A Critical Review on Root Cause Analysis on Gravel Packing Design and Installation Issues

by

Farah Badrul Hisham

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Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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(Noor Ilyana binti Ismail)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2015

CERTIFICATION OF ORIGINALITY

This is certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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FARAH BINTI BADRUL HISHAM

ABSTRACT

Sand control plays an important role in oil and gas industry throughout the years. The objectives of sand control are to prevent sand formation from entering the well and ensure the well reaches its highest productivity. Failure to include sand control plan in developing wells cause many problems to companies especially when dealing with unconsolidated reservoir. Among the problems that will occur are production losses, erosion of hardware, tubular blockage, sand disposal issues and many more. There are many techniques available in the industry. The most widely used sand control method is gravel packing. The fundamental of gravel pack is by placing sized particles in annular space between screen and formation. However, there are many aspects need to be considered in designing gravels and placing the gravels downhole. It is crucial to study and understand these factors and considerations to ensure gravel pack completion achieves its highest efficiency. The objectives of this paper are to identify the issues related to gravel pack design and installation in different well conditions and the factors that affecting it. By understanding the problems and causes, it will minimize the risk of gravel pack failure and consequently enhance the effectiveness of this method. Extensive study will be carried out in this project to identify the designs and installation criteria and select few case studies on different conditions. The study focuses on horizontal wells because the placement of gravel pack in this particular well is complex. According (Penberthy Jr, Bickham, Nguyen, & Paulley, 1997) the placement of gravel for highly deviated wells require greater pump rates and different completion geometry compare to vertical wells. At the end of this study, the author will present a summary of findings on the issues related to gravel pack completion in horizontal wells application and finally propose the most practical design and gravel pack placement with respect to different well conditions.

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INTRODUCTION

1.1 Project Background

Sand production has been one of the major challenges in oil and gas industry particularly in upstream sector (Roslan & Carigali, 2010). The industry spent millions of dollars every year to prevent sand production from unconsolidated formations which causes loss of production and damage to downhole and process equipment. It is important to achieve effective sand control installation as when the former installation failed, more costs need to be spent for remedy. The highest reliability of early sand-control practices is vital specifically offshore and in satellite locations with high operating costs (Gruesbeck, Salathiel, & Echols, 1979).

Gravel packing has been claimed to be the most popular technique for controlling sand production because of its efficiency and reliability. The general procedure of gravel pack is by putting a wire-wrapped screen in the wellbore acting as a barrier for gravel to flow back into the well and then pump in the gravels to be well-placed at the wellbore-screen annulus. Hodge (1982) found that in vertical wellbores, complete settlement of gravels is commonly accomplished. However, there is a problem encountered to place all gravels completely in horizontal wells. Gruesbeck et al. (1979) explained that in deviated well, gravel placement has less effectiveness due to incomplete and unstable placement around wellbore.

Gravel pack requires precise design considerations and the final result of gravel distribution in wellbore needs to be known. In this project, an extensive study will be done to identify issues and factors that affect the effectiveness of gravel pack design and placement for different well conditions. The main purposes are to come out with a summary of findings and recommendations for better design and placement of gravel pack in cased-hole and open-hole horizontal wells so that sand control can achieve highest its efficiency. Thus, critical analysis and further study from various sources will be carried out in order to accomplish these objectives.

1.2 Problem Statement

Gravel pack has been the most common method of sand control in the oil and gas industry (Wong, Fors, Casassa, Hite, & Shlyapobersky, 1993). In vertical wells, this technique is considered as the most accepted and flexible way to filter sand production (Brown & Huang, 1985). However, the efficiency of gravel pack is questionable in certain conditions such as in open-hole and horizontal wells. Horizontal gravel pack is more complex compare to vertical well due to its high angle. The efficiency of gravel placement in these wells might not reach its maximum without specific design and installation. Placing gravel inside the annulus of a highly angled well requires greater pump rates and altered completion geometry compare to vertical wells (Penberthy Jr et al., 1997). Many factors and considerations need to be thoroughly investigated in order to achieve highest efficiency of the system. Thus, it is crucial to understand issues related to gravel pack design and installation particularly for horizontal wells.

1.3 Objectives of the Study

i. To review possible issues in gravel pack design and installation and identify the root cause of the issues.
ii. To recommend a practical design and gravel pack placement with respect to well condition to achieve highest efficiency of the system.

1.4 Scope of Study

This project is a study review and it will look on three main areas. These areas are (1) gravel pack design and installation, (2) gravel pack completion in open hole and cased hole in horizontal wells and (3) gravel pack in HPHT wells. This project requires extensive literature review which will focus on design and installation of gravel pack and review of few case studies. The case studies are selected based on well conditions and they are classified into three main categories. An analysis will be carried out from the collected data and the gravel pack design and installation approaches for each case will be defined. The results will be compared. A root cause analysis will be done by constructing Ishikawa diagram to identify causes of the corresponding issue. Finally, the author will come out with a summary of the findings and recommendations.

1.5 Relevancy and Feasibility of Project

The project is relevant to the student and the oil and gas industry as it is known that sand production is a major problem in upstream sector. A thorough understanding on sand control technique, in this case gravel packing is acquired as it deals with the productivity of the well and importantly operation cost. Hence, failure of gravel packing needs to be avoided. The review on issues addressed can assist engineers to design gravel packing. This project is feasible to carry out by considering the capability of a final year student and time constraint with the assistance of supervisor. The student had the accessibility to journals, books and other sources. The project can be conducted and completed within the timeframe.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Sand Control Method

Several techniques are available in the industry for minimizing sand production from wells. The choices range from simple changes in operating practices such as restrictive production rate to expensive completions such as gravel packing. The sand control method selected depends on site-specific conditions, operating practices and economic considerations. Before proceeding to sand control technique, it is important to understand the mechanisms of formation sanding which includes the response to pressure drawdown and depletion as well as to choose the most suitable sand control completion (Sherlock-Willis, Morales, & Price, 1998). They also added that due to economical limitations and lack of sufficient data, the chosen sand control method might not be the best one.

Wagg, Heseltine, Faga, and McKinzie (2008) explained in their paper that operators experience a huge challenge in determining the appropriate sand control technique. The technique should provide excellent economics over the life of a particular field especially in complex and high pressure and temperature wells. Ripa and Pitoni (2001) stated that back in 1985, sand control technique generally was decided for any particular well based on the some considerations:

- Avoid solids production from reservoir formation;
- Prevent excessive pressure drop during completion for maximum productivity;
- Acquire long term reliability;
- Lower down operational costs;
- Present low or acceptable operational risk.

According to Schlumberger - Sand Management Service, there are many sand control methods provided in the industry and the most popular one is gravel pack technique. The methods available are (1) restrictive production rate, (2) in-situ sand consolidation, (3) resin coated gravel placement, (4) stand-alone screen, (5) expandable screen system, (6) gravel pack, (7) stimPAC and (8) screenless fracturing. These methods can be classified into three categories which are mechanical, chemical or combination techniques (Mohammed, Lesor, Aribo, & Umeleuma, 2012) . For mechanical sand exclusion, it is based on the relationship between the gravel, width of screen slot and formation sand size. Chemical type involves the chemical injection through perforation into the formation to cement the sand grains and for combination techniques, both gravel and chemicals are employed to consolidate the gravel pack after its placement without having a screen or slotted liner.

Restrictive production rate method requires the least cost but it may only apply for certain weak formations which have enough strength to produce sand free at low rates. In order to carry out this method, the well needs to produce below its critical sand production rate and selective perforations in the strongest formation. However, by producing below the critical point leads to loss of profit as the critical production rate generally is below economical production. Thus, other techniques should be applied to counter this problem and give higher rates of production.

One of the earliest sand control methods is by using slotted liner or screen. Sinclair and Graham (1978) stated in his research that back in the 1920s, wire-wrapped screen and slotted liner were used in open hole completion quite effectively. Nevertheless, around 10 years later when perforation gun were widely used in the industry, screens started to fail early because of the sand-blasting effect through perforations during production. Comparing between slotted liners, wire-wrapped screens and screens; slotted liner has the largest openings, wire-wrapped screen has smaller holes and pre-packed screen offers the finest filtering (Carlson, Gurley, King, & Price-Smith, 1992). They added that screens and slotted liners are most suitable on formations which are friable rather than total consolidated. Apart from that, these techniques are specifically suited for high deviated wells.

In-situ consolidation has also been widely used for sand control method which there is no need of mechanical screening device. This technique is applicable for formations which accept a quantity of packed sand, short and long intervals related to multiple completions, old wells and in several cases, newly completed zones (Young, Cook, & Donaldson, 1969). This objective of this method is to consolidate the formation sand by injecting chemical agent; usually uses resin which acts as liquid bonding material into the produced sand around the wellbore. This chemical coats the surfaces of formation sand grains and bonds these sands together to form a sand control barrier while maintain the value of permeability (Chen, Zhou, & Liu, 1986).

2.2 Gravel Pack Completion

Gravel pack has been one of the common applied techniques for sand control. Schlumberger defines gravel pack as the sized particles placed in annular space between unconsolidated formation and a screen. Gravel pack is installed as downhole filter and has two specific purposes which are (1) to prevent production of sand and (2) to allow maximum production. Sanchez and Tibbles (2007) described the main objective of conducting grave pack is to stabilize formation while contributing minimal impairment to productivity of the well. Carlson et al. (1992) explained that gravel packing method uses slurry of correct sized gravels in a carrier fluid to be pumped into annular space between either cased hole or open and centralized screen.

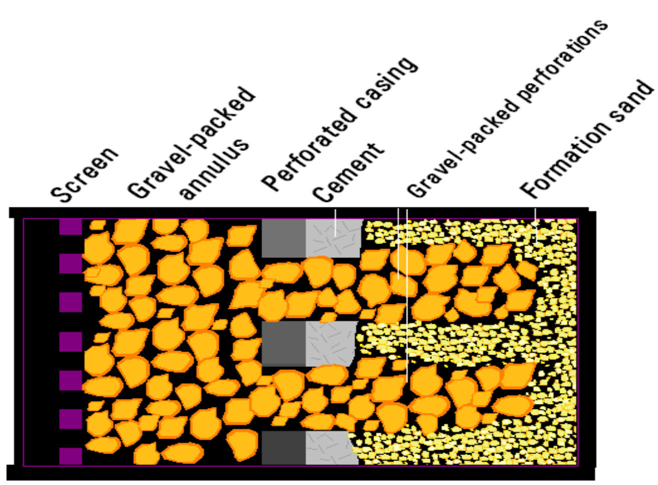

Figure 1: Typical Gravel Pack Completion (Schlumberger)

Schlumberger – Sand Management Service added this technique involves mechanical device such as slotted liner or screen to be placed downhole and accurately place well-sorted sized gravels around the mechanical devices. This technique allows the fluid from formation to flow into the well while gravel filters out the formation sand so that sand-free production can be achieved. As for the screen, its purpose is to prevent the gravel from entering back the well after being pumped. In a cased hole well, a slurry of gravel is pumped into the perforation tunnels first and then the annulus between perforated casing and screens while in open hole gravel packing, the screen used is packed off as there is neither casing nor liner to support producing formation (Sanchez & Tibbles, 2007).

2.2.1 Gravel Pack Design

Dehghani (2010) pointed out that in order to accomplish successful gravel pack, it is important to: (1) get the right size of gravel to completely stop the production of formation sand, (2) place the gravel in a tight pack which has largest radius possible and (3) enhance productivity while reducing formation damage. Designation of gravel pack has many factors to be considered to maintain a long-term productivity. Roscoe Moss Company described in their technical paper that typical considerations for gravel pack design are grain size sorting, pack thickness, ideal uniformity effective size and coefficient, and pack-aquifer ratio parameters.

According to Bouhroum and Civan (1995), there are three gravel pack design principles. These principles give a successful design and it results to higher productivity. The first principle is to prevent a majority of produced formation sand particles from migration. The second principle is providing acceptable flow capacity which means the permeability of gravels must be greater than the permeability of formation sand. Lastly, to minimize plugging and clogging of pore constrictions. This can be achieved by providing adequate pore openings of a suitable size so that when some smaller sand particles are transported through the gravel pack, they can flow through and not hinder the texture and flow of gravel pack.

One of the most crucial aspects of gravel pack design is the selection of gravel size to be used (Gurley, Copeland, & Hendrick Jr, 1977). Information of formation samples is needed to determine the gravel size. However, if the sample is not available, the rule-of-thumb is to use the smallest gravel possible yet does not restricting productivity. Size selection is based on formation sand particle-size distribution with the presence of sample. Generally, the particle-size distribution is acquired by sieve analysis from the formation samples. A sample can be taken in many forms, such as from surface equipment, bailed sample, sidewall cores and whole cores. Nevertheless, sand sample at the surface equipment and bailed sample are highly not recommended as it does not represent the real characteristic of the rock formation.

In gravel pack design, before giving any design recommendation is to have knowledge on formation grain size (Saucier, 1974). One of the selection of gravel size has been developed by adopting the ratio of the mean gravel size to the mean formation sand size irrespective of the type of gravel, completion type and formation fluids. The most well-known formula for this selection of gravel pack is Saucier formula. Saucier determines the relationship between median gravel pack sand diameter and median formation sand diameter. In order to determine what size of gravel sand is required, formation sample needs to be evaluated to find out the diameter of median grain size and its distribution.

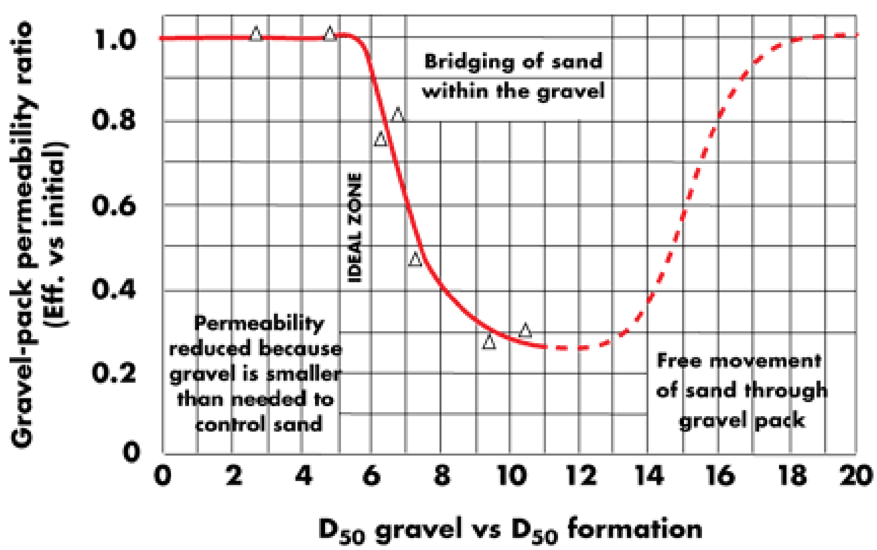

Figure 2: Effect of Gravel- Formation Sand Ratio on Gravel Pack Permeability (Carbo Ceramic Topical)

The ratio given by Saucier; ratio of 5 to 6 gravel sizes to mean size of reservoir sand is considered as the basic rule-of-thumb in gravel pack design (Bouhroum & Civan, 1995). However, this method is based completely on the median formation sand grain size without considering the range of sand grain diameters and sorting degree (Xiang & Wang, 2003) . Saucier formula is too general and limited because it does not take into account the type of gravel either it is conventional or synthetic, configuration of wellbore, operating conditions and the type of produced fluids (Oyeneyin, 1998a). He added that studies had shown the best design criteria to achieve effective gravel selection must consider the following:

- Formation sand size distribution, shape and sorting.
- Gravel type, structure and shape.
- Bridging efficiency of gravel pack at current operating conditions and type of wellbore.
- Pore blocking mechanism.

A research was conducted to identify the effect on productivity losses associated with slotted liners and screens. The result of experiment had shown that the slotted liner or screen with gravel pack did not give significant impact to the productivity of well except they became plugged. However, it is found that slotted liner could be plugged more easily compare to screens. In order to prevent plugging, the slot/screen openings are preferably equal to about half the smallest gravel size to assure gravel bridges to be on slot/screen rather than the gravel goes in. The slot liner and screen openings should be less than 75% of the smallest gravel size (Penberthy Jr & Cope, 1980).

Furthermore, a high quality gravel is also considered as an important factor to place unimpaired gravel pack completion (Zwolle & Davies, 1983). Spherical and well-rounded gravel provides higher permeability relatively and produces less fines during normal gravel pack operation. In a case study at offshore Brazil, good premium gravel was not available in that place and due to that they had used ceramic proppant with low density and intermediate strength. It has shown the advantages of ceramic gravel over domestic sand such as it has a greater crushing resistant; better sphericity/roundness parameters and it can be produced in a narrow size range because of its synthetic material (De Sa, Tavares, & Marques, 1989).

2.2.2 Requirements of Gravel Quality

Further study on the quality of gravel is carried out. The gravel quality may directly influence the effect of productivity after the completion and the sand control itself. The quality of gravel consists of the selection of gravel grain diameter, gravel strength, qualified degree of gravel size, gravel psephicity and sphericity, and acid solubility of gravel.

1. Selection of gravel grain diameter: The recommended gravel grain diameter in China and abroad is five to six times the median grain diameter of reservoir sand.
2. Gravel strength: The strength of gravel according to the API standard is that the crushed gravel content measured in the crushing test should not exceed certain value that has been standardized.
3. Qualified degree of gravel size: Based on API standard, it is that the gravel content larger than the required size in the sample of gravel should not exceed 0.1%, whereas the gravel content smaller than the required size should not exceed 2%.
4. Sphericity and psephicity of gravel: The mean psephicity and sphericity should be larger than 0.6 according to the API standard.
5. Acid solubility of gravel: The API standard of the acid solubility is that the weight percentage of gravel dissolved in standard mud acid must not exceed 1%.
6. Gravel conglomeration: Based on API standard, the gravel must be composed of single quartz sand grain and the gravel should not be used if the it contains conglomerate gravel grains of 1%.

2.2.3 Gravel Pack Placement

Gravel pack placement considers two important factors which are placement design and technique. Oyeneyin (1998a) explained the main objective of the design is to accomplish high annular packing efficiencies and high perforation. Penberthy and Echols (1993) said that it is critically important to pack the perforations with gravel for the productivity of gravel pack and completion longevity. Nonetheless, the design and technique of gravel pack placement became highly complex when in highly deviated or horizontal wells. In some cases, other sand control method needs to be considered other than gravel pack due to the complicated operation and high cost. “The technical complexities of high-angle gravel packing and its relatively high cost mean that alternative techniques are often considered” (Carlson et al., 1992). According to Oyeneyin (1998a) the placement design and techniques involves:

- Interval length
- Wellbore configuration
- Selection of the most suitable placement method
- Specification of slurry/fluid properties such as type of carrier fluid, viscosity, density and slurry concentration
- Determining the conditions of operation in terms of pumping rate

Gruesbeck et al. (1979) previously carried out experiments to determine pack efficiency in terms of screen parameter, gravel and fluid properties, completion configuration and the inclination of wellbore angle. They found out that gravel pack efficiency increases with lower gravel density and concentration, increasing flow rate and higher resistance of fluid flow. Furthermore, Elson, Darlington, and Mantooth (1984) concluded in their study that high viscosity carrier fluid and high gravel concentration result to good gravel transport in deviated wells. However it is not suitable for wells with an angle of 80° from vertical (Oyeneyin, 1998b).

In gravel pack operation for horizontal well, it can be divided into three stages which are the injection, the alpha wave propagation and third one, beta wave propagation. For the injection stage, it consists of gravel/fluid mixture pumping through the pipe until crossover tool where the flow goes into open hole annulus. Usually the velocity of this mixture decreases at this moment. This leads to form sediment by the solid in lower portion of annulus because the force that sustains the proppant is not high enough. The solids form a bed at given flow rate when reaches an equilibrium height (Martins, de Magalhaes, Calderon, & Chagas, 2005).

For alpha wave propagation, the wave packs from top to the bottom of a completion and leaves an open void over the gravel dune. After it reaches the bottom of the completion, a beta wave propagation proceeds in an opposite direction of the alpha wave which is towards the top of well until the whole interval is completely packed (Penberthy Jr et al., 1997). In field application, it is important to ensure that the pump rate used to operate horizontal open hole gravel pack is sufficient to propagate the two waves for a given well conditions and downhole geometry (Coronado & Corbett, 2001).

2.3 Type of Completion

2.3.1 Cased Hole Gravel Pack

According to Bellarby (2009) cased hole gravel pack provides reliable sand control completion specifically in environment where the other sand exclusion methods struggle. It also offers zonal isolation by using stacked packs. However, it has a significant complexity on the operation, logistics and time. For higher permeability reservoir, it is less suitable to use this type of completion as the productivity declines. Saucier (1974) mentioned that it is critically important that perforation tunnels are filled with gravels and not sand from the formation. Other additional restrictions that are acquired by getting perforation tunnels filled with formation sand can lead to large pressure drops through perforations which results to decrease in productivity (Chilingarian, John O. Robertson, & Kumar, 1989).

Cased hole grave l pack involves two basic methods – slurry packing and water packing. During treatment, one important concern should be the treatment pressure is not allowed to go higher than the fracture initiation pressure. Hence, a certain safety margin for pressure which is below fracturing pressure need to be included. In some situations, gravels trap perforating residual materials in place with no chance to clean it out especially when overbalance perforation operation. The residuals give negative impact to perforation permeability and well productivity. This gravel pack completion implies higher expenses in early stage due to the production casing, cementation and perforation. Nevertheless, in the end the life of well is prolonged because of its better flexibility and selectivity, and hence improved hydrocarbon recovery achieved (Matanovic, Cikes, & Moslavac, 2012).

2.3.2 Open Hole Gravel Pack

Open hole gravel pack completion is applied usually when the geological conditions allow (Renpu, 2011). In this condition, the casing is set before the productive interval. Then, the hole is under-reamed across productive zone and a screen or liner is set in that particular interval. Open hole typically is completed for horizontal wells. With precise design, open hole gravel pack technique can provide maximum productivity and a highly effective sand control as it has no restrictions by perforation (Chilingarian et al., 1989). This hypothesis was supported by Mader (1989) saying that this completion method provides the highest flow area for hydrocarbons and also the most effective filtration of sand plug. In a research conducted by Welling (1998), it was found out from the experiment result that open hole gravel pack should be done in oil reservoirs with permeability greater than 900mD and also high-rate gas reservoirs with permeability higher than 600 mD.

Based on Bellarby (2009), the purpose of this completion is to pack the annular voids with specific gravels to halt formation sand from entering wellbore and size the screen to filter gravel. If tis successfully installed, this will prevent formation collapse from occurring and hence reduce fines. Operationally, it is a challenging task especially with respect to selection of fluid and deployment. Gruesbeck et al. (1979) mentioned that many gravel pack completions have less than preferable effectiveness due to its incomplete or unstable gravel placement around the screen.

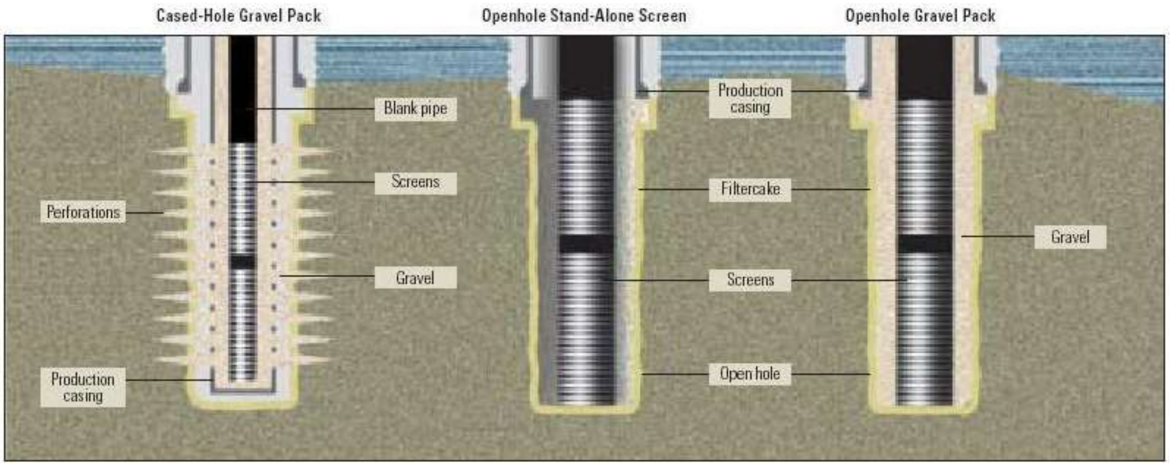

Figure 3: Cased Hole Gravel Pack vs Open Hole Gravel Pack (Schlumberger)

2.4 Gravel Pack in Horizontal Well

Horizontal well defines as a well that is constructed horizontally at depth for providing a higher production. It became economically feasible in the 1980s. Horizontal well is greatly more productive compare to vertical wells because it allows a single well to be produced at several points without having additional vertical wells. Typically the horizontal well starts by drilling a vertical well first. Through this vertical well, it allows engineers to analyse rock fragments for different layers so that they can determine where the reserves are. Horizontal well is usually associated with open hole completion.

Gravel packing can be done in horizontal well yet it requires additional considerations on the design to increase the possibilities to obtain a successful completion (Shryock, 1983). Maly, Robinson, and Laurie (1974) explained that packing efficiency declines drastically in deviated well beyond 60°. Laboratory tests show that the issue in horizontal well occurs because of the gravel dunes formation during the packing. When the dune forms, the carrier fluids will tend to flow into the tailpipe liner annulus and additional gravel on the dune is deposited (Chilingarian et al., 1989). A general sequence for a horizontal well is described below based on Bellarby (2009) book.

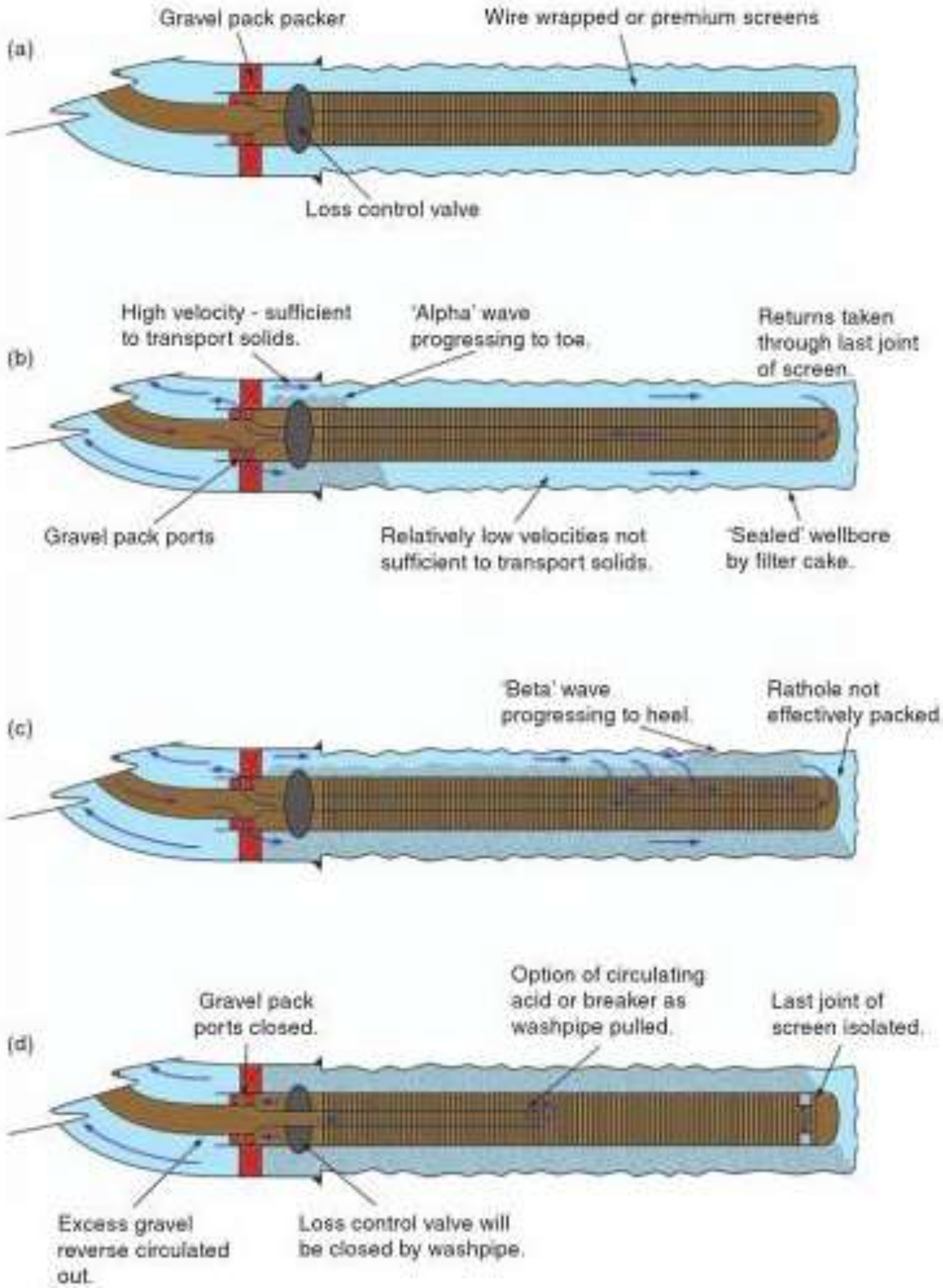

Figure 4: Sequence of Circulating Pack (Well Completion Design Book)

2.5 Case Studies of Gravel Pack Completion in Different Well Condition

2.5.1 Case Study #1 – Horizontal Cased-Hole Gravel Pack

Case 1: Alba Field, UK Continental Shelf

The first case study is conducted for cased hole gravel pack and it is based on Alba Field, 1995. The location of Alba Field is in Block 16/26 of UK Continental Shelf which is 138 metres of water and lies about 130 miles north-east of Aberdeen. The physical of the reservoir is narrow and long Eocene aged sandstone which located at approximately a depth of 6000 feet TVD. This field was discovered in 1984 and it was granted field approval in May 1991. The first production of this field was in January 1994. The well of this field was completed by gravel pack for a 700 feet cased hole horizontal well. This particular completion had used a number of recent technologies adopted for completion of horizontal cased hole along with both fluids and equipment.

In order to design the gravel pack completion, the first phase for this project was to collect all relevant materials either case histories or experimental work such that the identified problems had technical basis. Based on the research they had done, it was found out that gravel packing for high angle or horizontal wells using conventional methods and tools can be very difficult. The focus of this design is defined to the obstacles during gravel pack completion which may prevent high pack efficiency from being fully achieved. There were five obstacles had been identified and discussed in this paper which are (1) length of interval, (2) bridging, (3) perforation and annular pack efficiency, (4) formation damage and (5) fluid loss (Alexander, Winton, & Price-Smith, 1996).

Length of interval had been identified as a concern because at this time there was no experience in the industry on completing a 700 feet cased hole horizontal well. Thus based on Forrest's work, this indicated as a limitation in horizontals for pack length achievable and gravel pack tools as well. As for bridging, it often occurs in gravel packing of the screen-casing annulus especially before there is enough leak-off into the formation. It is not apparent for vertical wells as bridge usually collapses when pumping continuously yet, bridging causes voids in annulus pack for horizontal wells and very limited perforation packing. Hence, it is highly important to highlight on transport and placement of gravel.

Perforation and annular pack efficiency relates to the gravel pack transport which is a function of properties of gravel suspension of the carrier fluid as well as the energy requirements for moving the slurry. Study has shown that gravel placement depends on factors such as gravel concentration, gravel size, pump rate, type of carrier fluid and polymer concentration. The next concern is the formation damage that can exist in quite number of ways during drilling and also completion. The damage can gives some impacts on gravel packed well such as the remains of charge debris causes perforation tunnels to be partially filled with gravel due to poor perforating practise. Apart from that, Alba sands are high permeability of 3 Darcy approximately after perforation which could lead to 300-500 bph of fluid loss. Thus, it has been decided to require fluid loss control with non-damaging criteria.

Case 2: Heidrun field, Offshore Mid-Norway

This case study presents the evaluation of gravel pack efficiency for wells of Heidrun field. Heidrun field is located 120 miles offshore mid-Norway in approximately 1140 ft of water in Norwegian Sea. The hydrocarbons are present in three main reservoirs which are the Are formations, middle Jurassic Fangst group and lower Jurassic Tilje. The first oil production was discovered on 18 October 1995 and currently the plateau rate is more than 230 000 BOPD. During the early phase of this field development, five wells were pre-completed with cased-hole gravel pack method.

A test was done to the first well, A-53 which was pre-completed on summer 1993. The objectives of the test were to verify the quality of reservoir, well productivity and completion activities. Particularly after gravel pack had been completed, drill stem test (DST) was performed to find out the completion flow efficiency. The DST result showed that the production efficiency of well A-53 was 19% and a positive skin effect of 32.5. The maximum production rate of this well was only 28 300 bopd. A thorough study was done on the gravel pack installation performance and the main issue had been identified. During the gravel pack completion, loss control material (LCM) formula was added to control fluid leakage to the formation. It was found that this LCM gave the greatest damage effect on the performance of well. Consequently, a new LCM was formulated that incorporated an acid breaker with temperature-activated.

After recommendation had been done to the gravel pack completion for well A-53, the result of the post gravel pack test showed an increase in the production rate with an average of 32 000 bopd. From this test, improvement was done to the other four wells by taking well A-53 as reference. Based on the data obtained, performance of the wells had improved significantly. The data also shows that these wells exhibit degrees of clean-up due to the additional acid break action. The LCM formula with temperature-activated acid breaker together with suitable quality control procedures of mixing and storage gives an improved well productivity. It is also important to conduct a post-audit process in order to identify completion productivity improvements (Landrum, Burton, MacKinlay, Erlandsen, & Vigen, 1996).

2.4.2 Case Study #2 – Horizontal Open-Hole Gravel Pack

<u>Case 1: Campos Basin, Offshore Brazil</u>

A case study of oil fields in Campos Basin offshore Brazil, 2004 is chosen. The horizontal open hole gravel pack (OHGP) have been increasingly required for this field. The typical reservoirs in this giant field are turbidite sandstone with high permeability and low API gravity oil. The background of the field is based on a particular well which was drilled up to 13051 feet, horizontal section with an average of 93° upward geometry inclination and consisted of 8 ½ inch open hole of 2149 feet from the last casing shoe as well as having a water depth of 4318 feet. The permeability of reservoir was approximately 2 Darcy and having a porosity of 35%. Gravel pack on horizontal wells in unconsolidated formations proved to be an effective technique in Campos Basin (Farias, Mendez, & Calderon, 2004).

This paper highlights that it is equally important to prevent sand production effectively and also increasing the well's productivity. Stand-alone horizontal completions were usually used for controlling sand in this unconsolidated formation but many cases have shown that the device became plugged and consequently lead to low production. Hence, gravel pack technology gives a better option comparing to stand-alone screen in this particular case. Based on this case study, it had determined the success of gravel pack completion depends on several factors which are drilling techniques, drill-in fluids, open hole stability, wellbore clean-up, completion tools and equipment, completion fluids, software/simulators, sand control techniques, pumping schedules and field personnel experience.

Well configuration is one of the concerns in horizontal gravel pack as in order to achieve a successful horizontal OHGP, it requires an apparent velocity of equal or higher than 1.0 ft/sec in screen-open hole annulus depending on return rate. Premature screenout may occur if the rate is below that value because gravel deposition might cause alpha wave to hinder. It is also important to ensure that the fracture gradient does not exceed during high pump rates as it may result to lost circulation. In addition, for horizontal gravel pack crossover tool, the design of the tool must maintain the hydrostatic overbalance across the formation. When the hydrostatic pressure is lowered down to the static bottom hole pressure, the risk of borehole sloughing and removing filter cake increase highly. This tool had been designed to give positive tool locating with elimination of swab and surge pressures.

The next factor is the open hole stability which requires sufficient overbalance. For choosing the right displacement fluid, it is suggested to choose filtered completion brine and the fluid density must be at least similar to the density of drill-in fluid and sufficient in achieving overbalance pressure of 300 to 500 psi. By having this overbalance, it ensures the filter cake to be in place during wellbore cleaning and operation of gravel packing. Underbalance may lead to well control problems and hole collapse. Wellbore clean-up is also an important issue during gravel pack completion as debris in the wellbore cause completion failures. It is necessary to do wellbore clean-up in horizontal well for sand control as it significantly reduces any problems related to the completion installation.

Apart from that, screen and proppants are the factors in achieving efficient gravel pack. Initially slotted liners, pre-packed screens and wire wrapped screens were the completion technique used to limit the entry of sand from formation into horizontal well. Several new screens were designed during the past decade for stand-alone installation became available. The new generation of screen is called premium screen which were established to overcome the problem of stand-alone screen completion specifically on plugging and erosion. Thus, in Campos Basin it was recommended to use this premium screens with filter media which are customized for every field's size of formation sand and by using Saucier's rule to select the suitable ceramic gravel size.

Case 2: Giant Beaver and Santa Clara field, Offshore California

The Giant Beaver and Santa Clara fields are located at offshore California, west of Ventura. The Hueneme-Sespe sand (12° API) and Upper Repeto sand (24° API) produce low gravity crudes which are commonly pressured and have true vertical thickness of 60m (200ft) and 150m (480ft) respectively. In order to lift the crudes with low gravity, the operator has used electric submersible pumps. The two wells are producing from open hole gravel packed intervals which have a maximum deviation and were completed using downhole equipment designed for horizontal wellbore gravel packing. Well A was new well while Well B was a recompletion.

The major point that is highlighted in this paper is the viscosity of carrier fluid. Brine was used as the fluid consisted of 94% sodium chloride, 6% potassium chloride and 1.5 lb/bbl viscosified xanthan gum derivative polymer. This brine was shear mixed and filtered by 10 micron filters for well B completion, but was not on well A completion. The reason they used the xanthan viscosifier was due to its high viscosity at low shear rates; 20 Pa•s @ $0.63sec^{-1}$ or 25 000cp @ $0.63sec^{-1}$. Hence this property allows the viscous brine to suspend solids during static and it shows very low fluid loss to the open hole wellbore. Nevertheless, after the polymer has been added to the brine, it needs to be filtrate to remove insoluble products (Ashton, Liput, Lemons, & Summerlin, 1989).

An experiment was done by using gravel pack simulator to observe the gravel pack transport and placement. It has been repeatedly observed that when the slurry of gravel pack transits the screen annulus, it deposits proppant on the lower side of the annulus. Eventually the height of the deposited proppant grows and forming a dune in the annulus. It was recorded that as the height of dune increases, the velocity of slurry increases as well across the top of the dune. Thus, the gravel dune attains an equilibrium height and the height stays constant. This process continues to occur until the lower section of the screen annulus is filled with gravel completely. The vertical height of this dune is expressed in terms of the drag coefficient of slurry, slurry velocity, average diameter of gravel and density.

Based on the experiment as well, it shows that water as gravel slurry gives very good pack yet excessive fluid losses occur through simulated perforation. Water – gravel slurries were pumped down at turbulent flow a rate which is practised in the mining industry for mineral ores transportation through very long pipelines. Slurry with lower viscosity and higher displacement rates give a higher Reynold's and typically results in more complete gravel pack in simulator.

Case 3: Greater Plutonio, Block 18, Angola

Greater Plutonio was first discovered in 1999 and it was operated by BP. It is located 160km northwest of Luanda and it lies in 1200m to 1500m water deep. The total estimated reserves of Greater Plutonio are about 750 million barrels which is one of the biggest in Angola's coast. The development programme for drilling began in 2005 to complete and drill 15 wells. The field is produced from unconsolidated Oligocene, turbidite reservoirs and eventually sand control is needed in all development wells. The Angola field is located in immature and shallow sediments which generally has reactive shales. The shales have a range of reactivity from low to high depending on the field, location and burial depth.

Initially, the open hole gravel pack wells in Angola's offset were drilled with oil-based mud and brine was used for displacement before running the screen. However significant issues were encountered running screen because of shale instability. As a result, the system offset block set out the screen in oil-based mud. Initially, OHGP wells were drilled with oil-based mud system for the intermediate hole sections while water-based drill-in fluid system was used for production sections to facilitate the installation and execution of the completion system. The objective of using water-based drill-in fluid was to avoid complex displacement of oil-based to water-based fluid in open hole. However, performing such displacement raised concerns about the fluid-to-fluid interactions which could generate greatly damaging emulsions (Whaley, Price-Smith, Twynam, & Jackson, 2007).

Water-based filter cakes have a higher yield stress compare to the oil-based counterparts so the filter cakes are less susceptible to erosion which is important for the success of gravel packing during circulating operations. Furthermore, the water-based filter cake is easier to remove chemically if post OHGP stimulation is required. Although water-based mud is widely used, there are limitations for it especially in a reactive shale environment such as Greater Plutonio. It needs to maintain two separate mud systems which require additional cost and logistical complexity. It also creates relative thick mud filter cakes which give high lift off pressure, low flow efficiency and require frequent chemical stimulation for well productivity. Apart from that, it may create problems to the hole which affect drilling and completion activities. Water-based fluid also increases hole friction which prevents screen running in deviated wellbores.

OHGP completion has been conducted in wells where the intervals of reservoir were drilled with oil-based fluid in the attempt to realize the improved productivity. In OHGP completion, the improved productivity is highly attributed to Synthetic Oil-Based Mud (SOBM) filter cake which requires lower lift-off pressure and hence can be more produced back through gravel pack. It is particularly crucial for horizontal well in high transmissibility reservoirs where drawdowns are small. The early attempts at this method included displacing out oil-based mud to water-based fluid after it had reached the total depth and then running the screens in brine. Eventhough this method excluded the drilling problems related to water-based completion fluid, it usually caused the screens not properly reaching the bottom due to the reactive shales destabilization. The SOBM drill-in fluid improves the delivery of OHGP completion due to the design of the fluid and the non-damaging factor. The completion can be achieve when using SOBM without having to displace the hole to water-based fluids before deploying the assembly of lower completion.

2.4.3 Case Study #3 – Gravel Pack in HPHT Wells

The definition of High Pressure High Temperature (HPHT) was originally announced by the Department of Trade Industry (DTI) for United Kingdom Continental Shelf (UKCS) (Maldonado, Arrazola, & Morton, 2006). HPHT was defined as "where the undisturbed bottom hole temperature at potential reservoir depth is greater than 300°F (149°C) and the maximum prospective pore pressure of any porous formation to be drilled through surpasses 10000 psi or 18000 Newton/meter2/meter (0.8 psi/ft). Fjellstad, Strachan, Kaarigstad, Filbrandt, and Gyland (2014) explained that before gravel packing was introduced to HPHT wells, the only sand control method used was Stand Alone Screen (SAS). However, based on company best practice for North Sea HPHT field, the wells should have been packed with gravel. This is because shales need to be isolated effectively and it is a challenging task. Failure to do so will cause screen plugging. Hence, to avoid this matter, it is proposed to perform Open Hole Gravel Pack regardless the reservoir pressure and temperature. Nevertheless, there are resistance in the industry to perform this technique. There are three key issues that have been studied which are (1) narrow margin between fracturing gradient and pore pressure, (2) well control risks, cost and technical risks and (3) fluid selection.

HPHT field requires high density fluid generally. In order to achieve this particular density, the amount solid weight material required can be excessive especially for completion fluids. Thus, heavy density brines such as zinc bromide or cesium formate is often used but due to environmental aspect, zinc bromide is prohibited to be used in North Sea waters. Due to the small margin between fracture gradient and pore pressure, the operation of gravel pumping have to be conducted at low rates. The equivalent circulating density needs to be minimized during gravel placement. Thus, they place the gravel at low pump rates. Having a high density fluid for HPHT wells would also give enhanced buoyancy to the proppants compared to conventional carriers. The effect proppant density in the function of proppant settling should also be evaluated to enhance buoyancy and promote faster settling.

Apart from that, the fluid rheology and proppants need to be evaluated to understand if gravels can be installed effectively at low rates. In order to qualify the gravel placement, a yard testing was conducted in a mini scale gravel pack model. A screen reservoir drilling fluid had been used to successfully place the gravel at low rates. The main findings from the study were (1) the gravel can be effectively placed at low rates to lower the ECD impact in narrow fracture gradient and pore pressure operational window, (2) the gravel can be installed by using Reservoir Drilling Fluid (RDF) with screened formatted to maintain the filtercake intact and minimum risk of loss and (3) the particles present in the carrier fluid have no adverse effect on the permeability of gravel pack.

Maldonado et al. (2006) mentioned that it is possible to carry out both cased hole and open hole gravel pack in HPHT wells. For cased hole completion, the perforating gun is usually limited to pressures around 20 000psi and the perforating charges can withstand temperatures over 450°F. As for open hole completion, it requires a barrier to the well fluid leak-off that can contain the hydrostatic pressure exists in the well and consequently provide support to the formation until screen and gravel pack are installed. For gravel pack, the environment does not give serious challenge to both water and gel as the carrier fluids. If using gel, the choice of gel should be made based on the temperature. Nevertheless, current technology has provided gels that can withstand high temperature (350°F). In contrast, according to Bellarby (2009) gravel pack in HPHT condition can be challenging especially for gravel pack fluids as it is dependent on density, temperature stability and high temperature breakers.

Case 1: Albacora Leste Field, Offshore Brazil

Albacora East is one of the most challenging fields located at offshore Brazil, in the Campos Basin. The operator develops reservoirs from deep-water wells and they are pushing the technical boundary regarding horizontal extension. The water depth of this field ranges from 1100 to 1700m. The reservoir is completely unconsolidated sandstone since it is Oligocene-Miocene turbidite and has low rock sediments. Thus, it requires sand control and horizontal open hole gravel pack (HOHGP) completion has been selected due to its low uniformity of granulometric distribution as well as high amount of fines (155%). The reservoir has an inclined erosive character upward which causes unconformities and erosive superimposed surfaces. As time passes, normal faults disturbed these complex stratigraphic sequences.

In the context of sand control, wells that cross channels are likely to induce fluid losses during the operation. This had leaded to several gravel pack completions failed when using the conventional ceramic proppants. Hence, an alternative method had been developed for gravel packing to encounter extreme conditions in offshore Brazil which is Ultralight weight (ULW) proppant technology. This new technology is a simple and cost effective approach and can be applied under extreme well conditions. It was first introduced to offshore Brazil in 2005 to deal with extreme conditions; severe fluid loss, low fracture gradient and washed-out zone. Based on the study done, ULW proppant can be used in the most stringent well conditions for horizontal gravel pack placement: high fracture gradients, ultradeep water, low API gravity oil and horizontal extension more than 4000 ft (Neto et al., 2012).

For this particular operation, the initial plan of gravel pack activity was to use conventional ceramic proppant. However, when performing circulation test severe fluid loss was detected. The local operator needed to come out with a solution since performing HOHGP using conventional proppant in such condition would compromise the operation due to low equivalent rate at the open hole because of the leak-off. This equivalent rate is insufficient to transport regular ceramic gravels and causes a dune ratio greater than 85%. They had decided to apply ULW-1.25 to replace conventional gravel. ULW-1.25 is a very light particle which is a resin-coated and –impregnated, chemically modified walnut hull. The specific gravity is 1.25 and has a bulk density of 0.85 g/cm3. The shape of this gravel is not the typical spherical shape, but irregular with a high angular proppant. This allows permeable gravel packs in stress environment and produces no fines as stress becomes greater.

The challenge in using conventional proppants is the large difference in SG between proppant and the completion brine. The gravels tend to settle on the lower side of hole and eventually create a risk of gravel plug. This result to sand control failure especially in deepwater wells since it has extreme conditions. The low value of SG of ULW-1.25 shows small density differences compared with other completion brines which usually used as carrier fluids in offshore Brazil. This shows that there is a low or no proppant settling. According to table 1, the static settling velocity for ULW-1.25 proppants was 75% lower compare to the settling rate of conventional ceramics. The dramatically reduce in settling velocity enables lower rates to carry gravels without risk of plugging along the proppant path.

Table 1: Static Settling Rates for Various Proppants as Derived by Stokes Law (Ultralightweight Proppants: An Effective Approach To Address Problems in Long Horizontal Gravel Packs Offshore Brazil)

TABLE 3—STATIC SETTLING RATES FOR VARIOUS PROPPANTS AS DERIVED BY STOKES LAW

20/40 Proppant	Specific Gravity	Settling Velocity (ft/min)
Bauxite	3.65	23.2
Intermediate Strength Proppant	3.15	20.0
Carbolite	2.71	17.2
Ottawa sand	2.65	16.6
Resin Coated Sand	2.55	15.9
ULW-1.75	1.75	11.2
ULW-1.25	1.25	4.3

Case 2: Piceance Basin, Niobrara Shale, Western Colorado, USA

The case study on Niobrara Piceance basin was conducted by CARBO Company which focused on proppants. The primary objectives of the Piceance basin development were to increase productivity and at the same time reducing the costs of stimulation. The type of well is gas producer and it is a horizontal discovery well to 10200 ft TVD with a 4600 ft horizontal lateral. The well was completed with up to 10000 psi bottom hole pressure and bottom hole temperature up to 300°F. The challenge of this completion is the proppant selection as it needed to be critically analyzed to achieve optimal crush strength as well as flowback resistance to provide maximum conductivity.

As a solution for HPHT Picenace gas well, this company has selected ceramic proppant with low density and high transport. They referred Bakken wells as a study history, ceramic proppants were selected for the treatment and it showed comparatively greater conductivity than sand proppant which consequently increased the production of well. Apart from that, this ceramic proppant is known for its cost effective, exhibits higher conductivity than resin-coated sand and has high strength with superior thermal stability. The result of the discovery well obtained an initial rate of production of 16 MMscfd at 7300 psi flowing casing pressure. For the first 60 days, it was recorded that the well sustained an average rate of 10.6 MMscfd eventhough the well was being choked back significantly.

CHAPTER 3

METHODOLOGY

3.1 Study Review

This project is a review study on the issues of gravel pack design and installation. The methodology can be divided into three parts which will be explained below.

3.1.1 Extensive literature review

An extensive study will be done to identify all the factors and problems related to gravel pack in cased-hole and open hole horizontal wells. This literature review will include well preparation, design and placement of gravel pack and well completions. The review will be based on several sources such as, journals, conference papers, internet, text books and information from oil and gas companies to support the final result. The literature review will focus on two main topics which are an overview on gravel pack completion and case studies of horizontal gravel pack completion in various fields. For the first part, thorough study and investigation will be done to identify issues related to gravel pack design and installation. For the second part, few case studies will be selected and reviewed to identify issues related to horizontal gravel pack completion and standard practices on gravel pack completion job. There are three main categories for the case study which are (1) cased-hole horizontal wells, (2) open-hole horizontal wells, (3) HPHT horizontal wells. For each category, an analysis will be done to identify the common issues.

3.1.2 Ishikawa Diagram

The ishikawa diagram or known as fishbone diagram is a tool to identify possible causes for a particular problem. After a critical study has been done, all the major classifications of causes are listed down in this diagram. This will give a better visual representation of the study and analysis.

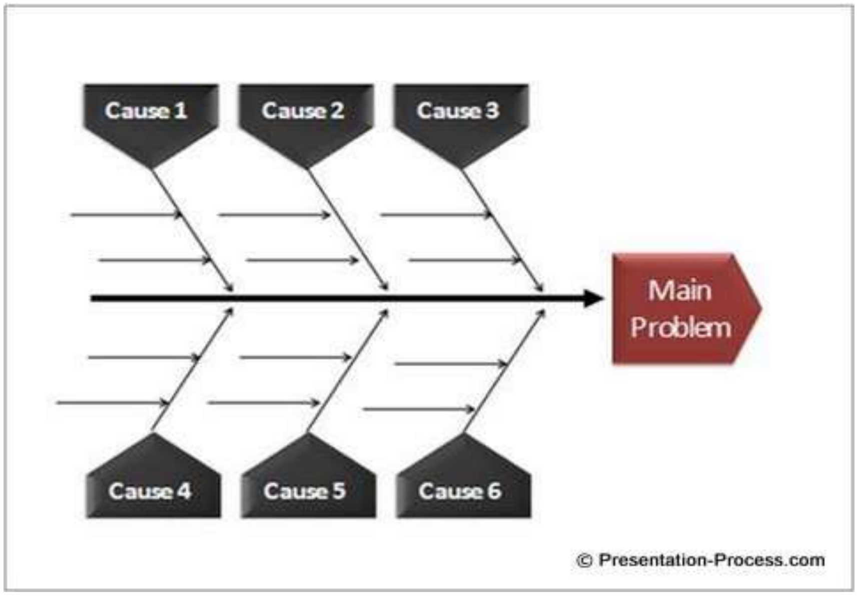

Figure 5: Ishikawa Diagram (presentation-process.com)

3.1.3 Table Analysis

After factors and problems have been identified, analysis on each gravel pack design and installation will be tabulated according to the case studies.

1. Cased hole horizontal gravel pack completion

2. Open hole horizontal gravel pack completion

3. Gravel Pack in HPHT wells

3.1.4 Summary and Recommendation

Further analysis will be carried out to analyse the factors that affect gravel pack design and installation with respect to well conditions. At the end of this project, a summary of all findings will be shown and classified based on the case studies. Recommendation based on the study will also be presented at the end of this project.

3.2 Project Process Flow

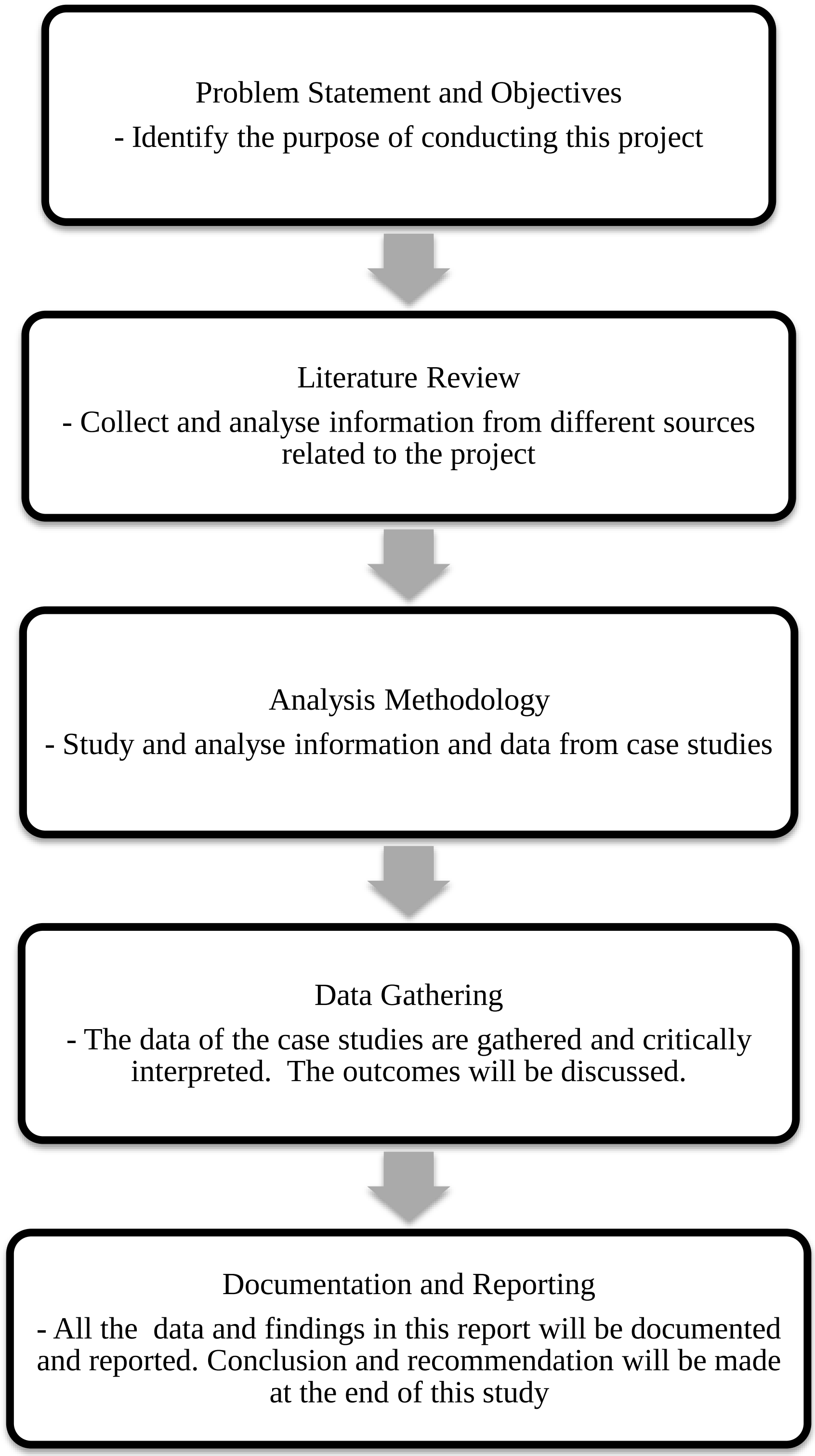

Figure 6: Project Process Flow

3.3 Gantt Chart

Table 2: Gantt chart and Key Milestone

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	Selection of Project Topic																													
2	Preliminary Research Work																													
3	Submission of Extended Proposal																													
4	Proposal Defence																													
5	Project Progression																													
6	Submission of Interim Draft Report																													
7	Submission of Interim Report																													
8	Project Progression																													
9	Submissio n of Progress Report																													
10	Project Progression																													
11	Pre-SEDEX																													
12	Submission of Draft Final Report																													
13	Submission of Dissertation (soft bound)																													
14	Submission of Technical Paper																													
15	Viva																													
16	Submission of Project Dissertation (hard bound)																													

Suggested Milestone

Process

3.4 Project Activities

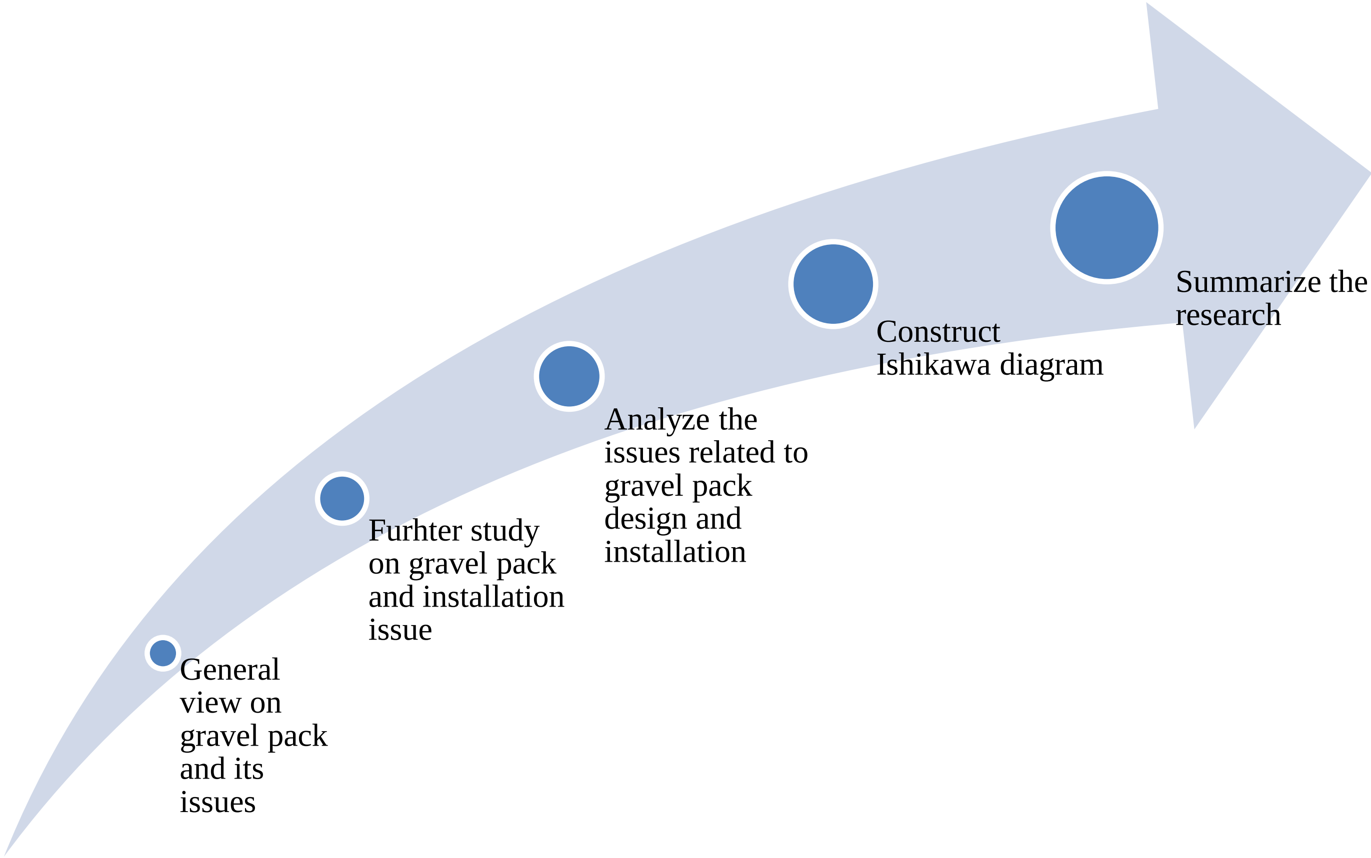

Figure 7: Project Activities

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Gravel Pack Issues Analysis

Issues addressed are based on literature review which includes case studies. The discussions can be categorized into two parts which are installation issues and design issues. From the analysis, an ishikawa diagrams are constructed to have a clear representation of the result.

4.1.1 Cased Hole Horizontal Gravel Pack

The reliability and credibility of cased hole gravel pack is well known in the industry. It can be installed in most environments where other sand control techniques struggle. Cased hole is significant for reservoirs with very unconsolidated formation because it minimize the hole stability concerns. Apart from that, it has a greater control over zonal isolation and pay interval as well as offers multi zone completions. Cased hole completion has a complex operation, logistics and time. It is also not suitable for high permeability formations as it will limit the production due to the perforation tunnels. In the context of horizontal wells, cased hole completion is uncommon to be practised in the industry. Some of the reasons are because there is difficulty in cementing casing and clean-up, higher cost for perforation and productivity limitation in high rate wells. However there were few case studies on this particular condition.

From the findings had been done, length of interval was one of the major concerns during the installation of gravel pack. There is a limitation in in the interval length that can be deployed in one go. Treating beyond the limit caused complete gravel packing to be unachievable and failure of tools. Bridging also occurred during the placement especially at the screen-casing annulus when there is not enough leak-off into the formation. Bridging leads to voids in annulus for horizontal wells and provides very limited perforation packing. The efficiency of perforation and annular pack could decline as well when installing gravels. Some of the factors that can be related to are gravel suspension of carrier fluid and the energy to move slurry. The gravel suspension and energy requirement must be optimum enough to ensure complete packing in horizontal wells.

As for the design issues, not many design issues were addressed in the case studies. One of the issues is the design of conventional tool itself. Based on the research done by Alexander et al. (1996), gravel pack in horizontal wells can be extremely difficult by using conventional tools and techniques. According to Penberthy and Shaughnessy (1992), the main disadvantage of cased hole gravel pack is it is unsuitable for high flow rates and much more complex to perform. One of the common issues in wells is formation damage. Formation damage exists due to many reasons during drilling and completion and it will decrease the productivity of the well. Hence, the design efforts in order to prevent damage must be focused on good perforation practice, compatibility of fluids and efficient clean-up before gravel pack takes place. Apart from that, fluid loss control also gave damage on productivity of gravel pack. This is due to the design of fluid loss control which is not compatible with the well. The result of the study is represented in table 3.

Table 3: Design and Installation Issues in Cased Hole Horizontal Gravel Pack

Design	Installation
• Conventional tool • Fluid loss control • Formation damage	• Length of interval • Bridging of gravel at screen-casing annulus • Perforation and annular pack efficiency • Gravel suspension • Energy requirement for slurry movement

4.1.2 Open Hole Horizontal Gravel Pack

Open hole horizontal gravel pack is comparatively new method yet increasing in popularity. This type of completion exposes more of a reservoir to a wellbore which increases injectivity and productivity while lowering pressure drop and flow velocity. Having a low drawdown and velocities may minimize production of some sand formations. Typically, open hole is completed for deviated and horizontal wells. With a correct design, open hole gravel pack can provide maximum productivity as well as highly effective sand exclusion method due to no perforation restrictions (Chilingarian et al., 1989). Open hole requires less cost compare to cased hole as it does not have casing, cementing and perforating operations. However it needs to maintain the stability of the hole during drilling and completion.

One of the main issues in open hole gravel pack design is the stability of the open hole itself. The open hole must be sufficiently overbalance to avoid underbalance which leads to hole collapse and well control problems. In order to get sufficient overbalance, it needs to use the right displacement fluid. The best one is filtered completion brine which can ensure the filter cake to be in place during gravel pack operation. Unsuitable sand exclusion method is also one of the issues occurred in industry. Stand-alone screen horizontal screen were installed previously but had shown failure. Hence, gravel pack technology gives a better option. Apart from that, design of crossover tool for horizontal gravel pack must maintain the hydrostatic overbalance across formation. Failure to maintain the hydrostatic pressure causes the risk of borehole sloughing and removal of filter cake. The concentration of gravel pack affects the effectiveness of gravel pack. According to an experiment done by Osisanya, Ayeni, and Osisanya (2006) the pack efficiency increased in higher gravel concentrations. Based on the case study on Campos Basin, previously the field had used several types of screen. The operator wanted to ensure there was no plugging and erosion occurred before wells were depleted and avoid well intervention. Hence they had specifically chosen premium screens.

Wellbore clean-up is an important issue for gravel pack completion because debris in the wellbore causes completion failures. It is crucial to carry out wellbore clean-up in horizontal wells for sand control because it significantly reduces problems related to the installation of gravel pack. The presence of debris may also result to premature screen out. Carrier fluid plays an important role in placing the gravel pack. Based on the result, it shows that water-gravel slurries gave better pack compare to viscous slurry. Slurry with lower viscosity and higher displacement rate results in more complete gravel pack. Viscous fluid is best suited for low well angles and short intervals relatively (Penberthy & Echols, 1993). Incomplete gravel placement can occur for several reasons. As for this study, the incomplete pack was due to mixing of water-based fluids for gravel pack with synthetic drill-in fluids and formation fluids. The mixing was incompatible and hence emulsions were formed. Excessive fluid loss also could happen during removal of impurities present in water-based drill in fluids. This is because of the fast reaction of acid, it quickly dissolved the filter cake and most acids would leak-off into the cleaned zone. High fluid losses resulted in mechanical fluid-loss device failure. The drill-in fluid and the completion fluid incompatibility is also one of the issues in open hole gravel pack. In the case of a particular field, it is highly reactive shale. This shale caused the problem when using oil-based mud and water-based mud. Hence, the company took an action to substitute the water-based mud with synthetic oil-based mud (SOBM). This SOBM has resulted in improved productivity.

Table 4: Design and Installation Issues in Open Hole Horizontal Gravel Pack

Design	Installation
• Open hole stability • Unsuitable sand control technique • Design of crossover tool • Design of screen • Gravel concentration	• Incomplete gravel placement • Carrier fluid • Excessive fluid loss • Premature screen-out • Wellbore clean-up • Fluid-fluid incompatibility

4.1.3. Horizontal gravel pack in HPHT well

Reservoir formations under high pressure high temperature (HPHT) conditions can be complex. Many HPHT reservoirs are greatly stressed. When this condition combines with high depletion and drawdown, production of sand formation can be an issue including relatively strong rocks. It is possible to execute both cased hole and open hole gravel pack in HPHT condition. There is a limitation for cased hole completion which the perforating gun cannot exceed pressure of 20 000 psi and perforating charges can withstand temperature up to 450°F. Meanwhile, open hole completion requires a barrier to the well fluid leak-off that contains hydrostatic pressure presents and provides support to the formation. Before gravel pack was installed in HPHT wells, the only sand control technique used was Stand Alone Screen (SAS). However, screen plugging occurred and this caused lower productivity.

In designing gravel, it is very important to select the right type of proppant. Conventional proppant is a challenge for this condition as it has a large difference in specific gravity between gravels and completion brine. As a result, the proppants tend to settle on the lower side of hole and in the long run can create a gravel plug. For a specific case study, the shape of proppant affects the effectiveness of gravel pack completion in Albacora Leste field. The typical spherical shape is not efficient for that particular condition. Hence, the shape of gravel is designed to be irregular with a high angular proppant to allow permeable gravel pack in stress environment. The design of proppant also needs to withstand the high pressure as generally, the higher pressure onto the proppant, the lesser the conductivity of gravel packing. Higher compression may also crush the proppant. Apart from that, the gravel pack fluids must also be designed correctly as it depends on the stability of temperature. It is also important to note that operating cost in HPHT wells is high. Hence, precise method on designation is crucial.

For the placement of gravel pack in horizontal well HPHT field, it requires high density of fluid. Conventional carriers do not give enough support to transport gravels into the hole. High density fluid gives enhanced buoyancy to the gravels. In contrary, the density of proppant must be low to ease the gravel placement completely. It had shown in case history, the ceramic proppant with low density resulted to higher conductivity. Gravel plugging also could occur if too much gravel settled. It would provide a void in that particular completion from the plug to toe which leads to failed sand control. Another issue is that the small margin between the fracture gradient and pore pressure. Hence, it cannot carry out gravel pack in conventional completion. The gravels needed to be installed at low rates so that the fracture gradient did not exceed the pore pressure. From their case study, it is possible to place proppants at lower rates effectively than the conventional operation in order to reduce the ECD impact which affects the small pore/fracture gradients.

Table 5: Design and Installation Issues in Horizontal HPHT wells

Design	Installation
• Conventional proppant • Shape of proppant • Pressure limitation • Temperature stability • Operating cost	• Density of fluid • Density of proppant • Gravel plugging • Narrow margin between fracture gradient and pore pressure

4.2 Gravel Pack Issues Results

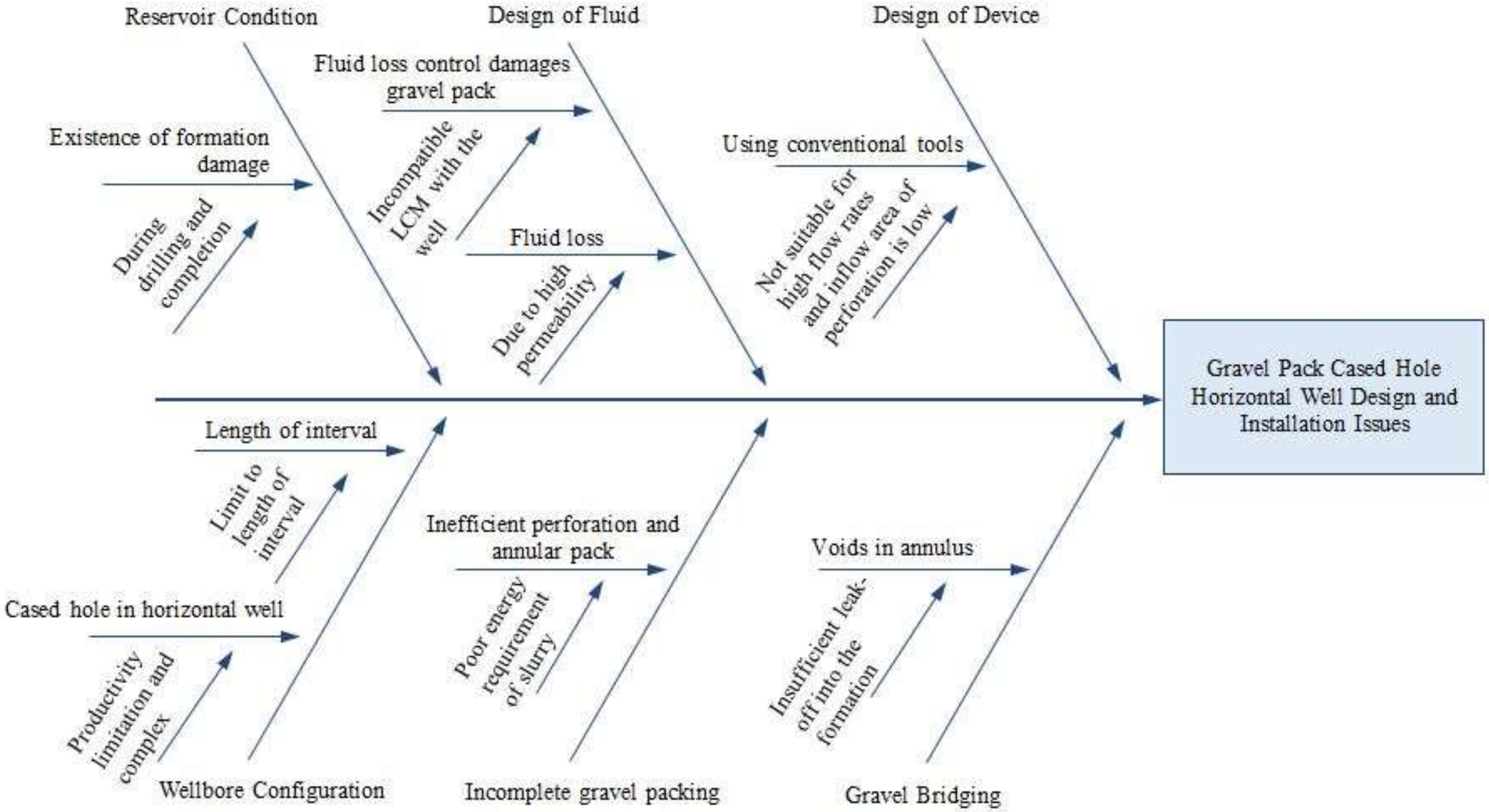

Figure 8: Root Cause Diagram for Gravel Pack Cased Hole Horizontal Well Design and Installation Issues

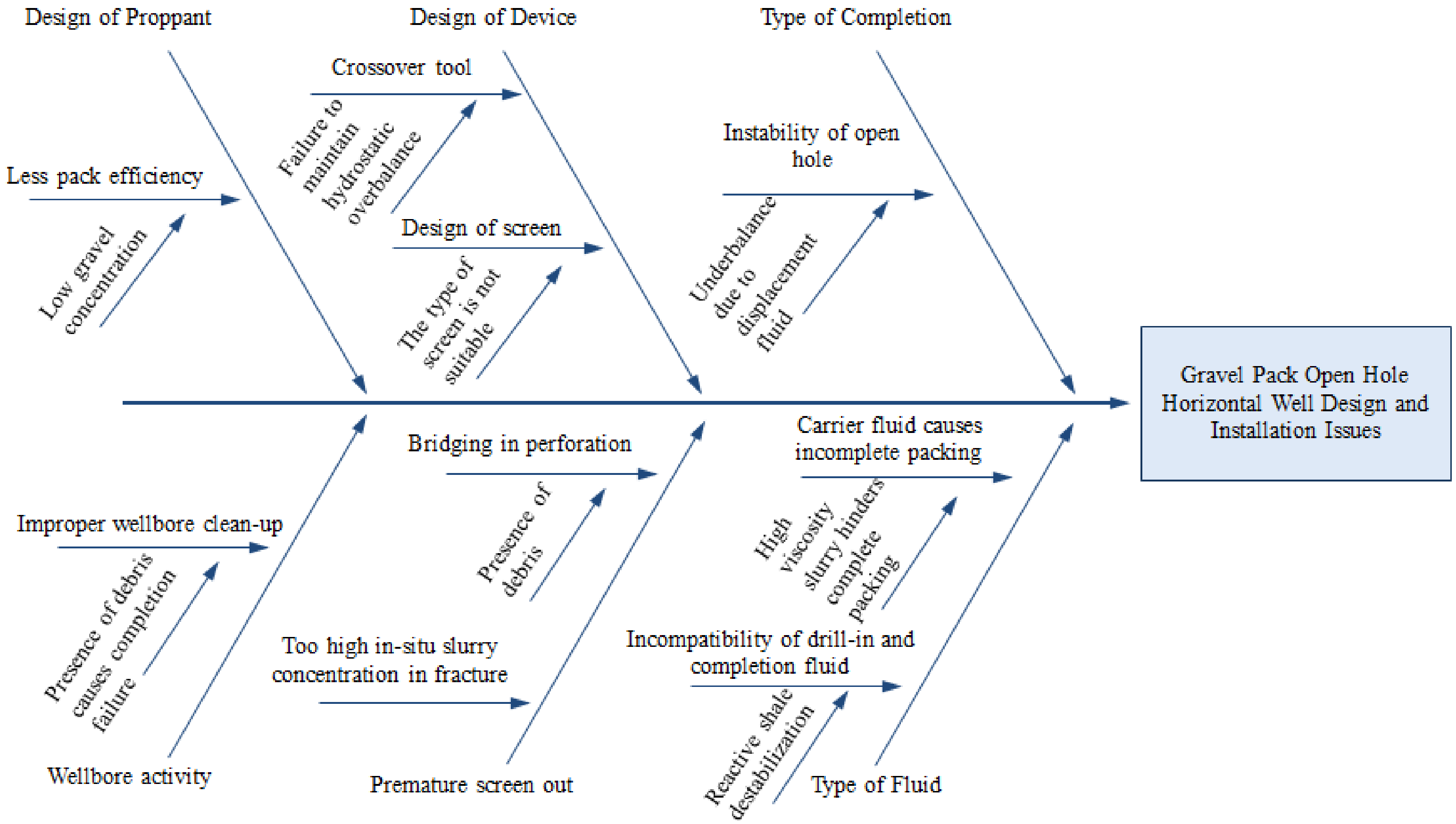

Figure 9: Root Cause Diagram for Gravel Pack Open Hole Horizontal Well Design and Installation Issues

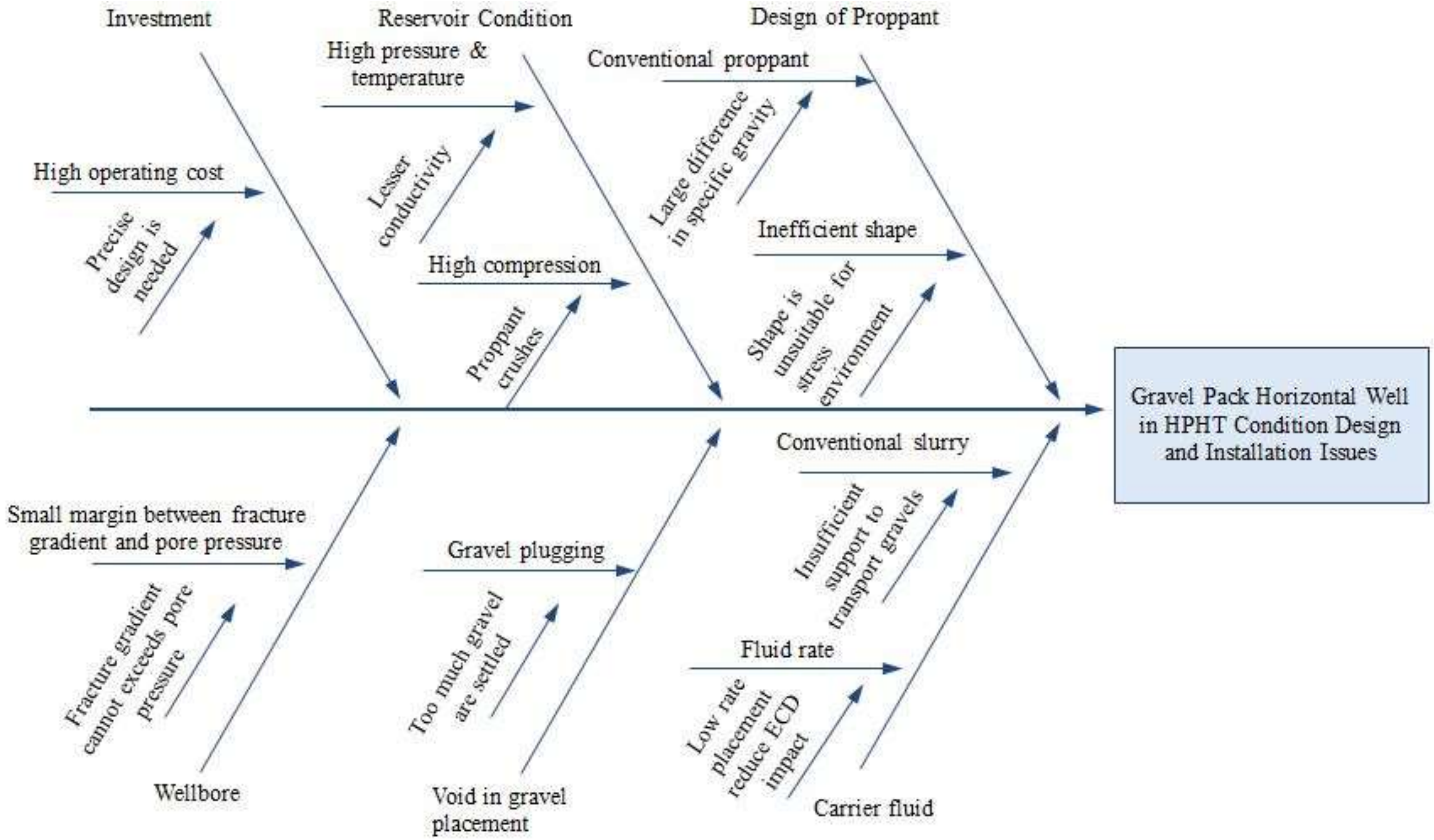

Figure 10: Root Cause Diagram on Gravel Pack Horizontal Well in HPHT Condition Design and Installation Issues

4.3 Summary of Result

Based on the analysis of all case studies, it can be concluded that there are several similar factors that contributed to the performance of gravel pack. In this section, a summary is carried out to recommend the suitable gravel pack design and installation. The recommendation is based on the analysis being done, literature review and additional information from reliable sources. Below are the recommendations for each condition.

Table 6: Recommendation for Cased Hole Gravel Pack in Horizontal Well

Cased Hole Gravel Pack in Horizontal Well	
Design	✓ Design of tools is suitable with the condition of wellbore – high productivity reservoirs is more suitable with open hole completion ✓ Prevent formation damage from occurring – perform good practice during drilling and completion operation ✓ Use compatible completion fluids with the reservoir ✓ Perform a good perforation practice – no presence of debris ✓ Loss control material is needed to ensure no high fluid loss occur after perforation ✓ The loss control material must be compatible with the wellbore
Installation	✓ Conduct open hole completion in horizontal well – cased hole provides complex operation and can cause decline in productivity ✓ High energy requirement for carrier fluid to place gravel completely to the end of wellbore ✓ Provide sufficient leak-off into the formation to prevent voids in the annulus

Table 7: Recommendation for Open Hole Gravel Pack in Horizontal Well

Open Gravel Pack in Horizontal Well	
Design	✓ Open hole to be sufficiently balance – presence of filter cake ✓ Design the right displacement fluid to provide stability to the open hole ✓ Design of the crossover tool must maintain the hydrostatic overbalance across formation ✓ Design high gravel concentration for a better efficiency pack ✓ Choose the right screen depending on the well condition and cost
Installation	✓ Carry out wellbore clean-up properly to avoid presence of debris ✓ Place the gravel at lower viscosity of carrier fluid for horizontal well ✓ Place the gravel at high velocity for complete placement ✓ Provide compatibility fluids during installing gravel pack ✓ Monitor fluid loss during gravel pack operation

Table 8: Recommendation for Gravel Pack in Horizontal HPHT Well

Gravel Pack in horizontal HPHT well	
Design	✓ Design a proppant that can withstand high pressure and high temperature ✓ Design a proppant with low specific gravity ✓ The shape of gravel might not have a typical spherical shape to withstand stress environment ✓ Design the fluid correctly to suits the temperature stability ✓ Consider the cost of operation as HPHT well requires high cost
Installation	✓ High density of carrier fluid to carry the gravels ✓ The gravel must not be settled too much to avoid plugging ✓ Install the gravel at low rates to prevent fracture gradient exceeds pore pressure ✓ Gravel can be installed using screened formate based RDF to maintain the filter cake with low risk of losses

CHAPTER 5

CONCLUSION

This project focuses on one of the sand control methods, gravel packing which is common in the industry. This project studies on the issues of gravel pack design and installation in horizontal well. By conducting extensive study and reviewing case studies, it gives a better understanding on common approaches of practical on the design and installation of gravel pack completion. Issues or problems identified from the case studies are analysed. According to the analysis done, there are common issues between different well conditions. However, each well has its own challenges and it needs specific gravel pack design to overcome the problems. In conclusion, it is very crucial to study about the characters of the field first before design the gravel pack. This is to ensure that the sand control method is successful after placement. A summary of findings and recommendation on gravel pack issues related to design and installation are presented at the end of this project. The summary gives a general guideline for the gravel pack design and installation.

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CHAPTER 6
RECOMMENDATION

As a recommendation for this project, the author suggests to include experiments either from research papers or carry out an experiment. This is to understand further on the design and installation before the operation takes place. The experiments can be done according to the respective well conditions to support the study. Another recommendation is to use software to analyze the parameters by conducting sensitivity analysis. From the sensitivity analysis, an effective gravel pack design can be achieved. Hence, other than analyzing the issues through research it can also be done by using software. One of the software that is proposed is SandCADE sand control software.

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