Economic Evaluation of Environmentally Friendly Vegetable Oil-Based Invert Emulsion

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Abstract:
Stringent environmental regulations and technical requirements of difficult formations such as shale demand the use of functional mud system to complete a well safely and economically.

The economic viability of 50/50 oil-water ratio invert emulsion which uses vegetable oil and egg yolk as a non-toxic emulsifier was evaluated.

The evaluation showed less cost of mud formulation by 67% and disposal by 47.5%. This equate to saving of $55.82 per barrel of invert emulsion formulated and $28.50 per barrel disposed.

The low oil-water ratio mud is viable for low fluid loss for enhanced wellbore stability and less oil retained on drilled cuttings

Keywords: Environmental compatibility, non-toxic additives, vegetable oil base fluid, low cost Wellbore stability.

1.Introduction

Drilling fluid or mud is an essential element that drives every drilling operation. It solely represents one fifth (15 -20%) of the total cost of well drilling [1]. Since no two drilling operations are the same it is difficult to get a standard drilling fluid. The difference in environmental regulations throughout the world contributed to the difficulty in finding an effective, high performance drilling fluid with low cost. A cost effective, customised fluid solution is necessary to ensure maximum drilling performance and reduce the risk of major down hole issues. According to [2], the economic losses caused by wellbore instability account for more than one billion dollars every year and the lost time accounts for over 40% of all drilling related non-productive time.

The choice of fluid depends mainly on the formation lithology, cost and environmental concerns. Invert emulsion mud has been extensively used in the oil and gas industry especially for difficult and challenging formations such as shale due to the fluids sterling properties such

as improved wellbore stability, penetration rate, and greater cleaning abilities with less viscosity. The enhanced shale inhibition ability of invert emulsion fluids is of particular importance in shale formations for multi-stage fracking. [1] defined invert emulsion mud as oil based drilling mud to which water is added. According to [2] while drilling through shale formation, the water activity of the invert emulsion fluid is maintained at lower level than the water activity of the shale. This creates an osmotic pressure that drives the flow of water from the shale to the invert emulsion fluid thereby preventing shale hydration. These properties may help to reduce operation cost. However, the use of potentially hazardous base fluids and chemicals like diesel pose environmental issues associated with the disposal and hazards to personnel. This has called for alternative base oils to diesel and non-toxic additives that will be environmentally friendly while maintaining high technical performance. Over the years several plant oils such as Rapeseed oil, Mahua oil, Cottonseed oil, Sesame oil, Soya bean oil, palm oil, Canola oil, Moringa seed oil, Soapnut and Jatropha have become popular as substitute for diesel because of their low toxicity. Some of these vegetable oils are relatively more expensive than diesel which could ultimately increase the cost of drilling fluid however, considering the harmful effect of diesel oil-based mud and high cost of disposal, the use of non-toxic vegetable oils becomes necessary.

[3] investigated the rheological, filtration and toxicity properties of palm oil-based mud. He observed that palm oil-based mud was non-toxic, cheap and had high flash point and good emulsion stability. However, the mud had undesirable properties such as high plastic viscosity, high pour point, low aniline point and high filter loss. [4] encouraged the use of oil based muds developed with palm oil and groundnut oil due to their high level of biodegradability and better eco-toxicological properties, however they exhibited adverse effects such as high viscosity and progressive gel. In a similar study, [5] investigated the physical and chemical properties of castor oil as vegetable oil-based mud and also observed relatively very high viscosity. [6][7] investigated the properties of Jatropha oil as vegetable oil-based mud, they observed that Jatropha oil exhibited better adaptability, higher carrying capacity and less pressure loss in pipe than diesel oil-based mud.

Above reviews on work with vegetable oils suggests that Jatropha oil is the most relatively technically, environmentally and economically viable alternative to diesel oil. However, the formulation of low oil-water ratio mud with vegetable oil has a major challenge. It adversely affects the mud rheology and stability. According to [8], low oil-water ratio of 60/40 is beneficial in producing low fluid loss although mud rheology will need to be considered. It is always a challenge to reduce oil-water ratio during the formulation of a mud system. So far the

industry was not able to reduce the oil-water ratio in their mud formulation beyond 85/15. This is a major gap in the previous work towards the development of sustainable oil based mud systems using vegetable oils [9]. In a preliminary test result of vegetable oil-based mud, [10] noted that duratone used as fluid-loss control additive in mineral oil-based muds is not suitable for vegetable oil-based muds. [11] emphasized the need for careful selection of additives for vegetable oil-based mud. He noted that additives that will function in base-oil from hydrocarbon or synthetic source may not be functioning well in vegetable grade oil-base medium. In line with compatible and non – toxic additives, [12] formulated 50/50 oil-water ratio invert emulsion using Jatropha oil and egg yolk as a non-toxic emulsifier. The electrical stability value of the mud was 353volts at 48. 9ºC. The high water content clearly improves the filtration property with a 30-minute fluid loss of 6ml which is essential for wellbore stability. This will also reduce the oil retained on drilled cuttings thereby reducing the cost of disposal.

This study therefore evaluates the economic viability of 50/50 oil-water ratio invert emulsion using Jatropha oil and egg yolk as a non-toxic emulsifier.

2. Physico-chemical Properties of Prospective Vegetable Oil Base Fluids

The knowledge of the physico-chemical properties of prospective vegetable oils base fluids is very essential as it helps in early estimation of the mud composition and behaviour. These properties include the following: *specific gravity flash point fire point pour point, kinematic viscosity,* a*niline point and cloud point*. According to [11], vegetable oil-based mud will have several advantages over the mineral oil-based mud due to the possession of the following superior properties such as high flash point, high fire point, and high biodegradability. He further stated that higher flash and fire points indicate better fire resistant capacity and minimum chances of causing operational problems associated with low flash and low fire points. The high flash and fire point also ensure enhanced safety in handling, storage and transportation. Vegetable oils are usually 95-100% biodegradable, non-toxic and pose little or no danger to aquatic or terrestrial, offshore or onshore environment compared to mineral oils of only 30% biodegradability. Table 1 compares the properties of Jatropha and Diesel oils as base oils in oil-based mud.

Table 1 Comparison of Properties of Jatropha and Diesel oils as Base oils used in Oil-Based Muds

Property	Aniline Point (^{O}C)	Pour Point (^{O}C)	Flash Point (^{O}C)	Fire Point (^{O}C)	Kinematic Viscosity @40^{O}C, cST	Aromatic Content (%)
Required Properties of Base Oil	> 65	<Ambient temperature	> 66	> 80	2.3 -3.5	4-8
Diesel Oil		- 6	65	78	2.86	
Jatropha Oil		6	214	256	36.92	

Source of Required Properties of Base oil- **Yassin et al 1991**

Key: **Green**- Compatible**, Red-** Not compatible, **White** –Not determined

Diesel and Jatropha oils were evaluated in relative to some characteristics such as availability, cost effectiveness, environmental compatibility, rheological and filtration properties. These characteristics were ranked in low, medium and high as shown in Table 2

Table 2 Evaluation Matrix of Diesel and Jatropha Oil

Base Oil	**Rheological Properties**	**Filtration Properties**	**Cost Effectiveness**	**Availability**	**Environmental Compatibility**
Diesel	High	High	Low	High	Low
Jatropha	Medium	High	High	High	High

2.1 Cost Comparison for formulation of 50/50 OWR Diesel and Jatropha Oil Based Muds

One barrel of 50/50 OWR invert emulsion mud was formulated using diesel and jatropha oils respectively. The conventional additives were used for diesel based mud while egg yolk was used as non-toxic emulsifier in the case of the Jatropha oil-based mud. The cost comparison of these muds was based on the base oil and the emulsifier. It is worth stating here, that not all the benefits of vegetable oil-based mud are measurable in financial terms considering all the environmental benefits. It is also difficult to find accurate comparative data for total cost of

formulation of diesel oil-based and vegetable oil-based muds. With the available data, comparison of the formulation cost of one barrel of diesel oil-based mud and vegetable oil-based mud is shown in Table 3.

Table 3 Cost Comparison for formulation of 1bbl of 50/50 OWR Diesel and Jatropha Oil Based Muds

Cost Parameter	**Diesel Oil-Based Mud**	**Jatropha Oil-Based Mud**
Cost of base oil (US$/bbl)	130.62	54.8
Required volume of base oil (bbl)	0.50	0.50
Cost of base oil per required volume (US$/bbl)	65.31	27.4
Cost of Mud Additive - emulsifier (US$/bbl)	1.5	0.007
Required volume of Mud Additive(emulsifier) (ml)	12	12
Cost of Mud Additive per required volume (US$/bbl)	18	0.09
Cost of base oil + Additives (US$/bbl)	**83.31**	**27.49**
Total cost of formulation of 1barrel (US$/bbl)	**83.31**	**27.49**

2.2. Cost Comparison of Management and Disposal of Diesel oil-based and Vegetable oil-based muds

Throughout the drilling process, drilling mud is recirculated, which helps to decrease waste by reusing as much mud as possible. However, when the drilling process is completed, the drilling waste must be disposed of. Method of disposal of the used mud and drilled cuttings vary depending on the choice of the operator. The choice to a large extent depend on the type of generated cuttings and cost of treatment and disposal. Disposal method could be onsite, offsite, using farmlands, landfills, and thermal technologies. Salt water muds and oily cuttings are not suitable for onsite management. In some cases environmental sensitivity precludes onsite waste management. Cost effectiveness is also another reason for commercial waste management facilities because rather than constructing, operating and closing an onsite facility for a relatively small volume of waste [13]. Oil-based mud cuttings from diesel and mineral oils

pose a complex and costly waste management challenge and cannot be discharged on-site. Waste streams high in hydrocarbons ranging from 10-40 % like oil-based mud are candidates for thermal treatment technology. Cost of thermal treatment of oily waste ranges from $75 to $150 per ton with labour being a large component [14]. Diesel oil-based muds pose greater risk than vegetable oil based mud through skin irritation and effects of inhalation. The added transport and disposal costs as well as potential liability issues associated with diesel oil-based mud have restricted the widespread usage while putting vegetable oil-based mud as a preferred alternative. In 1997 disposal costs reported by [15] offsite commercial disposal facilities for oil-based drilling wastes ranged from $0 to $57/bbl and for water based drilling waste ranged from $0.20 to $14.70. Most operators charge transportation cost by hour typically $55.00/hr to $175.00/hr. Others use per-load or per container basis for instance in one case $1.00/bbl to $3.00bbl [16]. Not all the benefits of management and disposal of vegetable oil based mud are measurable in financial terms considering all the environmental benefits. It is also difficult to find accurate comparative data for total drilling waste management costs for diesel oil-based and vegetable oil-based muds. With the available data, comparison of the disposal cost of one barrel of diesel oil-based mud and vegetable oil-based mud is shown in Table 4.

Table 4 Cost Comparison of Management and Disposal of Diesel oil-based and Vegetable oil-based muds

Cost Parameter	**Diesel Oil-Based Mud**	**Vegetable Oil-Based Mud**
Cost of transportation of drilling wastes to disposal site (US$/bbl)	3.0	3.0
Cost of Commercial disposal of drilling wastes (US$/bbl)	57.0	28.50
Cost of transportation + Disposal (US$ /bbl)	**60.0**	**31.50**
Total cost of disposal of 1barrel (US$/bbl)	**60.0**	**31.50**

3. Result and Discussion

Comparison of the cost of formulation of one barrel of mud evaluated on base oil and emulsifier showed that Jatopha oil-based mud at the cost of $27.49/bbl is cheaper than diesel oil-based mud at $83.31/bbl as illustrated in Figure 1. Similarly, the cost of disposal of drilling wastes of jatropha oil-based mud at $31.50 is lower than that of diesel oil-based mud at $60.00 as shown

in Figure 2. These evaluations as illustrated in Figure 1 and Figure 2 respectively have shown less cost of mud formulation by 67% and disposal by 47.5%. This equates to saving of $55.82 per barrel of invert emulsion formulated and $28.50 per barrel disposed as shown in Figure 3. The cuttings generated using diesel oil-based muds need special treatment before discharging them to prevent contamination of water with free oil. The use of more water in the formulation of 50/50 OWR invert emulsion mud means less cost of formulation. This is technically viable in reduction of fluid loss for enhanced wellbore stability. Less oil retention on cuttings will reduce cost of disposal and environmental impact. The high water content with no fluid loss additive also means less cost of mud formulation. [12] While drilling through shale, the water activity of the invert emulsion fluid is maintained at a lower level than the water activity of the shale creating an osmotic pressure that drives the flow of water from the shale to the invert emulsion fluid thereby preventing shale hydration and less fluid loss which are essential for wellbore stability. High wellbore stability will ensure maximum drilling performance thereby reducing non-productive down-time and economic losses. The comparison of the cost of formulation and disposal of diesel oil-based mud and Jatropha oil-based mud has shown that vegetable oil-based mud is relatively more economically viable than diesel oil-based mud.

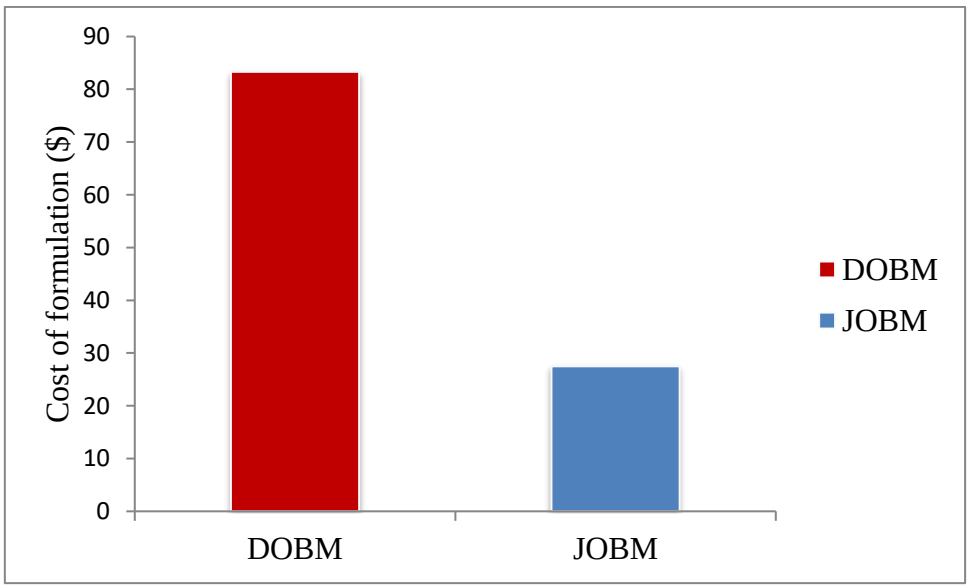

Figure1 Cost Comparison for formulation of 1bbl of 50/50 OWR Diesel and Jatropha Oil Based Muds

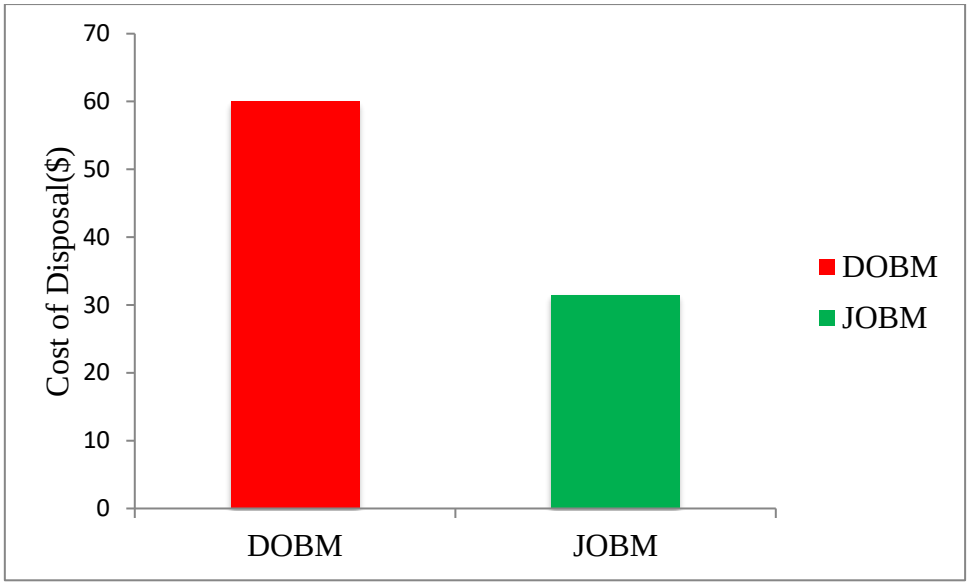

Figure 2 Cost Comparison of Management and Disposal of Diesel oil-based and Jatropha oil-based muds

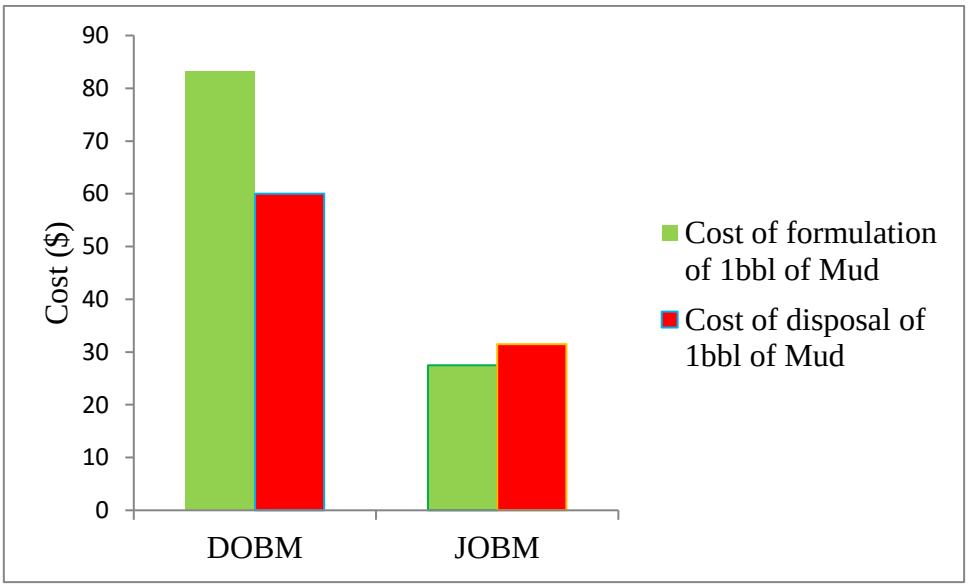

Figure 3 Cost Comparison of Formulation and Disposal of Diesel oil-based and Jatropha oil-based muds

Conclusion

The economic evaluation of 50/50 oil-water ratio invert emulsion using vegetable oil and egg yolk as a non-toxic emulsifier has shown less cost of mud formulation by 67% and disposal by 47.5%. This equates to saving of $55.82 per barrel of invert emulsion formulated and $28.50 per barrel

disposed. The low oil-water ratio mud is essential for low fluid loss for enhanced wellbore stability and less oil retained on drilled cuttings. It is difficult to find accurate comparative data for total drilling formulation, waste management costs for diesel oil-based and vegetable oil-based muds, however from available data, diesel oil-based mud exhibited higher cost compared to jatropha oil-based mud. Again, it is not all the benefits of formulation, management and disposal of vegetable oil based mud are measurable in financial terms considering all the environmental benefits. The use of Jatropha oil and egg yolk as emulsifier means more safety to personnel, no detrimental effect on the environment and overall reduction on cost of mud formulation, treatment and disposal.

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