Innovative Design of a Ball Injection Device for a Rapid Kill of Offshore Blowout Wells

By

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CERTIFICATION OF APPROVAL

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(MUHAMMAD SYAFIQ BIN A.RAHIM)

ABSTRACT

This project makes an innovative design of ball injection device for a well blowout response system. Blowout is an uncontrolled flow of gas, oil or other formation fluids into the atmosphere or another zone. If this flow of hydrocarbons is not stopped in time, the hydrocarbon can ignite into a deadly firestorm call blowout. Because of the immense cost and danger associated with oil well blowouts, the well control industry resolves around the prevention and avoidance of blowouts. Unfortunately, well blowout still occurred such as Montara gas well blowout in 2009, Macondo well blowout in 2010 and recently in 2013, a blowout in Gulf of Mexico.

Hence, it is necessary that there be a method in place to combat them when needed rises. For fast and effective well kill technology to kill blowout well, "A Rapid Kill Restoration System for Blowout Wells" has been invented. This method works by releasing heavy solid ball injection device to inject the solid ball into the well. Comparative study being made to analyses the suitable design of the injection device. A successful start of this research project will lead to successful application of a large fund for developing and prototyping of the rapid kill and restoration system for offshore blowout wells. The successfully developed technology will equip and safe guard PETRONAS in its endeavor to enter the area of deep water drilling and production.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

A blowout is the uncontrolled release of crude oil and/or natural gas from an oil well or gas well after pressure control systems have failed. Prior to the advent of pressure control equipment in the 1920s, the uncontrolled release of oil and gas from a well while drilling was common and was known as an oil gusher, gusher or wild well. An accidental spark during a blowout can lead to a catastrophic oil or gas fire. The undesirable flowing of formation fluids out of the well have to be stopped by regaining control of the well. To regain control means to kill the well

The probability for blowout to occur is always there as long as there are drilling operations. The result of blowout is severe even the most simple blowout can result in the loss of millions of dollars. Blowout can occur in every drilling operation regardless of the depth of the well, either in shallow or deep water operation.

To regain control of the blowout well, there are two traditional methods of well kill technologies. One method is dynamic top kill which pumps heavy drilling mud into the well. Another method is by drilling a relief well to intersect the blowout well and kill the well by pumping kill mud into the well. Dynamic top kill is not very effective and drilling a relief well took too much time.

Based on the problems with conventional kill method, there is a need for fast and effective well kill technology for offshore oil and gas blowout. So, this study is based on the patent “A Rapid Kill and Restoration System for Blowout Wells” invented by Xianhua Liu. This method works by releasing heavy kill balls (solid particles) into the well instead of using kill mud. These balls can be made from environmental friendly materials. These balls can be transport by any transporting fluid like nitrogen, air, water or any other fluid

1.2 PROBLEM STATEMENT

There is currently no fast and effective technology for offshore blowout well control. Dynamic top kill often fails for most of the well where energy is high and intense as the drilling mud will mostly be diluted away and blown out of the well by the strong oil or gas flow. Drilling a relief well is an effective method but it is too slow and too costly. The duration taken to successfully killed the well by this method, also the duration of continuous pollution to the environment by free flowing of hydrocarbon to the surrounding area.

Well blowout can result in catastrophic consequences. The damages include the loss of life and health of the workers, pollution to the environments which is the release of hydrocarbons into the sea and economic losses. Environmental pollutions have short and long term effect. Oil spills cause serious impact on marine wildlife. The effect by this pollution takes a long time to recover. In terms of economy, the cost to restore this environmental impact is as much as the cost to kill the well. Also, there is also litigation issues need to be solve after the well has been successfully killed, and this require another cost to be paid. As drilling operation move into more challenging area, this business has become even more risky than ever. Most operators are aware that the day of drilling conventional wells are almost over. Deeper wells are being drilled, with high pressure and high temperature and in harsh environment.

Thus, “A Rapid Kill and Restoration System for Blowout Wells” invented by Xianhua Liu may act as alternative for a fast and reliable solution to kill the well. Implementation systems for carrying out the ball kill operation consisting of a tubing system, a blower or a pump, a cage and a ball injection device. A ball injection device must be designed properly to reduce time consuming to kill the well; permit faster operation and safer operation by make sure the injection device have no any leakage during the operation.

In this project, the author will address the issues and making an analysis on innovative design of a ball injection device of a rapid kill and restoration system for offshore blowout wells. The issues are:

1. How to design suitable ball injection device for a rapid kill system for blowout wells?
2. What is the best mechanism of the ball injection device?
3. How to make sure the system provides safe operation and to ensure the reliability of the ball injection device?

1.3 OBJECTIVE

The objectives of this project are:

1. To make a comparative study on the previous ball injection device
2. To investigate and design suitable ball injection device for a rapid kill system for blowout wells.
3. To determine the mechanism of the ball injection device for easy operation and it simplicity

1.4 SCOPE OF SUDY

The scopes of study based on the objectives can be simplified as follows:

1. Design a ball injection device
2. Mechanical characteristics of the ball injector such as the gear profile of the device, material type, and the optimum design of the system.

1.5 RELEVENCY OF THE PROJECT

Study on new technology for well kill method is important in well engineering industry as currently there is no fast and reliable method for well kill technology. So it is a need to develop this ball kill process for oil and gas blowout. Advantages of this method are as following:

- **Reliability**: One of the conventional method of well kill is by pumping heavy kill mud from top of the well, but when encountering strong flow of blowout fluid, these mud more likely to be blown out of the well. On the other hand, kill balls is much denser and bigger from heavy kill mud. Even at the early stage some of these balls might be blown out of the well, they will still be in the system as there are cage install at the top of the well. Thus eventually the accumulate balls will suppress the blowout flow. So the reliability is guarantee by the kill process and also the properties of the kill balls.
- **Rapidity**: This method is effective on killing process so the time taken to control the well is greatly reduce from any conventional method.
- **Restorability**: Another advantage of this kill method, the blowout well can be keep until it is restored to normal production.

1.6 FEASIBILITY OF THE PROJECT

The total duration given to complete this project is about 28 weeks. This duration is considered sufficient as no chemical materials needed and also no laboratory experiment involve. All the required reference materials and software for simulation is available. Thus, this project is believed to be complete within the time frame.

CHAPTER 2

LITERATURE REVIEW

2.1 Blowout Wells

As oil and gas projects explore more and more challenging territories, and as public opinion is increasingly aware of risk from drilling operations, it is furthermost importance to better understand and systematically manage these risks. (Vandenbussche, 2012) .Well blowouts can occur during the drilling phase, well testing, well completion, production, or during work over activities. In a nutshell, a blowout is an uncontrolled flow of gas, oil or other formation fluids into the atmosphere or another zone (B. Cooper, 2007). In the article, he mention that blowouts are the most tragic and expensive accidents in the upstream petroleum industry. It can endanger life, the environment and future production from the lost well. On an economic level, an oil well gushing thousands or even millions of barrels of oil is costing a company not only in short term production, but also the long-term profitability of the well itself. It is vital to the profitability of the well that the blowout is stopped and the well put back online as quickly as possible.

Figure 1 Blowout wells

2.2 Causes of Blowout

Kick during drilling operation can result in well blowout. According to (Wilson, 2012), kick can be defined as uncontrolled flow of formation fluid into the well and also the influx of gas into the formation is more risky than any other hydrocarbon or formation water. There are several factors for kick to happen. One of the example is failure to keep the hole full while tripping, mud weight less than formation pressure, and several other reasons. Indication of kick can be any warning signals such as sudden increase in drilling rate, reduction in drill pipe weight and more (Grace, 2003). Another factor that can lead for kick is insufficient mud weight during drilling and completion operation. Kick can develop into blowout, so this is why it is important to control the kick.

Drilling rigs are equipped with blowout preventer (BOP) to prevent the kick to become a blowout by sealing the well in case of emergency. BOP is a heavy stack of valves assemblies attached on top of the well. BOP is designed to control the excess pressure in the wellbore, but when the system not properly designed or fail to function will result in the release of drilling mud and hydrocarbons out of the well (Dyb, Thorsen, & Nielsen, 2012). During the Macondo Well blowout, BOP failed to completely seal the well. One of the reason is blind shear ram was not able to seal the well because of trapped drillpipe inside the BOP stack. (Turley, 2014). BOP is designed to be the last barrier of the well so it is necessary to make sure it is able to function at all time.

One of the causes of blowout is the poor cemented job. This is what happened in Montara well blowout in Timor Sea. According to the report by Montara Commission of Inquiry, cemented job at the casing shoe had failed. Pressure test is not been done after the cementing job to test for cement integrity. The result is the flow of hydrocarbons into the well through this failed cemented job. (Borthwick, 2010).

Studied from (Kato & Adams, 1991) revealed that most of blowout occurrences are during drilling operation. There is only slight difference between drilling and tripping out operation in term of number of blowout rate. Figure below shows the operations that related to blowout occurrence in all areas except in Alberta, Canada.

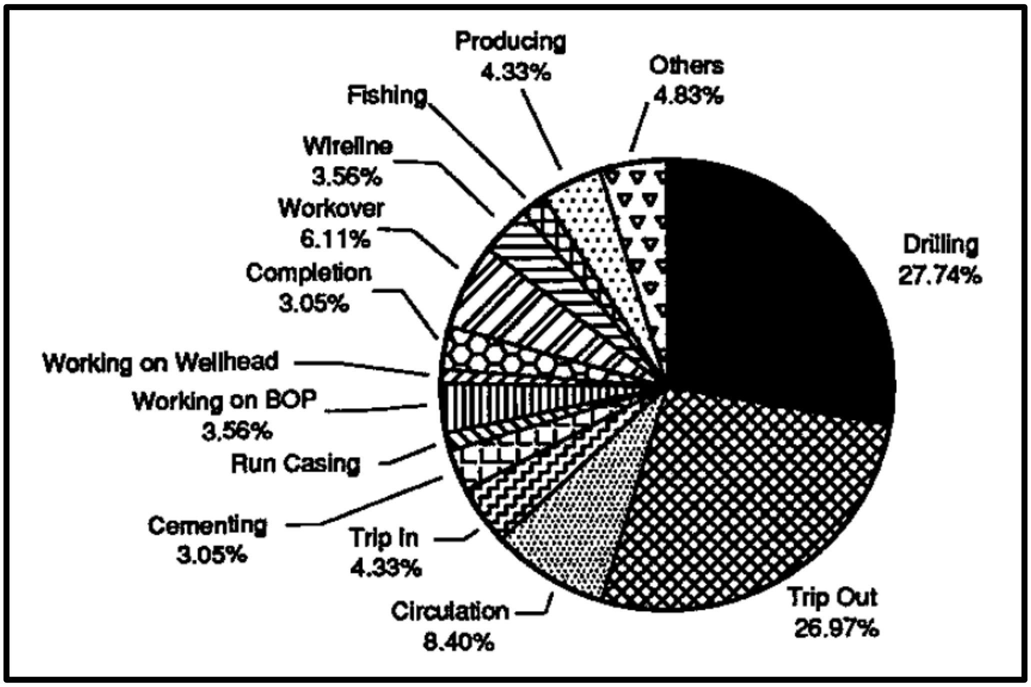

Figure 2 Operation related to blowout occurrence from (Kato & Adams, 1991)

Based on (Johnsen, 2012), from historical data, blowout risk is higher in exploration wells drilling operation compare to a development well. As an exploration well is the first well to be drilled in a particular area, there is a high uncertainty related to formation pressure and also the possibility of hydrocarbons trap.

2.3 Blowout Consequences on Economy and Environment

Legal action has been taken to the company involved in the blowout of Apache Key which involved hundreds of litigants. The legal issue took 17 years to be resolved and also cost about hundreds of millions of dollars. (Grace, 2003). This is an example that blowout incident causes a loss in term of economy to the companies involved in the tragedy. Apart from legal issue to be solved, the company involved in the blowout cases also suffers the loss of facilities and the equipment.

From (Al-Jassim, 1991), during Kuwait oil wells blowout there are about 615 wells are on fire. The fire plume from burning oil wells resulted in severe environment pollution. In addition, the plume dispersion and composition studies from several professional agencies discovered the existence of the plume about 1000 km away from the source. Sulphur dioxide, carbon monoxide and other associated burning matter are carried along within the plume. Other noticeable pollutions are on marine and soil ecosystem. Oil spillage later formed crude oil lakes affect the condition of the soil and plant life. Oil spills along the coastline of Kuwait affect the wildlife marine species. This occurrence had clearly showed that oil wells blowout give negative impact to the environment.

2.4 Well Kill Method

According to Liu (2012) in his study, for a blowout well, there are currently two techniques to avoid this accidents. One is the top kill technique by pumping in kill-weight mud from the top of the blowout well; the other is the relief well technique that intercepts the blowout well and pumping kill mud from the bottom. For kill the well by drill relief well, This well will intercept the blowout well at the bottom to relieve the pressure. Then, kill mud can be pumped into the well and effect a kill. This method usually works but it takes too much time. From the report by (Christou & Konstantinidou, 2012, p. 17), blowout at IXTOC I well at Gulf of Mexico in 1979 took 9 months to kill the well where two relief wells were drilled. The IXTOC I accident where 3.5 million barrels of oil released was the biggest single spill in this gulf before the event of Macondo well blowout. From Hagerty (2010), during *Deepwater Horizon* blowout, first relief well was drilled 12 days after the the rig exploded. The well was successfully killed 87 days after the blowout occured. This clearly indicate that drilling a relief well is a time consuming operation.

Another example, Wells A-1/A-1D located in Main Pass Block 91 (MP 91), Gulf of Mexico, off the Louisina Coast was observed leaking with gas on August 22, 2007. A relief well was drilled which took about 1 months of the drilling operation to completely killed the well. This well intersected the blowout well at 5391 feet true vertical depth (TVD) and drilling mud was pumped followed by cement into the well (Josey et al. 2008). Based on the depth of the intersection which is not very deep, we can estimate the time taken to drill a relief well when we double that intersection depth. Based on Hagerty (2010), blowout in the Montara oil field located in Timor Sea on August 21, 2009 was killed by drilling a relief well. This relief well was drilled to intersect the blowout well at the depth about 13,000 feet below the ocean floor. The leaking of the well finally stopped on November 3, 2009 which is about 10 weeks later. According to Herbst (n.d), on July 23, 2013 natural gas blowout occurred on Hercules 265 jack-up rig located in the Gulf of Mexico off the coast Louisiana. The rig was working on sidetrack well during the event.. Relief well took 74 days to complete. From these three wells described above, we can conclude that drilling a relief well takes too much time to complete.

Another conventional well kill method is top kill or also called bullhead. “Bullheading” is defined as pumping the kill fluid directly into the well against the pressure of the well by not considering the obstacles in the well. This technique is not always successfully worked when the annulus in a well is completely filled with gas. During the pumping operation the kill mud will bypasses the gas in the annulus. There is possibility the well will blowout again after the well is shut in. (Grace, 2003).

As a conclusion, both techniques use kill mud for solving the problem. The top kill technique failed for the PTTEPAA Montara gas well and the BP Macondo oil well blowouts. The failure could be due to kill mud being partially lost into oil reservoir or other formation in case of there was a fracture connection and flow between two formations through the well, but mostly it was due to the kill mud being diluted and washed out of the well. The relief well technique worked. However it was very costly and very late since it took about three months to drill the relief well.

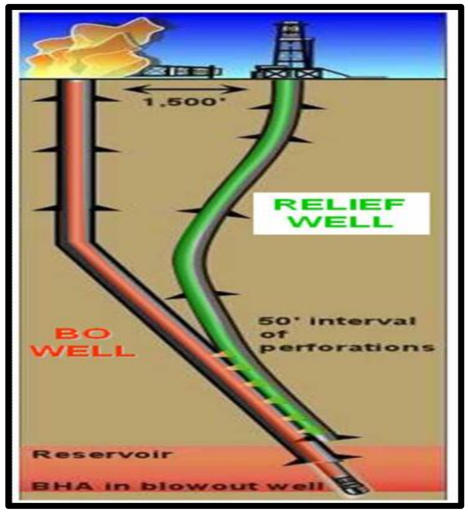

Figure 3 Relief well technique

The consequence was massive oil spill into the sea and gas into the atmosphere that devastated the environment, damaged the local industry and brought huge loss to the oil companies. Although the possibility of blowout for each single well is low, there is a certainly of well blowout in the future as more and more wells are drilled, especially in offshore water. It is only not known when, where and how the next well blowout will exactly happen. As a result, fast and reliable technology is needed for the kill of nature well blowouts.

2.5 Design Features

Kill blowout wells by injecting solid kill balls to the well provides a fast and reliable solution to do the job to avoid the disadvantage of the mud kill technology for the well blowout problem. It solves the problem in three steps: kill the blowout well to a significant extent that only a very small flow remains; allow time for repair or replacement of the damaged blowout preventer and other devices, and connection of production pipeline; restore the well to normal production. The technique achieves its goals by inserting a small diameter tubing or pipe deep into the well and releasing kill balls into the well to block and suppress the flow and later taking out some of them to increase the flow. The essence of the technique is to inject the volume of heavy solid particles to the well and the gravitational force to suppress the flow, while the ball shape is an optimum shape for the kill and restoration operation.

The kill procedure is to sequentially release large, medium and small density balls into the blowout well. Balls of different densities can be made of different materials such as lead, iron, stone or rubber and can have a shell cover made of iron, steel or other environmental friendly material.(Liu, 2012). An implementation system for the kill procedure consists of a tubing system, a blower or a pump, a ball injection device and a cage. The transporting fluid can be air, nitrogen, carbon dioxide, oil or other fluid depending on the operation safety assessment in regarding to the specific well blowout situation. The cage mounted on the tubing and sits on top of the well will temporally contain the blown out balls at the early stage of the kill process. Balls in the cage will fall down to the well as the flow is reduced. A technique for taking out some balls from the well to restore production is carried out by a tubing system, a pump and a balls storage tank.

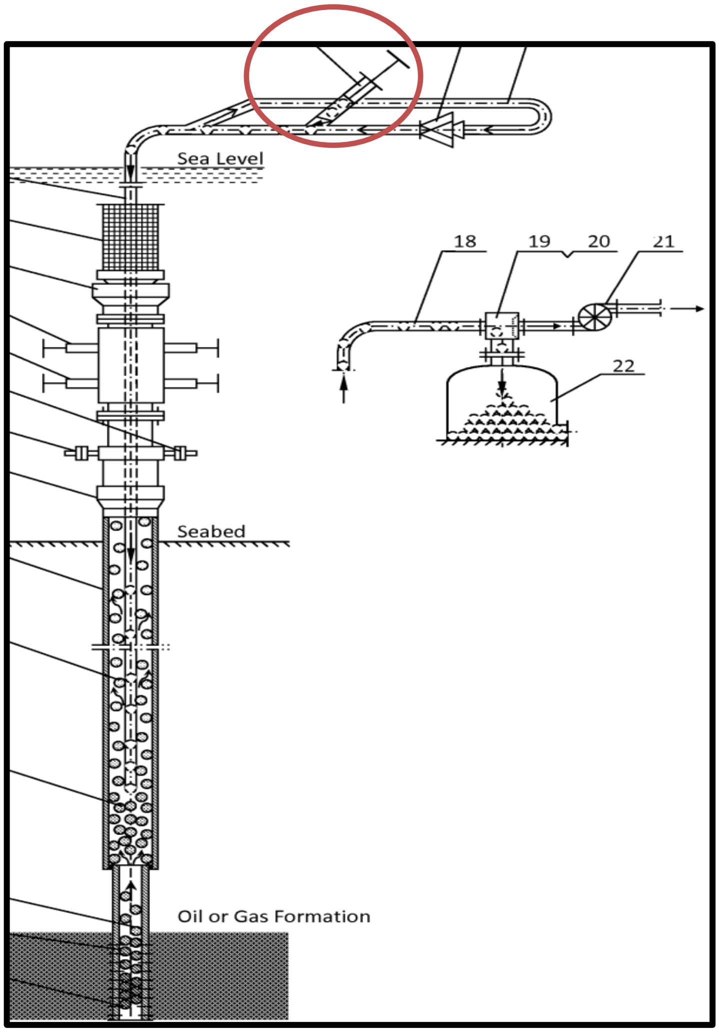

Figure 4 Rapid kill and restoration system for blowout well using a solid ball and highlighted the ball injection device in the system

By injecting a solid ball for rapid kill and restoration system for offshore blowout wells, it has several advantageous. The first advantageous of this technique is its reliability. Due to large size, the kill balls cannot be lost by being blown out of the well. In case some balls are blown out of the well in the early stage kill stage, they will be contained in the cage and will fall down to the well when the flow is reduced, and even in the cage they still suppress the flow. Hence every ball is an effective kill which guarantees the reliability of the kill process. The second advantage is its rapidity. Due to the effectiveness, it takes the kill process only about one day for the blowout to reduce to a minimum value. The third advantage is its capability of keeping the well as a valuable asset by restoring it to normal production.

2.6 Previous Invention of the Ball Injector

2.6.1 Ball Injecting Apparatus for Wellbore Operations by P.Cherewyk (2008)

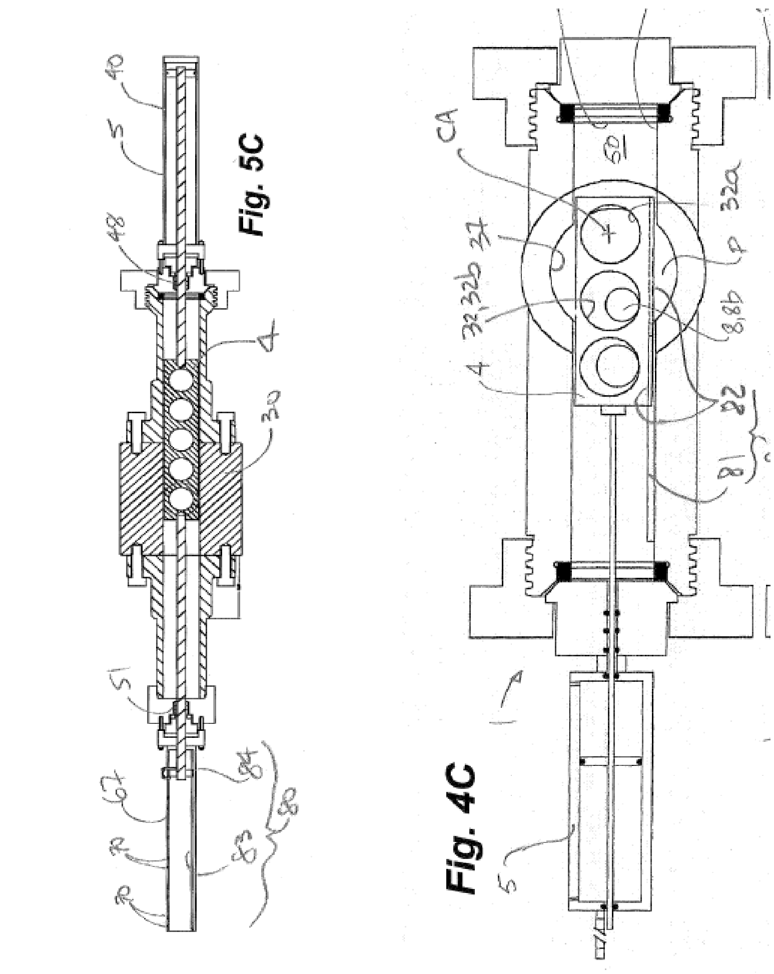

Figure 5 Case study design 1

Referring to pictures of the invention, a ball injecting apparatus can serially inject a first drop ball and subsequent drop balls into a wellbore. This function such as for set down hole tools. This invention contains a several important compartments which contains: a magazine housing having an axial bore formed there through and a transverse port, the transverse port being adapted for fluidly connecting to the Wellbore; a magazine axially movable in the axial bore, the magazine having two or more transverse chambers spaced axially there along, each chamber being adapted for receiving an individual drop ball therein; and an actuator for axially positioning the magazine within the axial bore between a loaded position where none of the two or more chambers are axially aligned With the transverse port, and an injection position where one selected chamber of the two or more chambers is moved into alignment with the transverse port wherein a drop ball for the selected chamber is injected from the selected chamber and through the transverse port to the wellbore. As suitable actuator includes a hydraulic ram which can be operated remotely connected by a piston rod to the magazine. A rod can extend from the magazine and through the magazine housing for indicating the relative position of the chambers and the transverse port. Sensors can complement the indicator.

The apparatus enables a system and methodology for injecting drop balls into a flow passage including systems for operations on wellbores. The ball injecting apparatus is provided. The first of the two or more of the chambers is loaded with a first drop ball loaded therein and each subsequent chamber having a subsequent drop ball loaded therein. The apparatus is mounted so that the transverse port is fluidly connected to the flow passage. The actuator is actuated to move the magazine in the magazine housing to axially align the first chamber with the transverse port for injecting the first drop ball from the first chamber and through the transverse port to the flow passage. As needed, one serially repeats the actuating step for each subsequent chamber for serially injecting each of the subsequent drop balls from the subsequent chambers.

2.6.2 Ball Injector Win, Jr. et.al (1978)

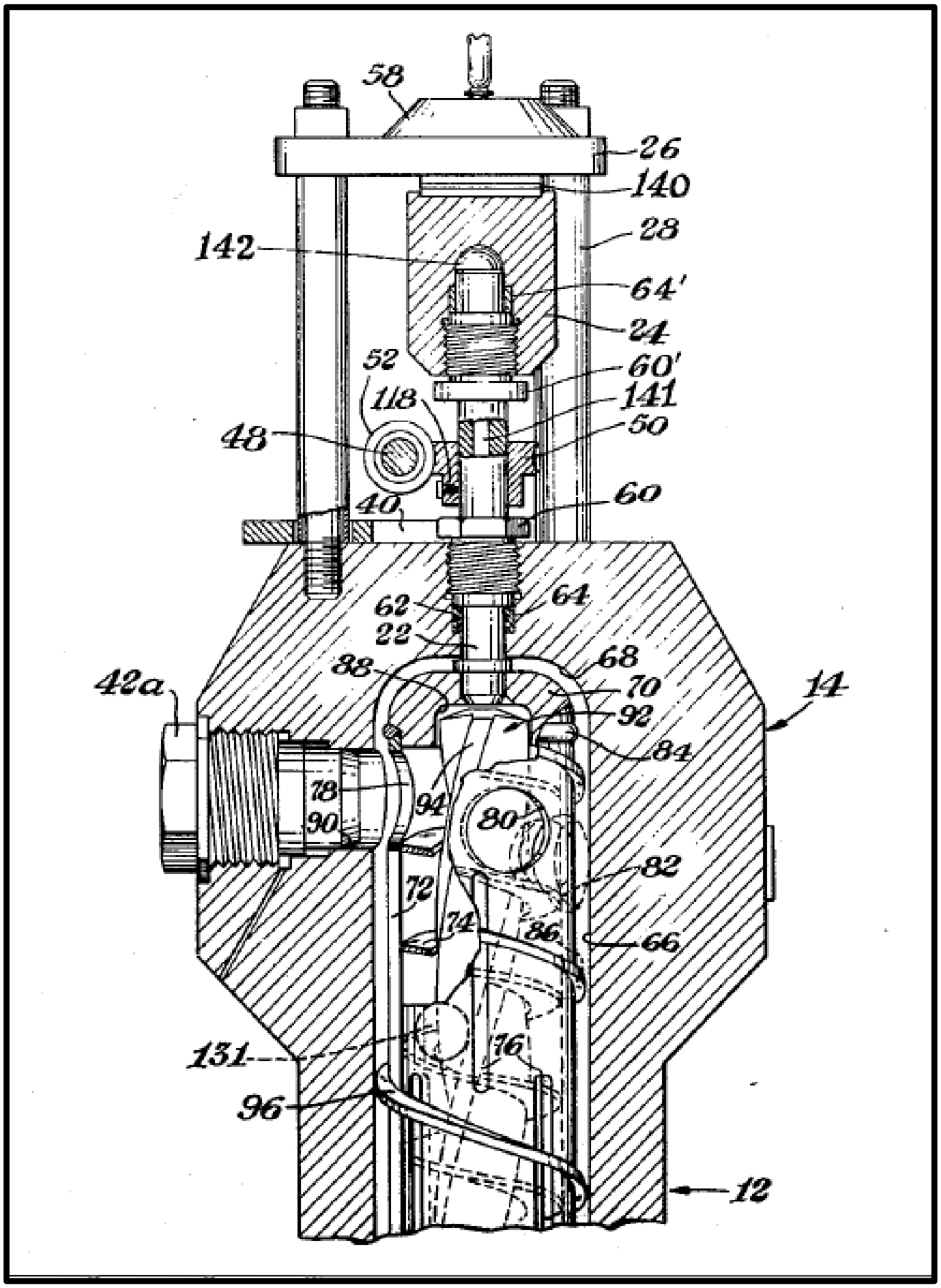

Figure 6 Case study design 2

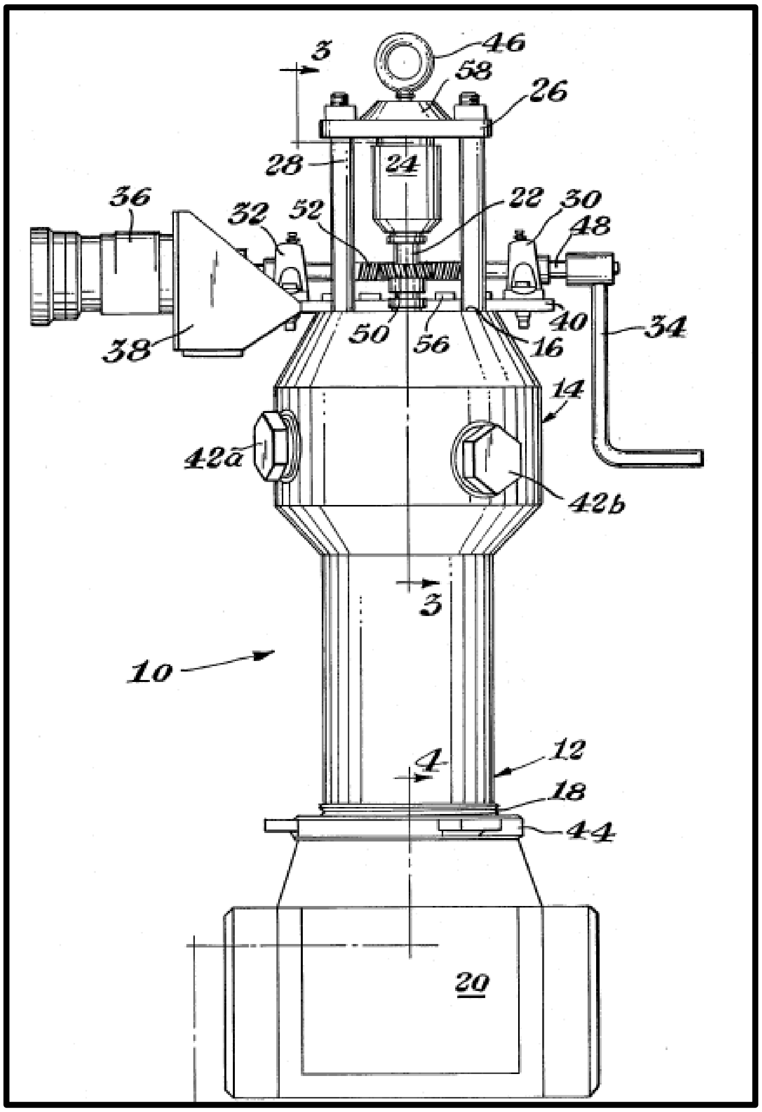

Figure 7 Case study design 2

This invention related to an apparatus for dispensing ball objects and more particularly to an apparatus with a grooved longitudinally disposed member and a surrounding sleeve having a helical inwardly extending rib therein rotatable mounted around the sleeve, the objects being dispensed by the rib pushing them along the groove and out of the apparatus as the sleeve is rotated.

A principal of this invention is to provide an improved ball injector device for use in earth well treating operations. Another object of this invention is to provide an improved, easy to use and reliable ball injector device. In accordance with this invention, there is provided ball injector apparatus including, within a housing, a centrally disposed grooved member surrounded by a rotatable sleeve having at least one inwardly extending helical rib therein, means for introducing balls into the space between the helical rib and the groove, means for rotating the sleeve to advance the balls downwardly, and means for coupling the housing to flow path means connected to an earth well whereby balls are metered into said flow path.

This invention operation is basically by the rotation of the sleeve by using a hand crank or drive by the motor which is gear coupled to the sleeve shaft. The apparatus will be loaded with the required number of balls before the apparatus is coupled to the well. A ball is inserted through the bore and will be push inwardly by rotating the sleeve. After three balls have been inserted, the shaft is rotated one turn to carry the balls downwardly along the spiral to make another three balls to be inserted. Hence, the capacity of the apparatus is three times the number of loops within the shaft made by the spiral. After the required numbers of balls have been loaded into the apparatus, the sleeve is rotated until ball would be freed to pass through one of the bores, and into the tubular passage to be carried along and being pumped into the well. The balls are sized to fit loosely within the space in which they are disposed between the non-rotating shaft and sleeve and to fall freely through each bore. The rate of dispensing balls from the apparatus is a function of the speed of rotation of the shaft. Balls will be dispensed at a rate of 3-20 per minute at treating pressure of up to 20 000 pounds per square inch.

Winn, Jr et.al invention has housing, a stationary shaft having a spiral groove, and a rotatable sleeve having a helical rib. The sleeve is rotated to move the balls along the shaft. The device is loaded by inserting balls into the top of the device and rotating the sleeve in the normal direction. Although these devices perform their intended function, there are few disadvantages to be able used as a ball injection device for blowout well. One of it, is the spiral groove of the invention makes them expensive to manufacture. It would also be desirable to be able to load the devices more quickly and to have a simple way to keep a count of the number of balls which have been loaded. Apart from that, the design used hand crank to rotate the sleeve make the device difficult to used.

2.6.3 Apparatus for injecting one or more articles individually into a tubular flow path. W.D. Kendrick et.al. (1973)

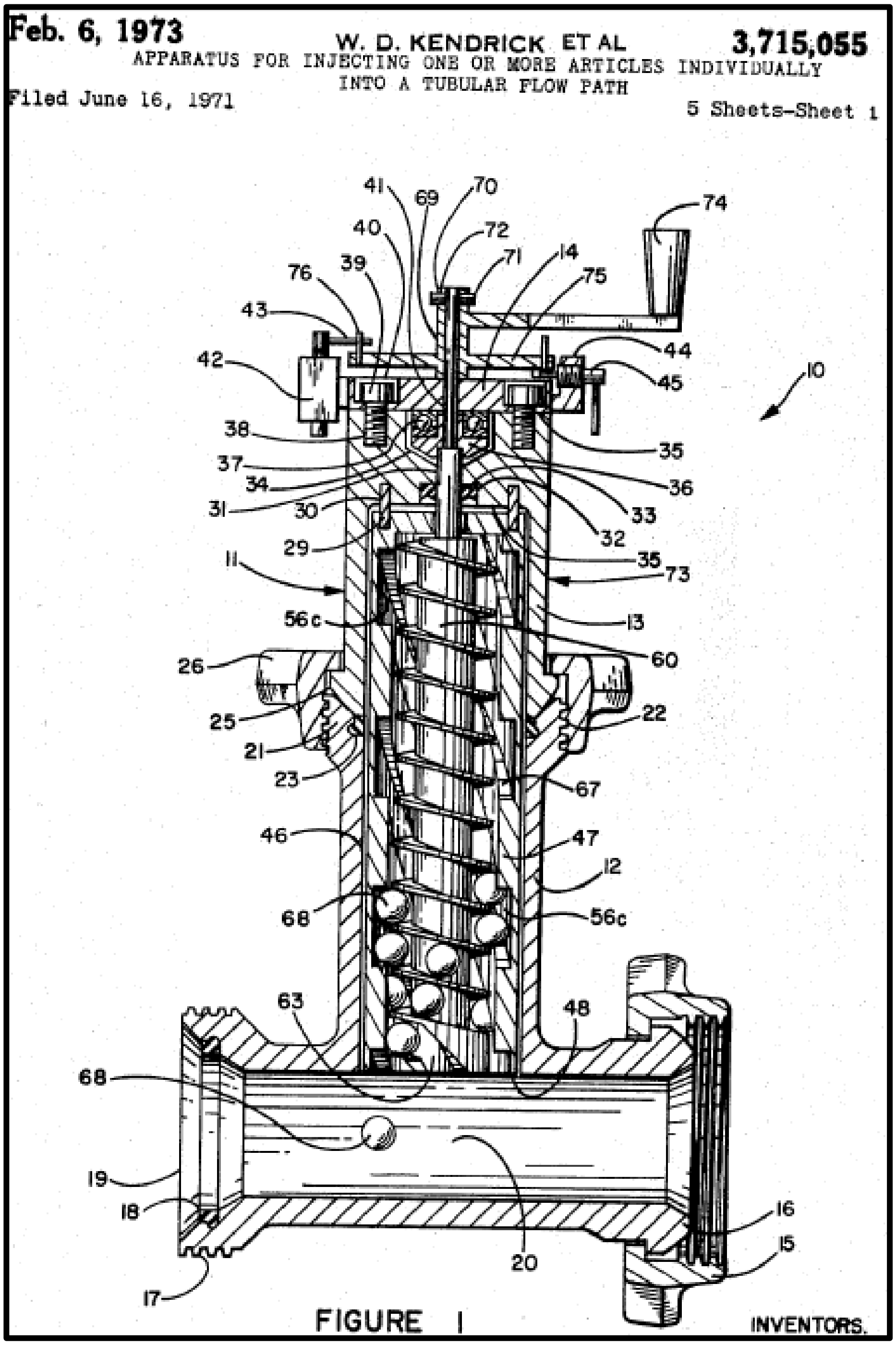

Figure 8 Case study design 3

This invention consists of three components which are lower case, upper case, and top plate. Lower case in the shape of pipe tee provides the connections for tying dispenser into the flow line leading to the well. The operation of this invention by the dispenser is connected into a flow line and required number of the balls loaded. Loading takes place by dropping a ball into outlet, rotating crank arm counterclockwise sufficient to align the next compartment with said outlet, dropping a second ball in, and so on. As is well known, the pressure required to treat oil and gas wells can be quite high. In fact, pressures in the range of 15 000 pounds per square inch.

Kendrick et al. (1973) has designed a ball injector which has housing, a rotatable shaft having a helical rib, and a sleeve having a spiral grove. The groove and the rib have different pitches, so they form separate compartments in which the balls are carried. As the shaft is rotated, the balls are forced downward out of the housing. The device is loaded by inverting the housing, dropping balls into the outlet, and rotating the shaft in the opposite direction. This ball injectors resemble heavy duty gum ball machines, with complicated mechanisms. The complexity of such machines make them expensive to manufacture and difficult to use and maintain.

The most important and novel feature of the instant invention is the structural arrangement of the grooves and helical rib. As stated, individual compartments are formed by the cooperation of the sleeve and rib so that each ball is mechanically captivated. As the shaft is rotated, the balls are forced along the grooves in the sleeve and out of the dispenser and only one ball is forced from the dispenser at a time.

Another advantageous feature of the instant invention is the interchangeability of the sleeves and shafts so as to accommodate balls of different sizes. The method of rotating shaft has been disclosed as being by hand. Other methods may be used as well; eg: a simple air cylinder and ratchet mechanism. Also, instead of a mechanical counter, remote counting can be provided by many electrical devices commercially.

CHAPTER 3

METHADOLOGY

3.1 Project flow chart

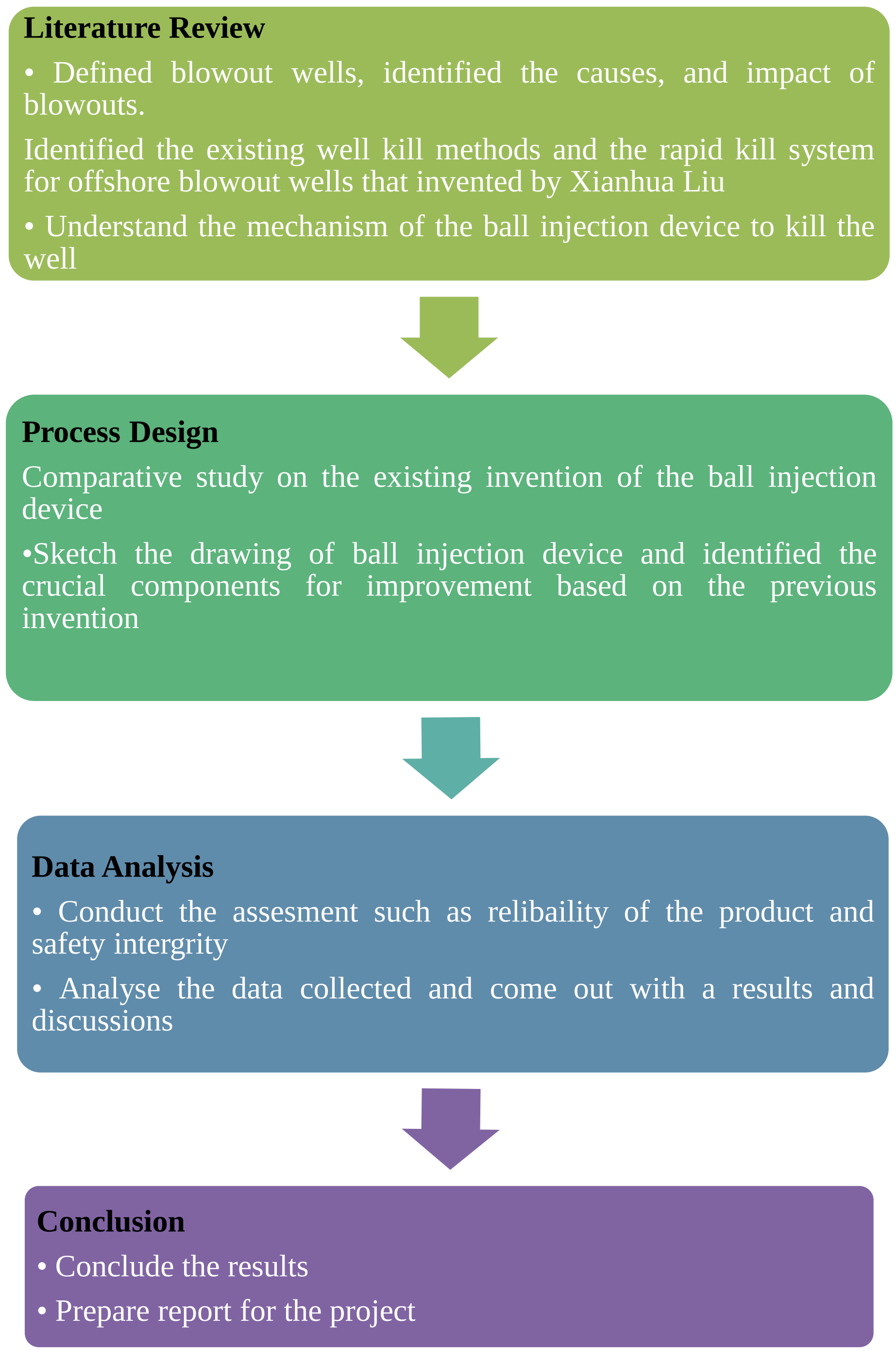

Figure 9 Project flowchart

3.2 Project activities

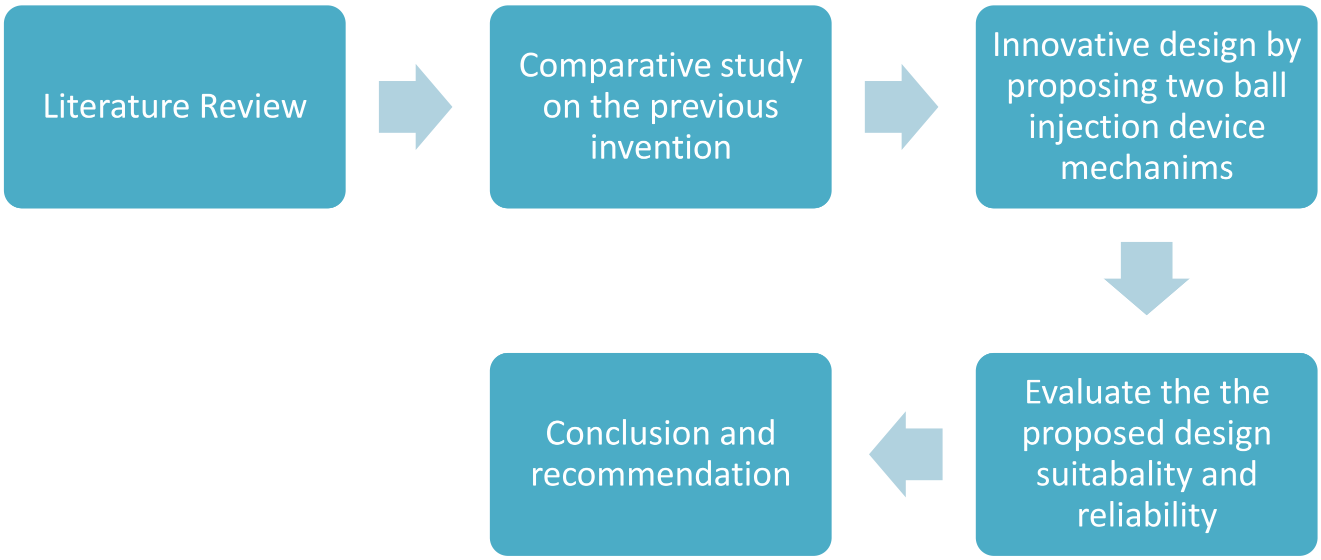

Figure 10 Project activities

a) Literature Review

This is the first step of this project. A research on well blowout problems, causes and its impacts can be identified. Apart from that, research being made on the existing well kill methods to identified their reliability to kill the well. A study being made to analyze the well kill method that being invented by Xianhua Liu in order to understand the need and the characteristic of ball injection device that want to being invented.

b) Comparative study on the previous invention

After a research have being done on blowout problems, a comparative study being made to analyze the previous invention of the ball injection device. This study to identify the mechanism needed to inject the ball, advantages and disadvantages of the inventions, hence for improvement in the new innovative design of the ball injection device.

c) Innovative design of a ball injection device

After make a comparative study, two innovative design of a ball injection device being proposed. This two design has different mechanism and one of the best design being chosen for further study and develop to optimize the design characteristics.

d) Evaluate the proposed design

A detailed study being analyzed to design the ball injection device from the top part until low part of the device. This to enable the modeling can be made in the future with a optimize design to increase the efficiency and reliability of the design.

e) Conclusion and recommendation

This is the last part of the project and will be done after critically analyzed the results. A firm and accurate conclusion have been made and related to the objective of the project. Besides that, recommendations regarding the project have also been suggested for the expansion and for a better result in the future. Conclusion and recommendation are further discussed in the last chapter of this report.

3.3 Gantt Chart and Key Milestone

***Table 1** Gantt Chart and key milestone for FYP1 and FYP2*

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of project topics	■	■												
2	Preliminary research work		■	■	■	■									
3	Submission of extended proposal						●								
4	Proposal defence								■	■					
5	Project work continous										■	■	■		
6	Submission of Interim Draft Report													●	
7	Submission of Interim Report														●

●	suggested milestone
■	process

No	Activities/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Literature Review	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2	Preliminary Research Work		■	■	■										
3	Identified important parameters					■	■	■							
4	Injection ball model selection							■							
5	Optimization of the model selection								■	■	■				
6	Completed a designed of injection device										■	■	■	■	1

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project work continous															
2	Submission of progress report							●								
3	Project work continues															
4	Pre-Sedex										●					
5	Submission of Draft Final Report											●				
6	Submission of Dissertation(soft bound)												●			
7	Submission of Technical paper												●			
8	Viva													●		
9	Submission of Project Dissertation															●

●	suggested milestone
	process

No	Activities/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Literature Review														
2	Analysis on the device					2				3					

1	Key Milestone 1: Completed a designed of injection device
2	Key Milestone 2: Completed modified on the model device
3	Key Milestone 3: Completed analysis on the new model device

CHAPTER 4

RESULTS AND DISCUSSION

For results and discussion part, the author tries to make a comparative study and make a summary on the previous invention of the ball injector into the well. This is important to know the advantage and disadvantages of each design to come out with the best design for solid ball injector device to kill the well.

4.1 Comparison of the Previous Invention

Table 2 Comparative study of previous invention

Design **Characteristics**	**Design 1**	**Design 2**	**Design 3**
Main components	A magazine axially movable in the axial bore Transverse chambers Actuator Rod	Centrally disposed spiral grooved Rotatable sleeve Helical rib Hand crank	Housing Rotatable shaft having a helical rib Sleeve with a spiral groove.
Mechanisms	A wellhead fluidly connected to the wellbore, wherein the ball injecting apparatus is mounted to a top of the wellhead for forming the flow passage extending downward from the transverse port to the wellbore, wherein the selected ball is injected to the flow passage by gravity	By rotating the hand crank, rotation of the sleeve will carry balls downwards. Sleeve is rotated until the ball would be freed into the tubing. The objects being dispensed by the rib pushing the them along the groove and out of the apparatus.	Shaft is rotated, the balls will be forced downward through the grooves in the sleeve out of the housing to the lower case, where pipe tee provides the connections for tying dispenser into the flow line leading to the well.

Advantages	Using actuator means not requires personnel to work in close proximity with the device (more safe). Balls can be ensure will not stuck	3-20 balls per minute at a treating pressure up to 20 000 pounds per square inch. Reliable mechanical means of forcing the balls into the flow stream.	Interchangeability of the sleeves and shafts so it can accommodate balls of different sizes. Method of rotating can use hand, or other methods such as simple air cylinder and ratchet mechanism.
Disadvantages	Only a few balls (max of 5 balls) will be injected in one movement of chambers.	Spiral groove of the invention makes them expensive to manufacture. More desirable to be able to load the devices more quickly and to have a simple way to keep count of the number of balls Hand crank-dangerous to the personnel.	Resembles heavy duty gum ball machines, with complicated mechanisms. The complexity of such machines make them expensive to manufacture and difficult to use and maintain.

From this comparative study, a few advantages and disadvantages have been identified. There is a need to make a new design of the ball injection device, since the invention is for injecting fracture ball. Furthermore, need improvement in term of the mechanism of the ball injection device such as manual rotation (using hand crank) to automatic motor drive to inject the ball for easy operation and safety of the personnel that used the injecting device. Apart from that, complexity of the previous invention made it expensive to manufacture and maintain. Thus, a new design of ball injection device need to be designed that has a simple mechanism operation, can inject a big amount of solid ball with optimum rate and not expensive to manufacture with a high reliability device that can be used to inject solid balls into the tubing fast and efficiently when blowout happen.

4.2 Preliminary Design

4.2.1 Design 1

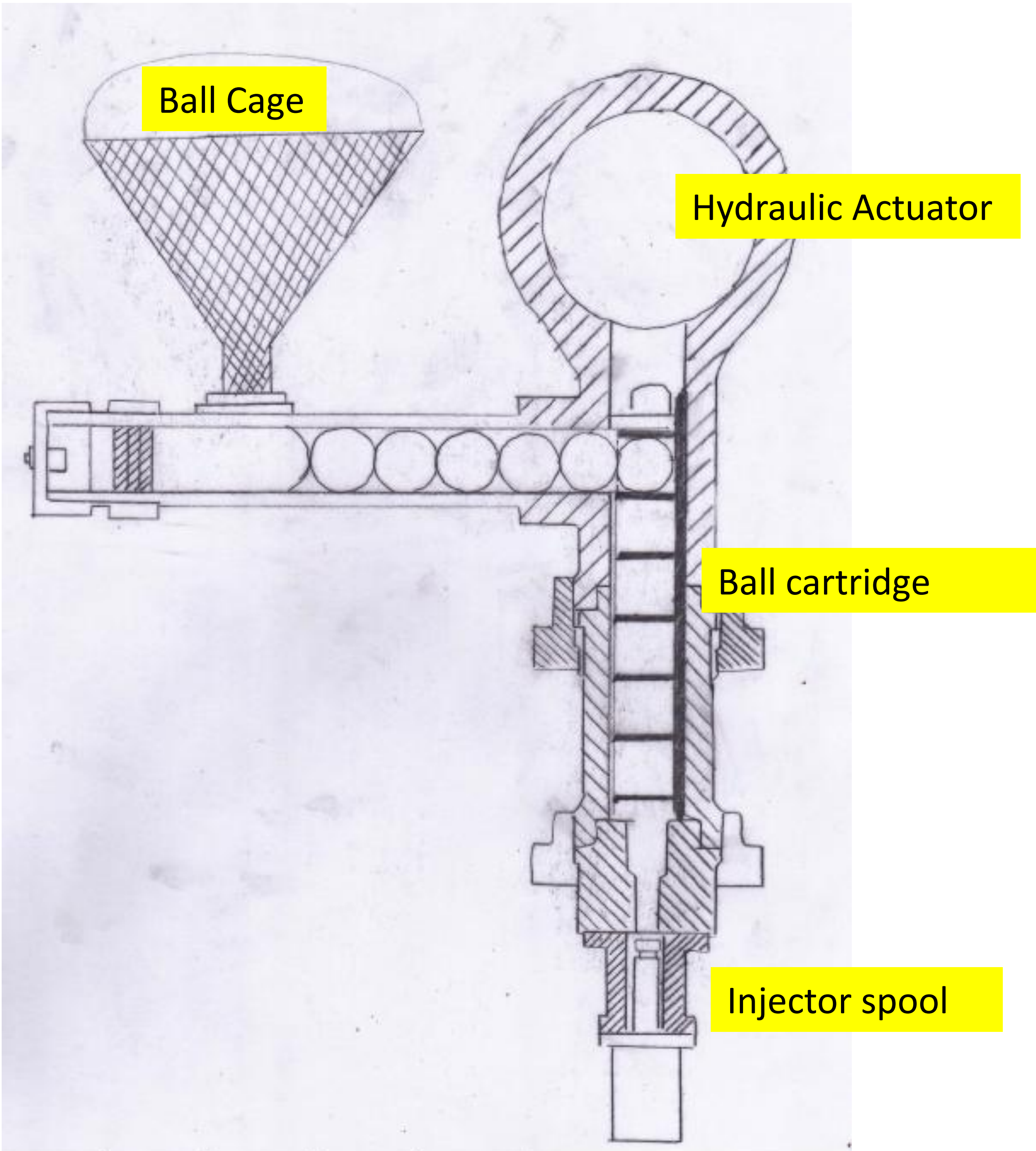

Figure 11 Preliminary Design 1

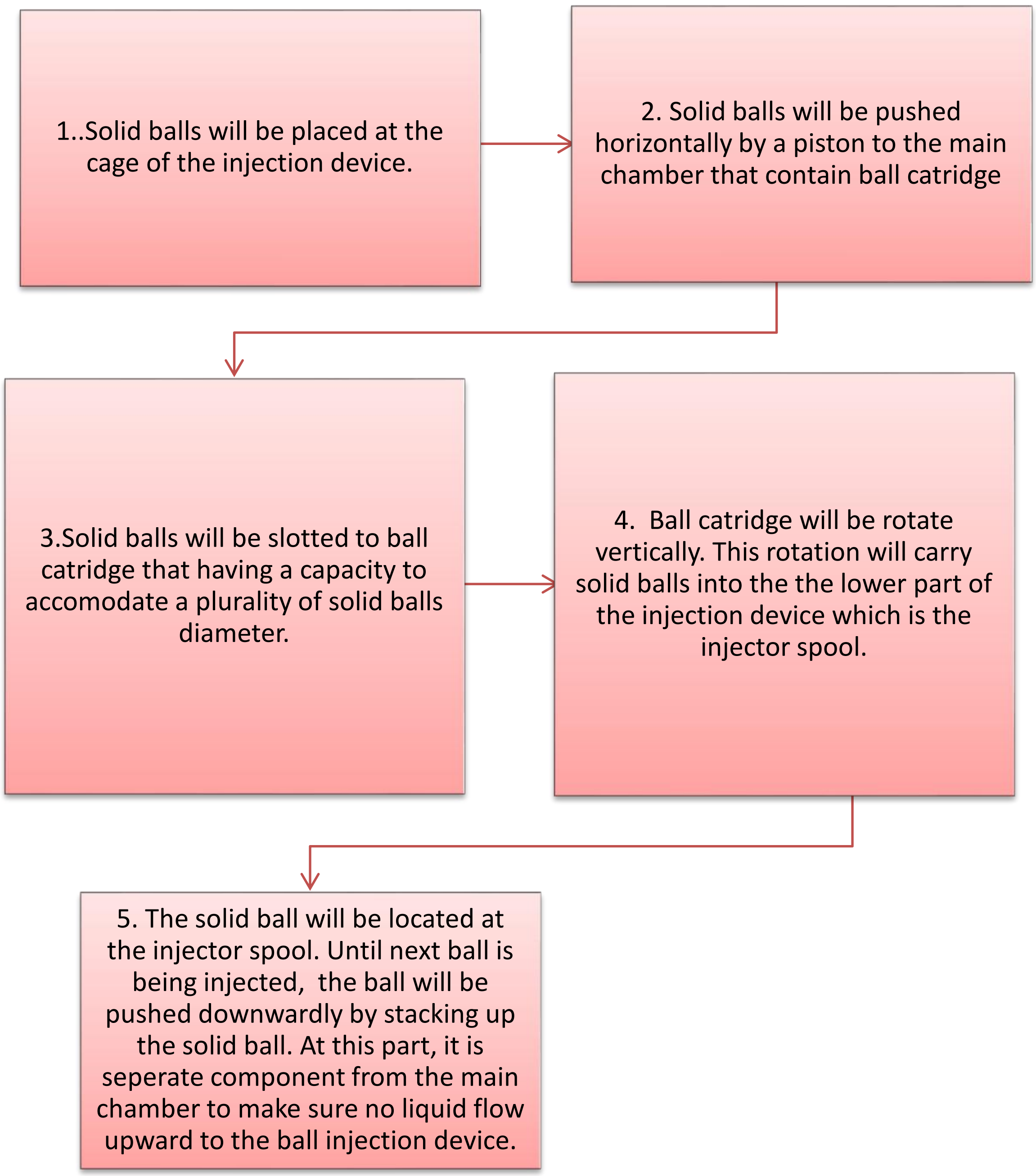

Figure 12 Mechanism of Design 1

4.2.2 Design 2

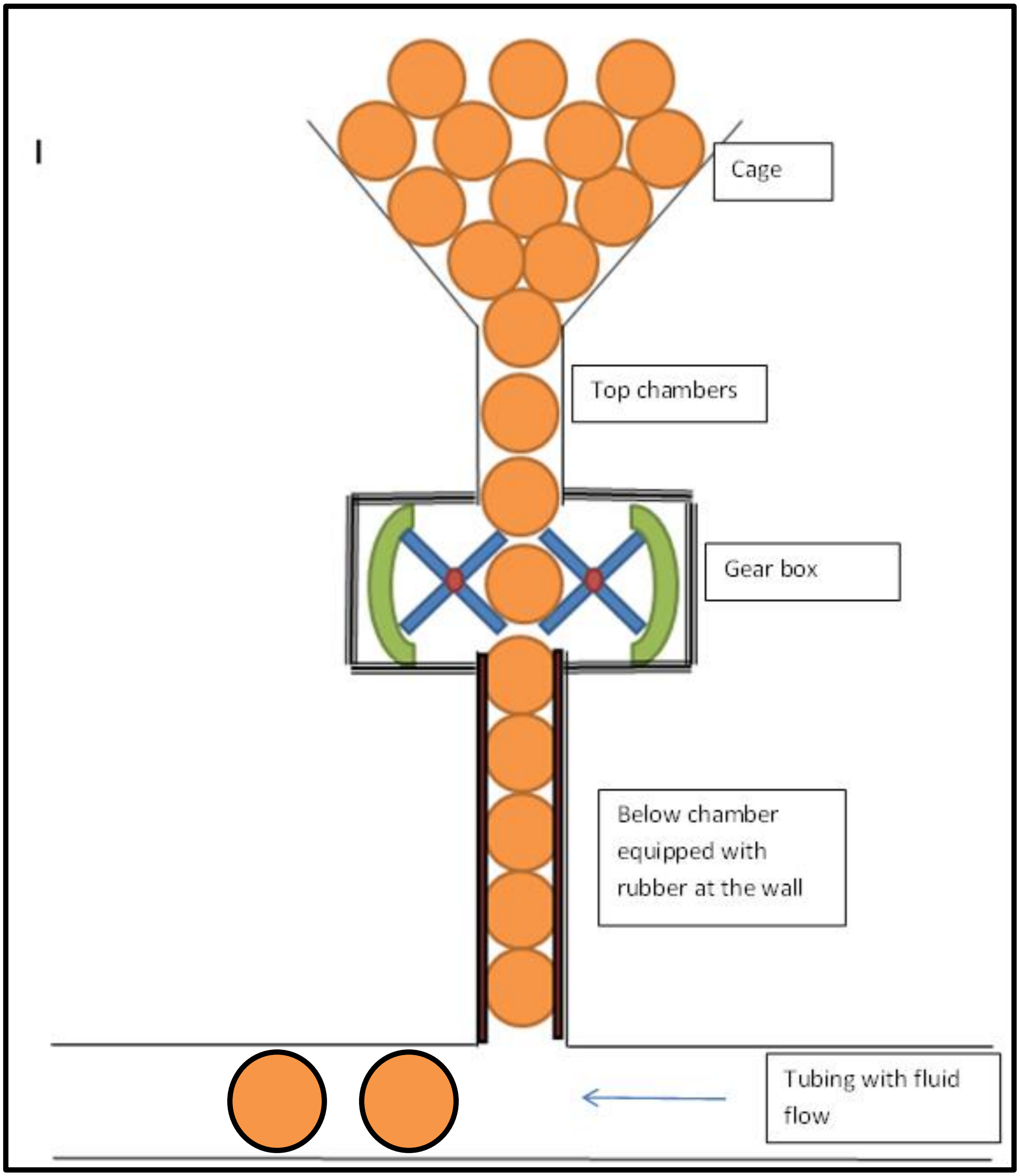

Figure 13 Preliminary Design 2

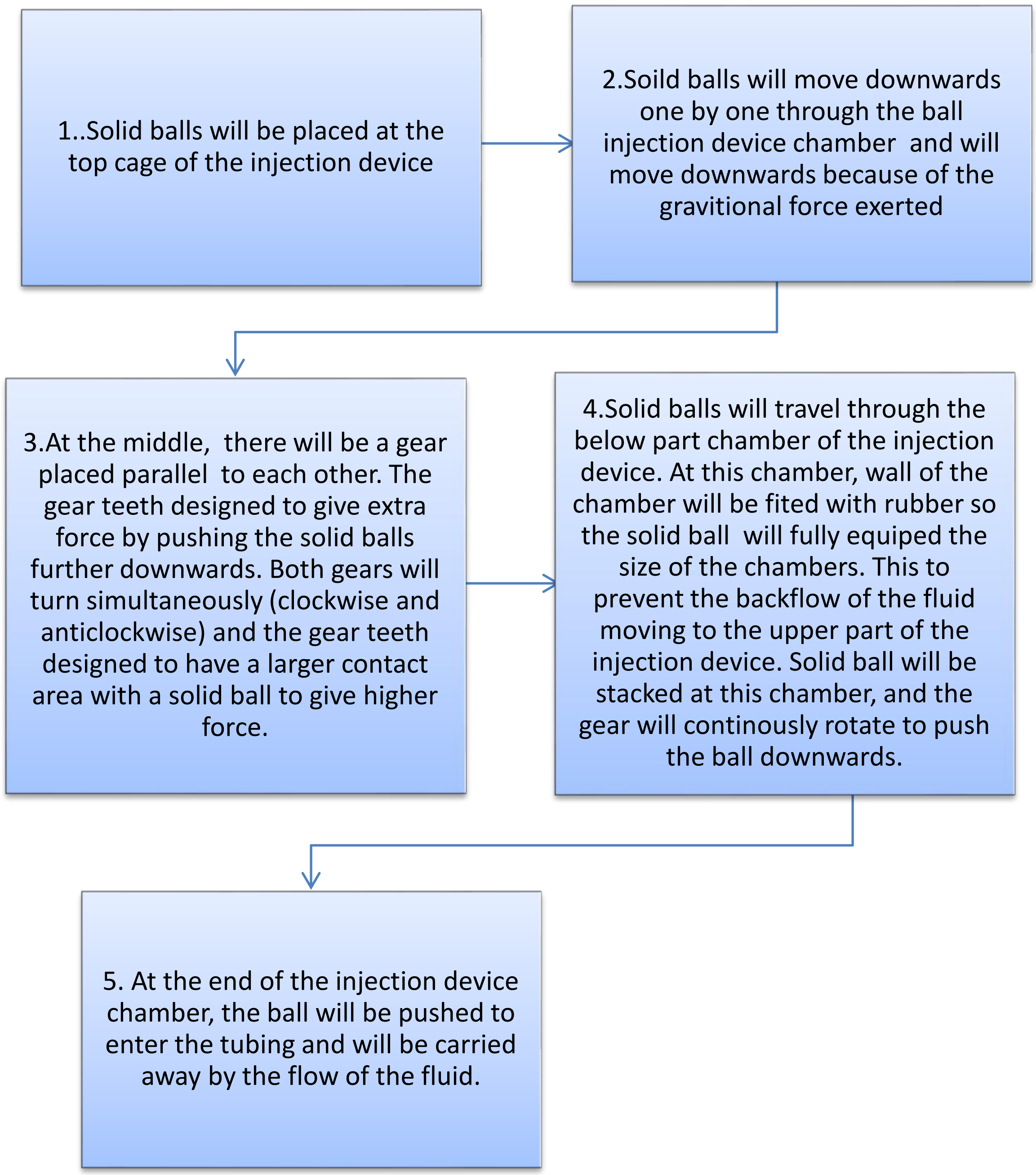

Figure 14 Mechanism of Design 2

After a discussion with the supervisor, the author decide to choose design 2 because of its simplicity and reliability for further study and make a design analysis.

4.3 Theories and Calculations

a) Friction

Friction is the resistance to motion of objects in contact with each other. The standard friction equation determines the resistive force of sliding friction for hard surfaces, when the normal force pushing the two surfaces together and the coefficient of friction for two surfaces.

When a force is applied to an object, the resistive force of friction acts in the opposite direction, parallel to the surfaces.

The standard equation for determining the resistive force of friction when trying to slide two objects together states that the force of friction equals the coefficient friction times the normal force pushing two objects together. This equation is written as

$$\mathbf{F_r = \mu N}$$

F_r = Resistive force of friction

μ = Coefficient of friction for the two surfaces (Greek letter "mu")

N= Normal or perpendicular force pushing the two objects together

Table 3: Friction coefficient

Materials		Static Friction μ_s	
		Dry and clean	Lubricated
Aluminum	Steel	0.61	
Copper	Steel	0.53	
Brass	Steel	0.51	
Cast iron	Copper	1.05	

Cast iron	Zinc	0.85	
Concrete	Rubber	1.0	0.30
Concrete	Wood	0.62	
Copper	Glass	0.68	
Glass	Glass	0.94	
Metal	Wood	0.20-0.60	0.20
Polyethene	Steel	0.20	0.20
Steel	Steel	0.80	0.16
Steel	PTFE (Teflon)	0.05-0.20	
PTFE (Teflon)	PTFE (Teflon)	0.04	0.40
Wood	Wood	0.25-0.5	0.20

b) Weight of the Kill Ball

The weight of the solid kill ball is dependent on the size and type of material used. Size of the ball is defined as the volume which is the function of the diameter. Different materials will have different density. So, to know the weight we have first to calculate the mass of the ball.

$$m = \rho \times Vb$$

Where:

m = mass, kg.

Vb = volume of the ball, m^3

ρ = density, $(\frac{kg}{m^3})$.

Volume of the ball is the same as volume of a sphere.

$$V_b = \frac{4}{3}\pi r^3$$

r = radius.

Some materials for the ball with their density are shown in the table below:

Table 4: Material density

Material	**Density ($\frac{g}{cm^3}$)**
Lead	11.34
Brass	8.55
Copper	8.3-9.0
Steel	7.86
Iron	7.8
Zinc	7.14
Aluminum	2.7

c) Ball sizes:

In this research, ball with different size will be used as the parameter. Ball diameter will be as the following table:

Table 5: Ball diameter

Ball Diameter (mm)	Ball Diameter (meter)	Cross Sectional Area (m^2)
25	0.025	4.909*10-4
30	0.030	7.069*10-4
35	0.035	9.621*10-4
40	0.040	1.257*10-3
45	0.045	1.590*10-3

Gravitational force on the ball is the same as the weight of the ball. Then, weight of the kill ball can be written as:

$$W = mg$$

W = weight, N.

m = mass, kg.

Gravitational acceleration constant is g = $9.8\frac{m}{s^2}$.

4.3.1 Basic Calculation

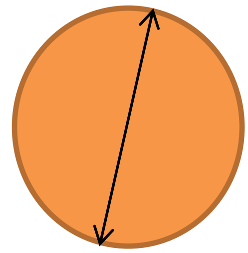

Figure 15 Ball diameter

Assumptions:

Steel solid ball

Density solid ball = 7.86 $^{kg}/_{m3}$

Gravitational acceleration constant is g = 9.8$\frac{m}{s^2}$.

Ball Diameter = 20 mm

Volume of solid ball

$$V_b = {}^{4}/_{3}\,\pi r^3$$

= $^{4}/_{3}\,\pi(0.01)^3$

= 4.188 x 10^{-6} m3

Weight of the solid ball

M= $\mathcal{D}\ x\ V_b$

7860 $^{kg}/_{m3}$ X 4.188 X 10^{-6}

= 0.03292 kg

Gravitational force

0.03292 kg x 9.8$\frac{m}{s^2}$.

= 0.322616 N

Friction

0.61 x 0.322616 N

= -0.1968 N

4.3.2 Gear Box Detailed Design

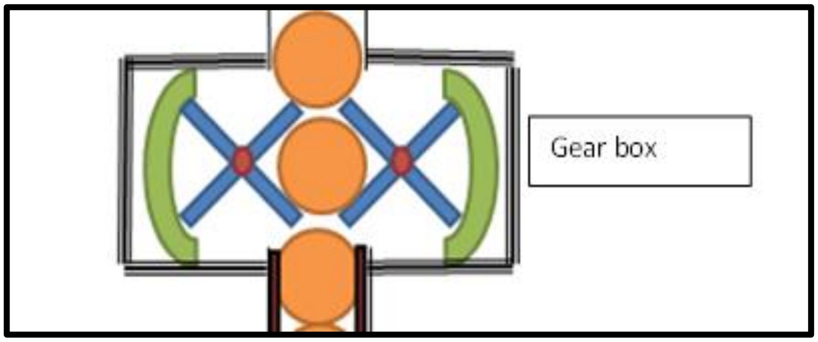

Figure 16 Gear Box

In order to design a gear box that can function smoothly, few parameters need to be consider to make sure the solid ball can be injected.

4.4.2.1 Gear teeth

a) 3 Teeth

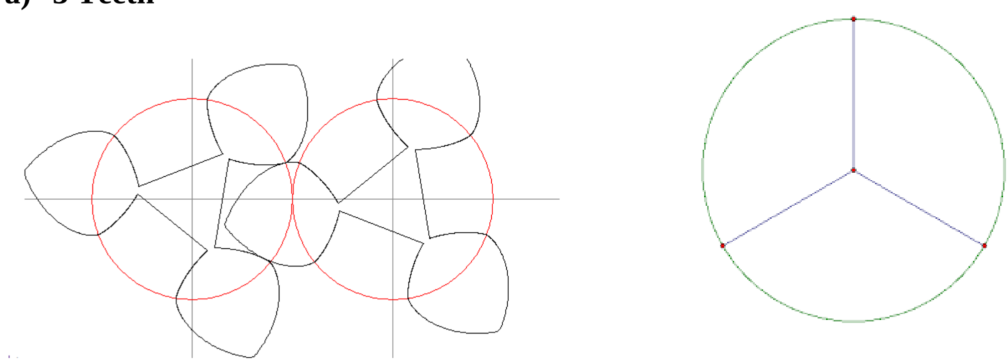

Figure 17 Three teeth gear

b) 4 Teeth

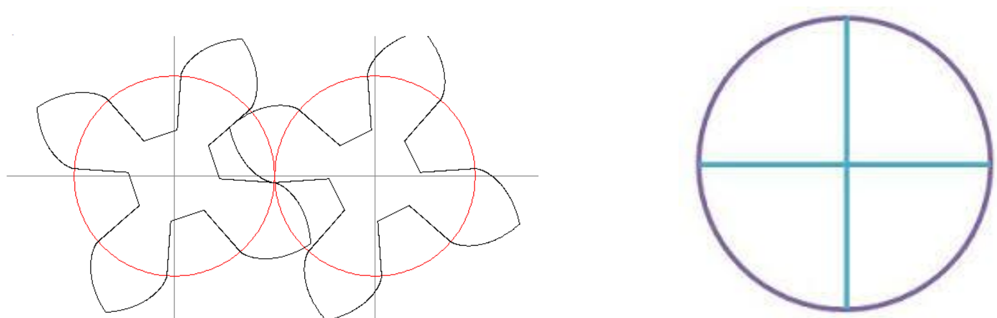

Figure 18 Four teeth gear

c) 5 Teeth

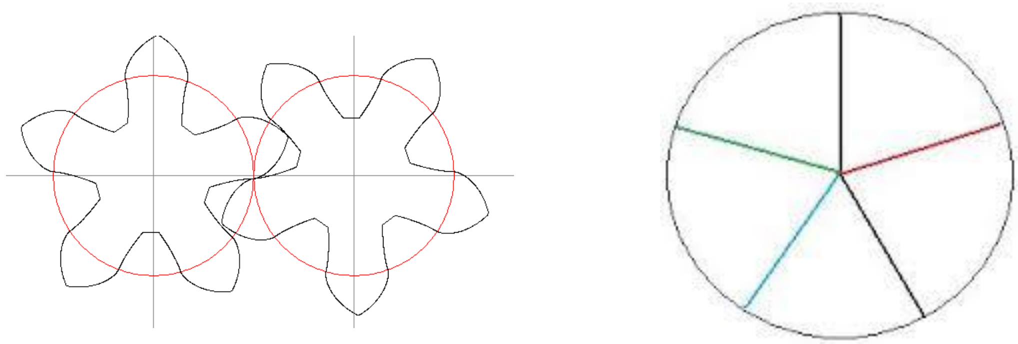

Figure 19 Five teeth gear

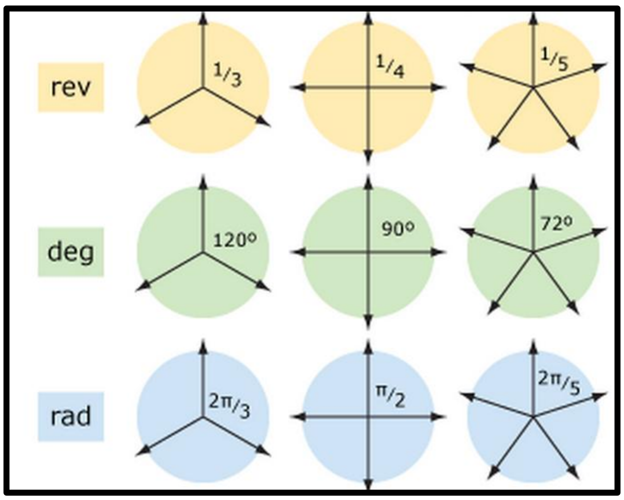

Figure 20 Angle for three types of gear

For this project, calculation will be made based on assumption four gear teeth.

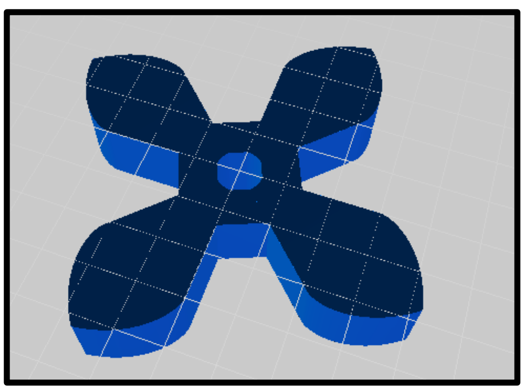

Figure 21 3D view of 4 teeth gear

4.3.2.2 Gear Tooth Profile

In order to have a full efficiency of ball injection device to inject the ball, gear teeth profile must be design properly to have a larger contact area between tooth and the solid ball. Thus, a calculation being made to analyses the coordinate point of teeth that touch the solid ball at different angle when the gear is rotating.

With this coordinate, thus a suitable profile of gear tooth can be designed properly letter.

In the calculation part, several assumptions being made:

4 teeth = 90°

Diameter of ball, d_b = 20 mm

Radius of ball, r_b = 10 mm

Diameter of wheel, d_w = 30 mm

Distance between centre of ball and centre of wheel, d = 16 mm

Velocity, V = 10 mm/s (constant)

Total time per rotation of wheel, T = 8s

Time for one ball = 2s

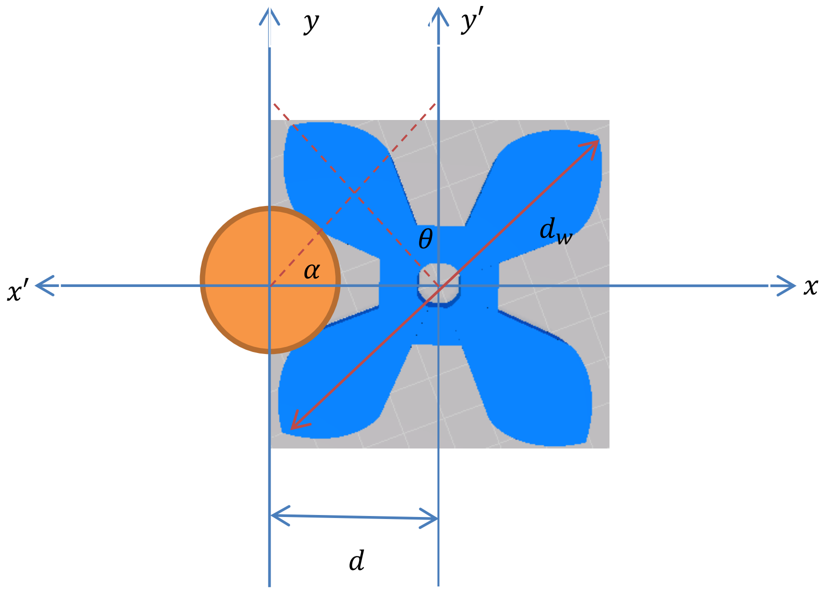

Figure 22 Coordination of the gear tooth and solid ball

a) Ball (contact point)

$x_{con\ i}$ = r cos α_i

$y_{con\ o}$ = r sin α_i

$y_{con\ i}$ = r sin α_i – ivΔt

$\boldsymbol{c_0}$ **=** $\boldsymbol{\alpha_0}$ **= 45°**

$x_{con\ 0}$ = r cos α_0 = 10 cos 45 = 7.0711

$y_{con\ o}$ = r sin α_0 = 10 cos 45 = 7.0711

$\boldsymbol{c_1}$ **=** $\boldsymbol{\alpha_1}$ **= 45° + 1° = 46°**

$x_{con\ 1}$ = r cos α_1 = 10 cos 46 = 6.9466

$y_{con\ 1}$ = r sin α_1 – vΔt = 10 sin 46 – 10(0.0222) = 6.9712

$\boldsymbol{c_2}$ **=** $\boldsymbol{\alpha_2}$ **= 46° + 1° = 47°**

$x_{con\ 2}$ = r cos α_2 = 10 cos 47 = 6.8200

$y_{con\ 2}$ = r sin α_2 –2vΔt = 10 sin 47 – 2(10)(0.0222) = 6.9712

$\boldsymbol{c_3}$ **=** $\boldsymbol{\alpha_3}$ **= 47° + 1° = 48°**

$x_{con\ 3}$ = r cos α_3 = 10 cos 48 = 6.6913

$y_{con\ 3}$ = r sin α_3 –3vΔt = 10 sin 48 – 3(10)(0.0222) = 6.7648

$\boldsymbol{c_4}$ **=** $\boldsymbol{\alpha_4}$ **= 48° + 1° = 49°**

$x_{con\ 4}$ = r cos α_4 = 10 cos 49 = 6.5606

$y_{con\ 4}$ = r sin α_4 –4vΔt = 10 sin 49 – 4(10)(0.0222) = 6.6583

$\boldsymbol{c_5}$ **=** $\boldsymbol{\alpha_5}$ **= 49° + 1° = 50°**

$x_{con\ 5}$ = r cos α_5 = 10 cos 50 = 6.4279

$y_{con\ 5}$ = r sin α_5 –4vΔt = 10 sin 50 – 5(10)(0.0222) = 6.5494

b) Tooth (contact point)

$$x_{con\,i} = \mathrm{d} - x_{con\,i}$$

$$y_{con\,i} = y_{con\,i} - \mathrm{i}\Delta t\mathrm{v}$$

$\boldsymbol{C_0^1 = \alpha_0 = 45°}$

$X^1{}_{con\ 0}$ = d – r cos d_0 = 16 – 10 cos 45° = 8.9289

$y^1{}_{con\ 0}$ = r sin α_0 = 10 sin 45 = 7.0711

$\boldsymbol{C_1^1 = \alpha_1 = 46°}$

$X^1{}_{con\ 1}$ = d – r cos d_1 = 16 – 10 cos 46° = 9.0534

$y^1{}_{con\ 1}$ = r sin α_1 - vΔt = 10 sin 46 – 10(0.0222) = 6.9712

$\boldsymbol{C_2^1 = \alpha_2 = 47°}$

$X^1{}_{con\ 2}$ = d – r cos d_2 = 16 – 10 cos 47° = 9.18

$y^1{}_{con\ 2}$ = r sin α_2 - vΔt = 10 sin 47 – 10(0.0222) = 6.8691

$\boldsymbol{C_3^1 = \alpha_3 = 48°}$

$X^1{}_{con\ 3}$ = d – r cos d_3 = 16 – 10 cos 48° = 9.3087

$y^1{}_{con\ 3}$ = r sin α_2 - vΔt = 10 sin 47 – 10(0.0222) = 6.7648

$\boldsymbol{C_{45}^1 = \alpha_{45} = 90°}$

$X^1{}_{con\ 45}$ = d – r cos d_{45} = 16 – 10 cos 90° = 16

$y^1{}_{con\ 45}$ = r sin α_{45} - vΔt = 10 sin 90 – 10(0.0222) = 10

With this contact point coordinate between ball and gear tooth surface, optimization of tooth profile can be designed in order to have a larger contact area between this two surfaces hence maximize the efficiency of the ball injection device. An excel spreadsheet or mathlab software coding should be made to calculate for any assumptions that need being tested to designed the tooth profile.

4.3.3 Low Chamber Detailed Designed

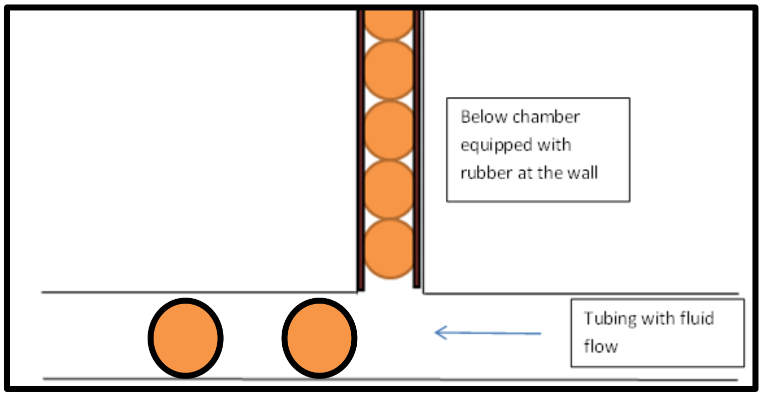

Figure 23 Low chamber of the ball injection device

For the low chamber part, a layer of elastic rubber will be equipping at the inner wall of the chamber. So the solid balls will fully fit in the chamber. Solid balls will not moving upwardly or downwardly, unless a force is exerted at the top of the ball that will be exerted by the rotation of the gear. By rotation of two gears, a force will be exerted to move the solid balls downward. Solid ball will stack at top of the next solid ball, until the ball being injected to the tubing along with fluid flow.

Figure 24 Illustration of chamber equipped with a layer of rubber

This characteristic to prevent the backflow of liquid from tubing into the injection device.

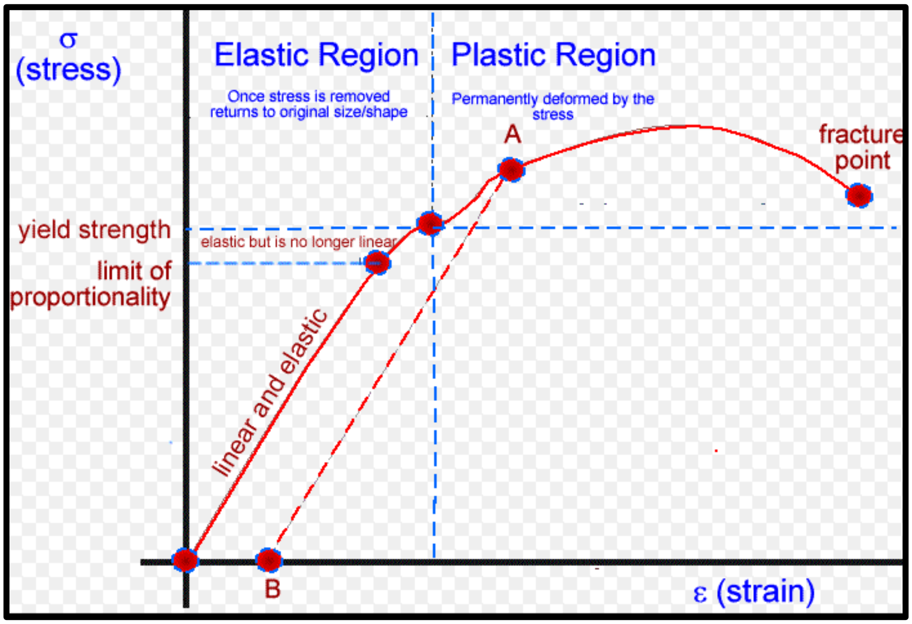

Figure 25 Graphical illustration of elastic region

A layer of rubber must be elastic enough to deform and make the solid ball not moving upwardly or moving downwardly unless there is enough force from the rotation of gear to push the solid ball downwardly. However, the stress and strain can't exceed the elastic region. If these two forces exceed the elastic region, the rubber will become a plastic characteristics region that it will not returns to original shape or size that can cause the low chamber is not tight enough for solid ball. This can cause the solid ball travel upward to the injection device and leaking where force from the liquid flow in the tubing pushing the ball upward.

4.4 Safety Measurements

a) Installing check valve

The function of the check valve is to allows fluid flow either liquid or gas to flow through it in only one direction. This check valve will be installed at the between end of low with tubing with flow of liquid. In industrial check valve, it only allows a liquid flow, however in this invention, innovative design of check valve need to be consider to allow only solid ball and liquid will go through outside of the ball injection device, the liquid flow from the tubing into the ball injection device (backflow) will be prevented in the present of check valve. This check valve can ensure the safety and reliability of the ball injection device from leaking, and to protect the personnel that doing the work related with this ball injection device during their operation.

b) Installing gear shaft

Gear shaft will be installed between two gears at the gearbox. Gear shaft is the axle of the gear, providing the rotation that allows one gear to engage with and turn another. A long rod that connecting between this two gear is essential and need to consider in order to make sure the alignment of the gear is fixed. This is important because if one gear is not parallel with the other gear, it can reduce the efficiency if the force that is exerted to the solid ball and if too much misalignment, it can cause cramp, the solid balls can't even being pushed downward.

Figure 26 Gear shaft

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Offshore well blowout brings a lot of disaster especially to the environment. Oil spill has always become a major issue when blowout happened. Time taken to control the blowout is very important as more oil will flow into the environment when it takes too long to control the well blowout. So, there is a need for fast and effective well kill method. Dynamic kill balls give fast and effective method compare to other conventional well kill technology. This method works by pumping heavy kill balls which are solid particles into the well to suppress the flow of blowout well.

For developing such a novel system, the ball injection device needs an innovative design. The main objective of this project is to design a ball injection device. The author has made a comparative study on the previous ball injection device in order to identify the mechanisms, advantages and disadvantages for improvement. The author also has come out with an innovative design of ball injection device with the few parameters that being analyzed in order to increase the efficiency and make sure the device is reliable.

This project successfully initiated the innovative design of a ball injection device and can be spark for a further study until it can be manufactured and tested. If successfully developed, the novel offshore blowout technology will have a tremendous impact on the petroleum industry. It will safeguard petroleum companies such as PETRONAS to enter the risky area of deep water drilling and production.

5.2 Recommendation

For further study, this project can be further continues with simulation where it will be tested the validity and rationality of the outcomes from the theory and design that have being made. In addition, improvement can be made on the design where it can has a plurality size of solid ball that will be injected so only one injection device can be manufactured for any size of solid balls. Apart from that, further study until it can be manufactured and tested prototype of ball injection device in future hence it can be a big contribution to this novel system.

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