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Modular Testing Facility for Downhole Sensor Evaluation

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Affidavit

I declare in lieu of oath that I wrote this thesis and performed the associated research myself using only literature cited in this volume.

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Ich erkläre an Eides statt, dass ich diese Arbeit selbständig verfasst, andere als die angegebenen Quellen und Hilfsmittel nicht benutzt und mich auch sonst keiner unerlaubten Hilfsmittel bedient habe.

Name, 08 June 2017

Abstract

Real Time Kick Detection (RKD) technology is becoming more and more known to the oil and gas industry. Since 2009, 30 fatalities and more than 1500 injuries have occurred in well control incidents, declaring well control one of the most critical situations in the industry. Real Time Kick Detection can add value to the reduction of well control incidents, saving human lifes and cost reduction.

The thesis generally describes the kick causes from geology and drilling perspective, Early Kick Detection (EKD) techniques and equipment, but also the principles of well control. Kick detection approaches are described based on kick indication and the necessary surface and downhole sensors equipment for the required measurements. Different well control procedures are described in detail for a successful shut in and killing operation of the well.

The purpose of the thesis, is to conduct experiments to evaluate sensors for kick detection. Therefore an initial artificial well testing facility was designed and built in a way to recreate wellbore conditions (wellbore size, drill string, influx. etc.) but also to allow the installation of various type of sensors for Real Time Kick Detection and other experiments.

Applying current technology and recent sensor development, an approach for Real Time Kick Detection is presented based on evaluating capacitive sensors in the developed test stand. A detailed description of the working principle of capacitive sensors (capacitor, capacitance, dielectric constant and strength, etc.) as well as relevant limitations (noise and temperature) for their application is given.

The results of this thesis are showing that the artificial well testing facility is capable of conducting gas and oil influx experiments as well as for testing different types of sensors for Real Time Kick Detection.

Recommendations for further research is to test conductivity and analogue capacitive sensors for detection of gas or oil kick, but also ultrasonic sensors to estimate downhole flow rates by cuttings velocity.

Zusammenfassung

Die Echtzeiterkennung von unkontrolliertem Zufluss aufgrund einer Änderung der Verhältnisse im Bohrvorgang (Kick) wird immer bekannter in der Öl- und Gasindustrie. Seit 2009 sind 30 Todesfälle und mehr als 1500 Verletzte durch Zwischenfälle in diesem Bereich zu beklagen. Daher ist Echtzeiterkennung ein wertvolles Werkzeug um Unfälle zu verhindern, Menschenleben zu retten und Kosten zu reduzieren.

Diese Diplomarbeit beschreibt die Ursachen von unkontrolliertem Zufluss aus der geologischen als auch aus der bohrtechnischen Perspektive, Techniken zur Echtzeiterkennung und deren Equipment und die damit verbundenen notwendigen Ober- und Untertageeinrichtungen um Messungen durchführen zu können. Zusätzlich werden verschiedene Methoden zur Sicherung und Schließung eines Bohrlochs im Falle eines Kicks beschrieben.

Die Arbeit umfasst Versuche zur Evaluierung verschiedener Sensoren zur Erkennung und Messung von Gasblasen in Flüssigkeit. Im Zuge dessen, wurde eine Testeinrichtung entworfen und konstruiert um die Zustände im Bohrloch möglichst genau widerzuspiegeln. Das Design wurde so implementiert, dass verschiedene Sensortypen als auch andere Experimente mit der Testanlage durchgeführt werden können.

Der Ansatz für die Echtzeiterkennung von Kicks zur Anwendung aktueller Technologie und neuester Sensortechnik wird in der Arbeit beschrieben und anhand von kapazitiven Sensoren diskutiert. Eine detailierte Beschreibung des Arbeitsprinzips von kapazitiven Sensoren als auch deren Einsatzgrenzen zur verlässlichen Anwendbarkeit ist beinhaltet.

Das Ergebnis der Arbeit zeigt, dass Versuche mit Hilfe des konstruierten Messstandes im Hinblick auf verschiedene Zuflussmedien wie Öl und Gas als auch verschiedene Sensortypen möglich und reproduzierbar sind.

Weiters beinhaltet die Arbeit Empfehlungen für zukünftige Forschung im Gebiet der Echtzeiterkennung von Kicks mit Bezug zu anderen Sensorgruppen wie analogen kapazitiven Sensoren. Zusätzlich wird auch die Anwendbarkeit von Ultraschalltechnik zur Bestimmung der Geschwindigkeit der Bohrflüssigkeitsrate im Ringraum des Bohrlochs anhand des Bohrkleinbestandes darin diskutiert.

Acknowledgements

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Contents

Chapter 1 Introduction and Objectives

Well Control is the most critical field in drilling engineering, among other problems in the wellbore, which costs billions of dollars. Thirty fatalities have occurred in well control incident and more than 1500 injuries since 2009 (Bureau of safety and environmental enforcement 2016), declaring well control one of the most critical situations in the industry. Meanwhile, in the past few years, oil and gas research programs are focusing on the evolution development/improvement of Real Time Kick Detection (RKD) for recognition of an influx entering in the wellbore in real time.

Early Kick Detection (EKD) measurements are referring to changes in indicators which might be a result from a kick. EKD measurements are not accurate and the safety window of the reaction time is small, especially in deep water wells (Chapter 2). Despite the accuracy and the certain indication that a kick has probably occurred, there is still a margin of improvement in the current technology. While tripping out or making pipes connections, the possibility of a kick to occur is 85% (D. Fraser, R. Lindley 2014), and the main reason is swap pressure or the static condition of the mud in the wellbore.

Kick detection has been significantly developed in the past years due to sensor technology. During drilling operations, various sensors, mostly on the surface, are monitoring multiple parameters that are influenced when influx starts entering in the wellbore (i.e. detection of return flow rate by ultrasonic flow sensors or Coriolis meters) (Chapter 3).

The development and reliability of real time monitoring of downhole conditions (i.e. recognition of gas influx in the wellbore), can increase significantly the possibilities of a successful shut in of the well, and reduces the chances of a blowout. RKD with downhole sensors that are attached in the drill string in several points is a promising solution. Ultrasonic sensor (Transmitter and Receiver) has been successfully tested for detection of air influx in the wellbore where acoustic properties are different for every material and taking into account gas solubility (D. Kutas 2016). The experiments were conducted in static conditions with two different wellbore fluids (Chapter 5).

To achieve the proposal work, experiments need to be obtained with new promising sensor technology, which has to be evaluated in the artificial wellbore facility. Capacitive sensors have been used in other industries for i.e. proximity sensing. There are capacitors, which converts a change in dielectric properties of a material or a change in position of electrical signal (Chapter 5).

The purpose of the thesis is to conduct experiments to evaluate sensors for kick detection. Therefore, an initial artificial well testing facility was designed and built in a way to simulate wellbore conditions (wellbore size, drill string, influx. etc.) but also to allow the installation of various type of sensors for evaluation of RKD and other experiments (Chapter 6). Different sensor options will be evaluated for the detection of gas and oil influx. Experimental setup will be designed in a way to allow the production of gas and oil influx depending on the experiment. The sensors are placed in minimum distance from the wellbore for the optimum results. A key factor to obtain RKD is the use of wired drill pipe for downhole data transmission. The thesis can add value to RKD technology because of the reduction of well control incidents, saving human lives, reduce non-productive time and cost.

In the last part of the thesis, which is based on the results of the experiments, a small overview and discussion of the results is provided as well as some ideas for future development (Chapter 7, 8, 9).

Chapter 2 Well Control and Blowout Prevention

A.1 Kick Causes

Well Control is a significant chapter in exploration and development part of oil industry, and specifically in drilling engineering because it can result losses of valuable resources and human lives. Over the last decades, 50 offshore well blowouts have occurred (Wikipedia 2012) and that impulse the oil/gas industry to invest millions of dollars in research for well control (Grace 1994).

During drilling operations, mud hydrostatic pressure, acting in the borehole, needs to exceed the formation pore pressure, for the prevention of formation fluids entering into the wellbore. When an undesired fluid flow is entering into the wellbore, it is called a kick. In most of the occasions, a kick occurs in wells where the formation pressure gradient is uncertain or unknown i.e. wildcat wells, which are exploration wells in unknown area. In a well control situation, when the kick cannot be controlled, then it has converted into a blowout. Kick can be derived from many parameters that have been influenced by geological structure and unpredictable uncertainties. Kick causes can be distinguished in the following cases:

- Insufficient mud weight
- Loss circulation
- Human error
- Geological structure
- Improper tripping and insufficient hole filling
- Cut mud

A.1.1 Insufficient Mud Weight

While drilling, minimum requirement is equilibrium between mud pressure and pore pressure. When the differential pressure is below zero, then formation fluids start entering the wellbore. Mathematically, the differential pressure is defined:

$$\Delta P = P_{mud} - P_{ff} \qquad (1)$$

Where:

P_{mud} is hydrostatic pressure of drilling fluid, psi

P_{ff} is pressure of formation fluids, psi

When $\Delta P<0$, then there are underbalanced conditions in the wellbore, $\Delta P>0$ overbalanced conditions and $\Delta P=0$ balanced conditions. The following Figure 1 describes the pressure conditions in the wellbore.

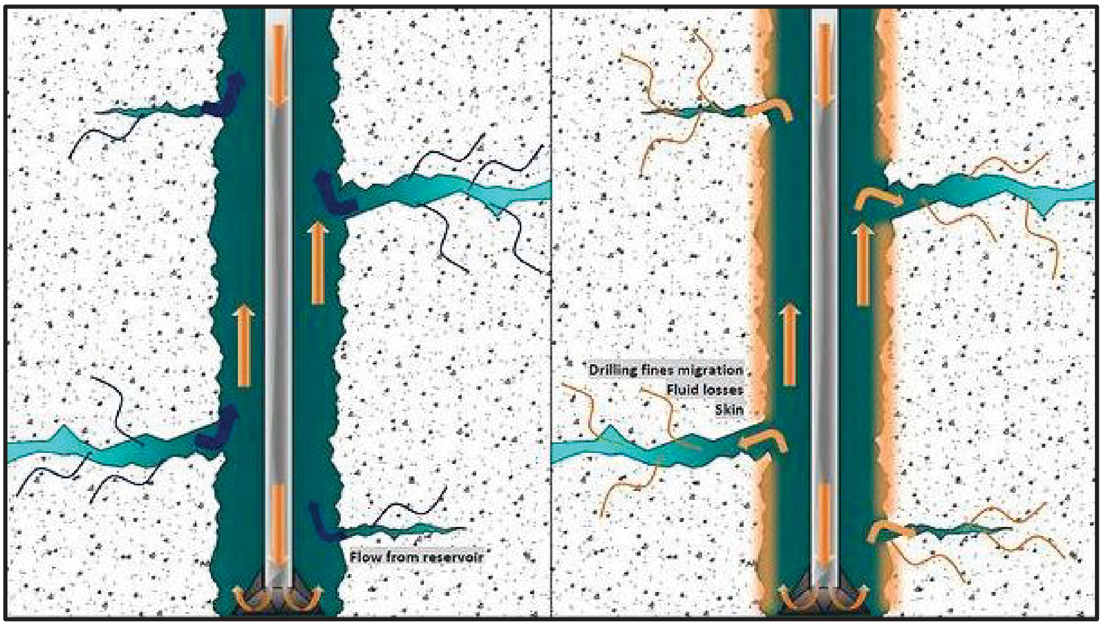


Figure 1: Pressure conditions in the wellbore (Condit 2013)

Hydrostatic pressure of the mud, during circulation is a function of fluid properties (density, viscosity, gel strength etc.) and pressure losses across the annulus (Condit 2013). It is called equivalent circulation density (ECD). In static conditions, the pressure of the mud is the hydrostatic column of the drilling fluid, but in dynamic conditions when the drilling fluid is circulating through the drill string, the bottomhole pressure will be greater than the hydrostatic pressure of the mud and that because of the frictional pressures (Equation 2).

$$ECD = Mw + P_{losses}/0.052xD \qquad (2)$$

Where:

ECD is the equivalent circulation density, ppg

Mw is the current mud weight, ppg

P_{losses} are the frictional pressure losses in the annulus, psi

D is the vertical depth, ft

After having drilled a stand of pipe, the driller raises up the drill string for few feet and stops the pumps, and causes the drilling fluid in the wellbore to be static. On the mud log, a short peak of gas index will appear, higher than normal when the circulation starts again. This could be due to the fact that formation pressure increased and it is higher than static mud pressure. This is called connection gas (Knezevic 2016).

Another reason could be due to the fact of surface dilution of the mud. An accidental dilution of the drilling fluid will cause a decrease of mud weight. It's crucial to monitor and maintain not only the ECD as higher than the formation pressure, but also the mud weight.

A.1.2 Loss Circulation

Loss circulation is referring to partial or total loss of drilling fluid to the formation. Fluid losses can occur in natural fractured formations which are formed by stresses in the formation (tectonic activity or faults), and when the hydrostatic pressure of the mud exceeds the formation fracture pressure (Netwas Group Oil 2016). Different types of tests can provide data for the pressure regime. Leak of test (LOT) or extended leak off test (XLOT) can determine the fracture pressure of the open formation after the casing shoe. Another parameter that influences fluid losses is bad filter cake. Filter cake is the fluid that passes through a medium, leaving the cake on the medium. The lower the fluid losses, the thinner the mud cake are which means a good fluid losses control and the mud is impermeable.

Inappropriate high tripping in speed can cause an excessive surge pressure which can cause a fracture of the formation in the casing shoe or bottom hole. Another reason, which is mostly referring to deep water wells, is the narrow pressure window. The narrow window of pore and fracture pressure has to be considered for the mud density. An improper hole cleaning can cause an increase of ECD and as a result fracture of the formation. In Figure 2, a decrease of the hydrostatic column because of losses can cause a kick from the formation at 6000 ft.

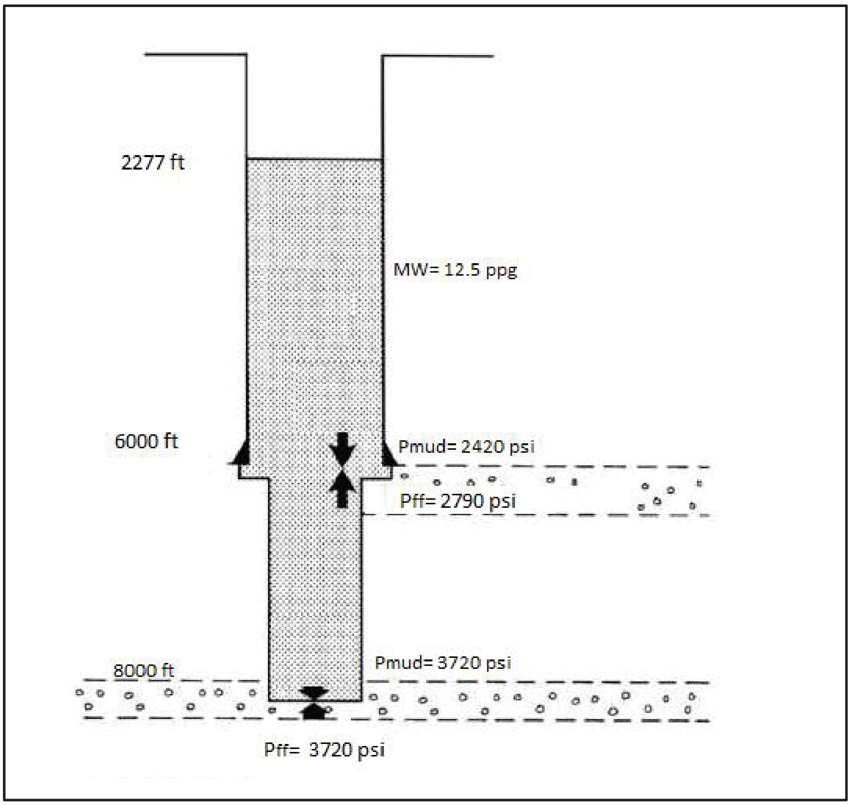


Figure 2: Loss circulation – Mud pressure greater than formation pressure (Netwas Group Oil 2016)

Having fractured the formation, drilling fluid start flowing into the formation. Loss of mud will cause a reduction in the hydrostatic column, and the pressure of the mud will start decreasing until there is equilibrium of the pressures. If the mud column drops the bottomhole pressure will be decreased, and it allows formation fluid to enter in the wellbore. During the time that the influx is entering in the wellbore, if the measures that the crew is applying are not sufficient and the reaction time is slow, the kick will convert into a blowout.

A.1.3 Human Error

Interpretation of data is an important parameter of optimization of drilling process and prevention of failures. Duties of a mud logger is to record any problems during the drilling. The mud logger is the first person in the rig that identifies if an influx entered the wellbore from well log plots by different detection techniques which will discuss in the next chapter. Misinterpretation and analysis of well log data, increases the chances of an oil or gas kick.

Well control seminars and certifications, are providing necessary advices, guidance and training to rig crew, which are fundamental for recognition and prevention of a kick or blowout.

A.1.4 Geological Structure

Within millions of years, a series of tectonic activity i.e. earthquakes, will form a geological structure. For oil and gas industry, the geological structure of an area of interest is a significant parameter for the well design. Well planning has been affected directly by the pore and fracture pressure of the area. Focusing on the pressure of the formation, various geological parameters are causing an increase of the pore pressure in certain depth and exceed the normal formation pressure (Santoso 2012).

When impermeable rocks such as shales are compacted in a period of time, the formation fluids cannot always escape, leading to a high pressure zone. This lithology zone is called abnormal or overpressure zone which can provide data not only for drilling related problems but also for reserves estimation.

The issue of overpressure zones is the unexpected high pressure of the formation which can cause a kick and in many cases a well to blow out.

A.1.4.1 Reverse Faulting

As mentioned in the previous paragraph, tectonic forces are pulling the sides apart; an uplift movement will cause a discontinuity and a significant displacement of a volume of rock and a creation of a fault. There are three types of faults normal, reverse and transcurrent or strike slip (USGS 2016). Oil and gas companies avoid drilling in faults because of an increased probability of loss circulation zone but reverse faulting is a different scenario.

Reverse faults are occurring in areas, where the maximum principal compressive stress derives from the horizontal direction and it is caused by tectonic forces. In normal faults, the maximum force derives from the vertical direction, which causes the movement of the fault.

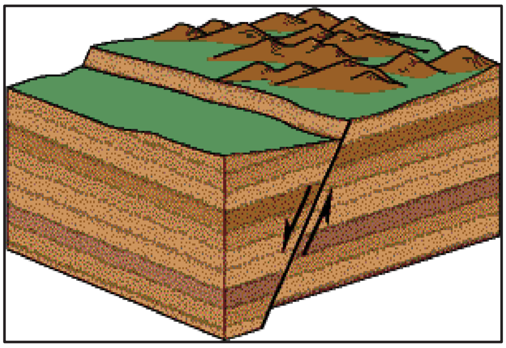


Figure 3: Normal fault (USGS 2016)

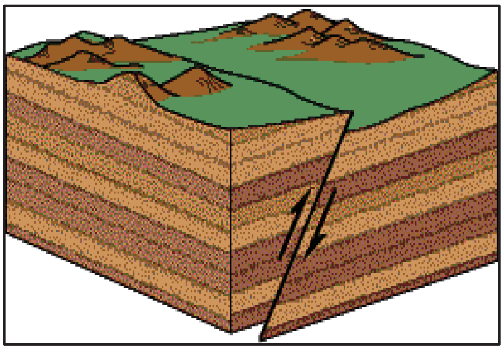


Figure 4: Reverse fault (USGS 2016)

In reverse faulting, due to the upper movement of the one block of the rock, if the formation contains an amount of fluids and it's a closed system, an overpressure zone will occur in shallower depth because of the initial formation pressure. Overpressure zones are an issue due to there are unexpected and it's difficult to have an exact estimate of pore pressure from seismic data if offset data are not available.

A.1.4.2 Formations under Compression

The phenomenon of compression can almost be found in every area. During the deposition of shale, porosity is higher than 50% (Zendenhboudi and Bahadori 2017). During the time of deposition, the weight of the overburden formations, starts compressing the shale formation, is causing a decrease of the porosity. Formation fluids escape through porous paths of shale to higher porosity formations, which in more situations are sands.

The compression will continue until the point in which the formation and the remaining water can withstand the overburden pressure. Because of the compression, the formation pressure is increased at a rate equal to the overburden instead of a column of salinity water.

Hence, shale formation has low permeability (permeability is the ability of a formation allows fluids to flow), which does not allow kick to occur. The escaped water flows through shale to the sands, where higher permeability increases the possibility of a kick to occur.

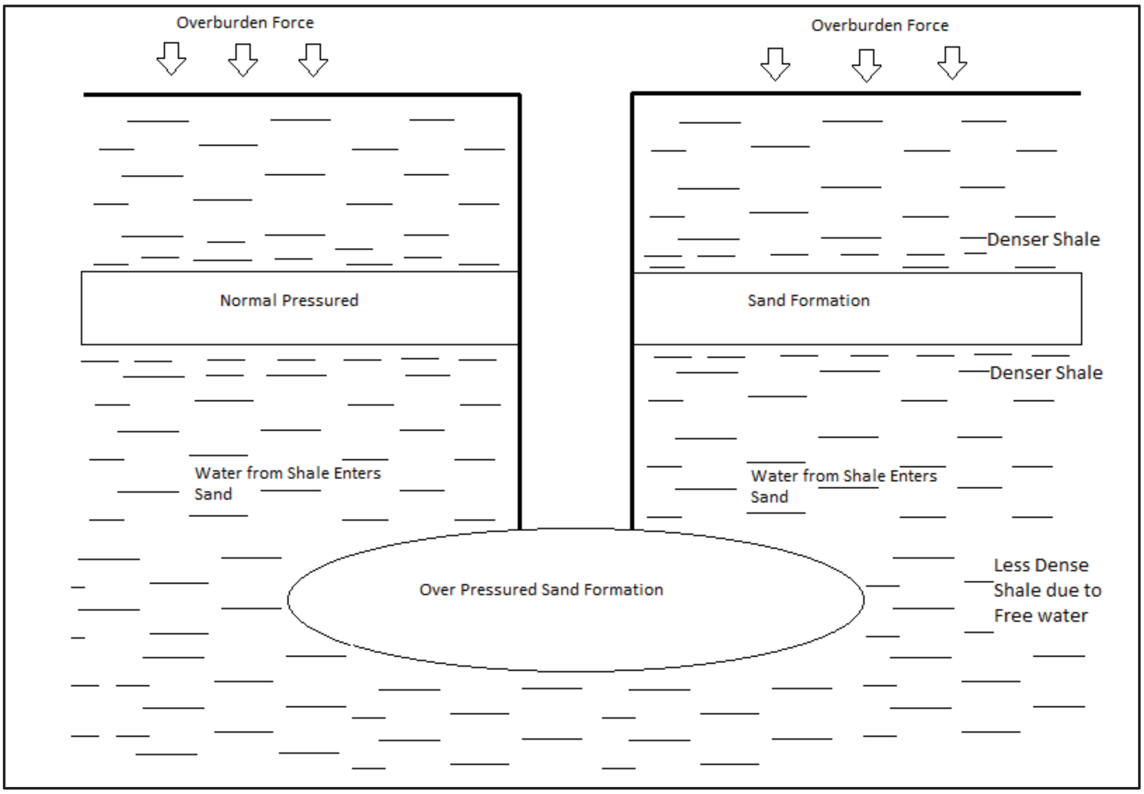


Figure 5: Abnormal pressure in shale and sands (Santoso 2012)

A.1.5 Improper Tripping and Insufficient Hole Filling

Having drilled the required depth or another operation needs to be obtained (i.e. change of drill bit, wire line loggings), the drill string is pulled back in the surface. The act of pulling the drill string out of the hole or running it in is called tripping procedure.

While tripping out, this upwards movement of the drill string, creates a phenomenon, which is called swab effect. The drill string behaves as a large piston (Drilling Formulas 2014), and creates pressure caused by friction losses drilling fluid and drill string. Swab effect, reduces the bottomhole pressure, and if this reduction is significant, formations fluids may flow in the well. Tripping speed, fluid properties and clearance of wellbore with drill string are important factors, which affect swab pressure during tripping.

The critical tripping out speed is the speed in which kick may occur. As shown in Figure 6, the increase of the mud density can provide a wide range of safety window for tripping out speed. On the other hand, it is the opposite case for tripping in speed.

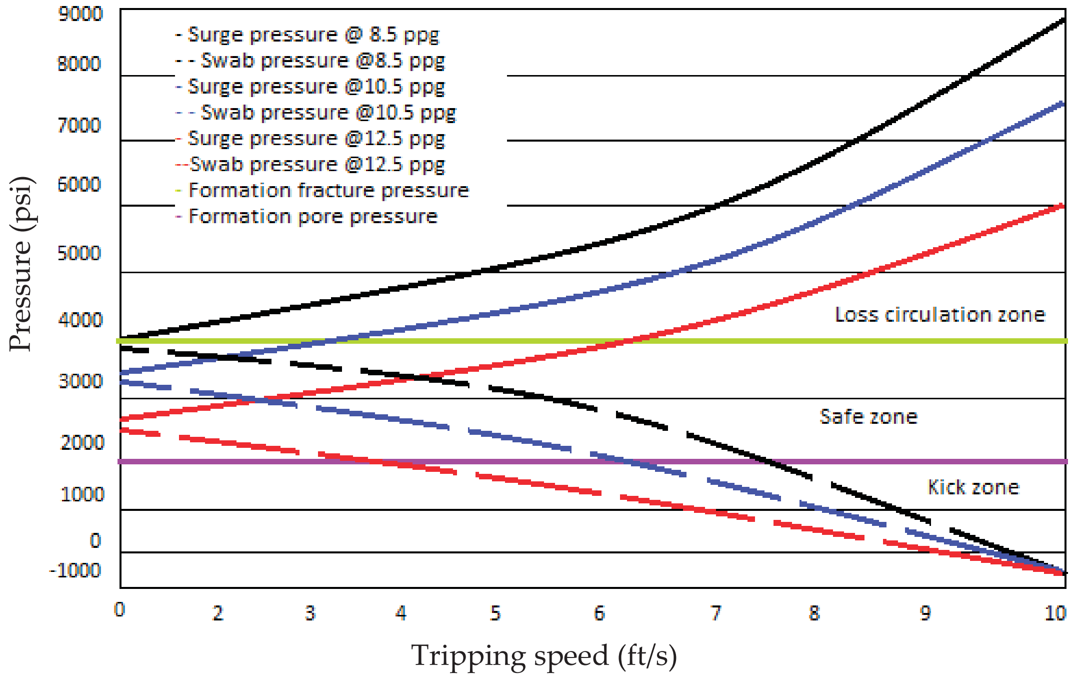


Figure 6: Tripping speed (Mme and Skalle 2012)

The clearance between borehole and drill string is another important parameter. Due to the piston – cylindrical action, drill collars, which have higher outside diameter than drill pipes, can increase the swab effect (Mme and Skalle 2012).

When pulling out of hole the drill string, the hole must be kept full the whole time due to the displacement of the drill string volume. The reason for using the trip tank is the most accurate monitoring of the displacement volume. If the hole filling is insufficient, the hydrostatic column of the drilling fluid will decrease and kick influx will enter the wellbore.

A.1.6 Cut Mud

As drill bit penetrating into the formation, in some cases, depending on the formation, gas bubbles starts entering the wellbore. The mud contamination from gas bubbles is known as gas cut mud. Gas will reduce the overall mud weight, causing a decrease of the hydrostatic pressure. If the hydrostatic pressure is decreased in a level near the formation pressure, it may cause a kick.

A.2 Early Kick Detection

Early kick detection is important in well control operations and in fast prevention of large amount of influx entering in the wellbore. Early kick detection is classified into two classes of primary and secondary kick indicators.

A.2.1 Primary Kick Indicators

Primary kick indicators are referring to the signs that a kick has already started entering the wellbore. During drilling operations, downhole and surface equipment is monitor any changes of drilling parameters i.e. flow rate, pit volume, etc. The change in the differential pressure between wellbore and formation from positive to negative and formation fluid that starts entering into the well will influence various parameters (J. Azar and R. Samuel 2007). Primary indicators are referring to:

- Increase of flow rate
- Increase of pit volume

A.2.1.1 Flow Rate

Circulation flow rate is monitored during drilling, which means that the flow out needs to be equal with the flow in. The reason that flow rate is being increased when a kick occurs, is that when formation fluid enters the wellbore, the pressure and the volume of the kick push the drilling fluid in the annulus towards the surface (A. Bourgoyne, K. Millheim, M. Chenevert, F.S Young 1986). The flow rate is monitored with special flowmeter in the return line, as a flow paddle, ultrasonic and coriolis tool, which will be described in the following chapter.

A.2.1.2 Pit Volume

While the flowing mud rate is constant during flow into and out the wellbore, therefore the volume of the drilling fluid in the pits needs to be approximately the same. An increase of the level of mud in active pits will signify that formations fluid entered the wellbore. Another indication would be when drilling fluid is in static condition and the volume in the trip tank increases. Pit Volume Totalizer (PVT) is a significant component for well control situations (Total Gas Connection Ltd 2016). It's a device that combines measurements from trip tank, main mud tank, returns flow rate and mud pumps, and displays the readings in the driller's panel. The monitoring procedure will be discussed in the next chapter.

A.2.2 Secondary Kick Indicators

Secondary kick indicators during drilling are referring to parameters that are not conclusive and the indication may be due to other conditions i.e. sudden increase of rate of penetration could be due to changes in lithology, increase of torque due to a poor hole cleaning. A correct recognition of an influx should be a combination of the following indicators and a flow check which will be discuss in the next paragraph:

- Increase of drilling rate
- Decrease of standpipe pressure
- Increase of hook load
- Decrease of d-exponent
- Increase of total gas levels
- Increase of torque and drag

A.2.2.1 Increase of Drilling Rate

The most common indicator for kick detection is an increase in rate of penetration. Sudden increase in rate of penetration, and more particularly if the rate of penetration is increased to double for one or two meters, it's called drilling break and this might be an indication that kick is invading in the wellbore. Furthermore, an increase of rate of penetration could be due to changes of the lithology, from harder to softer formation. The reason for the sudden increase of the rate of penetration is due to the reduction of the differential pressure between pore pressure and bottomhole pressure, while chip hold down effect is decreased (J. Azar and R. Samuel 2007).

As next step, the drill string should be risen up off bottom for flow check in the trip tank. Flow check involves the observation of the drilling fluid level. An increase of fluid level is an indication that a kick is in the wellbore and the well need to shut in.

A.2.2.2 Decrease of Standpipe Pressure

A decrease of the standpipe pressure could be derived either from a material failure of the drill pipe or kick. While a certain volume of kick is migrating to the surface, an equal volume of drilling fluid would be displaced decreased (J. Azar and R. Samuel 2007). The well fluid column contains the drilling fluid and the kick, which due to the differential pressure aids surface mud pumps in lifting drilling fluids in the annulus; as a result standpipe pressure will decrease.

A.2.2.3 Increase of Hook Load

When kick starts entering in the wellbore, the overall density of the drilling fluid will be decreased due to the lower density of the kick. Buoyancy force is a function of the density of the fluid and of the immersed object (A. Bourgoyne, K. Millheim, M. Chenevert, F.S Young 1986). Due to the lower density of the influx, a reduction of the buoyancy will cause an increase in the hook load. Increase of hook load can also be an indication of loss circulation.

A.2.2.4 Decrease of d-exponent

D-exponent is a function that oil and gas industry use for estimation of pore pressure gradient during drilling. During normal pressure zones, d-exponent is being increased with depth (Salimi 2016). A deviation from the trend line could be derived from a transition to an overpressure zone.

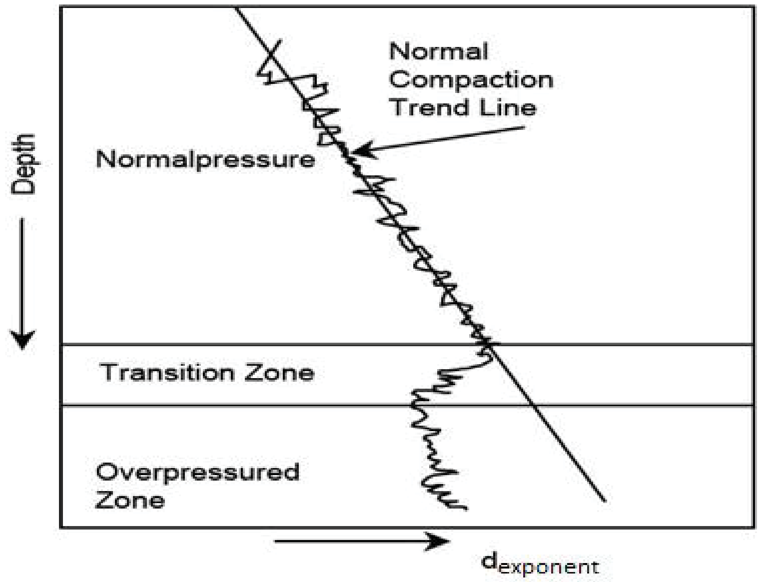


Figure 7: D-exponent trend line (Salimi 2016)

Under normal pressure zones, rate of penetration should be decreased in depth due to the greater formation strength which is a result of higher overburden pressures were acting to the formation for long period of time. As mentioned in a previous paragraph, a sudden increase of the rate of penetration leads to the reduction of the differential pressure between pore pressure and bottomhole pressure. Because of the increase of rate of penetration, d-exponent is being decreased (equation).

$$d_{exponent} = \frac{\log(\frac{R}{60N})}{\log(\frac{12W}{1000D})} * \left(\frac{pn}{MW}\right) \qquad (3)$$

Where:

R is the rate of penetration, ft/h

N is the rotational speed per minute, rpm

W is the weight on bit, lbs

D is the bit diameter, in

Pn is mud weight used, ppg

MW is the mud weight current, ppg

A.2.2.5 Increase of Total Gas Levels

During drilling, monitoring of gas levels is a significant work for mudlogger. Total gas logs interpretation, has an important use not only for recognition of oil or gas reservoir but also it may be an early indication for overpressures zones and kick. An innovative new technology of gas detectors can separate the hydrocarbons from C1 to C5 every second (Total Gas Detection 2016).

A.2.2.6 Increase of Torque and Drag

An increase of torque and drag can be an indication of kick. When a transition zone is being drilled, torque and drag trend to increase due to the fact that the formation may close in after drilled. Increase of torque and drag could also be due to poor hole cleaning or high dog leg severity.

A.3 Well Control Techniques

Since a kick has occurred, well control procedures are acting, to prevent the kick from converting into a blowout and from circulating safely the kick out of the wellbore. The best applicable method for shut in the well and circulating the kick out of the wellbore, involves a consideration of the total circulation time and the time to prepare the kill mud with maximum allowance casing and surface equipment pressure.

A.3.1 Shut in Procedures

The initial shut in procedures are classified in two types, hard and soft shut in. In both methods, initially when a kick indicator observed, stopped rotating, at the same time picked up off bottom, and stopped pumping drilling fluid. If the flow check is positive, meaning that a formation fluid is entering the wellbore, the well needs to be shut in (Drilling Formulas 2010). Shut in of the well can be establish by the activation of the blowout preventer (BOP). BOP is a large and heavy mechanical device used to seal off the space inside the BOP in order to isolate the well from pressure in the riser and control gas or oil kicks during drilling operations for preventing the event of a well blowout.

Shut in of the well can be obtained by follow the following procedure:

- Activation of annular preventer for close around the drill string or casing,
- Pipe rams for slide into place around the drill pipe sealing off the annular space around it,
- Blind shear rams for seal off the space if not drill string in the wellbore and in an emergency, the blades can shear the drill pipe (not the tool joints).

Hard shut in is the fastest, less complicated and the most efficient method for shut in the well, because it minimizes the volume of the kick in the wellbore (Drilling Formulas 2010). In hard shut in method, annular preventer is closing before and after the opening of the hydraulic choke remote valve (HCR) to monitor the readings for the casing pressure (Figure 8).

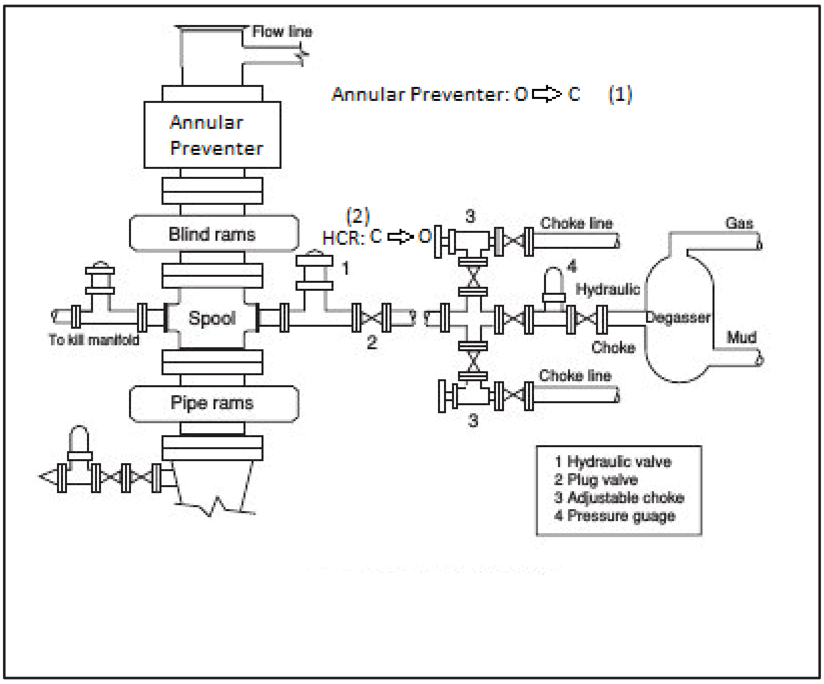


Figure 8: Hard shut in line up (Oil and Gas Drilling Engineering 2015)

On the other hand, soft shut in is more complicated. Before closing the annular preventer, the HCR needs to be open, and when the preventer is closed, and then the choke is closed. The reason for the invention of soft shut in was to reduce the water-hammer effect, which causes higher pressure in the surface equipment. Soft shut in method is recommended in well control situation when the formations fracture gradients are low and also when initial shut it casing pressure might be greater than formation fracture pressure.

A.3.2 Well Control Methods

Depending in company's policy and on the capabilities of the drilling rig, the methods to circulate the kick out of the wellbore and to obtain again an overbalanced regime are referring to the following types:

- Driller's method
- Wait and Weight method
- Concurrent method
- Volumetric method
- Bullheading

A.3.2.1 Driller's Method

A significant difference between driller's and wait and weight method, is that in the driller's method the well is under control again after two circulations and on the other hand wait and weight method requires one circulation. While the kick is circulated out of the wellbore with the original mud weight, the preparation of the kill mud is taking place in the surface. The result of the second circulation is that the bottomhole pressure would be higher than the formation pressure for preventing additional influx in the well.

The main advantage of the driller's method is that quickly after shut-in, the killing operation can proceed despite the fast corresponding operation to circulate the kick out of the wellbore, and the chances for gas migration are reducing as a result better control of the kick not to convert into a blowout (J. Azar and R. Samuel 2007).

On the other hand, circulating the kick out with the initial drilling fluid, is giving greater annular pressures due to the low mud weight, which in a situation of low fracture gradient on the formation after the shoe, fracture may occur.

A.3.2.2 Wait and Weight Method

In wait and weight method only one circulation is required in the wait and weight method. The heavier mud is circulated to displace the original mud and simultaneously to circulate the kick out of the wellbore. This method has been recommended as the safest way to remove the kick from the annulus, with the advantage that dynamic pressures in the surface equipment and in the annulus are lower than the driller's method. Lower pressures are reducing the possibilies of equipment failure or fracture the formation the shoe and reduce the unsafe time (A. Bourgoyne, K. Millheim, M. Chenevert, F.S Young 1986).

The main disadvantage is the time to prepare the heavier mud. The process of the preparation is time consuming and it allows the gas to expand and migrate.

A.3.2.3 Concurrent Method

Concurrent method is a combination of driller's and wait's and weight method, thus is the most complicated method of well control. The idea behind this method is to combine the quick response to circulate the kick out of the wellbore with driller's method, but simultaneously instead of waiting for the preparation of the required volume of heavier mud, part of the mud is pumping down, as the density is increased (J. Azar and R. Samuel 2007).

However, this method is used to determine the exact drill pipe pressure. Different mud densities are mixed in the drill string, and the determination of the total hydrostatic column is difficult.

A.3.2.4 Volumetric Method

In the volumetric method, the gas kick is allowed to migrate to the surface and expand. During the shut in procedure, if the casing pressure hasn't been increased after 30 minutes, the volumetric method cannot be used (Drilling Formula 2013). This gas expansion is adding an extra bottomhole pressure, and with the assistance of choke valve can be controlled. When the gas is in the surface, a lubricated and bleeding method is used for circulating heavier mud from kill line.

The volumetric method refers to circumstances that circulation cannot be obtained. The most common reasons are, either plugged nozzles in the drill bit or pump failure in the surface.

A.3.2.5 Bullheading Method

Bullheading method is referring when a circulation to circulate the kick out of the wellbore cannot obtain due to wellbore collapse or plugged nozzles in the drill bit. The idea of the bullheading method is to pump the formation fluids or kick back to the formation with the kill mud weight.

Chapter 3 Kick Detection Equipment

Kick detection during drilling operations can be achieved by the use of certain downhole and surface equipment. Different types of sensors for monitoring of fluid density are flow behavior and pit gain. Coriolis flow sensors, have been used from oil and gas companies for real time flow rate to indicate a lost circulation or kick event. The working principle of coriolis tool for measure flow rates have been already covered from another Master Thesis (Brezina 2017) and in this Chapter will be covered another part of Coriolis Effect, which is density estimation measurements.

A.1 Flow Monitoring Systems

Accurate monitoring of drilling fluid flow through mud return line can be crucial. Flow in measurements can be obtained by knowing the capabilities of the pump with different performance data (liner size, max. discharge pressure, and flow rates). Decrease or increase of the flow rate can be related to loss circulation and well control issues. Several types of sensors have been used for measuring the flow of drilling fluid, each using different policy of operating.

A.1.1 Flow Paddle

The most common tool for measuring of flow rate is the flow paddle. Flow paddle has been used in industry since 1953 (Yoder 2012), and nowadays, the idea behind the tool remains the same but more advanced.

Flow paddle measures the flow rate of the drilling mud coming out of the wellbore into the surface (Figure 9). It is installed under the rig floor in the return flowline of mud in the bell nipple and also after the mud pumps. Return flowline, is an inclined pipe, allowing the natural gravity flow of the fluid without any resistance.

The advantages of this tool is the easy installation and relatively cheap. On the other hand a significant disadvantage is the low accuracy of the tool.

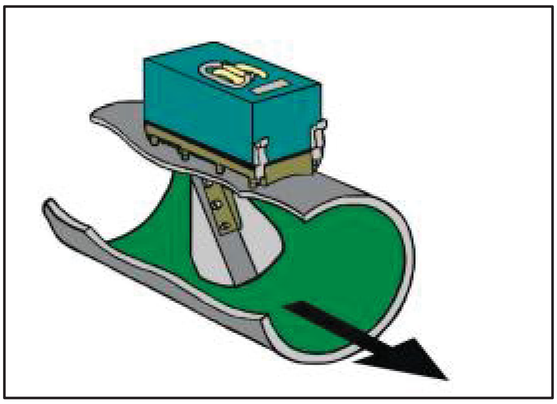


Figure 9: Flow paddle position in return flow line (Robbie 2016)

Modern flow paddles, have an analog transducer installed. As the drilling fluid passing through the bell nipple to the flowline, the paddle position is a function of flow rate. An increase or decrease of flow rate will affect the resistance values.

A.1.2 Differential Pressure Flow Meter

Differential pressure flow measurement method uses a fluid mechanical principal which was introduced 300 years ago (Wikipedia 2017). Bernoulli discovered the direct relationship between pressure and velocity of a fluid flowing in a pipe.

An orifice plate is installed in the inner part of the tube between the two tubes that are connected with a differential pressure sensor separated by a diaphragm as Figure 10 illustrates. The use of the plate is to produce a differential pressure among the tubes.

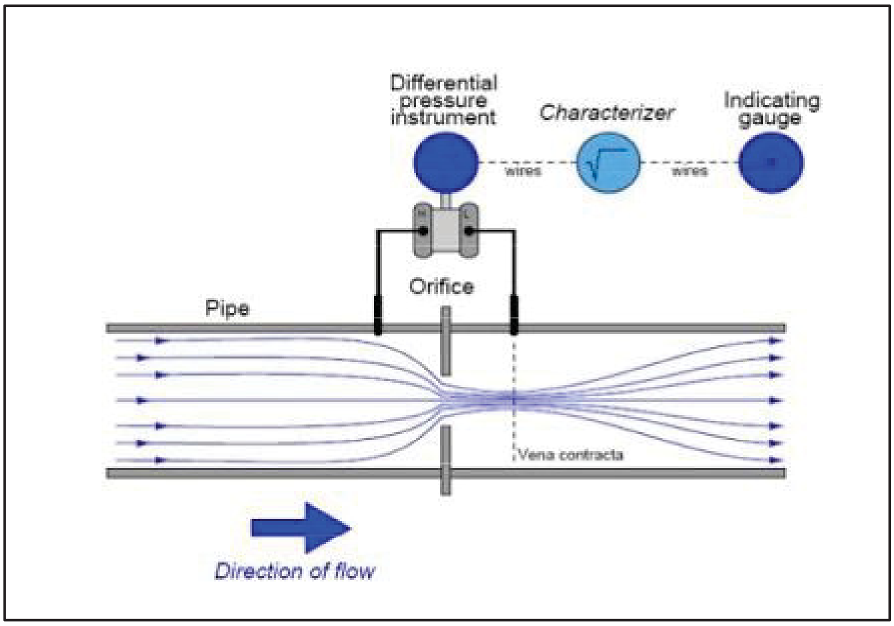


Figure 10: Differential pressure flow meter with Orifice (Salama 2014)

If the fluid in the tube is static, the pressure before and after the orifice are the equal. When fluid starts flowing, the higher the flow velocity is, the higher the differential pressure is measured. Due to the orifice shape, high pressure losses encounter during fluid entrance in the orifice. In the following Figure 11, the components of the cell are presented.

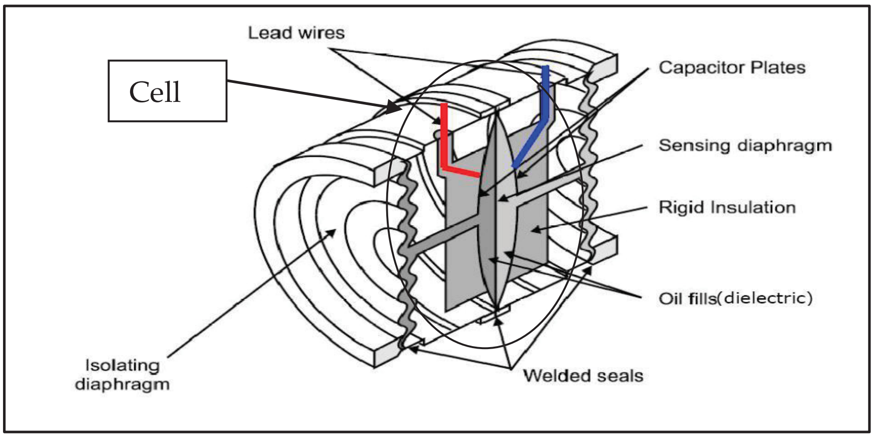


Figure 11: Design of the cell (Learning Instrumentation and Control Engineering 2011)

Diaphragm is installed between pressure inlet ports which are capacitive sensors. Capacitive pressure measurement is the change of the capacitance value, which is influenced by the movement of the diaphragm. The applied pressure affects the pressure in the cell, and it will force the diaphragm to move to the side with the less pressure. The result is a change of capacitance in the cell.

Using a high frequency detector circuit connected to the cell, the capacitance data are translated into a signal which a monitor is displaying into a pressure.

A.2 Pit Gain Detection Systems

A significant parameter that needs to be monitored repeatedly is the pit gain. Pit gain can be a positive indication of loss circulation or well control scenario. As influx starts invading in the wellbore, there is an increase of mud level in the trip tank due to an increase of mud return flow. For this reason, an accurate continuing measurement of pit volume is necessary for the prevention of well control situation.

A.2.1 Ultrasonic Measuring

Ultrasonic technologies have been used in the past for several applications in oil and gas industry i.e. flow rate monitoring, pipe corrosion measurements. Ultrasonic sensors are working through the principle of speed of sound.

The sensor emits a high frequency pulse of a range of 20 kHz to 200 kHz, towards to the liquid surface (Magnetrol 2017). As the ultrasonic pulse travels, at the time when the first wave will come in contact with the surface, a reflection phenomenon will be observed. The reflected wave is detected later by the sensor, which is acting as a receiver now (Figure 12).

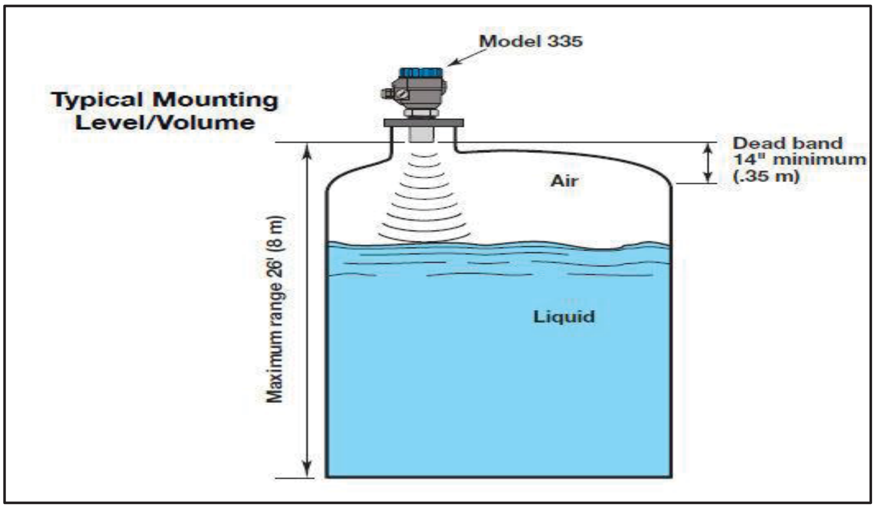


Figure 12: Ultrasonic sensor for liquid level measuring (Magnetrol)

A.3 Surface Density Measurement Systems

A.3.1 Coriolis Tool

As technology started evolving, density measurements and monitoring have become essential for safe drilling operations. Coriolis flow sensors, have been used from oil and gas companies for real time flow rate and density measurements, to identify indicators for potential loss circulation or well control scenarios through the comparison of the initial and final flow rate.

Coriolis sensors are classified to mass and volume flow rate, density and pressure sensors. A Coriolis tool is installed after the return flow line for monitoring the volume/flow rate of drilling fluid pumping out of the wellbore.

The idea behind the tool is the Coriolis Effect. This principle refers to the curved direction of an object when the frame of reference is rotating. Initially, when there is no flow in the system, the tubes are vibrated in a specific frequency. This frequency has been determined in advance and it depends on the material and mass of the tubes (Figure 13).

The incoming and out coming section are synchronized each other. The inertia flowing fluid impels the rotating tubes to twist (Brezina 2017). Due to the Coriolis Effect, the inlet and outlet sections of the tube are in different direction continuously.

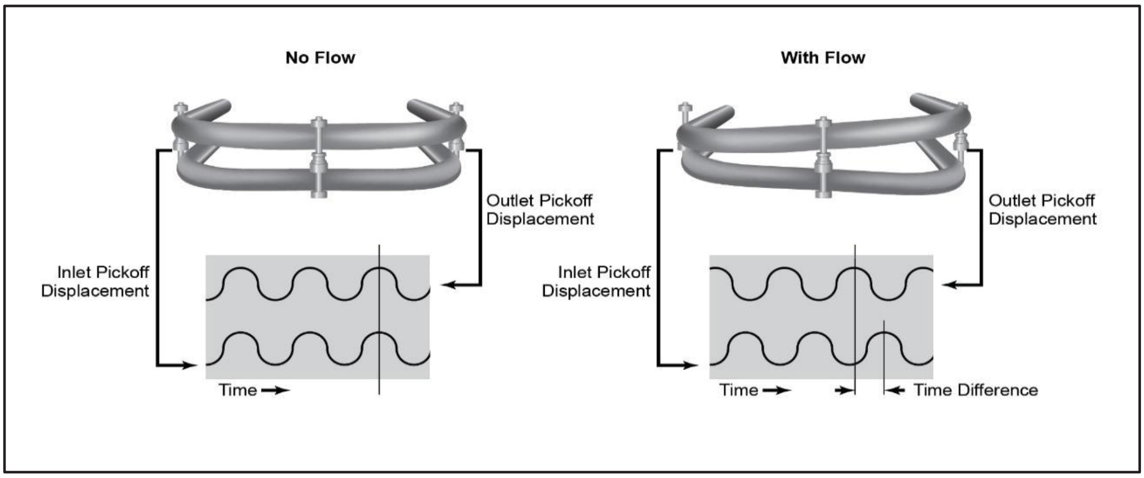


Figure 13: Twisting movement of tubes during no flow and with flow (Emerson 2014)

Electromagnetic sensors are also called pickoff sensors and they are placed in the inlet, middle way and outlet of each tube for accurate measurement of twist. Phase can be converted to time and time difference and it is proportional with the rate the mass flows in the tubes (Emerson 2014).

Since the volume inside the tubes is constant, a change in density leads the tubes to twist in different frequency, which can be detected from the electromagnetic sensors. The natural frequency of the tubes depends directly on the density of the fluid. Knowing the density and mass of the fluid, the volume can be calculated and estimated.

A.3.2 Electromagnetic Density Sensor

Density measurement sensors can provide accurate real time data by continuing measuring of density (Figure 14). Operating principles of the electronic sensors is the ability of the sensor to create an electromagnetic field. Instance changes of the electromagnetic field have an impact on the pressure, which is converted to density. Operating temperature of those sensors are with a range from – 40 to 60 ^{0}C.

Figure 14: Density measurement sensor (OPW Company 2017)

A transmitter is used to create an electromagnetic wave, and the wave travels through a medium, which can be detected after by a receiver. The density readings can be configured to either nominal or temperatures corrected density.

A.4 Downhole Density Measurement Systems

A.4.1 Nuclear Density Gauge

Nuclear density gauge is a technology that has been used in different industries i.e. mining, petroleum, civil construction to measure the density and inner structure of a material. It consists of a radiation source that emits a direct beam of particles and a sensor that detects and receives the reflected particles.

As a radioactive isotope decays, radiation is emitted as particles or electromagnetic waves (gamma radiation). The isotope is installed in a stainless steel capsule, which seals the radiation completely (Binder 2016). The tool is oriented in such a way, which only the gamma radiation is emitted in one direction. On the other side, a transmitter has been installed to detect the gamma radiation.

As the radiation is transmitted and penetrated to the particles, the density of the medium attenuates the radiation. The radiation decreases as the density of the medium increases. The following Figure 15 illustrates the required components of a nuclear density gauge.

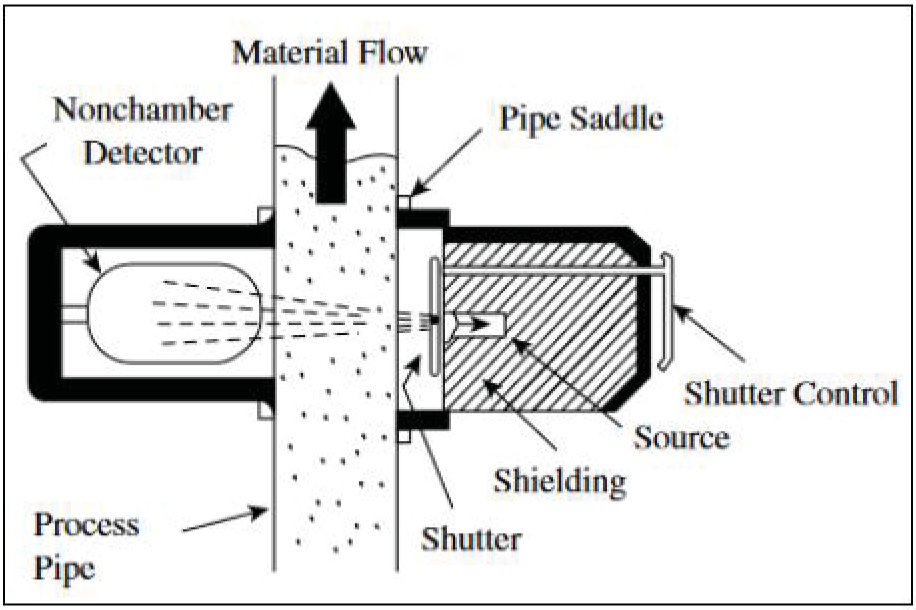


Figure 15: Nuclear density gauge components (Hoeppner and Liptak 1982, 1995)

When the transmitter detects the radiation, as this occurs, gamma photons are converted into an electrical signal, which then is amplified in a photon pulse in the photon amplifier which gives a measuring signal.

In downhole applications, the nuclear density gauge (the radiation source and the detector) need to be installed in the last casing shoe. The tool needs to be installed as last part of the casing, before the float shoe.

Many considerations have to be taken regarding Health Safety and Environment (HSE) as well as legal aspects in order to have a nuclear source the whole time in the wellbore. The main limitations of the tool are air entrainment, source decay and pipe wall deposits. A solution to minimize some of these problems is the vertical installation of the tool with a positive pressure head at the location of the gauge.

A.4.2 Microwave Density Measurements

The Microwave density tool is capable of measuring the density of fluids flowing through pipes. The working principle of the tool is the microwave phase difference for the determination of the fluid density. The phase difference is created due to the fact that the microwave travels through a known and unknown media with different travelling speeds (Binder 2016).

The phase difference Δθ as shows in Figure 16 is proportional to density. The received signals from both measurements are compared. The phase shift of those two signals is proportional to density estimation.

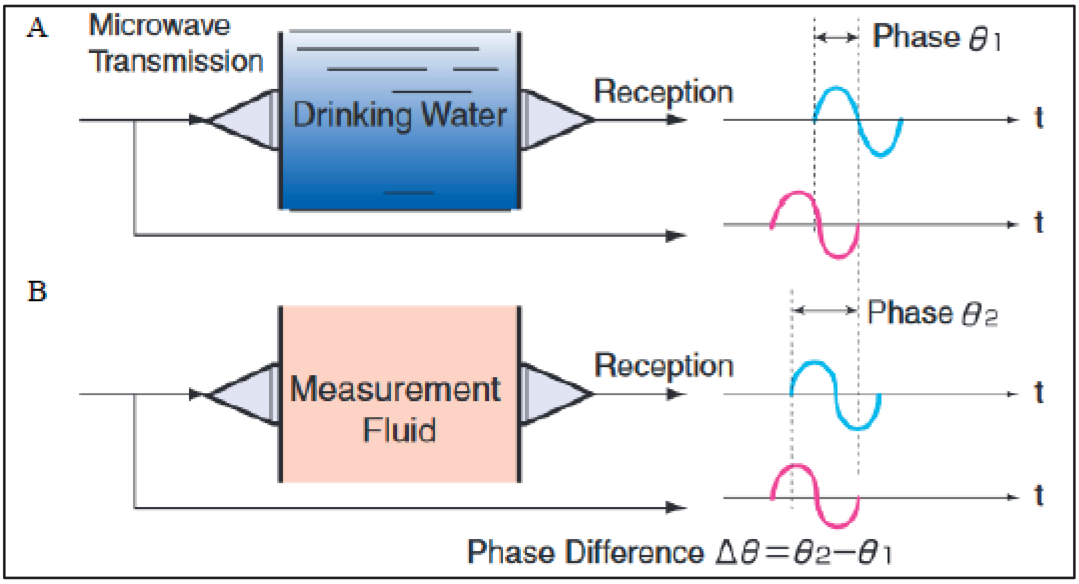


Figure 16: Measurement principle of microwave densitometer (Toshiba Corporation 2007)

The working principle of the tool requires the installation of a transmitter and receiver in the opposite side. The measurements are not influenced by the flow rate or the contamination of the fluid and it is limited to an installation in a tool with a flow path.

A.5 Downhole Pressure Measurement System

Downhole pressure mostly refers to a narrow pore and fracture pressure window situations, but it can also be a significant factor for a kick indication. Downhole pressure measurements provide information about equivalent circulation density and kick detection monitoring by converting pressure measurements to density depending on depth.

Annular pressure sensors are monitoring wellbore pressure continuously during drilling procedure, allowing the driller to make decisions. Decrease of annular pressure can be an indication of unexpected gas or oil kick in the wellbore. Pressure measurements can also be converted into equivalent circulation density.

High accuracy quartz pressure gauges, consistently deliver high-resolution pressure measurements in high temperature and pressure environments. The sensors (pressure gauges) are part of Measurement While Drilling tool (MWD) and are connected to a unit, which converts the information to digits transmitted to the surface by mud pulse system, which will be described to the next Chapter. Figure 17 illustrates the decrease of overall density due to gas mixture with drilling fluid.

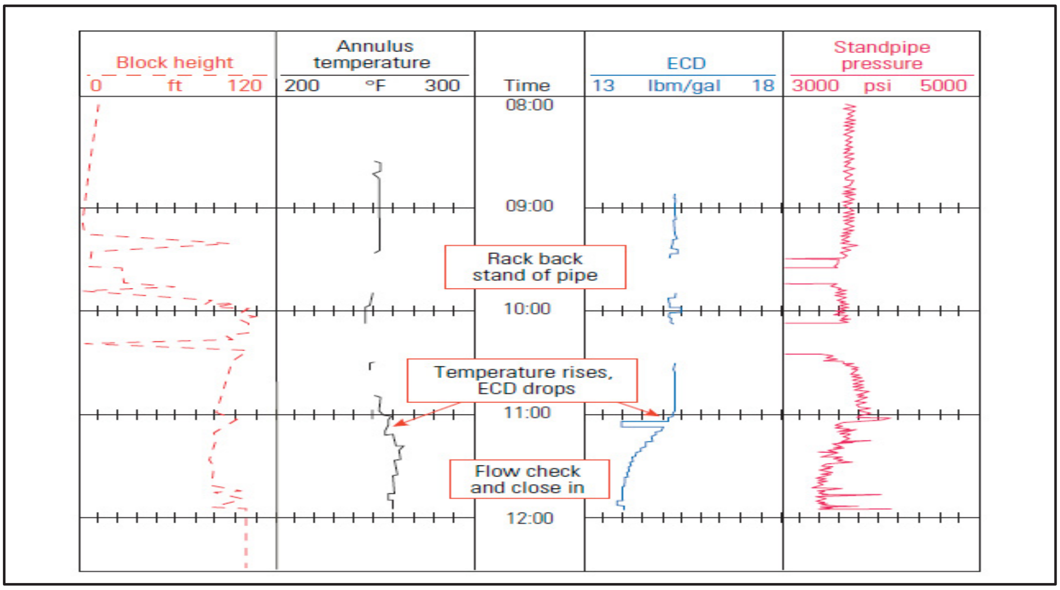


Figure 17: Gas influx. When gas mixes with drilling fluid, overall density decreases (Aldred, Cook, Bern, Carpender, Hutchinson, Lovell, Cooper, Leder 1998)

When a certain influx starts entering the wellbore, a displacement of equal volume of drilling fluid occurs. This gas or oil column causes a reduction in the standpipe pressure and equivalent circulation density. Mud loggers having identified those indicators, a flow check needs to be obtained for checking if the well is static or dynamic.

Chapter 4 Downhole Data Transmission

A.1 Mud Pulse Telemetry

The sensors are part of measurement by a drilling tool (MWD), which is a component of bottomhole assembly (BHA). The pressure or density data are transmitted to the surface by mud pulse with drilling fluid. The propagation of the signal is affected by the mud density behaviour during high temperature and pressure zones.

On MWD tool, a pulsar is installed and it is blocking the flow of the mud to create a pressure pulse (Figure 18), which are pressure fluctuations that can be detected on the surface with a pressure transducer (Hongtao Li, Yingfeng Meng, Gao Li, Na Wei, Jiajie Liu, Xiao Ma, Mubai Duan, Siman Gu, Kuanliang Zhu, and Xiaofeng Xu 2013). On the surface, computers process the signal and special software has to reconstruct the information from the pressure pulse.

Figure 18: MWD Rotary Pulser – Mud Pulse Transmitter (Aps – Technology)

A significant disadvantage of this method is that data can only be transmitted to the surface only through the circulation of drilling fluid, which makes it useless for kick detection during tripping operations. Also the data are not real time due to the time for the pulse to transmit to the surface. Even if it is a slow method of communication, it is the most rock solid way to communicate with downhole tools.

A.2 Electromagnetic Telemetry

Another type of data transmission in the surface is by electromagnetic pulse. The data transmission can be achieved either by using the drill string as a wire for the signal to travel in the surface or by using the conductivity of the formations. This method is an alternative of mud pulse, and is referring to drilling operations where air is used a drilling fluid (i.e. underbalanced drilling).

The electromagnetic telemetry system, transmits low frequency electromagnetic waves across the wellbore to the surrounding formations. Surface antenna rod is detecting the signal and a surface system is decoding and processing the signal (Figure 19).

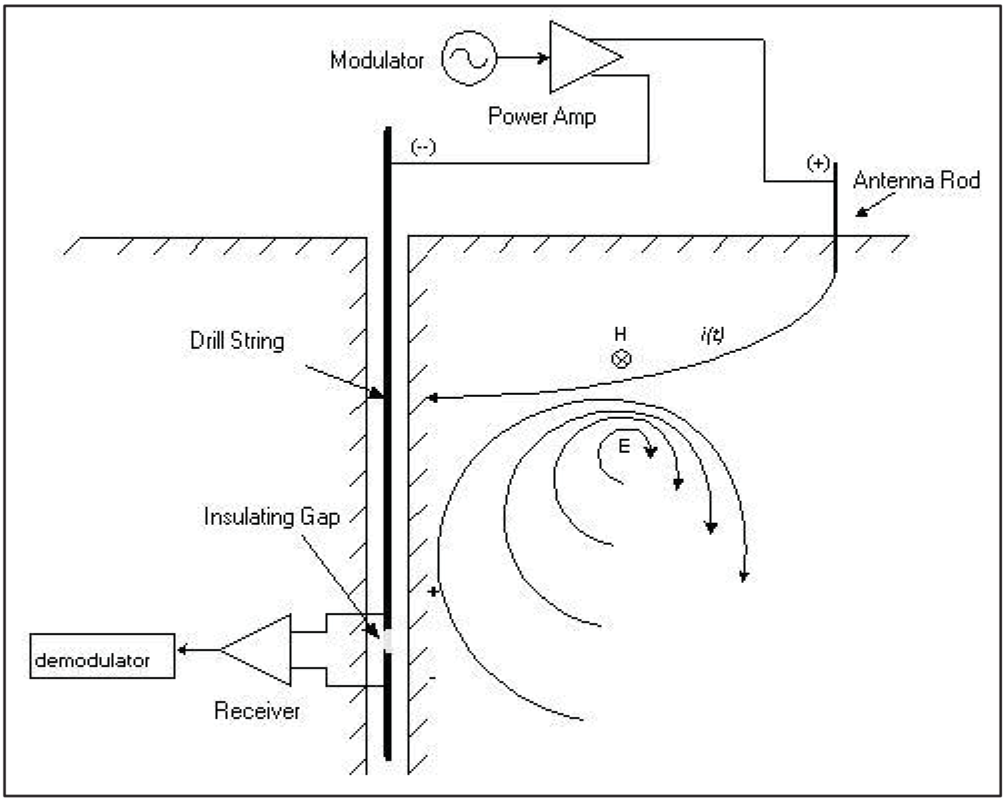


Figure 19: Schematic of EM Telemetry System (National Energy Technology Laboratory)

In both methods, no circulation is required for data transmission. While electrical signal is travelling through the drill pipe and formations, a significant amount of energy is lost, causing attenuation on the signal.

A.3 Wired Drill Pipe

New method for data transmission is so called wired drill pipe. A coil is placed in both pin and box end. A high-speed telemetry network enables the data to be transmitted in real time to the surface. Wired drill pipe enables faster data transmission for downhole data and increase drilling performance by reducing drilling time. Figure 20 illustrates the design of a wired drill pipe.

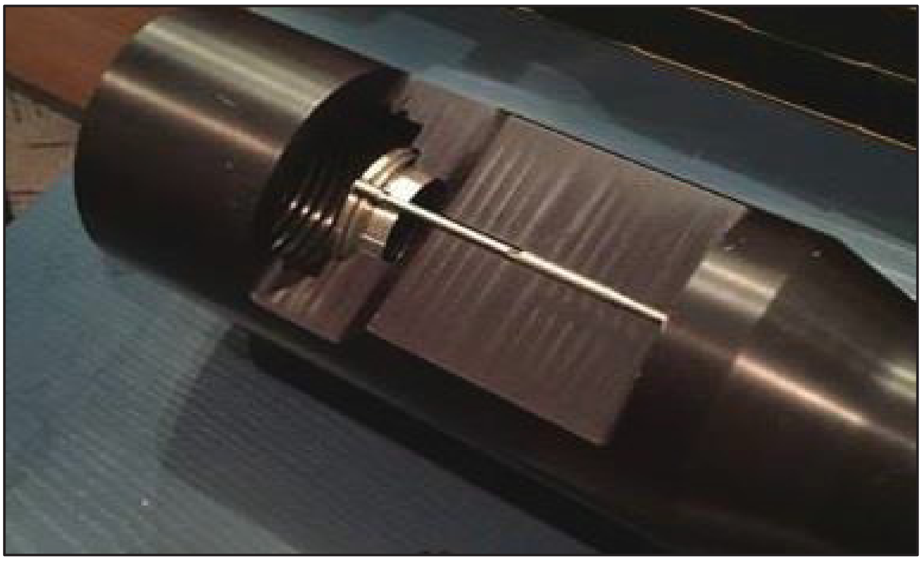


Figure 20: Wired Drill Pipe Design

An interface sub is installed after the BHA components and convert all the signal that received from MWD and LWD tools and then the data cable transfer the data through every joint of the drill pipe. During the travel of the data signal from bottomhole to the surface, the data are passing through a data link system, which purify and amplify the data (Martin Fosse 2015). As last part of the system is the data swivel (Figure 21). Data swivel allows to transfer the downhole data to the surface cabling. A significant component is the stator, which allows the connection between the coil of the wired drill pipe and the surface cabling during rotation mode.

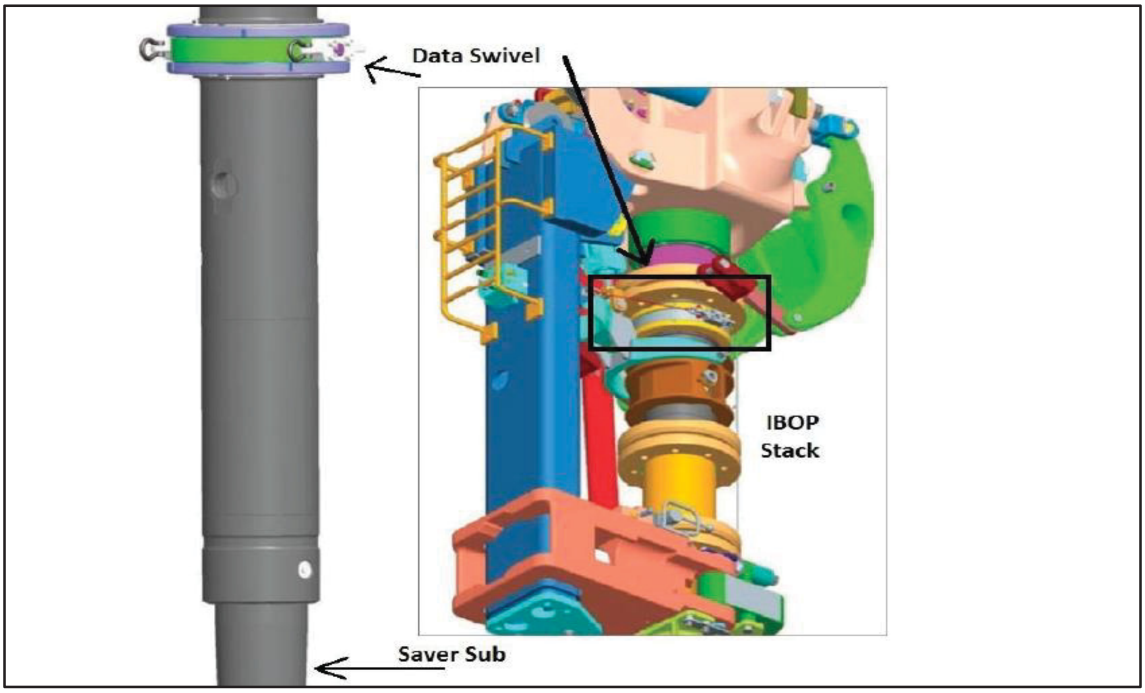


Figure 21: Data swivel mounted in Topdrive (IntelliServ 2015)

Chapter 5 Sensor Technology for Real Time Kick Detection

This chapter describes the fundamentals of capacitive sensing technology and their use in different industries. Capacitors have been upgraded into an innovative sensing technology for various kinds of measurements. Capacitive sensors are capable of operating in hazardous and liquid environments without any negative implementations in their performance.

Ultrasonic sensors have been used in different industries for various applications. Rapid development of technology has upgrade ultrasonic sensors and introduces them in automobile industry, oil and gas industry, etc.

A.1 Capacitive Sensors

A.1.1 Working Principle

A capacitor is an electrical device, which consists of two electrical components known as conducting plates for conducting electrical energy and an insulator between them, acting as a dielectric. The use of capacitor is to store electrical energy and the difference between batteries is the way that releases the energy. A capacitor releases energy much more rapidly often in a second or less (Woodford 2008/2017) i.e. production of a flash in camera. The following Figure 22 illustrates the circuit configuration of a capacitor.

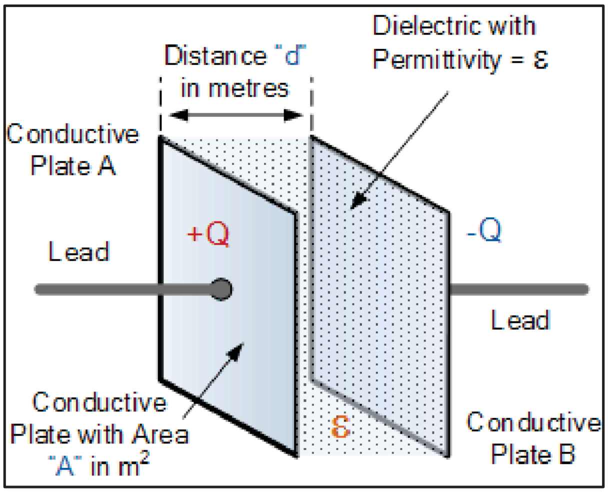


Figure 22: Capacitors used in a circuit for store electrical energy (Electronics Tutorial 2017)

As a basic principle, a capacitor, which is capable of storing electrical energy, a voltage, needs to be applied across the two terminals. In order to achieve it, the conducting plates are connected with a power supply, which acts as a source of electricity (Figure 23). When are charged, an electric field will be created between the two plates. The charge magnitude on both plates is the same (Springer 2012). Reversing polarity in the charging system, it will change the positive and negative charge for Conductive Plate A and Conductive Plate B respectively.

The time required for a capacitor to be fully charged is determined as Time Constant (τ) and it refers to the time that the capacitor will be charged 63% of total capacity. The Time Constant depends on the resistor (R) which is the resistance of the circuit and on the capacitance of the capacitor (Equation 4).

$$\tau = RxC \qquad (4)$$

Where:

R is the resistor contact line, Ohms

C is the capacitance of the capacitor, Farad (F)
τ is the time constant, s

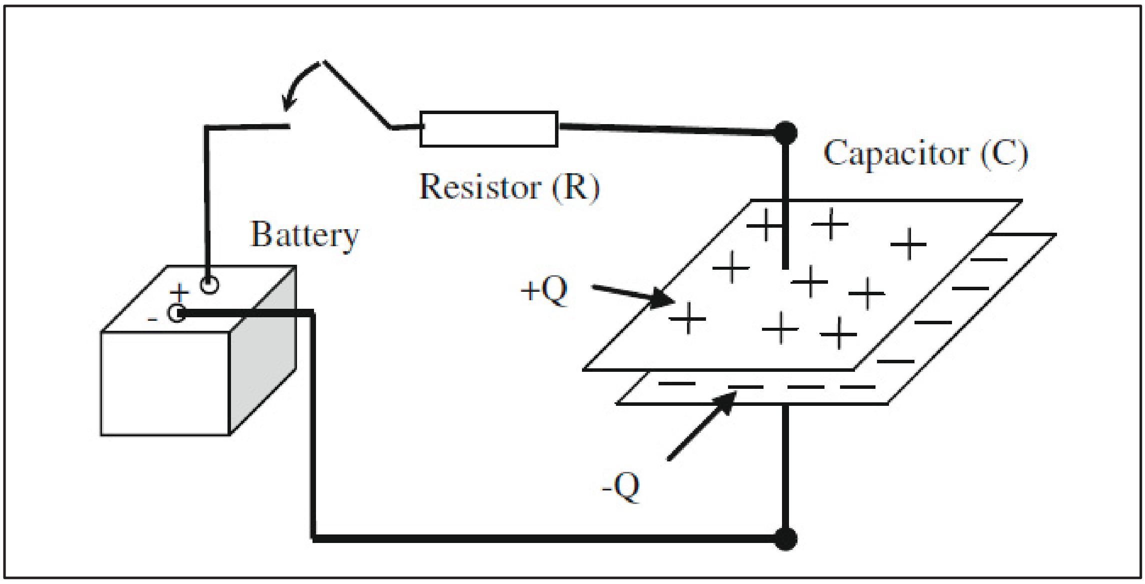


Figure 23: Capacitor circuited and position of resistor (Springer 2012)

A.1.2 Capacitance

Capacitance is the ability of a system to store electrical energy. Capacitors are capable of store large amount of electrical energy. It is measuring the amount of electrical energy that capacitor is capable to store for at a given voltage. Capacitance is measured in Farad and can be defined as coulomb per volt with the following equation (Equation 5).

$$C = \frac{Q}{V} \qquad (5)$$

Where:

C is capacitance, Farad (F)

Q is the magnitude of charge in every plate, Coulomb (C)

V is the applied voltage, Volts (V)

A capacitor with capacitance of one Farad, can store electrical charge of one Coulomb when the voltage in the terminals is one Volt. The capacitance can be increased as the distance between the two conducting plates decrease, the surface area of the plates is greater (L. Baxter 2000). An important role that has an impact on capacitance is also the insulator which will be discussed later.

When a voltage is applied in one of the plates, an electric field will exist between the plates. The reason that the electric field is created it is due to the electrical charging difference stored in the plates. As the distance between the two plates increases, the strength of the electric field decreases.

A.1.3 Dielectric Constant and Strength

A.1.3.1 Dielectric Constant

As mentioned in the beginning of this chapter, the space between the two conducting plates is filled with a non-conducting material, which is called insulator and acts as a dielectric (Wikimedia Commons 2008). A dielectric material is an electrical insulator that has low conducting ability but on the other hand can be polarized by an applied electric field, which can be illustrated in Figure 24.

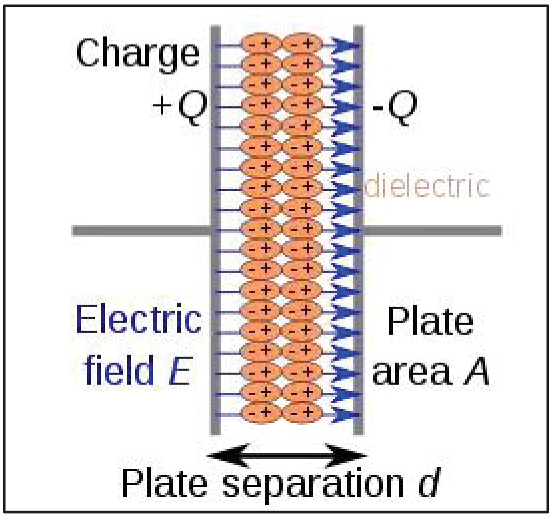


Figure 24: Dielectric polarization (Wikimedia Commons 2008)

Relative permittivity is known as dielectric constant and measures the capacitance of the capacitor with the dielectric material compared as it has vacuum as dielectric (Table 1). Permittivity depends on the conductivity of the material and their atomic structure. The unit of permittivity is Farads per meter. The greater the permittivity is the greater the resistance of the material to the electric field.

Material	Dielectric Constant
Air	1
Paper	1.6 – 2.6
Water	80
Mica	5.7 – 6.7
Alcohol	25.8

Table 1: Dielectric constants of different materials (Springer 2012)

The use of the dielectric is that it increases the capacitance of the capacitor. As a voltage has been applied in the conducting plates, depending on the type of the material of the insulator, the electrons are shifted and that creates an opposite field between the two plates. The dielectric is resisting in the electric field and as a result, it stores energy. According to the following equation (Equation 6), the capacitance is proportional to the dielectric constant (L. Baxter 2000).

$$C = \varepsilon r \frac{\varepsilon o A}{d} \qquad (6)$$

Where:

C is the capacitance, Farad

εr is the dielectric constant

$\varepsilon 0$ is the permittivity of free space, $8.854\ 10^{-12}$ F/m

A is the area of each plate, m^2

d is the distance between the two plates, m

A.1.3.2 Dielectric Strength

Dielectric strength of an insulating material, describes the maximum electric field that the material can withstand without conducting electricity. When the magnitude of the electric field exceeds the dielectric strength of the material, the insulator will begin to conduct. In the following table (Table 2), the dielectric strengths of different types of insulators are described.

Material	Dielectric Strength (10^6 V/m)
Air	3
Paper	16
Polystyrene	24
Teflon	60

Table 2: Dielectric Strength (Springer 2012)

The maximum voltage that can be applied in the capacitor without exceeding the dielectric strength is called rated voltage or breakdown voltage. Rated voltage is an important parameter that needs to be monitored continuously for avoiding measurement misinterpretations. Depending on the dielectric strength of the material, the operating voltage is approved. Factors that have an impact on the insulator are the frequency, operating temperature, thickness of the specimen and humidity

A.1.4 Applications of Capacitive Sensors

A.1.4.1 Proximity Sensing

The application of proximity capacitive sensors is the detection of metallic or non-metallic object without any contact. As an object passes through the field lines zone, the capacitance of the capacitor will be changed, causing an amplitude change in the electronic circuit of the sensor, detected by an oscillator, which is connected with the conducting plates (Springer 2012). In the following figure (Figure 25), the schematic illustrates the electrical field when an object approaches the field lines.

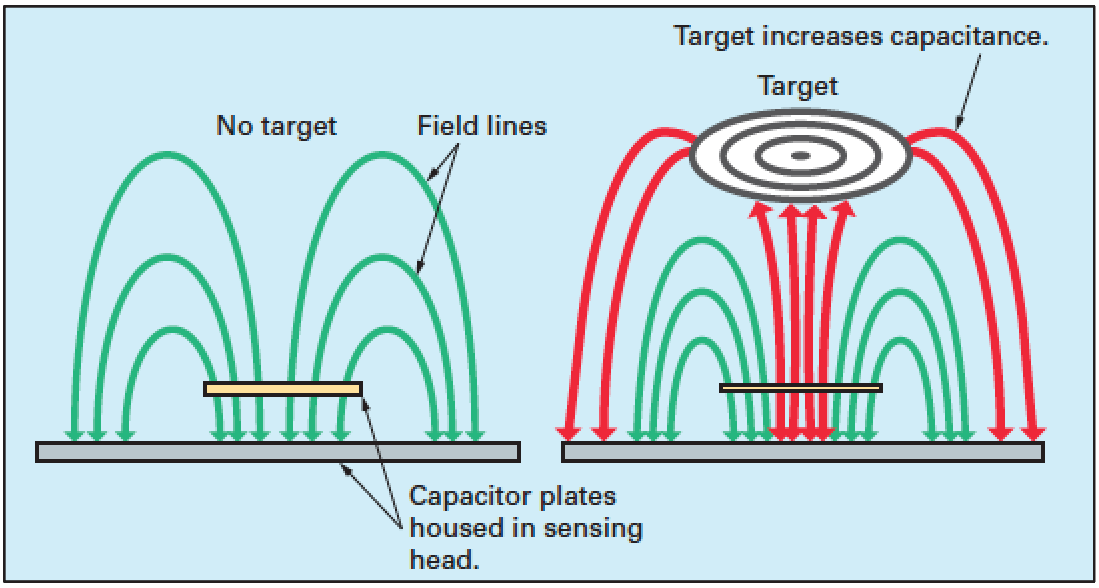


Figure 25: An increase of capacitance while an object passing through the electric field (Thomas Kinney 2001)

A Schmitt Trigger is a significant compound in the circuit. It converts an analogue input signal into a digital output signal. As the target starts entering in the field line zone, the capacitance of the sensor start increasing, forcing the Schmitt Trigger state to change and creating an output signal in the control unit (Thomas Kinney 2001).

Capacitive proximity sensors are capable of detecting an object through a wall but respectively to the nominal range. Nominal range is the maximum range in which a capacitive sensor can detect an object depending on the distance between the plates and the applied voltage.

A.1.4.2 Fluid Level

Another important application of capacitive sensors is to measure the fluid level in a tank. Capacitive sensors have gained popularity because of accuracy and resolution of the measurements. For this application, two electrode rods have been used and the working principle is the same. The electrodes are connected with an alternating current measurement circuit.

For calibration of the sensor, empty and full tank measurements conditions with storage liquid must be taken. The dielectric constant of the liquid required to be known for accurate capacitance measurements. As the liquid level increases, the capacitance changes progressively and liquid level can be measured (L. Baxter 2000). As mentioned in the previous paragraphs, the greater the dielectric constant of the liquid is, the higher the output capacitance.

In the following figure (Figure 26), a general schematic of liquid level capacitive sensor is given, showing the design of the storage tank.

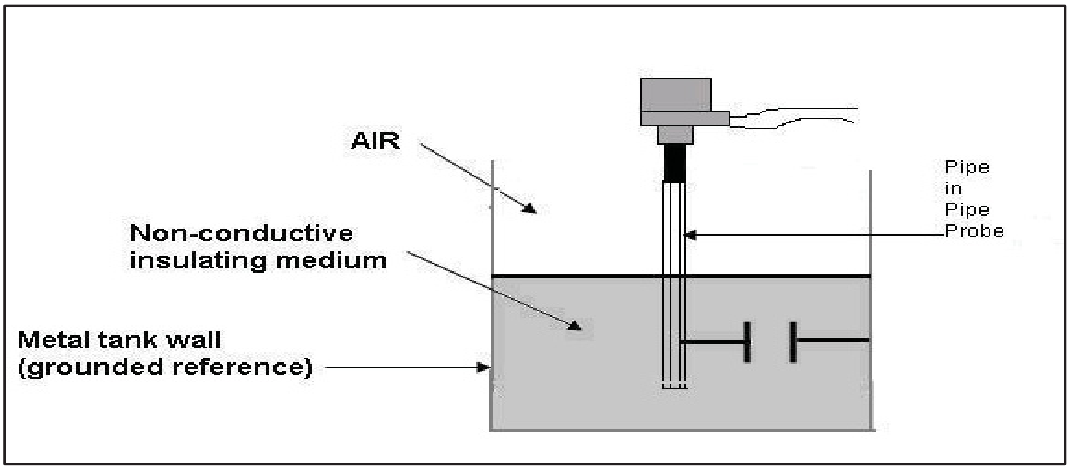


Figure 26: General schematic of liquid level capacitive sensor (Springer 2012)

The type and the shape of the electrode rods could be in various forms. The design of the electrode rods influences the capacitance between the two rods or plates. The distribution of the electrical field would be different in relation with the type of the electrode (rods, plates, etc.).

A.1.5 Effects of the Environment

Environmental factors such as noise, temperature, and pressure have an impact on the performance and accuracy of the capacitive sensor measurements. Dielectric constant can be affected by those environmental changes, influencing the output capacitance.

A.1.5.1 Effects of Noise Variations

One of the biggest challenges in capacitive sensors, are electromagnetic interferences from nearby noise sources. Capacitance is influenced negatively by a generated electrical noise, making the measurements inaccurate and the capacitance signal can be clearly detected.

New capacitive sensors are barely affected by noise capacitance signal with the use of LC resonator which serves as a filter, rejecting most of the noise and contributing to a clear capacitance signal.

A.1.5.2 Effects of Temperature

Changes in the temperature can have an impact on the dielectric constant of a liquid or gas, making the capacitance readings inaccurate. Variation in temperature can alter the geometry and size of the capacitive sensor. Changes in the electrode gap will alter the value of the capacitance of the sensor and furthermore, an inaccurate capacitance measurement will be obtained. Heat increases the conductivity of a liquid or gas and provides a kinetic energy to the electrons. The kinetic energy has an impact in the molecules polarization. Dielectric constant depends on the structure of molecules and atoms.

Sensing electronic devices and components behave differently in elevated temperature environments. A high performance thermal insulator is been used for isolating the system of the sensor from the environment.

A.1.6 Ultrasonic SensorsIntroduction to Ultrasound

Generally, sound is created by the vibration of particles and transmits energy through a medium. Ultrasonic sensors transmit ultrasonic waves to an object and receiving the reflected waves (APC International 2016). In most of the cases, ultrasonic sensors are used for distance measurements, detection of an object and also as mentioned in the previous chapter, for flow rate measurements. Ultra sound refers to sound wave which has a frequency of 20 KHz (20000 Hz) and can travel only in a medium. In Figure 27, the pressure variations, when sound are traveling through the air. Air molecules are associated with the direction of sound.

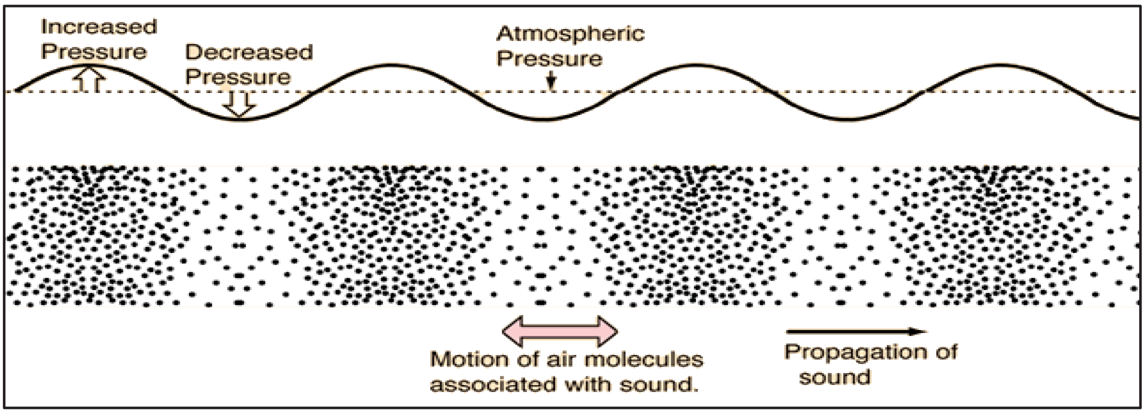


Figure 27: Pressure variations when sound travels through the air (Hyperphysics)

Ultrasonic waves can be characterized by amplitude, period and wavelength. Amplitude is the magnitude of pressure changes between maximum and minimum pressure peaks from the equilibrium position. The greater the amplitude is, the higher the energy of the wave. Wavelength refers to the distance between two peaks (Hyperphysics).

Period (T) of sound wave is defined as the required time for an air molecule to fully move back and forth one time. Period is the number of seconds per oscillation and frequency is the number of oscillations per second. In the Figure 28, the amplitude and wavelength versus distance and period versus time are described.

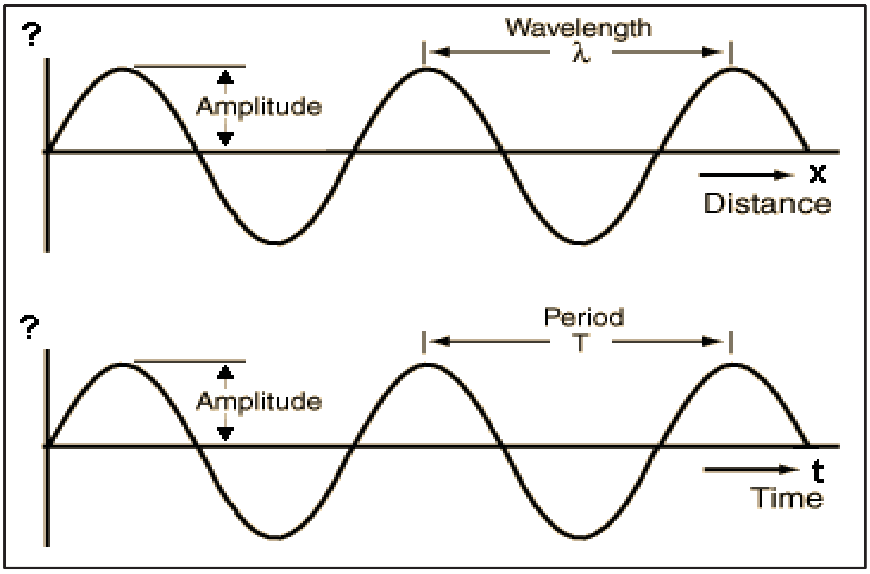


Figure 28: Amplitude, Period versus distance and time (Tontechnik – Rechner)

The velocity of a wave can be calculated by knowing the given wavelength and frequency. The velocity of a sound wave in air at 20 °C is 343, 14 m/s in comparison in with water at 1484 m/s in fresh water. In the following equation (Equation 7) the formula for the calculation of the wave velocity is given (APC International 2016).

$$v = f \times \lambda \qquad (7)$$

Where:

v is the wave velocity, m/s

f is the frequency, Hz

λ is the wavelength, m

A.1.7 Characteristics of Ultrasonic Waves

During the transmission of the sound to a medium, sound can be reflected, refracted and diffracted. As the wave travels through the material and reaches a boundary, part of the wave continues travelling through and a part of the wave is reflected back. Acoustic impedance is a significant ability of a medium which determines the reflection of a wave and it is a function of velocity and density as the following equation shows (Sprawls 2016):

$$Z = \varrho \times v \qquad (8)$$

Where:

Z is the impedance,

ϱ is the density,

v is the velocity in the medium,

The part of the wave that continues to travel through the material is considered as a loss of the initial sound wave. Material such as foam absorbs the sound wave, making the object invisible to the sensor.

To produce an ultrasound, a transducer is a necessary component. It converts electrical energy to ultrasonic wave and send a pulse. As the pulse is travelling to a medium, it reaches a boundary. A part of the wave is reflected back and another part of the wave continues to travel through the medium. The transducer detects the reflected wave and the distance between the sensor and the object can be calculated (Nihon Dempa 2017). In the following Figure 29, the production and transmission of an ultrasonic wave from a sensor to an object and the reflected wave for measuring distance are described.

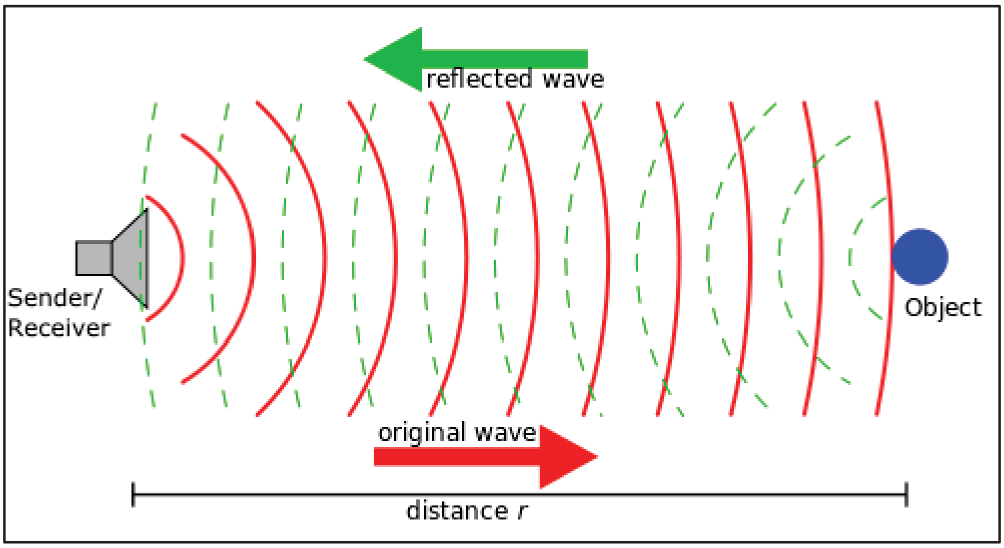


Figure 29: Working principle of ultrasonic sensors (Nihon Dempa 2017)

A.1.8 Principle of Ultrasonic Sensors

Ultrasonic sensors are based in high frequency waves approximately 20000 Hz. Frequency (f) is described as oscillations per unit time, measured in hertz (Hz), which is referred to oscillations per second. As mentioned in the previous paragraphs, ultrasound originates from mechanical oscillations of various crystals in the transducer, which is created by an electric energy.

Piezoelectric effect is an ability of materials to generate mechanical vibration when an electrical voltage is applied (Murata 2012). Conversely, an applied voltage will deform the static structure and it generates mechanical vibrations to the material. Thus, those vibrations are producing sound. The following figure (Figure 30) provides the number of the specific components that a transducer be created of.

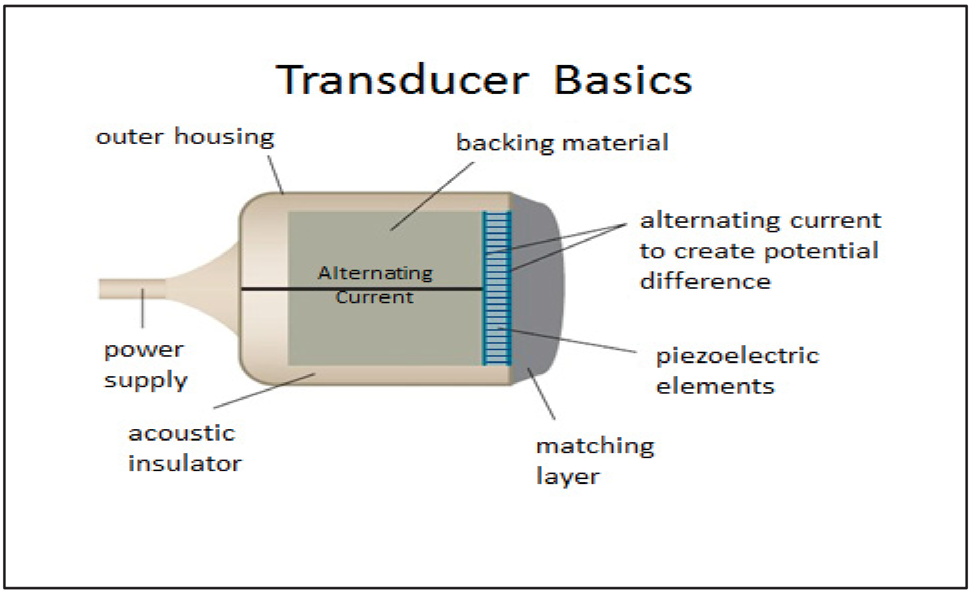


Figure 30: Transducer components and power supply (Raghu Galla 2015)

There are two operation types that an ultrasonic sensor can operate. The first one and the most common is the transmission of an ultrasound wave by a transmitter in the air, water, etc. and the receiver receives the reflected wave from the object. Distance can be calculated by knowing the time of the ultrasonic wave to travel from the transmitter and received back to the receiver (Michal Kelemen, Ivan Virgala, Tatiana Kelemenová, Ľubica Miková , Peter Frankovský, Tomáš Lipták, Milan Lörinc 2015). The second operational approach a single sensor emits an ultrasonic wave and receives the reflected wave. The working principle of an ultrasonic sensor is described in the following figure (Figure 31).

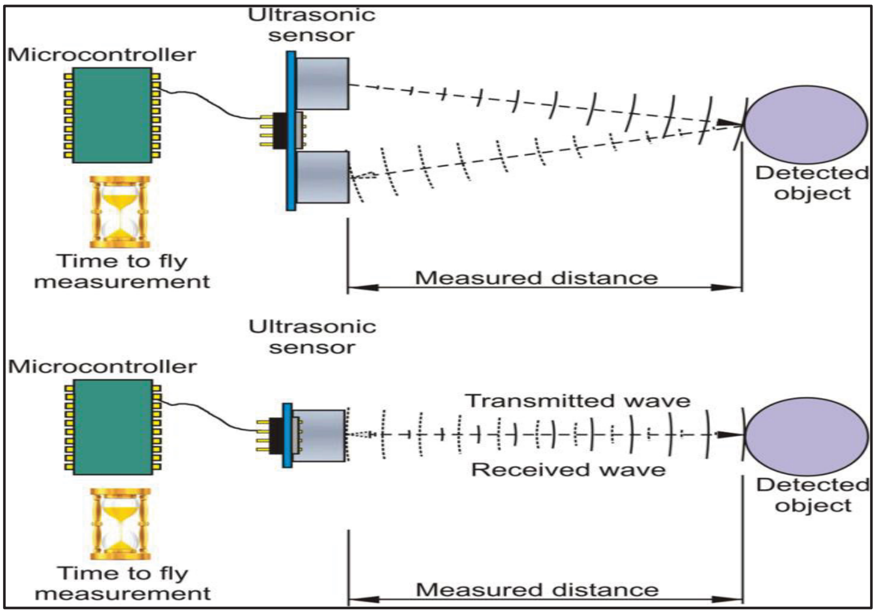


Figure 31: Ultrasonic sensor working principle (Michal Kelemen, Ivan Virgala, Tatiana Kelemenová, Ľubica Miková , Peter Frankovský, Tomáš Lipták, Milan Lörinc 2015)

An ultrasonic sensor components are clock – signal generator and a controller to excite the transducer, then a processor control circuitry is used for implementing and monitoring the process and output amplifier to handle the return signal.

Ultrasonic sensors can perform correctly and give accurate measurements in dirty environments. A limitation of this sensor is the detection of small targets in a large background, or as it mentioned in the previous paragraphs a material with high absorption ability of the ultrasonic wave.

A.1.9 Ultrasonic Sensors for Kick Detection

Experiments have been conducted for gas detection by ultrasonic sensors (Kutas 2016). The initial idea was to develop a 4D imagining device for monitoring wellbore quality (Kutas 2016) with two sets of ultrasonic sensors. The original set was in waterproof plastic cylindrical because of the requirement electronics for the sensors.

For the kick detection experiments, the sender and receiver transducers were installed opposite to each other for direct measurements of the travel time due to the limitations of the electronic design in rotational mode. Ultrasonic waves were transmitted from the sender transducer, travelling through the liquid phase (water or mud), and received by the receiver transducer (Figure 29).

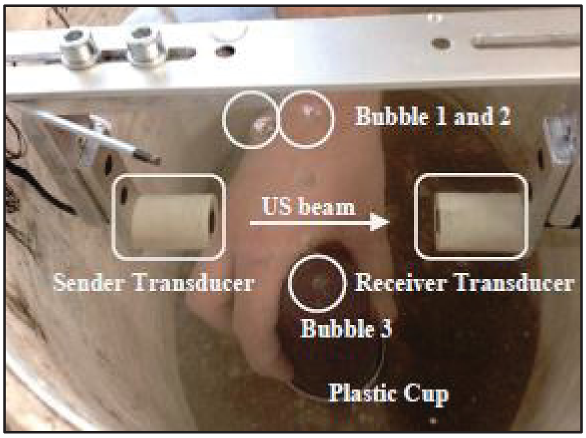


Figure 32: Placement of sender and receiver during the experiments (Kutas 2016)

The reliability of the ultrasonic sensors referring to kick detection were tested in the following experiments:

- Determine the closest distance between sender and receiver transducers, where results can be obtained,
- The distance that the most accurate measurements can be captured,
- The effects in different liquid regime (water and 1.3 SG bentonite mud),
- The changes in the travel time during an injection of a gas,
- Impact on the measurements on a different tool orientation.

The most important experiment was the detection of bubbles during static conditions. This experiments show if the ultrasonic sensors can detect the bubbles when they pass though the sender and the receiver transducer. As the previous figure has shown, a plastic cup was installed between the two transducers for producing a gas bubble through a small hole.

While the bubble was passing through the two transducers, the measured travel time indication was decreased to zero. In the following figure (Figure 30), during static conditions without gas bubbles, the travel time measurements are stable when babbles passed through the transducers.

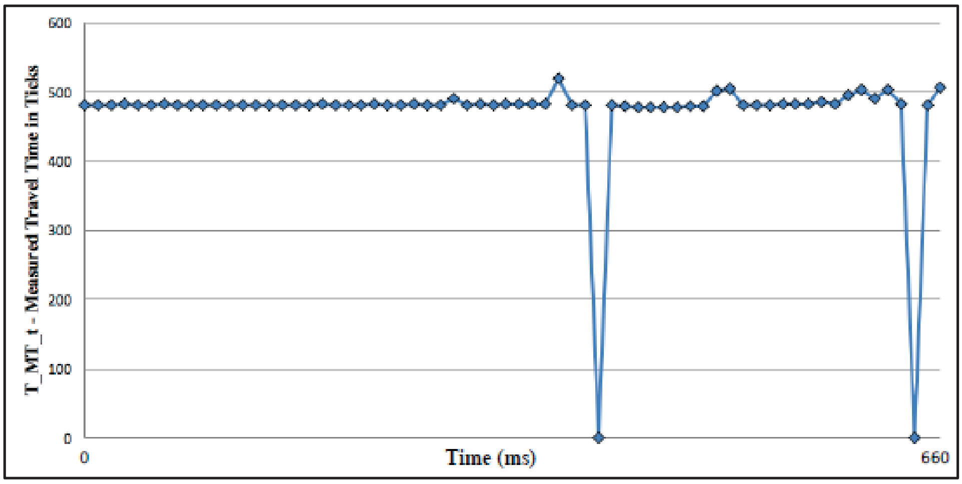


Figure 33: Impact on measurements travel time during gas injection (Kutas 2016)

The results show a promising idea for detection of a gas influx and reveal opportunities for the way for further research on Real Time Kick Detection by ultrasonic sensors.

Chapter 6 8 ½ in Artificial Well Testing Facility

This chapter refers to the part of the thesis, which is design and building of an initial artificial wellbore facility for the evaluation various sensors. The design of the facility needs to recreate wellbore size with drill string components etc. for testing the sensors in different conditions. The size of the well testing facility represents an 8 ½ in (215.9 mm) wellbore due to the fact that most of the kick events occur after intermediate section. Another reason was that the smaller the facility the lower the cost. The actual size of the facility is 8.66 in (220 mm) which was the closest available Plexiglas size for the 8 ½ in wellbore.

A.1 Design

For the initial design of the well testing facility, the free student version of PTC Creo Elements Parametric 6.0 (a featured CAD software) was used. PTC Creo is 3D design software which gives the possibility to an engineer to design a product with efficiency and accuracy a product, combining this range of capabilities with ease use.

Before designing the testing facility, the required diameter of the wellbore needs to be decided. Due to the fact most of the kicks are occurring during the intermediate section, for economic reasons the diameter of the wellbore was decided to be 8.66 in or 220 mm (outside diameter of Plexiglas is 9.05 in or 230 mm) and with a height of 19.68 in (500 mm). In the following Figure 34 the design of the artificial wellbore is described.

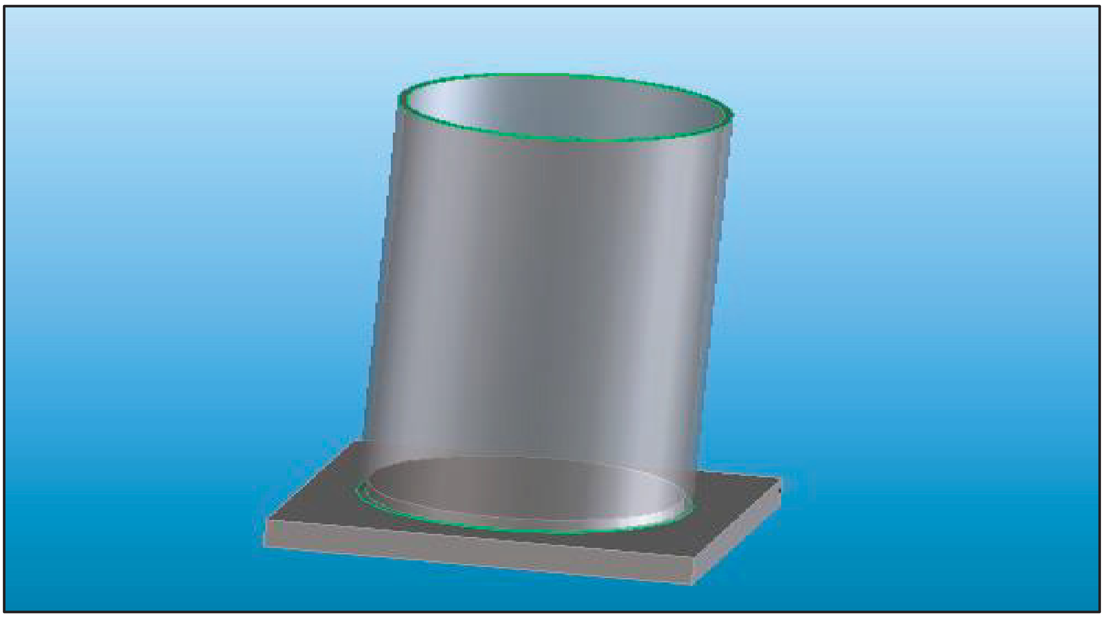


Figure 34: Artificial wellbore

In the base of the wellbore, an oil/gas diffuser is installed representing the environment of the borehole when an oil or gas kick enters into the wellbore (Figure 35). During the experiments a different shape of diffusers were used for practical reasons.

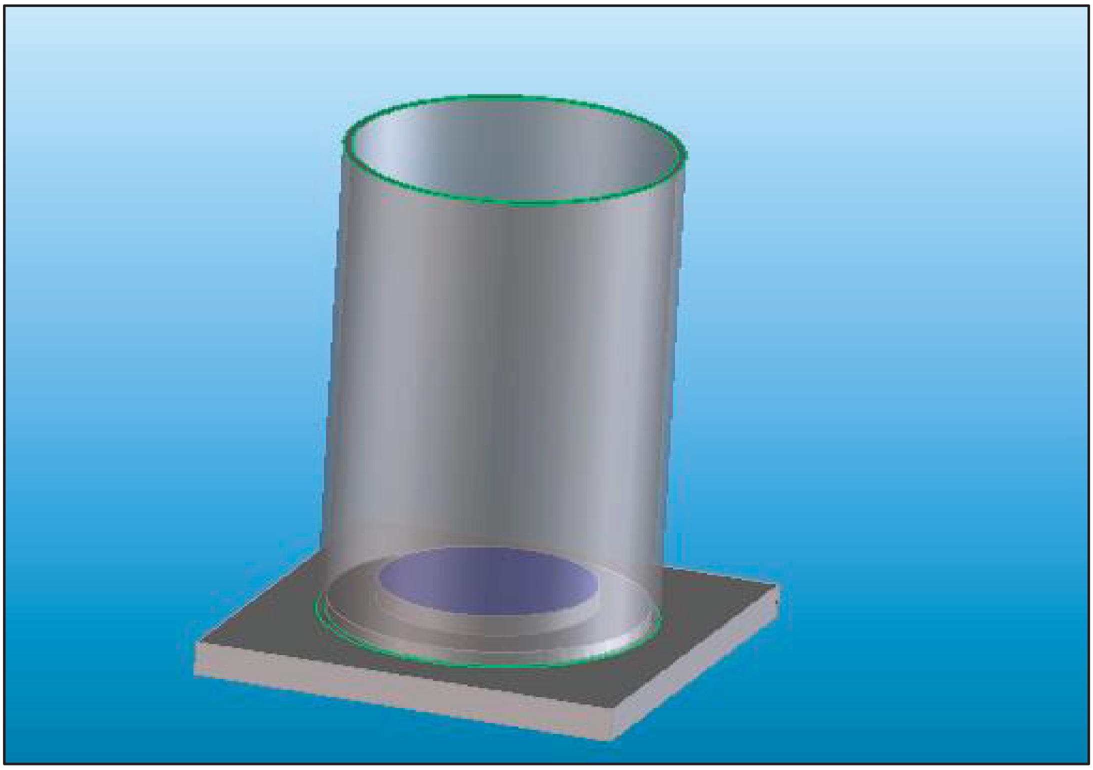


Figure 35: Gas/Oil diffuser

The 3D design of the drill bit was downloaded from a website (grabcad.com) and redesigned in Autodesk Inventor for changing the size of the initial file. The size of the drill bit is 0.15 in (4 mm) smaller than the wellbore 8.5 in (216 mm) in order to achieve easer installation of the drill string in the artificial wellbore (Figure 36) and also for the gas bubbles to travel easier towards the wellbore.

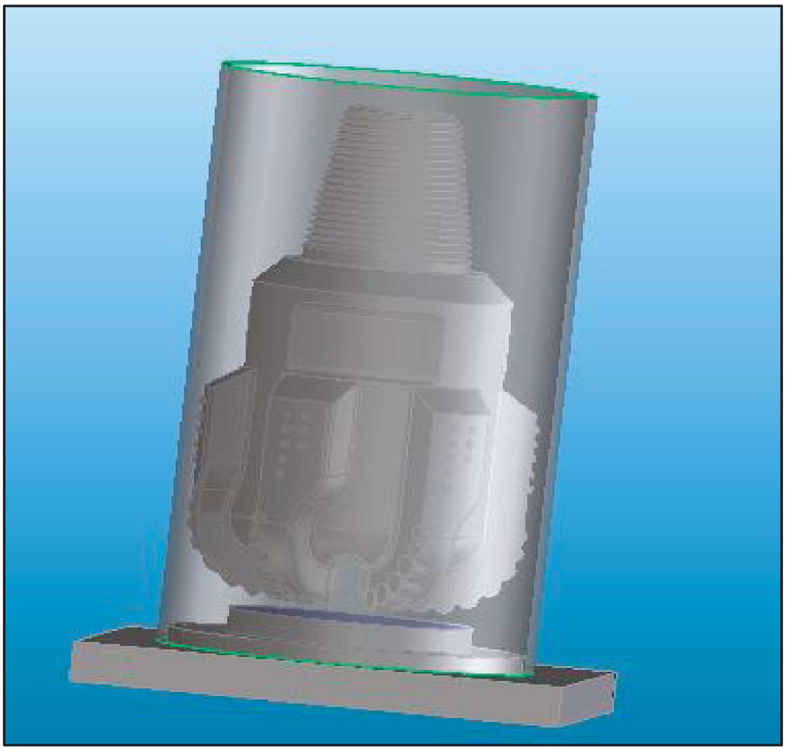


Figure 36: PDC bit

A significant part of the design was to combine the drill collars shape and size with a part that allows install and change any type of sensor without any issues. The outside diameter (OD) of the drill collar is 154 mm (6.06 in) and inside diameter (ID) of 152 mm, illustrating the diameter of the drill collars that are used in the industry for 220 mm wellbore size. The following figures (Figure 37, 38 and 39) illustrate the design of drill collars and the special design of the inner based combined with the artificial wellbore.

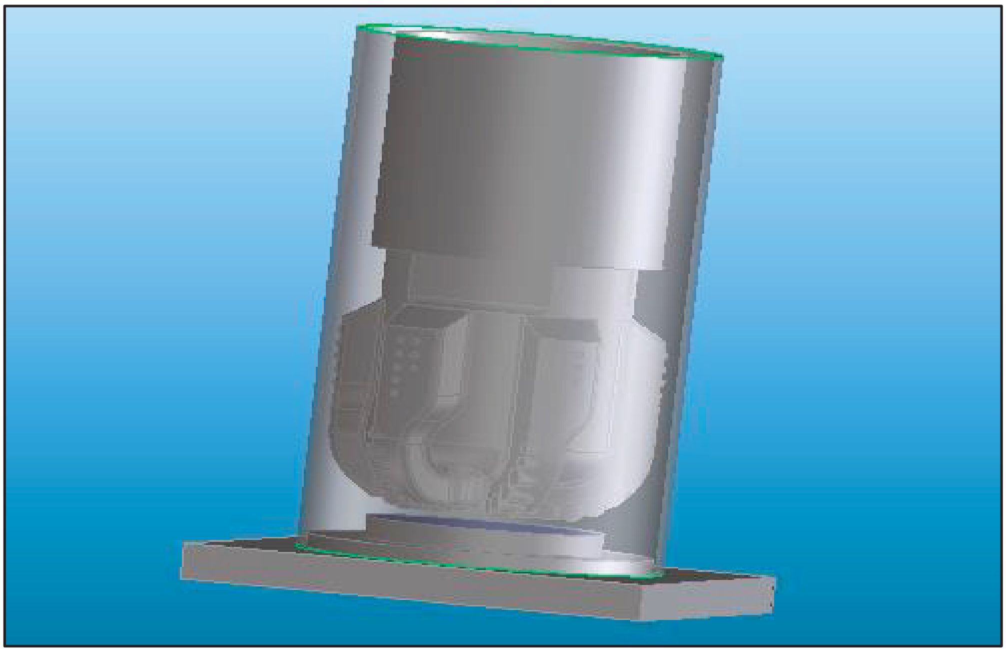


Figure 37: Drill collars

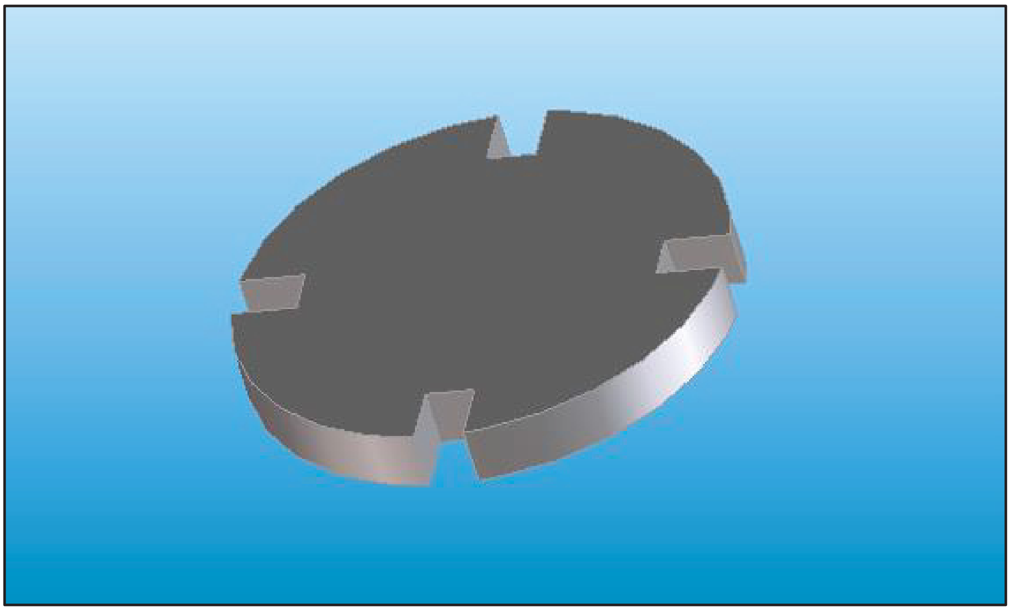


Figure 38: Special design for installation of sensors

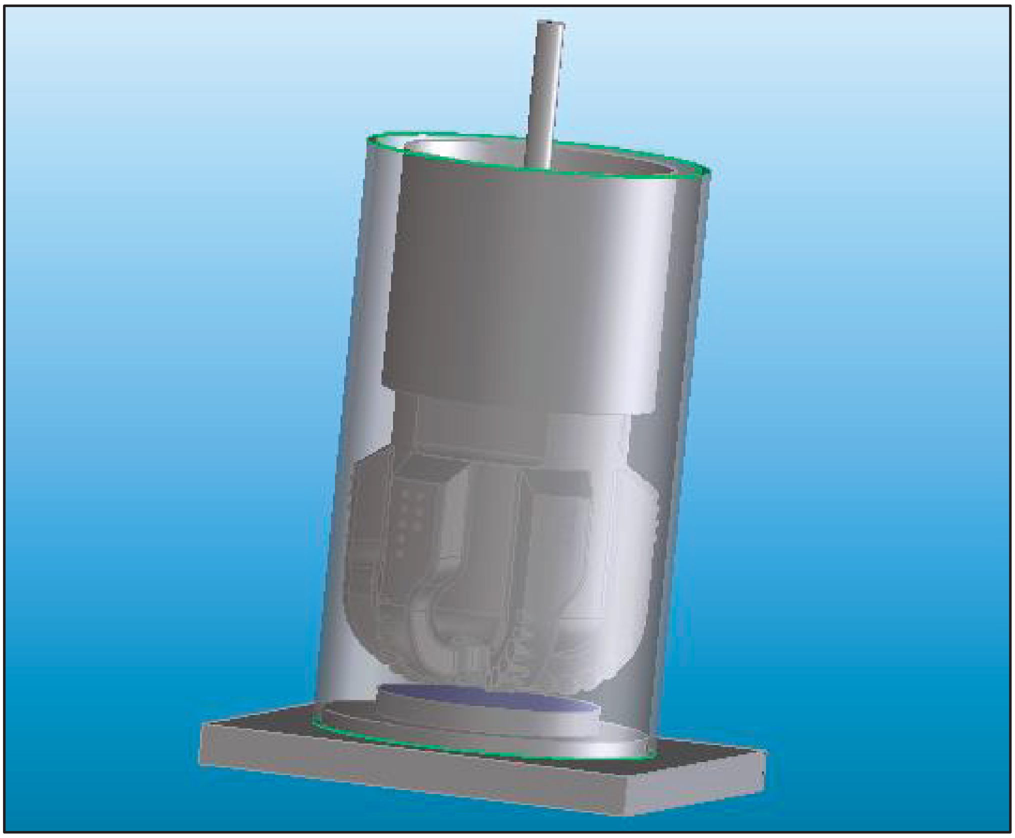


Figure 39: Final design of artificial well testing facility

A.2 Equipment

As first step to design the testing facility, a certain procedure needs to be obtained for the required equipment to represent the wellbore, the formation that the influx is entering from, and the drill string.

The design of the wellbore was needed to be transparent not only for better observation of the process during influx but also for reducing the reaction time if a leak or another problem occurred. For this reason, a Plexiglas was used for representing the wellbore. In the following Figure 40, the transparent design of the wellbore and the Plexiglas base. The Plexiglas base and wellbore were attached by a specific glue which is for better attachment between Plexiglas but in the same also for water proof to prevent a leak of liquid out of the wellbore.

Figure 40: Plexiglas design

Gas diffusers were used for representing the formation that the kick was entering from. For the gas experiments, gas diffusers were connected with an air pump by a plastic pipe for measuring a known volume of air (maximum pump rate of 100 liters per hour) until the sensors detected the changes. In the following figures (Figure 41) the circuit of those components can be observed.

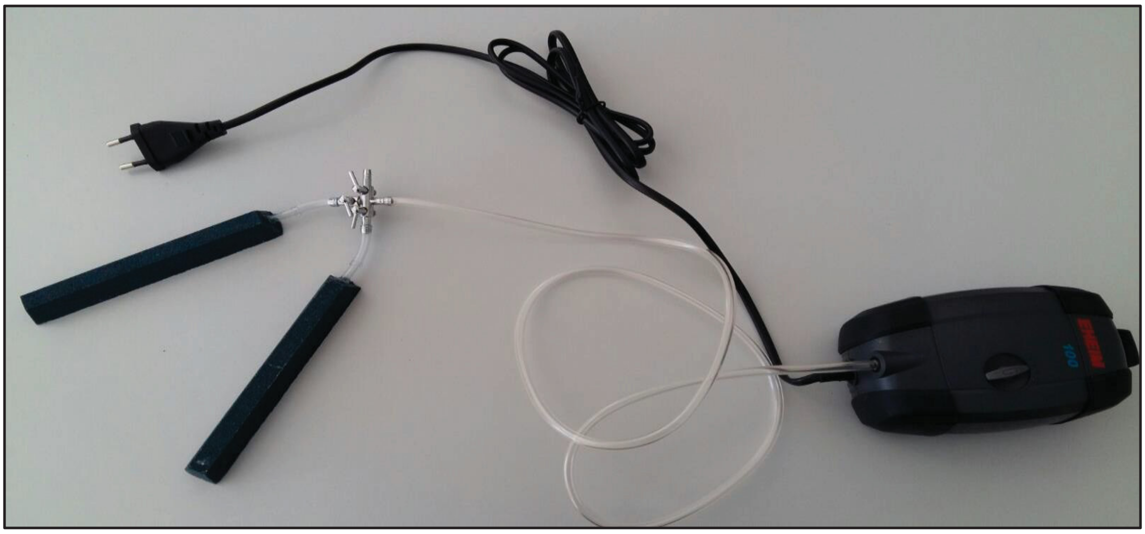


Figure 41: Air diffusers and air pump in circuit

An important part of the design was to recreate the drill string as effectively as possible. Starting from bottom to top, a Polycrystalline Diamond Compact (PDC) bit 8.5 in (216 mm) was 3D printed while influx started entering in the wellbore to travel upward as it would really happen. In the following Figure 42, the 3D printed design of the PDC bit as part of the drill string is given.

Figure 42: 3D printed PDC bit

The last part of the equipment was that of the drill string where the sensors would be placed and installed. This component also needed to represent the drill collars in the drill string and the same time to be able of the installation of various sensors. A plastic pipe (PVC) was used to represent the drill collars (6.06 in) which are described in the following figure (Figure 44). The PVC pipe was attached with the drill bit by opening few holes and screwing it to a PVC Cap (Figure 43).

Figure 43: PVC pipe (artificial drill string)

Figure 44: PVC Cap

Inside the PVC pipe, a special shape plastic base needs to be placed for the installation of sensors. In the inner part of the pipe, white plastic hangers were attached in the wall for making possible different heights inside the pipe but most importantly for maintaining and stabilizing the plastic base (Figure 45). The heights could be changed by grabbing the small rod and twisted to the right direction and lift it. Special hangers are installed to the top of the artificial wellbore, for keeping stable the artificial wellbore (Plexiglas) with the inside pipe (PVC).

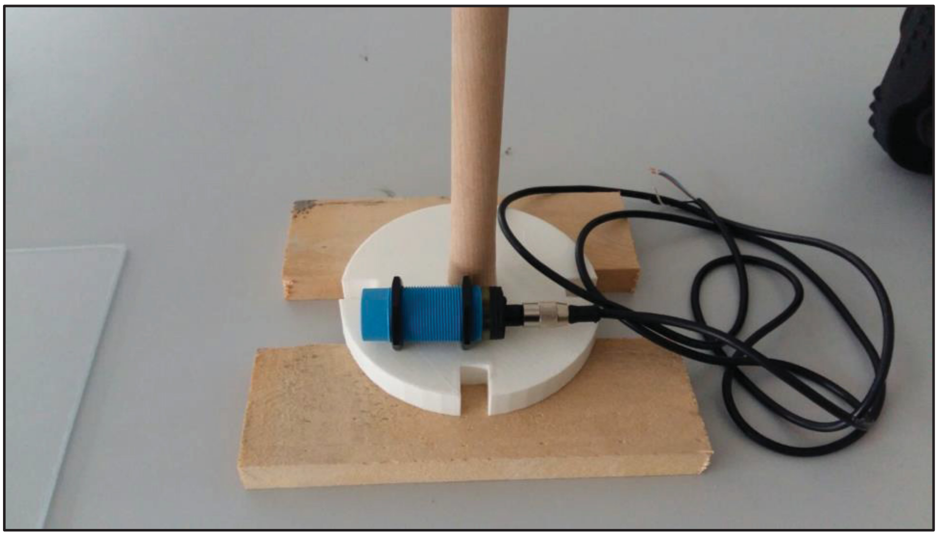


Figure 45: Special inside base for sensor installation

Chapter 7 Experiments

Numerous experiments have been contacted in the current research work. The experiments were contacted to fulfil the proposed research work:

- Evaluate the initial artificial wellbore facility if it is capable of recreating wellbore conditions and formation influx in the wellbore,
- Recreate gas and oil influx in various volumes,
- Test and observe if the capacitive sensors are capable of detect an influx.

A.1 Preparation Phase of Artificial Wellbore

In the initial part of the experiments, the artificial wellbore (capacity of 19 litres) was needed to test for withstanding 500 cm of water column (without drill string inside) with no leakage. That was an important scenario due to a water leakage from the artificial wellbore, which could cause a decrease on the water column and misinterpretation of the experiments results but also most important a water spill. A downward movement of the drill string in the wellbore would cause the proximity sensor to give an indication.

The wellbore was needed to be placed inside a plastic box with a capacity of 28.5 litres for controlling an undesirable leakage. In the following figure (Figure 46) the artificial wellbore with the plastic box is given.

Figure 46: Artificial wellbore with plastic box

As first step, the artificial wellbore was transferred empty in a location where the experiments could be conducted without any issues of installation and undesirable movement of the facility. Afterwards, the testing facility was filled up with water for 1 day for an observation of any leakage. Figure 47 illustrates the condition of the artificial wellbore after 24 hours with water. No leakage was observed.

Figure 47: Condition of artificial well testing facility after 24 hours

A.2 Digital Proximity Sensors

A.2.1 Gas Influx Experiment

After the successful installation and test of the artificial wellbore, the next step was the preparation and the installation of the gas diffusers. The circuit of the diffusers needed to be in that way to control the maximum capable bottomhole area, for better recreation of kick conditions and more efficient bubble transfer to the surface without remain on the nozzles of the drill bit. The following Figures 48, 49 illustrate the gas diffusers circuit in the bottomhole.

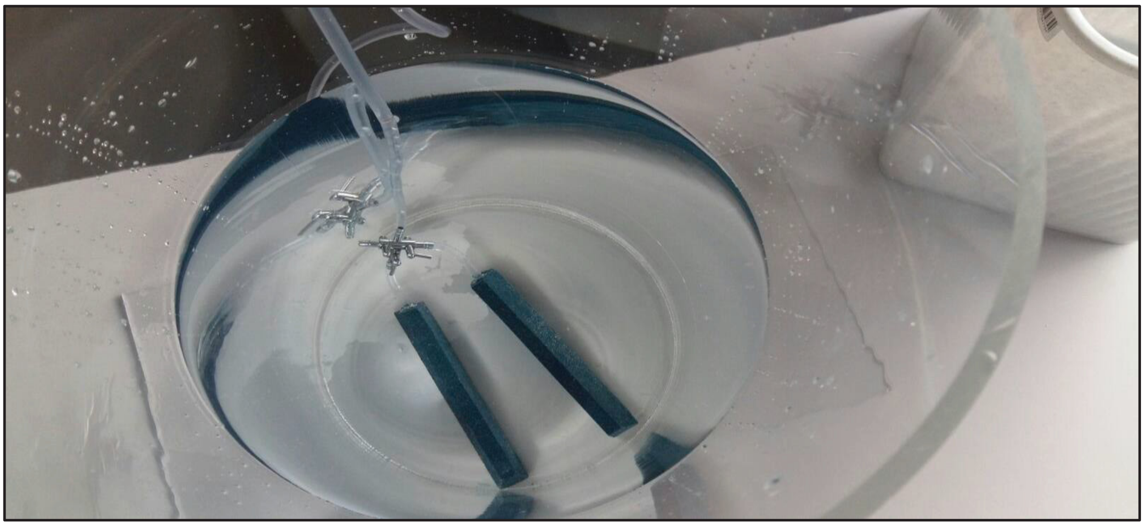


Figure 48: Picture from the top

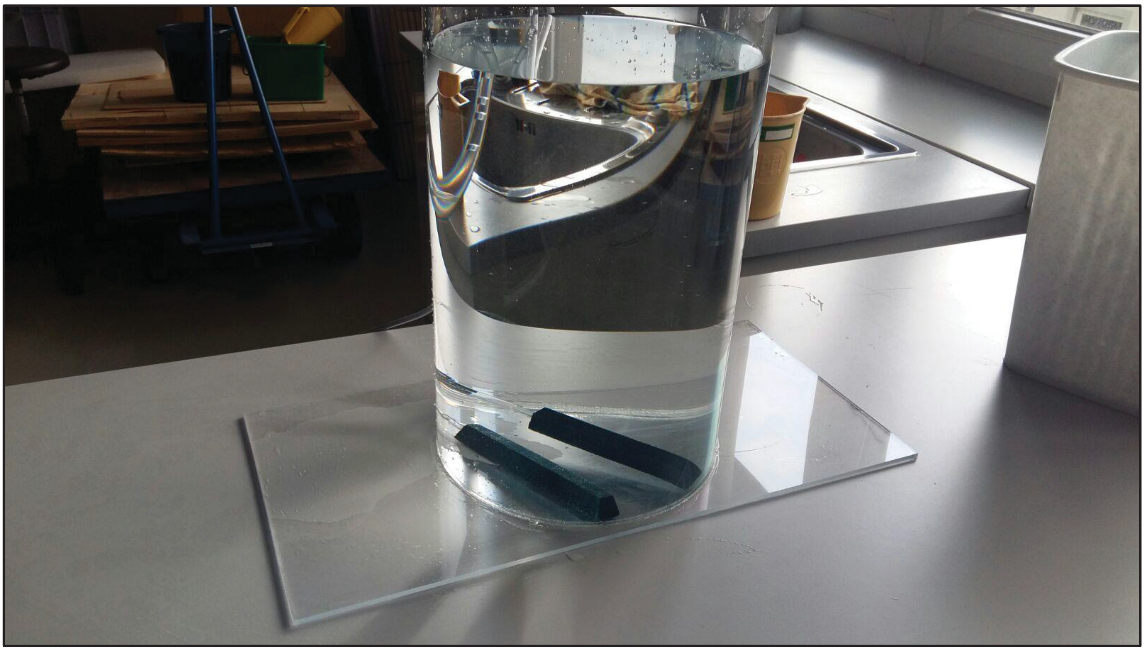


Figure 49: Bottomhole circuit of gas diffusers

Having obtained the installation of gas diffusers, the next step was the connection between the diffusers and the air pump. The air pump that was used is an EHEIM 100 model, meaning that has a maximum air supply of 100 liters per hour (26.4 gallons per hour). First part of the experiment was to evaluate the sensor after few seconds and after 1 min (1.66 liters). Figure 50 illustrates the time when the pump was turned on in maximum capacity for testing the capability of gas diffusers to produce bubbles.

Figure 50: Test of gas diffusers

The next step was the installation of the artificial drill string into the wellbore. For easier and better observation of the bubbles passing across the design, the drill string was painted in a black color. The following Figure 51 illustrates the drill string before and after the painting.

(A) (B)

Figure 51: (A) Drill string half painted, (B) New drill string design

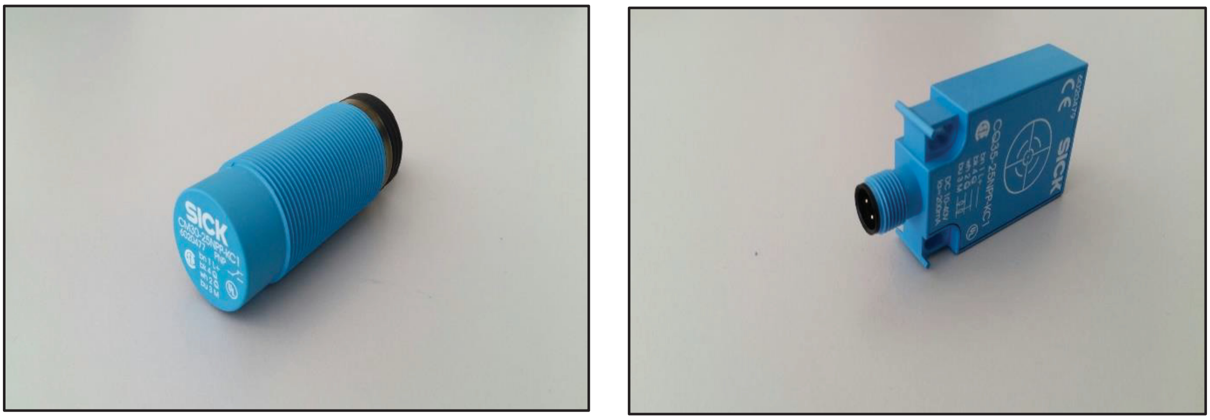
The most significant components of the experiments were the capacitors sensors that were used. The promising capacitor proximity sensor was a SICK CM30 – 25NPP – KC1 model with the following technical details (Sick 2017):

- Sensing range: 4 to 25 mm
- Switching frequency: 50 Hz
- Supply voltage: 10 to 40 V
- Continues current: 200 mA
- Ambient operating temperature: - 25 to 80 $^{\circ}$ C

The other capacitor proximity sensor was a SICK CQ35 – 25NPP – KC1 model with the following technical details (Sick 2017):

- Sensing range: 4 to 25 mm
- Switching frequency: 50 Hz
- Supply voltage: 10 to 40 V
- Continues current: 200 mA
- Ambient operating temperature: - 25 to 75 $^{\circ}$ C

The difference between those digital proximity sensors was the design. The design of the first sensor was cylindrical which makes it easier in the installation due to the cylindrical design of the drill string. Figure 52 shows the cylindrical sensor and while Figure 54 the flat capacitive proximity sensor.



(A) (B)

Figure 52: (A) Cylindrical capacitive sensor, (B) Flat capacitive sensor

For power supply, the sensors were connected with a PL303 power supply system. The system allows the increase or decrease of voltage and current. As mentioned in the previous paragraphs, the maximum allowance voltage and current limit is forbidden to exceed for technical reasons. In the following Figures 53, 54 the installation of the sensor in the special plastic base and the connection of the sensor with the power supply.

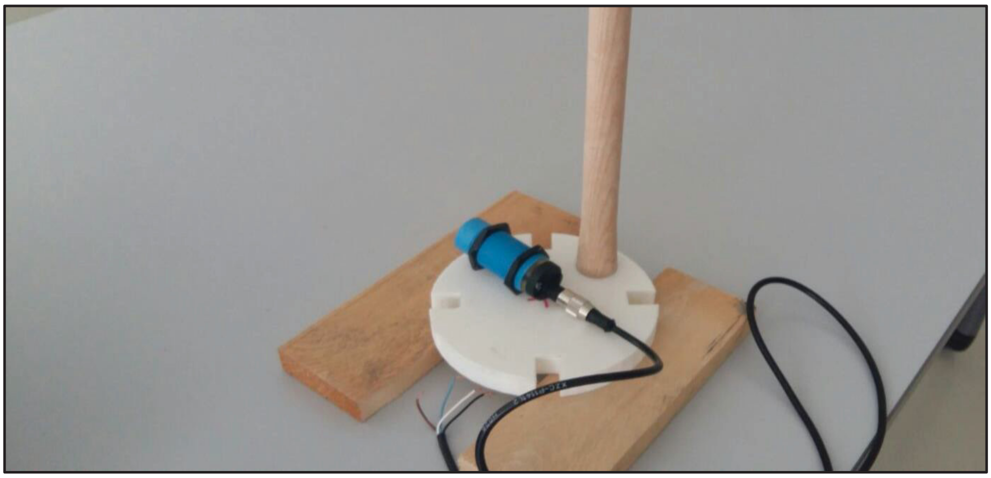


Figure 53: Sensor installation in the special base

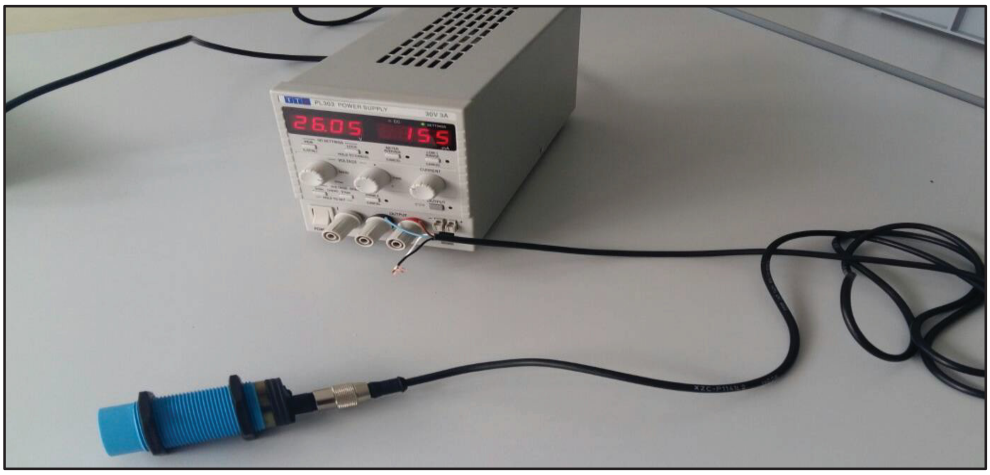
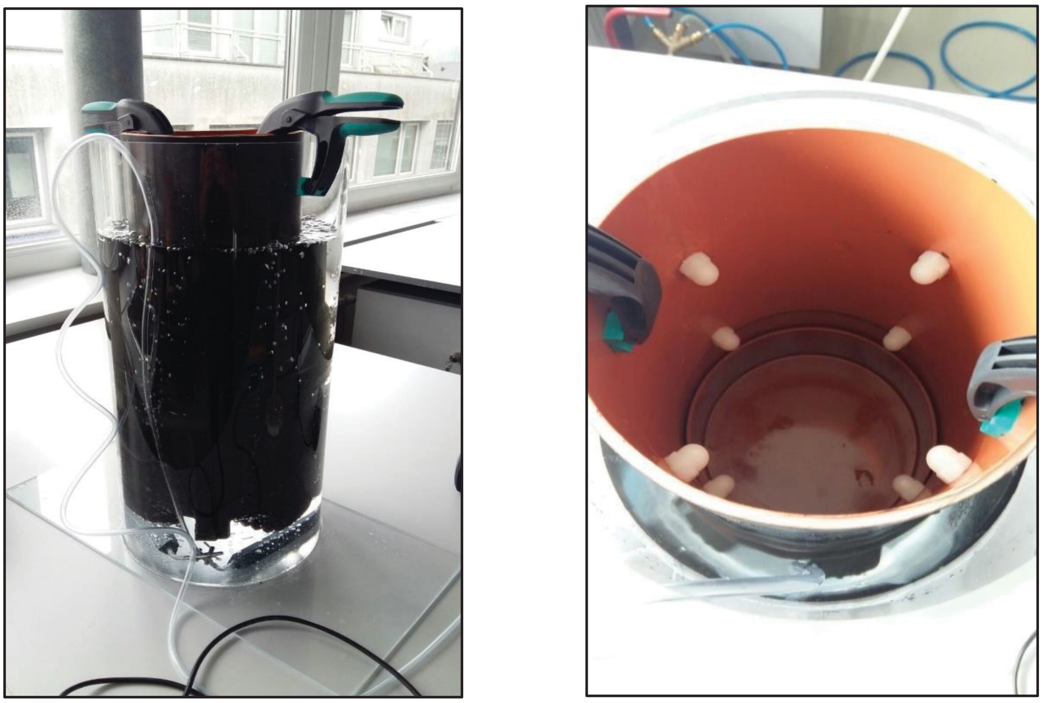


Figure 54: Sensor connected with the power supply unit

The next step was to place the artificial drill string into the wellbore. For this part, special hangers were used to hold the drill string stable during the experiments. Firstly the wellbore was filled up until the middle (250 mm) and then the drill string was placed to avoid any leakage out of the wellbore.

After the installation of the drill string in the wellbore, an observation was taken for testing the waterproof capabilities of the drill string. That was an important test to obtain for avoiding problems when sensors would be placed inside. Figure 55 illustrates the final design of the initial artificial well testing facility and the conditions of the inside part of the drill string.



(A) (B)

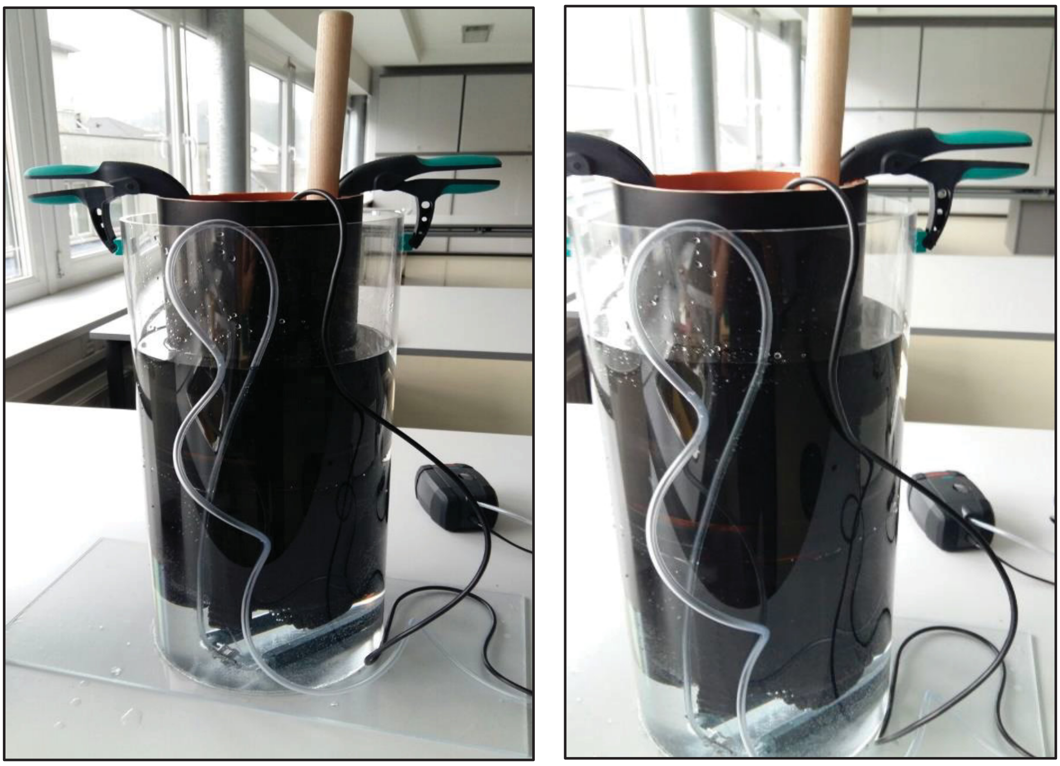
Figure 55: (A) Artificial wellbore facility, (B) Inside the artificial drill string

Since the facility proved that is waterproof, the sensor placed inside the artificial drill string with maximum safety. After the installation of the special plastic base with the sensor, the power supply turn on, and the following steps were followed:

- Increase the water level until the sensor light turns on (Figure 57 (A), 58 (A)),
- Reduce the sensitive of the sensor until light turns off,
- Increase the water level until it covers the sensor (Figure 57 (B), 58 (B)),
- Reduce the sensitive of the sensor until light turns off,
- Turn on the air pump to conduct measurements.

As a second backup system, for better observation of any changes during bubbles passing through the sensors, a multimeter was connected with the power supply system and concurrently with the sensor for more accurate measurements (Figure 56).

Figure 56: Workplace that experiments were conducted and the initial artificial wellbore facility connect with power supply and multimeter



(A) (B)

Figure 57: (A) Fluid level on phase one, (B) Fluid level on phase two

(A) (B)

Figure 58: (A) Sensor turned on during phase one, (B) Sensor turned on during phase two

In the following Figure 59, gas bubbles can be observed in the modular testing facility during gas influx enters the wellbore.

Figure 59: Conditions of artificial testing facility during gas influx entering the wellbore

Another capacitor type of sensor that was used is the CJ8 – 18GM – E2 (Figure 60) model with the following technical details:

- Sensing range: 8 mm
- Switching frequency: 100 Hz

- Supply voltage: 10 to 30 V
- Continues current: 300 mA
- Ambient operating temperature: - 30 to 70 ° C

Figure 60: CJ8 – 18GM – E2 capacitive sensor

The reason for testing this sensor was to observe and estimate the minimum operating range (minimum distance that can detect) of capacitive sensors which are capable of detecting gas or oil in the water. As next step, the sensor was attached with a tape in the special base before running it into the artificial drill string which is given in the following Figure 61.

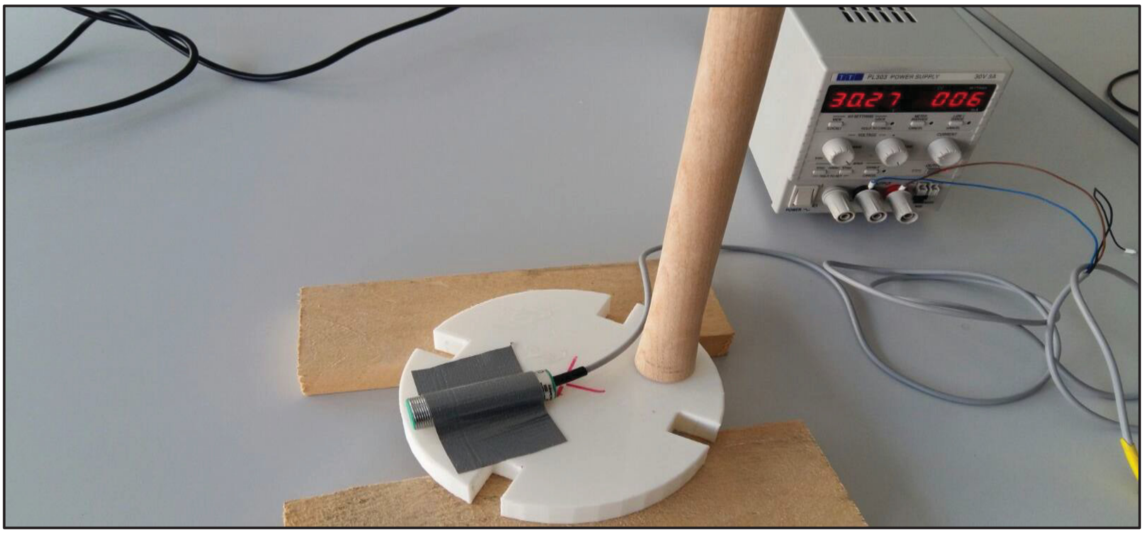


Figure 61: Sensor installation in the special base

After the installation of the special plastic base with the sensor, the power supply turn on, and the following steps were followed:

- Increase the water level until the sensor light turns on,
- Reduce the sensitive of the sensor until light turns off,
- Increase the water level until it covers the sensor,
- Reduce the sensitive of the sensor until light turns off,
- Turn on the air pump to conduct measurements (Figure 62).

Figure 62: CJ8 – 18GM – E2 capacitive sensor during gas influx experiment

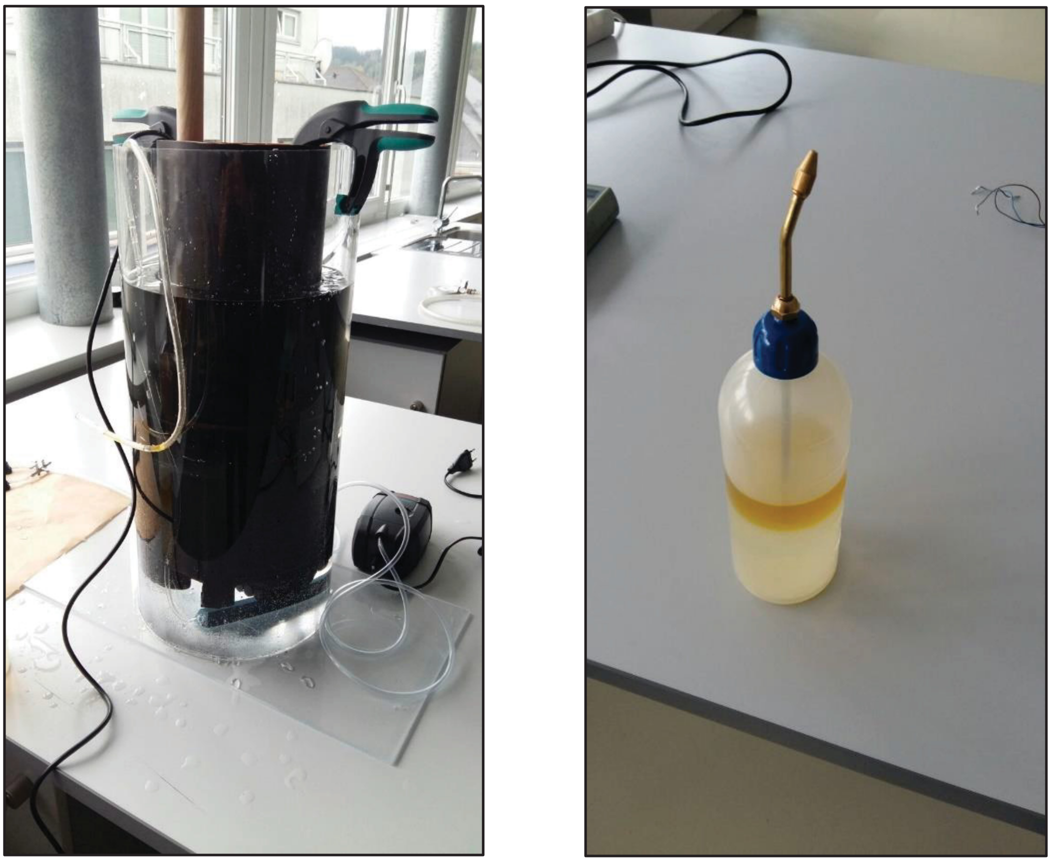
A.2.2 Oil Influx Experiment

For pumping oil in the wellbore, the experiments conducted on two ways:

- By a circuit of a gas diffuser,
- By attaching a plastic cable in the wellbore in front of the sensor.

For the first step, a single gas diffuser was used. The diffuser was installed in the middle of the wellbore and then the drill string was run in. After a plastic cable was connected with the following bottle (Figure 63 (B)) to start pumping oil into the wellbore. The final set up of the initial artificial testing facility before proceeds to the oil influx experiments is illustrating in the following Figure 63 (A).

An olive oil was used for representing crude oil due to the fact of disposal reasons. Olive oil has similar density with crude oil in 20 ^{o}C (800 - 920 kg/m^3).



(A) (B)

Figure 63: (A) A single gas diffuser placed in the centre of the wellbore, (B) Plastic bottle for the use of pumping oil in the wellbore

For the oil influx experiments, the procedure was the same as the gas experiment with the only difference that the air pump wasn't part of the operation. Having placed everything in order, the following steps were followed:

- Increase the water level until the sensor light turns on,
- Reduce the sensitive of the sensor until light turns off,
- Increase the water level until it covers the sensor,
- Reduce the sensitive of the sensor until light turns off,
- Start pumping oil in the wellbore.

Having obtained the procedure, a second experiment were conducted placing the plastic cable in front of the sensor for extra measurements. A tape attached the plastic cable in the artificial wellbore (Plexiglas). In the following Figure 64, the design for this experiment is given.

Figure 64: Artificial testing facility before oil experiments

Chapter 8 Results

A.1 Gas Influx Results

A.1.1 SICK CM30 – 25NPP – KC1 Capacitive Sensor

The first proximity capacitor sensor that was tested was the SICK CM30 – 25NPP – KC1 model. Due to the fact that the wellbore has a cylindrical design, the sensor could be placed in a way to obtain the optimum minimum distance between the sensor and the artificial drill string as was illustrating in Figures 62 and 63.

During gas influx experiment, due to the low dielectric constant of gas, neither capacitive sensors could detect changes in the capacitance by turned on the LED light (Figure 65), nor could the multimeter detect changes in voltage due to changes in the capacitance. Following Figure 66 illustrates the voltages of the capacitor before and during gas entering the artificial wellbore.

Figure 65: Sensor response during gas influx

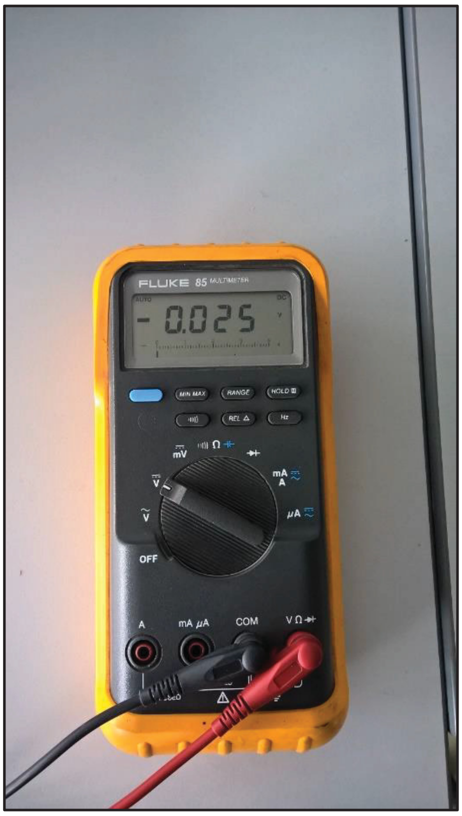


Figure 66: Multimeter values before and after gas entering the wellbore

A.1.2 CJ8 – 18GM – E2 Capacitive Sensor

As was mentioned in the previous Chapter (Chapter 7), the reason for testing the CJ8 – 18GM – E2 capacitive sensor was to estimate the minimum operating range that a capacitive sensor can detect gas influx. The following Figure 67 and 68 illustrate that the sensor respond during the gas experiment and the applied current before and during the gas influx experiments.

Figure 67: Sensor response during gas influx

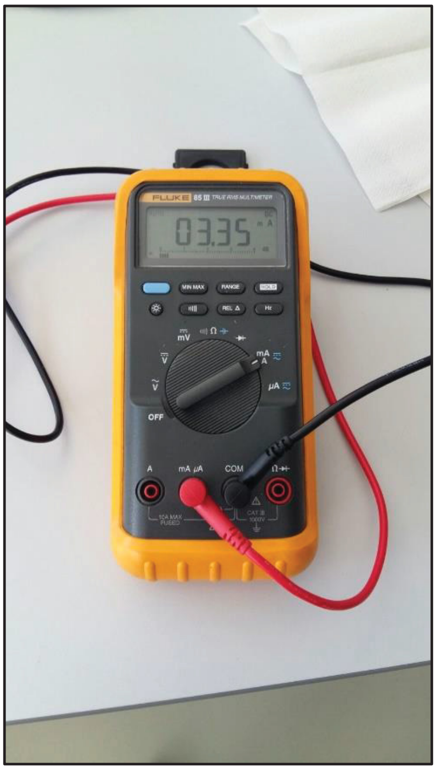


Figure 68: Initial and final current after the gas experiments

The reason that the gas influx didn't have any impact on the capacitance of the sensor was operating distance of the capacitor. Due to the low sensing range of the sensor, which is 8 mm, the adjustment of the sensitivity, and also the low dielectric constant of gas, the sensor was not able to detect the gas.

A.2 Oil Influx Results

A.2.1 SICK CM30 – 25NPP – KC1 Capacitive Sensor

Having conducted the gas influx experiments next step was to prepare the artificial wellbore for oil influx. As was mentioned in the previous Chapter, the experiment of oil influx was conducted by two different techniques. For this experiment, the initial voltage value on the mulitimeter was near the maximum applied voltage.

During the experiment with gas diffuser, due to the small holes of the diffuser, the oil couldn't get through the holes as a result the experiment to be unsuccessful.

As second experiment, the plastic cable was attached in the wellbore in front of the sensor. Due to that, the maximum operating range of the capacitive sensor was 25 mm, after the reduction of the sensitivity to adjust the sensor in the water level and to the PVC pipe, the operating range reduced significantly.

The plastic cable was in 40 mm distance from the sensor, making the detection of the olive oil unsuccessful. As second step, the plastic cable was attached in the artificial drill string 2 mm from the sensor. The following Figure 69 illustrates the design of the facility for the oil experiment.

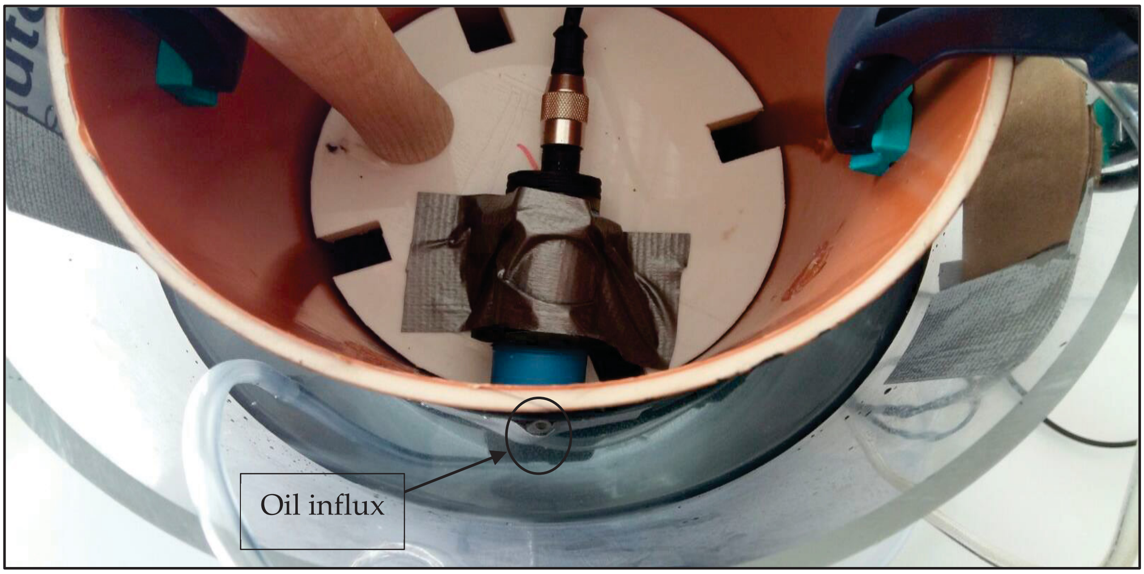


Figure 69: Position of plastic cable during oil influx experiment

The following Figure 70 illustrates that the initial and final voltage of the capacitive sensor during oil influx experiment is the same.

Figure 70: Initial and final voltage after the olive oil experiment

Again, the sensor was not capable to detect the small changes of capacitance due to low dielectric constant of olive oil.

A.2.2 CJ8 – 18GM – E2 Capacitive Proximity Sensor

Having conducted the gas influx experiments next step was to prepare the artificial wellbore for oil influx. Again, the process was similar with the previous capacitive sensor, with the difference that a gas diffuser wasn't tested due to the results of the previous experiment. The following Figure 71 illustrates the design of the facility for the oil experiment.

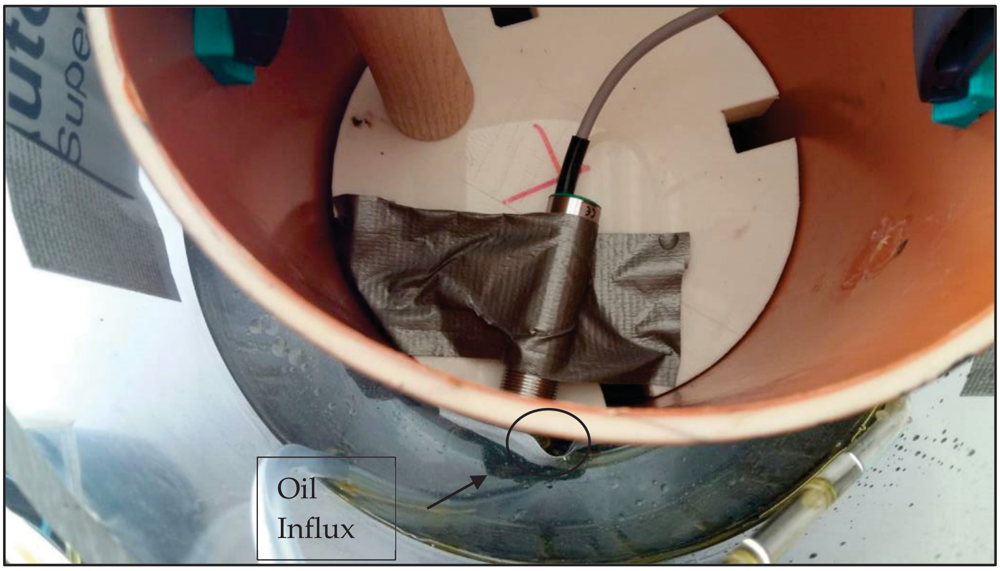


Figure 71: Position of plastic cable during oil influx experiment

Due to the low sensing range of the sensor, which is 8 mm, the adjustment of the sensitivity, and also the low dielectric constant of gas, the sensor was not capable to detect the oil. The following Figure 72 shows that the initial and final current of the capacitive sensor during oil influx experiment is the same

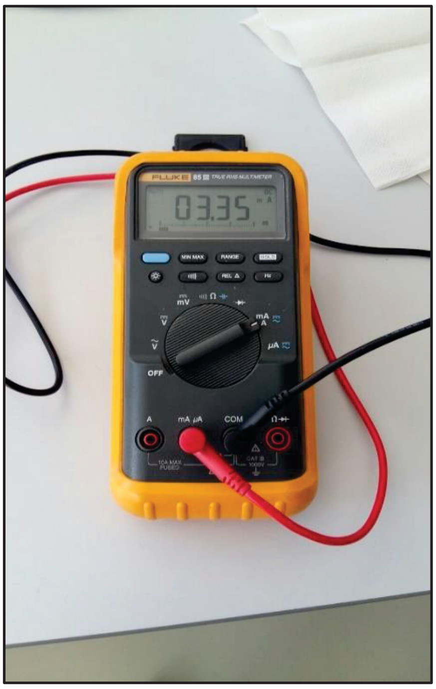


Figure 72: Initial and final current after the olive oil experiment

A.3 SICK CQ35 – 25NPP – KC1 Capacitive Sensor

The next sensor was the SICK CQ35 – 25NPP – KC1 model which has similar technical capabilities with the previous sensor. Unfortunately, due to the shape of the sensor and the internal size of the artificial drill string, the experiments couldn't be conducted to a way to be successful (Figure 73).

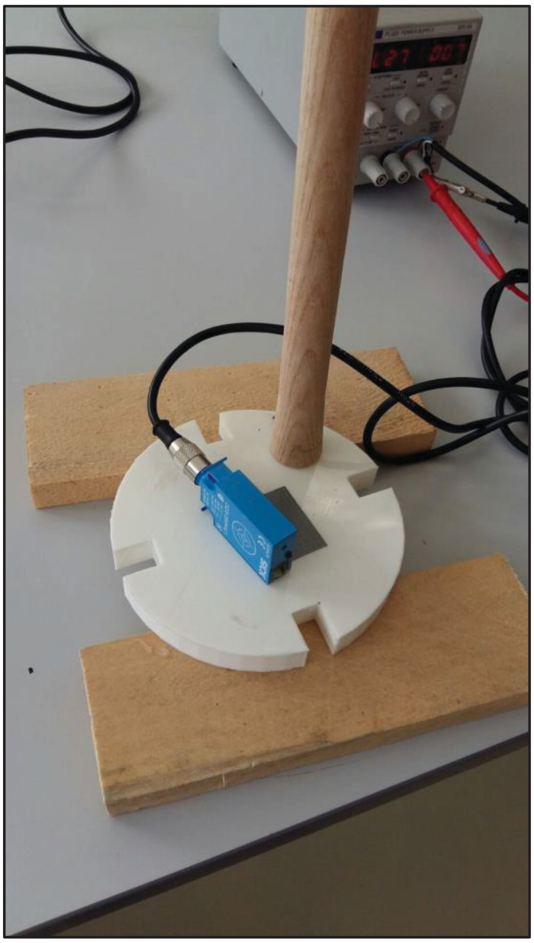


Figure 73: Insufficient sensor position for influx experiments

Chapter 9 Perspectives and Recommendations for Further Research

Based on the acquired results in Chapter 8, it can be stared that digital capacitive sensors are not capable of detecting gas or oil influx; furthermore, a way ahead research with that kind of sensor is not recommended.

It can be stated that with the currently results and the literature review that was obtained for the thesis, recommendations are given as follows:

- Analogue capacitive sensors might be able to detect the small changes of capacitance during gas and oil influx with the assistance of a software and multimeter,
- Conductivity sensors are capable to detect and determine various contaminations of impurities in water,
- A promising method of detection of influx could be real time measurements of downhole flow rates could be obtained by measuring the upward speed of cuttings with ultrasonic sensor during circulation,
- The Initial Artificial Well Testing Facility could be installed in a Mini Rig for testing sensors in different flow rates and rotation mode for detection of gas or oil influx,
- A bigger size of testing facility is recommended for easier installation of the sensors,
- Determination of the effectiveness of the sensors on detecting bubbles in case of high temperatures, pressures and also different drilling fluids.

Chapter 10 Conclusion

The initial artificial well testing facility successfully reached the objective of easy installation and adjustment of sensors without any issues that might affect the performance of the sensors. Also the facility successfully simulated conventional wellbore environment with an artificial drill string which was represented the exact sizes of an 8 ½ in wellbore and to produce a gas or oil influx of known volumes to evaluate sensors for kick detection.

The initial artificial well testing facility provides many advantages. The design of the facility allows easy installation and evaluation of various types of sensors i.e. capacitive sensors, ultrasonic sensors, conductive sensors etc. The inside special base can provide an installation of transmitter and receiver for measure and estimate downhole flow rate, which is the most promising way for Real Time Kick Detection.

Unfortunately, the experiments with digital capacitive sensors haven't showed the anticipated results of detecting gas or oil influx due to the low dielectric constant of gas and olive oil but also because of the digital signal of the sensor. The digital signal of the sensors didn't allow the observation of small changes in the capacitance during the experiments. The operating range was not an issue since the sensors could detect other objects with higher dielectric constant. Even though the investigated sensors are not capable of detecting gas or oil influx, the main objective of the thesis, which was to design, build and test the facility has been accomplished.

Real Time Kick Detection technology has come to stay. In the near future, further application of sensor technology as well as wired drill pipe will yield a revolution within the oil and gas industry, which is highly important to prevent well control incidents and to reduce non-productive time. As was described in Chapter 2 and 3, still there is a room of improvement in the field of kick detection, especially now where wired drill pipes are including during drilling operations.

As a further step of research for this field the performance of the sensors in downhole conditions should be evaluated. The biggest challenge for sensor evaluation is the rotation of the drill string. During rotation, the sensor signal is spread in the wellbore making the detection of gas or oil more challenging. The artificial well testing facility needs to be installed on a Mini Rig, where the drill string of the Mini Rig will be attached with the artificial drill string of the facility in a way to provide rotation mode but also a circulation system. The circulation system will allow to test the sensors in different drilling fluids, fluid properties and during circulation.

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Acronyms

RKD	Real Time Kick Detection
EKD	Early Kick Detection
FE	Finite Element
ECD	Equivalent Circulation Density
LOT	Leak-Off Test
XLOT	Extended Leak-Off Test
PVT	Pit Volume Totalizer
BOP	Blow Out Preventer
HCR	Hydraulic Choke Remote Valve
MWD	Measurement While Drilling
LWD	Logging While Drilling
BHA	Bottomhole Assembly
OD	Outside Diameter
ID	Inside Diameter

Symbols

Δp	Differential Pressure	[psi]
$Pmud$	Drilling Fluid Pressure	[psi]
Pff	Formation Fluid Pressure	[psi]
Mw	Current Mud Weight	[ppg]
$Plosses$	Frictional Pressure Losses	[psi]
D	Depth	[ft]
R	Rate of Penetration	[ft/h]
N	Rotation per Minute	[RPM]
W	Weight on Bit	[lb]
D	Bit Diameter	[in]
Pn	Mud Weight Used	[ppg]
HZ	Herz	[HZ]
τ	Time Constant	[s]
R	Resistor Contact Line	[Ohms]
C	Capacitance	[Farad]
Q	Magnitude of Charge in every Plate	[Coulomb]
V	Applied Voltage	[Volts]
εr	Dielectric Constant	
$\varepsilon 0$	Permittivity of Free Space	[F/m]
A	Area of each Plate	[m^2]
d	Distance between the two Plates	[m]
v	Wave Velocity	[m/s]
f	Frequency	[Hz]
λ	Wavelength	[m]
Z	Acoustic Impedance	[Pa x s/m^3]
ρ	Density of the Medium	[Kg/m^3]

List of Figures

List of Tables