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Characterization of Crude Oil Physical Properties Using Specific Gravity, Conradson Carbon Residue, Flash Point, and Ash Content Analyses

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Abstract

Crude oil characterization is used to evaluate crude oil properties before refinery processing. During an industrial internship at the Physical Properties Laboratory, LEMIGAS, two crude oil samples were analyzed for Specific Gravity (SG), API Gravity, Conradson Carbon Residue (CCR), Flash Point, and Ash Content. SG was determined using ASTM D1298, CCR using ASTM D189, Flash Point using ASTM D93 and IP 170, and Ash Content using ASTM D482. API Gravity was calculated from the corrected SG values. Samples XX and XY had SG values of 0.8276 and 0.8597, corresponding to API Gravity values of 39.5° and 33.1°, respectively. CCR values were 0.778 wt.% and 2.520 wt.%, while Flash Point values were 25.0 °C and 79.5 °C. Ash Content values were 0.033 wt.% and 0.008 wt.% for samples XX and XY, respectively. Sample XY had higher CCR and SG, while sample XX had higher API Gravity and lower Flash Point. These results show differences in the physical properties, carbon residue, flammability, and inorganic residue of the two crude oil samples.

Keywords: API Gravity, Ash Content, Conradson Carbon Residue, Flash Point, Specific Gravity

Introduction

Crude oil is one of the most important non-renewable energy resources and serves as a feedstock for petroleum refineries worldwide (Pang et al., 2023). Crude oils from different geological formations have different chemical compositions and physical properties (J. G. . Speight, 2019). These differences can affect refining efficiency, product yield, and the selection of processing units (Forman et al., 2014). Therefore, laboratory characterization of crude oil is performed before refinery processing to evaluate its properties and determine suitable refining processes (Hamza et al., 2018).

Specific Gravity (SG) is one of the physical properties commonly measured in petroleum laboratories and is used to describe crude oil density (Hamza et al., 2018). SG is related to API Gravity, which is used to classify crude oil as light, medium, or heavy (Niyonsaba et al., 2019). Crude oils with lower SG generally have higher API Gravity values and contain a higher proportion of light hydrocarbon fractions, which can be processed into products such as gasoline, kerosene, and naphtha (H. Al-Dahhan & MA Mahmood, 2019). In contrast, crude oils with higher SG generally contain more heavy hydrocarbons and may require more complex refining processes (Abou El Lei & Al Farjani, 2020).

Conradson Carbon Residue (CCR) is another parameter used to characterize crude oil. CCR indicates the amount of carbonaceous residue formed after thermal decomposition under controlled conditions (Singh et al., 2012). Higher CCR values generally indicate a higher content of heavy compounds, including resins and asphaltenes (Cheshkova et al., 2019), which can contribute to coke formation during refinery operations (Goncharov et al., 2019). Coke deposition can reduce heat transfer efficiency and contribute to equipment fouling and maintenance requirements (Bisht et al., 2018). Therefore, CCR is used to evaluate the tendency of crude oil to form carbon residue during thermal processing (Xu, 2015).

Flash Point (FP) is used to evaluate the flammability and handling safety of crude oil and petroleum products (Santos et al., 2020). It is defined as the lowest temperature at which sufficient vapor is produced to ignite momentarily in the presence of an ignition source (Saragih & Yudhatama, 2020). Flash Point is used in the classification, storage, transportation, and handling of petroleum products because it indicates their fire hazard under specified conditions (Dewinara Restu Yudandhiss, 2022; J. Speight, 2020). Ash Content represents the inorganic residue remaining after the combustion of a petroleum sample (Ismail, 2017). The residue may contain mineral matter, inorganic salts, and metallic contaminants, which can contribute to deposits, fouling, corrosion, and catalyst deactivation during refinery operations (Al-Moubaraki & Obot, 2021). Ash Content is therefore measured to determine the amount of inorganic residue in petroleum samples (ASTM International - D482-19, 2019).

During an industrial internship at the Physical Properties Laboratory, Research and Development Center for Oil and Gas Technology (LEMIGAS), Jakarta, Indonesia, two crude oil samples were analyzed using several laboratory tests. Specific Gravity, Conradson Carbon Residue, Flash Point, and Ash Content were selected for this study because they represent different properties of crude oil, including density, carbon residue formation, flammability, and inorganic residue. The analyses were performed using ASTM and IP methods.

Therefore, this article presents the characterization of two crude oil samples using Specific Gravity (ASTM D1298), Conradson Carbon Residue (ASTM D189), Flash Point (ASTM D93 and IP 170), and Ash Content (ASTM D482). API Gravity was calculated from the corrected Specific Gravity values to classify the crude oil samples. The results were then compared to describe the differences in density, carbon residue, flash point, and ash content between the two samples.

Method

This study was conducted during an industrial internship at the Physical Properties Laboratory, Research and Development Center for Oil and Gas Technology (LEMIGAS), Jakarta, Indonesia. Two crude oil samples were analyzed for Specific Gravity (SG), API Gravity, Conradson Carbon Residue (CCR), Flash Point (FP), and Ash Content (AC) using the applicable ASTM and IP methods. API Gravity was calculated from the corrected Specific Gravity values.

Materials

The materials used were two crude oil samples, designated as XX and XY. The samples were provided by the Physical Properties Laboratory, Research and Development Center for Oil and Gas Technology (LEMIGAS), Jakarta, Indonesia, as part of routine laboratory analyses during the industrial internship. No additional chemical reagents were used because the analyses were performed directly on the crude oil samples according to the applicable ASTM methods.

Instrumentation

Specific Gravity analysis was performed using a petroleum hydrometer, graduated cylinder, and calibrated laboratory thermometer according to ASTM D1298 (ASTM International - D1298, 2017). Conradson Carbon Residue analysis was performed using a Conradson Carbon Residue apparatus according to ASTM D189 (ASTM International - D189, 2019). An analytical balance was used to determine the sample mass before and after the carbonization process. Flash Point analysis was performed using Abel Closed Cup and Pensky-Martens Closed Cup flash point testers in accordance with IP 170 and ASTM D93, respectively (ASTM International - D93-20, 2020; IP 170/14, 2013). Ash Content analysis was performed using a muffle furnace, porcelain crucibles, and an analytical balance according to ASTM D482 (ASTM International - D482-19, 2019).

Procedure

Specific Gravity, Conradson Carbon Residue, Flash Point, and Ash Content were determined according to the applicable ASTM and IP methods. Specific Gravity was measured according to ASTM D1298, while Conradson Carbon Residue was determined according to ASTM D189. Flash Point was determined using the Pensky-Martens Closed Cup method (ASTM D93) or Abel Closed Cup method (IP 170), depending on the expected flash point range of the crude oil sample. Ash Content was determined according to ASTM D482. API Gravity was calculated from the corrected Specific Gravity values. The results from the four analyses were compared to describe the differences in physical properties, flammability, carbon residue, and inorganic residue between the two crude oil samples (ASTM International - D93-20, 2020; ASTM International - D189, 2019; ASTM International - D482-19, 2019; ASTM International - D1298, 2017; IP 170/14, 2013).

Specific Gravity and API Gravity Analysis

Specific Gravity analysis was performed according to ASTM D1298. Each crude oil sample was poured into a clean graduated cylinder, and a petroleum hydrometer was immersed until it floated freely. The hydrometer reading and sample temperature were recorded after equilibrium was reached. The measured Specific Gravity values were corrected to the reference temperature (60/60 °F) using the ASTM Petroleum Measurement Tables. API Gravity was then calculated from the corrected Specific Gravity values using Equation (1).

$$API\ Gravity = \frac{141.5}{SG\ 60/60^{\circ}F} - 131.5 \quad (1)$$

Conradson Carbon Residue Analysis

Conradson Carbon Residue analysis was performed according to ASTM D189. Approximately 10 g of each crude oil sample was weighed into a Conradson crucible and heated under controlled conditions until the volatile components were removed, leaving carbonaceous residue. After heating, the crucible was cooled to room temperature in a desiccator and weighed. The Conradson Carbon Residue (CCR) value was calculated using Equation (2).

$$CCR(wt.\%) = \frac{W_3 - W_1}{W_2 - W_1} \times 100\% \quad (2)$$

Where:

- W_1 = mass of the empty crucible
- W_2 = mass of the crucible containing the crude oil sample before heating
- W_3 = mass of the crucible containing the carbon residue after heating

Flash Point Analysis

Flash Point analysis was carried out using either the Abel Closed Cup method (IP 170/14, 2013) or the Pensky-Martens Closed Cup method (ASTM International - D93-20, 2020), depending on the

expected flash point of the crude oil sample. The sample was placed in the test cup to the prescribed filling mark and heated at the rate specified by the applicable standard while being stirred continuously. At predetermined temperature intervals, an ignition source was applied until a flash was observed. The lowest temperature at which the vapor above the sample ignited momentarily was recorded as the Flash Point after correction to standard atmospheric pressure, where applicable.

Ash Content Analysis

Ash Content was determined according to ASTM D482 (ASTM International - D482-19, 2019). An appropriate amount of crude oil was weighed into a previously ignited and weighed porcelain crucible. The sample was ignited and burned until the volatile components were removed, followed by heating in a muffle furnace at 775 ± 25 °C until complete oxidation was achieved. The crucible was cooled to room temperature in a desiccator and weighed to constant mass. The Ash Content was calculated using Equation (3).

$$\text{Ash(wt. \%)} = \frac{m_{\text{ash}}}{m_{\text{sample}}} \times 100\% \quad (3)$$

Where:

- m_{ash} = mass of ash after ignition (g)
- m_{sample} = initial mass of the crude oil sample (g)

Result and Discussion

The physical properties of two crude oil samples were evaluated through Specific Gravity (SG), API Gravity, and Conradson Carbon Residue (CCR) analyses. Specific Gravity was used to determine crude oil density, while API Gravity, calculated from the corrected SG values, was used to classify the crude oil samples according to their light or heavy characteristics (Awadh & Almimar, 2015). Conradson Carbon Residue analysis was performed to evaluate the tendency of the crude oil to form carbonaceous residue during thermal processing (Flórez et al., 2017). Flash Point analysis was conducted to evaluate the flammability characteristics and safe handling of the crude oil samples, whereas Ash Content analysis was used to determine the amount of inorganic residue that may contribute to fouling, corrosion, and ash deposition during refinery processing (ASTM International - D93-20, 2020; IP 170/14, 2013).

The laboratory test results obtained during the industrial internship at the Physical Properties Laboratory, Research and Development Center for Oil and Gas Technology (LEMIGAS) are presented and discussed in the following sections.

Specific Gravity and API Gravity Analysis

The Specific Gravity (SG) and API Gravity values obtained from the laboratory analyses are presented in Table 1. These parameters were used to describe the density of the crude oil samples and classify them based on API Gravity.

Table 1. Specific Gravity and API Gravity values of crude oil samples

Sample	Specific Gravity (60/60 °F)	API Gravity (°API)	Crude Oil Classification
XX	0.8276	39.5	Light crude oil
XY	0.8597	33.1	Medium crude oil*

The results in Table 1 show that sample XX had a lower Specific Gravity (0.8276) than sample XY (0.8597). Since Specific Gravity represents the relative density of crude oil compared with water, the lower SG of sample XX indicates a lower density than sample XY. The calculated API Gravity of sample XX (39.5°API) was also higher than that of sample XY (33.1°API), showing the inverse relationship between Specific Gravity and API Gravity.

According to the API Gravity classification, sample XX was classified as light crude oil, while sample XY was classified as medium crude oil. Light crude oils generally contain a greater proportion

of low-molecular-weight hydrocarbons and can produce higher yields of products such as gasoline, kerosene, and naphtha (Cleveland & Ayres, 2012). In contrast, crude oils with lower API Gravity generally contain a greater proportion of heavy hydrocarbon fractions and may require more conversion processes during refining (J. G. Speight, 2017).

The differences in SG and API Gravity between the two crude oil samples indicate differences in their density and hydrocarbon composition (Albahri, 2012). Sample XX had lower density and higher API Gravity, while sample XY had higher density and lower API Gravity. The higher density and lower API Gravity of sample XY are consistent with a greater proportion of heavy hydrocarbon fractions, which can affect the refining processes used for the crude oil (Demirbas et al., 2015)

Conradson Carbon Residue Analysis

The Conradson Carbon Residue (CCR) values obtained from both crude oil samples are summarized in Table 2.

Table 2. Conradson Carbon Residue values of crude oil samples

Sample	CCR (wt.%)
XX	0.778
XY	2.520

As shown in Table 2, sample XY exhibited a considerably higher CCR value than sample XX. Conradson Carbon Residue represents the amount of carbonaceous residue remaining after thermal decomposition under controlled conditions. Therefore, higher CCR values indicate a greater concentration of heavy petroleum fractions, including resins and asphaltenes, which promote coke formation during refinery operations (Nguyen et al., 2018).

The relatively low CCR value observed for sample XX suggests that this crude oil contains fewer heavy components and is therefore less likely to produce excessive carbon deposits during thermal processing. Conversely, the higher CCR value of sample XY indicates a greater tendency toward coke formation, which may reduce heat-transfer efficiency, increase equipment fouling, and require more frequent maintenance in refinery units (Firdaus et al., 2023)

Flash Point Analysis

The Flash Point values obtained from the crude oil samples are summarized in Table 3.

Table 3. Flash Point values of crude oil samples

Sample	Method	Flash Point (°C)
XX	Abel Closed Cup	25.0
XY	Pensky-Martens Closed Cup	79.5

As shown in Table 3, sample XY had a higher Flash Point (79.5 °C) than sample XX (25.0 °C). Flash Point represents the lowest temperature at which sufficient vapor is generated above a petroleum sample to ignite momentarily in the presence of an ignition source. Therefore, a higher Flash Point generally indicates lower volatility under the test conditions (Hossain & Davies, 2010).

The lower Flash Point of sample XX is consistent with its higher API Gravity (39.5°API) and lower Specific Gravity, indicating a greater proportion of lighter hydrocarbon fractions. These fractions generally have higher volatility. In contrast, sample XY had a higher Flash Point together with higher SG and lower API Gravity, which is consistent with a greater proportion of heavier hydrocarbon fractions. Flash Point is relevant to the storage and handling of petroleum products because it is used to assess their flammability characteristics (Fingas, 2011).

Ash Content Analysis

The Ash Content values obtained from the crude oil samples are summarized in Table 4

Table 4. Ash Content values of crude oil samples

Sample	Ash Content (wt.%)
XX	0.033
XY	0.008

The results presented in Table 4 show that sample XX had a higher Ash Content (0.033 wt.%) than sample XY (0.008 wt.%). Ash Content represents the inorganic residue remaining after combustion and may originate from mineral matter, inorganic salts, metallic contaminants, or other impurities in crude oil (Latarche, 2021).

The higher Ash Content of sample XX indicates a greater amount of inorganic residue than sample XY under the test conditions. The difference in Ash Content between the two samples provides additional information about their inorganic residue content, which can be related to deposit formation and other refinery operating concerns (Barton et al., 2022).

Conclusion

The physical properties of two crude oil samples were characterized using Specific Gravity (SG), API Gravity, Conradson Carbon Residue (CCR), Flash Point, and Ash Content during an industrial internship at the Physical Properties Laboratory, Research and Development Center for Oil and Gas Technology (LEMIGAS). Sample XX had a lower Specific Gravity (0.8276), higher API Gravity (39.5°API), lower Conradson Carbon Residue (0.778 wt.%), lower Flash Point (25.0 °C), and higher Ash Content (0.033 wt.%) than sample XY. Based on API Gravity, sample XX was classified as light crude oil, while sample XY was classified as medium crude oil.

Sample XY had a higher Specific Gravity (0.8597), lower API Gravity (33.1°API), higher Conradson Carbon Residue (2.520 wt.%), higher Flash Point (79.5 °C), and lower Ash Content (0.008 wt.%) than sample XX. The higher SG and CCR of sample XY are consistent with a greater proportion of heavy hydrocarbon fractions and a higher tendency to form carbonaceous residue during thermal processing. The two samples also showed different Flash Point and Ash Content values, indicating differences in their flammability characteristics and inorganic residue content.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

R.U. designed and conducted the experiments, collected and analyzed the data, interpreted the results, and prepared the manuscript. F.G.N. provided academic supervision and reviewed the manuscript. D.S. supervised the laboratory activities and provided technical guidance. Y. and M.W. reviewed the manuscript and provided comments and suggestions. All authors read and approved the final version of the manuscript.

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