THE STUDY OF FORMATION DAMAGE BY CUSTOM FABRICATED RIG

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ABSTRACT

This paper introduces a rig that enables the formation damage studies to be conducted at near downhole condition in the laboratory. The rig was equipped with many special features such as shuttle sleeve, multi angle rotating rig, and sensing devices. A drill pipe was installed in the testing unit in order to simulate the drilling operation. Thus, the introduction and integration of these features enable various forms of formation damage studies to be carried out under static and dynamic conditions. The custom fabricated rig has the potential to assist oil companies in their formation damage studies. It also provides an opportunity to the service companies to evaluate the performance their mud additives or based oil without risking the wells.

1.0 INTRODUCTION

Since the advent of the energy crisis and Arab Embargo, many studies on formation damage had been carried out with certain limitations to their experimental equipments. In the petroleum industry, one of the important objectives of oil companies is to obtain optimum oil recovery from reservoir. One of the constraints in achieving the objective is formation damage. Laboratory and field studies indicate that almost every operation in the field such as drilling, completion, and production is a potential source of damage to well productivity.[1] Formation damage, which is also known as wellbore damage, can cause major problems to oil production and should be given special attention by the reservoir and drilling engineers.

Formation damage can be defined as the impairments to the productivity of hydrocarbon bearing rock formation caused by the combination of mechanical/physical and chemical activities required to drill, complete or stimulate a well.[2] The physical mechanisms include pore deformation or collapse, drill string eccentricity, pipe sticking etc., while chemical mechanisms include emulsion blockage, wellbore sloughing etc.

In 1932, Gill[3] studied the formation damage caused by the rotary drilling mud without using any advance devices in laboratory studied. He found that particles and fluid invasion were the main contributors to the formation damage. Gleen *et al.*[4] and Krueger,[5] in 1954, investigated the effect of solid particles invasion on well productivity by using equipment that only comprised flow line and core holder without any sensing devices and computer software for monitoring and registering experimental data. This experimental work was conducted under low pressure and temperature conditions by using water-based mud and did not consider the field application during drilling process.

In 1984, Thomas *et al.*[6] conducted the formation damage studies caused by the oil-based mud and coring fluid at static condition. Again there was no sensing device was considered in the study. Azizi and Rahman[7] started to introduce advanced components such as pressure sensors fitted at the core holder to detect the pressure drop along the core for investigating the depth of particles invasion.

In 1985, Black *et al.*[8] carried out a research study on the effect of mud filtration on permeable sandstones, which involved a drill bit that drilled through a sandstones block. This equipment was not equipped with any pressure sensor along the core, thus it prevented the measurement of the depth of filtration and the experiment was conducted under low pressure and temperature conditions. In 1988, Mckinney and Azar[9] investigated the formation damage at elevated temperature and pressure due to the mud filtrate invasion. From this study, they started to install 3 pressure transducers along the core holder without shuttle sleeve to prevent the mud invasion before achieving the predetermined parameters, but no drill string was installed in the equipment set-up to simulate the actual drilling activities. Di Jiao and Sharma,[10] in 1992, had developed an experimental rig that was quite similar to Mckinney. The difference between them was more transducers were fitted along the core at an interval of 2 inches. From the field and laboratory studies, the invasion of the drilling mud particles was found to be significant at the first 2 inches of the core sample. Therefore, the larger interval (2 inches) of installing the transducer along the core holder was a disadvantage to the equipment, as it could not record the pressure drop profile along the core efficiently and precisely.

A rig was designed and constructed at the Heavy-duty Laboratory of FKKKSA in UTM, Skudai to conduct the formation damage study. Its design has improved most of the weaknesses encountered by previous studies, such as the shuttle sleeve to prevent drilling mud invasion before achieving the predetermined study parameters, more transducers were used with and the interval of each transducer was reduced to 1 inch instead of 2 inches in order to register pressure drop profile more accurately and precisely, a software system was used to record and monitor the flow rate, temperature and pressure in the system, and multi angles rig holder to allow the orientation of the rig at preset angle.

2.0 RIG DESIGN AND CONSTRUCTION

The major components involved in this equipment set-up is shown in Figure 1. The dynamic filtration cell which is capable of conducting the formation damage study in the laboratory under downhole conditions, consists of:

(a) mud tank,
(b) circulating/piping system,
(c) testing unit,
(d) multi angles rotating rig holder, and
(e) sensing devices and software system.

2.1 MUD TANK

The purpose of the mud tank is for mixing and storing of drilling fluid. The tank was fabricated using stainless steel plate grade 304 with an internal heater attached to it. The diameter and length of the tank are 660 cm and 1150 cm, respectively, which permit the preparation of 200 liters of drilling fluid at one time. An agitator equipped with a 30 inches long stellar shaft with a 10 inches propeller blade and also two 5 inches propeller blades attached at the top and bottom of the shaft, respectively, is used to improve the mixing process of drilling fluid.

The tank body consists of two layers. A heater was fitted at the internal layer of the tank to preheat the drilling fluid prior to conducting the experiment. The bottom part of the tank is slightly round in shape and has five baffle plates welded on the wall of the tank body. The purpose of having slightly cylindrical shape at the bottom and baffle plates is to minimize turbulent flow of the returning drilling fluid which could generate bubles into the system and consequently pump cavitation may occurs. A 3 inches ball valve attached at the bottom of the tank is used to control the mud flowing out from the tank towards the flow line.

2.2 PIPING SYSTEM

The piping system is made up of stainless steel grade 304 and the total length is about 50 feet. It consists of a main flow line and secondary flow line. The diameter of the main flow line is 3 inches, while the secondary flow line is 1 inch. Six unit of C-hook typed brackets were fitted at the bottom of the main flow line to prevent vibration from occurring during experiment due to the high flow rate and pressure generated by the centrifugal pump. The main and secondary flow lines were welded using the Tungsten Ignition Gas (TIG) technique to prevent leakage problem as it is a proven method to join stainless steel connections and can withstand high flowing pressure and temperature.

Two S-pattern and ball valves were attached along the flow lines. S-pattern valve or known as globe valve commercially is used to regulate flow rate in main the flow line, while the ball valve is utilized to open or close the fluid circulation in the flow lines. A centrifugal pump with 40 hp was installed in the main flow line in order to conduct the experiment under dynamic conditions. A secondary pump was attached to the secondary flow line to fill-up the main flow line in order to prevent air lock in the main flow line before the main pump is switched on.

2.3 TESTING UNIT

This unit is the heart of the rig, where the test sample is located. It consists of five main parts; top bore assembly, center bore, core holders, bottom bore assembly, and drill pipe. The top bore assembly, bottom bore assembly, and drill pipe were fabricated using stainless steel grade 304, whereas the stainless steel grade 316 was used to fabricate the center bore and core holders.

The top bore assembly (TBA) consists of inlet and outlet flow lines, flexible hose flanging, slip plate housing, slip plate, bronze bushing, drill pipe housing, thrust bearing, thrust bearing retaining ring, bore pipe flange, and bore pipe. Flanges were welded at the end of the inlet and outlet flow lines of the top bore pipe assembly to enable a flexible hose to be connected to the TBA by using stainless steel screws and nuts of size 30 mm. The drill pipe was inserted into the drill pipe housing where a bronze bushing was attached. Bronze bushing acts as a holder to ensure smooth rotation of the drill pipe. A thrush bearing was fitted at the outer perimeter of drill pipe to reduce the torque for rotating the drill pipe. A thrush-bearing retainer ring is fitted at the top end of the pipe to prevent the thrust bearing from jumping out of its position. A slip plate was attached to the drill pipe housing to allow the movement of the drill pipe, which initiates the eccentricity of drill string during the experiment. A flange was welded at the bottom of the slip plate. The slip plate was connected to the bore pipe via the flange towards the center body/center assembly.

The top and bottom sections of the center bore were equipped with flanges. The center bore was connected to the TBA by a set of screws. The center bore assembly (CBA) has four openings and it is the most important part where the core holders used for accommodating the test sample were attached. The major components attached to the CBA are shuttle sleeve, shuttle sleeve actuator gear, gear housing, teflon seating, core holder opening, bore pipe flange, fastening stud screw for core holders, and lower bore pipe. Four predetermined size plates equipped with eight stud screws were welded at the four opening of the center bore. This would allow the core holders to be connected to the center bore. The opening of the center bore can be opened or closed by activating the shuttle sleeve via actuator gear in the gear housing. An O-ring was placed at the lower portion of the shuttle sleeve to prevent drilling fluid from flowing into the core holders prior to achieving the predetermined testing parameters. A teflon seating was used to prevent the O-ring from jumping out of its glove, thus it would improve the sealing mechanism. Test sample will be exposed to drilling fluid when the shuttle sleeve is turned clockwise or vice versa.

A core holder is used to accommodate the test sample (berea sample). It was fabricated using stainless steel block of 10 inches diameter (grade 316). A confining port was made available in the body of the core holder, to allow the injection of fluid into the core sleeve in order to confine the core. Thus it would prevent the core/test sample from slipping out of the core sleeve. Besides, five transducer ports at the interval of 1inch were made available along the core holder body to allow the installation of the pressure transducers. The core sleeve was a unique fabricated component and it was obtained from core sleeve mould by underwent the injection molding process. The material used was nitrile known as NBR commercially. NBR was chosen due to lower cost and its suitability for usage at high temperature and pressure conditions. A push rod housing was attached at the end of the core holder to allow the adjustment of the test sample parallel to the opening of center bore to allow direct exposure of test sample to drilling fluid. An O-ring was placed between the push rod and push rod housing to prevent fluid leakage to the outlet through the sidewall of the push rod. A filtrate collecting port was also made available at the end of the push rod for recording the filtrate loss.

Lower bore pipe assembly (LBA) consists of a bore pipe, drill pipe flange, shaft seat, slip flange, transmission shaft, high pressure mechanical seal, bearing, motor support bracket, shaft coupling, and motor. The main functions of LBA are to transmit torque from motor to rotate the drill pipe and allow eccentricity movement of the drill string. A transmission shaft equipped with bearing to allow smooth movement of the drill pipe and was connected to the drill pipe via a shaft seat of size 75 mm with 20 mm preset hole. A high-pressure and temperature mechanical seal was placed in the transmission shaft housing to prevent drilling fluid leakage from transmission shaft during pipe rotation at severe conditions. A shaft coupling was also used to connect the transmission shaft and drill pipe motor and was chosen due to its ability for self-alignment, thus ensuring the smooth movement of the drill pipe.

The drill pipe was fabricated using stainless steel grade 304. The outer diameter of drill pipe is 3.5 inches to simulate the field condition for the slim-hole drilling technology, a term used when drilling a 6 inches hole with 3.5 inches drill pipe. At the bottom of the drill pipe, six holes of size 1/2 inch were made available to enable the injection of drilling mud and is driven by a 1/2-horse power inverter motor.

A control system is vital for facilitating of conducting the experiment. The control system is divided into primary control system and secondary control system, which are also known as main control panel and secondary control panel. The main control panel has a power supply of 100 amperes, 3-phase current, and used for operating the 40 hp centrifugal pump, which requires 60-ampere starting current. The secondary control panel housed the on-off button for the secondary pump, heater, drill pipe rotation and agitator motor.

2.4 MULTI ANGLE ROTATING RIG HOLDER

The rotating rig holder was made up of C-channel, angle bar, and mild steel plate to allow the orientation of the testing unit at preset angles such as vertical, highly deviated, or horizontal condition during experiment by inserting the locker shaft into the angle disk. This structure is very strong as it was supported by the supporting based structure locating at the both side of it. The supporting based also acts as a platform for installing and removing of the test sample during the experiment.

2.5 SENSING DEVICES

Three types of sensing devices used in this experimental work are pressure sensor, flow sensor, and temperature sensor. The pressure sensor is used to register the pressure drop profile along the test sample to determine the depth of particles invasion and sectional damage of the core, flow sensor that was mounted at the return flow line of TBA is used to register the annular velocity, and temperature sensor is utilized to monitor the drilling fluid temperature. A data acquisition software GeniDaq (Industrial Acquisition Software) would be used to integrate with these sensors to permit real time monitoring during the experiment. By adopting sensing devices and software, the data recording and interpretation become more accurate, efficient, and reliable.

3.0 DISCUSSIONS

Prior to the construction of this rig, many discussions had been carried out with oil and gas companies such as the Drilling Department of Esso Production Malaysia Inc., Kota Mineral and Chemicals Sdn. Bhd. etc. Generally, they supported this project very well by furnishing the chemicals, technical data, and assistance required. Presently, we are in the final stage of commissioning the rig and will be conducting the experiment soon.

The testing unit of the rig can accommodate four evenly-spaced test samples at one time that enables researcher to study the damage profile of the formation thoroughly. This rig was equipped with special features such as shuttle sleeve, sensing devices etc. to overcome the weaknesses encountered by previous researches of their experimental studied on formation damage. This rig is not only designed for academia purposes, but also to assist Malaysia oil/service companies in the formation damage study as well.

4.0 CONCLUSIONS

Several conclusions could be derived as follows:

(1) The custom fabricated rig furnishes an opportunity for the oil and service companies to improve oil production and quality of their services/product respectively, via reliable formation damage studies.
(2) A formation damage study under downhole condition (dynamic or static) can be conducted using this equipment, and the study parameters that can cause formation damage such as differential pressure, temperature, solid particles concentration etc., can be varied accordingly to the experimental requirements.
(3) This custom fabricated rig has hole size of 6 inches with 3.5 inches drill pipe, which represents the actual drilling condition of a slim hole.
(4) The use of the shuttle sleeve to prevent the invasion of drilling mud to the test sample prior to the predetermined parameters is one of the special features of the equipment.
(5) The system was equipped with sophisticated devices (sensing devices and data acquisition software), which permits the experimental data to be recorded, and interpreted in a more accurate, efficient, and reliable manner. Real time monitoring is incorporated in the system that permit researchers to capture and view the data as soon as the experiment is started.

ACKNOWLEDGEMENTS

The authors wish to thank the Malaysian Ministry of Science, Technology & Environment for sponsoring this work under the IRPA grant of 72232. Special gratitude to Kota Mineral & Chemical Sdn. Bhd. for providing the drilling fluid additives, Shell MDS for their generosity in sponsoring the Sarapar 147 based oil, and the Drilling Department of Esso Production Malaysia Inc. (EPMI) and Shell Sarawak Berhad (SSB) for providing valuable technical data. Special thanks deliver to Mr Charlie Chin for his contribution in the rig design and fabrication. The authors would also like to express their gratitude to the Petroleum Eng. Dept. of FKKKSA, UTM and the Research Management Centre (RMC) of UTM for permission given to the authors to present this paper at the Oil and Gas Symposium, University Technology Malaysia, Skudai, June 22-23, 2002.

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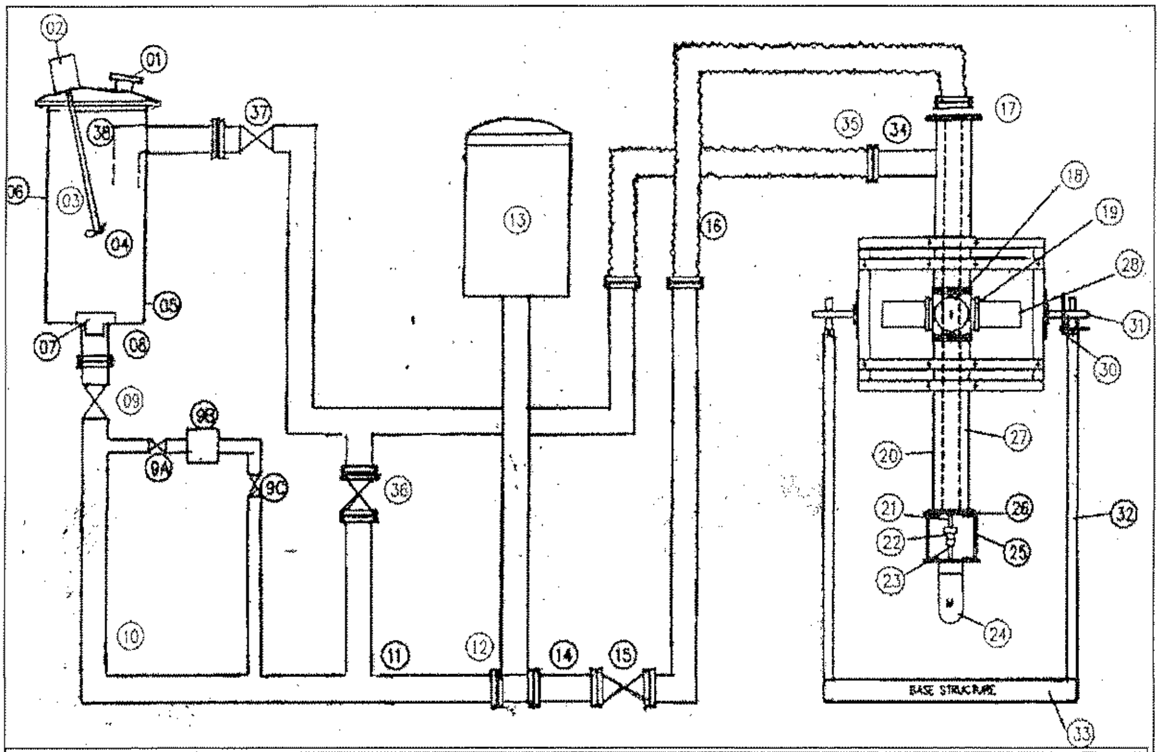

1. Opening
2. Agitator motor
3. Stellar shaft
4. Propeller shaft
5. Baffle plate
6. Mixing tank
7. Stopper
8. 3 inches ball valve
9a. 1 inches ball valve
9b. 1 inch ball valve
9c. Flooding pump
10 3 inches elbow
11. 3 inches tee
12. Flange (PN 25)
13. Centrifugal pump
14. Short pipe c/w flange
15. S-pattern valve
16. Flexible hose
17. Slip plate flange
18. Center bore
19. Shuttle sleeve
20. Lower bore assembly
21. Transmission shaft
22. Mechanical seal (HTHP)
23. Shaft coupling
24. Drill pipe motor
25. Motor bracket
26. Bottom slip plate
27. Drill pipe
28. Core holder
29. Transducer
30. Locking disc
31. Locking shaft
32. Testing unit structure
33. Base structure
34. Return flexible hose
35. Flow sensor
36. S-pattern valve
37. Ball valve

Figure 1 The custom fabricated formation damage rig