Efficient Reuse of Drilling Mud in Minimizing Frictional Pressure Losses

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Hassan Aziz[1], Muhammad Jawad Khan[2], Furqan Ahmed[3.]

[1, 2, 3] *Mehran University of Engineering & Technology, Jamshoro*

Abstract: Drilling operation is necessary for extracting the hydrocarbons from sub-surface which indeed requires large investments. Rate of penetration (ROP) and drill bit hydraulics should be optimized during drilling operation which could help in minimizing the operation cost. As the drilling operation is completed, drilling mud and produced cuttings (drilling wastes) are disposed of because they contain many harmful chemical substances that not only effect environment but also living life. This study suggest a reuse of an already utilized mud under environmental friendly scenario. The objective of this experimental work is to compose a drilling mud system by utilizing an already used drilling mud which should be capable to minimize the pressure losses caused by mud friction in the mud circulatory system. For this purpose, two fluid samples of density 9.5 lb/gal were prepared in the laboratory. Mud balance was used for measuring the density of prepared samples and a rotational viscometer was used for measuring viscometer dial reading which helped in determining the rheological properties of prepared mud samples. This study showed that reusing drilling mud can help meet environmental regulations. About 42-45 % of used mud is required which will act as an additive into a newly designed drilling mud hence; helps in meeting environmental regulations and minimizing frictional pressure losses. Additionally, the results also showed that the mud sample with minimum rheological properties that is 15 cp of plastic viscosity and yield point up to 4.5 lb/100ft^2 was recommended for achieving optimum pressure loss value of 1813.48 psi using jet impact factor criterion. Hence, the mud sample that yield minimum rheological parameter values was recommended as optimum mud compositional concentration.

Keywords: *Drilling mud, Drilling wastes, Hydraulics, ROP, Mud rheology*

1 Introduction

Drilling operation is necessary for extracting the hydrocarbons from sub-surface which indeed requires large investments.The efficiency of drilling process is the function of rate of penetration (ROP).It has been proved through laboratory experiments that ROP is significantly influenced by hydraulic energy at the drill bit, bottom hole differential pressure and bit nozzle fluid viscosity. These all factors which effect ROP are controlled by the type of drilling mud (fluid) used for drilling operation. Drilling fluid through an empty drill string is pumped down the hole, which after passing through the drilling bit, moves up the annuals transporting the drilled cuttings to the surface. The main functions of circulating drilling fluid during drilling operation is to keep the bit and drill string lubricated and cool, to keep the hydrostatic pressure above pore pressure for preventing the invasion of formation fluid into the drilled hole, and to carry the drilled cuttings out of drilled hole [1]. The drilling fluid and treatments involved from preparation to disposal of drilling mud are considered as source of pollutants because of harmful chemicals composition of drilling mud. Chemical additives like barite and bentonite are the most common additives used in the formulation of all types of drilling mud. In addition, oil is also sometimes used in the designing of drilling mud. The volume of oil varies according to the type of mud. Large volume of oil is required for oil based mud and small volume is required for water based drilling mud. [2]

During drilling operation two types of wastes are commonly generated that are produced drilled cuttings to the surface and drilling mud. Drilling mud in large volume is reserved in the mud tanks for fluid circulation into hole to transport the drilled cutting from subsurface to surface. As the fluid with cuttings reaches the surface it is passed through shale shaker for the removal of cuttings from the mud and then the mud is re-circulated. The amount of wastes generated during drilling depends on wellbore diameter and well depth. Drilling of Large diameter wellbore as compared to small diameter wellbore, generates large amount of drilling wastes [3].

There are very less scientists interested in designing a mud from indigenous resources as the properties of indigenous raw material vary from place to place and field to field. The other reason is the compositional design of mud developed from indigenous sources is not commercially acclaimed. In 1995, M. 0. Benka-Coker & A. Olumagin Studied the waste drilling-fluid-utilizing microorganisms which were isolated from drilling-mud cuttings, soil and creek water. The significance of their finding was focused on the environmental management in oil-producing areas. According to their investigation for biodegradation potential of the bacterial isolates proved that even though all the isolates were able to degrade and utilize the waste fluid for growth, species of Alcaligenes and Micrococcus were more active degraders of the waste. Hence, they suggested a compositional plan for developing a drilling mud from indigenous sources in Nigeria. [4] In 2016, Reginald B. Kogbara et.al Conducted a study which was

Corresponding author Email address: hassanaziz901@gmail.com

focused on the developing a treatment that must be able to manage the hydrocarbon and metallic ingredients of drilled cuttings, simultaneously. Under the span of this study bio augmentation was combined with stabilisation/solidification (S/S), within S/S monoliths and in granulated S/S monoliths. The research suggested that with better mixture optimization, combining S/S and bio augmentation could cause more sustainable treatment of drill cuttings. Thus, this study highlighted more of drill cuttings which can later be used as indigenous resource to design an optimum drilling mud. [5] In 2016, Md Amanullah et.al described the results of tests conducted on a locally developed date seed powder (DSP) as a fluid loss additive, which is an agricultural waste product in Kingdom of Saudi Arabia. The results of this study showed that the fluid loss additive is equally appropriate for both fresh and salt water-based drilling muds and thus validate its suitability for current and future exploration and exploitation of oil and gas resources. According to this study the values of plastic viscosity and yield point were found to be 23.3 cp and 10.2 lb/100ft2 respectively. [6] In 2017, Richard O. Afolabi et.al reviewed the key mineralogical characteristics and rheological properties of Nigerian bentonite clay deposits in various locations and their related application for drilling mud formulation. This study paid attention on the clay reserve estimates, mineralogy of the clay deposits, chemical modification of the clays, rheological properties of drilling mud formulated from these clays and its suitability for drilling operations. The discussion of this study uncovered that the ranges of rheological properties for mud designed from Nigerian bentonite clay deposits are Plastic viscosity: 1.06–15.55cp and Yield point: 0.88–15.22Ib/100ft^2 [7]. Similarly, Tayab, Muhammad R et.al, developed an integrated waste management scheme to minimize environmental effects of drilling wastes. Scheme includes the following:

- Two deep wells so that Water Based Mud can be injected into deep aquifers.
- Instalments of plants for Reconditioning of Oil Based Mud.
- Thermal treatment for cuttings disposal. [8]

Unfortunately, this type study has not been reported for the geological environment of lower Indus basin, Pakistan. Therefore, this study is dedicated to the designing of optimum drilling mud utilizing the pre-existing indigenous drilling mud obtained from the locality of Pakistan.

Investigation of bit hydraulics by the use already used mud to improve drill bit penetration rate by optimized hydraulics and to manage drilling waste for reducing environmental concerns are the objectives of this paper. For achieving objectives of this paper, two different water based drilling fluid samples were composed in the laboratory. All prepared mud samples were composed by the addition of already used mud and other additives. Both muds samples were compared in terms of frictional pressure losses. The volume of indigenous mud resource needed for the formulation of mud mixture for the purpose of higher ROP is also the part of this research.

1.1 Herschel-Bulkley rheological model

Herschel-Bulkley rheological model can be defined as a model in which a finite shear stress is required by a fluid to flow, below the determined shear stress fluids that follow this model stop to flow. [9] This mathematical model is used for approximating the pseudo plastic behaviour of the drilling fluids. This model is a composite model which consists two different models namely Bingham plastic and Power law rheological model. [10] Since, Herschel-Bulkley and power law rheological models looks alike. The difference can be determined using a log-log plot of shear rate and shear stress in which shear rate to shear stress line of power law model is a straight line while; line of Herschel- Bulkley rheological model turns upward y-axis. [11]

The equation that describes three-parameters of Herschel-Bulkley is given blow:

$$\tau = \tau_o + k * \gamma^n \qquad (01)$$

Herschel- Bulkley rheological model has been recognised as a standard rheological model by American Petroleum Institute (API) for calculating frictional pressure losses and drill bit hydraulic calculations because this model provides accurate and best simulation results. [12] Its shear rate to shear stress relationship can be seen in figure. 1.

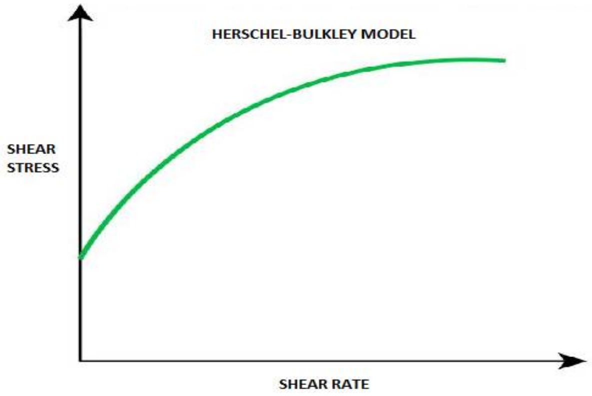

Figure. 1.Shear rate to shear stress relationship of Herschel-Bulkley fluid. [13]

Mathematical equations for determining yield stress (τ_o), fluid flow index (n) and fluid consistency index (K) are given blow: [14]

$$\tau_o = 2\theta_3 - \theta_6 \qquad (02)$$

$$n = 3.322 \log \left(\frac{\theta_{600} - \tau_o}{\theta_{300} - \tau_o}\right) \qquad (03)$$

And,

$$k = \frac{(\theta_{300} - \tau_o)}{511^n} \qquad (04)$$

1.2 Frictional pressure losses

Drilling fluid that is circulated down the bottom of the hole has very significant effects on overall performance of drilling operation. When drilling fluid is circulated from surface to bottom and then again to the surface, the circulating pressure becomes reduced due to frictional pressure losses and hence major percentage of pump pressure is lost. During fluid circulation, frictional pressure losses occurs in the following main areas: [15]

- Surface connections (P_{SUR})
- Inside drill pipe (PD_{DP}) and drill collar (PD_{DC})
- Annulus of drill pipe (PD_{ADP}) and drill collar (PD_{ADC})

Above losses of pump pressure can be described in the terms of mathematical equation as follow:

$$P_{max} = P_{SUR} + PD_{DP} + PD_{DC} + PD_{ADP} + PD_{ADC} \qquad (05)$$

1.2.1 Surface connection pressure losses

Pressure losses in the surface equipment due to friction can be calculated by using following formula [15].

$$P_S = 10^{-5} * k * \rho * q^{1.86} \qquad (06)$$

If the type of surface connection is known the value of surface pressure (k) can be determined from table. [15] The surface connection type for this study is 4 which has a value k = 3.

1.2.2 Drill string pressure losses

The mathematical formula for computing frictional pressure drop for Hershel Buckley fluid in a laminar flow regime from inside drill string is given by. [15]

$$P_f = \frac{4 \times k}{14400 \times D_i}\left\{\left(\frac{\tau_o}{K}\right) + \left[\left(\frac{3 \times n + 1}{n \times c_c}\right)\left(\frac{8 \times Q}{\pi \times D_I{}^3}\right)\right]^n\right\} \times L \qquad (07)$$

Also, drop of pressure from inside the drill string in a turbulent flow regime using a Hershel Buckley fluid is as follow:

$$P_f = \frac{f_c \times Q^2 \times \rho}{1421.22 \times (D_i)^5} \times L \qquad (08)$$

For Hershel Buckley fluids, friction factor (f_c) under turbulent flow regime can be calculated by the equation given blow

$$f_c = y \times (c_c \times N_{RE})^{-z} \qquad (09)$$

1.2.3 Annular pressure losses [9]

The drop of pressure in the annular section of drill string using a Hershel Buckley fluid for laminar flow regime can be calculated using following formula.

$$P_{fa} = \frac{4 \times k}{14400 \times (D_2 - D_1)}\left\{\left(\frac{\tau_o}{K}\right) + \left[\left(\frac{16 \times (2n + 1}{n \times c_a \times (D_2 - D_1)}\right)\left(\frac{Q}{\pi \times (D_2{}^2 - D^2)}\right)\right]^n\right\} L \qquad (10)$$

Also, the equation for calculating drop of pressure in the annular section of drill string using a Hershel Buckley fluid for turbulent flow regime can be calculated using following formula.

$$P_{fa} = \frac{4 \times k}{14400 \times (D_2 - D_1)}\left\{\left(\frac{\tau_o}{K}\right) + \left[\left(\frac{16 \times (2n + 1}{n \times c_a \times (D_2 - D_1)}\right)\left(\frac{Q}{\pi \times (D_2{}^2 - D^2)}\right)\right]^n\right\} L \qquad (11)$$

Under turbulent flow regime, annular friction factor (f_a) for Hershel Buckley fluids can be calculated by following formula

$$f_a = y \times (c_a \times N_{RE})^{-z} \qquad (12)$$

2 Maximum jet impact force criterion (JIF)

The maximum jet impact force criterion suggest that for the maximum removal of the drilled cuttings from the bottom of the hole can be achieved when jet impact force with respect to the flow rate (Q) is maximized. For this condition it is necessary that bit nozzles size and drilling fluid circulatory rate are choose in such a way that pressure drop around the drill bit should not be blow 48% of total available pump pressure.

Using Newton's second law of motion, the jet impact force induced at the bottom of the hole by the mud is given by the following equation. [16]

$$F_J = 0.01823\, QC_d\sqrt{\rho P_b} \qquad (13)$$

Optimum drop of pressure at the drill bit can be given by:[16]

$$P_{b\,opt} = \frac{m}{m + 2} P_{s\,max} \qquad (14)$$

Or

$$P_{b\,opt} = \frac{(8.3 * 10^{-5})\rho Q_{opt}}{A^2{}_{t\,opt} * c_d{}^2} \qquad (15)$$

Equation for calculating optimum pressure drop is given by:[16]

$$Q_{opt} = Q_a \text{antilog}\left[\frac{1}{m}\log\left(\frac{P_{f\,opt}}{P_f}\right)\right] \qquad (16)$$

Optimum nozzle area ($A_{t\,opt}$)can be derived from the equation above.

$$A_{t\,opt} = \sqrt{\frac{(8.3 * 10^{-5})\rho Q_{opt}}{P_{b\,opt} * c_d^{\,2}}} \qquad (17)$$

Similarly, diameter optimum can be calculated by the following equation:

$$d_{n\,opt} = 2\sqrt{\frac{A_{t\,opt}}{n\pi}} \qquad (18)$$

3 Environmental impacts of drilling wastes

The drilling of a well produces drilling wastes that are drilling mud and drilled cuttings. Muds are pumped down through the drill string for lubricating the bit and to transport the drilled cuttings up to the surface where cuttings from mud are separated. Mostly wells are drilled using water based mud (WBM) or oil-based mud (OBM) while synthetic-based muds (SBMs) are also used sometimes. [17]

In 1991, 30,000 wells were drilled in USA alone that produced 157 MM bbl of drilling wastes.

Environmental Protection Agency in USA has estimated E&P drilling wastes and concluded that "These wastes should retain their exemption from regulation as hazardous under RCRA Subtitle C. [18]

Many verifications showed that OBM and produced cuttings could have adverse effects on local ecosystem as significant deviations were seen nearby many oil and gas platforms in the North Sea. Oil-based wastes can affect the local ecology in following manners: directly covering organisms, presenting direct toxicity to surrounding organisms, and by forming anoxic conditions triggered by microbial degradation of the organic components in the produced waste. Experiments have proved that discharged oil based drill cuttings even after 180 days has shown biodegradation less than 5%. [19]

Drilling mud contains variety of complicated materials. For example: produced drilled cuttings from well, lubricants, formation oil, formation water and many more. In addition, it also contains many harmful chemical substances that not only effects environment but also living life.
Following are some impacts of drilling wastes.

1. Drilling wastes under natural conditions require 2-6 months to dry. In these cases snow, rain and wastes leakage pollutes ground and surface water, surface soil and groundwater resources.
2. Wastes may also lead to acidification of the soil, where plants are unable to survive. In addition, heavy metals in the muds can affect plant growth and propagation of microbes.
3. Drilling wastes also contains chemical which lead to affect the survival and reproduction of animal and birds. [20]

4 Laboratory work

For this study, to achieve objectives two water base muds samples of various concentration were prepared in the laboratory. A density of 9.5 lb/gal was used for all the samples which was confirmed by both theoretical formula and mud balance. Viscometer dial readings of both mud samples at different dial readings were determined using a 8 dial rotational viscometer. The rotor speed of 600, 300, 200, 100, 6, 3 RPM was used for measuring viscometer dial readings. Which in turn used to calculate rheological parameters of both the samples.

Well and mud data was obtained from a nearby oilfield. Table 1 shows the data of a well. Table 2 shows the composition of used mud used as an additive in a newly designed mud and the list of additives with their densities used for the preparation of mud samples. An assumed fluid flow rate of 300 gal/min for both the samples was chosen for the calculation of pressure losses.

Table. 1. Data of the well.

Hole size (Inch)	**8.5**
TVD (Ft)	**10909**
Drill pipe ID (Inch)	**4.276**
Drill pipe OD (Inch)	**5**
Drill collar OD (Inch)	**6.25**
Drill collar ID (Inch)	**2.8125**
Length of drill collar (Ft)	**837**
Mud flowrate (gal/min)	**350**
Density (PPG)	**9.5**
Max pump operating pressure (PSI)	**3500**
Pump horsepower	**1600**
Surface equipment type	**4**

Table. 2. Additives of mud samples and of used mud.

Additives of mud samples
Water
Caustic soda
Soda ash
Starch
Bentonite
Used mud
Additives of used mud
Water
KCL
Aquacol D
MIL-PAC LV
Caustic potsh
Xanthan Gum D
Aquacol D
Permalose HT
Barite

The elemental composition of drilling mud describes its density. The mathematical equation used for preparing the mud samples of desired density is as follow.

Mathematically,

$$\rho = \frac{M_1 + M_2 + M_3}{\frac{M_1}{\rho_1} + \frac{M_2}{\rho_2} + \frac{M_3}{\rho_3}} \qquad (19)$$

The above described formula can be set according to number of additives that will be used for mud preparation [6].

The composition of each sample with their viscometer dial reading, calculated rheological properties that are plastic viscosity (PV) and yield point (YP) and calculated frictional pressure loses are given in the table 3 through 5.

Table. 3. Additives of mud sample no. 1 and 2.

Additives of mud sample no. 1	Weight (grams)	Additives of mud sample no. 2	Weight (grams)
Water	498	Water	536
Caustic soda	4	Caustic soda	4
Soda ash	4	Soda ash	4
Starch	25	Starch	25
Bentonite	25	Bentonite	25
Used mud	421	Used mud	482

Table. 4. Viscometer dial reading of mud sample no. 1 and 2.

RPM	Readings	RPM	Readings
θ_{600}	43.5	θ_{600}	34.5
θ_{300}	27	θ_{300}	19.5
θ_{200}	20.5	θ_{200}	14.5
θ_{100}	13.5	θ_{100}	10
θ_{6}	5.5	θ_{6}	4
θ_{3}	4	θ_{3}	3.5

Table. 5. calculated PV and YP.

Sample 1		sample 2	
PV	16.5	PV	15
YP	10.5	YP	4.5

5 FRICTIONAL PRESSURE LOSSES

Frictional pressure losses for each sample were calculated using Hershel-Bulkley rheological model. In addition ECD was also calculated for each sample. The results of frictional pressure losses and ECD are given in the tables 6 and 7.

Table. 6.Calculated ECD and pressure losses for prepared mud sample no. 1.

D	P_{sur}	PD_{DP}	PD_{DC}	PD_{OHADP}	PD_{CHADP}	PD_{OHADC}	PD_{CHADC}	P_F	ECD
		Regime	Regime	Regime	Regime	Regime	Regime		
		Turbulent	Turbulent	Laminar	Laminar	Laminar	Laminar		
6474	11.54	220.571	206.915	0	52.409	0.027	17.978	509.44	9.624
6600	11.54	225.502	206.915	0	53.581	3.476	15.268	516.281	9.627
6800	11.54	233.327	206.915	0	55.44	8.949	10.967	527.139	9.633
7000	11.54	241.153	206.915	0	57.3	14.422	6.666	537.997	9.638
7200	11.54	248.979	206.915	0	59.159	19.896	2.365	548.855	9.644
7311	11.54	253.322	206.915	0.011	60.191	22.906	0	554.886	9.647
7400	11.54	256.805	206.915	0.994	60.191	22.906	0	559.352	9.648
7600	11.54	264.631	206.915	3.229	60.191	22.906	0	569.412	9.652
7800	11.54	272.457	206.915	5.463	60.191	22.906	0	579.472	9.656
8000	11.54	280.282	206.915	7.697	60.191	22.906	0	589.532	9.66
8200	11.54	288.108	206.915	9.932	60.191	22.906	0	599.592	9.664
8400	11.54	295.934	206.915	12.166	60.191	22.906	0	609.652	9.668
8600	11.54	303.76	206.915	14.4	60.191	22.906	0	619.713	9.672
8800	11.54	311.586	206.915	16.635	60.191	22.906	0	629.773	9.676
9000	11.54	319.412	206.915	18.869	60.191	22.906	0	639.833	9.68
9200	11.54	327.238	206.915	21.103	60.191	22.906	0	649.893	9.684
9400	11.54	335.063	206.915	23.338	60.191	22.906	0	659.953	9.688
9600	11.54	342.889	206.915	25.572	60.191	22.906	0	670.013	9.692
9800	11.54	350.715	206.915	27.806	60.191	22.906	0	680.074	9.696
10000	11.54	358.541	206.915	30.041	60.191	22.906	0	690.134	9.699
10200	11.54	366.367	206.915	32.275	60.191	22.906	0	700.194	9.703
10400	11.54	374.193	206.915	34.509	60.191	22.906	0	710.254	9.707
10600	11.54	382.018	206.915	36.744	60.191	22.906	0	720.314	9.711
10800	11.54	389.844	206.915	38.978	60.191	22.906	0	730.375	9.715
10909	11.54	394.109	206.915	40.196	60.191	22.906	0	735.857	9.717

Table. 7.Calculated ECD and pressure losses for prepared mud sample no. 2.

D	P_{sur}	PD_{DP}	PD_{DC}	PD_{OHADP}	PD_{CHADP}	PD_{OHADC}	PD_{CHADC}	P_F	ECD
		Regime	Regime	Regime	Regime	Regime	Regime		
		Turbulent	Turbulent	Laminar	Laminar	Laminar	Laminar		
6474	11.54	151.213	164.248	0	49.403	0.021	14.076	390.5	9.612
6600	11.54	154.592	164.248	0	50.507	2.658	11.954	395.5	9.615
6800	11.54	159.957	164.248	0	52.26	6.845	8.587	403.437	9.619
7000	11.54	165.322	164.248	0	54.013	11.031	5.219	411.373	9.624
7200	11.54	170.687	164.248	0	55.765	15.218	1.852	419.31	9.628
7311	11.54	173.665	164.248	0.01	56.738	17.52	0	423.721	9.631
7400	11.54	176.052	164.248	0.855	56.738	17.52	0	426.953	9.632
7600	11.54	181.417	164.248	2.775	56.738	17.52	0	434.239	9.636
7800	11.54	186.782	164.248	4.695	56.738	17.52	0	441.524	9.639
8000	11.54	192.147	164.248	6.616	56.738	17.52	0	448.809	9.643
8200	11.54	197.512	164.248	8.536	56.738	17.52	0	456.095	9.646
8400	11.54	202.877	164.248	10.457	56.738	17.52	0	463.38	9.649
8600	11.54	208.242	164.248	12.377	56.738	17.52	0	470.666	9.653
8800	11.54	213.607	164.248	14.297	56.738	17.52	0	477.951	9.656
9000	11.54	218.972	164.248	16.218	56.738	17.52	0	485.236	9.659
9200	11.54	224.337	164.248	18.138	56.738	17.52	0	492.522	9.663
9400	11.54	229.702	164.248	20.059	56.738	17.52	0	499.807	9.666
9600	11.54	235.067	164.248	21.979	56.738	17.52	0	507.093	9.67
9800	11.54	240.432	164.248	23.899	56.738	17.52	0	514.378	9.673
10000	11.54	245.797	164.248	25.82	56.738	17.52	0	521.663	9.676
10200	11.54	251.162	164.248	27.74	56.738	17.52	0	528.949	9.68
10400	11.54	256.527	164.248	29.661	56.738	17.52	0	536.234	9.683
10600	11.54	261.892	164.248	31.581	56.738	17.52	0	543.52	9.687
10800	11.54	267.257	164.248	33.501	56.738	17.52	0	550.805	9.69
10909	11.54	270.181	164.248	34.548	56.738	17.52	0	554.775	9.692

6 Results and discussion

The analysis of the frictional pressure losses indicates that for surface connections, the pressure drop was 15.375 psi which remained same for all the depths. A significant drop in pressure was observed inside the drill pipe for both the mud samples.

At the fluid flow rate of 300 gpm, fluid flow regime from in the pipes was turbulent, while flow regime was laminar in the annular section of pipes at the same flow rate.
Prepared mud Sample no. 2 that contains a plastic viscosity of 15 cp and yield point 4.5 Ib/100ft^2, experienced the minimum losses of 554.775 psi in the circulatory system.
On the other hand, least value of equivalent circulating density that is 9.69 ppg, was calculated for the same sample.

For this study, to ensure the maximum removal of the bottom hole cuttings for improving penetration rate using maximum jet impact force criterion. The prepared mud sample no. 2 was selected, as it has provided the minimum values of pressure losses and ECD. The optimum loss of pressure according to JIF criterion is 1813.48 psi and optimum pressure drop across the bit is 1686.52 psi. For achieving above mentioned conditions of optimum pressure loss and optimum pressure drop, surface circulating mud pumps should be operated with the conditions given in Table 8.

Table. 8.Optimum condition for JIF Criterion.

DEPTH (FT)	QOPT	AOPT	DOPT	JIF
6474	619.7454	0.446357	0.434873	1358.358
6600	615.0398	0.442968	0.433219	1348.044
6800	607.7686	0.437731	0.43065	1332.107
7000	600.7289	0.432661	0.428149	1316.677
7200	593.909	0.427749	0.425712	1301.73
7311	590.2115	0.425086	0.424384	1293.625
7400	587.5144	0.423143	0.423414	1287.714
7600	581.5604	0.418855	0.421263	1274.664
7800	575.7695	0.414684	0.41916	1261.971
8000	570.1344	0.410626	0.417104	1249.62
8200	564.6484	0.406675	0.415092	1237.596
8400	559.3052	0.402826	0.413124	1225.885
8600	554.0988	0.399077	0.411196	1214.474
8800	549.0235	0.395421	0.409309	1203.35
9000	544.0741	0.391857	0.40746	1192.501
9200	539.2454	0.388379	0.405647	1181.918
9400	534.5328	0.384985	0.403871	1171.589
9600	529.9318	0.381671	0.402129	1161.504
9800	525.438	0.378434	0.40042	1151.655
10000	521.0475	0.375272	0.398744	1142.032
10200	516.7565	0.372182	0.397099	1132.627
10400	512.5612	0.36916	0.395484	1123.432
10600	508.4583	0.366205	0.393898	1114.439
10800	504.4445	0.363314	0.39234	1105.641
10909	502.2933	0.361765	0.391502	1100.926

7 Conclusions

As mentioned earlier there were two samples prepared from pre-used mud. A large volume about 42-46 % of used drilling mud was used for the designing of new mud which improved rheological parameters of the newly designed mud. Based on laboratory investigation following are the conclusions of this study,

1. Produced wastes of drilling operation are also the pollutant sources which creates major environmental issues. Environmental concerns can be reduced as a large volume of previously used mud is consumed in newly designed mud.
2. Circulatory system pressure losses can be reduced by the use of (this new mud concept).
3. ROP can be improved by the optimum use of hydraulics which shows major cut in drilling operation cost. Besides, cost of mud disposal and treatment cost prior to mud disposal can be saved.
4. From the experiments it was achieved that sample 1 has plastic viscosity of 16.5 cP and sample 2 has 15 cP, where the yield point was observed to be at 10.5 lb/100ft^2 for sample 1 and 4.5 lb/100ft^2 for sample 2. Hence, it was concluded that sample 2 has minimum values of rheological properties
5. In fact, as sample 2 has minimum values of rheological properties which will yield minimum values of ECD and pressure losses that is 1813.48 psi according to Jet Impact factor Criterion and 1686.52 psi across the bit. Thus, the pressure losses are investigated to be optimum at these values.
6. Therefore, compositional concentration of sample 2 is recommended to design a suitable mud from indigenous sources at commercial scale.

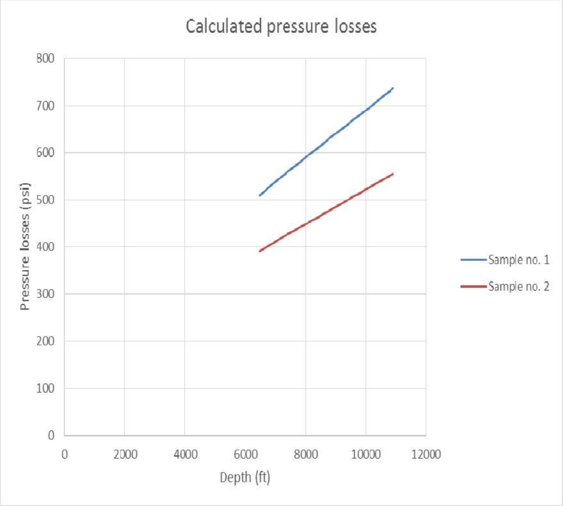

Figure. 2. Frictional pressure loses vs depth.

It can be seen in the above graph that minimum frictional pressure losses were calculated for mud sample no. 2 that were 554.775 psi at the depth of 10909 ft while mud sample 1 has higher frictional pressure losses as a result of this mud sample 1 will provide maximum power to the drill bit in efficient hole cleaning.

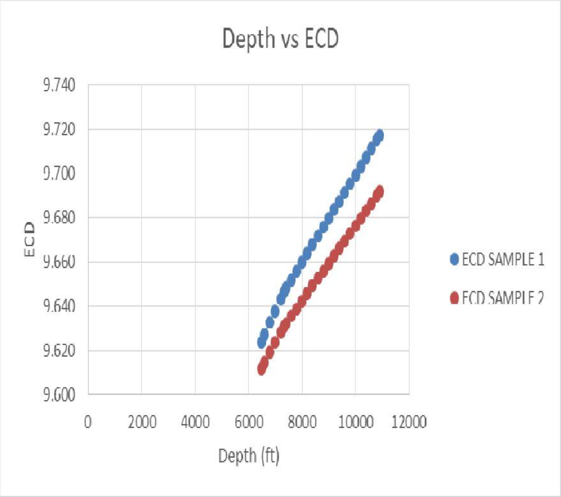

Figure. 3. Change in mud Equivalent circulating density with depth.

The above figure. 3, shows change in mud equivalent circulating density (ECD) with depth. It can be seen that minimum ECD recorded was for mud sample. 2. i.e. 9.692 psi. Whereas; sample 1 has higher ECD as compared to mud sample 2. This Lowest ECD value of mud sample 2 shows maximum pressure that will be applied by the mud at the bottom of the hole without fracturing the formation.

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About Authors

Hassan Aziz has bachelor's Degree in Petroleum & N.Gas engineering and Master's Degree in Petroleum engineering from Mehran university of Engineering & Technology, Jamshoro, Pakistan.

He has also worked in oil industry having a working experience of one year.

Muhammad Jawad Khan has bachelor's Degree in Petroleum & N.Gas engineering and Master's Degree in Petroleum engineering from Mehran university of Engineering & Technology, Jamshoro, Pakistan.

Furqan Ahmed has bachelor's Degree in Petroleum & N.Gas engineering and Master's Degree in Petroleum engineering from Mehran university of Engineering & Technology, Jamshoro, Pakistan.