“ A STUDY OF RELIABILITY BASED OPTIMUM SELECTION OF SAND CONTROL”

By

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Master in Production Management

EXAMINATIONS ROLL NO – M4PRD19002.

THESIS

SUBMITED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF PRODUCTION ENGINEERING IN

THE FACULTY OF ENGINEERING & TECHNOLOGY JADAVPUR UNIVERSITY

PRODUCTION ENGINEERING DEPARTMENT

JADAVPUR UNIVERSITY

KOLKATA-700032

INDIA

2019

JADAVPUR UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

CERTIFICATE OF RECOMMENDATION

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ACKNOWLEDGEMENT

It is my greatest fortune to perform the thesis work in the Production Engineering Department, Jadavpur University.

It is great pleasure to express my gratitude and indebtedness to my esteemed guide Dr. Bijan Sarkar, Professor, Production Engineering Department, Jadavpur University. It is because of his continuous guidance, encouragementandvaluableadviceateveryaspectandstrataoftheproblem from the embryonic to the development stage that my thesis has been in the light of the day.

My special thanks to Head of Production Engineering Department for allowing me to carry out the research investigation with various facilities of the department. I would like to express my warmest gratitude to all the respected faculty members and non-teaching staff members of this department who directly or indirectly helped and encouraged me during the thesis work.

I would also like to thank Mr. Debashish Das, M.E. scholar of Production Engineering Department for their continuous help in completion of this work. I express my appreciation to my friends for their understanding, patience and active co-operation throughout my Masters course.

I feel pleased and privileged to fulfil my parents' ambition and I greatly indebted to them for bearing the inconvenience during my Masters course. Thank you, my beloved parents and my elder brother.

Everything in this nature is time bounded, so thanks to 'Almighty' for successful completion of the work in time.

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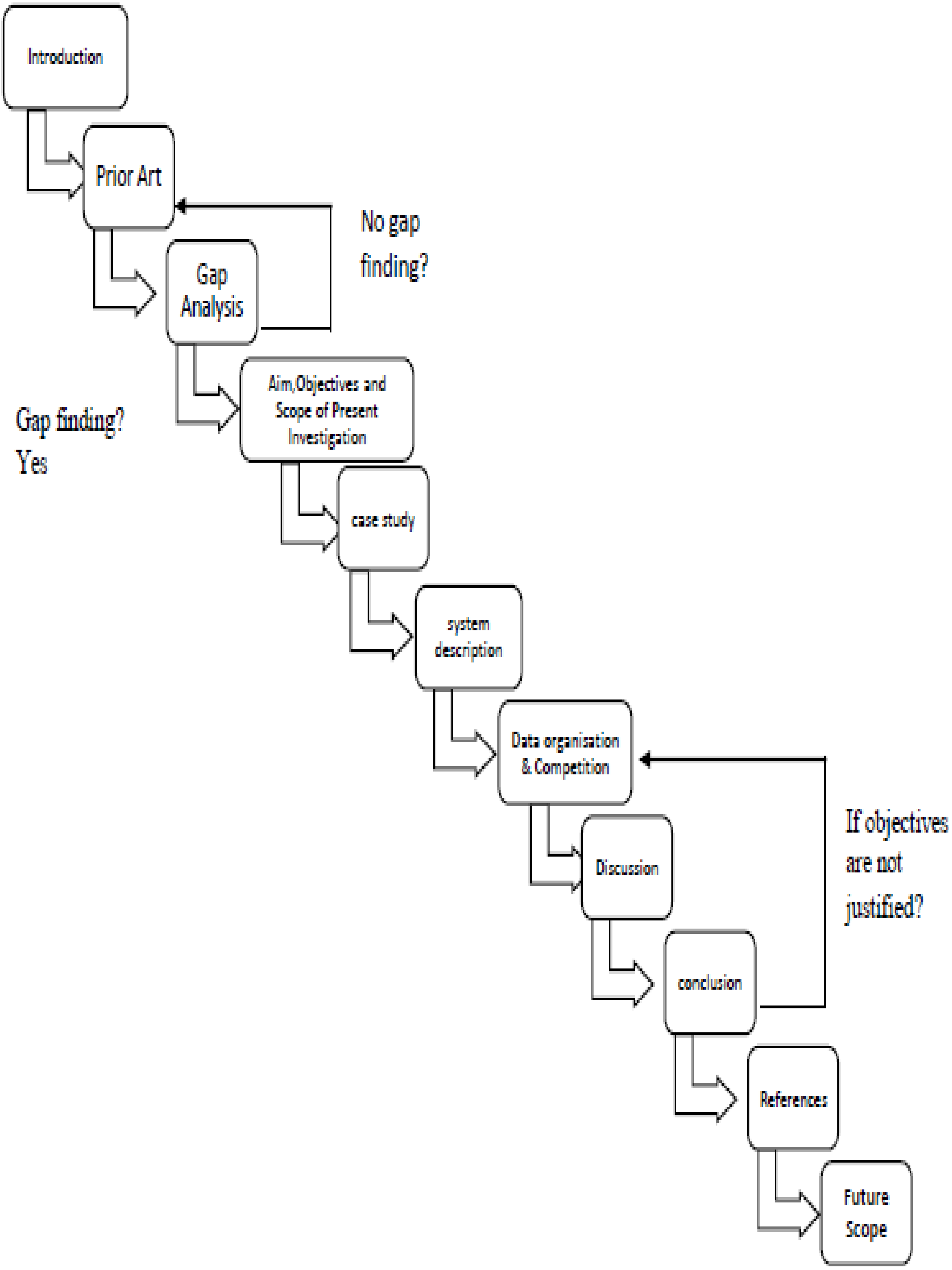

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Chapter 1

1. Introduction:

For normal flow of oil, formation should be porous, permeable and well cemented together, so that the large volumes of hydrocarbons can flow easily through the formations and into production wells.

There are few situations arises where these produced fluids may carry entrained there in sand. Unconsolidated sandstone reservoirs with permeability of 0.5 to 8 Darcie's are most susceptible to sand production. This may start during first flow or later when reservoir pressure has fallen or water breaks through. Sand production strikes with varying degrees of severity, not all of which require action. The rate of sand production may decline with time at constant production conditions and is frequently associated with clean up after stimulation.

Sometimes, even continuous sand production is tolerated. But this option may lead to a well becoming seriously damaged, production being killed or surface equipment being disabled. What constitutes an acceptable level of sand production depends on operational constraints like resistance to erosion, separator capacity, ease of sand disposal and the capability of artificial lift equipment to remove sand laden fluid from the well.

Sand entering production wells is one of the oldest problems faced by oil companies and one of the toughest to solve. Production of sand during oil production causes severe operational problem for oil producers. Every year the petroleum industry spends millions of dollars in sand cleaning, repair problems related to sand production and lost problems related to sand production and lost revenues due to restricted production rates.

Consequently, sand control has been a research topic for over five decades. The purpose of this document is to help in understanding the causes of sanding, and how it can be predicted and controlled. It will examine the main methods of sand control.
The production of formation sand into a well is one of the oldest problems plaguing the oil and gas industry because of its adverse effects on well productivity and equipment. It is normally associated with shallow, geologically young formations that have little or no natural cementation to hold the individual sand grains together. As a result, when the wellbore

pressure is lower than the reservoir pressure, drag forces are applied to the formation sands as a consequence of fluid production.

If the formation's restraining forces are exceeded, sand will be drawn into the wellbore. The produced sand has essentially no economic value. On the contrary, formation sand not only can plug wells, but also can erode equipment and settle in surface vessels. Controlling formation sand is costly and usually involves either slowing the production rate or using control techniques.

Often, reduction in the production rate is not an economic approach to overcome sand production problem. So, it is preferred to use sand control techniques. Using sand control techniques accompany with additional equipment for well completion. Although this equipment prevents formation sand entering the wellbore by various mechanisms, it decreases the reservoir productivity. On the other hand, additional skin factor is caused due to sand control technique. This indicates that the magnitude of the skin is also an important parameter to choose a sand control method for a sand producer well. So, before choosing a method to prevent sand production, it is important to know the skin factor of the method and evaluate well production economically for a specific period. In this paper, skin factors of different sand control methods are investigated and indicated the best method for real case economically.

With the growing complexity of practical engineering problems, the uncertainty relating to material properties, loads, geological, technical, economical etc. significantly affect the performance of sand control. Hence, for designing the safe sand control method, these uncertainties should be considered in sand control design and optimization processes. When sufficient information to determine the probability distributions of uncertain parameters is not available due to limited experimental data, the non- probabilistic model-based approaches are commonly used for evaluating the reliability and guiding the sand control design. The probability model-based design optimization approaches provides reasonable results when precise probability distributions for random variables are available.

1.1 Reliability

Reliability is the degree of consistency of a measure. A test will be reliable when it gives the same repeated result under the same conditions.

Although there is a consensus that reliability is an important attribute of a product, there is no universally accepted definition of reliability. Dictionaries define reliability as the state of being reliable, and reliable as something that can be relied upon or is dependable.

Another way of looking at reliability is by considering it as a way to maximize the inherent repeatability or consistency in an experiment. To maintain reliability, a researcher will use as many repeat sample groups as possible, to reduce the chance of an abnormal sample group skewing the results. This is a little like weighing the bowl several times and using the average reading.

Reliability can be determined statistically by calculating the correlation coefficient. If a test is reliable it should show a high positive correlation between repeat scores. If you use three replicate samples for each manipulation, and one generates completely different results from the others, there is likely something wrong with the experiment.

For most experiments of natural phenomena, results follow a normal distribution and there is always a chance that your sample group produces results at one of the extremes. Using multiple sample groups will smooth out these extremes and generate a more accurate spread of results. But if your results continue to be wildly different, then there is likely something wrong with the design itself. In this case, the entire experiment is externally unreliable.

When we talk about reliability, we are talking about the future performance or behaviour of the product. Will the product be dependable in the future?

Thus, reliability has been considered a time-oriented quality (Kapur 1986; O'Conner 2000). Some other definitions for reliability that have been used in the past include:

- ✓ Reduction of things gone wrong (Johnson and Nilsson 2003).
- ✓ An attribute of a product that describes whether the product does what the user wants it to do, when the user wants it to do so (Condra 2001).
- ✓ The capability of a product to meet customer expectations of product performance over time (Stracener 1997).

- ✓ The probability that a device, product, or system will not fail for a given period of time under specified operating conditions (Shishko 1995).

1.1.1 Quality Vs reliability

The word quality comes from the Latin qualis, meaning “how constituted.” Dictionaries define quality as the essential character or nature of something, and as an inherent characteristic or attribute. Thus, a product has certain qualities or characteristics, and a product’s overall performance, or its effectiveness, is a function of these qualities. In short, Quality is the degree to which something is fit for purpose.

Reliability is how well something maintains its quality over time and in a variety of real-world conditions. Quality is how well something performs its function. For example, a high speed train that is fast, energy efficient, safe, comfortable and easy to operate might be considered high quality.

Reliability is how well something maintains its quality over time as it faces real world conditions. For example, a high speed train that is durable for 20 years and remains safe in high winds and earthquakes.

Table1: Comparison of quality and Reliability

Quality Vs Reliability		
parameters	Quality	Reliability
Definition	Fitness for purpose.	Quality that endures over time and in a variety of real-world conditions.
Process	Quality Assurance	Reliability Engineering

1.1.2 Performance Vs reliability

Performance is usually associated with the functionality of a product—what the product can do and how well it can do it. For example, the functionality of a camera involves taking pictures. How well it can take pictures and the quality of the picture involves performance parameters such as pixel density, color clarity, contrast, and shutter speed.

Performance is related to the question, “How well does a product work?” For example, for a race car, speed and handling are key performance requirements. The car will not win a race if its speed is not fast enough. Of course, the car must finish the race, and needs sufficiently high reliability to finish the race. After the race, the car can be maintained and even replaced, but winning is everything.

Reliability is associated with the ability of a product to perform as intended (i.e., without failure and within specified performance limits) for a specified time in its lifecycle. In the case of the camera, the customer expects the camera to operate properly for some specified period of time beyond its purchase, which usually depends on the purpose and cost of the camera. A low-cost, throwaway camera may be used just to take one set of pictures. A professional camera may be expected to last (be reliable) for decades, if properly maintained.

1.1.3 Reliability and the System Life Cycle

Reliability activities should span the entire life cycle of the system. Reliability is associated with the ability of a product to perform as intended (i.e. without failure and within specified performance limits) for a specified time in its life cycle. In the case of the camera, the customer expects the camera to operate properly for some specified period of time beyond its purchase, which usually depends on the purpose and cost of the camera. A low-cost, throwaway camera may be used just to take one set of pictures. A professional camera may be expected to last for decades, if properly maintained. “To measure quality, we make a judgment about a product today. To measure reliability, we make judgments about what the product will be like in the future” (Condra 2001). Quality in this way of thinking is associated primarily with manufacturing, and reliability is associated mostly with design and product operation.

1.1.4 Reliability vs. Validity

Reliability and validity are often confused; the terms describe two inter-related but completely different concepts. Very simply:

Validity: does the test actually measure what it’s supposed to?

Reliability: does the test consistently give the same result under the same conditions?

This difference is best described with an example:

A researcher devises a new test that measures IQ more quickly than the standard IQ test:

- If the test consistently delivers scores of 135, and the candidate's true IQ is 120, the test is reliable but not valid.
- If the new test delivers scores for a candidate of 87, 65, 143 and 102, then the test is not reliable OR valid. It doesn't measure what it's supposed to, and it does so inconsistently!
- If the scores are 100, 111, 132 and 150, then the validity and reliability are also low. However, the distribution of these scores is slightly better than above, since it surrounds the true score instead of missing it entirely. Such a test is likely suffering from extreme random error.
- If the researcher's test delivers a consistent score of 118, then that's pretty close, and the test can be considered both valid and reliable. The closer to 120, the more valid, and the smaller the variation between repeat scores, the higher the reliability. A test that routinely underestimates IQ by two points can be as useful as a more valid test since the error itself is so reliable.

1.1.5 Reliability and Robustness

Reliability and Robustness are two very different things. Assume that you have a product called "The Super Cake". Let's say it is basically a powder mixture which when mixed with some water and cooked it becomes a delicious cake. The product specifications are as follows:

- The Super Cake shall be stored within the temperature range of 10°C and 30°C.
- The Super Cake shall be mixed with 1±0.1 litres of water.
- The Super Cake shall be cooked at 200±10°C for 45±5 minutes.
- The deliciousness level of The Super Cake shall be above 700 millichocs

So, if the reliability of The Super Cake is %99, it means that when it is stored under given conditions, mixed with the given amount of water, and cooked at the given range of temperature and duration, 99 out of 100 Super Cakes will turn out to have a deliciousness level of 700 millichocs or above.

The Super Cake being robust means that the temperature it has been stored or the amount of water you mixed it with or the temperature you cooked it at or duration you cooked it for doesn't affect its taste that much. So, let’s take two instances of The Super Cake, such that:

- Stored at 10°C, mixed with 0.9 litres of water, and cooked at 190°C for 40 minutes. Let the deliciousness level of this instance be 750 millichocs.
- Stored at 30°C, mixed with 1.1 litres of water, and cooked at 210°C for 50 minutes. Let the deliciousness level of this instance be 755 millichocs.

As this example points out the parameters of how The Super Cake is prepared doesn't matter on how delicious it becomes. So, it is safe to say The Super Cake is robust.

1.2 Reliability concepts:

1.2.1 Probability density functions:

Probability density function (PDF) is a statistical expression that defines a probability distribution for a continuous random variable as opposed to a discrete random variable. When the PDF is graphically portrayed, the area under the curve will indicate the interval in which the variable will fall. The total area in this interval of the graph equals the probability of a continuous random variable occurring.

1.2.2 Hazard rate

The failure of a population of fielded products can arise from inherent design weaknesses, manufacturing- and quality control-related problems, variability due to customer usage, the maintenance policies of the customer, and improper use or abuse of the product. The hazard rate, $h\ (t)$, is the number of failures per unit time per number of non-failed products remaining at time t. An idealized shape of the hazard rate of a product is the bathtub curve. A brief description of each of the three regions is given in the following:

1.2.2.1 Infant Mortality Period.

The product population exhibits a hazard rate that decreases during this first period (sometimes called “burn-in,” “infant mortality,” or the “debugging period”). This hazard rate stabilizes at some value at time $t1$ when the weak products in the population have failed. Some manufacturers provide a burn-in period for their products, as a means to eliminate a high proportion of initial or early failures.

1.2.2.2 Useful Life Period

The product population reaches its lowest hazard rate level and is characterized by an approximately constant hazard rate, which is often referred to as the "constant failure rate." This period is usually considered in the design phase.

1.2.2.3 Wear-Out Period.

Time $t2$ indicates the end of useful life and the start of the wear-out phase. After this point, the hazard rate increases. When the hazard rate becomes too high, replacement or repair of the population of products should be conducted. Replacement schedules are based on the recognition of this hazard rate.

Optimizing reliability must involve the consideration of the actual life-cycle periods. The actual hazard rate curve will be more complex in shape and may not even exhibit all of the three periods.

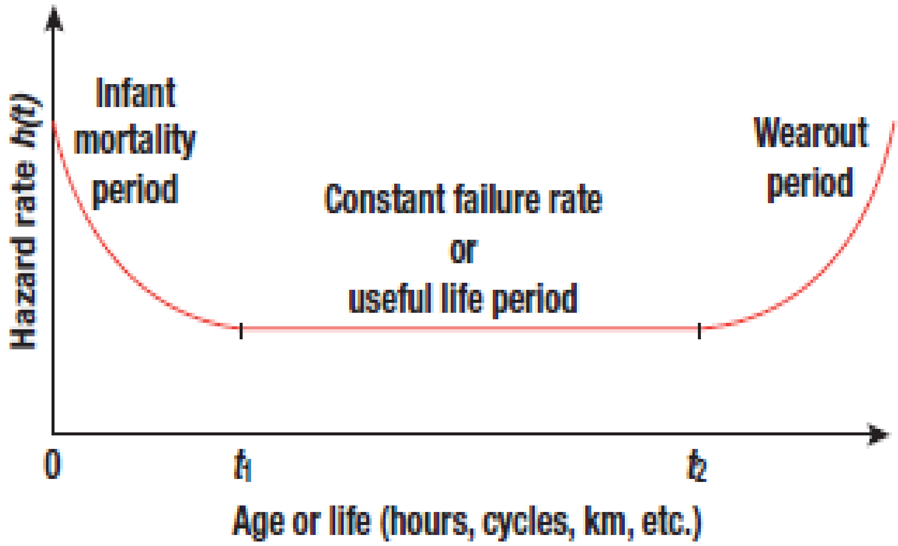


Fig 1: Bath Tub Curve of failure rate

1.2.3 PERCENTILE PRODUCT LIFE

The reliability of a product can be experienced in terms of percentiles of life. Because this approach was originally used to specify the life of bearings, the literature often uses the symbol B_α, where the B_α life is the time by which α percent of the products fail, or:

$$F(B_\alpha) = \frac{\alpha}{100}$$

1.2.7 Moments of Time to Failure

The mean or expected value of *T*, a measure of the central tendency of the random variable, also known as the first moment, is denoted as *E* [*T*] or μ, and given by

$$E[T] = \mu = \int_{-\infty}^{\infty} tf(t)dt$$

Higher order moments are discussed in the following section.

Moments about Origin and about the Mean

The *K*th moment about the origin of the random variable *T* is-

$$\mu'_k = E[T^K] = \int_{-\infty}^{\infty} t^k\, f(t)dt,\ k = 1,2,3, \dots$$

Expected Life or Mean Time to Failure

For a given underlying probability density function, the mean time to failure (MTTF) is the expected value for the time to failure. It is defined as-

$$E[T] = \text{MTTF} = \int_{0}^{\infty} t\, f(t)dt$$

Thus, *E* [*T*] is the first moment or the centre of gravity of the probability density function. *E* [*T*] is also called the mean time between failures (MTBF), when the product exhibits a constant hazard rate; that is, the failure probability density function is an exponential. The MTTF should be used only when the failure distribution function is specified, because the value of the reliability function at a given MTTF depends on the probability distribution function used to model the failure data. Furthermore, different failure distributions can have the same MTTF while having very different reliability functions.

Variance or the Second Moment about the Mean

Information on the dispersion of the values with respect to the mean is expressed in terms of variance, standard deviation, or coefficient of variation. The variance of the random variable T, a measure of variability or spread in the data about the mean, is also known as the second central moment and is denoted as V [T]. It can be calculated as-

$$\mu_2 = V[T] = E[(T - E[T]^2)] = \int_{-\infty}^{\infty} (t - E[T]^2) f(t)dt$$

Coefficient of Skewness

The degree of symmetry in the probability density function can be measured using the concept of skewness, which is related to the third moment, $\mu 3$. Since it can be positive or negative, a non-dimensional measure of skewness, known as the coefficient of skewness, can be developed to avoid dimensional problems as given below:

$$\alpha_3 = \frac{\mu_3}{\mu_2^{3/2}}$$

If α3 is zero, the distribution is symmetrical about the mean; if α3 is positive, the dispersion is more above the mean than below the mean; and if it is negative, the dispersion is more below the mean. If a distribution is symmetrical, then the mean and the median are the same. If the distribution is negatively skewed, then the median is greater than the mean. And if the distribution is positively skewed, then the mean is greater than the median.

Coefficient of Kurtosis

Skewness describes the amount of asymmetry, while kurtosis measures the concentration of data around the mean and is measured by the fourth central moment. To find the coefficient of kurtosis, divide the fourth central moment by the square of the variance to get a non-dimensional measure. The coefficient of kurtosis represents the peakedness or flatness of a distribution and is defined as:

$$\alpha_4 = \frac{\mu_4}{\mu_2^2}$$

1.3 Reliability Capability

1.3.1 Key Reliability Practices

The IEEE Reliability Program Standard 1332 (IEEE Standard 1332–1998; Pecht and Ramakrishnan 2000) defines broad guidelines for the development of a reliability program, based on three objectives:

1. The supplier, working with the customer, should determine and understand the customer’s requirements and product needs so that a comprehensive design specification can be generated.

2. The supplier should structure and follow a series of engineering activities so that the resulting product satisfies the customer's requirements and product needs with regard to product reliability.

3. The supplier should include activities that adequately verify that the customer's reliability requirements and product needs have been satisfied.

1.3.2 Reliability Requirements and Planning

During product development, the customer's needs and operational conditions for all phases of the product life cycle must be understood to arrive at a set of customer reliability requirements. The different considerations for establishing reliability requirements for a product include the design and operational specifications (information about the manner in which the product will be used), regulatory and mandatory requirements, definition of failure, expected field life, criticality of application, cost and schedule limitations, and business constraints, such as potential market size.

Establishing reliability requirements and planning early incorporates activities needed to understand customers' requirements, generates reliability goals for products, and plans reliability activities to meet those goals. The inputs for generating reliability requirements for products include customer needs, reliability data specifications for competitive products, and lessons learned from the reliability experience with previous products, including test and field failure data.

Fig 2: Key reliability practices

Reliability planning is needed to establish and maintain plans that define reliability activities and manage the defined activities. The planning activity starts with identifying available resources, such as materials, human resources, and equipment, and determining the need for additional resources. Reliability analysis and testing needed for the product and the logistics to obtain feedback on the implementation of these activities can be identified.

The output from this key practice is a reliability plan. The reliability plan identifies and ties together all the reliability activities. The plan should allocate resources and responsibilities and include a schedule to follow. Decision criteria for altering reliability plans can also be included.

1.3.3 Training and Development

Training and development enhances the specialized skills and knowledge of people so that they can perform their roles in the development of a reliable product effectively and efficiently. The aim is to ensure that employees understand the reliability plans and goals for products, and have sufficient expertise in the methods required to achieve those goals.

This includes the development of innovative technologies or methods to support business objectives.

1.3.4 Reliability Analysis

Reliability analysis incorporates activities to identify potential failure modes and mechanisms, to make reliability predictions, and to quantify risks for critical components in order to optimize the life-cycle costs for a product. Prior experience and history can be helpful in this analysis. The data used to make reliability predictions may be historical, from previous testing of similar products, or from the reported field failures of similar products.

Reliability analysis activities include conducting failure modes, mechanisms, and effects analysis (FMMEA) to identify potential single points of failure, failure modes, and failure mechanisms for a product. The next step is to identify the criticality of these failure modes and mechanisms. Criticality may be based on complexity, application of emerging technologies, demand for maintenance and logistics support and, most importantly, the impact of potential failure on overall product success. Reliability analysis also includes identification of reliability logic for products as a system, and creating reliability models at the component and product levels in order to make reliability predictions. Assessing adherence to design rules, including de-rating, electrical, mechanical, and other guidelines, is also a part of reliability analysis.

1.3.5 Reliability Testing

Reliability testing can be used to explore the limits of a product, to screen products for design flaws, and to demonstrate (or qualify) the reliability of products. The tests may be conducted according to some industry standards or to required customer specifications. The reliability testing procedures may be generic—that is, common for all products—or the tests may be custom designed for specific products. The tests may or may not be used for the verification of known failure modes and mechanisms.

Detailed reliability testing plans can include the sample size for tests and the corresponding confidence level specifications.

Important considerations for any type of reliability testing include establishing the nature of the test (failure or time terminated), the definition of failure, the correct interpretation of the test results, and correlating the test results with the reliability requirements for the product. The information required for designing product-specific reliability tests includes the expected life-cycle conditions, the reliability plans and goals for a product, and the failure modes and mechanisms identified during reliability analysis. The different types of reliability tests that can be conducted include tests for design marginality, destruct limits determination, design verification testing before mass production, ongoing reliability testing, and accelerated testing.

The output from this key practice is the knowledge obtained from different types of tests. Test data analysis can be used as a basis for design changes prior to mass production, for identifying the failure models and model parameters, and for modification of reliability predictions for the product. Test data can also be used to create guidelines for manufacturing tests, including screens, and to create test requirements for materials, parts, and subassemblies obtained from suppliers.

1.3.6 Failure Data Tracking and Analysis

Failure tracking activities are used to collect manufacturing, test, and field-failed components, as well as related failure information. Failures must then be analysed to identify the root causes of manufacturing defects and test or field failures and to generate failure analysis reports. These records can include the date and lot code of the returned product, the failure point (quality testing, reliability testing, or field), the return date, the failure site, the failure mode and mechanism, and recommendations for avoiding the failure mode in existing and future products. For each product category, a Pareto chart of failure causes can be created and continually updated.

The failure sources that initiate failure analysis of a product include manufacturing, production testing, reliability testing, pre- and post-warranty field returns, and customer complaints. Failure analysis includes statistical analyses of failure data and analysis of the cause of failure at various levels down to the identification of the root cause of failure.

1.3.7 Verification and Validation

Verification and validation through an internal review/audit of reliability planning, testing and analysis activities helps to ensure that planned reliability activities are implemented so that the product fulfils the specified reliability requirements. Benchmarking can be used to study the best internal practices that produce superior reliability performance and for ensuring that noncompliance is addressed. Part of the process is to understand how some practices are better than others and to find ways to improve others by pushing for improved facilities, equipment, and methodologies.

The inputs for this key practice are the outputs from previous practices like planning, analysis, testing, and failure data tracking. The inputs include reliability plans and goals for products, potential failure modes and mechanisms identified during reliability analysis, information on failure mechanisms from reliability testing, specific reliability test plans and specifications, and the corrective actions database. Verification and validation activities include comparison of identified potential problems against those experienced in the field. This includes comparison of expected and field failure modes and mechanisms and of reliability prediction models for a product against field failure distributions.

The outputs from this key practice include an updated failure modes and mechanisms database, modification of reliability predictions and failure models for a product, and modification of warranty costs and spares provisioning. Reliability test conditions may also be modified based on field information on products.

1.3.8 Reliability Improvement

Reliability improvement is concerned with applying lessons learned from testing, reported field failures, technological improvements, and any additional information from previous tests or experiences. This key practice primarily involves implementing corrective actions based on failure analysis. It also involves initiating design changes in products or processes due to changes in reliability requirements or in life-cycle application conditions (operating and non-operating).

Reliability improvements can be affected either by making design changes in products or by using alternative parts, processes, or suppliers. Design changes can include an improved design using an established technology, or implementing developing technologies within an older design. New modelling and analysis techniques and trends that could improve reliability can also be used.

The inputs required to initiate reliability improvement also come from previous key practices. Such information includes Pareto charts for field failure modes and mechanisms, recommendations from the corrective actions database, and documented anomalies from verification and validation. Other factors that can initiate a reliability improvement process are changes in life-cycle usage conditions for a product or changes in reliability requirements due to business or other considerations.

The outputs from this practice include methods to prevent the recurrence of identified failures and implementation of corrective actions stemming from failure analysis. Corrective actions can be implemented by issuing engineering change notices, or through modifications in manufacturing and design guidelines for future products.

Chapter 2

2.1 Prior Art

Many authors have studied various well completion methods under different downhole conditions. Some of them have discussed sand production consequences, while, few specialists have worked on sand control method selection.

Tausch and Corley (1958) found the economics and selection of the sand control method, based on bridging and consolidation of sand grains, is a function of the expected producing rate, time periods of work over's, location, and condition of wells.

Tiffin et al. (1998) proposed new criteria for screen and gravel selection for sand control. These criteria are mainly based on reservoir sand size distribution. Hodge et al. (2002) developed a valuation method for a stand-alone screen design, and gravel packed completion with consideration of plugging resistance and sand retention.

Denney (2002) worked on field and laboratory tests to evaluate the relative effectiveness of two types of sand control methods used in the field with respect to optimizing operating expense.

Farrow et al. (2004) used a new method based on the combination of a sand control matrix and flowchart. Accordingly, the selection criterion was compared conforming to a probability of consequence ranking. Selection criteria were reservoir management, Particle Size Distribution (PSD), well condition and shales, installation risk and reliability, and cost.

Mathisen et al. (2007) studied the importance of the selection of the screen process and fluid qualification. The authors presented a sand control selection method, which takes into account the effects of screen type, fluid qualification process, sand retention, and plugging properties.

Slayter et al. (2008) presented a methodical framework with consideration of tasks (sand screen selection), activities (petrology analysis), and objectives (productivity) for designing as and control.

Chanpuraetal (2011) proposed a new method for selecting optimum stand-alone screen (SAS) based on sand-retention performance, and screen/sand pack permeability analysis to maximize productivity.

Latiff (2011) presented a Modified flowchart, which takes into account the effects of several parameters including the length of production zone, well inclination, and particle size distribution on sand control method selection.

Chan et al. (2013) investigated the effects of various factors including well life, type of well completion and particle size distribution on maximizing recovery of oil and gas per well for the long-term production life cycle.

Khamehchi et al. (2015) studied the optimum sand control selection by considering screen types, mechanical skin, and economic assessment. They concluded that in the case of low oil production rate, factors of the reservoir productivity index, oil price, and time of capital return are more important than sand control skin. In general, it is better to preliminary analyzing the predictive models, regardless the sand production is happening or not.

Many researchers have studied the sand-production prediction models using different methods including numerical, analytical models (Morita et al., 1989a, 1989b; Khamehchi and Reisi, 2015), and experimental tests (Van den Hoek et al., 1996; Fattahpour et al., 2012).

A review of previous studies shows that all sand control selection methods consider only a limited number of criteria in determining the best method. Nonetheless, there are many factors influencing the selection simultaneously.

Due to the complexity and uncertainties found in the field of petroleum engineering, considering these factors is valuable (Latiff, 2011).

Slope instability can be catastrophic events often leading to loss of life and property. It is widely recognized that there are multiple failure modes induced by structural planes in rock masses How to assess the system reliability of rock slopes have received extensive attentions recently. For example, Low investigated the system reliability of a rock wedge with four failure modes by employing the First Order Reliability Method (FORM).

Jimenez Rodriguez et al. and Jimenez-Rodriguez and Sitar used a disjoint cut-set formulation in which each cut set corresponds to a failure mode.

Li et al. proposed a non- dimensional equivalent method to study the system reliability of rock slopes with multiple correlated failure modes.

Lee et al. developed a knowledge-based clustered partitioning (KCP) technique for the system reliability analysis of rock wedges.

Johari and Lari performed system reliability analysis of rock wedges with four correlated failure modes using a sequential compounding method (SCM).

This study proposes a simulation based on a combination of Multiple-Criteria Decision-Making (MCDM) and Design of Experiment (DOE) techniques. MCDM is a part of operations research, which explicitly appraises multiple inconsistent criteria in the decision making process. There are several MCDM methods including Analytic Hierarchy Process (AHP), Elimination and Choice Expressing Reality (ELECTRE) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Zavadskas et al., 2014). After selection of best sand control method by applying MCDM, DOE and Response Surface Methodology (RSM) are used to optimize the parameters of the best-selected sand control method. DOE is a powerful technique to gain maximum information from a data set with the minimum number of experiments. In this regard, Full Factorial design (FFD) is used to perform required reservoir simulations. FFD is one type of DOE in which one can measure responses at all combinations of the factor levels. Also, Response Surface Methodology (RSM) is a collection of statistical methods to develop a significance mathematical relationship between various independent factors and one or more dependent variables. Finally, simulation is applied to perform sensitivity and uncertainty analysis of the derived proxy equation of NPV for the best-selected sand control method.

2.2 Gap Analysis

The design of an optimal sand control method and production management is a complex problem due to the simultaneous influence of various factors. Typical effective variables for choosing an optimum sand control method include geological, technical, economical, and expert's experience on similar projects. Some technical factors, which affect the optimum method, are the type of exclusion, gravel size of gravel pack and pre-packed screen, slot width and liner slot length, and productivity index reduction. The situation could be more complicated due to the uncertainty associated with various contributing factors. Therefore, it is crucial to develop a novel approach based on simulation in order to select the best sand control method with a maximum level of confidence.

Table 2: list of literature reviews

Sl no	Thesis title	Author and Year	Areas covered	Issues not addressed
1.	Optimum selection of sand control method using a combination MCDM & DOE techniques	Mohammad Hossein Shahsavari, Ehsan Khamehchi 2018	To select an optimal sand control method, MCDM techniques including AHP, TOPSIS and ELECTRE are used. To simulate fluid flow, an integrated model of reservoir, well, and surface facility is used based on actual oil field data collected from the south of Iran. Then, DOE and RSM are applied to optimize the controllable variables of the best selected sand control method by MCDM. Finally, MCS is applied to perform sensitivity and uncertainty analysis in order to determine the crucial factors that control net present value (NPV).	The investigation of the sensitivity and uncertainty Analysis has shown that the greatest uncertainty in estimating the best variables of the slotted liner is associated with two factors of slot width and slot density. But in actual practice there are so many factors that should be counted. Therefore, these factors should carefully be characterized prior to designing the best slotted liner for the sand control in order to maximize NPV.
2.	Reliability and validity of the simulation	Teresa A. Bates, Patricia C. Clark 2018	Psychometric properties of the English version of the Simulation Learning Effectiveness Inventory, which	Although the sample size was adequate for the analysis conducted, larger samples are needed to

Sl no	Thesis title	Author and Year	Areas covered	Issues not addressed
	learning effectiveness inventory		included internal consistency reliability and construct validity with factor analysis, were examined in a sample of 132 undergraduate nursing students.	conduct EFA and CFA. The English version of the SLEI used, with minor wording changes, was the one reported in Chen et al. (2015) and in that article there are no details of the translation process used for the instrument.
3.	Analytical model for fast reliability evaluation of composite generation and transmission system based on sequential Monte Carlo simulation	LvbinPeng, Bo Hu, KaiguiXie, Heng-Ming Tai, Kaveh Ashenayi & 2019	This paper proposes an analytical reliability evaluation (RE) model for composite generation and transmission system (CGTS) based on the sequential Monte Carlo simulation (MCS) method. The main idea is to partition the chronological system state sequence produced by sequential MCS into a set of mutually exclusive events based on the law of total probability. An analytical model is developed by extracting the component reliability parameters (CRPs) from system reliability index calculation formula of each mutually exclusive event. A 4-unit generation system, the CGTS of IEEE-RTS system and a 91-bus power system are used	The proposed analytical model is based on the sequential MCS, it can be easily applied to the reliability analysis of power systems incorporating renewable energy.

Sl no	Thesis title	Author and Year	Areas covered	Issues not addressed
			for case study to validate the correctness and effectiveness of the proposed analytical RE model.	
4.	A Monte Carlo Simulation-based Decision Support System for Reliability Analysis of Taiwan's Power System: Framework and Empirical Study	Hsiang-Hua Yu, Kuo-Hao Chang, Hsin-Wei Hsu, Robert Cuckler 2019	Considering a general national power system that consists various sources of renewable and conventional power, the proposed framework allows for a scenario-based calculation under the realistic situation that various conventional energy sources can be ramped up to dynamically meet losses of load. To make the methodology more user-friendly and applicable to power systems, a decision support system was developed.	A reliability analysis of Taiwan's power system was conducted to show how to evaluate the impact of energy policy by 2025. Sensitivity analyses on two scenarios (with and without limiting coal-fired power generation) on LOLE were done. A recommendations related to the reliability of the power system under Taiwan's energy transition were provided.
5.	Route Reliability Based Simulation Model for HMA Delivery in Urban Areas	Mario Galic, Ivana Barisic, Irena Istoka Otkovic & 2017	As an optimization problem the model is structured as a combination of the well-known optimization problems (i.e. transportation and vehicle routing problem).	The model was tested on a small scale case study problem of HMA delivery in city of Osijek. The results have proved that the model has the potential to become a useful planning and optimization tool for solving such problems.
6	Time-variant	Weiqi Du ,	Parallel subset simulation is	Two numerical examples

Sl no	Thesis title	Author and Year	Areas covered	Issues not addressed
	reliability analysis using the parallel subset simulation	Yuan xin Luo , Yongqin Wang& 2017	applied to deal with time-dependent reliability analysis in this paper. A new method is proposed to construct a function called principal variable. The principal variable can represent limit state at each time instant to generate conditional samples. The update procedure of ―principal variable‖ should be set at each simulation stage to keep the correlations between principal variable and n_t limit states strong.	are used to demonstrate the effectiveness and accuracy of the developed parallel subset simulation for time-variant reliability analysis.
7.	Warship reliability evaluation based on dynamic bayesian networks and numerical simulation	Xiao Feng Liang, Hong Dong Wang, Hong Yi, Dan Li& 2017	The proposed method is the inheritance and development of current methods for reliability evaluation based on numerical simulation. Hence, it overcomes the limitations of the analytic method and multilevel synthesis method, as well as provides an effective means for the reliability evaluation of warships.	The proposed method is suitable for the overall reliability evaluation not only of warships but also of other complex dynamic systems.
8.	New simulation-based frameworks for multi-	Naser Safaeian Hamzehkolaei, Mahmoud	The valuable characteristic of presented approaches is that only one simulation run is required for WSM during entire optimization process, even if	WSM-NSGA-II out performs NSWSM in terms of solutions quality and computational efficiency, specifically for

Sl no	Thesis title	Author and Year	Areas covered	Issues not addressed
	objective reliability-based design optimization of structures	Miri, Mohsen Rashki 2018	solutions for different levels of reliability be desired. Illustrative examples indicate that NSWSM with the proposed local search strategy is more efficient for small dimension continuous problems.	discrete MORBDOs. Employing global optimizer in WSM-NSGA-II provided more accurate results with lower samples than NSWSM.
9.	Experimental estimation of time variant system reliability of vibrating structures based on subset simulation with Markov chain splitting	S.D. Sonal , S Ammanagi , O Kanjilal , C.S. Manohar 2017	The study investigates the application of ideas from variance reduction schemes, developed in the area of computational structural reliability modelling, to the problems of experimental estimation of time variant reliability of randomly excited vibrating structures. The study considers series/parallel system reliability of vibrating systems under multi-component random excitations. An experimental protocol, based on subset simulation with Markov chain splitting, is proposed to estimate probabilities of failure as low as 10^{-5} to 10^{-4} with a relatively smaller number of samples and hence with reduced test times. Illustrative examples consist of earthquake shake table studies on a three-storied bending-	The inelastic behaviour of the material is expected to manifest locally (e.g., in vibration isolators, braces, etc.,), it seems feasible to extend the procedure proposed in this paper in a reasonably simple manner. Work on expanding the scope of the present study, to include these features, is being pursued by the authors.

Sl no	Thesis title	Author and Year	Areas covered	Issues not addressed
			torsion coupled building frame under bi-axial non-stationary, random earthquake support motions.	
10.	Efficient system reliability analysis of rock slopes based on Subset simulation	Shui-Hua Jiang, Jin song Huang, Chuang-Bing Zhou 2017	This paper proposes an efficient approach for the system reliability analysis of rock slopes. The correlations among multiple potential failure modes are properly accounted for with the aid of the ‘‘max” and ‘‘min” functions. A benchmark rock slope and a real engineered rock slope with multiple correlated failure modes are used to demonstrate the effectiveness of the proposed approach.	The proposed approach can work as an effective reliability based method for rock slope engineering.
11.	Choosing an optimum sand control method	Ehsan Khamehchi, Omid Ameri, Ali Alizadeh 2014	This paper found the best sand control method is the result of thorough study. Global oil price, duration of sand control project and costs of necessary equipment for each method as economic and politic conditions and well productivity index as reservoir parameter are the main parameters studied in this paper.	At low production rate and for low PI reservoirs, choice of suitable method is influenced by global oil price and investment interest rate. In other words, choice of suitable method is not directly affected by the well skin.
12.	Effects of different secondary biological	Weixiao Qi, Hua Zhang, Ruiping Liu,	Four classical STPs in Beijing (A~D) with different secondary biological treatment processes but all with flocculation and	Flocculation and sand-filtration performed not well in removing DBPs precursors especially for

Sl no	Thesis title	Author and Year	Areas covered	Issues not addressed
	treatment processes followed by flocculation and sand-filtration on subsequent DBPs control from sewage treatment plants	Huijuan Liu, JiuhuiQu 2018	sand-filtration as advanced treatment process were selected to investigate DBPs formation potentials and DOM characterization variation during these processes and their relation trichloroacetic acid (TCAA) and dichloroacetic acid (DCAA) dominated among four trihalomethanes (THMs) and nine haloacetic acids (HAAs) formation potentials respectively during chlorination of both secondary and sand-filtration effluents with the order of TCAA>chloroform>DCAA.	chloroform and DCAA except for C STP, which had higher hydrophobic fraction percentage removal and molecular weight decreasing during the advanced treatment process.
13.	A new approach to DEM simulation of sand production	Yifei Cui, Alireza Nouri, Dave Chan, Ehsan Rahmati 2015	This paper presents a model for the investigation of sand stone degradation and sand production mechanisms coupled with fluid flow analysis using the Discrete Element Method (DEM). The model was used to investigate the effects of in-situ stresses and flow rate on sand production.	Boundary stress dominated the sanding response at higher boundary stress conditions. Much lower sanding occurred under higher boundary stresses but low boundary fluid pressures. High tangential stresses around the bore hole caused by high confining stress resulted in strong frictional interlocking that alleviated sand production. Thus

Sl no	Thesis title	Author and Year	Areas covered	Issues not addressed
				Massive sanding was observed at lower far-field stress but higher boundary pore pressure.
14.	Experimental investigation on chemical grouting of inclined fracture to control sand and water flow	Yankun Liang, Wanghua Sui,*, Jianfeng Qi 2019	This paper presents an experimental investigation of the propagation of chemical grout in an inclined fracture model to control sand and water flow. The experimental grouting setup for an inclined fracture examines the propagation of chemical grout in water and sand flows by considering the different inclination angles of the fracture.	The experimental work is not intended to simulate any specific project and the experimental design is not strictly followed similarity law. Never the less, the results in this study have important engineering implications in underground engineering or landslides control. It is found that increases in the settling rate of sand particles stop water and sand flow. Therefore, it is vital to take steps to increase particle sedimentation, such as reducing the gelling time during grouting. A shorter gelling time should be used in an area that has fractures with a greater inclination angle.
15.	Disturbance of the inclined	Jian-jun Cheng, Jia-qiang Lei,	The paper indicate that the inclined inserting-type sand fence was able to deflect the	Among the sand control engineering systems laid out along the railways, the

Sl no	Thesis title	Author and Year	Areas covered	Issues not addressed
	inserting-type sand fence to wind–sand flow fields and its sand control characteristics	Sheng-yu Li, Hai-feng Wang& 2015	flow of the sand and was able to easily form an upward slant acceleration zone on the leeward side of the sand fence. It has shown by the percentage change in sand collection rates on the windward side and the leeward side of the sand fence, the sand flux per unit area at 4 m height in the slant upward direction increased on the leeward side of the inclined inserting-type sand fence.	inclined inserting-type sand fence only represents one type, and sand-resistance engineering measures are usually a combination of sand-stabilization engineering measures to maximally control the effects of passing drift sand on railways.
16.	A hydro-mechanical sand erosion model for sand production simulation	Xiaorong Li, YongcunFeng, K.E. Gray & 2018	This paper presents a finite element based approach for simulating the realistic sanding process, considering coupling between mechanical failure and hydrodynamic erosion of the rock. A well calibrated sand criterion proposed by Papamichos was implemented to model sand erosion. An adaptive meshing technique was used to track receding of the eroded surfaces and to progressively modify boundary conditions on new surfaces, which are important for capturing the realistic sanding process.	Calibration of this approach with experimental results and field data is needed to provide further confidence for field applications.
17.	Incorporation	Xuezheng	This paper is based on Foamed	The regularity of the

Sl no	Thesis title	Author and Year	Areas covered	Issues not addressed
	of sand-based breathing bricks with foamed concrete and humidity control materials	Wang, WenyuanGao, Shuang Yan, MeihongNiu, Guishan Liu, HongshunHao & 2017	concrete with five densities were prepared without sintering, then compounded with the humidity controlling slurry to prepare the sand-based breathing bricks (SBB). The accurate porous parameters of foamed concrete were characterized and quantified by Image-pro Plus 6.0 and Matlab 2015a. The effect of these porous parameters on the properties of the SBB were investigated. The optimal physical, mechanical and humidity controlling properties of SBB were achieved with FCa9 of foamed Concrete.	change between the humidity controlling performance of SBB and the circularity factor is not very clear. Means that porosity and pore size are the main factors affecting the humidity controlling performance of SBB.
18.	Simulation test on mixed water and sand inrush disaster induced by mining under the thin bedrock	Weifeng Yang, Lu Jin, XinquanZhang & 2018	This paper has shown inclination angles under the water pressure of 0.06 MPa and 0.08 MPa. The results show that the water and sand inrush took place instantly in the mined area. Based on the characteristics of water pressure variations, changes in water pressure are divided into two phases: rising phase and lowering to stable phase. Under the other same conditions, when the fissure channel angle increases, the pore water	The test model of the mixed water and sand inrush transfer is designed and manufactured only to simulate the transfer and inrush process of the mixed water and sand inrush in the “\ /” type fracture channel which is wide at the top and goes narrower down to the base.

Sl no	Thesis title	Author and Year	Areas covered	Issues not addressed
			pressure and its sudden drop will increase too, and the inrushing process will get more rapidly; the bigger the water pressure is, the pore water pressure increases more rapidly and violently. From this, the transfer characteristics and dynamic mechanism of the mixed water and sand inrush were explored.	

2.3 AIM:

The design of an optimum sand control is a complicated process because choosing an optimum sand control method depends on different effective factors. These factors include the type of exclusion, gravel size of gravel pack and pre-packed screen, slot width and length of the slotted liner, PI reduction and operating costs. Optimum selection is further intricate due to the uncertainty associated with variables influencing sand control methods. Therefore, it is crucial to select the most appropriate method in terms of minimum skin (pressure drop), cost, and maximum net present value (NPV).

While both experimental and analytical models of sand control are necessary to understand the phenomenon, numerical models are essential for realistic predictions. A review of previous studies shows that all sand control selection methods consider only a limited number of criteria in determining the best method. Nonetheless, there are many factors influencing the selection simultaneously.

2.4 OBJECTIVES:

i. Sand control methods may be classified as mechanical and chemical. Mechanical methods of sand control prevent sand production by stopping the formation with liners, screens or gravel packs. Larger formation sand grains are stopped, and they in turn stop smaller formation sand grains. So there will be a chance to develop a reliability based approach that can tell the sand production control where to control and when it is to be controlled?

ii. Another objective of this study is to design reliability based guideline in the form of a visual chart that can potentially be used in practice when optimal sand control methods and implementation of completion techniques are considered in sand producing wells. The flow chart could also serve as a tool during the decision-making process where sand control is deemed necessary.

iii. In the process of sand control reliability, trial information is utilised in the development production and actual application stages. Mathematical statistics, numerical simulation or other methods are then employed in the interval estimation of sand control reliability indexes under given conditions.

2.5 SCOPE OF PRESENT INVESTIGATION:

The solid material produced from a well can consist of both formation fines and load bearing solids. The production of fines cannot normally be prevented and is actually beneficial. The critical factor to assessing the risk of sand production from a particular well is whether or not the production of load bearing particles can be maintained below an acceptable level at the anticipated flow rates and producing conditions which will make the well production acceptable.

Compressive strength shows how strong the individual sand grains are bound together. The cementation is typically a secondary geological process for consolidation. Poorly consolidated sandstone formations usually have a compressive strength that is less than 1,000 pounds per square inch. This indicates that sand production is normally a problem when producing from poorly consolidated sandstone. This problem may be solved by predicting the compressive strength by reliability based random simulation forecasting.

Resin injection simply considered as artificial consolidation of sand. Which Involves injection of plastic resins, which are attracted to the formation sand grains. The resin hardens and forms a consolidated mass, binding the sand grains together at their contact points. If successful, the increase in formation compressive strength will be sufficient to withstand the drag forces while producing at the desired rates. The resins are in a liquid form when they enter the formation and a catalyst or curing agent is required for hardening. Some systems use “internal” catalysts that are mixed into the resin solution at the surface and require time and/or temperature to harden the resin.

Gravel pack has been used in industry since 1930s; today it's the most widely used on sand control treatment. Gravel packing account for three quarters of the sand control treatments.

Gravel packing relies on the bridging of formation sand against larger sand with the larger sand positively retained by a slotted liner or screen. The larger sand (referred to as gravel pack sand or simply, gravel) is sized to be about 5 to 6 times larger than the formation sand. Gravel packing creates a permeable downhole filter that will allow the production of the formation fluids but restrict the entry and production of formation sand. Because the gravel is tightly packed between the formation and the screen, the bridges formed are stable, which prevents shifting and resorting of the formation sand. If properly designed and executed, a gravel pack will maintain its permeability under a broad range of producing conditions.

Gravel packs are performed by running the slotted liner or screen in the hole and circulating the gravel into position using a carrier fluid. For optimum results, all the space between the screen and formation must be completely packed with high permeability gravel pack sand. Complete packing is relatively simple in open hole completions, but can be challenging in cased hole perforated completions. Although expensive, gravel packs have proven to be the most reliable sand control technique available and are, therefore, the most common approach used.

Improper formation sand sampling techniques can lead to gravel packs which fail due to plugging of the gravel pack or the production of sand. Because the formation sand size is so important, the technique used to obtain a formation sample is also important. In well producing sand, a sample of the formation sand is easily obtained at the surface. Although such a sample can be analysed and used for gravel pack sand size determination, produced samples will probably indicate a smaller median grain size than the formation sand. The most representative formation sample is obtained from conventional cores. In the case of unconsolidated formations, rubber sleeve conventional cores may be required to assure sample recovery. Although conventional cores are the most desirable formation sample, they are not readily available in most cases due to the cost of coring operations.

Sieve analysis is the typical laboratory routine performed on a formation sand sample for the selection of the proper size gravel pack sand. Sieve analysis consists of placing a formation sample at the top of a series of screens which have progressively smaller mesh sizes. The sand grains in the original well sample will fall through the screens until encountering a screen through which that grains size cannot pass because the openings in the screen are too small. By weighing the screens before and after sieving, the weight of formation sample retained by each size screen can be determined.

There have been several published techniques for selecting a gravel pack sand size to control the production of formation sand. The technique most widely used today was developed by Saucier. The basic premise of Saucier’s work is that optimum sand control is achieved when the median grain size of the gravel pack sand is no more than six times larger than the median grain size of the formation sand. Saucier determined this relationship in a series of core flow experiments where half the core consisted of gravel pack sand and the other half was formation sand as illustrated in Figure

Maintenance and work over is a passive approach to sand control. This method basically involves tolerating the sand production and dealing with its effects as and when necessary. Such an approach requires bailing, washing, and cleaning of surface facilities on a routine basis to maintain well productivity. This approach can be successful in specific formation and operating environments. The maintenance and work over method is primarily used where sand production is limited, production rates are low, risk of performing some service is low and economically feasible, or in marginal wells where the expense of other sand control techniques cannot be justified. Of importance are the formation characteristics, which determine how much sand is produced and the effects on safety and productivity.

Chapter 3: CASE STUDY UNDERTAKEN

3.1 SYSTEM DESCRIPTION:

In order to perform the required reservoir simulations with the sand control option, an actual carbonate reservoir was selected in the south of Iran. The geometry of the field has been modelled using corner-point geometry. This model contains 83×115×28 grid blocks, of which156631 blocks are active. The field contains 24 production wells that are completed in the oil column and 19 wells have sand production problems. The wells operate under constant-rate production constraints. After falling below a limiting bottom hole pressure, they will switch to a BHP-constraint. The Particle Size Distribution (PSD) method is used for designing the sand control method. Using PSD method, samples of the formation sand are evaluated to determine the median grain size diameter and the grain size distribution. For this purpose, a sieve analysis is performed on a formation sand sample to select the proper-sized gravel-pack sand. In this regard, the weight of formation sample, retained by each size screen, can be specified by weighing the screens before and after sieving. Then, the cumulative weight percent of each sample against screen mesh size is plotted on semi-log coordinates to obtain a sand size-distribution plot. According to formation grain size distribution plot, reading the graph at the 50% cumulative weight shows the median formation grain size diameter (d50). This procedure is the basis of the sand control method designing, for example, grains of gravel pack method is defined when the median grain size of the gravel-pack sand, D50, is no more than six times larger than the median grain size of the formation sand, d50 (Zhang et al., 2014).

Formation sand size is between 0.00032and 0.00125m in diameter. The following shows that the formation grains are coarse. The sand control properties are designed Based on below given Figure.

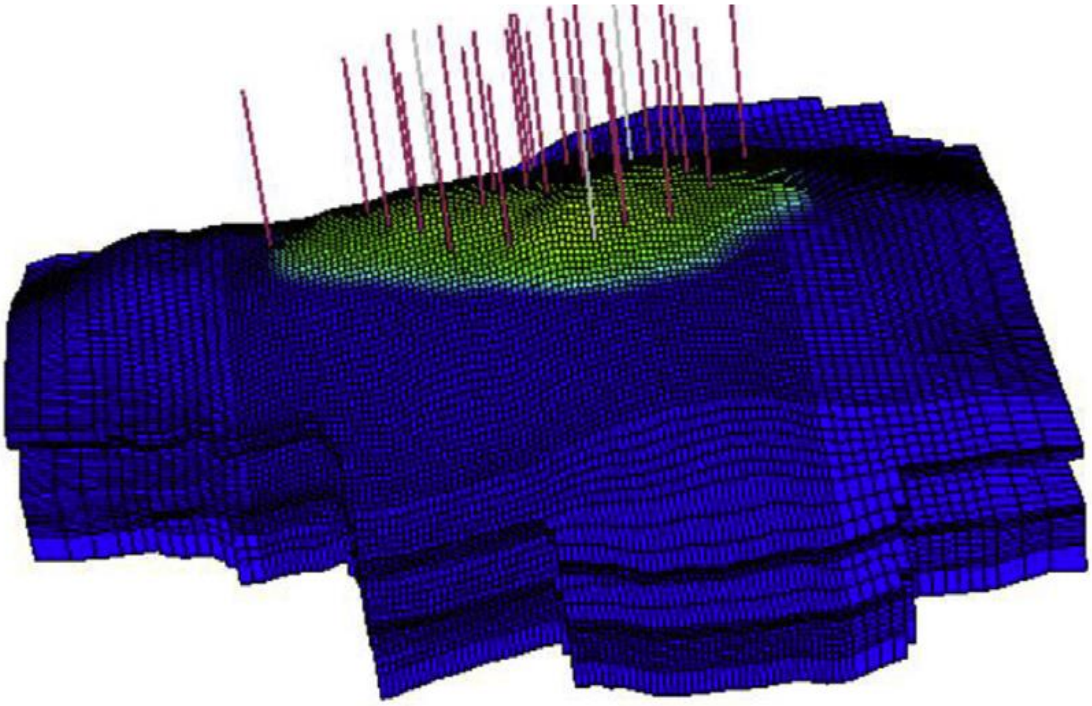


Figure3: 3D Reservoir Model

Table 3

Properties of the simulated reservoir

Properties	Value
Producing tubing ID	0.0760984m
Top of producing sand face	4107.13m
Wellhead temperature	25°c
Production fluid	Oil
Thickness of producing layer	30.5m-91.5m
Wellbore radius	0.1098m

Table 4: Fluid properties and reservoir data

Properties	Value
Reservoir pressure	60673861.6Pa
Solution GOR	1.721 MSCF/STB
Oil gravity	33.71API
Gas gravity	0.83 sp. gravity
Oil viscosity	0.296 CP
Oil FVF	1.898 RB/STB
Bubble point pressure	33694677.46Pa
Reservoir temperature	145.722°c

Table5: Well test data

Properties	Value
Skin factor	0–25
Average reservoir permeability	110 md

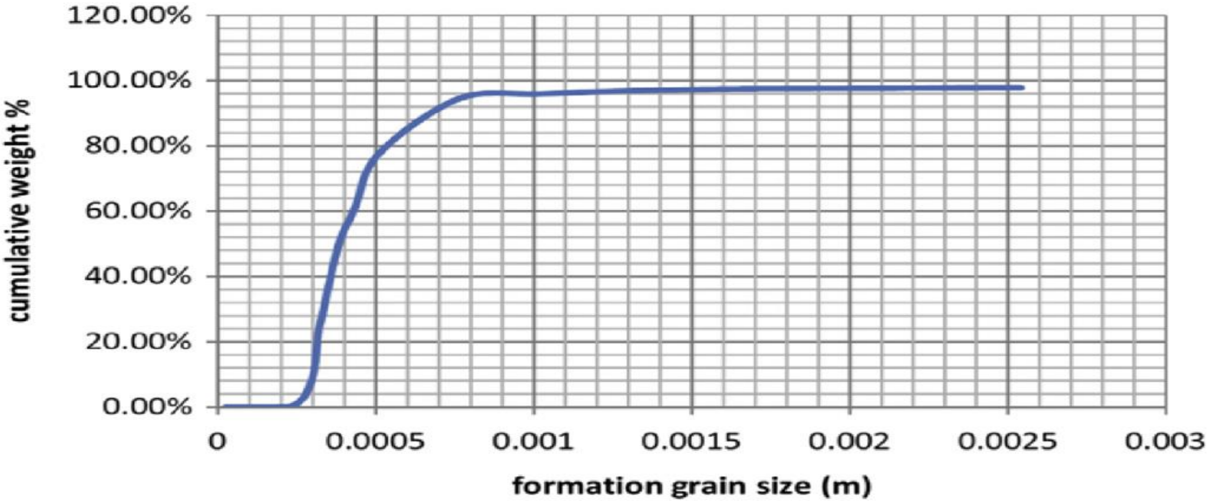


Fig4: Formation grain size distribution (adapted from Iranian Oil Company)

3.2 Properties of the sand control methods

3.2.1 Gravel Packs

While the selection of sand control completion depends on knowledge of the formation properties and will vary with geographic location, gravel packing has been a globally dominant technique since the turn of the century. In gravel pack operations, a screen is placed in the wellbore and the surrounding annulus is packed with high permeability gravel sized to prevent the passage of formation sand. The main objective is to stabilize the formation while causing minimal impairment to well productivity, which means that it is critical to completely pack the space between the screen and formation, preventing the movement of formation sand. If properly designed and installed, a gravel pack will maintain its permeability under a broad range of producing conditions.

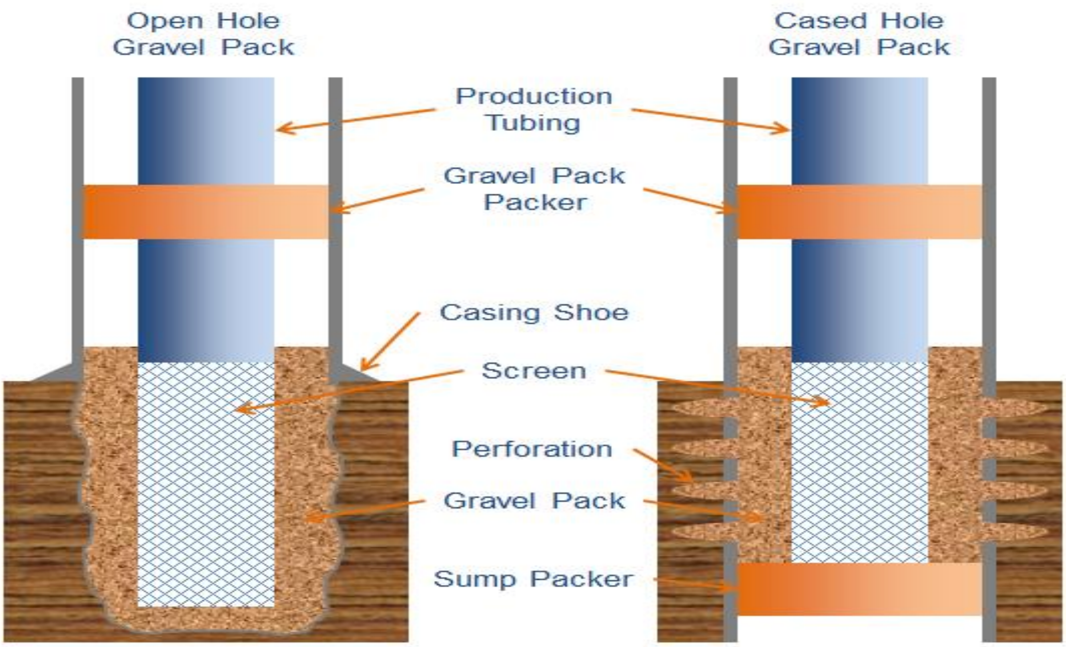


Figure5: Gravel pack

Table6: Gravel pack method data

Gravel pack	Value
Mesh size	30/50
Permeability	90 D
Length of penetration	0.1525m

3.2.2 Slotted liner

Slotted liner is a popular sand control screen in long horizontal completions and low productivity wells. Precision slotted liners are manufactured by CNC controlled slotting machines or laser machine. All slots are de-burred, cleaned and drift tested according to API standards. Base pipe are per API casing or tubing specification with diameters from 1.5 inch to 18 inch. Pipe lengths of any diameter are available.

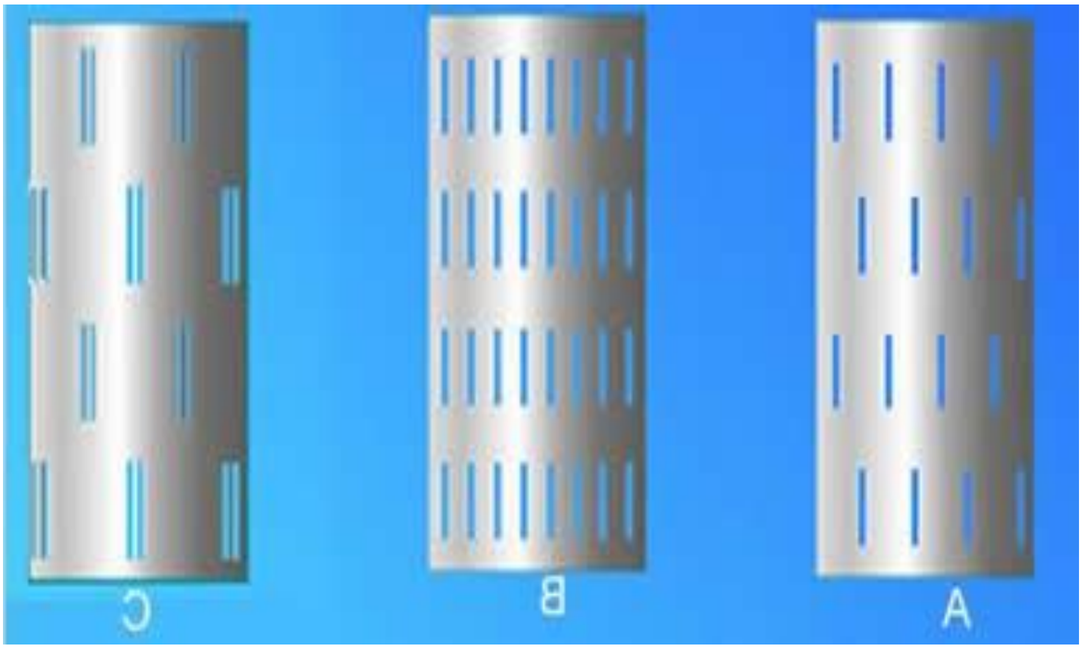


Figure 6: Slotted liner

Table7: slotted liner method data

Slotted liner	Measurements
Liner inner radius	0.0687324m
Liner outer radius	0.0738378m
Slot height	0.2032m
Slot width	0.001016m
Shot density	18.605/m

3.2.3 Pre packed sand screen

It contains perforated base pipe, inner and outer screen jackets and graded sand between the jackets. It is a modification of wire wrapped screen which is used in well sorted sand or stand-alone completion. Graded sand, with or without resin coating, is considered as a filter for reservoir particles. Wire wrapped pre packed sand control screen is used in wells where conventional gravel packing is not feasible or economical. The thickness of gravel layer can be varied to meet special requirement.

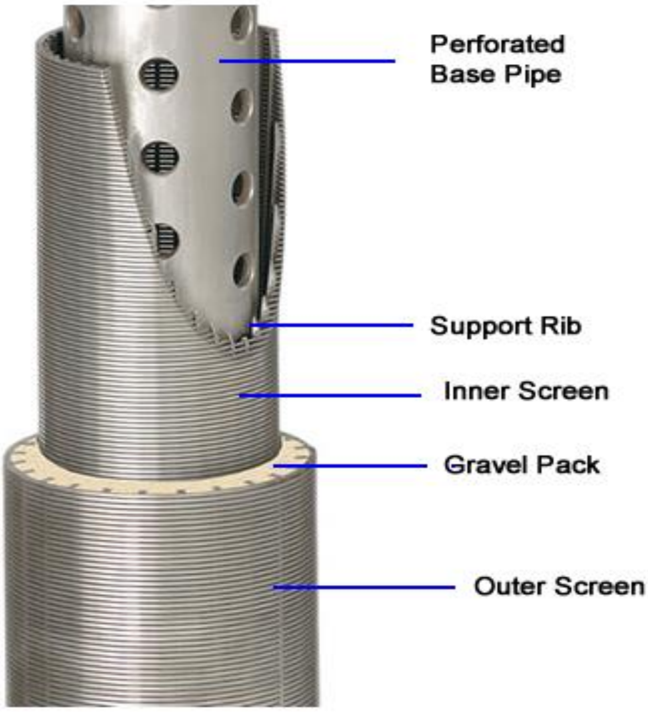


Figure 7: Pre-Packed Screen

Table 8: slotted liner method data

Pre-packed	Measurements
Screen inner radius	0.0540004m
Screen outer radius	0.05681472m
Screen permeability	5000 md

3.2.4 Wire wrapped screen

A type of screen used in sand control applications to support the gravel pack. To form the screen, a profiled wire is wrapped and welded in place on a perforated liner. Screens are available in a range of sizes and specifications, including outside diameter, material type and the geometry and dimension of the screen slots. The space between each wire wrap must be small enough to retain the gravel placed behind the screen, yet minimize any restriction to production.

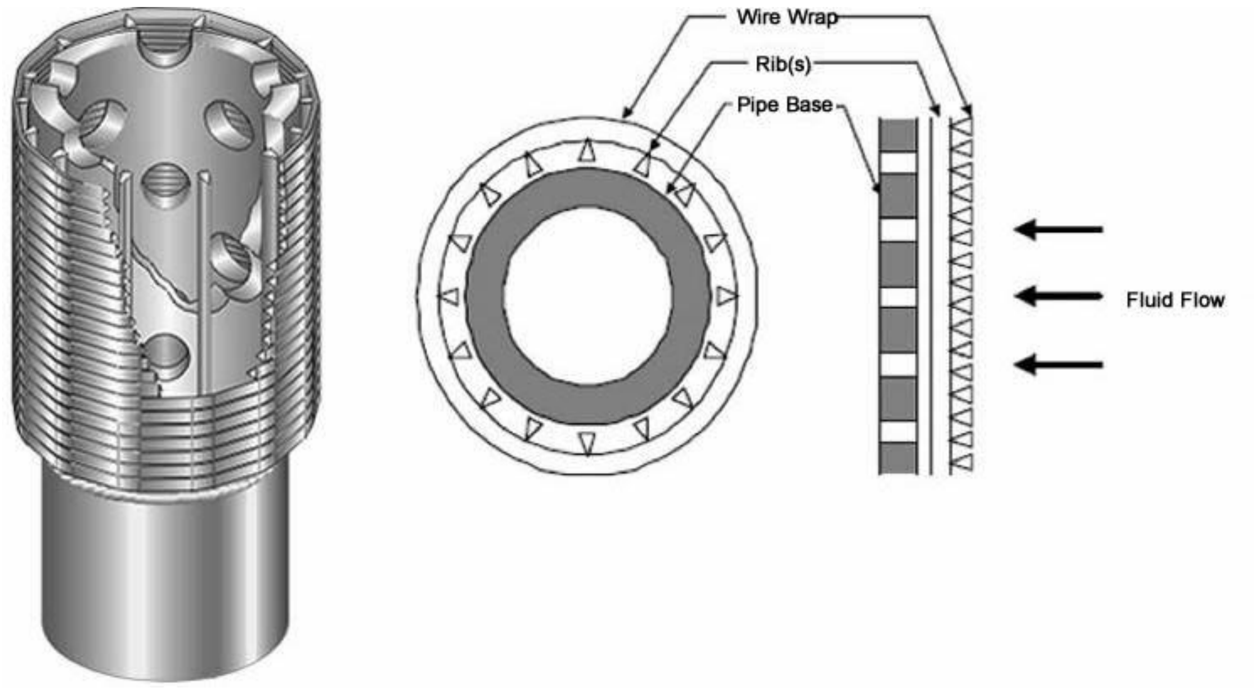


Fig 8: Wire wrapped screen

Table 9: slotted liner method data

Wire wrapped	Measurements
Screen inner radius	0.067001136 m
Outside permeability	1000 md

Chapter 4: DATA ORGANIZATION AND COMPETITION

4.1 TOPSIS for sand control method selection

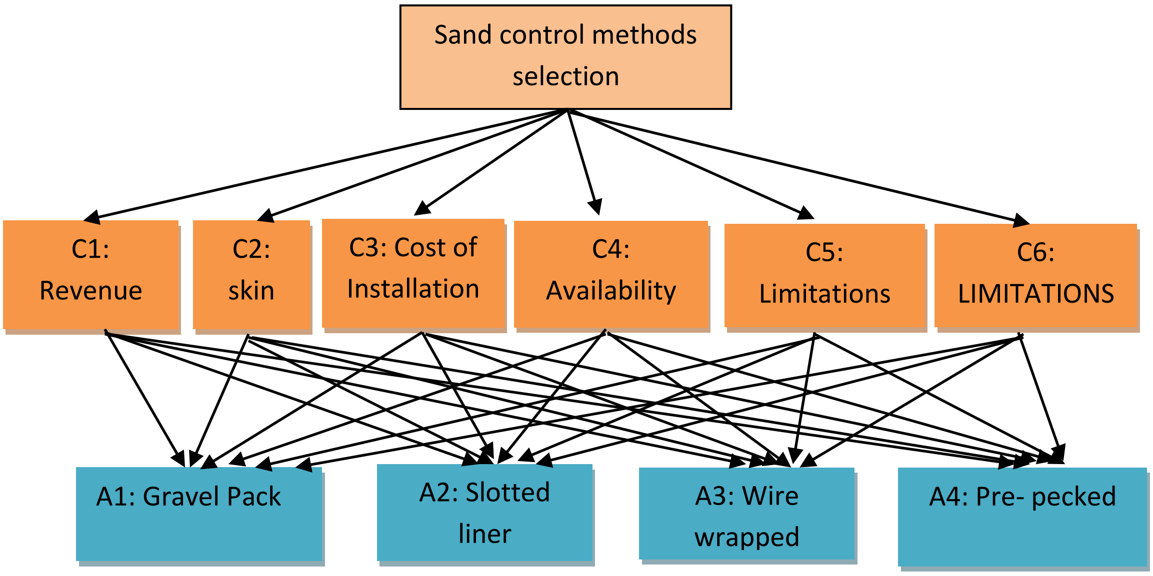


Fig 9: The criteria and alternatives

Table 10: Intensity and explanation for comparing i rows with j column in a matrix of pairwise comparisons

Intensity	Definition	Explanation
1	Equal importance	Two activities contribute
3	Moderate importance	Slightly favors one over another
5	Essential or strong	Strongly favors one over another
7	Demonstrated importance	Dominance of the demonstrated in practice
9	Extreme importance	Evidence favoring one over another of highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed

Table 11: Different alternatives and criteria as a Decision matrix

ALTERNATIVES	OBJECTIVE FUNCTIONS					
	Revenue (+)	Skin (-)	Cost of installation (-)	Availability (+)	Limitation (-)	Reliability (+)
Gravel pack	63450318257.76	9.595	6350000	High	Very High	Moderate
Slotted liner	63736507202.97	3.647	1600000	Very High	Very Low	Low
Wire wrapped	63737079173.70	7.233	3300000	Very Low	Moderate	High
Pre-packed	63985386733.05	5.091	5000000	Moderate	Low	Very High

Table 12: Conversion of quantitative ones from qualitative criteria

ALTERNATIVES	OBJECTIVE FUNCTIONS					
	Revenue (+)	Skin (-)	Cost of installation (-)	Availability (+)	Limitation (-)	Reliability (+)
Gravel pack	63450318257.76	9.595	6350000	5	7	3
Slotted liner	63736507202.97	3.647	1600000	9	1	2
Wire wrapped	63737079173.70	7.233	3300000	1	3	5
Pre-packed	63985386733.05	5.091	5000000	3	1	7

Table 13: Normalization of Decision Matrix

Alternatives	OBJECTIVE FUNCTIONS					
	Revenue (+)	Skin (-)	Cost of installation (-)	Availability (+)	Limitation (-)	Reliability (+)
Gravel pack	0.49782444	0.70812444	0.715462	0.464238	0.903696	0.32163376
Slotted liner	0.50006985	0.26915371	0.180274	0.835629	0.129099	0.21442251
Wire wrapped	0.50007434	1.42074249	0.371815	0.092848	0.387298	0.53605627
Pre-packed	0.50202253	0.37572293	0.563356	0.278543	0.129099	0.75047877

Table 14: Weights of individual criteria obtained from using Shannon Maximum Entropy method

	CRITERIA	WEIGHTS
1	REVENUE	0.06
2	SKIN	0.09
3	COST OF INSTALLATION	0.15
4	AVAILABILITY	0.25
5	LIMITATION	0.35
6	RELIABILITY	0.10

Table 15: Weighted normalized matrix

Alternatives	OBJECTIVE FUNCTIONS					
	Revenue (+)	Skin (-)	Cost of installation (-)	Availability (+)	Limitation (-)	Reliability (+)
Gravel pack	0.029869467	0.063731199	0.10731926	0.116059586	0.31629364	0.032163376
Slotted liner	0.030004191	0.024223834	0.027041073	0.208907255	0.045184806	0.021442251
Wire wrapped	0.03000446	0.127866824	0.055772214	0.023211917	0.135554417	0.053605627
Pre-packed	0.030121352	0.033815064	0.084503354	0.069635752	0.045184806	0.075047877

Table16: Ideal solution determination from weighted normalized decision matrix

Alternatives	OBJECTIVE FUNCTIONS					
	Revenue (+)	Skin (-)	Cost of installation (-)	Availability (+)	Limitation (-)	Reliability (+)
Gravel pack	0.029869467	0.063731199	0.10731926	0.116059586	0.31629364	0.032163376
Slotted liner	0.030004191	0.024223834	0.027041073	0.208907255	0.045184806	0.021442251
Wire wrapped	0.03000446	0.127866824	0.055772214	0.023211917	0.135554417	0.053605627
Pre-packed	0.030121352	0.033815064	0.084503354	0.069635752	0.045184806	0.075047877
PIS	0.030121352	0.024223834	0.027041073	0.208907255	0.045184806	0.075047877
NIS	0.029869467	0.127866824	0.10731926	0.023211917	0.31629364	0.021442251

Table 17: Determination of separation measure

Alternatives	S_i^+	S_i^-
Gravel pack	0.135886911	0.113353476
Slotted liner	0.227308674	0.21991349
Wire wrapped	0.154185241	0.205299996
Pre-packed	0.140260091	0.147358609

Table 18: Findings of relative closeness index

Alternatives	Relative closeness index
Gravel pack	0.454795779
Slotted liner	0.491732091
Wire wrapped	0.571094373
Pre-packed	0.512340154

According to relative proximity the order of alternatives are -

wire rapped >Pre-packed> Slotted liner > Gravel pack

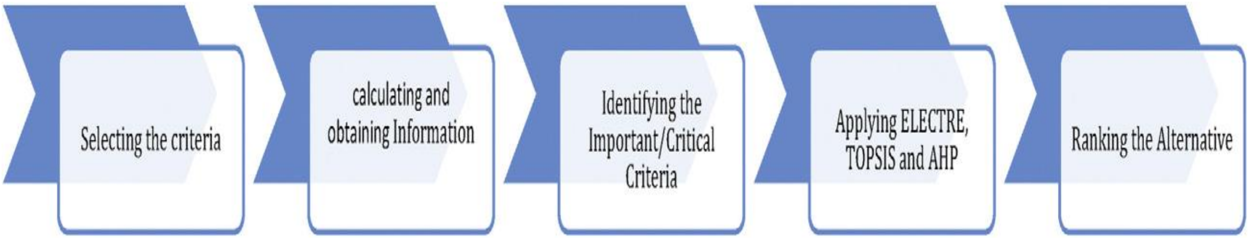


FIG 10: Procedure of applying MCDM tools to select the best sand control

The result of TOPSIS based on relative proximity (CL) is shown. The results show that slotted liner, gravel pack, pre-packed, and wire wrapped are the best alternatives for the sand control method, respectively. In order to find the best sand control method, a collection of economic and technical criteria was used. These criteria had a different concept that lead to difficult choices. These criteria and scoring were done by using experts' questionnaires in order to construct the decision matrix. As shown in below fig, which is obtained from the TOPSIS method, revenue has the lowest weight and limitation has the highest weight. The revenue includes oil and gas income with water cost subtracted. The well with more skin (due to sand control pressure drop) has less oil and gas production. Therefore, the reservoir depletion was slower and water and gas coning were postponed, which resulted in less water production. Eventually, the income deficit from oil and gas was compensated by lesser water production..

Table 19: Relative proximity (CL) and sand control method ranking with TOPSIS method.

Method	CL	Rank
Gravel pack	0.454795779	4
Slotted liner	0.491732091	3
Wire wrapped	0.571094373	1
Pre-packed	0.512340154	2

Table 20: Results of three methods and average score of different sand control methods.

	TOPSIS	ELECTRE	AHP	Average score
Gravel Pack	4	3	4	3
Slotted liner	3	1	1	1
Wire wrapped	1	3	3	3.333333
Pre-packed	2	2	2	2.333333

The three MCDM methods have slightly different results and are not equal. The discrepancy occurs because of different weights, score scales, and distributions of scores. The decision maker must be aware of the strengths and weaknesses of all methods. Therefore, in some conditions, it would be logical to use one of the simplest methods. Nonetheless, to test the consistency, a better comparison and to increase the reliability of the results, the application of various methods are indeed trialworthy. Finally, to select the best sand control method, the TOPSIS method was used. This method determines the best option based on the average rankings obtained from different MADM priority methods. According to the average rating method, in this carbonate reservoir, a wire wrapped is the best tool to control sand particles. Prepacked is in second and slotted liner comes in third rank. The gravel pack alternative is the last option for controlling sand particles.

4.2 Optimization of the best sand control method

After selecting the best sand control method, namely wire wrapped, a combination of DOE and MCS is applied to perform optimization and uncertainty analysis. DOE provides a tool to investigate the effects of parameters in results concurrently. DOE has a feasibility to provide a predictive knowledge of a complicated, multi-variable process (Lazić, 2005). DOE has have been successfully applied to a wide range of problems in the petroleum and natural gas industry including: a risk optimization approach to water drive gas reservoir production optimization, well placement and individual well controls optimization, and cutting transport efficiency prediction (Naderi and Khamehchi, 2016, 2017, 2018). To develop proxy models, sets of reliability based simulations should be carried out to obtain the importance and priority of parameters and their interactions. By the methodical design of simulations, DOE allows exploring a full range of parameters swiftly and efficiently. For generating a response surface model, the three level full factorial design was selected. Full Factorial design (FFD) is used to perform required reservoir simulations. FFD is one type of DOE in which one can measure responses at all combinations of the factor levels. In this design, the number of required simulations for n factors with three levels is equal to 3n. Due to the fixed ratios of well bore in this study, only slot height, slot width and density are considered and liner inner radius and linerouter radius remain constant. Below given Table shows the input parameters for each simulation run. According to the three level full factorial method, 27 simulations should be performed. Data are expressed in relative values between 1 (for minimum valve), 2 (for moderate value) and 3 (for maximum value).

Table 21: Ranges of data used in this study.

Parameter	Symbol in study	Minimum	Moderate	Maximum
Height (in)	H	4	8	12
Width (in)	W	0.01	0.04	0.07
Shot density (1/ft.)	D	2	6	10

Table 22: Three level full factorial design in DOE.

RunOrder	StdOrder	H	W	D	NPV (US$)
1	21	3	1	3	6.33E+10
2	18	2	3	3	6.38E+10
3	1	1	1	1	4.50E+10
4	13	2	2	1	6.21E+10
5	20	3	1	2	6.26E+10
6	5	1	2	2	6.30E+10
7	17	2	3	2	6.38E+10
8	7	1	3	1	6.13E+10
9	10	2	1	1	5.56E+10
10	14	2	2	2	6.39E+10
11	2	1	1	2	5.95E+10
12	4	1	2	1	5.99E+10
13	27	3	3	3	6.38E+10
14	3	1	1	3	6.13E+10
15	11	2	1	2	6.18E+10
16	23	3	2	2	6.37E+10
17	22	3	2	1	6.29E+10
18	12	2	1	3	6.24E+10
19	16	2	3	1	6.32E+10
20	15	2	2	3	6.37E+10
21	6	1	2	3	6.34E+10
22	26	3	3	2	6.36E+10
23	9	1	3	3	6.37E+10
24	8	1	3	2	6.36E+10
25	24	3	2	3	6.38E+10
26	19	3	1	1	5.86E+10
27	25	3	3	1	6.35E+10

The significance of derived response functions was investigated by analysis of variance (ANOVA). From below table, it is very obvious that the interactions among variables have a considerable effect on the NPV. In this analysis, α is equal to 0.1

Table 23: ANOVA TABLE.

Source	Degrees of freedom	Adj Sum of squares	Adj Mean Squares	F-Value	P-Value
Model	18	3.69E+20	2.05E+19	8.33	0.002
Linear	6	2.39E+20	3.98E+19	16.17	0
H	2	3.82E+19	1.91E+19	7.76	0.013
W	2	1.09E+20	5.46E+19	22.15	0.001
D	2	9.16E+19	4.58E+19	18.59	0.001
2-Way Interactions	12	1.30E+20	1.09E+19	4.41	0.022
H*W	4	2.85E+19	7.12E+18	2.89	0.094
H*D	4	3.00E+19	7.49E+18	3.04	0.085
W*D	4	7.19E+19	1.80E+19	7.3	0.009
Error	8	1.97E+19	2.46E+18		
Total	26	3.89E+20			

If P-Value≤α, then the dependency is statistically significant. In each step, the variable with the least impact will be omitted from the model. When all variables in the ANOVA table have been taken a P-Value less than or equal to the alpha to remove, the process stops. Simply, a P-Value shows us the information about the reality of a result. Technically, this parameter is a decreasing index of the reliability of an outcome, and the larger it is, the confidence in the reality of the results reduces. In these figures, the means for each level of a factor are plotted and linked with a line. Factorial points and Center points are shown by different symbols. A reference line is also shown at the grand mean of the response data by dots. As shown in the main effect plot for NPV, respectively the width, the shot density, and the height, have the most effect on NPV variations. As can be seen, NPV always increases by increasing these three parameters. The changing any factor and holding the value of the second factor constant has also importance in this analysis. Fig. shows the interaction plots of NPV. An interaction plot is a plot of means for each level of a factor by holding the level of a second factor constant. The relative strength of the effects across factors can be compared using interaction plots.

However, the interpretation, as also for the main effects, is meaningful only if the interaction effects are statistically significant. By considering the interaction effects in the statistical model the complex nature of the optimization process becomes more understandable (Fegade et al., 2013). The most significant interaction effects on NPV are W×D and H×D. Table 19 shows the coefficient of determination (R2) and the adjusted coefficient of determination (R2adj) for the proxy equation of NPV 94.94% and 83.54%, respectively. These parameters used to show the quality of fit for the regressions. To show how well the data fit a statistical model, R2 is considered between zero and one. This parameter shows the percentage of variability in the process defined by the fitted model. Therefore, the closer the R2 to 100 is, the higher the regression quality. 100% indicates that the regression line perfectly fits the data, while a value of zero percent indicates that the regression does not fit the data at all. The R2adj is defined in terms of the coefficient of determination which has the effect of the number of independent variables on regression goodness of fit. A little difference between R2adj and R2 means that the unnecessary terms have not been included in the model. Analyzing Table using optimization reveals that run order and NPV=63.8226 billion dollars is the optimum design for slotted liner. The optimum design for slotted liner results in a greater income of 86092797.03 dollars (0.135%).

4.3 Sensitivity and uncertainty analysis of NPV

Sensitivity studies of the NPV response function were conducted using analysis of variance and performing MCS. Prior to Monte Carlo simulation, it is necessary to assign the appropriate probability distribution function for factors. A probability distribution function is a function that applied to specify a particular probability distribution. To evaluate the possibility of the occurrence of a specific event, probability distribution functions is first developed. Then, MCS begins with a model, often built in a spreadsheet, which includes input distributions and output functions of the inputs (Sánchez et al., 2007). In this regard, based on the available information, we assigned three distributions of normal, triangular, and uniform for all factors of slot height, slot width, and slot density (Gilman et al., 1998).

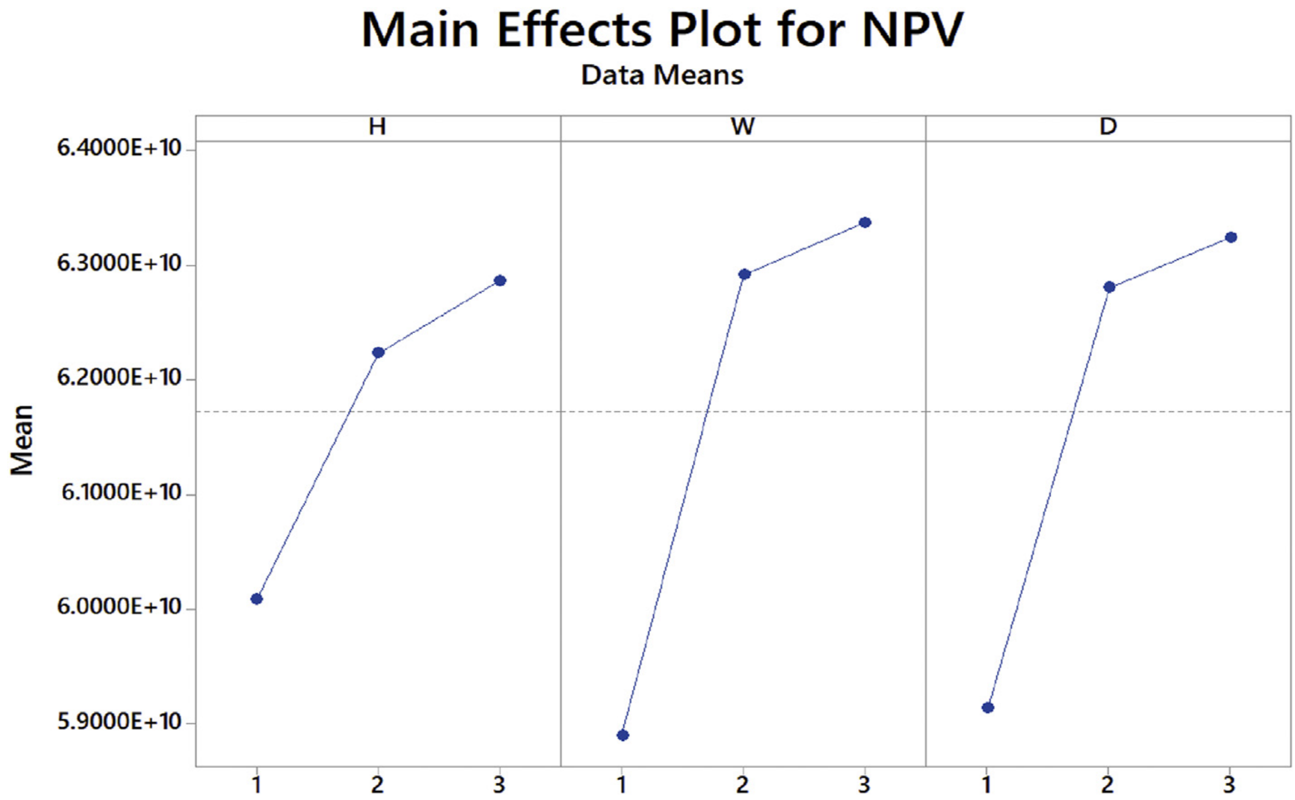


Fig 11: Main effect plots for NPV.

The main effect plots illustrate the relative strength of the effects across different levels of factors.

To perform the reliability based simulation a constant has been used which is found by trial and error method. The constant is k = RAND ( )*45*10^8.

Table 24: Three level full factorial design in Reliability based Simulation.

Run Order	Standard Order	H	W	D	NPV (US$)		Simulation result
							6.5E+10
1	21	3	1	3	6.33E+10	1	6.14E+10
2	18	2	3	3	6.38E+10	2	5.96E+10
3	1	1	1	1	4.50E+10	3	6.18E+10
4	13	2	2	1	6.21E+10	4	6.81E+10
5	20	3	1	2	6.26E+10	5	5.36E+10
6	5	1	2	2	6.30E+10	6	5.79E+10
7	17	2	3	2	6.38E+10	7	6.48E+10
8	7	1	3	1	6.13E+10	8	6.15E+10
9	10	2	1	1	5.56E+10	9	5.42E+10
10	14	2	2	2	6.39E+10	10	6.38E+10
11	2	1	1	2	5.95E+10	11	5.4E+10

Run Order	Standard Order	H	W	D	NPV (US$)		Simulation result
12	4	1	2	1	5.99E+10	12	7.31E+10
13	27	3	3	3	6.38E+10	13	5.6E+10
14	3	1	1	3	6.13E+10	14	6.65E+10
15	11	2	1	2	6.18E+10	15	6.66E+10
16	23	3	2	2	6.37E+10	16	5.58E+10
17	22	3	2	1	6.29E+10	17	5.59E+10
18	12	2	1	3	6.24E+10	18	6.21E+10
19	16	2	3	1	6.32E+10	19	6.28E+10
20	15	2	2	3	6.37E+10	20	5.86E+10
21	6	1	2	3	6.34E+10	21	7.69E+10
22	26	3	3	2	6.36E+10	22	6.71E+10
23	9	1	3	3	6.37E+10	23	6.65E+10
24	8	1	3	2	6.36E+10	24	6.38E+10
25	24	3	2	3	6.38E+10	25	6E+10
26	19	3	1	1	5.86E+10	26	5.89E+10
27	25	3	3	1	6.35E+10	27	5.6E+10
						28	5.85E+10
						29	5.22E+10
						30	6.94E+10
						31	6.75E+10
						32	7E+10
						33	6.64E+10
						34	7.25E+10
						35	6.08E+10
						36	6.56E+10
						37	5.73E+10
						38	6.78E+10
						39	6.89E+10
						40	5.94E+10
						41	6.35E+10
						42	5.98E+10
						43	6.22E+10
						44	6.1E+10
						45	4.91E+10
						46	6.48E+10
						47	5.37E+10
						48	6.39E+10
						49	6.1E+10

4.4 Discussions:

Fig 12: Scatter Results of Experimental NPV:

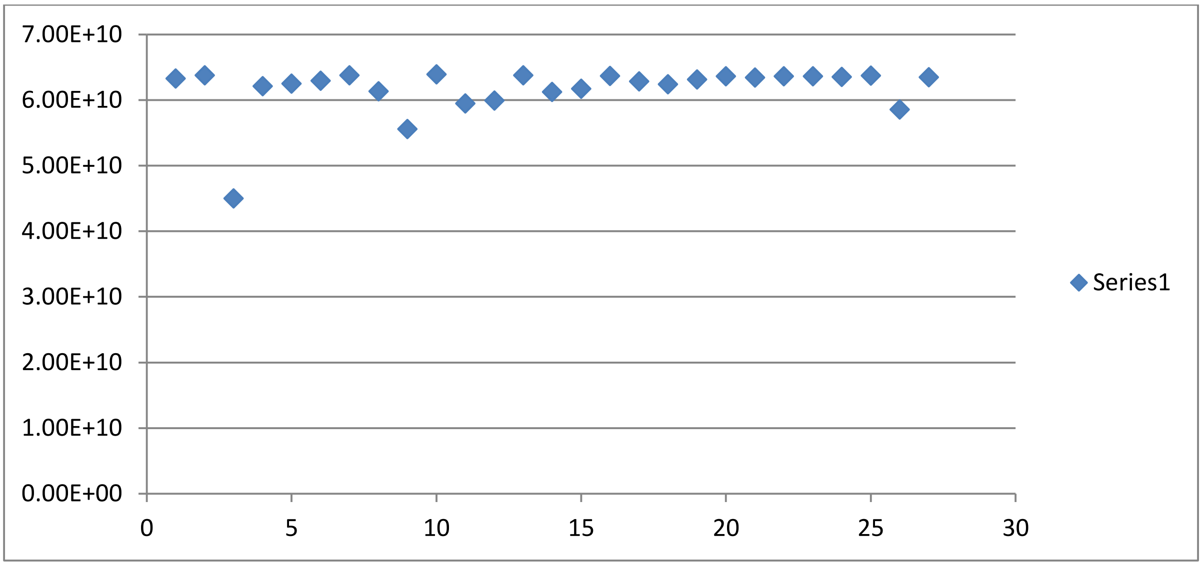


Fig 13: Scatter Plot of Simulation Results:

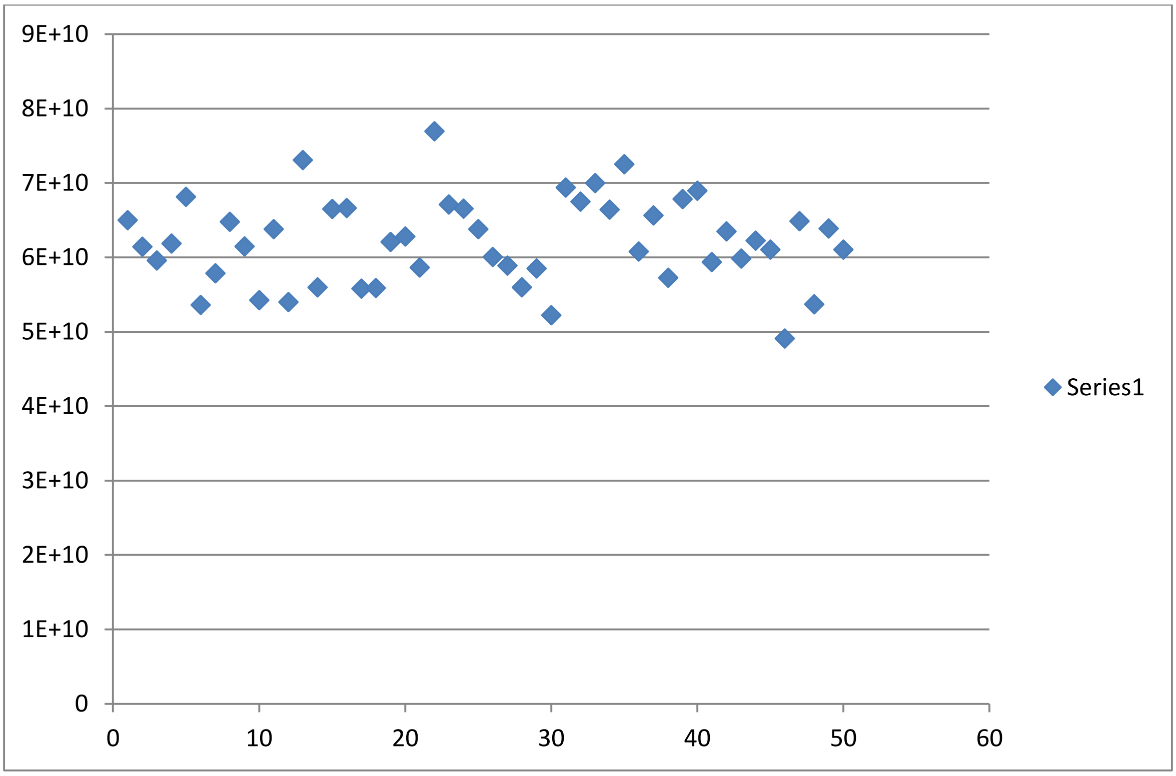


Fig 14: Radar Chart of Experimental NPV Results:

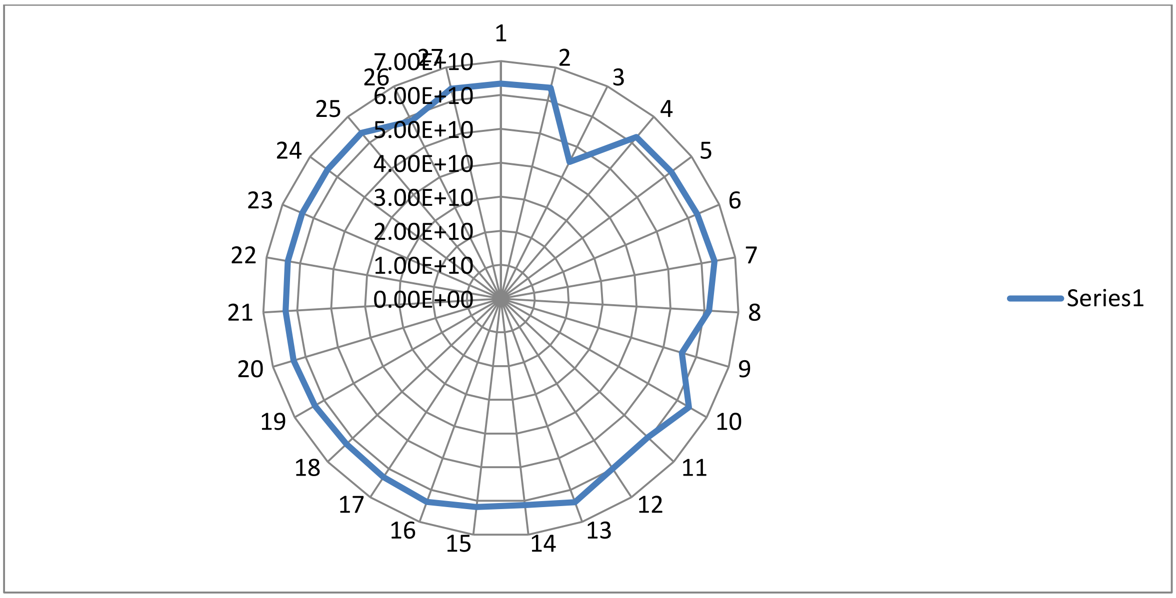
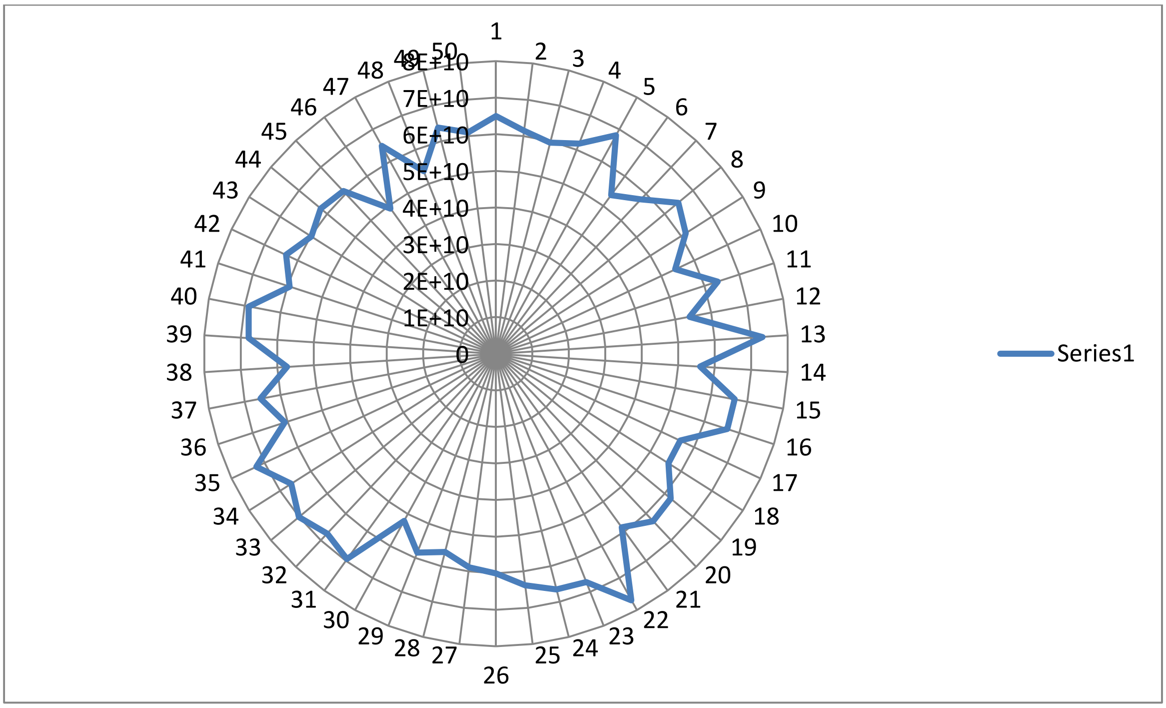


Fig 15: Radar Chart of Simulation Results:



Chapter 5

5.1 Conclusion

The purpose of the current study was to determine the reliability based best sand control method based on considering economic and technical criteria. Overall it has shown a fruitful results that can be used as substitute of the experimental values.

The investigation of the sensitivity and uncertainty analysis also has shown that the greatest uncertainty in estimating the best variables of the slotted liner is associated with two factors of slot width and slot density. Therefore, these factors should carefully be characterized prior to designing the best slotted liner for the sand control in order to maximize NPV.

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Future Scope:

. Research work carried out can be further extended:

1. Tool developed here to evaluate Reliability cost and benefits due to savings in power loss cost as a whole can be extended in Real time measurement, monitoring and control.
2. Any sand control equipment has some characteristics that their variations will affect both their price and magnitude of skin caused by them.
3. At low production rate and for low PI reservoirs, choice of suitable method is influenced by global oil price and investment interest rate. In other words, choice of suitable method is not directly affected by the well skin.
4. At high PI reservoirs and for long-time project, the best method is the one that has higher oil production. So, the skin value has an intense effect on choosing the sand production method.
5. Designing of sand control systems and practices in the past have been focused only to such variations in formation conditions and production parameters – that alter through the well life cycle. The produced sand is oil-contaminated, so due the environmental protection it cannot be thrown away without control. Thus some kind of controlled disposal site or re-injection through injecting wells can be applied.