Development of a waste management technology for pilot-scale production of an organic fertilizer from rural abattoir wastes

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By

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STATEMENT OF ORIGINALITY

I …***ANKITA BHOWMIK***.……registered on …***1ST NOVEMBER 2019***....do hereby declare that this thesis entitled "***Development of a waste management technology for pilot-scale production of an organic fertilizer from rural abattoir wastes"*** contains literature survey and original research work done by the undersigned candidate as part of Doctoral studies.

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DECLARATION

I do hereby declare that the thesis entitled **'Development of a waste management technology for pilot-scale production of an organic fertilizer from rural abattoir wastes.'** submitted by me for the for the fulfilment of the continuous assessment of Ph. D. degree course in Engineering from Jadavpur University, Kolkata, India. The thesis embodies research work carried out by me at School of Environmental Studies, Jadavpur University, Kolkata under the supervision of Dr. Joydeep Mukherjee, Professor & Director, School of Environmental Studies, Jadavpur University, Kolkata 700032 Neither this thesis nor any part of it has been submitted for either any degree / diploma or any other academic award anywhere before.

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(Ankita Bhowmik)

ABSTRACT

Slaughterhouses, where animals are butchered to meet the rising demand of meat consumption and huge application of cattle by-products globally. The amount of waste generated from slaughterhouses is neither easy to handle nor simple to dispose. In developing countries where rural slaughterhouses are the major source for meat and by-product industry, the generated waste that has no profitable outcome are discarded untreated in the surroundings raising concerns towards environmental hazard and human health. This ignorance of rural abattoirs, towards proper and scientific waste disposal makes this huge profitable industry an environmental liability. On the contrary, if the true value and potential of the organic waste generated from abattoirs is evaluated and recycled accordingly, it may become a major asset towards developing a sustainable economy and a cleaner environment.

This research work not only identifies the problems regarding these unorganised slaughterhouses but also gives a practical and implementable solution for such hazardous waste management. Rural abattoirs evaluated for the presented research work are situated in the villages of Magrahat block- 2, South 24 parganas, West Bengal. These are poorly facilitated slaughterhouses handling a huge demand for meat everyday and simultaneously generating a vast amount of organic waste, harbouring pathogens, choking local sewer systems, polluting water bodies and streams. Almost every day approximately 20 buffaloes are annihilated in an abattoir, all the edible parts and the non-edible parts of the animal that has monetary return are conveniently dispersed to their respective outlets. Bovine blood and the ruminal content are the wastes that are ignorantly discarded

from the system. Characterization of these waste confirmed that biological oxygen demand (BOD), chemical oxygen demand (COD) and other effluent parameter are higher than the permissible limits. Due to economical constrains its not feasible for these abattoirs to adopt any advanced and complicated technologies demanding huge capital investment and operating cost. In literature there has been reports that a blend of bovine blood and rumen digesta in a ratio of 3:1 has shown remarkable potential as a soil conditioner.

The mixture of ruminal content and cattle blood through drying treatment is valorised into a potential organic fertilizer free from infectious pathogens. This research work presents and describes the fabrication and evaluation of a drying cum recycling unit, 'helical-ribbon-mixer-dryer' as a cost-effective solution for abattoirs to their waste disposal problem. Developing an easily installable recycling unit for these rural abattoirs would be a profitable transition from small scale cook drying process of organic fertilizer production. In the recycling unit the organic waste (mixture of bovine blood and rumen content) is heated at 90-110 °C for 3-4 hours, as a result the obtained dried product had final moisture content of 15.6 % and properties of a nitrogen rich soil amendment. This initiative has launched a development in the economy of these rural slaughterhouses and in return providing the local farmers to enter into organic farming depending on the produced and tested to be a nitrogen rich organic fertilizer recycled from slaughterhouse waste named BBRDM (Bovine-Blood Rumen-Digesta-Mixture). The presented research work may bring a sustainable circular economy to these rural sectors surrounding slaughterhouses.

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List of Abbreviations

USDA	: United States Department of Agriculture
%	: Percentage
APEDA	: Agricultural and Processed Food Products Export Development Authority
BOD	: Biochemical oxygen demand
COD	: Chemical oxygen demand (COD)
TSS	: Total Suspended Solids
TDS	: Total Dissolved solids
CH_4	: Methane
CO_2	: Carbon dioxide
CPCB	: Central Pollution Control Board
EC	: European Community
mg l^{-1}	: milligram per litre
mg kg^{-1}	: milligram per kilogram
pH	: Potential of Hydrogen
TS	: Total Solid
TKN	: Total Kjeldahl Nitrogen
C/N	: Carbon Nitrogen ratio
heme-Fe	: heme- (precursor to haemoglobin) iron
H1N1	: Hemagglutinin Type 1 and Neuraminidase Type 1
MRSA	: Methicillin Resistant *Staphylococcus aureus*
EU	: European Union
°C	: Degree Celsius
BSE	: Bovine Spongiform Encephalopathy
kPa	: kilo Pascal
NABC	: National Agricultural Biosecurity Centre
GHGs	: Greenhouse Gases
BBRDM	: Bovine-Blood-Rumen-Digesta-Mixture
NPK	: Nitrogen Phosphorus Potassium ratio
N_2	: Nitrogen
NH_4^+	: Ammonium ion

Kg	: Kilogram
sq. ft.	: square feet
m^2	: meter square
ASTM	: American Society for Testing and Materials
KCl	: Potassium Chloride
DO	: Dissolved Oxygen
RNA	: Ribonucleic Acid
MJ kg^{-1}	: Megajoule per kilogram
SMER	: Specific Moisture Extraction Rate
MER	: Moisture Extraction Rate
MJ	: Mega joule
SDG	: Sustainable development Goal
l	: Litre
m	: metre
m^3	: meter cube
kg m^{-3}	: Kilogram per meter cube
EPA	: Environmental Protection Act
µg g^{-1} h^{-1}	: microgram per gram per hour
LPG	: Liquified Petroleum Gas
HP	: Horsepower
rpm	: rotations per minute
kg h^{-1}	: Kilogram per hour
kwh	: kilo-watt-hour
kg kwh^{-1}	: Kilogram per kilo-watt-hour
kwh kg^{-1}	: kilo-watt-hour per kilogram
min	: minutes
MJ m^{-2}	: Mega joule per meter square
INR	: Indian Rupee
DAP	: Diammonium phosphate

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Chapter 1:

Introduction

1. Introduction

Over the decades food habit has changed worldwide and so has the type of waste generated from food producing industries: be it cultivation-derived or from livestock farms. In recent years animal husbandry has increased three times than it was in last two decades and now India holds the largest fleet of livestock in the world [1]. When it comes to beef producer and domestic consumer India ranks fourth in world ranking, according to a report published by USDA named "Livestock and Poultry: World Markets and Trade" [2]. According to these surveys conventional staple diet of Indians is changing rapidly. The meat consumption has increased in India over the past few years and in 2020 dietary meat expanded from 52% to 63% [3]. Meat industries in India cannot depend only on the formal and sophisticated slaughterhouses, rather they are majorly depending on rural small-scale abattoirs. The current scenario thus raises concern on the operational realities of rural slaughterhouses and their ways of waste disposal.

1.1 Brief scenario of rural slaughterhouses

According to Agricultural and Processed Food Products Export Development Authority (APEDA) established by Government of India, there are 1176 formal slaughterhouses and 75 modern abattoirs. Slaughterhouses using heavy and sophisticated machineries are categorized as modern abattoir. Apart from these, there are hundreds of informal and rural ones in the country that are off the records. Domestic market of Indian meat industry is growing rapidly as the structure of diet has changed for billions of people and it is a primal force that cannot easily be reversed. Although meat consumption is on increase, this sector is poorly organized and waste disposal aspects have not been adequately addressed or acted upon. Approximately 35000 slaughterhouses in the country are unaccounted for improper and untreated disposal of waste, most of these are dated back to British period meaning they are very old and are still in primitive condition. These age-old slaughterhouses operate with inadequate basic amenities such as proper flooring of the slaughtering ground, lairage, appropriate ventilation, proper drainage system, water supply, electricity. Along with the said insufficiency of basics, disposal of the waste is done in an inappropriate and environmentally unacceptable manner, also lacking in hygienic standards leads to major public health concern and environmental hazards. Majority of these slaughterhouses are scattered in rural areas and they cater to the needs of urban consumers. Besides selling the edible parts of the slaughtered animals for meeting the needs of meat consuming industries, these abattoirs also provide raw materials to various other sectors like soap factories, tanneries, tallow and adhesive manufacturing industries, live-stock feed processing units and bone mills. Concurrently, the butchers are getting an alternative source of secondary income from the inedible parts (skin, fats, cartilages, bones, horns and hoovers). The only waste generated from these rural abattoirs which does not have any monetary importance to the owners are cattle blood and ruminal contents. Consequently, slaughterhouse owners are not concerned about the safe disposal of these wastes and are reluctant to invest in any non-profitable scientific and proper waste management technique.

Figure 1: One of the rural slaughterhouses, lacking in basic facilities

1.2 Effects of improper slaughterhouse waste disposal

Worldwide, waste generated from the slaughterhouses comprises mostly of bovine blood and rumen digesta, which are concentrated in nature and they have a non-homogeneous composition [4]. The wastewater generated from these abattoirs is mixed with cattle blood and is concentrated with 45% soluble and 55% suspended organic matter [5]. The high moisture content of the waste serves as a potential ground for the fast proliferation of microbes and pathogens [6]. Due to lack of infrastructural facilities and the reluctance of these slaughterhouses the waste is discharged untreated, directly into the local water bodies and sewer systems. Additionally, the semi-solid waste is either dumped or burnt openly. These ways of disposal further lead to choking of discharge channels and simultaneously increasing the biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS) and total dissolved solids (TDS) making the wastes more difficult to treat [7]. On the other hand, dumping grounds are not only potential reservoirs of infectious pathogens like *Bacillus*, *Brucella*, *Salmonella*, *Clostridium*, *Mycobacterium*, *Staphylococcus* and *Erysipelothrix* [6,8,9], but also release leachate, CH_4 and CO_2 like greenhouse gasses along with various other toxic compounds with annoyance of foul odor attracting vector insects like flies, mosquitoes, rats and stray animals like cat, dogs, or pigs. Such unorganized and unregulated management of abattoir generated organic waste may act as potential source of plague, malaria, typhoid, and cholera and adversely affects the environment, thus raising deep concerns on the risks of human health and public well-being [10]. It has been reported that almost 60 % of all the human infections are caused by animal source and in past two decades it has increased to 75% [11]. Additionally, *Escherichia, Shigella, Klebsiella, Streptococcus* like heterotrophic bacterial population is found to be growing profusely in slaughterhouse wastewater that affects human health negatively [12].

Figure 2: Choked on cattle blood channels and ruminal contents in open dumping sites.

1.3 Classification, Characterization and Composition of abattoir generated wastes

Waste characterization of slaughterhouse discharge is performed after classifying them into categories and types.

1.3.1 Classification

Classification of the slaughterhouse generated waste is done based on slaughtering capacity, process adopted and types of animals that are slayed in the abattoirs, briefed in Table 1.

Table 1: Classification and distribution of Slaughterhouses in the country, CPCB 2017 report

Classification	*Basis*	*Distribution*
Large	Type of animal Slaughtered	50%
Small	Type of animal Slaughtered	46%
Both (Large and Small)	Type of animal Slaughtered	4%
Manual	Process of Slaughtering	95%
Semi-Mechanized	Process of Slaughtering	1%
Mechanized	Process of Slaughtering	4%
Large	Capacity of Slaughtering per Day	> 200
Medium	Capacity of Slaughtering per Day	50-200
Small	Capacity of Slaughtering per Day	< 50

According to the Regulation 5 (EC) No. 1774/2002 and potential risk assessment for animal by-products, abattoir waste is classified into three categories, (a) Type-1, includes material of specified risk like eyes, spinal cord, brain. (b) Type-2, mostly comprises of condemned meat, digestive tract, and manure. Type-1 & 2 wastes are assessed as high risk and on the other hand (c) Type-3, consisting entrails, lungs, fat, kidney, livers, bone are of low risk in accordance to the assessment. Similarly, abattoir generated solid waste are broadly classified as Type-I and Type-II waste according CPCB, India ,2004. The Type - I waste is basically vegetable matter such as rumen, stomach and intestine waste contents, dung, agriculture residues and semi-solid mass made up of undigested to partially digested grass. On the contrary Type - II waste composed of animal matter such as inedible offal, tissues, meat trimmings, condemned meat, bones.

1.3.2 Characterization and composition

The abattoir generated waste is chemically and physically comparable to sewage from domestic drainage, but much more concentrated in nature. Approximately only 45-50% of the slaughtered animal can be turned into edible products, about 40-45% of the animal is turned into by-products such as leather, soaps, tallow, and adhesives. However, the 15% is waste, primarily bovine blood and rumen digesta are discharged as solid waste and effluent without any treatment to the surroundings by most of all the rural slaughterhouses. The chemical oxygen demand (COD) of this typical discharged waste is between 4400-18000 mg l-1. It is also being reported that the COD of slaughterhouse blood to be 375000 mg l-1 [13]. Major soluble contaminant of abattoir waste is blood, COD 260000 mg l-1 and 152000 mg kg-1 COD in ruminal waste [14]. Bovine blood and effluent discharged are reported to have 268571 mg l-1 and 266000 mg l-1 of COD respectively [15,16]. In addition to COD, the other parameters like pH, TS and TKN are studied on which waste generated from different types of slaughterhouses are characterized and, summarized in Table 2.

Table 2: Characterization of Abattoir waste based on physio-chemical parameters

Slaughterhouse Waste type	**Parameters**			**Reference**
	pH	*TS*	*TKN*	
Bovine blood	8.0	8,24,672	12,414	Roy et al. (2013) [15]
Rumen Digesta	8.0	7,400	945	
Rumen Fluid	7.1	10,000	412	Zhang et al. (2016) [17]
Cow Blood	7.4	1,98,000	37,620	Alvarez and Liden (2008) [18]
Rumen Content	6.1	1,33,000	19,817	
Waste blood	Nd	1,96,000	31,700	Palatsi et al. (2011) [14]
Effluent	Nd	7,440	35,000	Garcia et al. (2016) [16]

Having an insight of the physical and chemical composition of slaughterhouse waste gives a better understanding of its nutritional potential and challenges to be faced during the handling and recycling of such organic waste on mass scale. Bovine blood and rumen content of slaughtered cattle have high water content and low fiber content that enhances the carbon-nitrogen (C/N) ratio [19]. Alternatively, the waste is of high nutritional potential as the waste blood has 17.3% protein, 0.07% carbohydrates, 0.23% fat and 0.62% minerals [19]. Abattoir generated effluent contains a substantially high amount of waste blood that is a rich source of high-quality protein (80-90% crude protein high on essential amino acids). Blood protein not only has functional properties but also works as a nutritive supplement [20]. Dehydrated blood-plasma contains 80% protein and 7.9% minerals and the cellular part contains the most of iron in the form of heme-Fe which is ten times higher as compared to the iron found in, meat [22, 23, 20]. Effluent discharged from these rural slaughterhouse abattoirs are rich in organic carbon, nitrogen, and phosphorus, when discharged untreated possess a great threat to land and soil agronomic ecosystem, risk of health hazards to humans and adversely affects water resources [24]. Similarly, such organic wastes from cattle abattoirs also contain various inorganic components like synthetic hormones, antibiotics, probiotics, polychlorinated phenols, and traces of several metals [25, 19]. Heavy metals like arsenic, cadmium, chromium, nickel, mercury, and lead traces were found to be constituents of slaughterhouse waste [26,9].

1.4 Difficulties and constraints during the handling and processing of slaughterhouse waste

Management of organic wastes that are both equally vast in quantity and complex in composition is challenging. There are quite a few difficulties that are to be kept in consideration during the processing and recycling organic waste. Segregation of abattoir waste, high moisture content of the organic mass, presence of highly infectious pathogens and removal of pollutants are the major challenges.

1.4.1 Abattoir waste segregation

Immediately after annihilation of cattle, high volume of waste fluids and waste blood is discharged. Similarly, 15% of the weight of a slaughtered animal is discarded as solid waste and 40-45% of it meets the demands of by-products. The type of waste generated from slaughterhouses varies from abattoir to abattoir. Therefore, segregation of waste based on its nutritional potential, conversion process and the by-product feasibility are a determining part of slaughterhouse waste processing. The slaughterhouses annihilating large animal produce waste consisting 56% of rumen content and 18% of inedible fats [27,28]. Screening of the inedible parts of slayed animal plays a vital role for valorization of waste. Segregation of animal fats, skin, bones and cartilages, waste-blood and rumen content serve as a valuable method of reserving feed stock or raw materials for by-product industries like soap manufacturing, leather tanneries, bone meal production. Waste to organic fertilizer conversion technologies and process are also benefited from such sorting arrangement available in abattoirs. Only 39% of a slayed animal is converted to edible flesh and meat, the distribution of inedible animal wastes and the by-products sectors they serve as raw material is briefed below in the Table 3.

Table 3: Distribution percentage of inedible parts of slaughtered animal weight and leading by-product sectors

Animal Waste Type	***Distribution***	***By-Product Sector***
Skin	4%	Leather Tanneries
Fats	7%	Wax, Soap, and adhesive industries
Bones & Cartilages	17%	Animal feed, bone-meal, medical purpose
Blood & Rumen Content	21%	Blood-meal, poultry feed, fertilizers

1.4.2 Excessive water retention of generated organic mass

High moisture content of the organic waste generated from these rural abattoirs is not a factor to neglect, rather to be addressed very cautiously. Such high-water content of the slaughterhouse waste makes it particularly sensitive towards enzymatic deterioration and microbial infestation. Despite high fats and protein content in rural abattoir wastes, that are appropriate choice of low-cost and rich in value source for the feedstock used in waste-to-value production chain, are commonly neglected due to its high moisture content [29]. The reason behind this selective exclusion is high-cost technologies like anaerobic digestion, bio-gas plants are to be introduced to handle such high moisture containing organic mass and the transportation of such water holding waste is very expensive [30, 31]. Few reports of moisture content values of different types of slaughterhouse waste have been summarized in Table 4

Table 4: Percentage of moisture content in different types of abattoir discharges

Type of Slaughterhouse Waste	***Moisture content***	***References***
Slaughterhouse hides	40-48 %	Jayathilakan et al. (2012) [32]
Pig Slaughterhouse waste	96.77 %	González-González et al. (2013) [33]
Hatchery waste	45-71%	Glatz et al. (2011) [34]

1.4.3 Presence of infectious pathogens

Organic mass discarded by slaughterhouses are rich protein source, so it is a proliferation ground for infectious pathogens and are easily susceptible to microbial contamination. As the abattoirs are ignorant towards animal screening, infectious diseases like H1N1 influenza, swine-influenza and Hepatitis E virus caused by zoonotic pathogens are highly probable to get transferred to the workers handling such slaughterhouse waste. A survey from a slaughterhouse reported that close to 16-19% of the workers on livestock farm were suffering from different vector-borne diseases like typhoid, malaria, tetanus. Along with these zoonotic diseases the workers were found to be suffering from respiratory and gastrointestinal diseases, skin infections and fever [35,6].

Slaughterhouse waste pathogens prominently found in waste blood and rumen content are *Staphylococcus*, *Bacillus*, *Brucella, Salmonella*, *Clostridium*, *Mycobacterium*, *Escherichia*, *Erysipelothrix*. *Salmonella* causes illness like typhoid and strains of *Escherichia coli* can not only infect, humans but also can lead to their untimely death. Presence of methicillin resistant *Staphylococcus aureus* (MRSA) has been reported to show coughing symptoms in the workers from slaughterhouses [36]. Therefore, a great caution must be kept in mind while handling such infectious organic waste from the abattoirs and it is essential to be very particular about removal of such pathogens before it's recycled use.

1.4.4 Occurrence of inorganic pollutant traces

Slaughterhouse generated wastes are most likely contaminated with organic pollutants that contributes to the elevated levels of COD and BOD values in discharged channels or grounds. In addition to these, traces of heavy metals like lead (Pb), chromium (Cr), nickel (Ni), arsenic (As), were found to be prominent in animal-derived wastes. Along with these heavy metals few inorganic pollutants like synthetic hormone, antibiotics are also existent in waste generated from the abattoirs. Presence of these pollutants not only makes the organic waste dangerous to handle and causes environmental toxicity, but also increases the expenses of waste processing. Proper treatment of such organic wastes is necessary to at least keep them within standard permissible limits before its application in any form.

1.5 Technologies adopted for slaughterhouse waste processing and recycling

Popularly known alternatives for processing slaughterhouse waste that are practiced worldwide are anaerobic digestion, alkaline and enzymatic hydrolysis, rendering, incineration, composting and drying treatments. Most of these methods are industrial processing that involves sophisticated infrastructure and complex technologies that requires high capital outlay for investment and operating cost.

1.5.1 Incineration

This is a very common and easy process of disposing slaughterhouse waste other than landfilling. As to follow EU Landfill Directive 1999/31/EC and restriction over landfilling of abattoir waste, more of these generated wastes are directed towards incineration [37]. In the process of incineration, the abattoir wastes are converted to inorganic ashes at above 850 °C temperature, industrial plants using this combustion process produces electricity and simultaneously removing harmful agents. Incineration is a convenient process to follow for processing organic waste, but on the contrary its feasibility in rural slaughterhouses is debatable. Rural abattoirs lack in basic facilities to install an incineration unit, rather the generated waste is burnt openly. Even during incineration to assure the removal of harmful pathogens like bovine spongiform encephalopathy (BSE) the process must be conducted at above 850° C for at least two seconds [38,39,6]. Gaseous emissions from incineration plants of abattoirs on waste combustion like, polycyclic aromatic hydrocarbon, dioxins and furans levels were found to be higher in atmosphere around. Additionally, increased contamination of metal was reported in flue gas and fly-ash produced as a result of incineration. Fly-ashes are further land-spread to enhance soil fertility, as a result it is causes potential damage to environment by increasing metal-toxicity in soil, surface, and ground water. Due to the mentioned limitations incineration is not an economically feasible and sustainable method to be adopted by rural slaughterhouses [40,10].

1.5.2 Anaerobic Digestion

Anaerobic digestion of slaughterhouse waste involves biological degradation of organic-mass under precise conditions to produce bio-gas and a by-product that have soil-amendment properties. This process involves four stages, hydrolysis, acidogenesis acetogenesis and methanogenesis and the conditions that are followed is either thermophilic (at 55° C for 12-14 days) or mesophilic (at 35° C for 15- 30 days). Among these two, thermophilic conditions were more effective in terms of methane yield than the mesophilic conditions [6,41]. Although anaerobic digestion involves four stages of processing but it still requires an exposure to 70° C for 60 minutes of pasteurization prior to the anaerobic treatment for complete inactivation of pathogens and an aerobic treatment after the process of digestion for reducing phytotoxic effects in the by-products [42,43]. Thermophilic treatment in anaerobic digestion is found to be more successful and faster in removing pathogens like enterovirus, parvovirus, and rotavirus including *Salmonella*, *Cryptosporidium* and *Giardia* than mesophilic digestion [44,27]. On the contrary few contaminants like transmissible spongiform encephalopathy were found to be still present after anaerobic treatment in both mesophilic and thermophilic conditions. Additionally, ammonia gets accumulated during the digestion process [45, 46].

1.5.3 Alkaline and enzymatic hydrolysis

Alkaline hydrolysis is a process where the hazardous waste mass is exposed to a temperature of 150° C for three hours at 180 kPa, sodium or potassium hydroxide are used to accelerate the hydrolysis. This method is relatively new in comparison with the traditional ways of recycling and has become a cleaner alternative for valorization due its complete pathogen inactivation and limited emissions of harmful gases [47,48]. The high-quality hydrolysate is the product of alkaline hydrolysis which is either used as animal feed or fertilizer. As slaughterhouse wastes are rich source of proteins and fats, hydrolysis conducted under specific conditions are proficient in 90% protein recovery. Although alkaline hydrolysis is proved to be an efficient process for pathogen inactivation, prion removal and even eradication of thermophilic bacteria like *Geobacillus stearothermophilus* but, simultaneously highly-alkaline effluent is discharged as wastewater which is a hindrance in its further treatment before releasing it to the environment [48,49]. Alternatively, when hydrolysis of the crude mass involves use of typical enzymes under certain pH levels at 50° C for 135 minutes, the process simply becomes enzymatic hydrolysis. The idea of using enzymes in hydrolysis was first patented by Eckmayer et al. (1980) [50]. Papain (at pH 5.5), alcalase (at pH 8.5) and pepsin (at pH 3.0) are few such enzymes which were used for protein recovery [51]. In the following years there are many other reports of protein recovery from cattle blood and their stomach content using different enzymes at specific pH levels during hydrolysis, the recovery percentage of proteins were 34% from abattoir blood and 75% from sheep stomach content using enzymes, papain (pH 7.5) and fungal proteases (pH 7.1) respectively [52, 53]. Despite showing remarkable protein recovery and industrial applications, enzymatic hydrolysis is not preferable choice, mainly for its ineffectiveness on pathogens. Additionally, hydrolysis using enzymes demands certain pH range, specificity, and their long time of processing and with that, implementation of a complex valorization technique like this is not cost feasible for small-scale slaughtering units.

1.5.4 Rendering

Another popular abattoir waste recycling technique is rendering. The method follows heating of animal wastes and converting them to stable and usable materials. Waste animal tissues, fats, bone, offal and even carcasses are heated at 133°C for 20 minutes under pressure of 300 kPa according to EU Directive 1990/667/EC for complete pathogen removal. In this process the bone, protein residues and water are separated from fats that are further purified for the production of lards, tallow, meat meal, bone meal and many other by products [54, 55]. It supplies low-value products like protein for animal-feed production and fats for bio-diesel, grease, soap, and candle factories. Melted fats were found to be an effective raw material for steel rolling industries and rendered meals may be applied as organic fertilizers [37,6]. Rendering is an effective way of recycling slaughterhouse waste to usable materials but, the recontamination of final products with transmissible spongiform encephalopathy and *Salmonella* infections needs further processing. To avoid the problem of recontamination an efficient filtering and few steps of bio-chemical treatment is needed and cold-water treatment removes almost 90% of the odor. Although the environmental concerns like high COD effluent, gas emission are addressed in rendering after multi-step processing, there remains an undesirable issue of biosecurity due to re-survival of pathogens [4].

1.5.5 Composting

Along with anaerobic digestion, composting is another technique of slaughterhouse waste conversion that is used widely. It is a cost-effective and sustainable alternative for abattoir waste recycling process that undergoes four consecutive phases, starting with mesophilic, thermophilic, cooling and maturation respectively. For composting hazardous and organic waste from slaughterhouses mainly two types of processing are followed. One is in-vessel composting and the other is windrow composting (NABC, 2004) [56]. The thermophilic phase is observed to be the most effective stage for pathogen inactivation, the pH levels greater than 8.0 was also a contributing factor during composting [57, 10]. Though composting is appreciated for its land application properties that proves to be a productivity enhancer and a beneficial soil conditioner, the temperature of composting is not adequate for complete sterilization. Soil beneath the composting ground is susceptible to leachate contamination during rainy days in small-scale composting and windrow composting demands larger space, emits higher levels of greenhouse gases (GHGs) in atmosphere and the efficiency of the process is low. Although, due to inexpensiveness of this process it is more acceptable solution for the rural slaughterhouse waste management in developing countries [58, 59].

1.5.6 Drying treatment of slaughterhouse waste

Other than using complex technologies and use of chemicals and enzymes for slaughterhouse waste processing, drying treatment is one of the economically sustainable methods. Thermal treatment of organic waste has been an effective recycling method ensuring the nutritional potential and simultaneously ensures moisture content reduction along with pathogen removal. Freeze drying, microwave drying and vacuum drying are few of the drying treatments that have reported to be used for recycling waste blood but, for the fact that these drying techniques demand huge energy consumption these are not so cost beneficial for poorly facilitated rural abattoirs [60]. Drying of slaughterhouse generated bovine blood and ruminal contents was first adopted in a rural slaughterhouse of India. Mixture of bovine blood and rumen digesta were cook-dried on domestic-scale for 90 minutes followed by sun drying for 3 days, the final product, ‘bovine-blood-rumen-digesta-mixture’ (BBRDM) is used as organic fertilizer by local farmers. Recently tray drying was also used to obtain BBRDM by exposing the abattoir waste to the temperature of 100-120°C for 6-8 hours [61, 15]. This cook drying and tray drying were also found to be very successful in eliminating pathogens and recorded higher productivity in cultivation followed by showing remarkable residual fertility. This recycling technique is an economically feasible solution to prevent the rural abattoirs from openly dumping their waste untreated and polluting the environment. In process of dumping of rumen content and waste blood, a nutritionally valuable feedstock is lost and eventually a loss of economy. On other hand using the drying technology may promote a sustainable circular-economy for rural slaughterhouse owners and farmers. Following

Table 5 summarizes different methods of recycling slaughterhouse wastes, their operating temperature and their final produce.

Table 5: Temperature ranges and the by-products of different waste processing technologies

Recycling Process	***Operating Temperature***	***Final Produce***
Incineration	850°C	Fly Ash
Anaerobic Digestion	Thermophilic (55° C) Mesophilic (35° C)	Bio-Gas Manure
Hydrolysis	Alkaline (150° C) Enzymatic (50° C)	Animal feed Protein & Fats
Rendering	133° C	Low-value fats
Composting	-	Fertilizer
Drying	90-120° C	Fertilizer

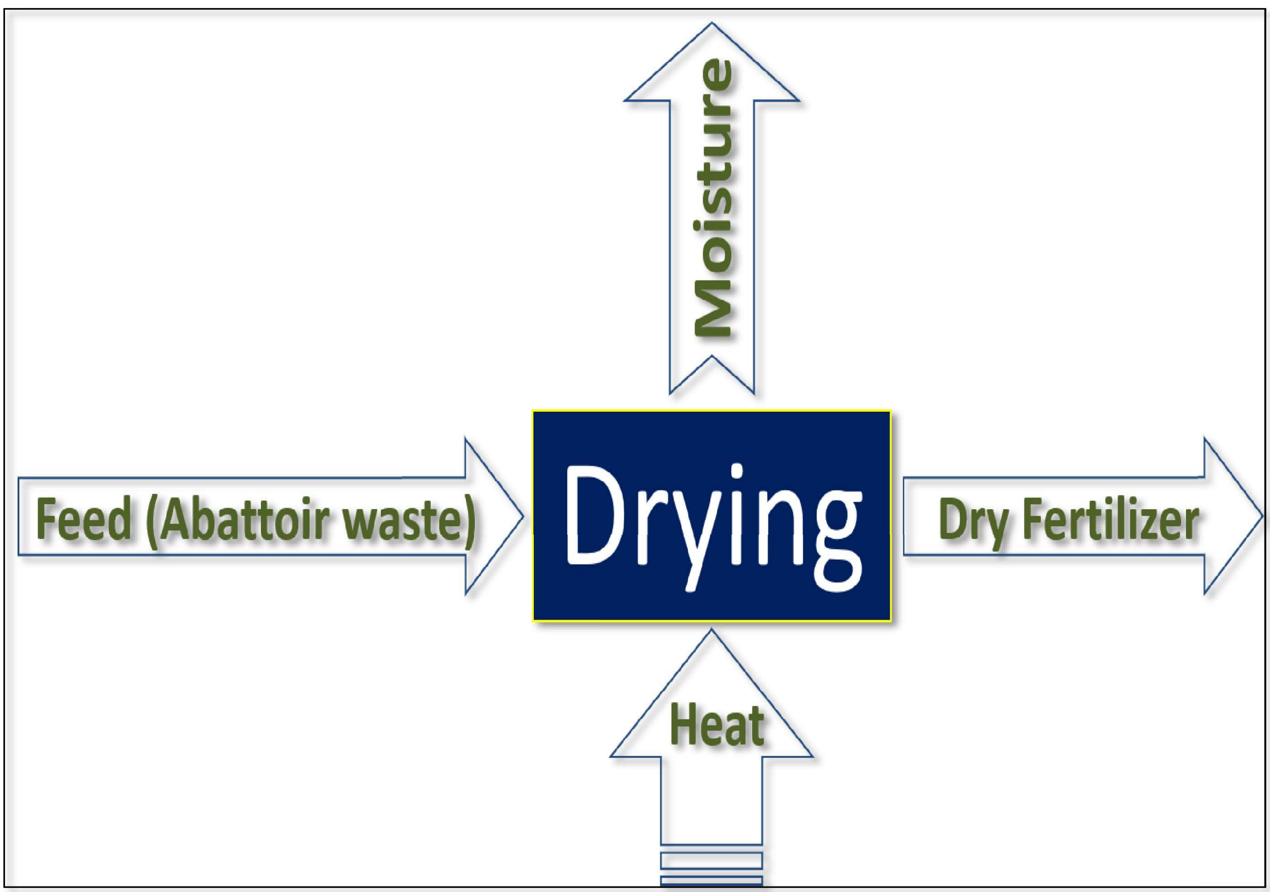


Figure 3: Migration of moisture from the interior of a material to its surface (Drying principle)

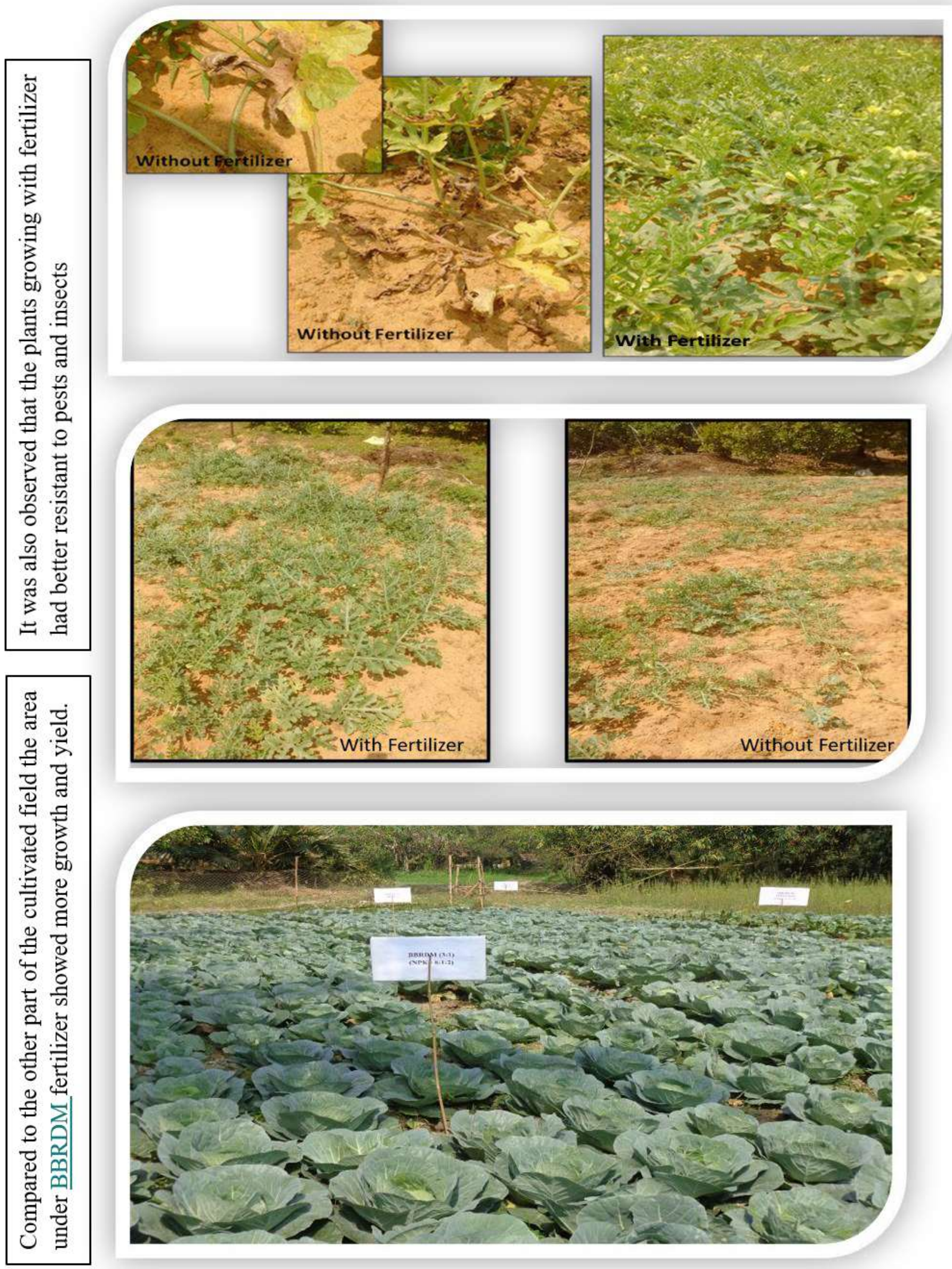


Figure 4: Visual feedback from field on application of fertilizer, recycled from slaughterhouse waste

1.6 Slaughterhouse waste converted organic fertilizer

Animal waste to fertilizer conversion encourages use of organic fertilizer, which is potentially attractive for small farmers around the rural slaughterhouses who are competing with rapidly increasing demand for organic farm produce. Additionally, there is a valid possibility of higher returns for both the slaughterhouse owners and farmers. A sustainable circular economy may be developed from this abattoir waste to organic fertilizer conversion strategy. Anaerobic digestion, composting, vermicomposting, pyrolysis and drying are the few alternative treatments that are used for fertilizer production.

1.6.1 Fertilizer efficiency of recycled abattoir wastes

Composting in its stage of maturation produces a humus like product rich in nutrients that are comparable with commercial inorganic fertilizers as it improves soil properties, acceptable agronomically and ecofriendly [62, 63]. Composted poultry litter mixed with wastewater contaminated with cattle blood contains NPK of 1%, 2.5% and 0.2% respectively. 18.5% organic carbon is found in cattle manure compost, carbon-nitrogen ratio (C/N) less than 20 acts as a soil conditioner that maintains the agro-ecosystem health [5].

Vermicomposting is basically composting, it's only a biotechnological approach of composting using earth-worms to convert the organic waste into nutrient rich fertilizer. At maturation phase of vermicomposting the compost mass turns dark-brown and final moisture content within the range of 25-30%. This peat-like material is used for land application and is rich in essential micronutrients, beneficial microbes like N_2-fixing bacteria for soil replenishing and conditioning. Vermicomposting is a process which produces an organic fertilizer rich in NPK, the plant available nutrients are in its soluble form for their easy uptake. Additionally, the process reduces total and bioavailable heavy metals. Fertilizer produced at the end of vermicomposting of cow waste showed NPK percentage of 2.8% 1% and 0.9%, greater mineral composition was also reported [64]. Though the lack of thermal phase during the composting process raises digestate. End produce of anaerobic digestion of organic waste from slaughterhouses are highly rich in plant available nitrogen (NH_4^+) content with 51-61% of mineral nitrogen that makes it an excellent fertilizer option [65]. The risks of phosphorous run-off from the fertilizer are canceled out while using digestate as fertilizer because during anaerobic digestion fractions of labile phosphorous are reduced. Vegetables are usually nitrogen demanding crops, digestate used as fertilizer supplies need of nitrogen appreciably in addition, the process is effective in pathogen inactivation during its 30 minutes' period of thermophilic digestion [44].

Bio char obtained after pyrolysis of animal waste are said to report 3.3% of organic carbon and 0.1% nitrogen. Presence of recalcitrant carbon in bio char reduces the chances of microbial attack on soil. Risks of leaching phosphorous in the soil is restricted when bio char is used as soil amendments and affects soil health positively. Slaughterhouse waste converted to organic fertilizer has greater nutrition potential than commercial inorganic fertilizers. Application of animal-derived organic fertilizer has shown higher crop productivity, better agro-ecosystem quality and lastly the cost effectiveness of the production. Therefore, using such organic fertilizer for vegetable crop cultivation is growing mostly in rural areas as it is also serving a sustainable economy at local level.

Chapter 2:

Aim & Purposes

2. Aim and purpose

Sole aim and objective of this research work was to find and implement a practical solution for the rural slaughterhouses of developing countries, lacking in basic infrastructural amenities and incapable of capital investment on sophisticated and complex technological units for waste processing. Such shortcomings of these abattoirs are leading to environmental exploitation by its current ways of disposing, which is both a public health and environmental concern.

Along with implication of an economically acceptable process and technology, this research work is also oriented towards achieving a sustainable circular economy adopting the concept of waste valorization.

2.1 Problem Identification

As discussed in previous chapter a remarkable work has been done using slaughterhouse wastes, majorly the most unwanted and untreated discharge, bovine blood, and rumen digesta. Converting the abattoir generated waste into an organic fertilizer is a benchmark for the solid waste management as these reported informal rural slaughterhouses were contributing a greater concern to human health and pollution to the environment. There have been many processes and technologies that are being developed and adapted for animal derived waste-to-fertilizer conversion. Environmental hazards related to abattoir's open dumping of waste can be eliminated by the process of either tray drying or cook drying in result producing an organic fertilizer (BBRDM) As previous works of Roy et al. [27] and Bhunia et al. [61] have reported BBRDM converted from slaughterhouse waste, to be a potential organic fertilizer when mixture of bovine blood and rumen digesta in the ratio of 3:1 is dried at 90-130°C. The fertilizer (BBRDM) is being counted upon by local farmers as it is observed and confirmed scientifically to be showing higher growth and yield of vegetable crops compared to the conventional fertilizers. As blood and rumen contents are the major abattoir wastes and it is reported that on an average 20 buffaloes are slaughtered everyday generating around 400 liters of cattle blood and 400 kg of rumen content. Disposal of this vast amounts of animal wastes is a challenging problem to rural slaughterhouses, using industrial processing of blood & rumen waste requires high capital outlay as their processing involves high investment and operating costs. On the other hand, cook-drying and tray drying have few setbacks concerning time of processing and the moisture content of the final produce.

Therefore, the evolution of an acceptable processing technology and equipment is as important as it is necessary for valorization of abattoir waste to its true potential and developing a sustainable economy at rural level.

2.2 Objectives of the study

There is an immediate need of scaling up the current domestic-scale cook drying process to an economically feasible commercial-scale processing technology, to address the challenges of handling and disposal huge amount of waste and simultaneously a practical application of waste valorization to develop a sustainable economy where the rural slaughterhouse owners can install a manufacturing unit for producing organic fertilizer from slaughterhouse discarded waste.

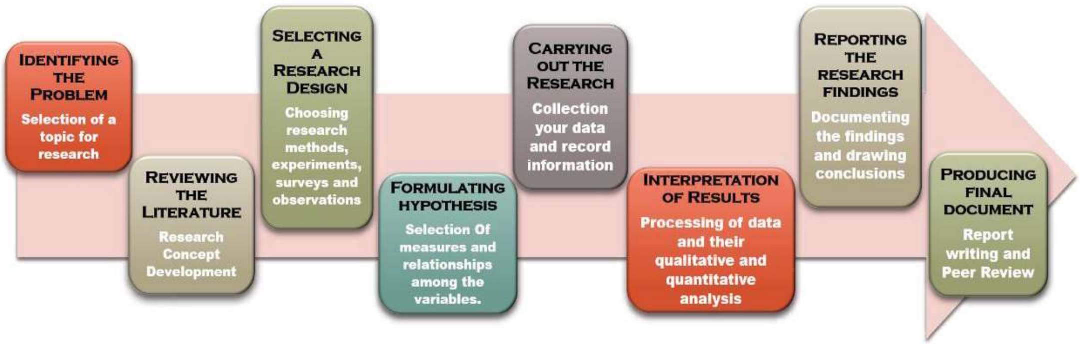
Two objectives:

- To develop a low-cost recycling method for the welfare of both the slaughterhouse owners and environmental safety.
- To design an equipment for enhancing the production system and commercialize the product for market interest and a profitable commodity in favor of the slaughterhouse owners and farmers.

2.3 Research Design

In order to develop a novel manufacturing unit, it is essential and beneficial to have an organized research planning for a positive flow and progression of the research work. A flexible research design which provides opportunity for considering many different aspects of a problem is considered appropriate if the purpose of the research study is to be achieved. The preparation of such a design facilitates research to be as efficient as possible in yielding maximal information.

The following figure is a schematic representation of the research design that has been followed during the research work.



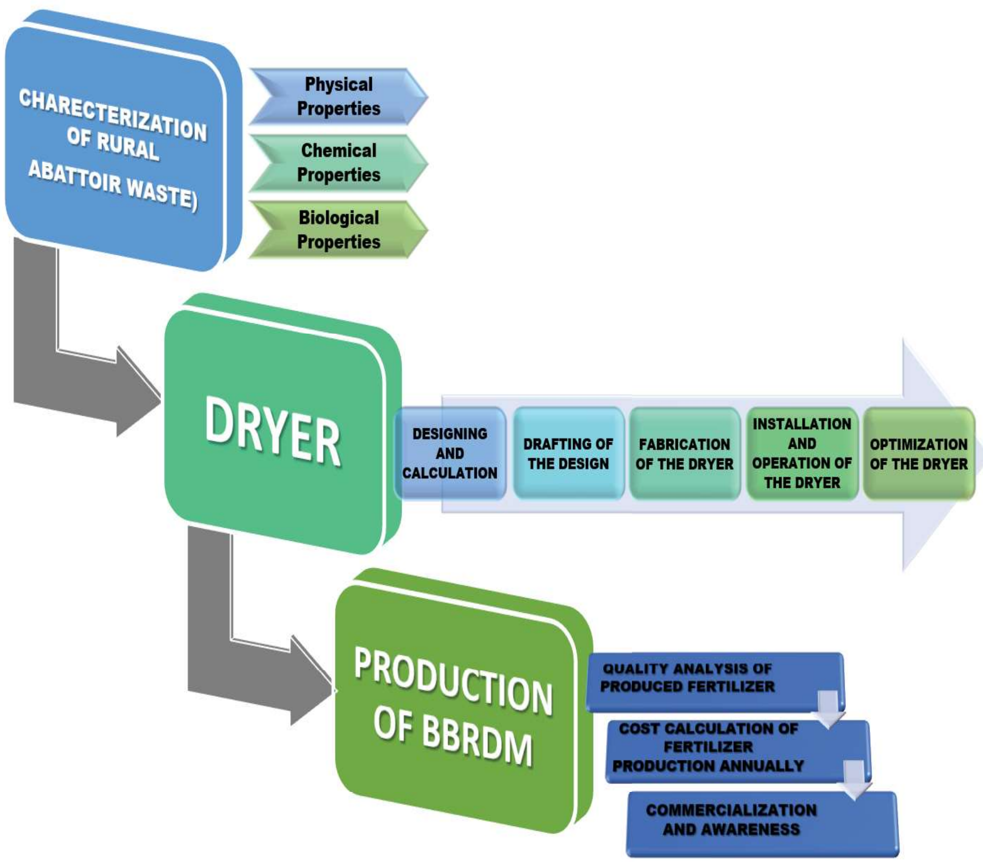


Figure 5: Research design for developing a novel dryer and its application for developing a sustainable economy

Chapter 3:

Theoretical & Experimental Considerations

3. Theoretical and Experimental considerations

Slaughterhouse wastes can be converted to beneficial products using different methods, which can easily interest the rural slaughterhouse owners to invest on those recycling technologies which on implementation will not only dispose the generated waste properly according to the environmental norms but also provide economic benefits in return.

3.1 Beneficial conversion method

As discussed in introduction section there are various methods by which slaughterhouse waste can be converted to a product of market value. Among the by-products recycled from abattoir waste, organic fertilizers are found to be quite popular among local famers surrounding these rural slaughterhouses. Organic fertilizers produced within the slaughterhouses are easily available to these farmers on cheaper rates as compared to the market price of existing fertilizers. Amid the conversion methods like anaerobic digestion, hydrolysis, rendering, incineration which demands proper infrastructure, water supply, electricity, complex processes, and a huge capital investment, composting and drying are found to be most practical and economical for implication to the rural slaughterhouses. Composting have quite a few advantages like low cost, easy to implement involves no critical process, over complex processes of recycling. On the contrary there are few downsides of composting that may lead to its rejection in rural slaughterhouses. Implementation of composting as recycling process for slaughterhouses have drawbacks like it requires a considerable amount of space, produces odor along with harmful gases and more importantly it is time consuming. This leaves us to the process of drying for efficiently recycling the abattoir wastes into profitable entity for the welfare of both rural abattoir owners and farmers.

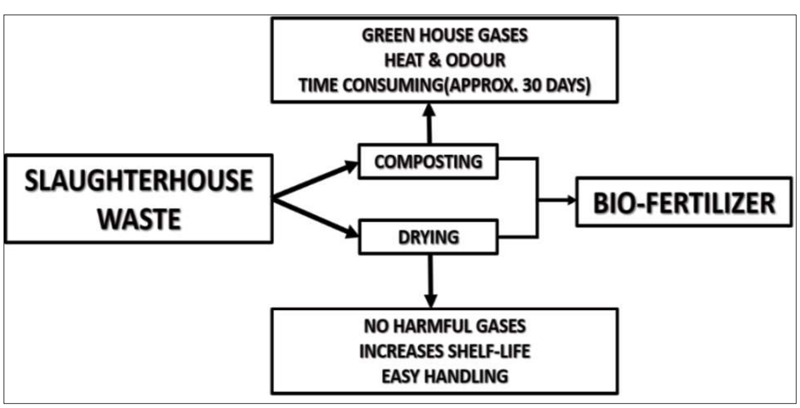


Figure 6: Importance of drying treatment over composting of abattoir waste

3.2 *Drying treatment of slaughterhouse generated waste vis-à-vis composting*

Practicing drying technology as a recycling process of hazardous slaughterhouse waste is either converted to animal feed or organic soil conditioner. Drying treatment has been very popular in the fertilizer production for many years and is still in demand for mass scale production efficiency. This popularity is due to its moisture removal competence. Drying operation is an important step among all the processing as this treatment is one of the efficient techniques when it comes to moisture removal. This step alone can enhance few qualities of the final product, moisture levels after drying further prevents moisture-mediated deteriorative biochemical reactions, that leads to shelf-life prolongation of the final product. In industrial processing of organic waste, the unit process of drying plays a major part, dryers that are most commonly preferred in the process, like drum, flash and spray dryers not only requires heavy equipment but, also demands a centralized slaughtering and collecting system for generated waste [66]. As the other complex dryers require heavy machinery, they are not feasible in developing countries where slaughterhouses operate in scattered units. There is an urgent need of a portable and simple drying equipment that is easy to install in scarcely facilitated rural abattoirs for recycling the generated waste.

3.3 *Drying procedures, previously involved in BBRDM production*

BBRDM production methods, that were adopted previously are: tray drying, cook drying and sun drying. Sun drying process of cattle blood and rumen content mixture first involves 90 minutes of boiling and then followed by exposure to solar radiation over the boiled waste mass that was spread over 100 sq. ft. (9.3 m^2) area for three successive days. Similarly, in cook-drying the mixture of rumen digesta and cattle blood was boiled in a metallic container for 5-6 hours over a wooden fired oven. Lastly, tray drying of the mentioned mixture was done in a ten-tray modelled dryer, the mixture was spread over the trays evenly, surface area of each tray was 0.768 m^2 and drying was carried out for 9-10 hours [15, 61]. For production improvement and economic feasibility of the recycling process, the evaluation of total consumption of energy, production time and final moisture content of the product are few major parameters that are to be kept in considerations.

Figure 7: Previously used methods for preparation of Bovine Blood Rumen Digesta Mixture (BBRDM). (a) Cook Drying, (b) Sun Drying and (c) Tray Drying

3.4 Drawbacks in existing methods adapted for production of BBRDM

Conventionally, bovine blood and rumen digesta were mixed and then dried through cooking in this process there are few setbacks, (a) It takes 5-6 hours of constant hand-stirring, (b) Wood burning as fuel for a stretch of 4-5 hours for production of BBRDM, (c) the process is laborious and time consuming, (d) can handle and process only a small quantity of generated waste. The mentioned process was then converted to sun-drying process followed by initial cook-drying. During sun-drying process in the production of BBRDM few inevitable challenges were observed,

(a) depending on sun-drying is very risky during bad weather conditions, (b) time required for drying is more as compared to other methods, (c) unhygienic way of drying organic waste as the mixture mass is infested by flies, insects and rodents, (d) contaminated by dirt, dust as well as regrowth of bacteria, results poor quality product output. Lastly, the recent adaption of tray drying technique by Bhunia et al. [67] in addition to the initial drying by conventional method of cook-drying was reported. Output from tray-drying process was remarkably of better quality than the produce from previous methods. Although, tray drying process also have few shortcomings, notable among them are, (a) initial water removal, substantially making the mixture mass free of water so that it can be fed to the tray dryer, (b) only a fraction of the solid particles is directly exposed to heat causing uneven drying of the mass in trays, (c) not suitable for handling the amount of waste blood and rumen content generated from a rural abattoir every day, and (d) it is time consuming and intensive labor is associated with loading and unloading of the trays time to time, (e) lastly, the huge energy requirement in the form of electricity, and is very often hindered in these sparsely equipped rural abattoirs. The observed shortcomings lead to a conclusion that a drying technique that has shorter drying time, lower requirement of energy and also capable of producing good quality product having longer shelf-life will be an efficient development for a sustainable recycling of slaughterhouse generated waste.

Chapter 4:

Experimental Design for Dryer Fabrication & Performance Evaluation

4. Experimental design for dryer fabrication and performance evaluation

As previously discussed, there is an immediate need for technical evolution in recycling process of abattoir waste leading to BBRDM production. Few important technicalities like, the amount of waste-mass that could be processed on everyday basis utilizing the equipment's maximum capacity is proportional to the amount of waste generated daily and the quality of the output product were kept under active consideration. For the performance evaluation of previously used BBRDM production methods and of the fabricated dryer few physical and chemical parameters were tested and few drying curves were plotted for better interpretation and understanding.

4.1 Parameters measured for dryer fabrication

Fabricating the recycling unit is a crucial part of the research work and the essential fragment of the construction was the vessel in which the waste-mass is to be processed. The size of the vessel was calculated on the basis of physical parameters of generated waste, (a) amount of waste generated: On daily basis from one rural abattoir in mass (b) moisture content: Until constant value of mass was obtained, the sample was kept in a hot air oven running at 105 ° C for convective drying, to determine the moisture content on wet as well as dry basis., (c) Bulk density of cattle blood and rumen content: Following the active standards of ASTM D7263 [68], (d) minimum and maximum operating volume of the vessel: Calculated based on vessel diameter and height up to which it was filled during each cycle of production. Mixing spindle used in the recycling unit was designed on the basis of density of the mixing mass and for fulfilling the purpose of uniform mixing along with equal distribution of heat during the whole during process. The energy source for the operation of the recycling unit is kept hybrid for convenient use of available fuel and other facilities accordingly.

4.2 Evaluation of parameters before and after processing of abattoir waste

The abattoir generated wastes are usually discharged untreated in the rural areas as discussed earlier. Parameters evaluated before processing of the waste were much higher than the permissible limits as prescribed in the environmental standards issued by the Government of India under the Ministry of Environment, Forest and Climate Change and the Environmental Protection Act (of

India), 1986 & Rules 1986 : (a) pH was determined following electrometry using pH meter of glass combination electrode saturated in potassium chloride (KCl), (b) Total Solids (TS) was calculated by sample evaporation in a heat resistant dish, weight of the dish without the sample was predetermined. Evaporation was conducted in an oven at 105 °C for one hour followed by cooling down in desiccator and recording the before and after weights, (c) Total Suspended Solids (TSS) of the waste was measured by filtering a well-mixed diluted sample through the glass-fibre filter, the filtrate was then collected in a pre-weighed dish followed by evaporation at 105 °C for one hour in an oven, the weights were recorded, (d) Biological oxygen demand (BOD_5) is a vital parameter in waste characterization. It is the ability of naturally occurring microorganisms to digest organic matter expressed in mg of oxygen in one litre. Well mixed sample was added to BOD bottles following proper sealing of the bottle caps and they were kept in the incubator for five days at a temperature of 20 ° C. Dissolved oxygen (DO) was measured before and after incubation for calculating the BOD, (e) Chemical Oxygen Demand (COD) is an independent measurement of organic matter and toxic strength of waste using dichromate reflux followed by titration using ferrous ammonium sulphate, (f) Oil and grease concentration was determined using organic solvent which forms an emulsion having two separate aqueous and organic layers which is then distilled in separating funnel and following evaporation technique of measuring residue weight.

Factors dominating the qualities of end product as an organic fertilizer were precisely and quantitatively measured for each batch of production, (a) Moisture content, of the final product was measured for each of the BBRDM production methods, by drying a sample mass in an oven at 105° C until constant mass was reached (b) Nitrogen content, a decisive factor for comparing the fertilizer potential of the final produce was determined using Kjeldahl method, (c) Size of the particles of end product was determined using experimental grade sieving meshes of different size, and (e) pathogen inactivation extent was observed through traditional plating and incubation techniques and absence was confirmed through 16S rRNA metagenomic analysis. Extent of methane emission from the open waste dumping sites of slaughterhouse and the soil amended with BBRDM, an organic fertilizer converted from the same slaughterhouse waste was also one of the parameters that was measured. Air-soil methane flux was quantified using gas chromatography [61].

4.3 *Performance evaluation of the fabricated recycling unit*

The fabricated waste processing unit was operated for converting slaughterhouse waste into an organic fertilizer, the unit was made modest for easy operation in low facilitated abattoirs. The process involved here is drying, simple water removal from mixture mass leaving behind the dried material. The factors those were determined in order to evaluate the performance of new drying unit: (i) Consumption of energy was estimated in terms of drying time and energy utilized, (ii) Energy utilized for water removal was calculated on the basis of calorific value of fuel used for processing, (iii) Specific energy consumption was calculated on the basis of energy consumed in mega joules to remove one kilogram of water (MJ kg^{-1} of water). Two other parameters that were determined were calculated according to the following formulas [69]:

(a) Specific moisture extraction rate (SMER):

$$SMER = \frac{Amount\ of\ water\ evaporated\ from\ the\ product}{Total\ energy\ input\ for\ the\ drying} \quad (1)$$

(b) Moisture extraction rate (MER):

$$MER = \frac{Amount\ of\ water\ evaporated\ from\ the\ product}{Total\ drying\ time} \quad (2)$$

4.4 *Experimental Drying Curves during the waste conversion process*

A relation between drying temperature, drying time and drying rate was derived following differential and integral calculus. The drying time was observed on the condition of constant drying rate period. The rate of drying (N) or drying rate is a function of temperature, flow rate and transfer property that can be represented in terms of change in moisture content (X), difference between final and initial moisture content with time, it is expressed as follows [70]:

$$N = -\frac{W_S}{A} \cdot \frac{dX}{dt} \quad (3)$$

In the above-mentioned equation N represents drying rate, dried solid mass is denoted by W_s, drying surface area is symbolized by A and the % moisture content is X. There are various ways by which the drying curves for a drying process or equipment can be represented. Few inter-related curves are mentioned in literature which represents the evaluation of a drying process and will provide characteristic drying curves. These curves were plotted in this research work for assessment: (1) drying curve – a plot between moisture content(%wet basis) and time, (2) drying rate curve – It is a curve that is plotted for calculated drying rate and time, the rate can be calculated by derived formula using experimental drying time, (3) Krischer curve – This curve is independent of time which is plotted between the rate of drying and moisture content (% wet basis) and (4) Lastly, The curve of moisture removal plotted against drying time.

4.5 Comparative performance evaluation of BBRDM production processes

As already discussed in details, the processes used for BBRDM production previously and the process presently being used are most feasible for rural slaughterhouse waste conversion to a value-based product. The processes are compared and evaluated on the basis of: (i) Energy consumption (MJ/ batch) : that is the energy consumed by each process during whole production time of one batch, (ii) Fuel consumption: different processes use different types of fuel for operating to remove water from waste-mass, their cost inevitably effects the cost of production, (iii) Drying time: The time required for recycling the waste mass into a dried product, (iv) Final moisture content : The water content in the final product is an important parameter used to rate the quality of produce. Lastly, the nitrogen content determined using Kjeldahl method, of final produce indicates its quality and potential as an organic fertilizer and its ability to compete with market available fertilizer. Simultaneously, the extent of pathogen inactivation is an important property that is to be checked in a final produce of organic waste conversion.

4.6 Development of an economically sustainable waste management system

The transition from previously used methods for conversion of rural abattoir waste, to an innovative technology and equipment driven production, not only addresses the problem of improper and unhygienic approach of discarding slaughterhouse waste but, also meets societal demand for a technological and economically feasible solution for such organic waste-disposal. To develop a sustainable economy from generated rural abattoir waste, it is essential to assess the supply sector readiness and the demand for waste converted fertilizer in the surrounding areas where abattoir owners install the recycling unit for waste processing. A business model is developed for the rural slaughterhouse owners, who otherwise are reluctant in investing towards any scientific waste disposal technique or process by installing the fabricated dryer as an abattoir waste recycling as well as organic fertilizer (BBRDM) manufacturing unit. Overall, through installing this unit in the rural abattoirs, will generate a secondary source of income besides the benefits of being a part of meat producing industry. Additionally, this low-cost manufacturing of a potential organic fertilizer paybacks to local farmers who can now avail the fertilizer at reasonable price against highly expensive and trending market available organic fertilizers. This valorisation of waste not only promotes a sustainable economy but also meets Sustainable Development Goal (SDG) 12 which is ‘Sustainable production and consumption’. A survey was conducted for understanding the demand and supply readiness of the produced fertilizer around these rural abattoirs, specifically the slaughterhouses of Magrahat II block, South 24 Parganas of West Bengal, India where the fabricated recycling unit was installed.

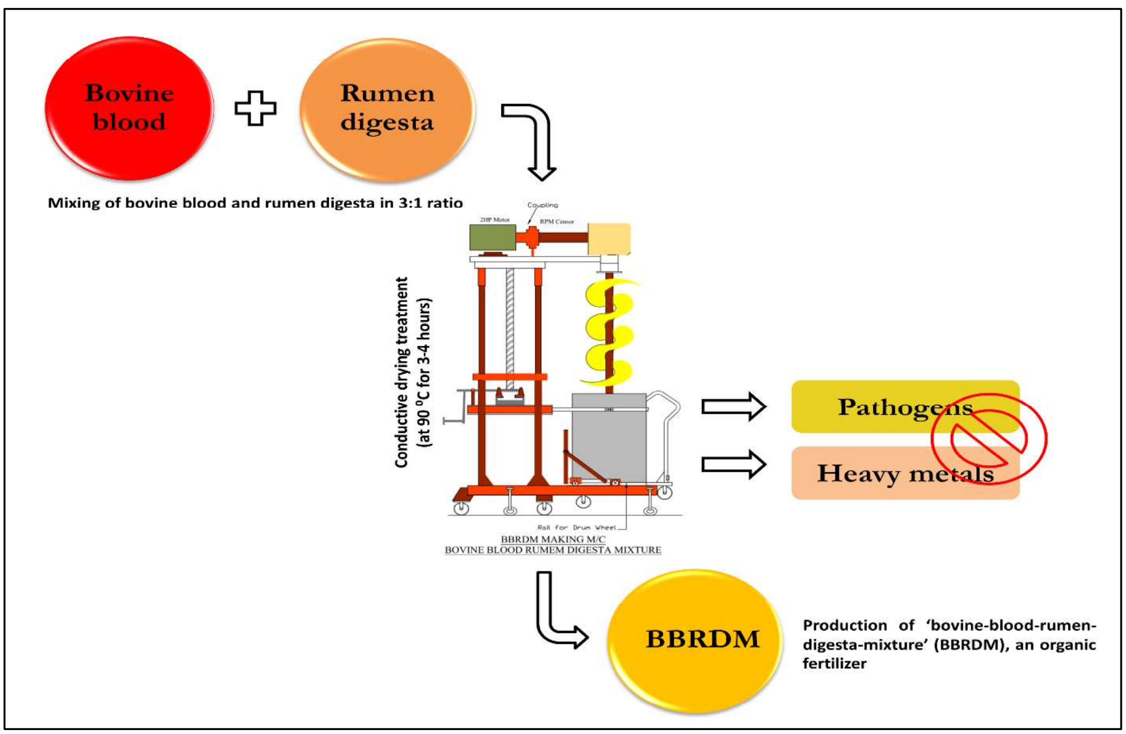


Figure 8: Conversion of major slaughterhouse waste (bovine blood and rumen content) into an environmental-friendly and low-cost fertilizer

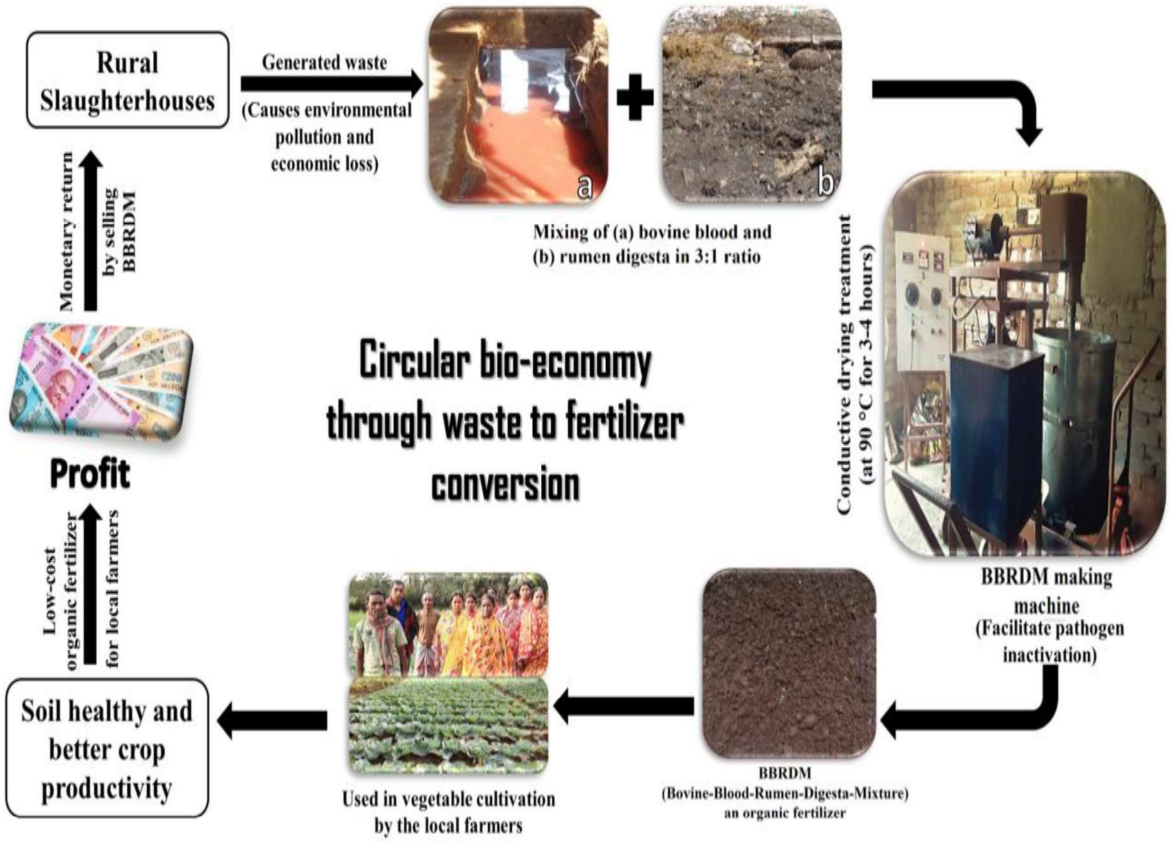


Figure 9: Valorization of abattoir waste leading to an economically acceptable alternative for rural slaughterhouses and development of a circular bio-economy.

Chapter 5:

Experimental Results, Interpretations & Discussion

5. Experimental results, interpretations and Discussion

Execution of the experiments according to the pre-planned design as discussed in the previous chapter gave an enormous amount of remarkably significant indication towards the slaughterhouse waste recycling as well as the concept of waste valorization implemented a circular economy alongside sustainable development of society and environment. The scientific experiments based on which the present recycling unit is fabricated were conducted for a rural slaughterhouse located in Magrahat II block, South 24 Parganas of West Bengal, India

5.1 Quantification and Characterization of slaughterhouse generated waste

20 buffaloes are slaughtered every day in a single abattoir on an average basis. One buffalo leaves approximately twenty kilograms of rumen content and twenty liters of blood as waste, that does not turn out of any use in terms of primary profit. Consequently, the abattoir generates nearly about 400 kg of rumen content and 400 l of bovine blood as waste. Considering the amount of waste generated the recycling vessel was constructed of 0.61 m diameter and 0.71 m height so that it is able to handle at least close to 250 kg mass load in one run. The full vessel volume is 0.212 m^3 (volume = π radius^2 × height) as the bulk density of bovine blood and rumen content was measured to be 1142 ± 7 kg m^{-3}, therefore the maximum load that the vessel can hold is 242.104 kg. The mixing spindle, is the part of fabrication that goes into the vessel for even mixing and is designed in a shape of helical ribbon having three helical turns, it requires 1/4th part of the total vessel volume as head-clearance for smooth and efficient running. Therefore, the total waste mass mix that can be processed in one run would be approximately 180 kg. Considering the equipment to be new and yet to be fully optimized the equipment was operated at its minimum load capacity that is 50% of total, 90kg. The operating load can be easily escalated according to the demand for processing and production. The bulk densities of the waste that has been used as raw material for processing in the drying vessel is listed below in form of a table in Table 6.

Table 6: Bulk densities of the waste material before processing.

Waste Type	*Bulk Density*
Bovine Blood (BB)	1160 ± 2 kg m^{-3}
Rumen Content (RC)	923 ± 3 kg m^{-3}
3:1 Mixture of BB & RC	1142 ± 7 kg m^{-3}

Further few parameters were determined for characterization of slaughterhouse generated waste before processing and was also compared with the permissible limits issued by the Ministry of Environment, Forest and Climate Change, Government of India, The Environmental Protection Act (of India), 1986 and Rules 1986 for slaughterhouse generated effluent. The results are presented in tabular form in Table 7

Table 7: Physico-Chemical properties of abattoir generated waste effluent

Waste Parameters	***Permissible Limits***	***Waste Type***	
		Bovine Blood	*Rumen Content*
pH	*5.5-9.0*	*8.1*	*8.0*
Total Solid (TS) mg L^{-1}	-	*821,517*	*57,220*
Total Suspended Solid (TS) mg L^{-1}	*100*	*409.737*	*44,072*
Biological oxygen demand (BOD_5) mg L^{-1}	*30*	*66,011*	*140*
Chemical oxygen demand (COD) mg L^{-1}	*250*	*270,403*	*35,997*
Oil and Grease Concentration mg L^{-1}	*10-20*	*25*	*7,6992*

In conclusion of the above table, the parameters are much higher than the permissible limits as of EPA, 1986. Along with the mentioned parameters other factors were determined to study the nature of waste more specifically, amount of water contained in the waste and the flux of methane emission from the dumping site. The moisture content of the bovine blood and rumen digesta mixture on dry basis was recorded as 583%. This value of moisture content on dry basis simply indicates that the amount of water is almost 5.8 times more than that of solids in the waste mass. Wet basis moisture content, which is been used for other calculations and plotting the different drying curves was determined to be 85 %. The methane emission in terms of air soil flux from the dumping site of the slaughterhouse where bovine blood and rumen content are discarded openly without any treatment was recorded to be between 13.13 to 28.55 µg g^{-1} h^{-1} [61]

5.2 Process description of abattoir waste conversion in presented recycling unit

Cattles were annihilated, the blood and contents of its rumen were collected separately and immediately. These two typically major rural abattoir wastes were then added to the recycling vessel in a proportion where the mixture was 3 parts bovine blood and 1-part rumen content measured by weight. Specifically, during preliminary runs for optimization and evaluation approximately 20kg of rumen content and 60kg of bovine blood was fed for all the batches under observation. The vessel carrying the mixture mass was further proceeded towards drying operation. The vessel was heated at 90-110 °C temperature until the dried product attained the required final moisture content. As from literature it was concluded that final product having less than 20 % moisture content are accepted for their increased shelf-life. The removal of volatile substance (mainly moisture) from the waste mass to get dried solid product is the fundamental principle of all the drying operations. Application of thermal technique is the general idea behind all drying processes therefore, involvement of heat application comes naturally. For the fabricated recycling unit, the convective heating was provided by an external source of heat fueled by either diesel or LPG, using a hybrid burner. The whole drying part involves simple water removal from the feed. Amount of water removal from the mentioned amount of waste being processed in the drying vessel was calculated, after the completion of waste processing and obtaining the results for final moisture content of the product and total amount of dried product.

Moisture content was determined on both wet and dry basis,

$$\textbf{Moisture Content on dry basis } (M_{db}) = \frac{(Sample\ Weight\ before\ drying - Sample\ Weight\ after\ drying)}{(Sample\ Weight\ before\ drying - Weight\ of\ crucible} \times 100$$

$$= \frac{Water\ in\ sample}{Weight\ of\ the\ wet\ sample} \times 100$$

$$\textbf{Moisture Content on wet basis } (M_{db}) = \frac{(Sample\ Weight\ before\ drying - Sample\ Weight\ after\ drying)}{(Sample\ Weight\ after\ drying - Weight\ of\ crucible} \times 100$$

$$= \frac{Water\ in\ sample}{Weight\ of\ the\ dried\ sample} \times 100$$

Final moisture content (% wet basis) of the dried product was recorded to be 15.6 % and on dry basis, 18.4%. Further this value was used for the water removal calculation as follows:

Initial moisture content on wet basis of the raw material = 85.37%

Total mass of the feed under processing = 60 kg bovine blood+20 kg Rumen content (80kg)

Weight of water in 80kg feed mix = 85.37 % of 80 kg (68.296 kg)

Weight of solids in 80kg feed mix = 14.63 % of 80 kg (11.704 kg)

Final moisture content of the dried product (% wet basis) = 15.6 %

Total mass of final produce = 14 kg.

As during process only water is removed by simple drying therefore, the weights of solids remain same after drying. It is inferred from final moisture content of the product that 84.44% of product mass is solid and 15.6% of product mass (14 kg) is water, 2.184 kg. Therefore, water removed during the process of drying can simply be stated as follows also see Figure 10

$$\boldsymbol{Mass\ of\ water\ Removed\ (Y) = Mass\ of\ water\ in\ feed - Mass\ of\ water\ in\ product}$$

$$\boldsymbol{Y = (68.296 - 2.184)kg, \Rightarrow Y = 66.19\ kg}$$

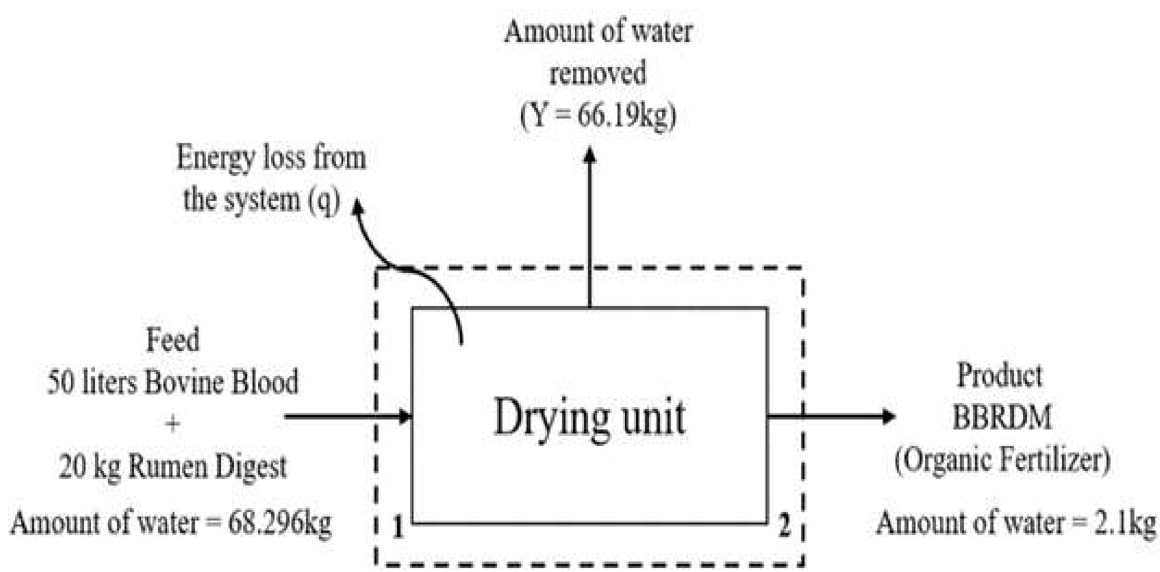


Figure10: Schematic diagram of developed helical-ribbon mixer drying unit representing the moisture removal from slaughterhouse waste, where 1 represents the input side and 2 the output side of the drying system, respectively.

All of the above calculations were based on the results observed and recorded during three consecutive full runs of recycling process for 3 consecutive days for two different fuels (LPG and Diesel) separately. Hence, on an average 14 kg of product was obtained from the present recycling unit when fueled with LPG for three hours and thirty minutes, drying time to be 3.5 hours. Simultaneously, on the other hand the fabricated drying unit when fueled with diesel gave on an average 10 kg product having final moisture content of 18.8 % on wet basis in 4.5 hours. For further interpretations, observations were made only on LPG fueled runs of BBRDM production, as final moisture content of the product, drying time and production(kg) per batch in this process is noticeably better than that of diesel fueled production

5.3 Specification and description of the fabricated recycling equipment.

The fabricated recycling unit is basically a dryer designed and constructed of three sections (refer to figure 10). Firstly, the **vessel** where the whole process of drying and mixing occurs (8) material of construction for the vessel was SS 304 grade stainless steel. Diameter of the vessel was 0.61 m along with a height of 0.71 m, and specifically opened from the top. The vessel was so designed that it could be mounted on a movable cart (7), The main frame (5) of the equipment was fitted with attachments for holding the mentioned movable cart having castor wheels (10) to slide on rails (9). Secondly, the **mixing blade** (11) was designed in helical-ribbon shape having three prominent concentric turns with sharp edges the ribbon width was kept 0.58 m from the centre of axis for smooth rotation inside the vessel. The length of the axis along which the blade was turned was 0.70 m for. The unique design of the blade ensured proper mixing and heating within the recycling vessel. An electric driven spindle (4) that operated on a 2 HP shunt motor (1) was attached to the ribbon mixing blade through coupling (3). Two other attachments, screw jack (6) and its hand wheel (12) were used for the movement of mixing blade inside the vessel. This whole mechanism of the mixing was facilitated with both reverse and forward rotation that can be controlled within the range of 50-250 rotations per minute (rpm) for easy and hassle-free unloading. A panel for monitoring and regulating the drying equipment was attached mainly to control the rotation of the spindle The panel displayed primarily the readings for number of rotations, voltage and current during the processing of waste. Lastly, the application of heat was provided through a **hybrid burner** (13) facilitated to run on both diesel or liquid petroleum gas according to fuel availability. The heat source supplied up to 110 ° C for 3-4 hours to the processing unit. The proposed drying cum recycling unit was patented in India (Patent number: 370569 of 2021) by Bhowmik et al. [70]. Considering the design and function of the equipment it is referred to as 'helical-ribbon mixer dryer'. The equipment description and operation can be better visualized through series of figures that are presented in the following pages.

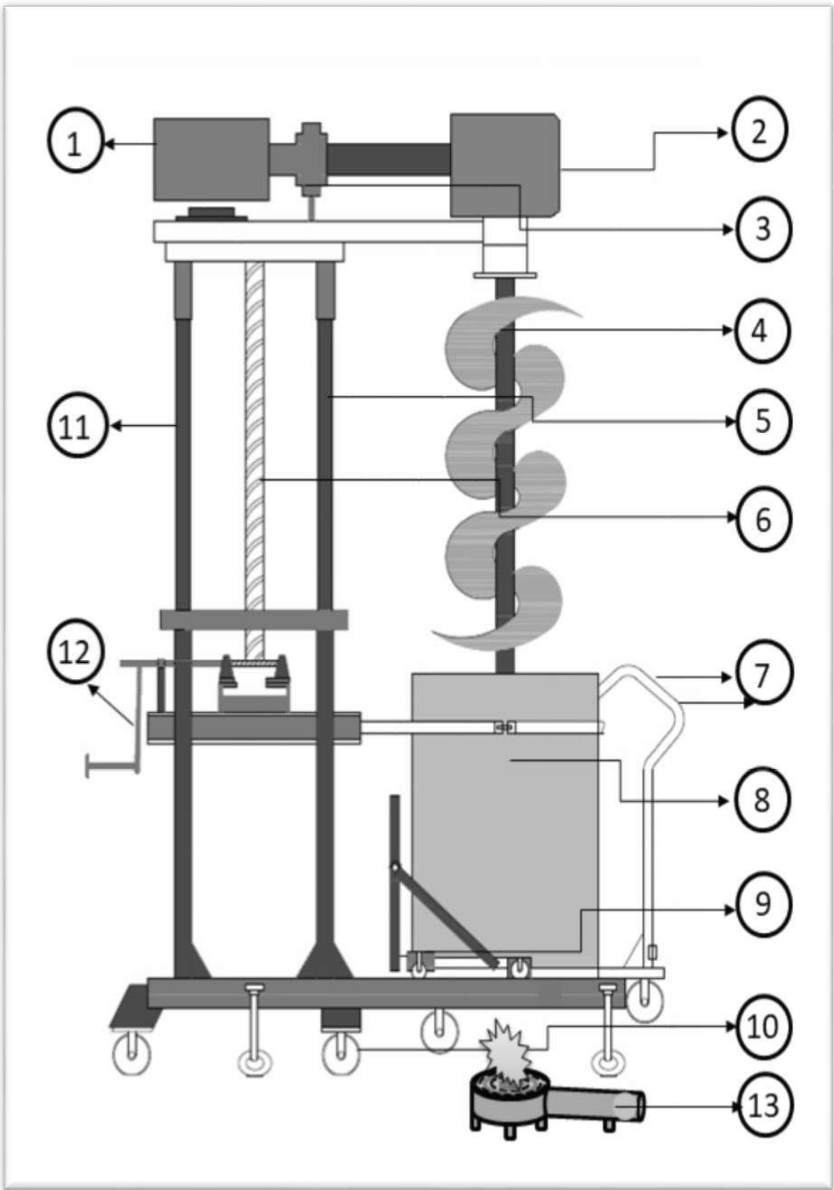


Figure 11: Whole drying cum recycling unit in its isometric view

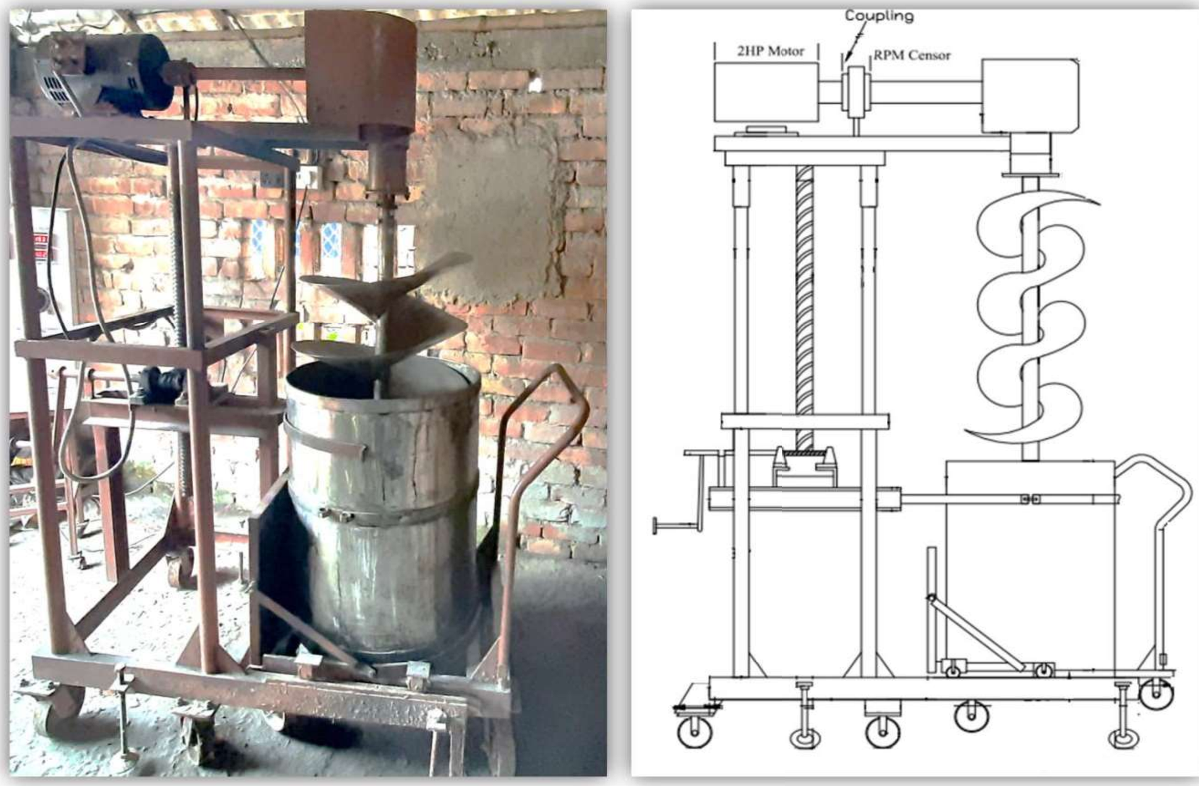


Figure 12: Operational view of the presented drying unit. Position of the mixing spindle is raised up before loading

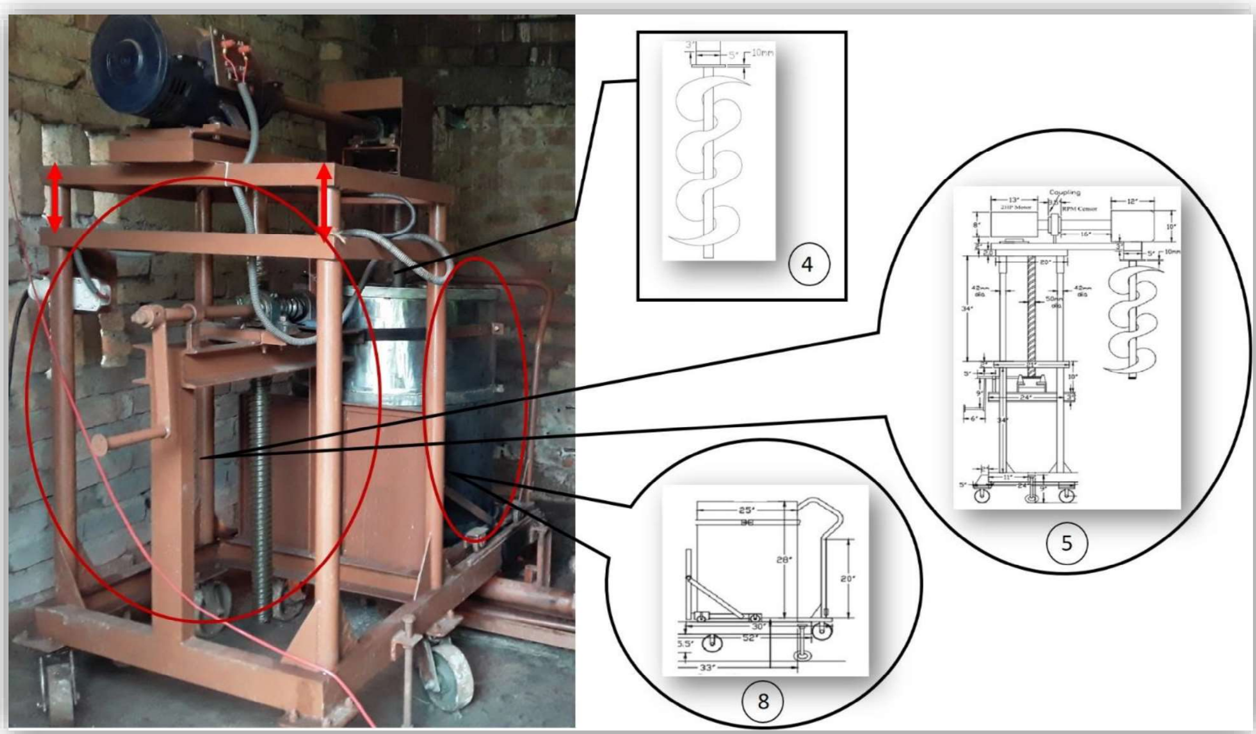


Figure 13: A detailed view of the designed drying unit, highlighting the position of inserted mixing spindle (4) in the vessel (8) after loading and the magnified view of main supporting body arrangement of the equipment.

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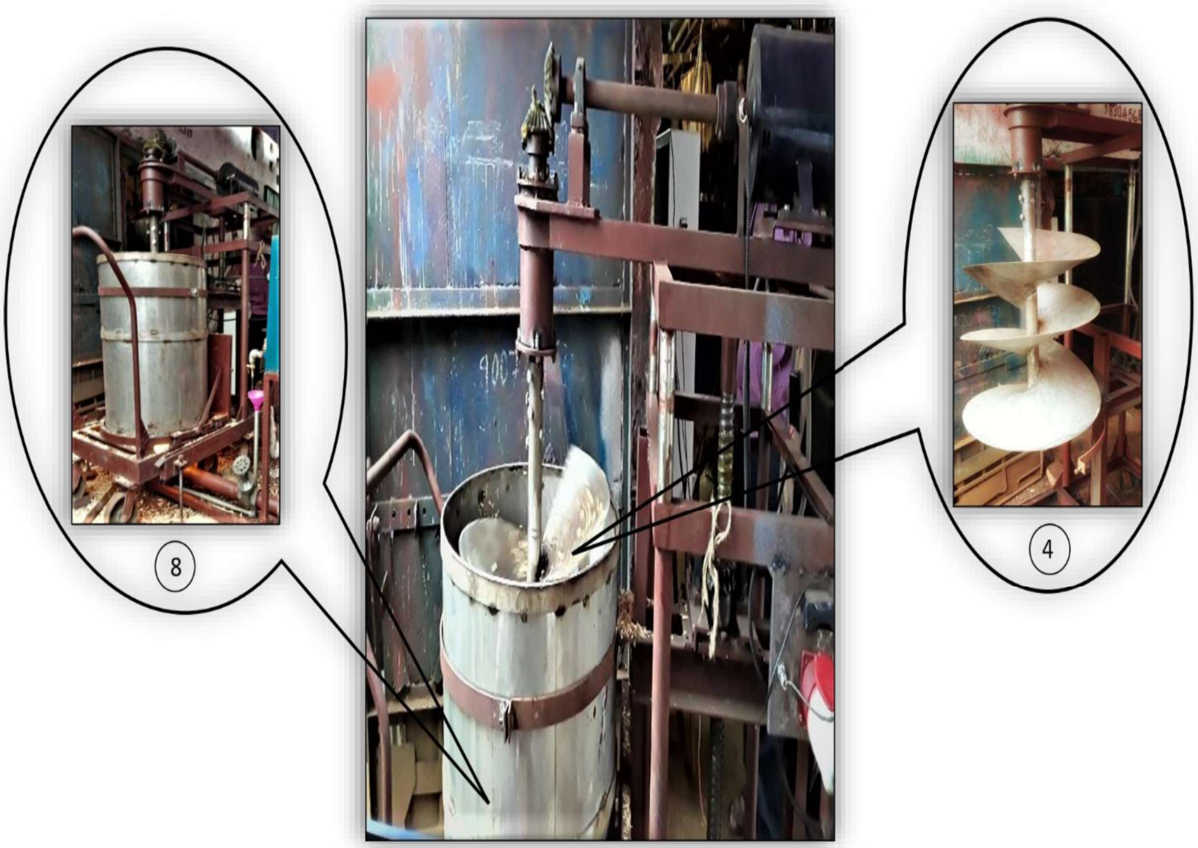
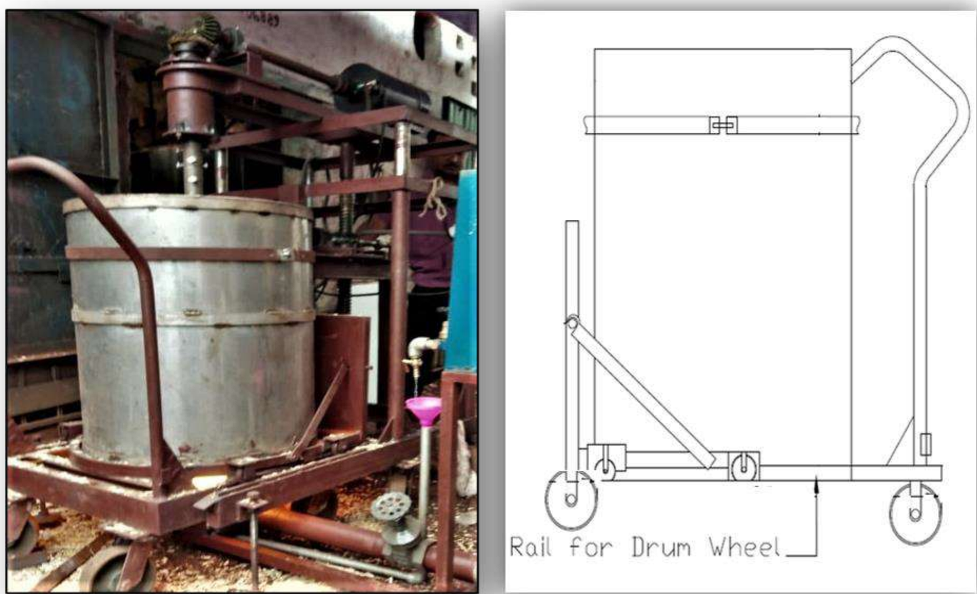
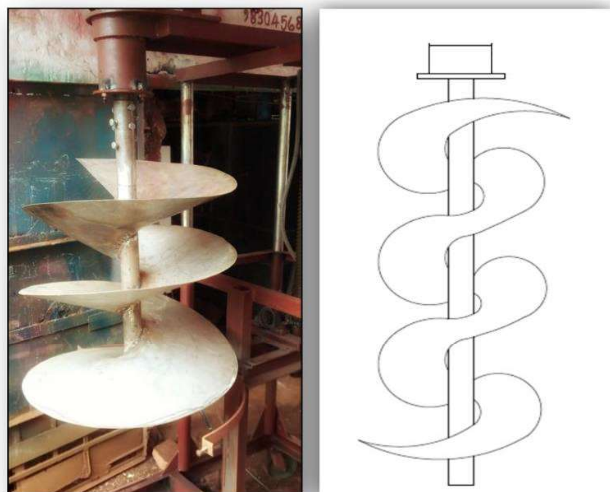


Figure 14: Detailed photographic view of novel design of the spindle (4) inserted into the drying vessel (8)

(a)



(b)



(c)

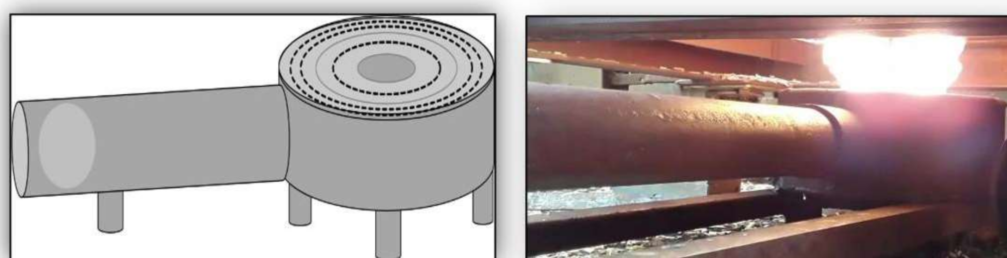


***Figure 15: (a) T*he drying and mixing vessel (8) mounted on a movable cart (7)**

(b) The helical mixing spindle (4) with sharp edges for distribution of heat to be equal and mixing to be uniform

(c) The hybrid burner (13) fueled by both diesel & LPG with all necessary fittings and attachment for heating the vessel with material

5.4 Dryer performance in terms of energy consumption and moisture extraction.

The presented dryer was evaluated for its conversion efficiency on the basis of:

1. Moisture extraction rate (MER)

It is the total mass of water removed; over the total drying time, it is simply the rate at which water is removed from the measured feed, $66.112\ (kg)/3.5\ (h) = 18.89\ kg\ h^{-1}$

2. Specific Moisture extraction rate (SMER)

This parameter is related to the rate at which energy is supplied for per kg water removal. Total energy consumed by the recycling unit for production is 49.4 MJ/batch (13.722 kwh), this total energy was utilized for removing 66.112 kg of water therefore, 4.8 kg of water is removed per kilo-watt-hour(kwh) supply of energy, 4.8 kg kwh^{-1}.

3. Total Energy consumption

For the total waste mass mix of 80 kg that was fed into the recycling vessel, the energy required was supplied through two sources. For full-operation of drying and completion of process; till the desired dried end produce is obtained, (a) 1 kg LPG (Calorific value = 45.8 MJ kg^{-1}) was consumed for fueling the hybrid burner, used for heating the vessel and (b) For the rotation of mixing spindle, electricity of 1kwh (3.6 MJ) was spent. Therefore, in total energy consumption by the recycling unit when fueled by LPG for complete processing (3.5 hours) was 49.4 MJ/batch or 13.722 kwh/batch of production. As on average it is observed that the production per batch is 14 kg the total energy consumption can be expressed as 3.528 MJ kg^{-1} or 0.98 kwh kg^{-1}.

4. Specific Energy consumption

Energy consumed to remove water, is the specific energy consumption. For the fabricated novel dryer, the energy is consumed in two forms for two different operations but both the operations are major contributor in water removal therefore, from amount of water removed (66.112 kg) and total energy utilized (13.722 kwh) for water removal, specific energy consumption was calculated to be 0.207 kwh energy was consumed to remove one kg water, 0.207 kwh kg^{-1}. The parameter evaluated and the results obtained for performance of the novel dryer are briefly tabulated as Table 8.

Table 8: Parameters after processing the slaughterhouse waste into organic fertilizer

Parameters	***Helical-Ribbon mixer dryer (LPG driven)***
Fuel consumption	1 kg LPG and 1kWh electricity
Production quantity	14 kg per batch for feed of 80 kg
Process Time	Three hours and thirty minutes
Total Energy Consumption	49.38 MJ per batch
Specific energy consumption	0.207 kWh kg^{-1}
Specific moisture extraction rate (SMER)	4.8 kg kWh^{-1}
Moisture extraction rate (MER)	18.89 kg h^{-1}

Values for the specific moisture extraction rate of existing dryers like tumble dryer (0.90 kg kWh^{-1}), spray dryer (0.5-1.0 kg kWh^{-1}), heat pipe screw dryer (2.04 kg kWh^{-1}) were low as compared to the proposed fabricated dryer. The recycling unit provided better drying than commonly used dryers whereas it is also noted that heavy dryers like heat pump and compression (10 kg kWh^{-1}) have higher moisture extraction rate [71, 72]. However, comparing the energy consumption; these heavy built units used for recycling consumes a huge amount of energy for operation. On the other hand, the lowest energy consumed for waste conversion is shown by composting (0.07 kWh kg^{-1}), but again it has to compete for the conversion time compared to alternately available methods [73]. For both the options LPG driven and diesel driven runs the parameters were evaluated, from the results it was clearly indicated that LPG driven runs were more efficient than compared to diesel runs for BBRDM production.

5.5 Characteristic curves of drying obtained during experimental processing.

The experimental graphs were plotted following the drying rate equation and data collected during the process of drying. Results from the LPG run production were noted and further used for deducing characteristic drying curves. Samples were collected at the interval of every 15 minutes till the end of process, for determining the moisture content on wet basis and moisture removed. Drying rate equation was used for plotting and interpreting the characteristic drying curves, The drying rate equation:

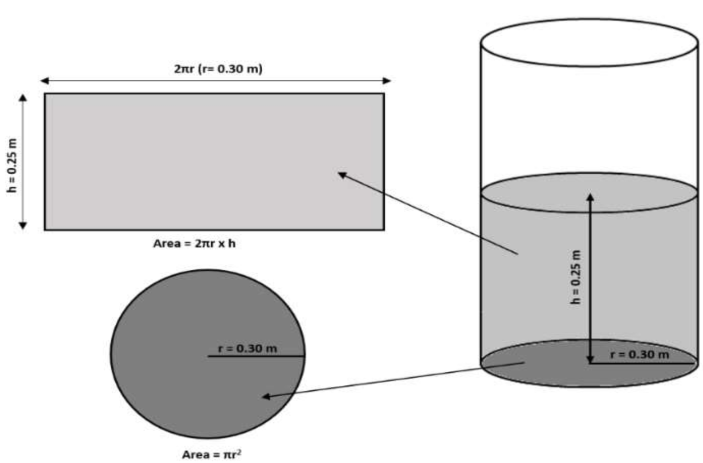
$$N = -\frac{W_S}{A}\cdot\frac{dX}{dt} = -\frac{W_S}{A}\cdot\frac{\Delta X}{\Delta t}$$

Drying surface area and dried solid mass are constant for the drying vessel under observation and the waste under processing. $W_{s,}$ bone-dry weight of the raw material used, was determined to be 11.70 kg. Simultaneously drying surface area, A of the drying vessel was calculated on the volume of feed in the vessel. During all the runs under observation:

$$\textbf{Mass of raw material (abattoir waste)fed} = \textbf{60 kg waste blood} + \textbf{20 kg of rumen waste}$$

$$\textbf{Volume of raw material (abattoir waste)fed} = \left({}^{60}/_{1160}\right) m^3 + \left({}^{20}/_{923}\right) m^3 = 0.07\ m^3$$

1160 kg m^{-3} and 923 kg m^{-3} are the bulk densities recorded for cattle blood and rumen waste respectively. As the shape of the vessel is cylindrical and closed only at one end, the surface area depends on the volume of the feed. According to the above calculation volume of feed is 0.07 m^3. Volume ($\pi r^2 h = 0.07\ m^3$) and radius of the vessel is 0.30 m (diameter = 0.61 m), therefore height (h) to which the vessel can be filled is 0.25m. Hence the drying surface area was calculated as follows:



$$A = Bottom\ circular\ area, \pi r^2 + Lateral\ surface\ area, 2\pi rh,$$

Hence A= 0.75 m^2

Further in the equation ΔX is the change in moisture content with change in time (Δt). Negative sign in the equation shows the decrease in moisture content. Curves obtained are as follows:

(a) Curve of drying (plotted for moisture content vs. time):

From the drying rate equation, a curve was plotted for moisture content over the time period of processing using the following data collected during experimental runs of the drying process inside recycling unit. The plot obtained was represented as Drying Curve in the Figure 16

Time, t (minutes)	Moisture content on % wet basis, x
0	85.37
15	84.42
30	81.90
45	72.36
60	62.86
75	53.38
90	43.83
105	34.31
120	24.79
135	19.09
150	15.56
165	15.56
180	15.56
195	15.56

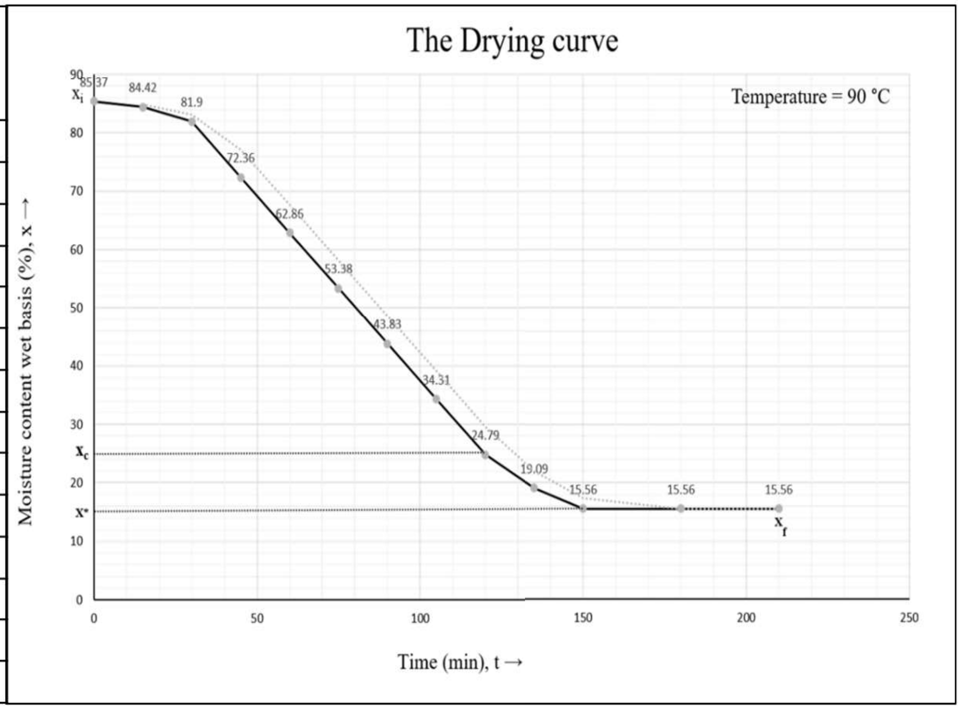


Figure 16: Curve for drying obtained during the process of drying, by plotting the values of moisture content (%wet basis) against time in the fabricated dryer.

In the above equation of drying rate, (dX/dt) represents the slope of the curve obtained while plotting time (t) vs. moisture content (X), that remains constant till critical moisture content that is represented as x_c in the plot, is reached. Till the point of critical moisture, the curve can be seen to be linear in nature. Where, $\mathbf{x_i}$ represents initial moisture content**,** $\mathbf{x_c}$ represents critical moisture content**,** $\mathbf{x^*}$ is the critical point in moisture content and $\mathbf{x_f}$ is the final moisture contents

(b) Curve for drying rate plotted against time

Data collected for plotting the said graph are presented in a tabular form along with the plotted graph. As the values of Ws and A are constant therefore from the rate equation dx/dt represents drying rate and time as t.

Time, t (minutes)	Drying rate (dx/dt)
0	0
15	0.06
30	0.168
45	0.43
60	0.633
75	0.632
90	0.635
105	0.634
120	0.634
135	0.45
150	0.23
165	0.23
180	0.23
195	0

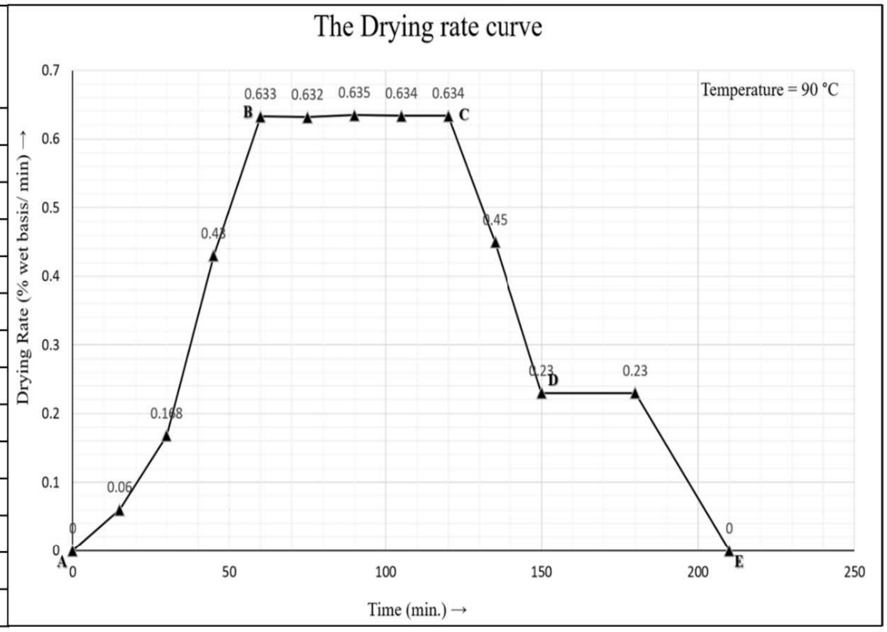


Figure 17: ***Drying rate curve –drawn using experimental data of drying rate and total drying time. In this plot the region from A to B indicates the initial period for adjustment, in the zone bound under B to C the rate of drying is constant and further from point C-D-E the drying rate is said to be falling.***

The above figure is visualization of drying rate curve plotted from the data collected. In the figure 17 it can be observed that from initial point A of drying, the rate increases gradually till the point B, this is the phase where material to be dried is cold and slowly gaining temperature to accelerate the drying rate. During evaporation of unbound moisture, the water is on surface with a water activity of one which facilitates removal of maximum moisture and a constant rate of drying, in the plot it lies between B and C [73]. Beyond the point C the rate of drying decreases as waster activity in surface starts falling from value 1 and the region is said to be the zone of falling rate period. Further, for better understanding falling rate period is divided into two parts, period I from C to D and period II from D to E. In falling rate period, I the moisture of material diminishes to we spot and in falling rate period II the surface of the material is free from moisture. At point E the equilibrium moisture content is reached and drying rate comes down to zero.

(c) The Krischer curve (Drying rate vs moisture content)

This curve is basically time independent curve and is derived from the two previously plotted drying curves namely drying curve (Figure 16) and drying rate curve (Figure 17). The curve is shown in figure 18 as follows:

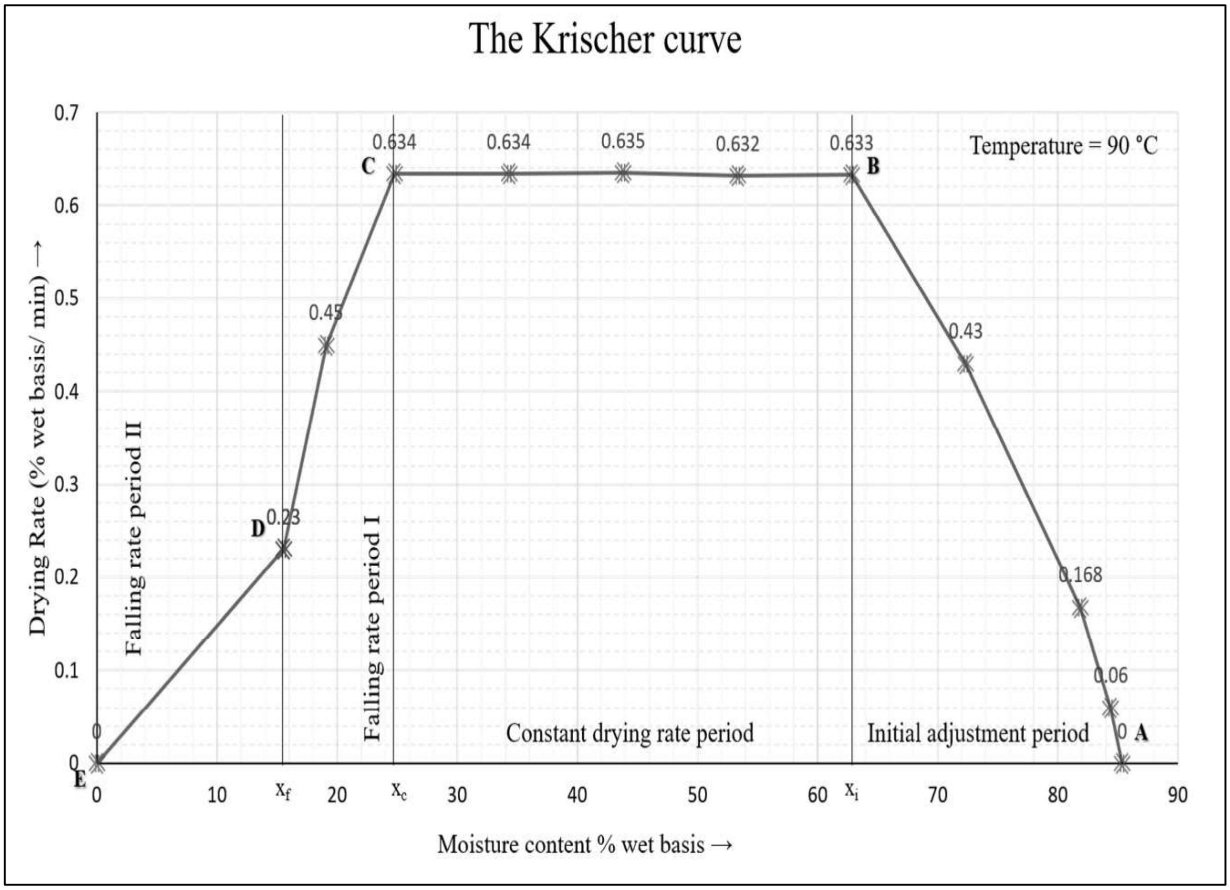


Figure 18: Krischer curve, ascent of this curve is totally independent of time as it is plotted between drying rate and moisture content. Constant rate period and falling rate period are represented from B to C and C to E respectively.

The plotted graph shows characteristic phases of drying four phases of drying: adjustment period, constant rate period, falling rate period I and II. Constant rate period continued till the point C, ending of constant drying and entering to the first falling rate period that continued till the point D and further till point E as second falling rate period.

(d) Curve for removal of moisture (percentage moisture removed vs time)

The curve of moisture removal was plotted on the basis of following data recorded in for moisture removal percentage over time of drying and is represented in the figure 19 below.

Time, t (minutes)	Moisture removal
0	0
15	0.95
30	3.47
45	13.01
60	22.51
75	31.99
90	41.54
105	51.06
120	60.58
135	66.28
150	69.81
165	69.81
180	69.81
195	69.81

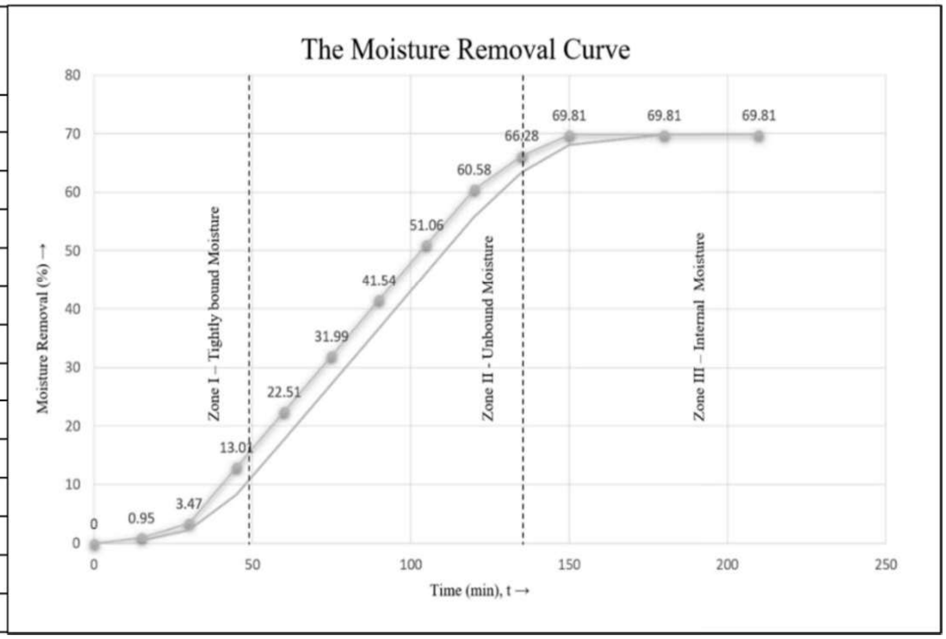


Figure 19: Water removal curve of the waste mass under processing, passing through all the three moisture zones inbound to material under drying

The drying rate ceases and becomes zero at the point where equilibrium moisture content is achieved. After this point, there is no further moisture removal from the material as any further removal of moisture will involve internal moisture, which is not feasible by any kind of physical treatments. The recorded data and four plotted graphs exhibited similar trends to the curves presented for kinetics of experimental drying. On the other hand, though schematic drying curve for anaerobic digestion was obtained but the parameters considered for plotting the curves were moisture content and flux of evaporation but, there were no reports of producing any characteristic curves [74, 75]. There are no mentionable reports on plotted drying curves for slaughterhouse waste processing where drying or moisture removal takes place on a remarkable scale, like rendering and pyrolysis. Energy consumption and drying time, both the parameters for the fabricated recycling unit working on basic principles of drying are low. Drying time for proposed fabricated when run on LPG is 3.5 hours, but in contrary it is being reported that air dryer takes up to 8.2 hours, freeze dryer takes 41.23 hours and microwave dryer requires 0.25 hour for the complete processing or drying. It is also being found in literature that to obtain a desired final moisture content on wet basis of 12-15 % a freeze dryer takes up to 11.00 hours and another alternative system for drying, pulse-spouted microwave vacuum dryer requires a time of 6.00 hours for drying. Similar reports of time-consuming method of drying are found in literature from Ghana, where drying beds used for organic waste and animal waste treatment takes up to 10-15 successive days [76-78]. Despite of being portable, easy in installation and are applicable for recycling blood waste, the mentioned dryers are not suitable for poorly facilitated rural slaughterhouse waste treatment as they demand huge consumption of energy. Energy consumption for air dryers (49.2 kWh kg^{-1}), microwave dryer (4.38 kWh kg^{-1}) and freeze dryer (75.8 kWh kg^{-1}) are much higher when compared to the fabricated dryer (0.21 kWh kg^{-1}) [76, 79]. Correspondingly, dryers used at industrial level like fried drying or drying in flash drum dryers, bio-dryers and spray dryers are loaded with complicated mechanisms and expensive attachments. Also, the methods like ensiling and drying on fluidized bed dryer which are presently being used for disposal of abattoir waste, possess high processing and operational costs [1]. Such setbacks which are inevitable due to lack in infrastructure, resources and facilities for rural abattoirs demanded a technique and process that not only has reasonably acceptable drying time and affordable energy consumption but also ensures a good quality produce [80]. From the results and calculations of data from the fabricated helical-ribbon mixer dryer it is been reported that the drying time and energy consumption were 3.5 hours and 0.21 kWh kg^{-1} respectively, for LPG run BBRDM production. Further in this chapter the parameters involved in slaughterhouse waste processing, drying time and consumption of energy values to produce BBRDM using different drying treatments are discussed.

5.6 *Comparative evaluation of parameters for different methods of BBRDM production.*

Different methods are being used in the rural slaughterhouses for valorizing the generated waste into a low-cost and environment friendly fertilizer due to its organic origin. Popular methods adopted by the abattoirs in rural areas are mainly either tray drying or cook drying along with sun drying, recently the abattoir generated waste is processed in the presented drying unit that use either

LPG or diesel in its fuel system. Energy consumption for water removal for each system was calculated on the basis of type and amount of fuel or resources being used up by the system during the whole process of waste conversion, the calculation from the observed data is briefed below.

Table 9: Type, amount of fuel resource and drying time involved in each method of drying

Drying Method	***Type of resource or fuel used***	***Amount of resource or fuel used per batch production***	***Drying Time (hours)***
Sun drying	Solar radiation	Exposure over 9.3 m^2	72-96
Cook Drying	Wood	5 kilograms	5-6
Tray Drying	Electricity	80 kilo-Watt hours	9-10
Drying in Helical-ribbon dryer (Diesel)	Diesel Electricity	5 liters 2 kilo-Watt hours	4-5
Drying in Helical-ribbon dryer (LPG)	LPG Electricity	1 kilogram 1 kilo-Watt hour	3-4

The total energy consumption by the above-mentioned dryers were further calculated in terms of MJ of energy consumed for one batch of production using the calorific values of the fuel or resources used in them. Calculations were made on the basis of the conversion factors listed in the following table.

Table 10: Calorific values of different fuel sources

Resource/Fuel	***Conversion units***
Solar Radiation	15 MJ m^{-2}
Wood	17.5 MJ kg^{-1}
Electricity	1 kWh = 3.6 MJ
Diesel	42.2 MJ kg^{-1}
LPG	45.8 MJ kg^{-1}

From the conversion table 10, the energy consumption in mega joules per batch of production as well as in terms of Kilo-Watt hour per kilogram of production was calculated for the different production methods The comparative study of energy consumption by all the methods used for BBRDM production was summarized and represented through following bar graphs for better understanding and interpretation, presented as Figure 20.

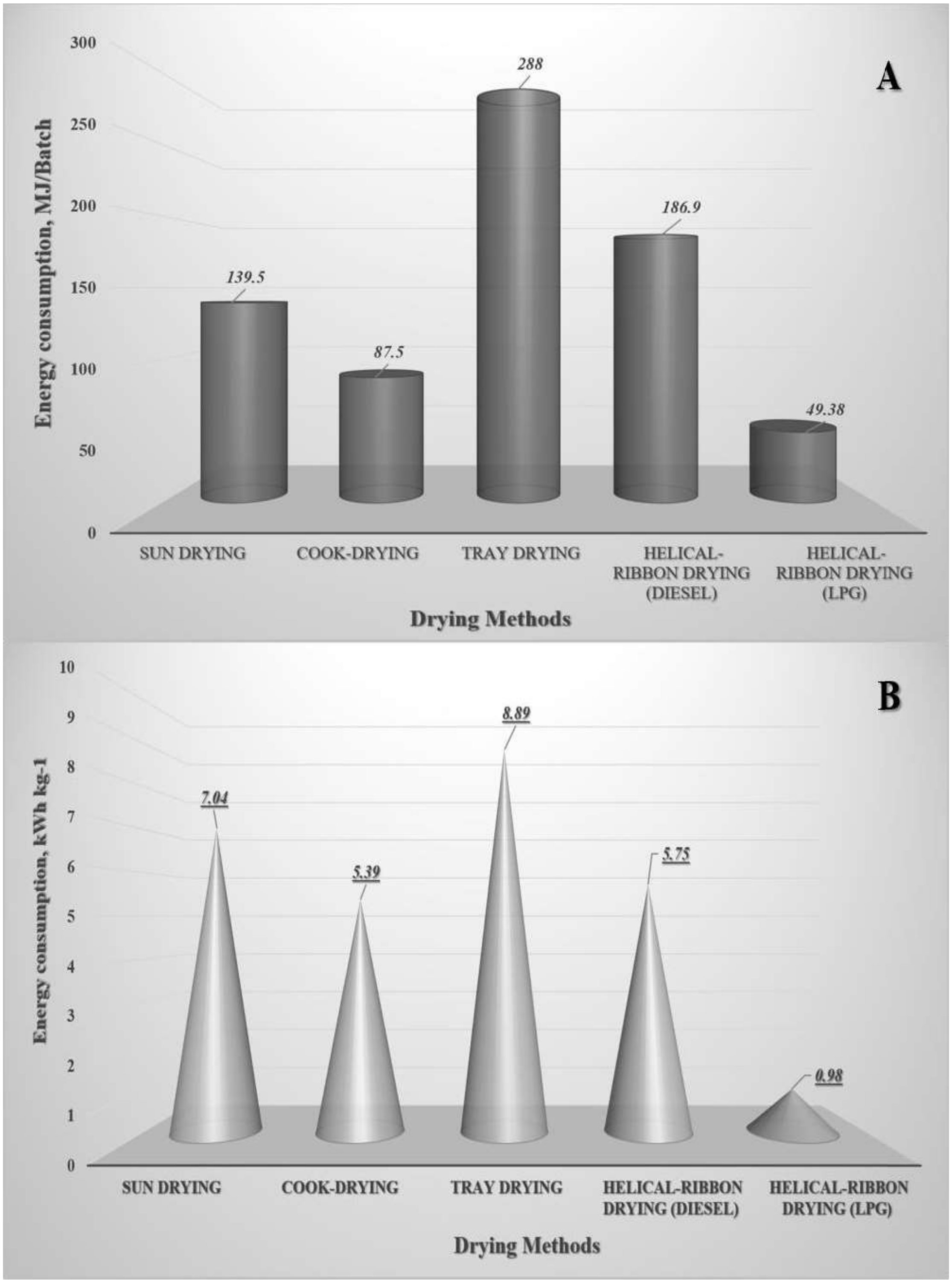


Figure 20: Comparative plot of energy consumed in terms of: A) Mega joules per batch and B) Kilowatt-hour per kilogram of product by the methods adopted for BBRDM production in rural slaughterhouse

Further the production in kilograms per batch, nitrogen content, extent of pathogen inactivation and final moisture content of the end product was recorded in the following Table 11 for easy comparison of the parameters.

***Table 11: Comparison of the recycling processes used by rural abattoirs for the conversion of abattoir waste into a value-added product*.**

Evaluating Parameters	Method of Drying for BBRDM Production				
	Sun Drying	Cook Drying	Tray Dryer	Helical-Ribbon Dryer (Diesel)	Helical-Ribbon Dryer (LPG)
Energy consumption (MJ/batch)	139.50	87.50	288.00	186.59	49.38
Energy consumption (kWh kg^{-1})	7.04	5.39	8.89	5.75	0.98
Drying temperature (°C)	30–35	50–60	70- 80	65–70	90–110
Moisture content (%)	19–21	23–25	15–18	18.80	15.60
Production/batch (kg)	5–6	4–5	8–10	8–10	10–15
Nitrogen content (mg kg^{-1})	ND	49,440	5977	12,678	15,456
Pathogen inactivation	x	xx	xxx	xxx	xxx

In addition to the above stated parameters, the curves plotted for reduction in moisture content were obtained for other drying methods over a time period of thirteen hours, represented in figure below.

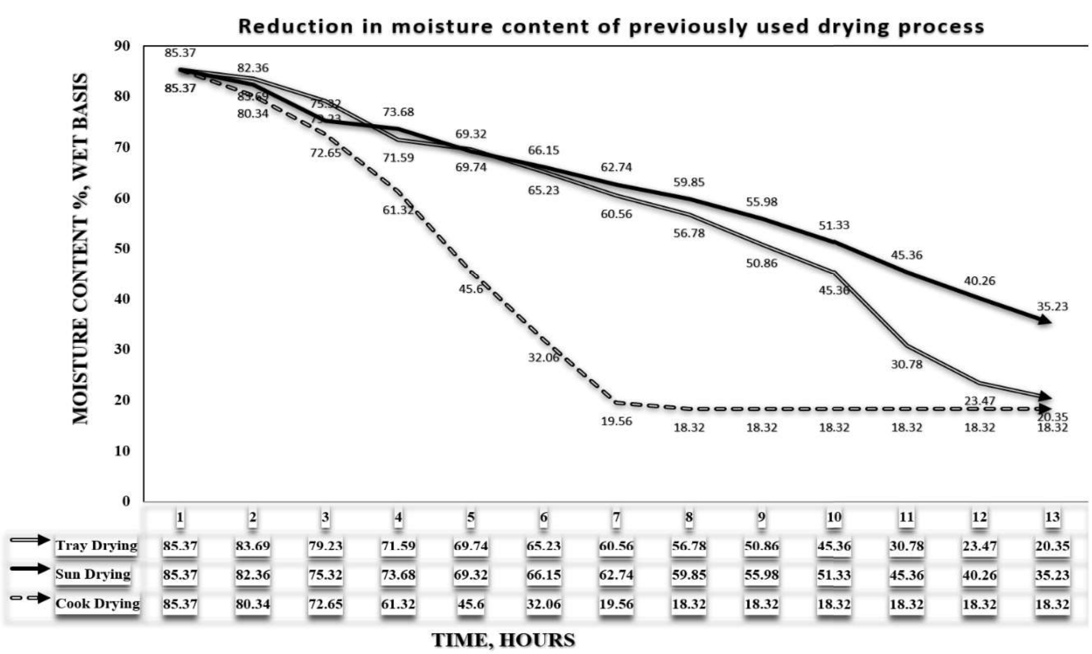


Figure 21: Moisture removal from the waste during its processing under different conversion methods over a time period of thirteen hours.

The plots clearly present a non-characteristic curve for drying, this set back of not obtaining any characteristic curve for the drying processes is due to prolonged and uneven exposure of the material to heat. This also leads to oxidation and further deterioration in nutrient quality of the dried product, also longer drying time poses a drawback leading to increase in consumption of energy and hence the operational cost [80, 81]. Results shows that the fabricated helical-ribbon dryer consumes less energy and time both.

5.7 Product parameters after completion of waste processing

According to the obtained results it can be stated that the end product of slaughterhouse waste processing in the fabricated dryer is a successful organic fertilizer used as a low-cost organic amendment to the soil. The particle size of the end product was determined to be D_{70} indicating that 70 percent of the particles of end product retained on a mesh of 2 mm along with this the bulk density was noted to be 1190 ±7 kg m^{-3}. Further final moisture content of the product was recorded to be 18.4 % and 15.6 % on dry and wet basis respectively. Abattoir wastes under drying treatment, removal of moisture is an important procedure as it involves inactivation of biochemical reactions inside the waste as well as reduction of waste volume [82]. Other parameter that reflected potentially the environmental aspect, methane emission recorded from BBRDM amended agricultural soil, ranged between 0.01-0.15 µg g^{-1} h^{-1} which was 150 times lesser than that was recorded from soils of the dumping site, which ranged from 13.13-28.55 µg g^{-1} h^{-1} of slaughterhouses.

Chapter 6:

Socio-Economic Benefit of the Research Work

6. Socio-Economic Benefit of the research work

How fast a small-scale traditional economic operation (abattoirs and agricultural farms) in rural areas can get out of subsistence level through cleaner production process is a major socio-technical challenge. The rural abattoirs provide livelihood options for a large number of people. Developing from present small-scale production on household level using cook drying to an equipment driven production is essential for meeting societal demands. An economically feasible technology can be a solution to the waste disposal problems of rural abattoirs as well as an initiative towards developing a circular economy among abattoir owners and local farmers. As the small-scale farmers are expanding towards the market of high-value organic produce, this conversion technique of producing low-cost organic fertilizer will be a profitable development. Science, technology and socio-economic practices need to co-evolve and complement each other for finding quick practical solutions. Local community who will be technology adopters need to be involved wherever possible to run through technology development, trial and commercialization process.

6.1 Readiness of the consumers for accepting the presented process of recycling

The farmers around the slaughterhouses where the new fabricated recycling unit is installed were surveyed and was concluded that among the local farmers 49% of them uses chemical fertilizer, 32% used both inorganic and organic fertilizer where as 19% used purely organic amendment for their agricultural soil. Organic fertilizer used by the farmers were 48% in animal origin and 22 % in plant origin. The total amount of investment that farmers make towards their cultivation was and will be mainly focused on buying fertilizers. The present profit levels, quality of the produce and deterioration in soil health due to intensive use of chemical fertilizer failed to satisfy the poor farmers. All farmers wanted to adopt BBRDM as a primary substitute for chemical fertilizers for cultivation. Due to better quality nutrition wise, the organically grown foods are desirable to 87% of the farmers. During the survey it was noted that 45% of the farmers were willing to adopt the BBRDM production system and 55% of them were keenly willing to purchase the abattoir was converted fertilizer for their farming lands.

6.2 *Environmental and economic benefit of the fabricated dryer for rural abattoirs*

Cost calculation for the installation and operation of the fabricated dryer was done along with the annual production cost of BBRDM. Operational costs include both one-time investments (non-recurring) as well as the expenses contracted for operation throughout the year (recurring). The financial analysis of the whole operation can be summarized below:

(1) Non-recurring costs (INR)	
Equipment fabrication cost	250,000
Water connection	10,000
Sub-total	**260,000**
(1) Annual recurring costs (INR)	
Operation and maintenance costs	50,000
Fuel and electricity charges	100,000
Local transport	20,000
Sub-total	**170,000**
(1) Annual labour cost (INR)	
One skilled labourer @ 10,000 per month.	120,000
One manager @ 20,000 per month	240,000
Sub-total	**360,000**
Total cost (INR)	***790,000***

As the production of BBRDM was under observation for a year it is been recorded that when the equipment runs three times a day then the production rate is 60-70 kg per day. During the research work it was also observed that 5% days of the year were non-productive due to inevitable incidents.

For an economically sustainable production the selling price of the recycled product was calculated by keeping a profit margin of 5% over production cost. Product cost calculation can be summarized as below:

YEAR	NON-RECURRING COST	RECURRING COST	LABOUR COST	TOTAL COST (PER YEAR)	ANNUAL PRODUCTION (IN KG)	PRICE (INR. PER KG)
YEAR 1	260,000	170,000	360,000	790,000	21,000	39.50
YEAR 2	–	170,000	360,000	530,000	21,000	26.50

According to the survey made in the local markets of Magrahat, the area under study it was found that among the market available organic fertilizer horn dust (150 INR per kg) is the most expensive and cow dung (30 INR per kg) is the cheapest. The prices of other fertilizers like vermicompost, mustard cake, neem cake varied from 60-80 INR per kg also the prices of inorganic fertilizer like DAP or urea costs around 30-35 INR per kg. On the contrary the BBRDM was sold at 26 INR per kg once the non-recurring cost of product is eliminated from 2nd year of production and it is reasonable and acceptable for local farmers that has created a ready market for this waste converted organic fertilizer. The proposed technology and the fabricated dryer therefore, enables slaughterhouse owners to recycle the slaughterhouse wastes in an easy and cost-effective way into an organic nitrogen fertilizer, the selling of which provides additional income to the abattoir owners. Such monetary benefit encourages them to reuse the wastes instead of dumping and landfilling. Furthermore, this effective recycling practice sustains cleaner production leading to cleaner and healthy surroundings for rural abattoirs.

Chapter 7:

Conclusion

7. Conclusion

The findings and results of the research work solved two major issues (a) unhealthy environment around rural slaughterhouses and (b) unavailability of cheap, locally produced organic fertilizers for poor farmers. The process and the equipment were developed for processing and valorizing abattoir waste (blood and ruminal waste of slaughtered animals). Slaughterhouses of villages, South 24 Parganas district (India) discards cattle blood as wastewater into public sewers and other water channels and the ruminal waste is dumped openly near to their residential houses. Such practices were making the surroundings extremely unhygienic. During our field visits, we have noticed that slaughterhouse workers and local people are suffering from fever, skin infections, gastrointestinal illness, respiratory disease and coughing problems.

The research work could be the solution hence, concluded in the following lines:

a. **Designed recycling equipment is portable single-unit 'helical-ribbon mixer dryer' dryer system converts abattoir-derived bovine blood and rumen digesta into an organic nitrogen fertilizer that may be an effective alternative of chemical supplementation during agronomic practice.**
b. **This waste management technology is completely cost-effective and provides hassle-free installation of the equipment to such scattered rural slaughterhouses as we noticed in Magrahat village without adequate basic amenities, where the existing treatment technologies including anaerobic digestion, alkaline pretreatment, in-vessel composting, rendering, and incineration are found unviable.**
c. **Fabricated drying unit minimizes waste generation, reduces environmental pollution limiting open waste disposal and risks of acquiring zoonotic infections as well as provides an additional income to the slaughterhouse owners.**
d. **The technology promotes bio-based circular economy for the society and helps to achieve sustainable rural economy through organic farming.**
e. **BBRDM was applied as an organic fertilizer and it was reported that two-fold higher productivity of vegetable crops in soils fertilized with BBRDM as compared to the commercial fertilizers during each season of cultivation**
f. **Highly hazardous waste generated from the rural abattoirs can be profitably converted to a value-added product and hence promoting a hygienic and cleaner environment as well as a sustainable approach towards waste management**

Chapter 8:

Future Scope

8. Future Scope of the research work

There is always a scope for improvement in a technology:

1. In the presented dryer the heating system involve consumption of either LPG or Diesel to create heat energy. This can be modified to electric heating by introducing electric heating belts supported by solar panels. Making this technology a completely green technology
2. Parameters effecting product shelf-life are to be studied and new approaches of achieving better quality long lasting organic fertilizer.
3. Proper labeling. Packaging and branding require more innovative approaches.
4. Encouraging the rural abattoir owners and local farmers to engage in mutually beneficial investment for embedding a sustainable circular economy at societal level.
5. Marketing of the presented product BBRDM, a nitrogen rich organic fertilizer by valorization of slaughterhouse waste among local farmers. Raising awareness about the socio-economic benefits and environment improvement.
6. The presented work can be of significant and well-established entity for the future of establishing a rural entrepreneurship around these mentioned rural slaughterhouses.
7. This valorization of slaughterhouse waste into organic fertilizer may further be used for developing a sustainable production system leading to a circular bio-economy for the rural abattoirs and local agriculture.

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