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Fiber Sweeps Improve Hole Cleaning

Reza Majidi, Nicholas Takach, University of Tulsa, Drilling Research Projects

Abstract

Poor hole cleaning can lead to costly drilling problems such as stuck pipe, slow drilling rate, lost circulation and excessive torque and drag. Corrective methods such as drilling-fluid sweeps are often applied in the field to clean the borehole of cuttings that have not been removed during normal fluid circulation.

Field observations indicate that fiber-containing sweeps, which were originally used as lost circulation materials and to reduce torque and drag, have been very effective in cleaning high angle and extended-reach wells. Despite the encouraging field experience and recent experimental studies, the sweep efficiency of fiber sweeps under various drilling conditions is not well understood.

This paper investigates the hole-cleaning performance of weighted and unweighted fiber sweeps in horizontal and inclined configurations. Flow-loop experiments were carried out to evaluate and compare sweep efficiencies of weighted (barite-containing with density of 10 ppg) and unweighted (0.5% Xanthan gum and 0.05% synthetic fiber) fiber sweeps by measuring equilibrium bed heights at various sweep flow rates in horizontal and inclined configurations. The outcomes of this study improve the understanding of these fluids and establish a procedure for the design and application of fiber sweeps.

Introduction

Drilling deviated and horizontal wells has become increasingly common in the oil and gas industry. During the drilling of such wells, gravitational forces cause deposits of drill cuttings along the lower or bottom side of the wellbore and results in the formation of a “cuttings bed.” If left unattended, this accumulation of drill cuttings can become severe enough to lead to hole pack offs, stuck pipe, high torque and drag on the drill-string, wear and tear on the equipment and other unwanted incidents of lost or non-productive time. Removal of these cuttings, particularly from wells drilled at a high angle, has proven to be problematic. Limited pump rate, eccentricity of the drill pipe, sharp build rates, high bottom hole temperatures and irregular shaped wellbores can all contribute to inadequate hole cleaning. Commonly used drilling fluids generally fail to remove cuttings from such cuttings beds when they are circulated through the wellbores.

Over the years, various field procedures have been introduced to control the formation of cuttings beds. Most of these procedures involve addition of drilling fluid additives such as viscosifiers and weighting agents that enhance the cuttings transport ability of the drilling fluid. Unfortunately, these methods are inefficient in completely preventing the formation of a cuttings bed. At best they delay the buildup of cuttings beds but often cause additional problems. As a result, corrective methods such as drilling fluid sweeps are often applied in the field. In highly inclined and horizontal wells, drilling fluid sweeps can be applied to reduce cuttings bed thickness. As documented by Hemphill et al.[1] drilling fluid sweeps generally fall into the following categories: i) high-viscosity; ii) high-density; iii) low-viscosity; iv) combination and v) tandem.

A recent experimental study[2] with conventional sweeps indicated that in the absence of drill pipe rotation, high viscosity and high-density sweeps are ineffective in a horizontal configuration. However, field observations (Cameron et al. 2003)[3] show the effectiveness of fiber sweeps in cleaning highly deviated and extended reach wells. Particularly when applied with drillpipe rotation, fiber sweeps not only clean cuttings from the low side of the hole, they also help reduce ECD and torque. A field study (Bulgachev et al. 2006)[4] conducted on different types of sweep fluids (conventional and fiber sweeps) reports that tandem sweeps containing monofilament fiber (MFF) are very effective in cleaning highly inclined wells. Applying fiber-containing sweeps with well-optimized drilling practices greatly improves drilling efficiency and safety. Although field observations are encouraging, currently very little is known about flow behavior, hydraulics and cuttings transport efficiency of fiber sweeps. Therefore, investigating hole-cleaning performance of fiber sweeps can be useful to have a better understanding and establish a procedure for designing and application of fiber containing sweeps.

The previous experimental studies[5] conducted at our research center showed that without inner pipe rotation, adding fiber materials into drilling sweeps significantly improves sweep efficiency of the fluid, especially in the horizontal configuration. We speculated that high density fiber-containing sweeps could be more effective in preventing cuttings accumulations. The increased density of the base fluid might help keep the cuttings in suspension through buoyancy force. The sweeping process will be potentially more effective when cuttings and barite particles remain in suspension with the amplified effect of fibers. Moreover, for a constant sweep flow rate, turbulence is more likely to occur in a denser fluid. The primary objective of this work is to improve our understanding of cuttings and solids transport with weighted and unweighted fiber sweeps and to formulate fluids that substantially improve hole-cleaning and reduce associated costs. The sweep efficiencies of weighted fiber sweeps in horizontal and inclined configurations are evaluated and compared to those of unweighted fluids.

Experimental

The current investigation involved experiments that were conducted to study hole-cleaning performance of barite-fiber sweeps in horizontal and inclined configurations. A small-scale flow loop (Fig. 1) was used to conduct tests in order to investigate the effect of fiber and barite on the sweep efficiencies of drilling fluids. The flow loop was designed and developed to conduct sweep experiments with the base fluid, fiber-containing fluid and weighted fiber-containing fluid. The sweep efficiency is evaluated in terms of the amount of cuttings removed from a previously formed stationary cuttings bed by the base-fluid as a drilling fluid. Fig.2 represents an example of a cuttings bed measurement at a station along the test section. Tests were conducted in the horizontal and inclined (70º and 55º) configurations without inner pipe rotation. The flow loop has a transparent 12-ft long annular section (2" × 1"). The annular test section is made of a 2-inch polycarbonate tube and a 1-inch, fully-eccentric inner pipe (stainless steel rod). A schematic of the flow loop is presented in Fig. 3, which demonstrates how the sweep tests are performed and the desired bed thickness and liquid circulation rates are maintained. All tests were conducted at ambient temperature conditions. A centrifugal pump with maximum capacity of 32 gpm (base fluid) is used to circulate the fluid in the flow loop. The pump flow rate is automatically controlled by varying the motor speed using a variable speed drive (VFD). A magnetic flow meter placed downstream of the centrifugal pump measures the flow rate. A test section bypass line was constructed in parallel with the test section. After accumulating the desired quantity of cuttings (river sand with mean particle diameter of 0.12-in) in the test section, the bypass line is opened while closing flow through the test section using a three-way valve installed at the inlet. The bypass line is used for flushing out cuttings deposited in the piping outside the test section.

The current investigation involved experimental studies conducted on hole cleaning performance of weighted fiber-containing sweeps. Four test fluids were used in the sweep experiments as i) base fluid, ii) fiber-containing sweep fluid, iii) barite-containing fluid with density 10 ppg and iv) fiber and barite-containing sweep fluid. Compositions and rheological parameters of the test fluids are presented in Table 1. All test fluids show similar rheological behavior. However, adding the barite to the base fluid slightly increases the viscosity of the fluid (Fig. 4).

A special synthetic super-sweep fiber was used in this investigation. The fiber is processed 100% virgin synthetic monofilament fiber that is designed to increase the lifting, carrying and suspension characteristics of drilling fluids. Physical properties of the fiber are presented in Table 2.

Test Procedure

The following steps were taken to accomplish a sweep efficiency test with the flow loop:

i. **Fluid Preparation:** The sweep experiment begins by mixing water and Xanthan Gum, XCD (0.5% w/w) in the mixing tank while the test fluid is being circulated using the centrifugal pump. After sufficient mixing, a homogeneous suspension (base fluid) forms in the system. In weighted fluids, barite is added to the base fluid until it reaches the desired properties (i.e., density of 10 lb/gal). A rheology test (using rotational viscometer) with the base-fluid is performed before starting cuttings injection. Viscosity and density of the test fluid is adjusted by adding water, polymer or barite while mixing and circulating.

ii. **Cuttings Bed Formation:** The ball valve placed at the bottom of the collection tower is opened to begin injection of cuttings into the system. The test fluid and cuttings are circulated through the test section to build a cuttings bed. As the cuttings injection proceeds, the cuttings bed builds in the piping and test section. The injection of cuttings and fluid circulation are stopped when the desired quantity of cuttings is accumulated in the test section. The remaining cuttings accumulated in the piping are flushed by diverting the flow from the test section to the bypass line using a three-way valve.

iii. **Preparation of Fiber Sweep:** The fiber-containing fluid is prepared by adding the desired quantity of fiber (0.05% w/w) to the test fluid in the mixing tank. The mixer is turned on to disperse fiber particles while the pump circulates test fluid through the test section bypass line. After sufficient mixing, a homogeneous fiber suspension forms. The rheology of the fiber sweep is measured and adjusted (by adding water or polymer) before starting the sweep test.

iv. **Circulation of Sweep-Fluid:** The original bed thicknesses in the test section are measured before starting the sweep fluid circulation. Flow through the bypass line is then diverted to the test section using the three-way valve. The sweep fluid erodes the cuttings bed gradually at a constant flow rate until an equilibrium condition is established. Subsequently, the sweep circulation is stopped and bed thicknesses are measured at seven different locations along the test sections. The measured bed thicknesses are used to determine the average equilibrium bed height that corresponds to a given flow rate. Tests proceed with a stepwise increase in the flow rates until a critical flow rate, the minimum flow rate at which all cuttings are flushed, is reached.

Results and Discussion

Flow loop tests were conducted to investigate the effect of fiber and barite on the sweep efficiencies of four types of polymer-based drilling fluids at different inclination angles. The sweep efficiency is evaluated in terms of the amount of cuttings removed from a stationary cuttings bed formed in the test section. Tests were conducted in horizontal (90º) and inclined (70º and 55º) configurations without inner pipe rotation. Figures 5 through 7 show measured bed heights along the test section. For the horizontal configuration (Fig. 5), the fiber-containing fluid initially shows better cleaning efficiency than the base fluid; however, the critical flow rates to completely clean the test section are similar. The base fluid, the fiber-containing fluid and the barite fluid all completely flush the cuttings at 24 gpm. The barite-fiber-containing fluid (Fig. 5(d) flushes the cuttings from most of the test section at 14 gpm. Figures 6 and 7 (70^o and 55^o inclination angles, respectively) show trends similar to those in Figure 5. The main mechanism under which fluid containing fibers provides a better cleaning efficiency is the mechanical agitation (brushing) of cuttings bed particles by a network structure (fiber mat) that forms due to the entanglement of fiber particles. Therefore, improvement in sweep efficiency is most likely due to mechanical effects.

For a better analysis of results, one can look into the variation of the average bed height versus circulating flow rates. Figures 8 to 10 present average equilibrium bed heights as a function of mean flow rates. For a horizontal configuration, although fibers improve the cuttings removal efficiency, the effect of barite on improving the cuttings transport efficiency is more significant (Fig. 8). The addition of barite to the base fluid lowered the critical flow rate from 22 to 20 gpm. The fiber-barite-containing fluid gives the best efficiency with a critical flow rate of 16 gpm. Similar results were obtained for other inclination angles. It seems that at low inclination angles, the increased density of barite-containing fluids (10 ppg) significantly helps the cuttings stay in suspension through buoyancy force. The combined effects of buoyancy and the fiber-mat network lead to a better cuttings sweeps at all the inclination angles investigated.

As we decrease the inclination angle, the effect of fiber diminishes and the effect of barite dominates (Figs. 9 and 10). While the fiber sweep shows better hole-cleaning efficiency than the base-fluid in horizontal or highly inclined configurations, adding barite consistently reduces the bed height for all inclinations. At 70º inclination, the base-fluid and fiber sweep show approximately the same effectiveness in reducing the bed thickness (i.e. to less than 10% bed height) at low flow rates. However, improvements were observed with the fiber sweep at higher flow rates. The critical flow rates to completely clean the test section were reduced by at least 25% upon adding fiber to the base and weighted fluids. At 55º inclination, the fiber sweep does not shows improved efficiency but adding barite to the base fluid and the fiber fluid results in significant improvement in cuttings removal (at least 40%). Generally, improved hole-cleaning efficiency was observed when using fiber and weighted sweeps.

Summary

From the experimental studies that were performed to investigate hole-cleaning performances of weighted fiber containing fluids, the following conclusions can be drawn:

- Without inner pipe rotation, adding fiber materials into drilling sweeps improves sweep efficiency of the fluid in fully eccentric annuli, for horizontal and near horizontal configurations;
- Weighted sweeps cleaned the test section predominantly better than the base fluid; the weighted fluid shows better cuttings transport efficiency at lower inclinations angles.
- As the inclination angle decreased (from horizontal to vertical) the cuttings removal efficiencies of the fluids tested were dominated by the fluid density (barite content) rather than by fibers alone. Therefore by using a combination of weighted and fiber-containing fluids, cuttings transport efficiency can be improved over a higher range of inclination angles.

Experimental results indicate that adding fibers improves the cuttings transport efficiency. However, the effect of fiber on hole-cleaning performance is more pronounced in horizontal configuration while in inclined configuration the effect of barite dominates. Weighted fiber-containing sweeps show better hole cleaning capabilities than unweighted fluids, especially in the horizontal configuration.

Acknowledgments

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Nomenclature

MMF=monofilament fiber

VFD= Variable Frequency Drive

ppg= lb/gallon

k = consistency index, m/Lt^{2-m},$Pa.s^m$

m = flow behavior index,

τ_y = drilling mud yield value, m/Lt^2, Pa

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Table 1: Composition and Rheological Parameters of Test Fluids

Fluid	Composition [w/w]		Rheological Parameters			Density
	XCD	Fiber	k [lbf.s^m/100ft^2]	m	τ_y [lbf/100ft^2]	ρ [ppg]
Base Fluid	0.5%	0.00%	2.1	0.41	3.5	8.34
Fiber Sweep	0.5%	0.05%	2.4	0.4	2.9	8.34
Barite-containing	0.5%	0.00%	2.3	0.42	3.1	10
Fiber-barite-containing	0.5%	0.05%	2. 8	0.39	2. 5	10

Table 2: Physical Properties of Super-Sweep

Appearance: White "hair-like"	
SG: Slightly lighter than water	
Absorption: Nil	
Softening Point: 315°F.	

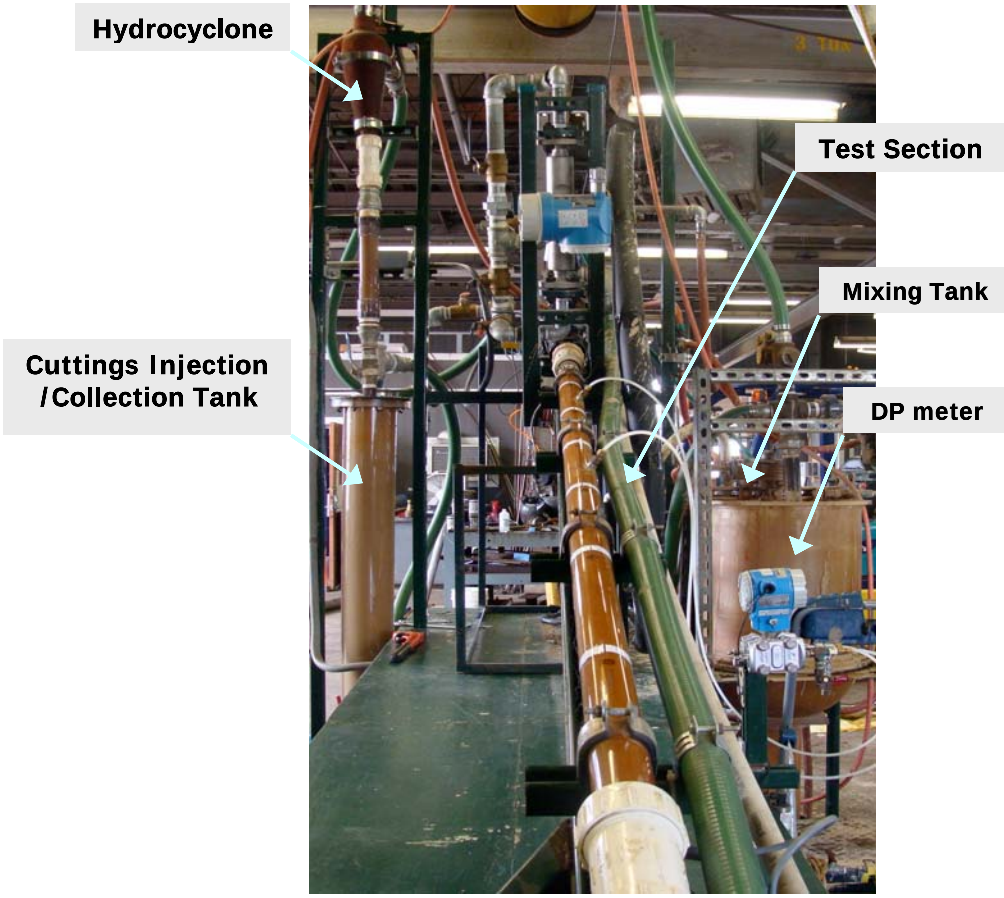


Fig. 1: Small-Scale Indoor Sweep Flow Loop

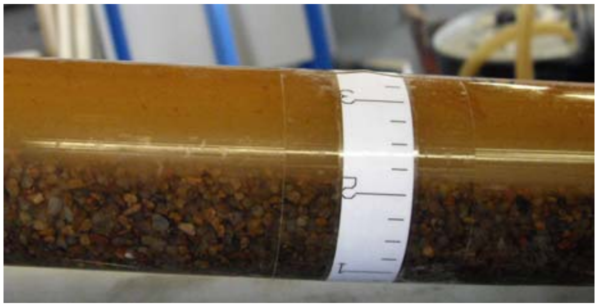


Fig. 2 Example of a bed height measurement along the test section

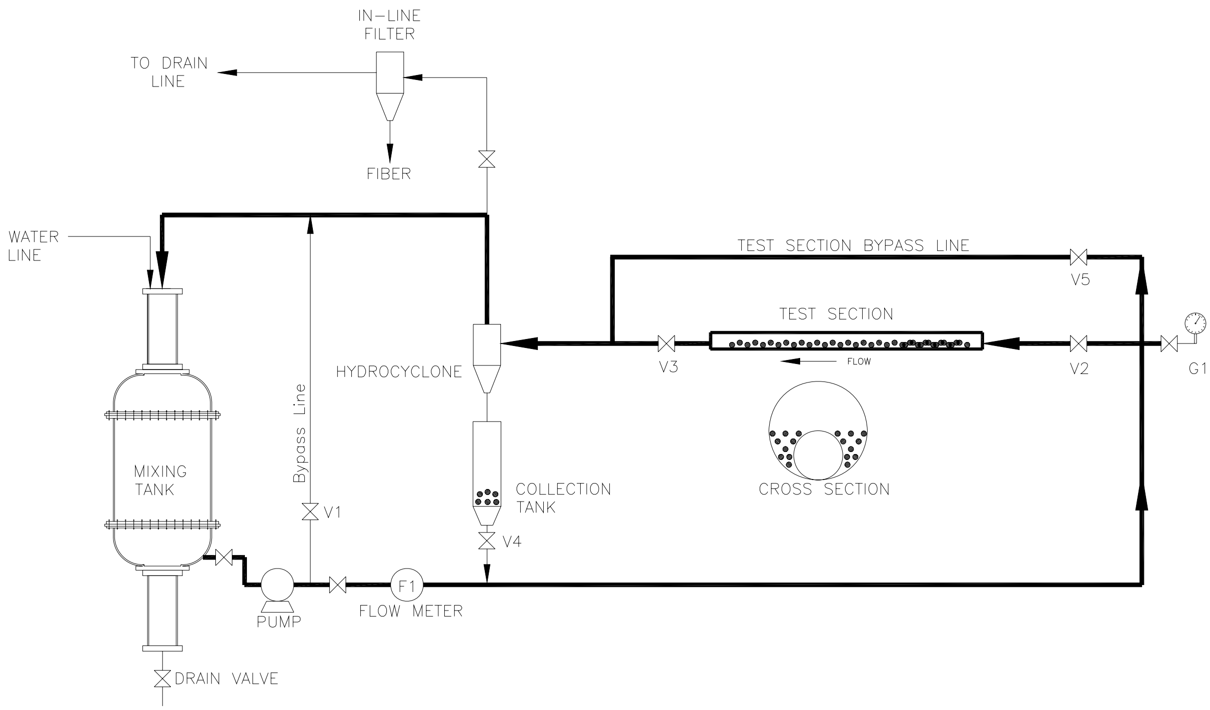


Fig. 3 Schematic of the Sweep Flow Loop

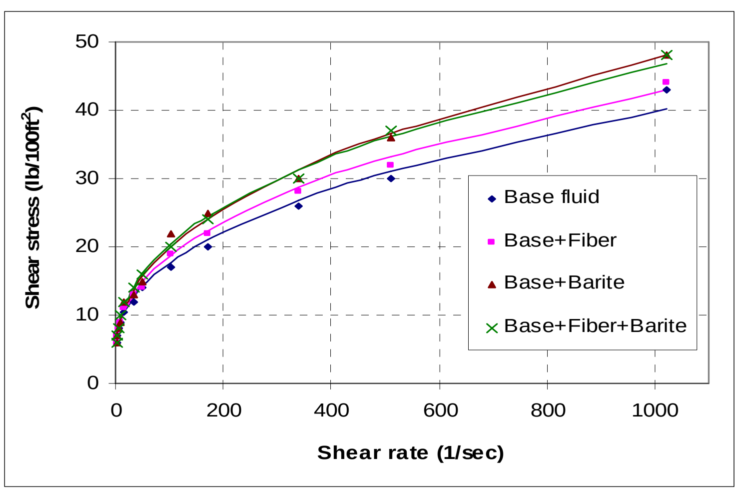
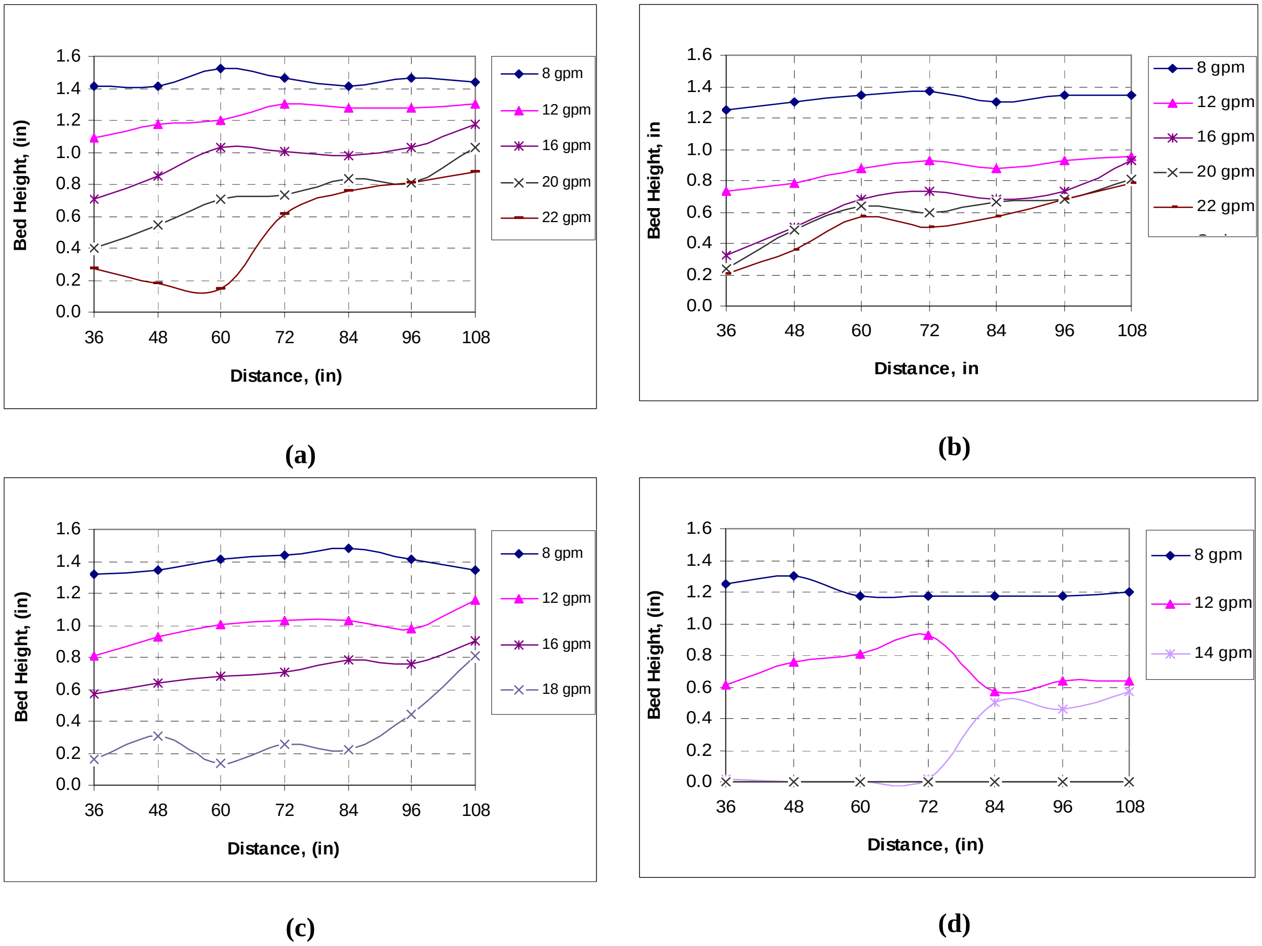


Fig. 4: Rheological measurement from rotational viscometer



(a) (b) (c) (d)

Fig. 5: Measured bed heights at different locations along the test section for horizontal configuration: a) Base-fluid; b) Fiber Sweep; c) Barite-containing fluid; d) Fiber-Barite-containing Fluid;

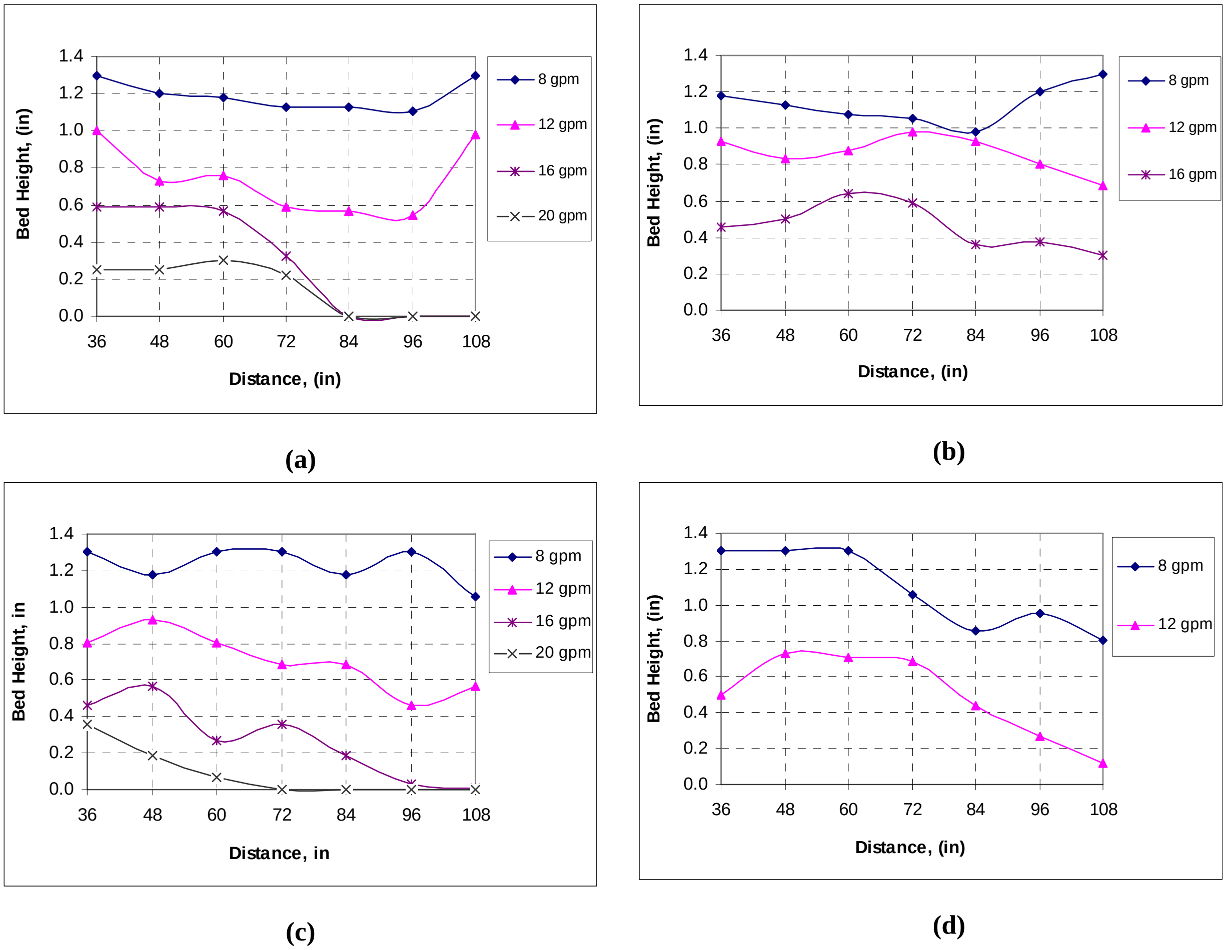


Fig. 6: Measured bed heights at different locations in the test section for 70º inclination angle: a) Base-fluid; b) Fiber Sweep; c) Barite-containing fluid; d) Fiber-Barite-containing Fluid.

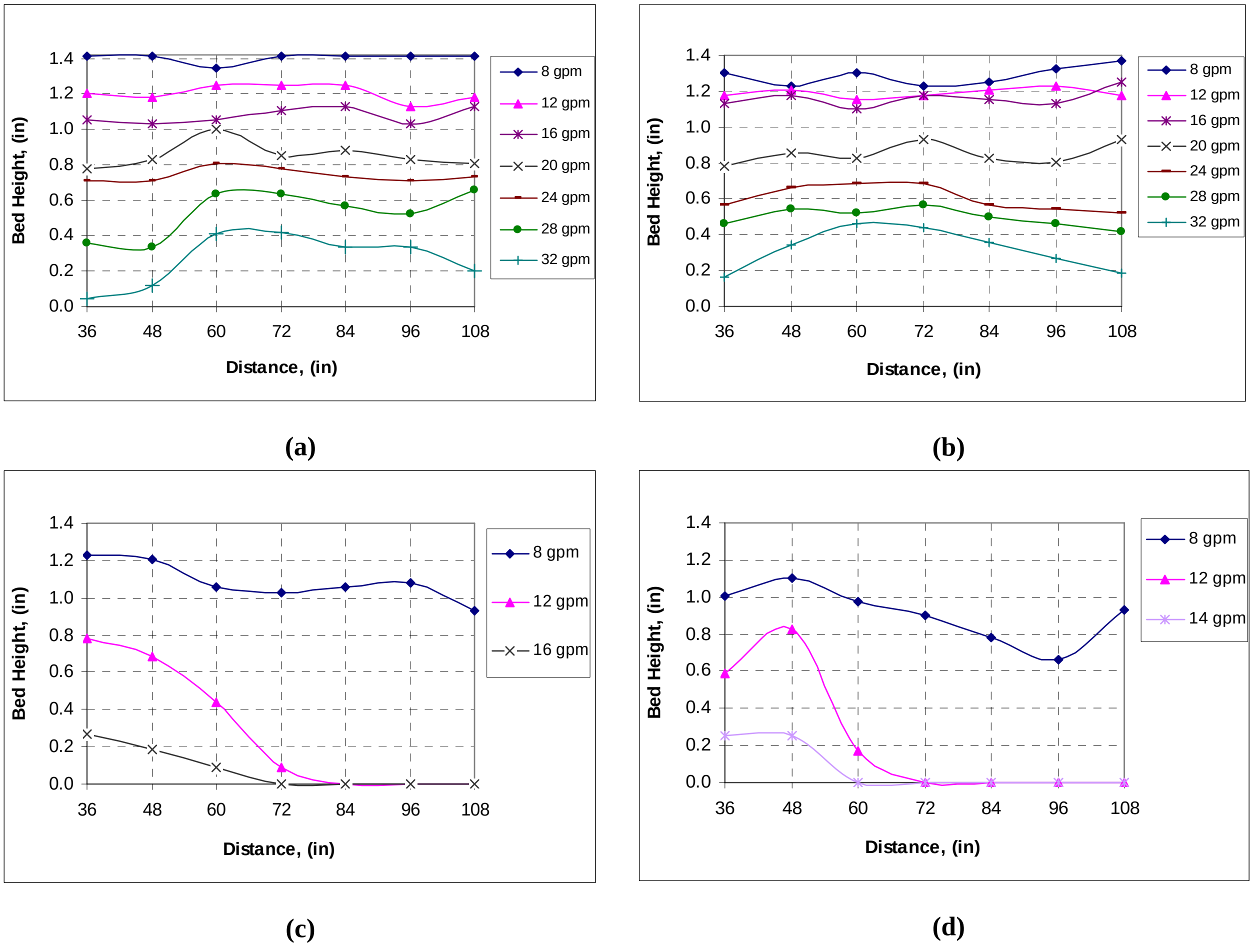


Fig. 7: Measured bed heights at different locations in the test section for and 55º: a) Base-fluid; b) Fiber Sweep; c) Barite-containing fluid; d) Fiber-Barite-containing Fluid.

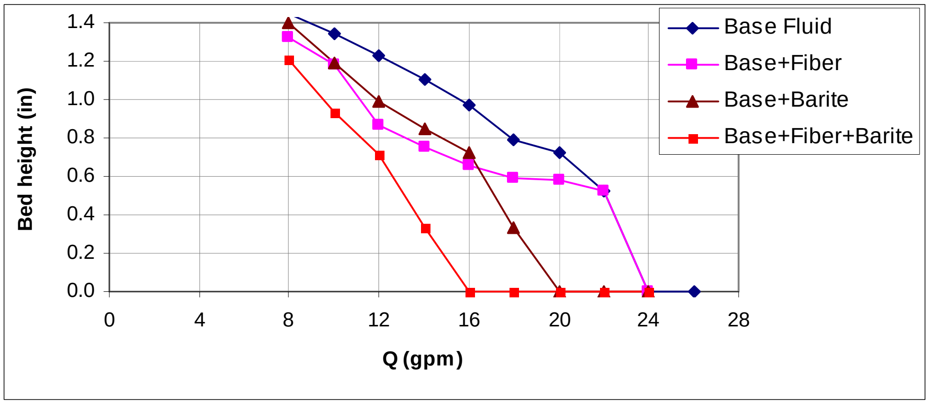


Fig. 8 Measured average bed heights as a function of flow rate for horizontal configuration

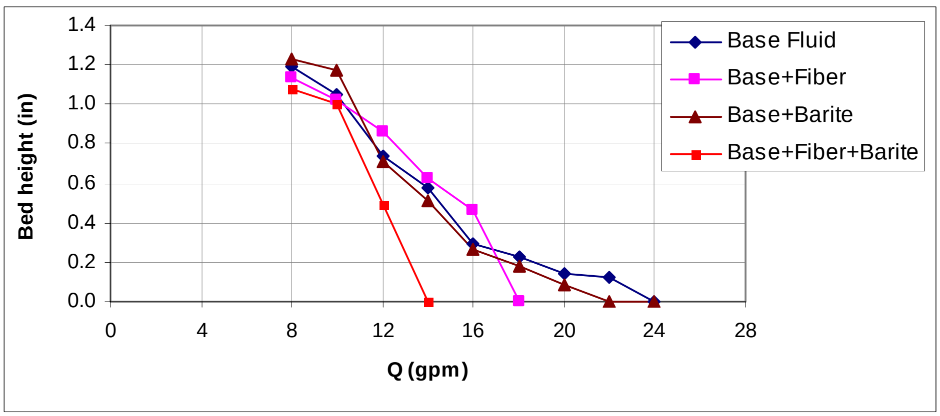


Fig. 9 Measured average bed heights as a function of flow rate for 70º inclination angle

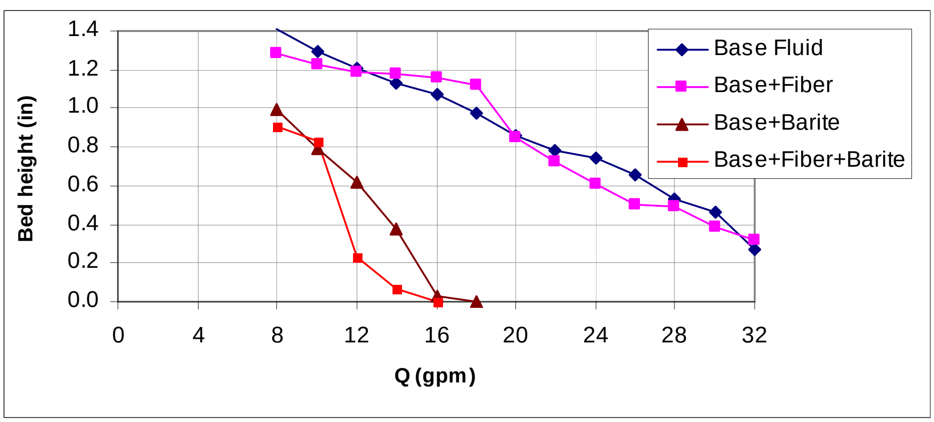


Fig. 10 Measured average bed heights as a function of flow rate for 55º inclination angle