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TÍTULO DO TRABALHO:

EXPERIMENTAL MEASUREMENT OF SPECIFIC HEAT CAPACITY AND THERMAL CONDUCTIVITY OF OLEFIN BASED DRILLING FLUID

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Resumo

Após os estágios de completação e comissionamento de um poço de petróleo, os espaços anulares dentro da estrutura do poço permanecem preenchidos com fluidos de perfuração. Durante a produção, os hidrocarbonetos de alta temperatura trocam calor com esses fluidos de perfuração e a formação rochosa. Como consequência, o fluido de perfuração se expande, aumentando a pressão nos anulares. Essa pressão extra, conhecida como Annular Pressure Buildup (APB), é a causa de vários colapsos em estruturas de poços. Para selecionar revestimentos compatíveis com a carga durante toda a vida útil do poço, é importante modelar a troca de calor e a expansão de tais fluidos. A composição dos fluidos de perfuração é tipicamente complexa, muitas vezes compreendendo três fases distintas - uma aquosa, um óleo e sólidos inertes em suspensão. A maioria das formulações usadas para modelar as propriedades termodinâmicas e de transporte são puramente empíricas ou semiempíricas, exigindo dados experimentais para capacidades de previsão precisas. No entanto, a revisão da literatura revela uma falta de dados sobre a calor específico isobárico e a condutividade térmica para as formulações de fluidos mais comuns. Para remediar esse problema, este artigo apresenta novos dados experimentais sobre essas propriedades para uma composição real do fluido de perfuração. Para medir o calor específico, foi utilizado um Calorímetro de Varredura Diferencial (DSC) comercial. Para a condutividade térmica, foi utilizado um dispositivo comercial baseado na técnica de Placas Paralelas Protegidas. Este equipamento foi projetado para medir condutividades térmicas na faixa de 0,1 a 10 W/m/K e tem uma precisão conhecida de 3% da condutividade medida. O fluido de perfuração medido é uma mistura composta por 58% v/v de 1-hexadeceno, 36,7% v/v de salmoura NaCl saturada e 5,2% v/v sólidos (barita e calcita), com vestígios de aditivos (por exemplo, emulsificantes). Ambas as medições são realizadas sob pressão atmosférica de temperaturas que variam de 5°C a 90°C. Os dados resultantes da medição do calor específico indicam uma variação de 8,16% no intervalo de temperatura medido, exibindo comportamento quase linear. A medição de condutividade térmica apresentou redução de 15.28% no intervalo medido.

Palavras-chave: Propriedades termofísicas, Fluidos de Perfuração, Integridade de poços, Olefinas, Emulsões

Abstract

After the completion and commissioning stages of an oil well, the annular spaces within the wellbore structure remain filled with drilling fluids. During production, high-temperature hydrocarbons exchange heat with these drilling fluids and the surrounding rock formation. Consequently, the drilling fluid expands, increasing the pressure in the concentric annuli. This extra pressure, known as Annular Pressure Buildup (APB) is the cause of several collapses in wellbore structures. To select casings compatible with the load during the entire lifespan of the well, it is important to model the heat exchange and the expansion of such fluids. The composition of drilling fluids is typically complex, often comprising three distinct phases - one aqueous, one oil and solids in suspension. Most formulations used to model the thermodynamic and transport properties are purely empirical or semi-empirical, requiring experimental data for accurate prediction capabilities. However, literature review reveals a lack of data regarding the specific heat capacity and thermal conductivity for most common fluid formulations. To remediate this problem, this paper presents new experimental data on specific heat capacity and thermal conductivity for a real drilling fluid composition. To measure the heat capacity, a commercial Differential Scanning Calorimeter (DSC) was used. For thermal conductivity, a commercial device based on the Parallel Guarded Plates technique was used. This piece of equipment is designed to measure thermal conductivities within the range of 0.1 to 10 W/m/K and has a known precision of 5% of the measured conductivity. The drilling fluid measured is a mixture comprising 58% v/v of 1-hexadecene, 36.7% v/v of saturated NaCl brine, and 5.2% v/v solids (barite and calcite), with trace amounts of additives (e.g., emulsifiers). Both measurements are performed under atmospheric pressure from temperatures ranging from 5°C to 90°C. The resulting data from the measurement of specific heat indicate a variation of 8.16% in the measured temperature interval, exhibiting almost linear behavior. The measurement of thermal conductivity resulted in a reduction of 15.28% of the value in the interval.

Keywords: Thermophysical properties, Drilling fluids, Wellbore integrity, Olefins, Emulsions.

Introduction

During the design and construction of an oil producing wellbore, the loads to be sustained during the entire lifespan of the well must be considered for a safe project (BOURGOYNE JR. et al., 1991). One of the most important design criteria involves the correct selection (type and weight) of the fluids used during drilling. These fluids are responsible for cooling and lubricating the drill bit and ensuring chemical and mechanical integrity of the rock formation surrounding the well (CAENN; DARLEY; GRAY, 2017).

However, in recent years, risks of failure in some wells have increased due to excessive loads caused by the heating of the trapped fluids in the annular spaces. This temperature increase leads to fluid expansion, which, in a confined space, results in a pressure increase. This phenomenon, known as Annular Pressure Buildup (APB), has been the focus of several studies (DA VEIGA et al., 2020; HASAN; IZGEC; KABIR, 2009; MOE, GEORGE ROBERT; ERPELDING, 2000). There are well-documented cases of structural collapses resulting from unmanaged APB (BRADFORD et al., 2007).

Therefore, it is crucial to predict the heat exchange during production at the design stage of wellbore planning. Simulations are important tools for increasing the safety of a project without incurring excessive costs, thereby enhancing the safety factor of the project. However, there is limited data on the thermophysical properties of drilling fluids. Most drilling fluids are composed of emulsions, typically with one oil-based phase, one water-based phase, and inert solids added to meet specific requirements (CAENN; DARLEY; GRAY, 2017). Over the years, many fluids have been used in the oil phase, ranging from pure diesel to more ecologically friendly options like internal olefins (BOURGOYNE JR. et al., 1991; CAENN; DARLEY; GRAY, 2017). The water-based phase often consists of saturated brines, such as NaCl or $CaCl_2$, to increase the density of the finished mixture. Additionally, many soluble additives are incorporated to enhance fluid performance. For instance, emulsifiers are commonly added to ensure that the fluid mixture maintains non-Newtonian behavior regarding its viscosity within the wellbore structure during drilling.

In the literature, only a few studies address the measurement of specific heat and thermal conductivity of drilling fluids (CORRE; EYMARD; GUENOT, 1984; SASAKI; AKIBAYASHI; KONNO, 2000; SULEMAN, 2019), and no data is available for more modern olefin-based fluids. This paper presents measured values for both isobaric specific heat and thermal conductivity at atmospheric pressure using two commercial pieces of equipment. The fluid measured was provided by an industry partner and reflects an actual composition used in real wellbores.

Methodology

The composition of the drilling fluid sample is illustrated in Table 1. It consists of an oil-water emulsion with solids in suspension. Barite is added to the mixture to achieve the desired drilling fluid density of 1138.35 kg/m³ (9.5 ppg) at standard conditions.

Table 1. Composition of the drilling fluid.

Components	Amount	Unit
Intern Olefin	0,58	bbl/bbl
Primary Emulsifier	7	lb/bbl
Secondary Emulsifier	3	lb/bbl
Lime	5	lb/bbl
Filter Control	2	lb/bbl
Viscosifier	5	lb/bbl
Brine NaCl (Saturated)	0.39	bbl/bbl
limestone	10	lb/bbl
Rheology modifier	2.75	lb/bbl

The drilling fluid was provided in a 5-liter container. Before sampling for the experiment, the container was manually agitated to re-homogenize the fluid. Additionally, a mechanical agitator, TURRAX 25 Easy Clan with the shaft S 25 N – 18 G, was used. Based on prior experience, the methodology adopted involved agitation at 5000 rpm for 6 minutes.

The measurement of thermal conductivity was performed using the FOX 50 Heat Flux Meter from LaserComp (TA INSTUMENTS, 2015). This device was previously used by Alves et al., (2022) to measure the thermal conductivity of a paraffin-based fluid. It is based on the guarded heat plate method, in which two parallel plates are kept at specified temperatures and a sample is pressed between them. By measuring the heat flux necessary to maintain this temperature difference, the thermal conductivity of the sample can be determined.

The device is periodically calibrated using reference samples made of Pyrex 7740. Calibration involves measuring the thermal conductivity of two similar samples of different thicknesses. This procedure is best described in Alves et al. (2022) and will be omitted here for brevity. An uncertainty of 6% was applied for a 95% confidence interval.

The measurement of specific heat was performed using the MicroCalvet differential scanning calorimeter (µDSC) from Setaram (SETARAM KEP, 2020). The device was configured to use the three-experiment step measurement method. In this setup, the calorimeter runs a sequence of heating ramps, and the differential signal is integrated for each experiment, indicating the total difference in heat required to increase the temperature. This procedure is also used in other studies in literature (GUPTA et al., 2018; SYED et al., 2012).

The device requires calibration with two fluids within the range of 0°C to 100°C, the temperature range of interest in this study. Two calibrations were performed: the first using n-heptane as a calibration fluid from 0°C to 25°C, and the second using water from 25°C to 100°C. The specific heat values of the calibration fluids outside their respective calibration intervals (e.g., water from 0°C to 25°C) were calculated and compared to the values from RefProp 9.1 (LEMMON; HUBER; MCLINDEN, 2013). This comparison confirmed the quality of the experiment and validated both calibrations. The calorimeter is reported in the literature to have an uncertainty within 1% (SHARMA; ROHILLA, 2013). Therefore, for a coverage factor of 95%, the uncertainty of these measurements is reported as 2%.

Results and Discussions

Following the procedures described above, both the specific heat and thermal conductivity were measured within the range of 4°C to 90°C. The measurements for each condition were performed twice to ensure repeatability of the initial measurement. Table 2 presents the measured values for specific heat with its uncertainties.

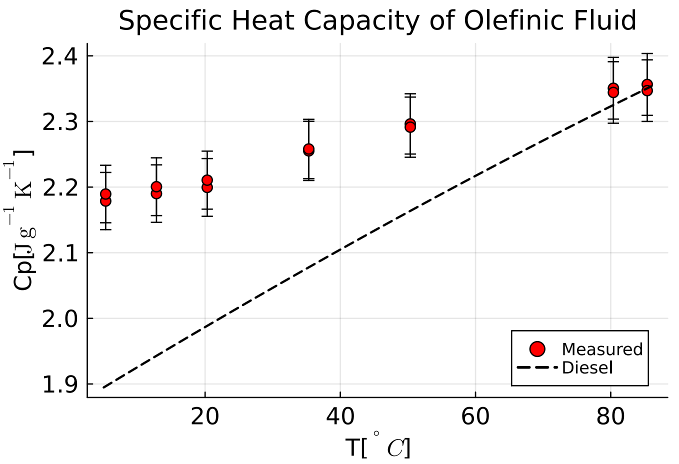
Table 2. Measured values of specific heat with uncertainties. The first three columns relate to the first measurement, and the last three to the second one.

T [°C]	Cp [J/g K]	U [J/g K]	T [°C]	Cp [J/g K]	U [J/g K]
5.2955	2.179	0.044	5.295	2.189	0.044
12.805	2.190	0.044	12.805	2.201	0.044
20.315	2.200	0.044	20.314	2.211	0.044
35.334	2.255	0.045	35.334	2.258	0.045
50.353	2.296	0.046	50.353	2.291	0.046
80.392	2.351	0.047	80.392	2.344	0.047
85.398	2.356	0.047	85.398	2.347	0.047

Based on the results reported, a variation of 7.5% in specific heat was perceived along the temperature interval. Note that the values obtained are lower than those of pure water (around 4.2 J/g K in the temperature range), indicating a clear decrease due to the presence of the olefin phase.

Figure 1 presents the experimental data along with common prediction methods for the specific heat of drilling fluids. One of such approaches is to consider the specific heat of the olefin-based fluids equal to that of diesel (ALVES; BARBOSA, 2023), this approach was a common approximation for paraffinic fluids which can be justified based on the approximate number of carbons in the most representative molecules of both compounds. Although this hypothesis incurs a maximum deviation of 13% at low temperatures, the accuracy of the prediction increases with temperature, reaching the lowest deviation of 0.15% at 85°C. The specific heat of the diesel was taken from numerical fits performed against data generated from a general diesel composition implemented in the Multiflash program (KBC; INFOCHEM, 2024) the advanced Peng-Robinson equation was used with its default parameters.

Figure 1. Measured values of specific heat of olefinic drilling fluid compared to Diesel's specific heat.



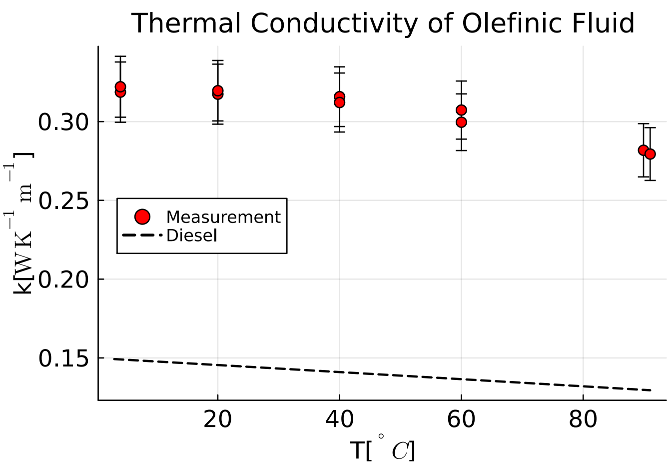
Regarding the thermal conductivity measurement, the experiments were performed once heating up the sample and then cooling it down. The results are reported in Table 3.

Table 3. Experimental data and uncertainty for the thermal conductivity of the drilling fluid. The first three columns relate to the first experiment and the last three to the repetition.

T [°C]	K [W/m K]	U [W/m K]	T [°C]	K [W/m K]	U [W/m K]
4.01	0.319	0.019	4.01	0.322	0.019
20.01	0.317	0.019	20.01	0.320	0.019
40.00	0.316	0.019	40.00	0.312	0.019
60.00	0.307	0.018	60.00	0.300	0.018
89.91	0.282	0.017	91.00	0.279	0.017

Figure 2 presents the thermal conductivity data together with the thermal conductivity from diesel.

Figure 2. Measured values of thermal conductivity of the drilling fluid compared to the properties of Diesel.



Contrary to the specific heat, the thermal conductivity is not well predicted by approximating it with the value for diesel. Within the measured interval, the variation of thermal conductivity is 15.28%, with a clear tendency to increase variation at higher temperatures. However, as expected for the thermal conductivity of liquids, the thermal conductivity decreased with increasing temperature.

Conclusions

This paper provides data on key thermophysical properties, namely the isobaric specific heat and thermal conductivity, of fluids mixtures in the drilling of offshore wells. Both quantities were measured using state-of-the-art commercial devices.

A variation of 7.5% in the specific heat value was noted within the measured interval of 5 to 85˚C, with values close to those obtained for the pure olefin phase. For the thermal conductivity, a reduction of 15.28% was observed over the temperature range of 4 to 90°C, with absolute values also close to those of the olefin base. The standard approach of assuming fluid properties equivalent to those of diesel showed poor performance for the specific heat at lower temperatures and for the thermal conductivity across the entire temperature range. This approximation is therefore not advisable.

Future work should aim to provide more data on both the pure components and the fluid mixtures to better predict the properties of these drilling fluids.

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