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Investigative Review on Cutting Transportation Ability of Ionic Liquid-Based Drilling Mud

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Abstract: The inadequate removal of cuttings from the wellbore leads to poor wellbore cleaning, thus causing wellbore instability, impeding the whole drilling process. Many parameters affect the cutting transportation phenomenon of the drilling mud. The fluid parameters that depend upon mud rheology are the most important ones. Lately, various investigators have been using different combinations of ionic liquids (IL) as a drilling fluid additive to improve the Yield point vs. Plastic Viscosity ratio (YP/PV) of the mud, which is considered as the best indicator of mud rheology. This study aims to review and investigate the efficiency of different ionic liquid-based drilling muds to improve the mud cutting transportation ability. The conducted systematic review shows that the 'imidazolium' based ionic liquids are the most popular among various investigators. The paper presents the comparative analysis of drilling fluid compositions, optimized concentration, the effect of alkyl chain length, and type of ionic liquids with the resultant Yield Point (YP) vs. Plastic Viscosity (PV) ratio utilized by various research groups. Lastly, Moore's correlation has been used to comparatively analyze the YP and PV effect on cutting transport ratio, which demonstrates that high mud rheology will improve the cutting transportation ability up to 96%.

Keywords: ionic liquids, cutting transport, drilling mud, Moore's correlation.

降低离子液体基钻井泥浆运输能力的研究综述

摘要：从井眼中去除钻屑的不足会导致井眼清洁性差，从而导致井眼不稳定，从而阻碍整个钻井过程。许多参数影响钻探泥浆的切割运输现象。取决于泥浆流变学的流体参数是最重要的参数。最近，各种研究人员一直在使用离子液体（白介素）的不同组合作为钻井液添加剂，以提高泥浆的屈服点与塑性粘度比（YP/光伏），这被认为是泥浆流变性的最佳指标。本研究旨在回顾和研究不同离子液体基钻井泥浆提高泥浆切割输送能力的效率。进行的系统审查表明，基于"咪唑鎓"的离子液体在各种研究人员中最受欢迎。本文介绍了钻井液成分，最佳浓度，烷基链长的影响以及离子液体类型的比较分析，各种研究小组都使用了所得的屈服点（YP）与塑性粘度（光伏）之比。最后，利用摩尔相关性比较了 YP 和光伏对切割石运输比的影响，表明高泥浆流变性将提高切割运输能力高达 96%。

关键词：离子液体，切削运输，钻探泥浆，摩尔的相关性。

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1. Introduction

Drilling mud performs several functions, among which suspension, removal, and transportation of the cuttings from the hole are most crucial [1, 2]. The inefficient removal of the cutting from the bit area to the surface will lead to poor wellbore cleaning and wellbore instability, leading to non-productive time [3, 4].

Many parameters control the cutting transportation phenomenon, which can generally be categorized into three groups: tabulated in Table 1 [5, 6].

Table 1 Grouping of cutting transportation parameters

No.	Grouping	Parameters
1	Cuttings' based	Cuttings' shape, size, density, and concentration
2	Fluid based	Drilling fluid rheology
3	Operation based	Rotation speed, Inclination angles, Eccentricity

Many models reported in the literature help understand the effect of Cuttings and Operational parameters on cutting removal. However, few reported work publications report about the effect of drilling fluid rheology on its transportation ability [7]. Rheology generally deals with non-Newtonian fluids such as drilling mud which shows shear thinning behavior [8, 9]. Shear-thinning is a behavior in which the viscosity of fluid decreases under shear strain [10]. When the drilling mud is circulating through the drill string, low viscosity is required for easy circulation. However, when it passes through the annulus with cuttings, high viscosity is expected for the effective suspension and transportation of the cuttings [11, 12]. Therefore, shear-thinning behavior is recommended for the drilling fluids [13].

The shear-thinning behavior and cutting transport capability of the drilling fluids can be characterized by YP/PV (ratio) [14]. Drilling fluids with very low YP/PV fail to transport cuttings and clean the wellbore while drilling fluids with high YP/PV offer worse drilling hydraulics and overload the circulating system of drilling fluids [15, 16]. The YP/PV values in the range from 0.36 to 0.48 (Pa/mPa.s) (0.75-1 lbm/100ft2/cp) are more suitable because, in that case, the drilling fluids can transport the cuttings and clean the wellbore more efficiently [17, 18].

The drilling mud should be designed so that the drilling fluid will affect the mechanical properties of the formation as least as possible [19]. Different additives affect mud rheology in different ways. Lately, ionic liquids are used as a drilling fluid additive as rheology modifiers [20] due to their various applications. ILs are organic salts that remain in a liquid state at room temperature possessing high thermal stability, no vapor pressure, and a greener nature [21]. Many researchers are utilizing ionic liquid as a drilling fluid additive for improving mud rheology. The YP vs. PV curves have been used to evaluate the drilling fluid conditions.

Various researchers have used the YP/PV ratio as a vital indicator of mud rheology and fluid properties. The survey on the literature of the utilization of Ionic liquid as a drilling fluid additive for rheology modifiers has led to the conclusion there is not much work done, particularly in this domain. However, in this paper, the application of ionic liquid as a potential water-based and polymer-based drilling fluid additive for improving the cutting transportation ability of the mud has been critically explored from the limited available literature. Lastly, Moore's correlation has been used to check the sensitivity of YP and PVon Cutting Transport Ratio (CTR).

2. Ionic Liquid and Cutting Transportation-Related Parameters

All parameters contribute differently to the cutting transportation ability of the mud. A brief review of the individual parameters and the respective effect of ionic liquids on them has been presented in the following section.

2.1. Flow Regimes and Wellbore Cleaning

Wellbore cleaning is a complicated phenomenon that incorporates basic physics, thermodynamics, and fluid mechanics [22]. Usually, in drilling hydraulics, we deal with three flow regimes; laminar, transitional, and turbulent [23].

Laminar flow regime exists at very low pump rates. It causes low friction pressure and minimum hole erosion, but they are most problematic for hole cleaning [24]. In laminar flow, the flow is in layers where the central layers usually move at greater rates than the layers near the wellbore and pipe. This disruption causes a variation in the velocity profile [25]. This variation is dealt with by taking control over the shear-resistant properties of the mud [26].

Turbulent flow occurs at high velocities when shear strength exceeds the layers and fluid can no longer be laminar [27].

From Moore's correlation [28], it can be seen that the addition of ionic liquid will have a direct effect on the flow regime of the drilling fluid, thus changing the drag coefficient (f) and cutting transportation ratio (CTR), which has been tabulated in detail in Table 7 below.

2.2. Effect of Mud Rheology

YP/PV is very significant in determining the effect of cutting transportation [18]. When the fluid is laminar, higher Yield point values, i.e., higher YP/PV values, will give efficient cutting transportation and decrease the cutting bed thickness [29, 30]. Increasing plastic viscosity will also increase the cutting transportation phenomenon to a certain limit [31]. If Plastic Viscosity is increased too much compared to the Yield point, the results will be the opposite, i.e.; it will slow down the cutting transportations [32]. However, mud rheology does not really contribute to the cutting transportation phenomenon when the flow is turbulent [33, 34]. It has also been reported that the increasing ratio of n and K (n/K) from YPL (Yield power-law) will give better cutting transportation [35, 36].

The viscosity of the drilling fluid also plays its role in determining the cutting transportation ability of the mud [37]. The effect of viscosity is directly linked with the fluid flow regime, i.e., laminar or turbulent [33]. An efficient hole cleaning is obtained with a low viscous fluid in turbulent flow for directional wells. However, high viscosity will give an efficient hole cleaning for vertical or near-vertical wells [38].

Ionic liquid directly affects mud rheology. It is one of the reasons why the ionic liquid is recommended by many researchers to customize the mud design according to the requirements. The addition of ionic liquid will increase the YP, PV, and viscosity of the drilling mud, thus altering the mud rheology [39, 40]. However, mud rheology can be controlled by choosing the type of ionic liquid discussed in section 3.2.

2.3. Effect of Cutting Size

The hole cleaning phenomenon is oblivious of cutting size for horizontal wells [41]. The smaller cuttings (2-7mm) are the hardest to remove, but their removal can be made efficient by using high-density mud with a high circulation rate [42, 43]. Compared to smaller cuttings, the larger cuttings can be removed easily with the low viscous fluid [44, 45].

2.4. Effect of the Hole Inclination Angle

The cutting bed problem arises when the inclination angle is between 35^o and 55^o. In general, the cutting transportation phenomenon gets harder when the inclination angle is between 40^o and 60^o.

Laminar flow gives good wellbore cleaning for inclination angles ranging from nearly vertical to 45^o. However, for inclination angles greater than 60^o, the turbulent flow will give better results [34].

2.5. Effect of Drill Pipe Rotation

The pipe rotation does not significantly affect the cutting bed flow rate, but it will significantly affect the cutting bed height. Pipe rotation also has an important role in removing cuttings at low ROP (less than 60rpm) for directional wells.

As reported in [44], the pipe rotation between 80-120 rpm significantly controls the wellbore cleaning. The orbital speed will cause a reduction in critical velocity that is required to remove the cuttings, but the rotary motion does not have any effect after a specific rpm.

It is interesting to note here that the addition of ionic liquids will affect only certain parameters, and it will not have any effect on the independent parameters such as cutting size, hole inclination, and drill pipe rotation.

3. Ionic Liquids and YP/PV Ratios

Mud rheology is the only parameter directly affected by the addition of Ionic liquids in drilling mud. The investigators used different approaches to study the effectiveness of Ionic Liquid to estimate the YP/PV of various ionic liquid-based muds using API 13B/1 standards. Some of them studied only a single Ionic liquid, while some compared IL water-based mud with polymer-based mud. Aging also has a significant effect on the rheological properties of the mud. In this review, the effect of ionic liquid on cutting removal ability will be reviewed separately for the aged and non-aged samples of water-based and polymer-based mud.

3.1. Effect of Ionic Liquids on YP/PV of the Water-Based Mud and Polymer Mud

Yield point (YP) is the measure of the stress required to break the internal resistance of the fluid to make it start flowing. It is also worth mentioning that the yield point for a water-based mud system increases with the increase in temperature, contamination, and caustic overtreatment. In oil field units (OFU), it is measured in $lb/100ft^2$, whereas the investigators prefer to use the SI units of Pa to exhibit yield points. (Pa = 0.47*OFU)

On the other hand, plastic viscosity (PV) is simply measuring the resistance of the fluid in a flow. In other words, particularly, PV measures the solid content in the mud. In OFU, it is measured in cp where investigators tend to report PV in Pa.s (1cp = 1 m Pa.s).

Table 2 summarizes the effect of various ionic liquids in a water-based mud system with no aging. In the table, only optimum concentration has been reported at which the YP/PV values fall into or falls nearer to the recommended range of (0.38-0.48) Pa/m Pa.s. Among the reported ionic liquids, it can clearly be seen that the 1-butyl-3-methylimidazolium chloride and 1-dodecyl-3-methylimidazolium chloride showed better results in terms of YP/PV, which can be attributed to the chain length whose effect has been discussed in the later section and shown in Fig. 1.

Table 3 shows the effect of aging on the reported ionic liquids. It is clearly evident that aging also improves the YP/PV of the mud by altering the mud structure. Table 2 and Table 3 show that aging has improved the YP/PV of the 1-butyl-3-methylimidazolium chloride compared to the non-aged water-based mud system.

Table 2 YP/PV of the WBM with no aging

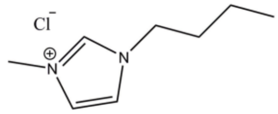
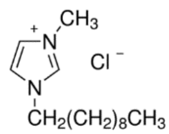
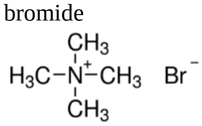
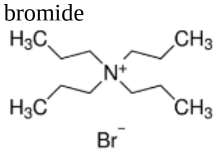
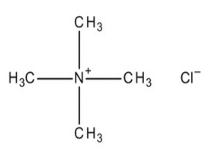
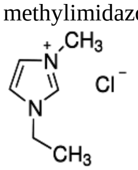
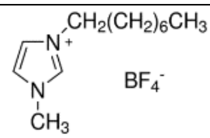
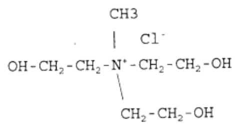
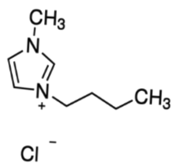
Research Group	**Ionic Liquid**	**Optimum Conc.**	**Drilling Fluid Composition**	**Aging ºC**	**YP/PV (Pa/mPa.s)**	**Blank Sample YP/PV**
Titus Ntow Ofei et al. [1]	1-butyl-3-methylimidazolium chloride 	0.5%	Bentonite Barite Caustic soda Soda ash BMIM-Cl	No	0.504	x
Luo Zhihua Song Bingqiang	1-dodecyl-3-methylimidazolium chloride 	0.05%	Freshwater puree Formulation: water 10L, 3% of sodium bentonite clay + 0.05% by mass of sodium carbonate	No	0.25	0.143
Cornelius et al. I [2]	Tetramethylammonium bromide 	1%	3 wt% NaCl + 0.8 wt% xanthan gum+3 wt%KCl + fresh water + Bentonite	No	1.63	2.21
	Tetrapropylammonium bromide 	1%			1.37	
	Tetramethylammonium chloride 	1%			1.28	
	1-Ethyl-3-methylimidazoliumchloride 	1%			0.94	

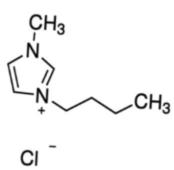
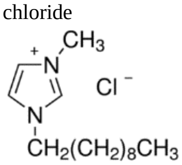
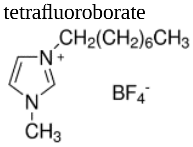
Table 3 YP/PV of aged WBM

Research Group	**Ionic Liquid**	**Optimum Conc.**	**Drilling Fluid Composition**	**Aging ºC**	**YP/PV (Pa/mPa.s)**	**YP/PV blank sample**
Zhihua Luoa et al. [3]	1-octyl-3-methylimidazolium tetrafluoroborate	0.05 %	Fresh water Bentonite and Sodium Carbonate	160	0.33	0.21

						
Arvind et al. [4]	Triethanolamine – methyl chloride condensates 	1.89 %	Bentonite Sea-water Lube 167 PAC-LV Barite KOH KCl Xanthan Gum Bentonite	160	0.125	0.125
Titus Ntow Ofei et al. [1]	1-butyl-3-methylimidazolium chloride 	3% (mass of water)	Bentonite Barite Caustic soda Soda ash BMIM-Cl	150	0.4158	x

From Table 4, it can be seen just like a water-based mud system, the water-based polymer mud also shows the effect of alkyl chain length on YP/PV ratios. 1-dodecyl-3-methylimidazolium chloride used as an additive in polymer water-based mud improved the YP/PV ratio to 0.47, which fell into the recommended range. 1-butyl-3-methylimidazolium chloride, the counterpart having a smaller chain length, did not much improve the YP/PV of the mud, as shown in Fig. 2 below.

Table 4 YP/PV of the polymer – WBM

Research Group	**Ionic Liquid**	**Optimum Conc.**	**Drilling Fluid Composition**	**Aging ºC**	**YP/PV (Pa/mPa.s)**	**YP/PV of the blank sample**
Titus Ntow Ofei et al. [1]	1-butyl-3-methylimidazolium chloride 	3% mass of water	x	No	1.65	x
Luo Zhihua Song Bingqiang et al. [5]	1-dodecyl-3-methylimidazolium chloride 	0.05%	3% bentonite ionic liquid polymer PHPA 0.4% 0.5% NaOH used to adjust the ‘Ph value to 9	No	0.47	0.143
Zhihua Luoa et al. [3]	1-octyl-3-methylimidazolium tetrafluoroborate 	0.05%	Fresh water NaMt and Na2CO3 PHPA	No	0.89	0.21

3.2. Effect of Alkyl Chain Length

Ionic liquids are comprised of two constituents: a cation and an anion. Alkyl chain constituents the cationic portion of the Ionic liquids, while anionic substrate can be a halide or any other nucleophilic species. The cation and anion have different effects on the rheology of the mud. To see the effect of an alkyl chain, ionic liquids with the same anion should be compared to make a rational conclusion. Table 2 shows that 1-butyl-3-methylimidazolium chloride, 1-dodecyl-3-methylimidazolium chloride, Tetramethylammonium chloride, and 1-Ethyl-3-methylimidazoliumchloride can be compared because all of them contain the same anion, i.e., Cl-.

The ideal YP/PV should lie between 0.36-0.48 Pa/m Pa.s. It is evident from Table 2 that 1-butyl-3-methylimidazolium chloride, 1-dodecyl-3-methylimidazolium chloride show close values to the optimum range. It can also be observed that increasing the alkyl chain length will decrease the YP/PV. For 1-dodecyl-3-methylimidazolium chloride, the YP/PV came out to be lower than the optimum range. Thus, the YP/PV can be controlled by customizing the alkyl chain length.

Ionic Liquids containing longer alkyl chains are more efficient in reducing the viscosity due to their higher hydrophobicity and less polarity. The shorter alkyl chain will have rather higher polarity and will develop a polar-polar interaction with the polar part of the drilling mud. Thus, the more intermolecular interaction between the alkyl chain and the mud will result in lesser viscosity reduction and lesser alteration of mud rheology.

4. Investigation of Impact of Ionic Liquid on Fluid Based Parameters on Cutting Transport Ability Using Moore's Correlation

4.1. Moore's Correlation

Moore's graphical method [28] is one of the most used oil and gas industry methods to find the cutting transportability of the drilling mud. It incorporates various parameters in determining the slip velocity, such as hole diameter, cutting size, mud rheology, flow rate, fluid density, and cutting density. In this section, Moore's correlation will be applied to the mud rheology (YP and PV) values of the ionic liquid-based drilling mud discussed under heading 3 by keeping the rest of the parameters constant as given in Table 5 and the results shown in Table 6.

Table 5 Constant parameters for Moore's correlation

Parameter	Value	Parameter	Value
Hole size (d2)	7.875 inches	Fluid density (ρ_f)	9.1 ppg
Pipe size (d1)	4.5 inches	Cutting size (ds)	0.196 inch
Cutting density(ρ_s)	21 lbm/gal	Flow rate (q)	340 GPM

Table 6 CTR estimation by Moore's correlation

Research Groups	**Ionic Liquid**	**Mud type**	**Aging**	**YP**	**PV**	**vs (Est)**	**vs (cal)**	**CTR**
			^{O}C	**lbm/100ft^2**	**cp**	**ft/sec**	**ft/sec**	**%**
Zhihua Luoa et al.	1-octyl-3-methylimidazolium tetrafluoroborate	WBM	No	3.64	2.5	0.604902	0.5976644	82.027483
			120	1.56	1.5	0.781263	0.7823051	76.475105
			160	1.144	2.5	0.781263	0.8344203	74.907935
		Polymer-based	No	8.32	7.5	0.461809	0.4548193	86.323013
			120	2.08	1.5	0.732421	0.7206956	78.327779
			160	1.56	2	0.773093	0.7710643	76.813128
Titus Ntow Ofei et al.	1-butyl-3-methylimidazolium chloride	WBM	25	100	45	0.137058	0.1180168	96.451088
			90	104	48	0.132823	0.1139565	96.573184
			150	86	56	0.154968	0.1353428	95.930072
			180	55	25	0.224139	0.2035266	93.879699
			200	57	11	0.257054	0.2104067	93.672808
		Polymer-based	25	97	28	0.138552	0.1194524	96.407918
			90	92	28	0.144924	0.1255958	96.223178
			150	60	40	0.207501	0.1874307	94.363725
			180	56	37	0.221454	0.2004549	93.97207
			200	41	42	0.294616	0.2701956	91.87488
Luo Zhihua Song Bingqiang	1-dodecyl-3-methylimidazolium chloride	WBM	No	3.12	6	0.598418	0.5911819	82.22242
		Polymer-based mud	No	9.36	9.5	0.43889	0.4319855	87.009655

Cornelius et al.(a)	1-methyl-3-octylimidazolium tetrafluoroborate	XGUM WBM	No	10.4	2	0.452489	0.4239813	87.250351
Arvind et al.	Triethanolamine - methyl chloride condensates	WBM	160	3.64	14	0.511173	0.5040452	84.842728
Cornelius et al.(b)	Tetramethylammonium bromide	WBM	No	11.376	3.36	0.414189	0.4073919	87.749214
	Tetrapropylammonium bromide			12.9584	4.55	0.397873	0.3911566	88.23743
	Tetramethylammonium chloride			10.8784	4.09	0.387784	0.406307	87.781839
	1-Ethyl-3-methylimidazoliumchloride			11.21112	5.74	0.421896	0.4151838	87.514903

Flow velocity can be found by using eq (1). Power Law factors n and K can be found out by using the Power Law model. Apparent viscosity has been found out by using eq. (2). After this, a value of slip velocity has been assumed and used to find Reynold's number and friction factor 'f' using equation (3) - (7). An assumed value of slip velocity can be taken as half of the flow velocity. Then the calculated value will be used to iterate until the estimated and calculated slip velocities match. Cutting transport ratio (CTR) can simply be found by the formula $(v - v_s) / v$ where v is flow velocity and v_s is slip velocity, as shown in table 6, where the slip velocities of matching iteration steps have been reported.

$$v = \frac{q}{2.448(d_2^2 - d_1^2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\mu_a = \frac{K}{144}\left(\frac{d_2^2 - d_1^2}{v}\right)^{1-n}\left(\frac{2+\frac{1}{n}}{0.0208}\right)^n \ldots\ldots\ldots\ldots..(2)$$

$$N_{RE} = \frac{928\,\rho_s v_s d_s}{\mu_a} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$v_s = 1.89\sqrt{\frac{d_s}{f}\left(\frac{\rho_s}{\rho_f} - 1\right)} \ldots\ldots\ldots\ldots\ldots\ldots.(4)$$

$$f = \frac{40}{N_{RE}}\ ; N_{RE} < 3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

$$f = \sqrt{\frac{22}{N_{RE}}}\ ; 3 < N_{RE} < 300 \ldots\ldots\ldots\ldots\ldots..(6)$$

$$f = 1.5\ ; N_{RE} > 300 \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(7)$$

The effect of alkyl chain length on YP/PV and CTR can clearly be seen from Fig.1 and Fig.2. Fig.1 presents the comparison of Ionic liquid incorporated WBM (no aging), which shows that the longer alkyl chain length will result in lower YP/PV and CTR. The justification of the effect of the alkyl chain length has been given in heading 3.2. The same trend can be seen in Fig.2 as well for ionic liquid incorporated polymer-based mud.

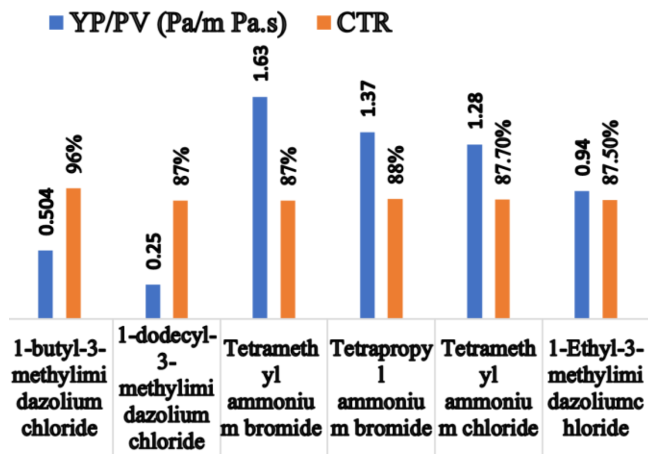


Fig. 1 YP/PV and CTR comparison of ionic liquid in WBM

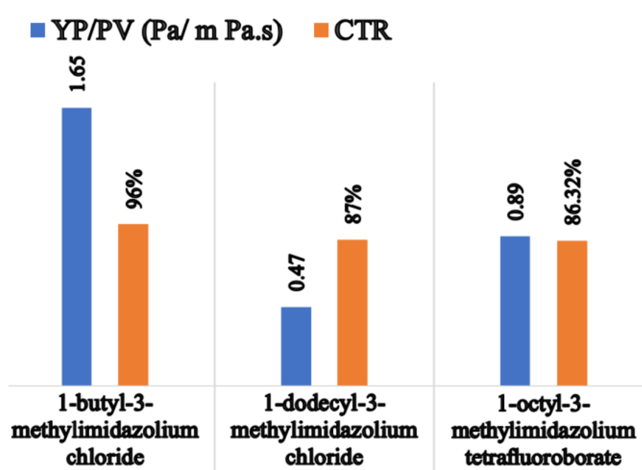


Fig. 2 YP/PV and CTR comparison of ionic liquid-based polymer mud

To understand the effect of mud rheology on effectively cutting transport, YP and PV values have been categorized from very low rheology values to very high rheology values, as shown in Table 7. It can be noted that Moore's model incorporates the effect of YP and PV on CTR. However, this model is not very sensitive to rheology parameters as YP and PV values will have an indirect effect on drag coefficient (f) only. From Table 7, it can be seen very high rheology values give the best cutting transportation, but very high rheology values will cause many operational difficulties. Thus, it can be concluded that this model gives more like a qualitative idea about the cutting transportation ability than quantitative approximation as a function of rheology values.

Table 7 shows that the effect of mud rheology can explicitly be concluded on CTRs. Very low rheology will give relatively poor transportation ability. Intermediate rheology, compared to high and very high mud rheology, gives satisfactory results as in this range of rheology values, there will not be many operational problems associated. Thus, it is recommended to design a mud ranging in intermediate rheology values.

Table 7 Approximated CTR as a function of mud rheology

Rheology	**Yield point (lb/100ft2), Plastic viscosity (cP) ranges**	**Cutting Transportation Ability**
Very Low	YP (1-10) /PV (1-5)	(70-75)%
Low	YP(10-20)/PV (6-10)	(75-80)%
Intermediate	YP (20 -60)/PV (10-20)	(80-90)%
High	YP (61-100)/PV (21-40)	(90-95)%
Very High	YP > 100/PV > 40	>95%

Thus, ionic liquids can be utilized as potential drilling fluid additives to customize the mud design according to the drilling requirements. This review also sheds light that the longer alkyl chain will result in a lower cutting transportation ratio and rheological properties. The same ionic liquid behaves differently for water-based and polymer-based mud systems. Hence, by varying the alkyl chain length, mud rheology can be changed according to the drilling needs. It is also worth mentioning here that this study focuses only on ionic liquid behavior as a rheology modifier in a water-based mud system. Therefore, a different study might be needed to see the ionic liquid behavior in an oil-based mud system.

5. Conclusions

- The YP/PV values in the range from 0.36 to 0.48 (Pa/mPa.s) are more suitable because, in that case, the drilling fluids can transport the cuttings and clean the wellbore more efficiently.
- The higher the alkyl chain length, the lesser will be the YP/PV and CTR.
- Aging improves the YP/PV of the mud.
- Moore's correlation gives a qualitative idea about the cutting transportation ability of the mud, and it is rather lesser sensitive to mud rheology values because the rheology values will, indirectly, only change the drag coefficient (f).
- High mud rheology (high YP and PV values) will apparently result in better cutting transportation ability.
- Very high mud rheology is not really recommended because it will cause a lot of operational difficulties. Therefore, the mud must be designed in an intermediate rheology range.

6. Recommendations

Since mostly imidazolium-based ionic liquids have been used as drilling fluid additive, it is high time for researchers to look for cheaper and rather greener solutions as some of the imidazolium-based ionic liquids have been reported toxic. A new class of ionic liquids, Deep Eutectic Solvent (DES), has been in discussion. They are considered cheaper and greener than conventional ionic liquids, and their in-house preparation is really simple and cheap. DES can be used as a drilling fluid additive, and its effect on mud rheology can be studied.

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