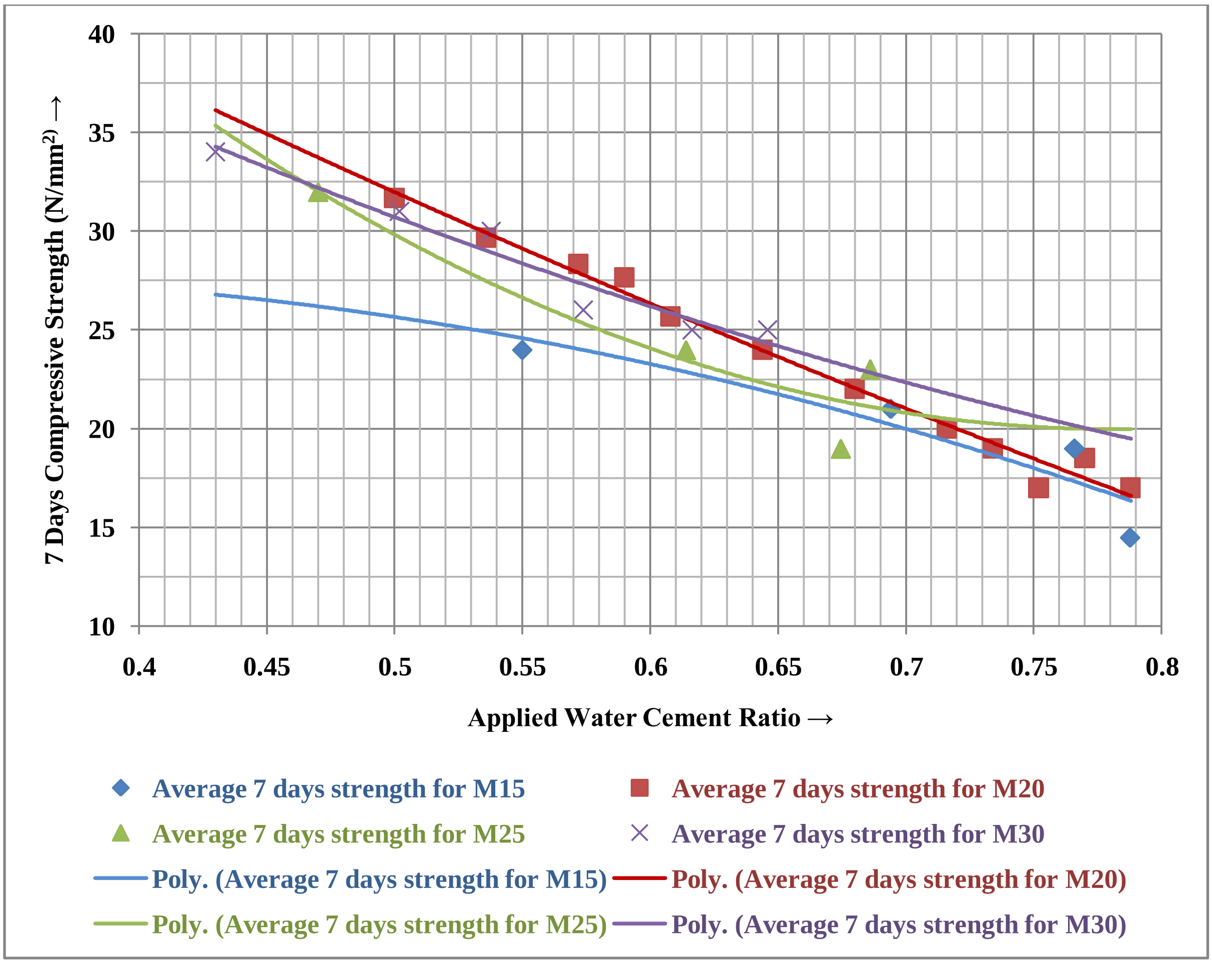


Figure 7.45: Applied Water Cement Ratio v/s 7 Days Compressive Strength Graph for All Grades of Concrete

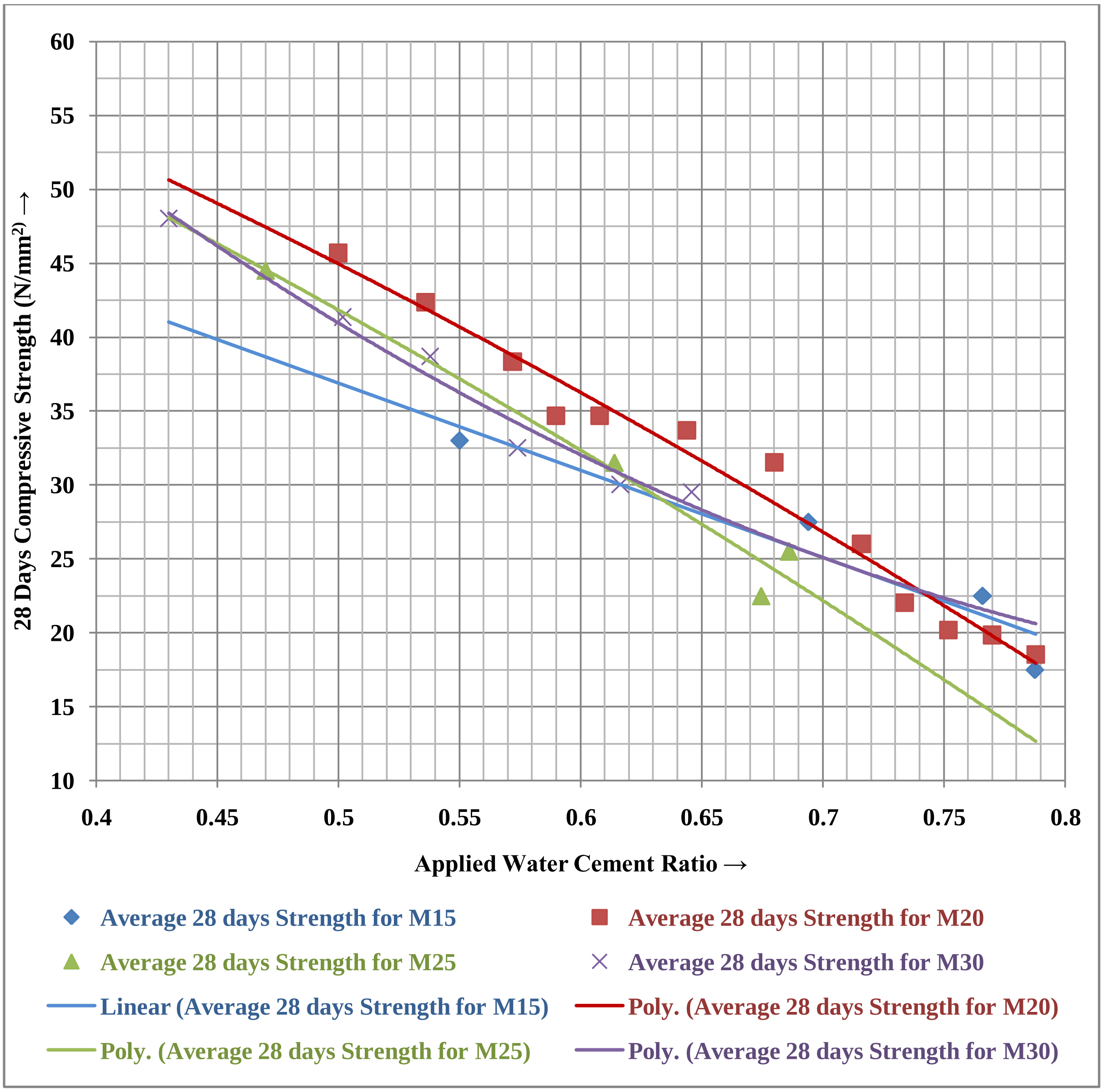


Figure 7.46: Applied Water Cement Ratio v/s 28 Days Compressive Strength Graph for All Grades of Concrete

From the above graph, it had been observed that with the increase in applied water-cement ratio, the strength of the concrete had deceased. In this study, the sludge mixed had a very high OMC value which signifies that the sludge had a higher ability to hold moisture than sand. So to compensate this extra water equivalent to the OMC of the mixed sludge amount had been added in addition to mix design water requirement. So with the increase in sludge amount mixed, the water added had also increased which in turn had increased the water-cement ratio. So here the term ‘Applied WC Ratio’ had been used.

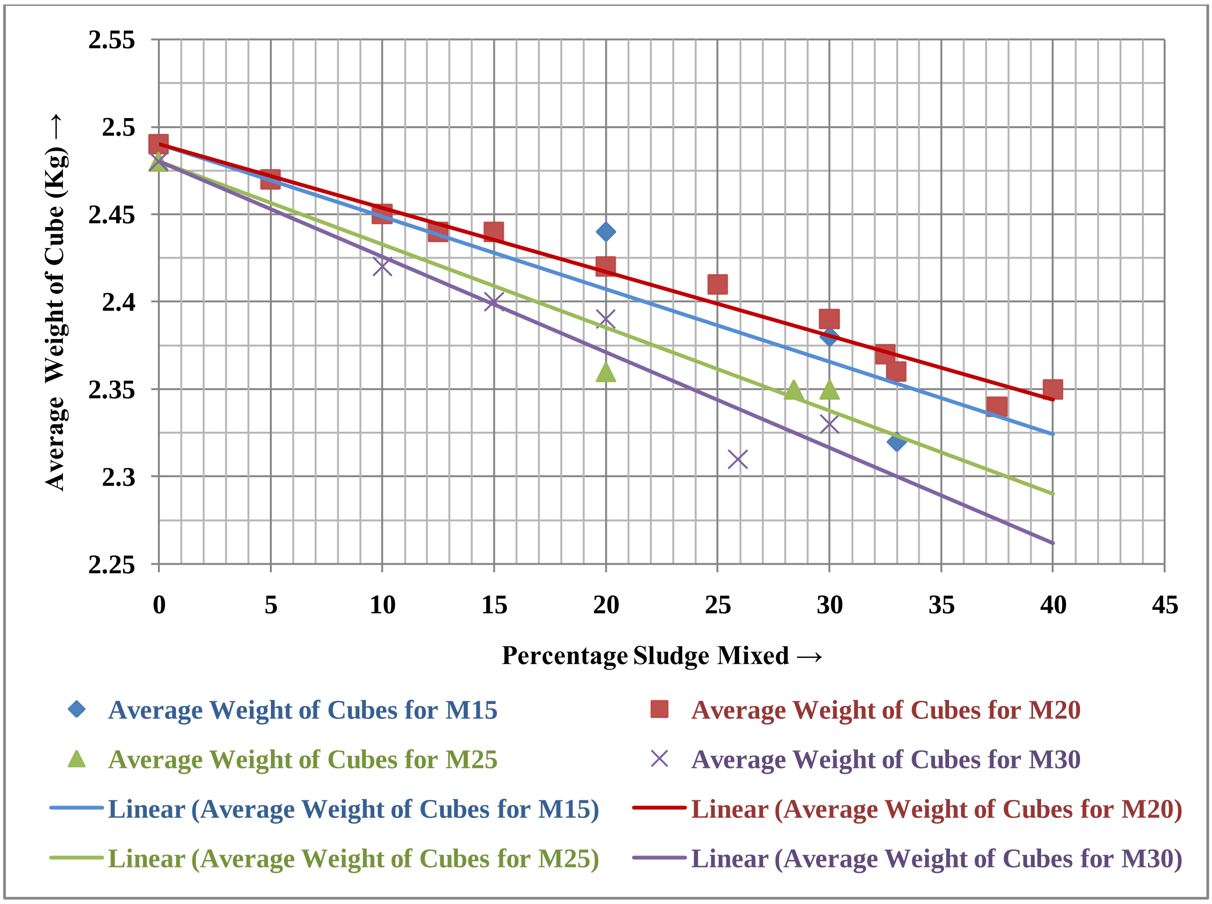


Figure 7.47: Percentage Sludge Mixed v/s Average Weight of Cube Graph for All Grades of Concrete

From the above graph it is seen that with the increase in percentage of sludge mixed, the average weight of the concrete cubes is decreasing. This may be due to the fact that the maximum dry density (0.883 gm/cc) of this sludge is less than the other constituents of concrete like cement, sand and stone chips. This low density owes to the fact that the void ratio (2.281) of the sludge sample is higher than the other constituents of concrete. So the amount of voids in much higher in the sludge sample. But the design mix weight of concrete cube is fixed and with this low density it is taking up more volume. So the overall weight of the concrete cube is becoming less as we are increasing the amount of sludge mixed.

For M20 grade concrete the average weight of the concrete cubes is 2.49Kg for 0% sludge (by weight of cement) mixed cubes. It has decreased to 2.39 for 30% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M20. So there had been a 4% decrease in average weight of concrete cubes.

For M15 grade concrete the average weight of the concrete cubes is 2.49Kg for 0% sludge (by weight of cement) mixed cubes. It has decreased to 2.32 for 33% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M15. So there had been a 6.8% decrease in average weight of concrete cubes.

For M25 grade concrete the average weight of the concrete cubes is 2.48Kg for 0% sludge (by weight of cement) mixed cubes. It has decreased to 2.36 for 20% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M25. So there had been a 4.8% decrease in average weight of concrete cubes.

For M30 grade concrete the average weight of the concrete cubes is 2.48Kg for 0% sludge (by weight of cement) mixed cubes. It has decreased to 2.4Kg for 15% sludge (by weight of cement) mixed cubes which the maximum percentage of sludge that can be mixed to achieve the target mean strength of M30. So there had been a 3.3% decrease in average weight of concrete cubes.

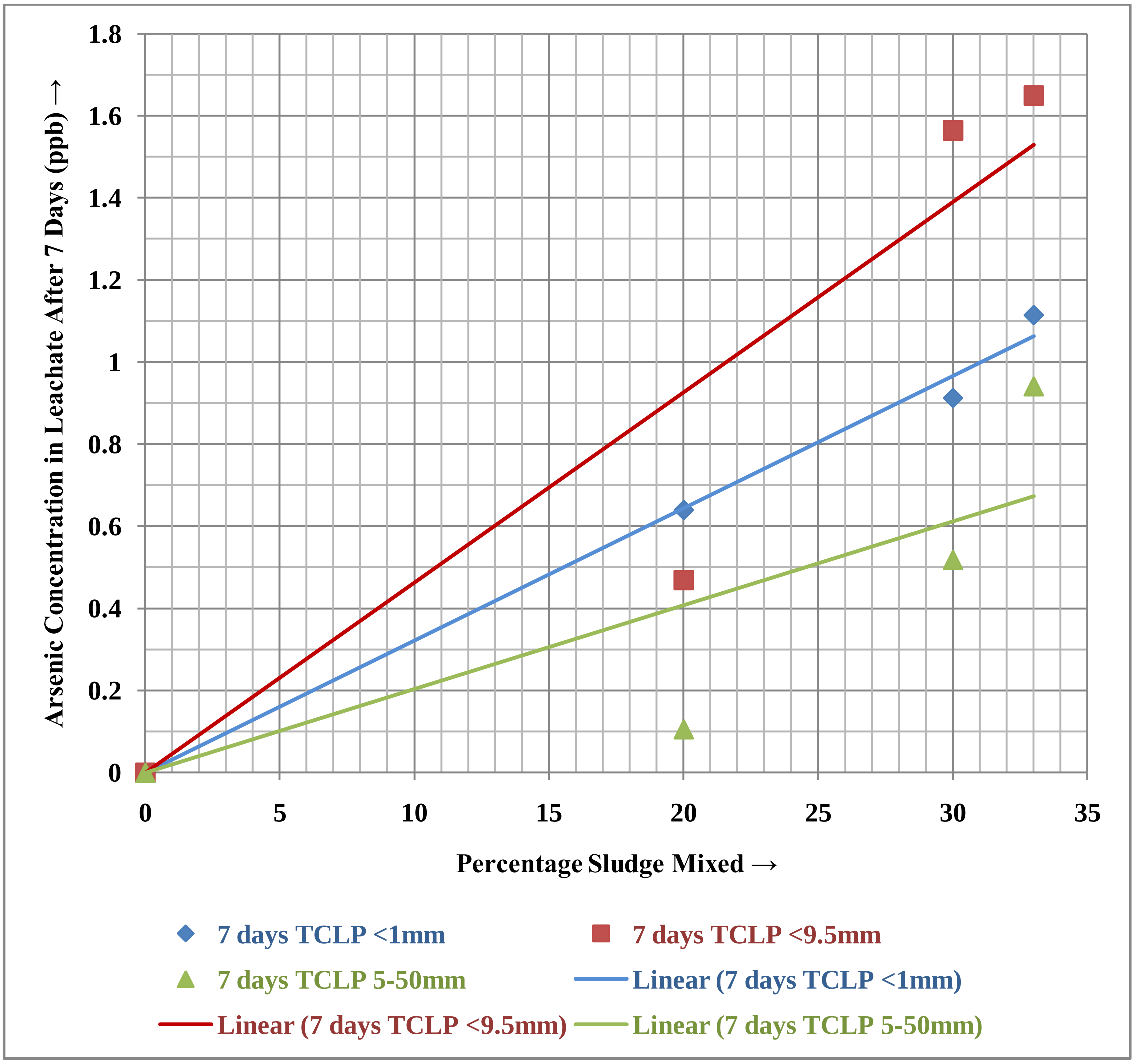


Figure 7.48: Percentage Sludge Mixed v/s Arsenic Concentration in Leachate After 7 Days Graph for M15

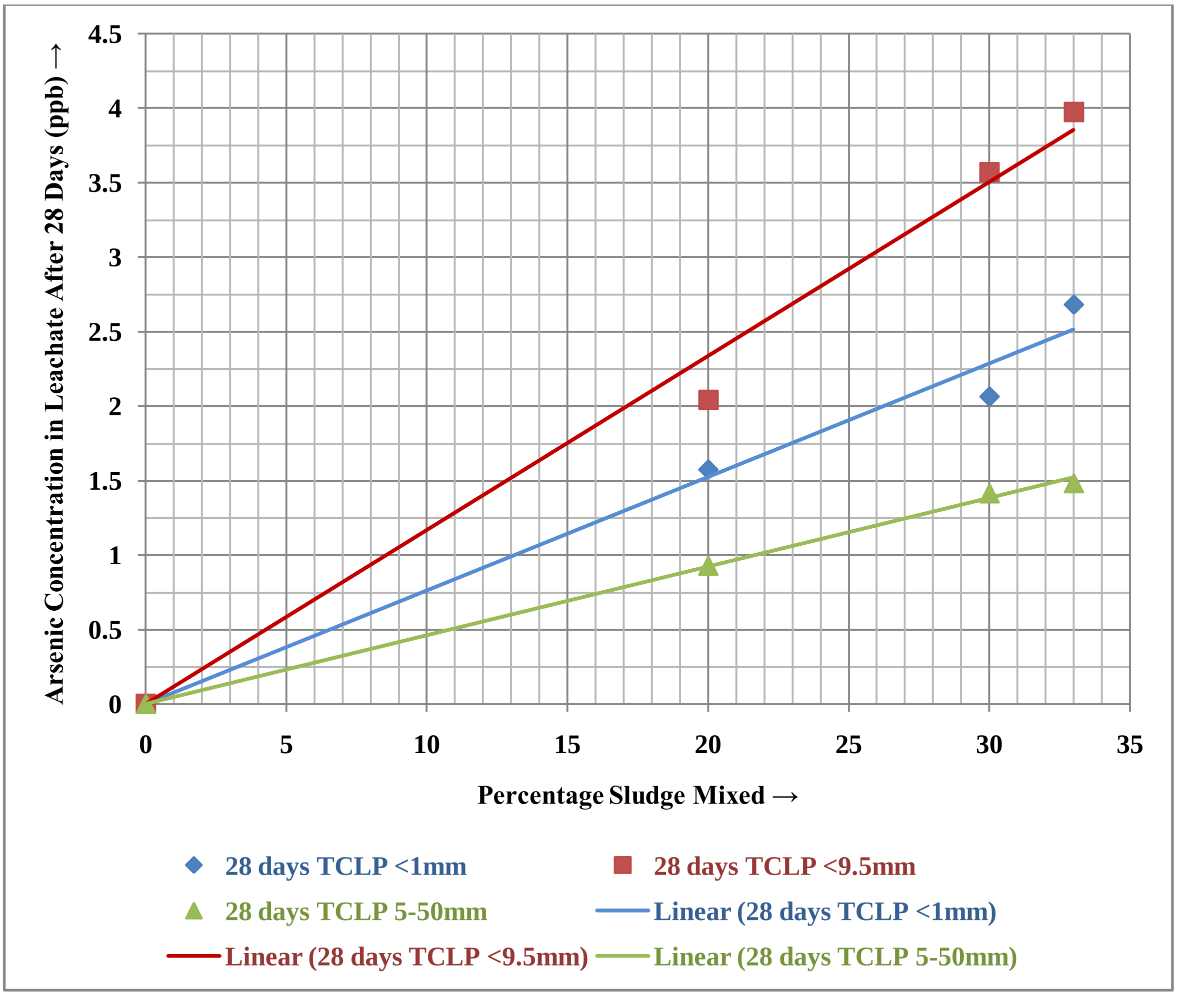


Figure 7.49: Percentage Sludge Mixed v/s Arsenic Concentration in Leachate After 28 Days Graph for M15

The sludge mixed concrete cubes have been checked for leachability of arsenic by TCLP. For this it had been pulverized into three size zones: i) <1mm ii) <9.5mm and iii) 5-50mm.

The above two graphs shows that for M15 grade concrete, the leached arsenic concentration in the leachate tested for the cubes after both 7 days and 28 days of curing shows an increasing trend i.e. with increase in percentage of sludge mixed the arsenic concentration in the leachate increases. But still all the arsenic concentrations are well below 200 ppb (the limit of arsenic for safe disposal of leachates) and also below 10ppb (the drinking water acceptable limit of arsenic as per IS10500:2012). The size zone <9.5mm shows the worst case scenario in terms of leached arsenic concentration and the results of this size zone can be taken as the representative one. USEPA has also recommended this size zone of <9.5mm for the determination using TCLP.

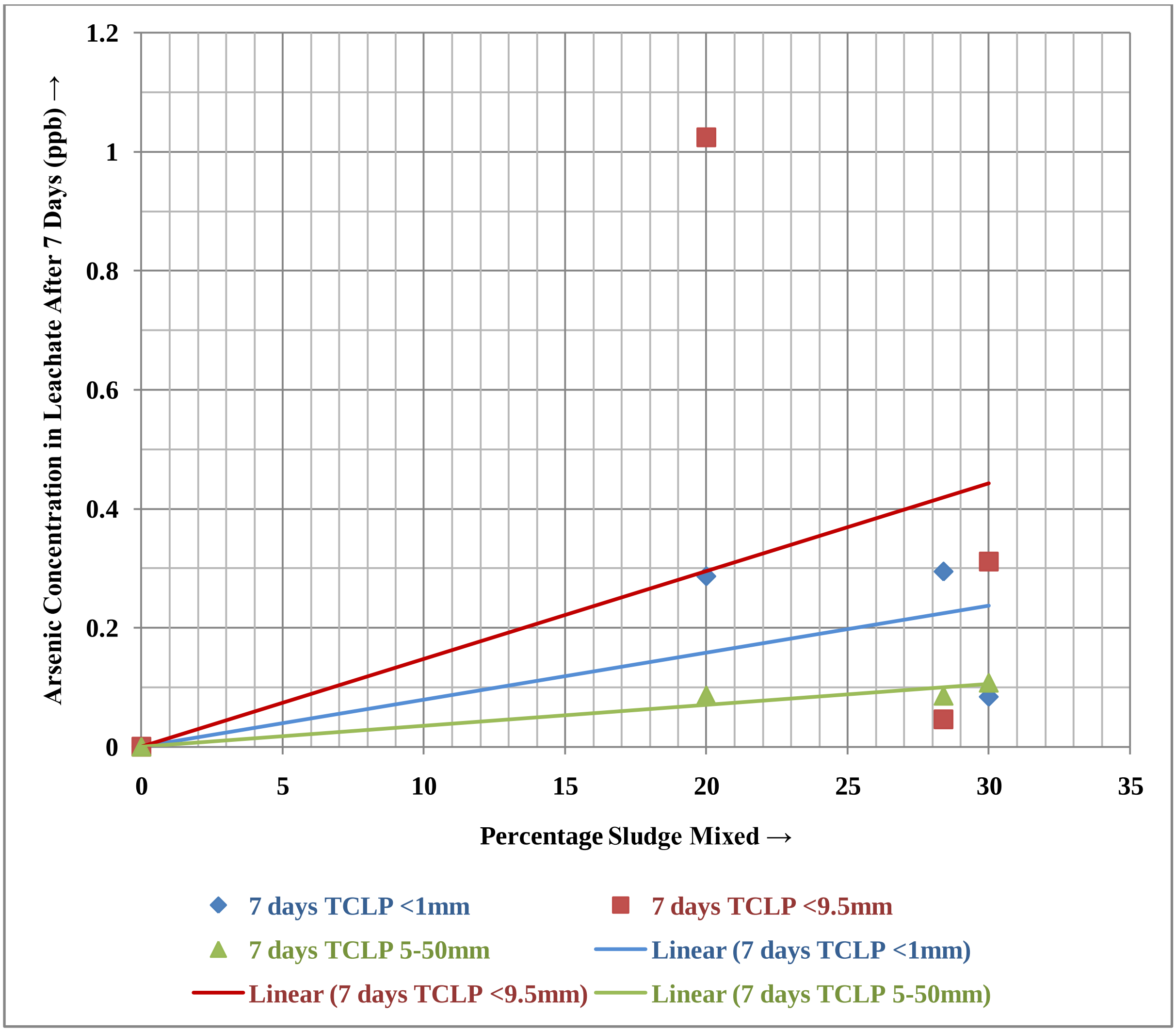


Figure 7.50: Percentage Sludge Mixed v/s Arsenic Concentration in Leachate After 7 Days Graph for M25

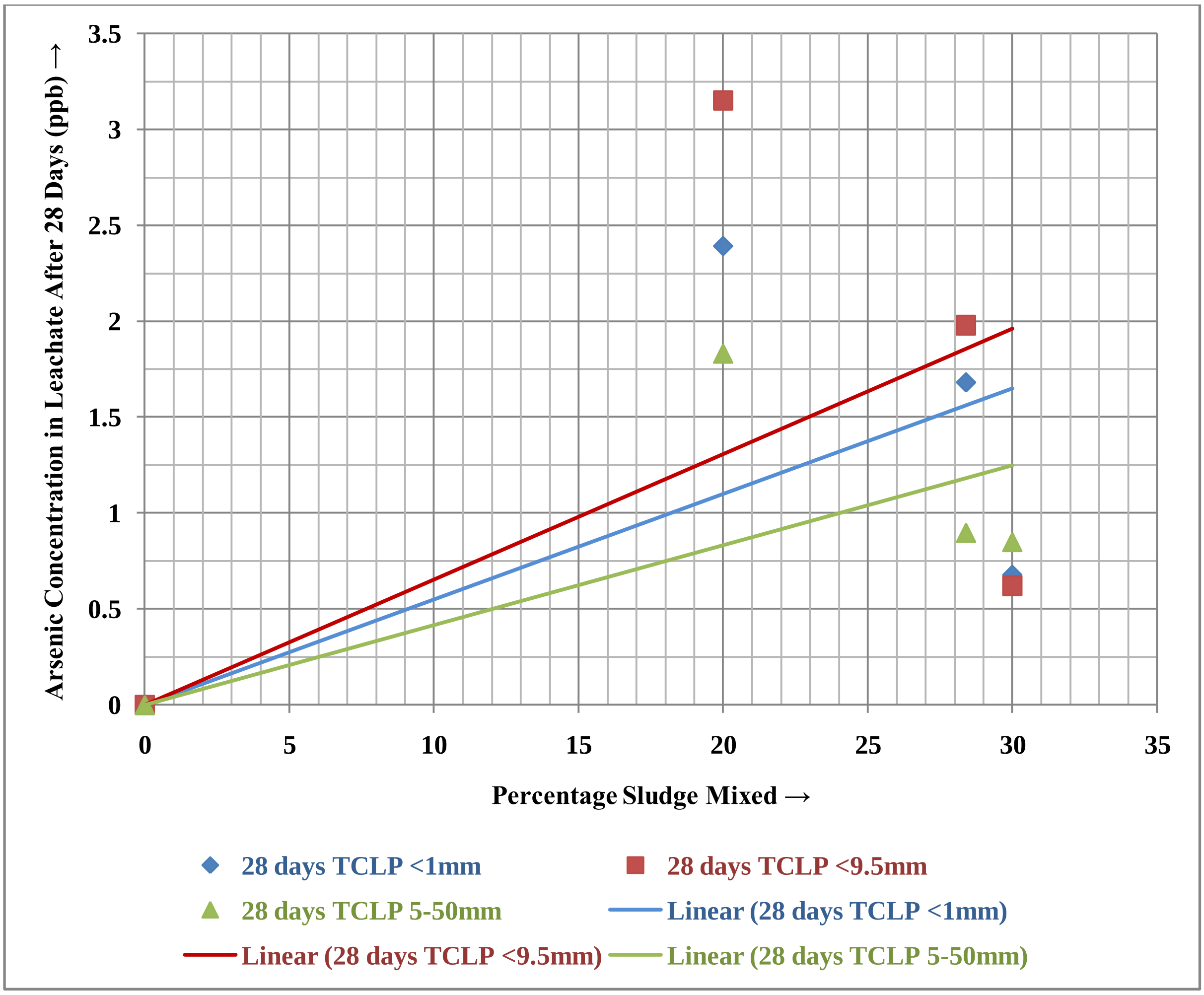


Figure 7.51: Percentage Sludge Mixed v/s Arsenic Concentration in Leachate After 28 Days Graph for M25

The sludge mixed concrete cubes have been checked for leachability of arsenic by TCLP. For this it had been pulverized into three size zones: i) <1mm ii) <9.5mm and iii) 5-50mm.

The above two graphs shows that for M25 grade concrete, the leached arsenic concentration in the leachate tested for the cubes after both 7 days and 28 days of curing shows an increasing trend i.e. with increase in percentage of sludge mixed the arsenic concentration in the leachate increases. But still all the arsenic concentrations are well below 200 ppb (the limit of arsenic for safe disposal of leachates) and also below 10ppb (the drinking water acceptable limit of arsenic as per IS10500:2012). The size zone <9.5mm shows the worst case scenario in terms of leached arsenic concentration and the results of this size zone can be taken as the representative one. USEPA has also recommended this size zone of <9.5mm for the determination using TCLP.

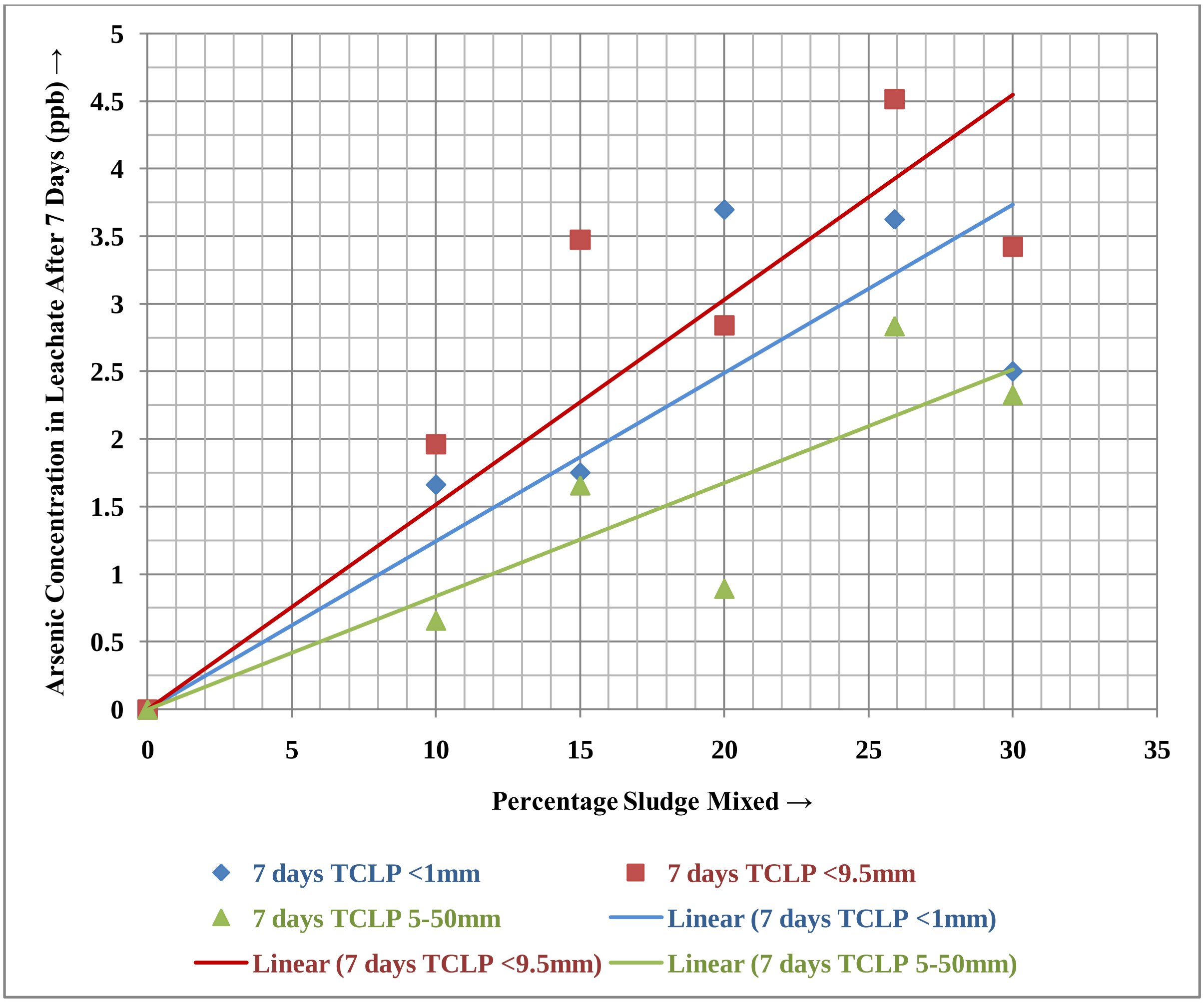


Figure 7.52: Percentage Sludge Mixed v/s Arsenic Concentration in Leachate After 7 Days Graph for M30

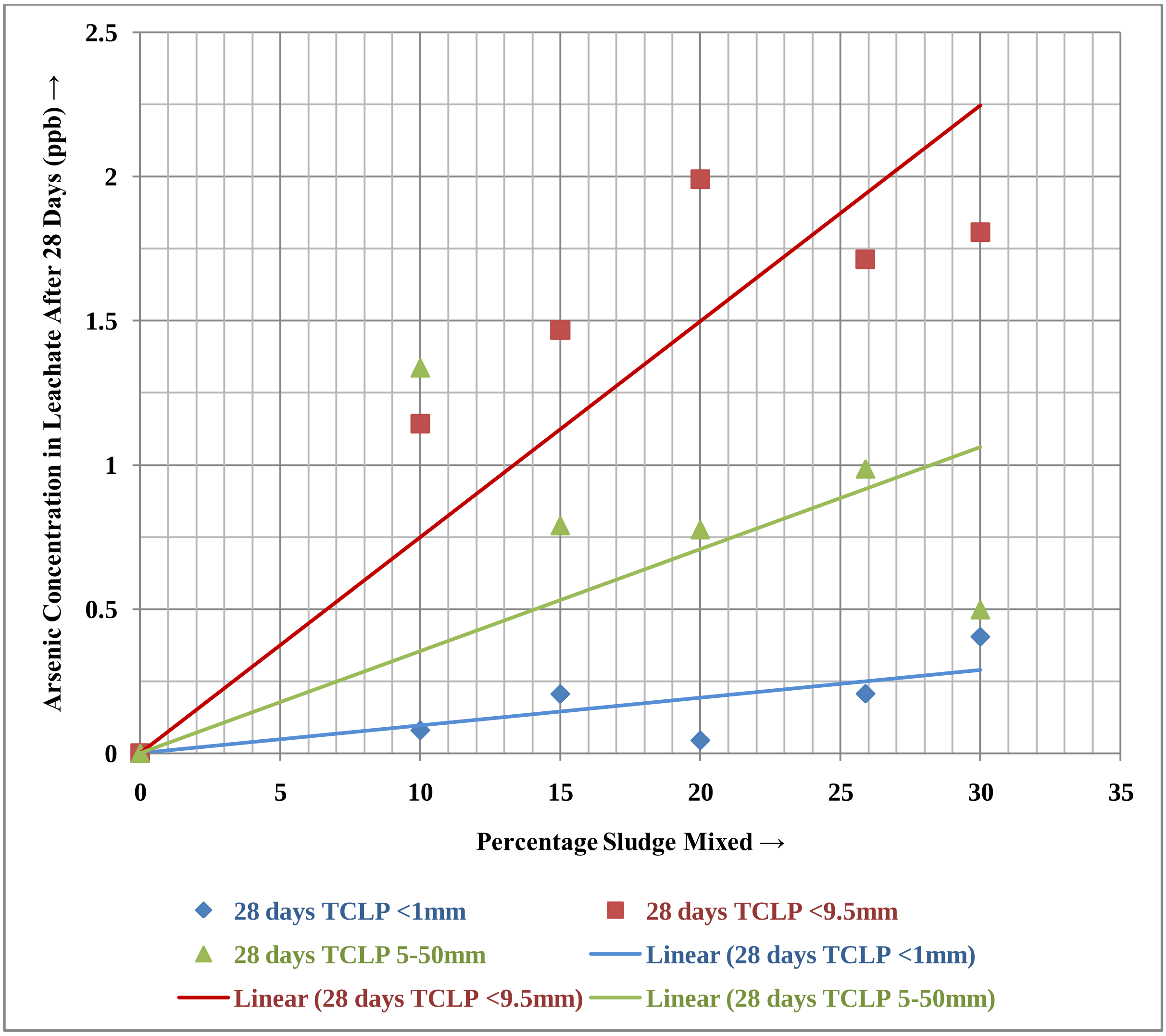


Figure 7.53: Percentage Sludge Mixed v/s Arsenic Concentration in Leachate After 28 Days Graph for M30

The sludge mixed concrete cubes have been checked for leachability of arsenic by TCLP. For this it had been pulverized into three size zones: i) <1mm ii) <9.5mm and iii) 5-50mm.

The above two graphs shows that for M30 grade concrete, the leached arsenic concentration in the leachate tested for the cubes after both 7 days and 28 days of curing shows an increasing trend i.e. with increase in percentage of sludge mixed the arsenic concentration in the leachate increases. But still all the arsenic concentrations are well below 200 ppb (the limit of arsenic for safe disposal of leachates) and also below 10ppb (the drinking water acceptable limit of arsenic as per IS10500:2012). The size zone <9.5mm shows the worst case scenario in terms of leached arsenic concentration and the results of this size zone can be taken as the representative one. USEPA has also recommended this size zone of <9.5mm for the determination using TCLP.

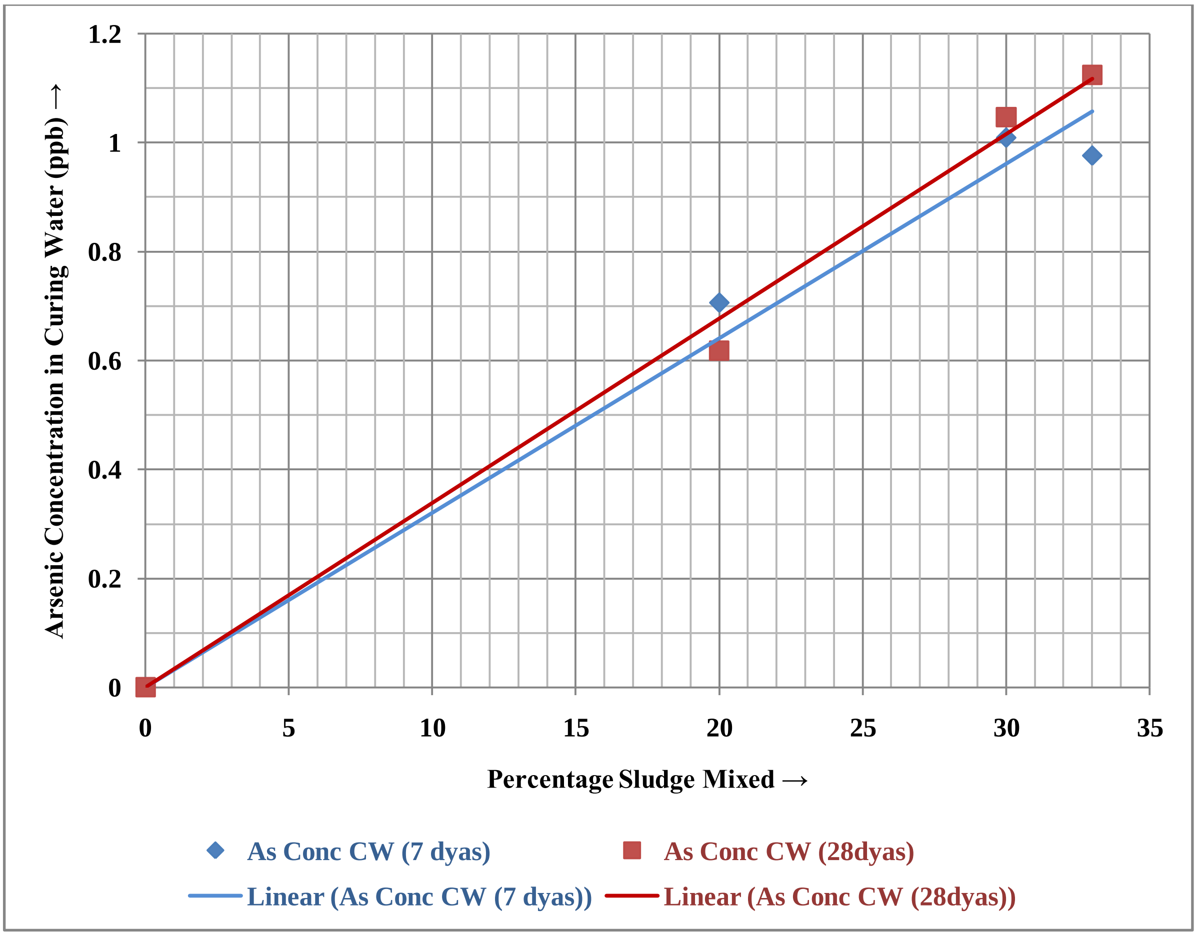


Figure 7.54: Percentage Sludge Mixed v/s Arsenic Concentration in Curing Water after 7 Days and 28 Days Graph for M15

The above graph shows the arsenic concentration in curing water tested after both 7days and 28days of curing.

For M15 grade of concrete it shows an increasing trend i.e. for increase in percentage of sludge mixed the arsenic concentration in curing increases. But still all the arsenic concentrations tested after both 7 days and 28 days of curing are well below 10ppb (the drinking water acceptable limit of arsenic as per IS10500:2012). The arsenic content in the curing water after 28 days of curing is slightly higher than that after 7 days of curing.

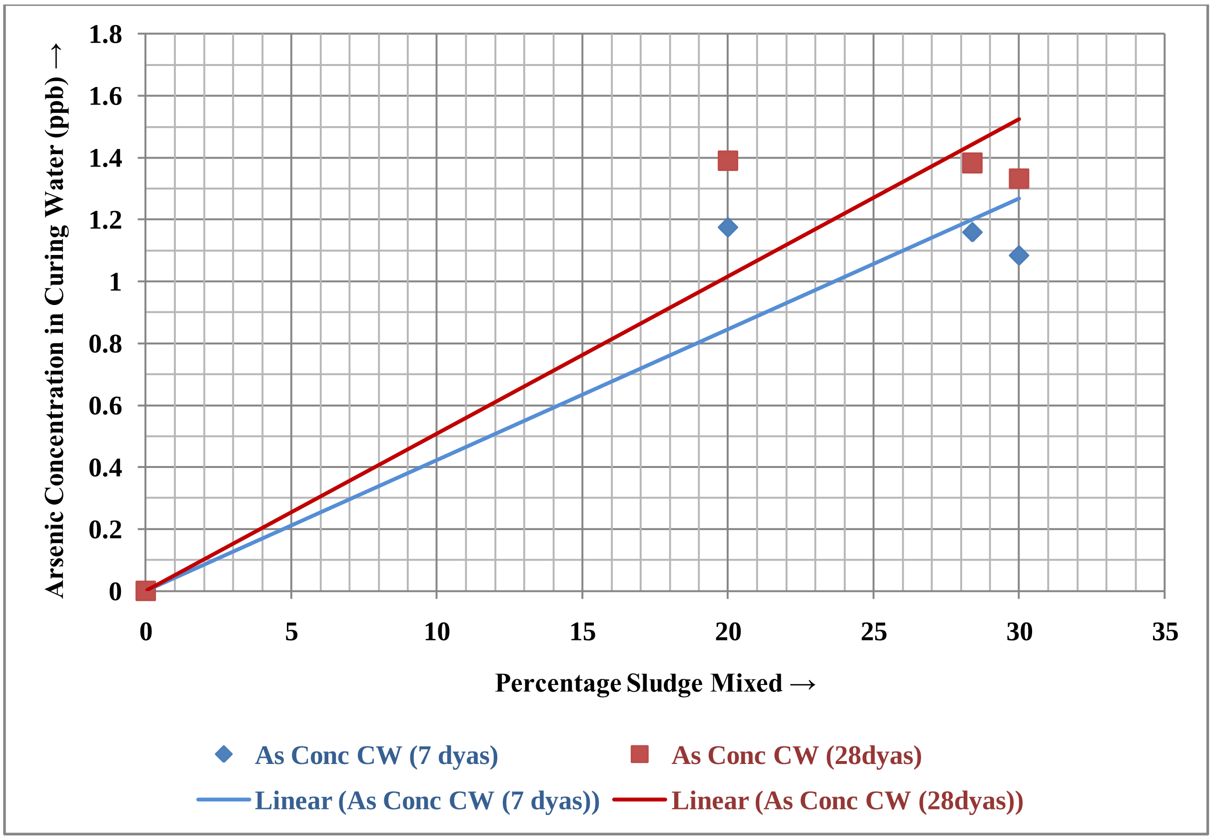


Figure 7.55: Percentage Sludge Mixed v/s Arsenic Concentration in Curing Water after 7 Days and 28 Days Graph for M25

The above graph shows the arsenic concentration in curing water tested after both 7days and 28days of curing.

For M15 grade of concrete it shows an increasing trend i.e. for increase in percentage of sludge mixed the arsenic concentration in curing increases. But still all the arsenic concentrations tested after both 7 days and 28 days of curing are well below 10ppb (the drinking water acceptable limit of arsenic as per IS10500:2012). The arsenic content in the curing water after 28 days of curing is slightly higher than that after 7 days of curing.

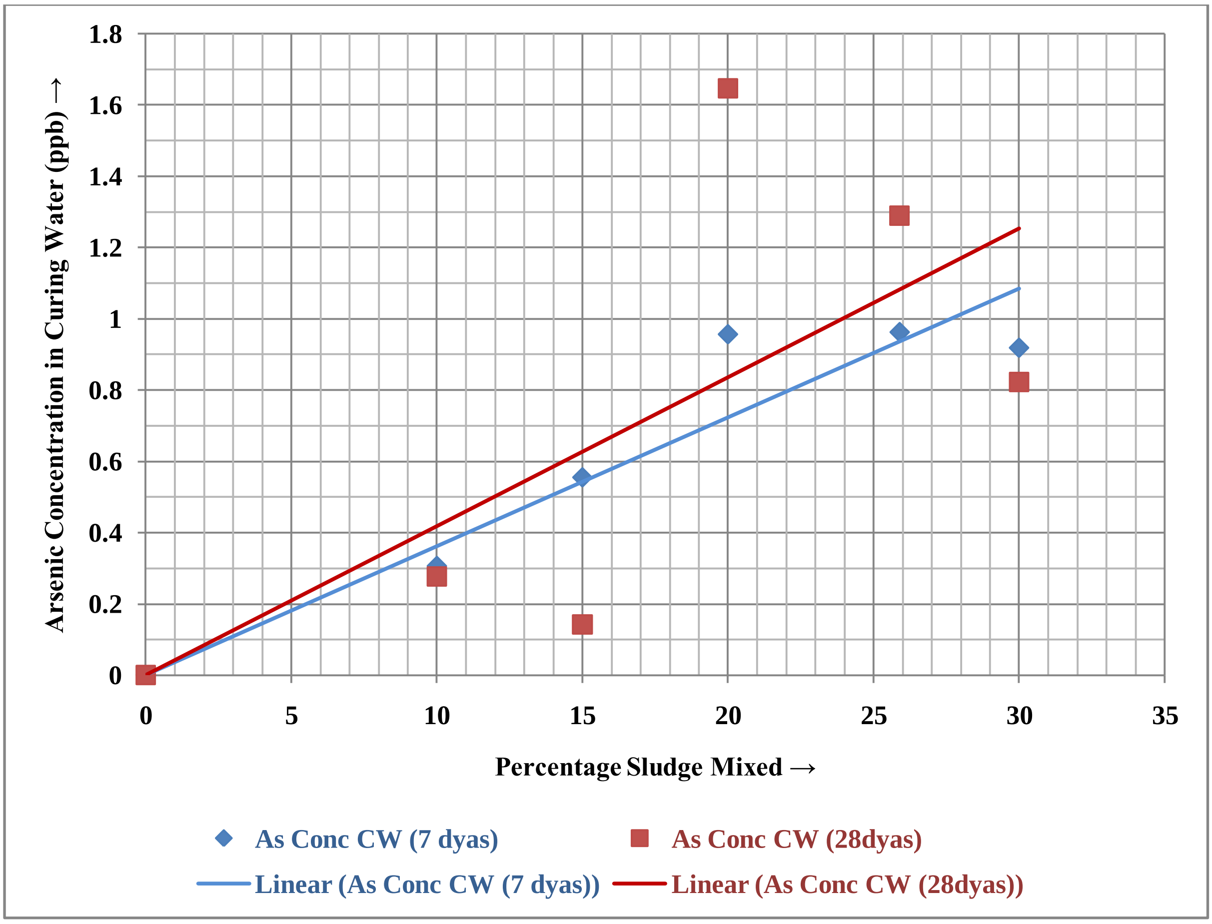


Figure 7.56: Percentage Sludge Mixed v/s Arsenic Concentration in Curing Water after 7 Days and 28 Days Graph for M30

The above graph shows the arsenic concentration in curing water tested after both 7days and 28days of curing.

For M30 grade of concrete it shows an increasing trend i.e. for increase in percentage of sludge mixed the arsenic concentration in curing increases. But still all the arsenic concentrations tested after both 7 days and 28 days of curing are well below 10ppb (the drinking water acceptable limit of arsenic as per IS10500:2012). The arsenic content in the curing water after 28 days of curing is slightly higher than that after 7 days of curing.

Chapter 8
Conclusion

This study focused on characterization of sludge generated by ECAR process in terms of pertinent physical and chemical parameters, keeping in mind the ultimate objectives of disposal, re-usability and stabilization of the sludge.

The physical characterization results indicated that the sludge is very similar to high plasticity silt (MH) as per Unified Soil Classification System. Physical parameter such as cohesion and shearing strength shows similarity with sand. The permeability or hydraulic conductivity is very low like that of clay. However, the parameter such as specific gravity, optimum moisture content, void ratio and porosity differs from that of silt and sand. Grain size is similar to filler materials used in concrete, which suggests that there is potential for the sludge to be embedded in concrete, thus emphasizing its immobilization.

The results of chemical analysis of the ECAR sludge show that it has very high iron content. The high iron content imparts a reddish brown color to the sludge. The pH of the aqueous solution of sludge is in the neutral range. Arsenic concentrations in the sludge are found to be much higher than the value mentioned in Hazardous Material (Management, Handling and Transboundary Movement) Rules, 2008. Silica content is also high in the sludge which can account for the fact that ground water is being treated which itself may have high silica content. Aluminum is present in moderate concentration in the sludge and its primary source is alum used as coagulant in the ECAR process. Lead, nickel, mercury, barium, cadmium and chromium concentrations in sludge are low which suggests that they will probably not affect disposal or re-usability. Calcium is present in the sludge in moderate quantity and its presence as sulfate can cause damage to concrete. Calcium oxide however plays a role in enhancing the mechanical properties of concrete. Magnesium is present in very low quantities and only in its sulfate form can cause some damage to concrete. But the sulfate content is low so as its chloride content so it there will be no problem regarding sulfate attack and chloride attack in concrete. Phosphate and Nitrate concentrations in the sludge are too low to cause any damage in context of disposal and re-usability.

The arsenic bearing ECAR sludge was immobilized in four grades of concrete and it was observed that:

- For M15 grade of concrete, the maximum percentage of sludge that can be mixed safely in terms of compressive strength is 30%.

- For M20 grade of concrete, the maximum percentage of sludge that can be mixed safely in terms of compressive strength 30%.

- For M25 grade of concrete, the maximum percentage of sludge that can be mixed safely in terms of compressive strength 20%.

- For M30 grade of concrete, the maximum percentage of sludge that can be mixed safely in terms of compressive strength 15%.

- The arsenic concentration in the leachate produced from the concrete cubes of all the four grades was well below the prescribed safe limit.

Thus this sludge being a Class A Hazardous Waste can be immobilized in concrete which is a good stabilization option both in terms of economy and simplicity.

Chapter 9
Future Scope of Study

The future scope of this study can be summarized as follows:

i. X-Ray Diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), Scanning Electron Microscope (SEM) studies can be conducted on the sludge for better understanding of its micro-structure. From these above studies the internal structure of the sludge can be known. The size and constituents of the molecules of different elements present in the sludge can be known. The percentage content and organization of the constituting elements of the sludge can also be determined.

ii. The concrete cubes which had been casted had been checked only for 7 days and 28 days. The long term leachability can also be studied. The long term effect means the concrete cubes to be kept exposed to natural weathering process and also in contact with soil in natural environmental conditions.

iii. The casted concrete cubes can be checked for durability studies.

iv. In this study the sludge used had been procured from prototype model of ECAR where the natural groundwater had been spiked with arsenic salt. So here the arsenic content had been more or less constant in the sludge. This same study can be conducted on field sludge obtained from ECAR plant where natural groundwater with varying arsenic content is been treated.

v. Characterization of Iron based Arsenic bearing sludge generated from removal processes other than ECAR may be done so as to draw a comparison between the sludges. For example sludge obtained from Zero Valent Iron Removal Technology can be studied.

vi. In this study it had been seen that the workability of concrete mix is showing a decreasing trend with increase in sludge percentages mixed. So in order to improve the workability plasticizers, super plasticizers and air entraining agents can be used. These admixture added concrete can be studied.

vii. In this study only Portland Pozzolana Cement (PPC) had been used. The study can also be conducted using other types of cements like Ordinary Portland Cement (OPC) and Portland Slag Cement (PSC).

viii. Here immobilization of this arsenic bearing sludge had been done only in concrete. It can be embedded in other building materials like cement mortar, bricks, plaster of paris, etc.

ix. The leachability studies had been done by TCLP. Other leaching procedures like California Waste Extraction Test (WET), German 38 414 S4 Standard (DIN), Netherlands 7341 Standard (NEN) and Australian 4439.3 Standard (AS) can also be conducted. Also the effect of rotation variation during extraction procedure can also be studied.

Chapter 10
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