

Imparting Hydraulic Shear in Invert Emulsion Drilling Fluids

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Abstract

This paper describes the development, design and benefits of a high pressure shearing device for emulsifying modern invert-emulsion drilling fluids. This prototype, in-line shearing device is able to impart effective hydraulic shear at high rates with a single pass in a safe and efficient manner.

Introduction

Modern low ECD (Equivalent Circulating Density), low PV (Plastic Viscosity) SBM's (Synthetic Based drilling fluids) developed for deepwater drilling need no organophilic solids to aid in maintaining their rheological profile, relying instead, on polymers. All drilling fluids benefit from the shear provided downhole while circulating. SBM's using organic polymers and surfactants require high energy shear in order to obtain stable rheological properties at the optimal concentrations of these components. Adding a temporary viscosifier to newly mixed fluids is sometimes used to dramatically increase the viscosity of the fluid. Shearing the fluid before transport can materially reduce top oil separation and the need for temporary viscosifiers that are later remediated at the rig site. Figure 1 below demonstrates top oil separation of a normally mixed, un-sheared SBM without and with a cross-linked resin as a rheological modifier. The resin is present to provide temporary viscosity to the fluid making it more suitable for transport to the rig site.

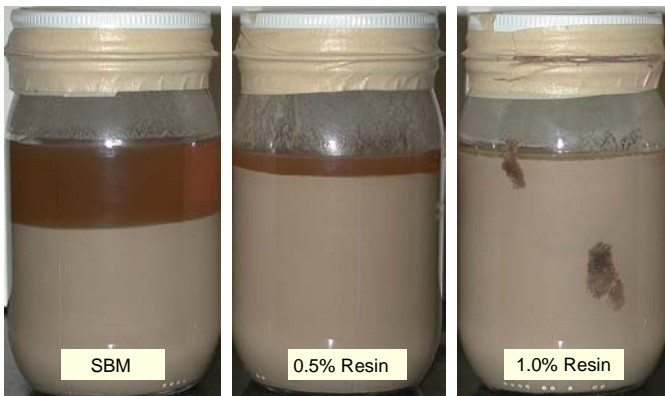


Fig 1 – Static aging of non-sheared SBM - 5days @ room temperature plus 16hrs @150°F – The 'Resin' is a cross-linked rheological modifier – not an organophilic solid.

Shore-based, liquid mud plants (LMP's) supporting deepwater operations are frequently required to produce high volumes of SBM on short notice. Newly mixed SBM requires shear to ensure that they continue to exhibit and maintain desirable rheological properties from the time they are mixed until they are transported to the drilling rig and placed into use. Transport often involves a number of days on a boat with little or no agitation before being transferred to the drilling rig.

The shearing device described in this paper produces a stable, homogeneous fluid, using optimal chemical concentrations in a single pass. The low pressure discharge can be delivered into a low pressure hose or manifold without fear of the fluid velocity destroying the hoses or receiving manifold.

Background

Conventional mechanical emulsification devices include high-pressure homogenizers, rotor-stator systems, ultrasonic droplet disruption systems and microporous membranes. Droplet (discontinuous phase) surface area is increased by disruption of large droplets in a premix using high energy inputs.¹

Shearing water based, oil-based and synthetic-based fluids through the nozzles of a drill bit in liquid mud plants without the benefit of downhole circulation has been a challenge for drilling fluids companies worldwide. The large volumes of SBM required for deepwater drilling operations in the Gulf of Mexico (GOM) have increased the importance of meeting this challenge in a timely manner.

Many types of shearing devices, including hoppers utilizing shear nozzles, centrifugal pumps with special impeller designs, units with mixing teeth, rotors and stators and cavitation inducing units, are able to shear water based drilling fluids (WBM) with varying degrees of effectiveness. Invert emulsion drilling fluids (OBM) and SBM are more difficult to shear because of the high energy levels required to break up and emulsify water droplets as well as the difficulty of getting rheological modifiers to 'yield' in order to provide stable suspension properties. Some of the previously mentioned devices are able to shear SBM, but require repeated circulation to obtain acceptable results. This results in unacceptably long periods of re-circulation through these devices while tying up the mixing pits.

¹ Membrane emulsification systems form uniformly small droplets at low energy levels but thus far, have not been proven viable in the emulsification of oilfield drilling fluids.

Shearing Drilling Fluid through a Bit – Prototype 1

Once the constituents of invert emulsion fluids are combined, the production of fine droplets from the discontinuous phase by mechanical methods requires enough energy input to exceed a critical power density. Critical power density will vary with the surface tensions of the two liquids.² In this example, the two liquids are a base oil (the continuous phase) and water (the discontinuous phase). The resulting droplet size and size distribution will vary with the type of flow and the energy input into the process, e.g. Turbulent or laminar elongational flow.

Shearing OBM or SBM in the field is often achieved in the well-bore when circulating the fluid through bit nozzles at high pressures. With a high pressure homogenizer type system, the hydraulic horsepower of one or more triplex pumps is required to exceed critical energy density and in turn, to impart the hydraulic shear required to create the desired stable emulsions and rheologies in these fluids. Although there are other methods that may provide approximately similar results, the simplicity of using high pressure to disrupt water droplets is a robust, repeatable process appropriate for fluids that may contain abrasive solids. The energy density or volumetric energy input from positive displacement pumps will normally exceed the critical external stress level required for droplet disruption. A graphical depiction of the process is shown below in Figure 2.

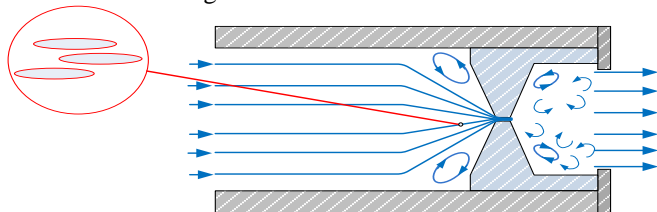


Fig 2 – Laminar Elongational Flow

As the fluid enters the nozzles in laminar elongational flow, it moves to a dispersion phase and then into a stabilization zone where chemical emulsifiers prevent the newly created small droplets from coalescing.³ The pressure drop (ΔP) at the bit nozzles in most drilling operations is seldom more than 1000 psi and usually less than 1000 psi while at the LMP these pumps are capable of exceeding a ΔP of 3000psi.

Several different methods are used around the world to pump drilling fluid through bit nozzles to achieve adequate shearing. A system was set up in a GOM (Gulf of Mexico) LMP using a triplex cementing pump (Figure 3). In this first prototype system, (Figure 4), drilling fluid was pumped through a high pressure 2-inch line to a 500 barrel mixing pit through an 8½-inch PDC bit with 10/32^{nds} inch nozzles. The bit was set into a section of 10-inch casing with a sub to center and hold it in place. The mud was mixed in one 500 barrel mixing pit, fed to the suction of the triplex pump and through the shearing device set up into a second 500 barrel mixing pit

to avoid recirculating sheared fluid.



Figure 3 – HT 400 Positive Displacement Pump



Figure 4 Prototype 1 general arrangement of 8½ “ PDC bit and sub set into 10 inch casing in a mixing pit –

Tests were conducted to compare rheological properties of SBM before shear and after shear and SBM returned from the field which had been down hole and sheared through the bit.

Table 1 - Property Comparison - New Vs Field Mud – Before & After – Single Pass

	SBM mixed from Scratch		SBM returned from field		
	Mixed No shear	Sheared Four 10/32" Nozzles	Mixed No shear	Sheared Four 10/32" Nozzles	
WT, ppg	14.5	14.5	WT, ppg	14.3	14.3
PV, 120°F	47	38	PV, 120°F	56	51
YP	12	32	YP	14	22
ES	255	704	ES	591	737
600	106	108	600	126	124
300	59	70	300	70	73
200	43	55	200	51	55
100	27	39	100	30	35
6	9	18	6	6	8
3	8	17	3	4	6
PSI, pump		1,800	PSI		2,000
bbls./min.		4.0	bbls./min.		4.2

Fluids sheared using this device showed marked improvement in PV, YP, 6 & 3 rpm rheologies and Electrical Stability (ES). The short distance from the pump to the bit nozzles result in negligible pressure drop until the fluid passes through the nozzles. Improvements in the properties of the used field mud suggest the SBM appears to be obtaining more effective shear in the LMP than downhole.

Shearing Unit - Prototype 2

Maintenance was improved by designing a 6-inch bull nose with the 4 nozzles' centerlines directed to intersect at a distance of ≈ 13.3 inches from the face of the bull nose; directing the flow inward instead of outward toward the casing as in Figure 5. The 6-inch bull nose was set into one end of the horizontal 10" stabilization chamber (Figure 6). This chamber acts as stabilization area where the fluid velocity is reduced and the newly formed droplets are prevented from coalescing by being encapsulated by the emulsifiers. The result is a fluid with stable properties discharged at a relatively low pressure. (8-10 psig @ 4 bbls/minute)



Figure 5 – Prototype 2

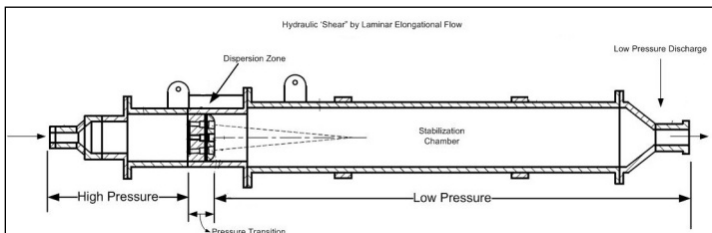


Figure 6 – Prototype 2 concept with Stabilization Chamber

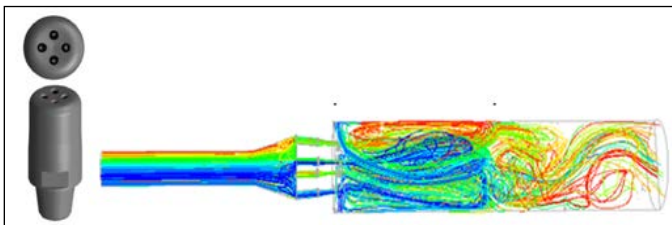


Figure 7 - Bull Nose w/ CFD flow pattern in the stabilization chamber

The process rate issue was addressed by refurbishing two 335hp pumps mounted on a production enhancement trailer. This doubled the flow rate to over 8 barrels per minute to allow large mixes to be sheared in a reasonable time and allowed experimentation with higher ΔP . Extensive tests were run on several different mud weights. The results were similar to the original shearing unit with the process rate doubled to ≈ 8 bpm. All shearing was completed in one pass through the

unit with the discharge directed to storage tanks at low pressures. Even at 8 bpm, the discharge pressure at the 4" hose did not exceed 10 psi. Hydraulic horsepower required was calculated using the following formula:

$$\text{HHP} = (\text{psi} \times \text{Rate (bpm)}) / 40.8$$

Improvements were made by installing the shearing device between the two triplex pumps on the trailer, thereby keeping all high pressures around the pump and away from the mixing areas in the LMP (Figure 8).



Figure 8 - Pumps are fed from rear of the trailer - all high pressure lines remain on the pump unit.

Additional testing was performed with un-weighted 7.8 and 10.0 ppg SBM with various nozzle sizes, shearing pressures and flow rates. The resulting improvements in rheology and ES are shown in the following tables 2a & 2b.

Table 2a – Mix #1

	As Mixed No Shear	Sheared 4 x 8/32"
WT, ppg	7.8	7.8
PV, 150°F	7	12
YP	3	18
ES	79	349
600	17	42
300	10	30
200	7	25
100	5	19
6	2	8
3	2	7
PSI, pumps		2950
RPM, pumps		2050
bbls./min.		7.3

Table 2b – Mix #2

	As Mixed No Shear	Sheared 4 x 10/32"
WT, ppg	10.0	10.0
PV, 150°F	15	17
YP	10	24
ES	155	470
600	40	58
300	25	41
200	19	33
100	12	25
6	5	9
3	4	8
PSI, pumps		2,000
RPM, pumps		1,920
bbls./min.		8.5



Figure 9 – Side Discharge at low pressure.

STABILITY OVER TIME

A low ECD SBM was mixed at the stock point LMP and sent to the rig after one pass through the shearing unit. The rheological properties remained virtually unchanged when the boat arrived at the drilling location and unloaded 10 days later. After 7 additional days without agitation in the rig pontoon, a slight reduction in YP was observed but the density remained unchanged (Table 3). The minor reduction in emulsion strength and rheology over 17 days was encouraging. Little free oil was observed on top of the SBM.

Table 3 – Rheological Stability over Time

	No Shear	Sheared As loaded Day 1	Fluid As rec'd* + 10 days	Mud in pontoon** +7 days
WT, ppg	13.7	13.7	13.7	13.7
PV, 150°F	17	22	23	21
YP	11	18	16	11
ES	391	683	671	622
600	45	62	62	53
300	28	40	39	32
200	21	31	30	24
100	13	21	21	16
6	5	9	8	6
3	4	8	7	5
PSI, pumps	2,000			
bbls/min	4.4			

*Fluid was on the boat for 10 days prior to loading onto rig.

**Fluid was in the rig pontoon for over 7 days w/o agitation.

COMMERCIAL UNIT – UNDER DESIGN

Prototype 2 met all preliminary design criteria for safety, low maintenance and repeatable results. However, as it is not a finished, engineered product, efforts are underway to reduce the size, weight and complexity of the seals. Accordingly, the commercial unit will be smaller, probably lighter, less cumbersome, easier to manufacture and have a high margin of safety as related to pressure.

Conclusions - Prototype 2

- 1) The same shearing capabilities were achieved with the prototype unit as with shearing unit with the PDC bit with the following advantages:
 - a) **Safety:** While pumping through the shearing unit, pressure at the discharge going through a 4" hose into a LMP storage manifold was only 10psi. With the shearing unit installed on the pump truck, personnel exposure to high pressures is reduced.
 - b) **Process rate:** The time to shear drilling fluid was reduced by half by using two pumps and two 335hp diesel engines instead of one. Single pass emulsification at 8 barrels per minute has been consistently and repeatedly demonstrated.
 - c) **Maintenance:** The centerline flow direction of the bull nose in the stabilization chamber eliminates wear issues in the stabilization chamber and absorbs the velocity of the fluid. The prototype unit shows no signs of erosion or wear with 85+ hours of operation.
 - d) **Portability:** The shearing unit with pump truck can be sent to any location accessible by tractor trailer or installed on a drilling rig using the rig triplex pumps or other suitably sized positive displacement pumps available at the rig site.
- 2) The stabilization chamber is a key part of the shearing process. The combination of conjoined high velocity streams under a laminar elongational flow regime with a stabilization chamber is able to provide stable rheological properties in a single pass.
 - a) Pumping through used drill bits into open pits without a stabilization chamber elsewhere has not provided consistent results.
- 3) The production of fine droplets by mechanical emulsification requires sufficient energy density to achieve laminar elongational flow. This must exceed the critical power density for the relative surface tensions of the fluids being emulsified. Thus far the most consistent results with these fluids (Internal Olefin and water) have been obtained in the 1850 to 2100 psi range.
- 4) Droplet coalescence immediately after droplet formation is avoided by a combination of fast stabilizing emulsifiers and a stabilization zone following the dispersion zone inside the shearing unit.

Nomenclature

SBM	= Synthetic Based Drilling Fluid (Internal Olefin based)
PV	= Plastic Viscosity
OBM	= Oil Based Drilling Fluid
YP	= Yield Point
LMP	= Liquid Mud Plant
ES	= Electrical Stability
GOM	= Gulf of Mexico
ECD	= Equivalent Circulating Density
WBM	= Water Based Drilling Fluid
CFD	= Computational Flow Dynamics

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