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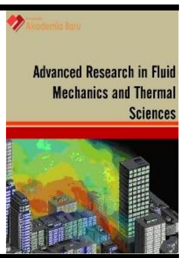

Heat Moisture Modified Rice Flours as Additive in Drilling Fluids

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ABSTRACT

Drilling mud is a dense, viscous fluid mixture used in oil and gas drilling operations to bring rock cuttings to the earth's surface from the boreholes as well as to lubricate and cool the drill bit. Water-based mud is commonly used due to its relatively inexpensive and easy to dispose of. However, several components and additives in the muds become increasingly cautious and restricted. Starch was introduced as a safe and biodegradable additive into the water-based drilling fluid, in line with an environmental health concern. In this study, the suitability of four local rice flours and their heat moistures derivatives to be incorporated in the formulation of water-based drilling fluid was investigated. They were selected due to their natural amylose contents (waxy, low, intermediate, and high). They were also heat moisture treated to increase their amylose contents. Results showed that the addition of the rice flours into water-based mud significantly reduced the density, viscosity, and filtrate volume. However, the gel strength of the mud was increased. The rice flours, either native or heat moisture treated, could serve as additives to provide a variety of low cost and environmentally friendly drilling fluids to be incorporated and fitted into different drilling activity.

1. Introduction

Rice has been consumed as a daily meal due to its high content of carbohydrates, and sometimes it is presented in the form of cookies or rice cake. Through time, rice application has evolved in both the food industry and non-food industry. Rice starch could be modified to make it possible to endure the harsh conditions of those demanding environments in non-food applications. This includes the process of altering starch physical and chemical characteristics to meet the specific requirements in numerous applications. Physical heat moisture treatments (HMT) are preferable in industrial use, as it does not generate undesirable chemical wastes [1]. These hydrothermal treatments could modify

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the starch properties and structure physically without destroying its granular structure. They change the starch gelatinization transition temperature, granular swelling, amylose leaching, and thermal stability [2-5].

The drilling process is an essential part of the oil and gas exploration and production. It requires a fluid medium to control the drilling into a hard rock formation. The drilling fluid, also known as drilling mud, was introduced in 1887 and used until 1901 as essential mixtures of clays and water that had no impact on the surrounding environment [6-8]. The mud was further improved by adding polymers and chemicals to meet the desired specification. It is needed to cool, lubricate, and support drill bit while drilling. In this manner, it must be able to transport the drill cutting to the surface and suspend the drill cuttings to prevent accumulation at the bottom of the well.

There are gas-based, aqueous-based, and non-aqueous based drill fluids available for the oil and gas industry. The type of drill fluid selected in each drilling process mainly depends on a few factors such as reservoir types, costs, and disposal methods and its effect on the environment. Water-based mud is widely used due to its low cost and easy waste handling and disposal. However, some components in water-based muds are becoming increasingly restricted or prohibited [9]. In line with the importance of sustaining the natural environment, starch flours are introduced as a safe and biodegradable additive in drilling fluid. Corn and potato flours are the most common sources of starches to satisfy this purpose. The application of rice flour is rather new as an additive to drilling fluid, and, therefore, this study tends to investigate its suitability for the fluid formulation.

2. Methodology

2.1 Materials

A total of four local Sarawak rice cultivars, namely, *Pulut Merah*, *Bario Merah*, *Pusu,* and *Hitam,* were selected in this study, based on their amylose content of 5%, 10%, 15%, and 20% respectively [10]. Rice samples were ground and sieved to 100 µm in size. The drilling grade bentonite was supplied by Scomi Oil Tool Sdn Bhd.

2.2 Heat Moisture Treatments of Rice Flours

The heat moisture treatments were conducted based on procedures described by Hormdok and Noomhorm [11]. The moisture content of rice flours was adjusted to 15%, 20%, and 25% by adding an appropriate amount of distilled water. Samples were mixed thoroughly during the addition of water, followed by equilibration at 4°C over four days. Samples were then autoclaved at 110°C for 60 minutes. The treated rice flour samples were air-dried until it reaches constant moisture of approximately 11%.

2.3 Amylose Content in Rice Flours

Amylose content was determined using the standard protocol developed by Juliano [12]. Rice samples of 100 mg were mixed with 1.0 ml of 95% ethanol and 9.0 ml of 1M NaOH in an Erlenmeyer flask. The samples were heated in a water bath for 10 minutes to gelatinize the rice flours before diluting them up to 100 ml. A 5 ml of the cooked starch solution was diluted into 100 ml solution with 1.0 ml of 1M acetic acid and 2.0 ml of iodine solution (a mixture of 0.2 g of iodine and 2.0 g of potassium iodide in 100 ml of aqueous solution). The solution was shaken and allowed to stand for 20 minutes before tested at 620 nm using a spectrophotometer. Amylose content (in dry weight basis) was determined by comparing it to a known amylose content standard curve.

2.4 Preparation Drilling Fluids

All drilling mud analysis was conducted based on a standard protocol described in API Recommended Practice 13B-1, December 2003 [13]. A total of 22.5 g of bentonite and 2 g of starch were added into 350 ml of distilled water while stirring using a multi-mixer. The bentonite and starch were added slowly to avoid any lump formation. Stirring were continued for 20 minutes to achieve homogeneity.

2.5 Drilling Fluids Properties
2.5.1 Fluid density

The density of mud was determined using a mud balance. Mud samples were poured into the vessel until it is full and capped on. The vessel with the graduated bar was put on the fulcrum in equilibrium. The slider was move until the bubble of air is in the center. Mud density was expressed in lb/gal.

2.5.2 Rheology test

Rheology tests consist of plastic viscosity (PV), apparent viscosity (AV), yield point (YP), and gel strength were determined using a Fann VG Rheometer. Drilling mud sample was poured into a thermo-cup until it reaches the line indicated. Viscosities were measured at 600, 300, 200, 100, 6, and 3 RPM. Gel strength was measured in 10 seconds and 10 minutes time interval using the same instrument. The mud sample was stirred at high speed (600 RPM) for 10 seconds and then allowed to settle undisturbed for another 10 seconds. Exactly after 10 seconds, the handwheel was steadily turned to a direction to produce a positive reading. The maximum reading is recorded at the initial gel strength. The same procedures applied to final gel strength with the settling time was changed to 10 minutes. Plastic viscosity (PV), apparent viscosity (AV), yield points (YP) were determined using the following formula:

Plastic Viscosity, cP = [600 rpm reading] – [300 rpm reading]
Yield Point, lb/100 ft^2 = [300 rpm reading] – Plastic Viscosity
YP/PV ratio = Yield point ÷ Plastic viscosity

2.5.3 Filtration test

Mud samples from the viscosity test can be directly used for filtration tests. Filtration was conducted at room temperature and pressure of 100 ± 5 psi (690 ± 35 kPa) using a filter press instrument set up. The sample was poured into the filter press cell, and a measuring cylinder was placed under the cell to collect the filtrate volume. Filtration was done in 30 minutes, and the volume collected in the measuring cylinder was recorded at 5 minutes intervals. After 30 minutes, the filter cell was carefully open to remove the sample. Sediment accumulated on the filter paper at the bottom of the cell was measured using a caliper to get the mud-cake thickness. Three spots on the filter paper were measured randomly to calculate the average value.

2.6 Statistical Analysis

This research was based on the factorials in a completely randomized design (CRD) method. The analysis was carried out in three (3) replications, and the data were evaluated by Analysis of Variance (ANOVA) procedures. Treatment means were statistically compared by Duncan Multiple Range Test (DMRT) at 5% significant level using Statistical Analysis System (SAS) version 9.0.

3. Results

3.1 Heat Moisture Treatment on Rice Flours

This study was conducted to evaluate the effect of heat moisture treatments on amylose content in each rice cultivars, and the result was summarized in Figure 1. Here, native or untreated rice flours were used as a baseline for comparison. As the moisture content in the heat moisture process increased, amylose content also enriched. This trend was observed in all rice cultivars, although their natural and untreated flours varied in amylose content. A similar result was also reported on the effect of heat moisture treatment on the physicochemical properties of early *indica* rice throughout treatments and temperatures [14]. It was noticeable in this study that moisture levels during heat moisture treatments also played an essential role in enhancing amylose content in rice flours. The increment in amylose content might due to the degradation of exterior linear amylopectin chains during treatments, leading to an increase of the apparent amylose content [15]. These exterior linear amylopectin chains might become just like amylose chains after degradation treatments [16].

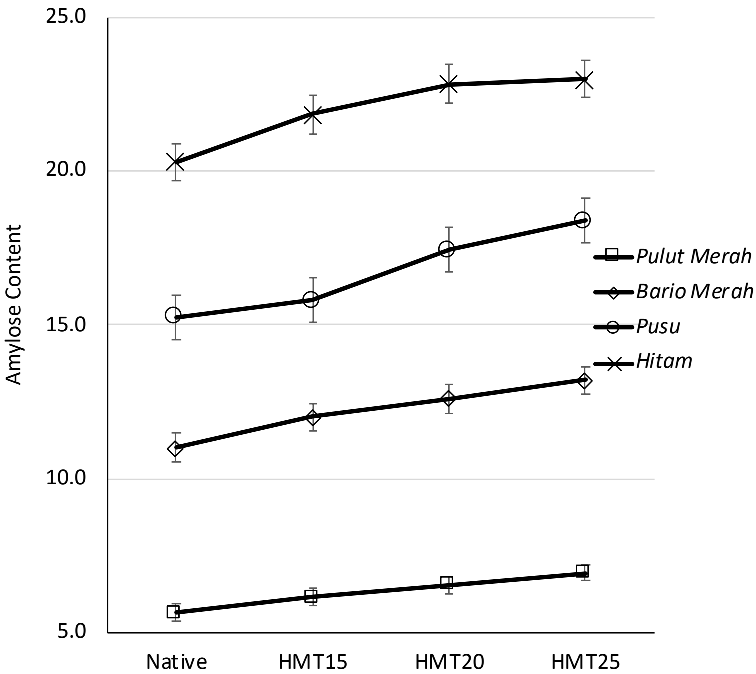

Fig. 1. Amylose content of rice flours (Note: Native=Rice flour without heat moisture treatment; HMT15=Heat moisture treatment on rice flour with 15% moisture content; HMT20=Heat moisture treatment on rice flour with 20% moisture content; HMT25=Heat moisture treatment on rice flour with 25% moisture content)

3.2 Drilling Fluid Properties

All drilling fluids were prepared by mixing the bentonite and native or heat moisture treated rice flours with water in a multi-mixer. A control drilling mud was prepared with only bentonite and water. All drilling fluids properties like mud density, viscosity, gel strength, mud-cake thickness, and filtrate volume were evaluated.

3.2.1 Mud density

The density of drilling mud prepared from native and heat moisture modified rice flours was shown in Figure 2. Results showed the density of drilling muds decreased by adding native rice flours to bentonite during formulations. However, the density of drilling mud prepared from heat moisture modified rice flours increased as compared to rice flours in native, but there is no significant change as compared to control. In terms of moisture content (15 % to 25 %) in the rice flours, it showed no significant effect on the density of drilling muds except *Hitam*. Drilling mud prepared from heat moisture treated *Hitam* showed a significant increase in mud density at 15 % moisture content but started to decrease as the moisture content was further increased to 25%. This was probably due to the reduction in the rice flours relative crystallinity during heat moisture treatments, especially on high-amylose flours [17]. *Hitam* showed the highest amylose content before and after treatments, which was discussed clearly in the previous section.

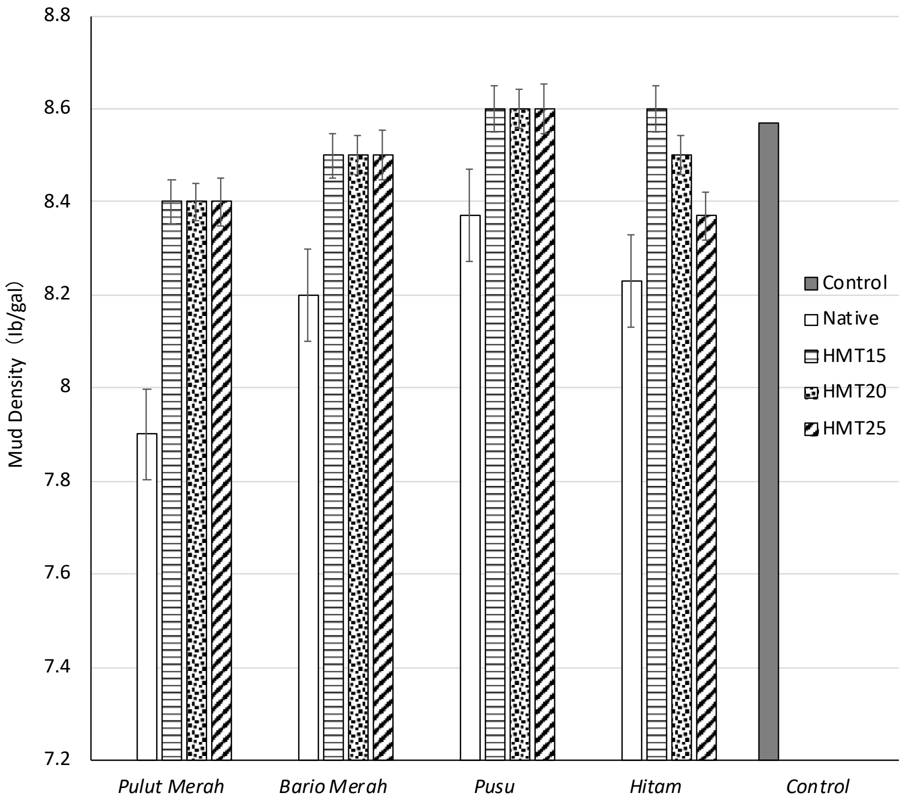

Fig. 2. Mud density of prepared drilling muds (Note: Native=Rice flour without heat moisture treatment; HMT15=Heat moisture treatment on rice flour with 15% moisture content; HMT20=Heat moisture treatment on rice flour with 20% moisture content; HMT25=Heat moisture treatment on rice flour with 25% moisture content)

A variation in mud density data can be useful in actual drilling conditions. There is a need to change the mud density to associate with good condition and pressure during the actual drilling activity. In this study, the optimum density of drilling mud prepared from heat moisture modified rice flour was 8.60 lb/gal, as shown in *Pusu* and *Hitam*. This was comparable to that of the density formulated from 100 % bentonite (control). The density of drilling fluid is highly dependent upon the formation pressure of drilling well. Drilling personnel needs to handle different formation pressures according to drilling depths. The density of the drilling fluid must be controlled to provide an adequate hydrostatic head to prevent an influx of formation fluids into well-bores, but not so high as to cause loss of circulation or adversely affect the drilling rate and damage the formation. The higher the formation pressure, the higher density is needed in drilling fluid. Drilling with lower mud weight such as a higher rate of penetration, lower standpipe pressure, lower circulating temperature, and higher pump rate will improve the hole cleaning [18].

3.2.2 Rheological properties

Rheology is the study of the flow of matter, primarily in the liquid state, but also as 'soft solids' or solids under conditions in which they respond with the plastic flow rather than deforming elastically in response to an applied force [19]. The plastic viscosity (PV), yield point (YP), and gel strength of formulated drilling muds were determined using a Fann VG Rheometer as described in the methodology, and their rheology property was summarized in Table 1.

3.2.2.1 Plastic viscosity (PV)

The plastic viscosity of drilling muds prepared from different types of rice flours was evaluated. In this study, it was calculated as the viscosity difference between the rotating speeds of 600 and 300 rpm. According to API standard, the viscosity of drilling grade bentonite must be at least 30 cP at 600 rpm. All the drilling muds prepared in this study met the standard.

Drilling muds containing native and heat moisture modified rice flours showed a reduction of plastic viscosity as compared to control. Plastic viscosity for pure bentonite (as control) gave a value of 11.28 cP. Meanwhile, plastic viscosity for drilling muds containing rice flours was in between 7.67 to 11.33 cP. Heat moisture treatments increased the plastic viscosity of resulting drilling muds as compared to native rice flours. The plastic viscosity of formulated drilling muds improved if the rice flours contained more moisture during treatments. Drilling muds made from *Pusu* showed the highest plastic viscosity with 11.33 cP at 25% moisture level during heat moisture treatment.

Results proved that drilling mud containing heat moisture treated rice flours from *Pusu* were comparable to pure bentonite drilling mud in terms of plastic viscosity property. Bentonite is known as a useful additive in most muds for viscosity and fluid loss control. It gives an excellent carrying capacity and suspension of cuttings if there is enough bentonite present in the mud. However, bentonite in the market contains variable proportions of polymers, which could make viscosity prediction uncertain and difficult to control [20]. Therefore, rice flours could be a suitable additive substituent for drilling muds.

3.2.2.2 Yield point (YP)

The yield point is defined as the stress required to move the fluid or the stress at which a material begins to deform plastically. The yield point of drilling mud reflects its ability to carry drilled cuttings out of drill holes. Drilling muds with native rice flours as additives gave low yield point values as compared to the control (22.33 lb/100 ft^2). The readings were between 15 to 20.67 lb/100 ft^2. However, heat moisture treatments on rice flours boosted up the yield points, particularly, if the rice flours held high levels of moisture. All drilling muds formulated from heat moisture treated rice flours with 25% moisture level gave yield point readings from 19.33 to 23 lb/100 ft^2. This was near to the control yield point, which indicated that drilling muds containing heat moisture treated rice flours as additives could behave similarly to pure bentonite drilling mud.

According to API standard, yield point over plastic viscosity (YP/PV) ratio must be less than 3 for drilling grade bentonite [21]. In this study, the YP/PV ratio for the pure bentonite drilling muds (control) is 1.98. Drilling muds prepared by adding either native or heat moistures treated rice flours showed various YP /PV ratio ranging from 1.45 to 2.32. All drilling muds met the API standard, which is less than 3. The YP /PV ratio is a useful value to indicate the stability of the potential drilling mud system. Hence, all the formulated drilling muds reflected their capability of carrying drill cuttings.

Table 1
The rheology test of prepared drilling muds

Drilling muds		Rheology Test Plastic Viscosity, PV (cP)	Yield Point, YP (lb/100 ft^2)	YP/ PV
Bentonite	(Control)	11.28	22.33	1.98
Additives				
Pulut Merah	Native	9.67	20.67	2.15
	HMT15	10.00	22.33	2.23
	HMT20	10.00	23.00	2.30
	HMT25	10.00	23.00	2.30
Bario Merah	Native	10.33	15.00	1.45
	HMT15	10.00	18.33	1.83
	HMT20	10.67	19.33	1.83
	HMT25	10.67	19.33	1.81
Pusu	Native	11.33	17.67	1.56
	HMT15	11.00	20.33	1.87
	HMT20	11.00	19.33	1.76
	HMT25	11.33	21.00	1.86
Hitam	Native	9.00	16.00	1.78
	HMT15	7.67	17.67	2.32
	HMT20	10.00	17.33	1.73
	HMT25	10.00	20.00	2.00

(Note: Control=Drilling muds prepared from bentonite; Native=Rice flour without heat moisture treatment; HMT15=Heat moisture treatment on rice flour with 15% moisture content; HMT20=Heat moisture treatment on rice flour with 20% moisture content; HMT25=Heat moisture treatment on rice flour with 25% moisture content)

3.2.3 Gel strength

Gel strengths for all drilling muds were varied from 5.3 to 15 lb/100 ft^2 at 10 seconds interval, as shown in Table 2. Overall, drilling muds with native rice flours as additives showed lower gel strength as compared to the control (15.67 lb/100 ft^2). However, drilling muds with heat moistures treated rice flours showed a significant increase in gel strength as compared to native rice. Besides, drilling muds containing high moistures treated rice flours resulted in better gel strengths.

A similar trend was also observed even as the gel strengths were measured at 10 minutes time interval. Heat moisture treatments contributed a significant effect to increase the gel strengths.

Drilling mud prepared from pure bentonite gave a reading of 25 lb/100 ft^2. The gel strength of drilling mud containing heat moistures treated *Pulut Merah,* was noticeable higher than the control. The gel strengths of the drilling muds increased from 25.00 to 28.00 lb/100 ft^2 as the moisture contents in rice flours increased from 15 to 25%.

The measurement of both gel strength at 10 seconds and 10 minutes time interval indicates the amount of gelation that will occur after circulation ceased, and the mud remains static. The more the mud gels during shutdown periods, the more pump pressure will be required to initiate circulation again. On the other hand, low gel strength will not be able to suspend the cuttings in the drilling process efficiently, where cuttings will quickly drop once pumps are shut down. Therefore, the addition of rice flours could provide a wide range of drilling muds selection to fit the actual drilling conditions.

Table 2
The gel strength of prepared drilling muds

Drilling Mud		Gel Strength (lb/100 ft^2)	
		10 Seconds	10 Minutes
Control	(bentonite)	15.67	25.00
Additives			
Pulut Merah	Native	9.00	24.00
	HMT15	13.00	26.00
	HMT20	14.00	27.00
	HMT25	15.00	28.00
Bario Merah	Native	5.30	19.30
	HMT15	7.30	22.00
	HMT20	9.33	23.33
	HMT25	11.33	20.00
Pusu	Native	9.00	22.67
	HMT15	9.67	24.67
	HMT20	9.00	23.33
	HMT25	10.00	23.33
Hitam	Native	7.00	19.67
	HMT15	7.00	18.00
	HMT20	8.00	20.33
	HMT25	11.00	24.00

(Note: Native=Rice flour without heat moisture treatment; HMT15=Heat moisture treatment on rice flour with 15% moisture content; HMT20=Heat moisture treatment on rice flour with 20% moisture content; HMT25=Heat moisture treatment on rice flour with 25% moisture content)

3.3 Filtration Properties

The liquid loss from mud due to filtration is controlled by the filter cake formed by the solid constituents in the drilling fluid. In this test, filtration volume and mud-cake thickness were recorded.

3.3.1 Filtrate volume

Filtrate volumes for all drilling muds were examined and showed in Table 3. Results indicated that the filtration volume of bentonite mud was reduced from control (15.17 ml) with the presence of native flours. Here, the filtration volumes of drilling muds loaded with native rice flours were varies from 14.90 to 15.13 ml. However, drilling muds packed with heat moistures modified rice flours showed no specific filtration volumes trend. Similar findings were also reported by Amanullah and Yu [22], where starch in the bentonite mud reduced the API filtration of the bentonite mud.

Table 3
Filtration test on prepared drilling muds

Sample		Filtration Test Filtrate Volume (ml)	Mud-cake Thickness (mm)
Control	(bentonite)	15.17	2.99
Additives			
Pulut Merah	Native	15.07	3.03
	HMT15	14.17	3.02
	HMT20	14.03	3.22
	HMT25	14.60	2.89
Bario Merah	Native	15.13	2.34
	HMT15	15.10	2.29
	HMT20	14.93	2.49
	HMT25	14.67	2.67
Pusu	Native	14.90	2.55
	HMT15	15.07	2.81
	HMT20	14.80	2.91
	HMT25	14.43	2.81
Hitam	Native	14.97	2.75
	HMT15	14.37	3.03
	HMT20	15.27	3.26
	HMT25	15.03	3.16

(Note: Native=Rice flour without heat moisture treatment; HMT15=Heat moisture treatment on rice flour with 15% moisture content; HMT20=Heat moisture treatment on rice flour with 20% moisture content; HMT25=Heat moisture treatment on rice flour with 25% moisture content)

According to API Standard [21], the acceptable maximum filtrate volume for bentonite is 15 ml. All the mud samples in this study met these criteria as compared to control. It is noticeable that drilling muds prepared from rice flours or heat moistures treated rice flours have lower filter volume as compare to control. A low filter volume would cut down the fluid loss control in drilling muds. It could also minimize the deposition of mud solids on the walls of the drill hole and cause the pipe sticking problems. Loss of fluid to the formation would lead to excessive water consumption [23]. A buildup of filter cake would also cause a tight hole, increased torque, increased circulating pressures, and could cause "*stuck pipe*".

3.3.2 Mud-cake thickness

The mud-cake thickness of all types of drilling muds was recorded in Table 3. Results indicated that drilling muds incorporated with native rice flours gave lower or equal mud-cake thickness as compared to control. There was no specific trend observed in drilling muds formulated from heat moistures modified rice flours. The variation in mud-cake thickness was similar to the filtrate volume in the previous section, ranging from 2.29 to 3.26 mm.

Mud-cake is a formation of solid caused by the fluid loss in the drilling process. The thicker the mud-cake formed, the higher the risk of pipe sticking problem will occur. Mud-cake formation needs to be controlled by reducing fluid loss. Correct fluid loss control is to form a thin, tough filter cake on the walls of the hole in permeable formations and prevent excessive loss of filtrate. Therefore, a certain degree of mud-cake buildup was desirable to isolate formations from drilling fluid [23].

4. Conclusions

This study was to evaluate the potential of heat moistures modified rice flours as additives in drilling fluids. Waxy, low, intermediate, and high amylose contents rice cultivars were selected. Amylose content in starched increased after excessive moisture and heat treatments.

Rice flour was the good choice of biodegradable additive for drilling fluid when it came to environmental concern. The addition of rice flours into water-based mud significantly reduced the density, viscosity, and filtrate volume, while the gel strength of the mud was increased. These findings would offer a low cost and environmentally friendly drilling fluid additive in drilling activity for the oil and gas industry. Different levels of heat moistures modifications could also provide a wide selection of preferable drilling muds properties to incorporate and fit into different drilling conditions.

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