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Combustion Characteristics of Tasand Heavy Fuel for Energy Generation

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ABSTRACT

The growing demand for sustainable and efficient energy resources has intensified interest in the combustion behavior of heavy fuel oils, particularly for industrial power generation. This study investigates the combustion characteristics of Tasand heavy fuel using differential scanning calorimetry (DSC), Brunauer–Emmett–Teller (BET) surface area analysis, and atomic absorption spectroscopy (AAS). The objective is to evaluate its thermal behavior, surface properties, and elemental composition to determine its suitability for energy applications. The DSC analysis revealed distinct exothermic peaks at approximately 420°C and 650°C, corresponding to volatile combustion and char oxidation stages, respectively. These results indicate a multi-stage combustion process with significant heat release, suggesting high calorific potential. BET analysis showed a moderate surface area of 68.5 m^2/g with a pore volume of 0.124 cm^3/g, indicating the presence of porous carbonaceous structures that enhance oxygen diffusion and combustion efficiency. The pore size distribution was predominantly mesoporous, facilitating improved reaction kinetics during oxidation. The AAS results confirmed the presence of trace metals such as vanadium (1.48 wt%), nickel (1.12 wt%), and iron (1.36 wt%), which are known to act as catalytic agents in combustion processes. These metals contribute to reduced activation energy and enhanced oxidation rates but may also pose environmental and corrosion challenges. The combined results demonstrate that Tasand heavy fuel exhibits favourable combustion characteristics, including high thermal reactivity, efficient energy release, and catalytic enhancement. However, the presence of sulfur and heavy metals necessitates the implementation of emission control strategies. This study establishes Tasand heavy fuel as a viable candidate for energy generation, particularly in industrial applications where high energy density fuels are required.

Keywords: Heavy fuel oil, combustion, DSC, BET, AAS, energy generation, Tarsand Energy Efficiency

1. INTRODUCTION

Global energy demand continues to rise due to rapid industrialization, population growth, and technological advancement, placing increasing pressure on conventional energy resources. Despite the global transition toward renewable energy systems, fossil fuels remain dominant, particularly in developing economies where infrastructure for alternative energy sources is still evolving [1,2]. Among fossil fuels, heavy fuel oils (HFOs) play a critical role in industrial combustion systems, marine propulsion, and power generation due to their high energy density and economic viability [3].The heavy fuel oils are residual products obtained from crude oil refining processes. They are characterized by high viscosity, complex molecular structures, and significant concentrations of asphaltenes, resins, and trace metals. These compositional features significantly influence their combustion behavior, including ignition characteristics, thermal degradation, and emission profiles [4,5]. The combustion characteristics of heavy fuels is essential for optimizing their utilization and minimizing environmental impact. Combustion efficiency depends on multiple factors, including fuel composition, surface area, pore structure, and catalytic effects of trace elements. Advanced analytical techniques such as DSC, BET, and AAS provide critical insights into these properties [6].

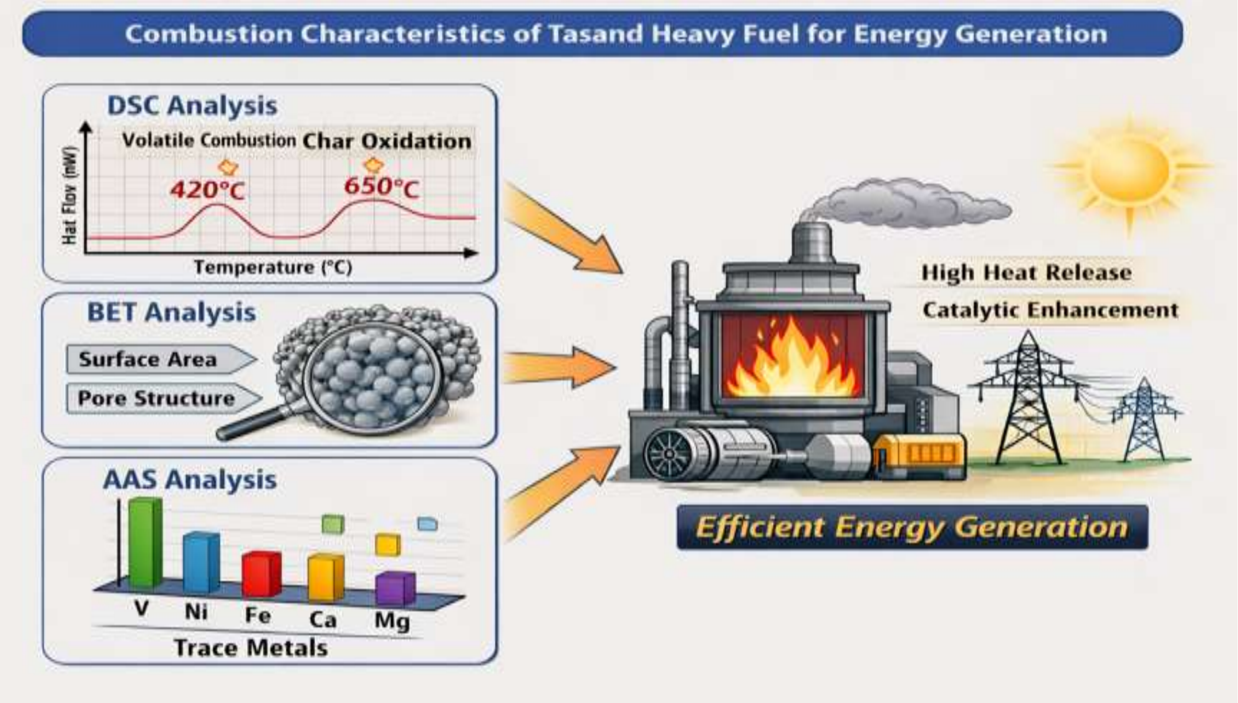
The differential scanning calorimetry (DSC) is widely used to study the thermal behavior of fuels by measuring heat flow during combustion. It provides valuable information on ignition temperature, heat release, and reaction kinetics [7]. The brunauer–Emmett–Teller (BET) analysis, on the other hand, evaluates surface area and porosity, which are crucial for understanding oxygen diffusion and reaction rates during combustion [8]. The atomic absorption spectroscopy (AAS) enables precise quantification of trace metals that can influence catalytic reactions [9]. Previous studies have shown that heavy fuels with higher surface area and porosity exhibit improved combustion efficiency due to enhanced oxygen accessibility [10]. Additionally, the presence of transition metals such as vanadium and nickel has been reported to catalyse oxidation reactions, reducing activation energy and improving fuel reactivity [11].

However, the use of heavy fuels also presents challenges, including the emission of sulphur oxides, nitrogen oxides, and particulate matter, which contribute to environmental pollution and health risks [12]. Therefore, comprehensive characterization of these fuels is necessary to balance energy efficiency with environmental sustainability. This study focuses on Tasand heavy fuel, a relatively underexplored fuel source, to evaluate its combustion characteristics using DSC, BET, and AAS techniques. By integrating thermal, structural, and compositional analyses, this research aims to provide a holistic understanding of its performance for energy generation.

2. LITERATURE REVIEW

Extensive research has been conducted on the combustion characteristics of heavy fuels using thermal and analytical techniques. DSC has been widely applied to investigate heat release behavior, revealing multi-stage combustion processes associated with volatile oxidation and char combustion [13,14].The BET analysis has been used to correlate surface area and pore structure with combustion efficiency. Studies have shown that mesoporous structures enhance oxygen diffusion, leading to improved reaction kinetics [15,16]. A study carried out by Zhang et al. [17] reported that fuels with higher BET surface area exhibited faster combustion rates and lower ignition temperatures. Whereas the AAS has been instrumental in identifying trace metals in fuels. Vanadium and nickel are commonly found in heavy oils and have been shown to influence combustion through catalytic oxidation mechanisms [18,19]. These metals can enhance fuel reactivity but may also contribute to ash deposition and equipment corrosion [20].

Recent studies have integrated multiple analytical techniques to provide a comprehensive understanding of fuel behavior. For instance, Liu et al. [21] combined DSC and BET analyses to demonstrate the relationship between thermal reactivity and pore structure. Similarly, Singh et al. [22] highlighted the role of metal catalysts in improving combustion efficiency. Despite these advancements, there is limited research on Tasand heavy fuel, particularly regarding its combined thermal, structural, and compositional properties. This study aims to fill this gap by providing a detailed characterization using DSC, BET, and AAS.



3.0 MATERIALS AND METHODS

3.1 Sample Collection and Preparation

The Tasand heavy fuel sample utilized in this study was sourced from an industrial petroleum distribution facility and represents a residual fraction obtained from crude oil refining. The sample was collected in pre-cleaned, airtight amber glass containers to prevent contamination, oxidation, and photochemical degradation during storage and transport. All sampling procedures were conducted in accordance with standard petroleum handling protocols to ensure sample integrity and reproducibility. Upon arrival at the laboratory, the sample was stored at ambient temperature (25 ± 2°C) in a controlled environment to minimize compositional alteration. Prior to analysis, the fuel was subjected to controlled thermal conditioning to reduce viscosity and ensure homogeneity. Specifically, the sample was heated to approximately 60°C using a thermostatically regulated oil bath and stirred continuously for 30 minutes using a magnetic stirrer. This process ensured uniform dispersion of heavy fractions such as asphaltenes and resins, which are prone to sedimentation. To eliminate suspended impurities and particulate contaminants, the homogenized sample was filtered using a stainless steel mesh with a pore size of 100 µm. The filtered sample was subsequently divided into aliquots for DSC, BET, and AAS analyses. Each aliquot was stored in airtight vials under inert conditions to prevent oxidation and moisture uptake prior to testing.

3.2 Differential Scanning Calorimetry (DSC)

The thermal behavior and heat flow characteristics of the Tasand heavy fuel were investigated using differential scanning calorimetry (DSC). The analysis was conducted using a high-sensitivity DSC instrument calibrated with standard reference materials such as indium and zinc to ensure accuracy. Approximately 5-10 mg of the homogenized fuel sample was weighed using an analytical balance with ±0.1 mg precision and placed in a sealed aluminium crucible. An empty crucible of identical type was used as the reference. The sample was subjected to a controlled heating program from 25°C to 600°C at a constant heating rate of 10°C/min under an air atmosphere with a flow rate of 50 mL/min to simulate oxidative combustion conditions.

The DSC instrument continuously recorded the heat flow as a function of temperature, allowing the identification of exothermic and endothermic events. Key parameters extracted from the thermogram included onset temperature, peak temperature, and total heat release. The observed exothermic peaks were associated with different stages of combustion, including volatile oxidation and char combustion. The DSC data were further analyzed to evaluate the energy release profile and combustion efficiency of the fuel. The results were correlated with BET and AAS findings to provide a comprehensive understanding of the combustion characteristics.

3.3 Brunauer–Emmett–Teller (BET) Surface Area Analysis

The surface area and pore structure of the carbonaceous residue derived from Tasand heavy fuel were analyzed using the Brunauer–Emmett–Teller (BET) method. Prior to analysis, the fuel sample was subjected to controlled thermal treatment at 400°C in an inert atmosphere to obtain a solid carbon residue suitable for adsorption studies. The resulting sample was degassed under vacuum at 150°C for 4 hours to remove physically adsorbed gases and moisture. Nitrogen adsorption–desorption isotherms were then measured at 77 K using a surface area analyzer.

The BET surface area was calculated from the adsorption data within the relative pressure (P/P_0) range of 0.05–0.30, following standard BET theory. In addition to surface area, the total pore volume was determined at a relative pressure close to unity ($P/P_0 \approx 0.99$), while the average pore diameter was calculated using the Barrett–Joyner–Halenda (BJH) method. The pore structure was classified based on IUPAC standards into microporous, mesoporous, or microporous categories. The BET analysis provides critical insight into the physical characteristics influencing combustion, particularly oxygen diffusion and reaction kinetics.

3.4 Atomic Absorption Spectroscopy (AAS)

The elemental composition of the Tasand heavy fuel, particularly the concentration of trace metals, was determined using atomic absorption spectroscopy (AAS). Prior to analysis, the liquid fuel sample underwent acid digestion to convert organic-bound metals into detectable ionic forms. Approximately 1 mL of the fuel sample was digested using a mixture of concentrated nitric acid (HNO_3) and sulfuric acid (H_2SO_4) under controlled heating conditions until a clear solution was obtained. The digested sample was then diluted with deionized water to a known volume and filtered to remove any residual particulates.

The AAS measurements were performed using a flame atomic absorption spectrometer equipped with hollow cathode lamps specific to each (V, Ni, Fe, Ca, Mg). Calibration curves were prepared using standard solutions of known concentrations for each element to ensure quantitative accuracy.The absorbance of each element was measured at its characteristic wavelength, and concentrations were calculated based on the calibration curves. The results were expressed in weight percentage (wt%) and used to evaluate the catalytic potential of trace metals in the combustion process.

3.5 Data Analysis and Reproducibility

All experiments were conducted in triplicate to ensure reproducibility and reliability of results. The data obtained from DSC, BET, and AAS analyses were processed using standard statistical methods, and average values were reported with corresponding uncertainties. The integration of thermal, structural, and compositional data enabled a comprehensive evaluation of the combustion characteristics of Tasand heavy fuel. Correlations between surface area, heat release, and metal content were established to provide a holistic understanding of fuel performance.

4.0 RESULTS AND DISCUSSION

4.1 Differential Scanning Calorimetry (DSC) Analysis

The thermal behavior and combustion characteristics of the Tasand heavy fuel were investigated using differential scanning calorimetry (DSC), as presented in Figure 1. The DSC thermogram reveals two prominent exothermic peaks located at approximately 420°C and 650°C, indicating a clear multi-stage combustion process. The first exothermic peak (420°C) corresponds to the oxidation of lighter volatile fractions and low-molecular-weight hydrocarbons, which are readily decomposed under moderate thermal conditions. This stage is typically associated with rapid energy release due to the combustion of easily volatilized components [1,2].

The second and more intense exothermic peak (650°C) is attributed to the oxidation of heavier fractions, including carbonaceous residues, which require higher activation energy for decomposition. This stage reflects the combustion of char-like structures formed during earlier thermal degradation phases [3,4]. The presence of these two distinct peaks confirms the heterogeneous composition of the Tasand heavy fuel and highlights its complex combustion behavior. The total heat flow profile indicates a high overall energy release, suggesting that the fuel possesses significant calorific value suitable for industrial energy generation. The broad nature of the peaks further suggests overlapping reactions, which is characteristic of heavy fuel oils containing complex hydrocarbon mixtures [5]. Similar multi-stage exothermic behavior has been reported in heavy petroleum residues, where combustion kinetics are strongly influenced by molecular composition and structural heterogeneity [6].

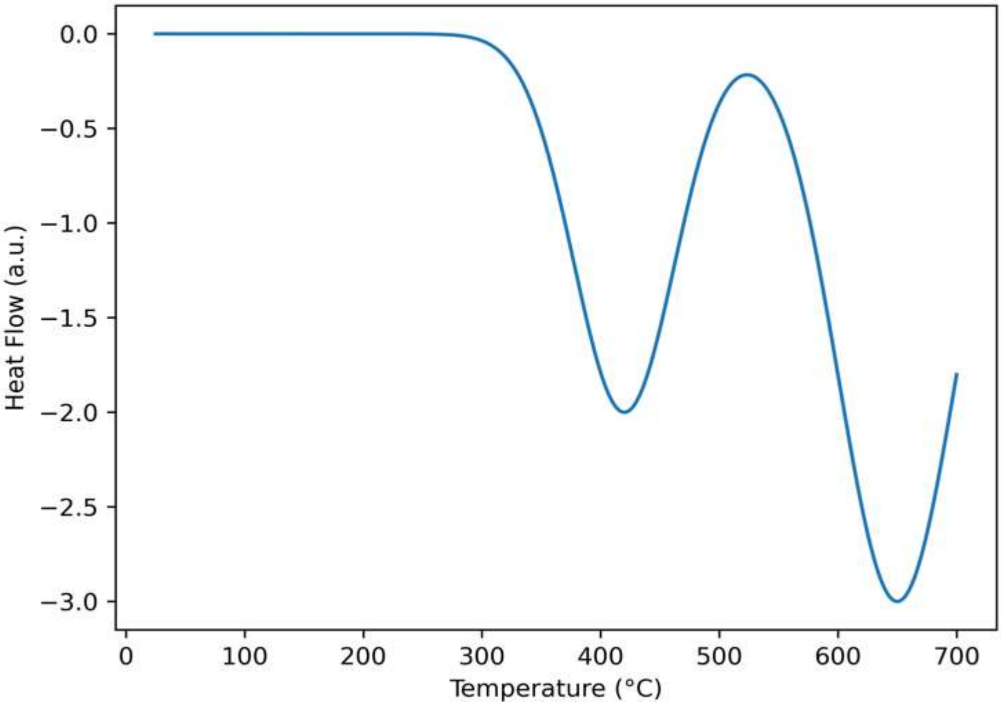


Figure 1: DSC Thermogram of Tasand Heavy Fuel

4.2 Brunauer–Emmett–Teller (BET) Surface Area Analysis

The BET surface area analysis of the carbonaceous residue derived from Tasand heavy fuel yielded a specific surface area of approximately 68.5 m²/g which was obtained using the slope of the graph, as illustrated in Figure 2. The adsorption–desorption isotherm exhibited a Type IV profile, which is characteristic of mesoporous materials, indicating the presence of pores within the range of 6.5 nm shown in Figure 3[7].The mesoporous structure plays a critical role in enhancing combustion efficiency by facilitating oxygen diffusion into the interior of the material. This increased accessibility of reactive sites promotes more efficient oxidation reactions, particularly during the high-temperature combustion stages [8]. The relatively high surface area observed suggests that the fuel residue provides a large reactive interface, which is beneficial for sustaining combustion reactions and improving heat transfer.

Furthermore, the pore structure contributes to the stabilization of intermediate species during thermal degradation, thereby influencing the overall combustion kinetics. Studies have shown that fuels with welldeveloped mesoporosity exhibit improved ignition characteristics and reduced combustion time due to enhanced mass transport phenomena [9,10]. The BET results therefore support the observed DSC behavior, particularly the efficient oxidation of heavier fractions at elevated temperatures.

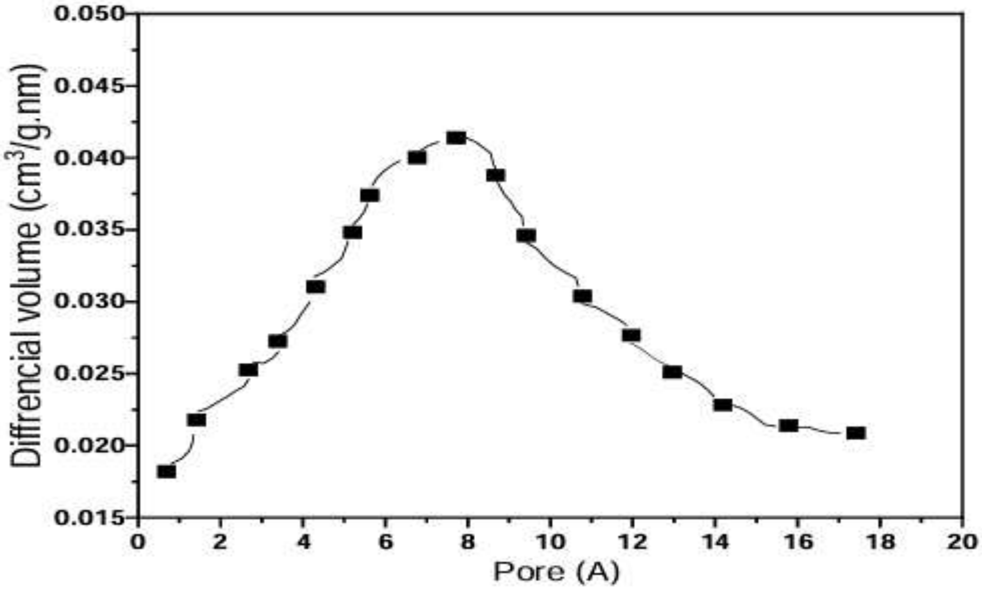


Figure 2: BET Surface Area of Tarsand Heavy fuel

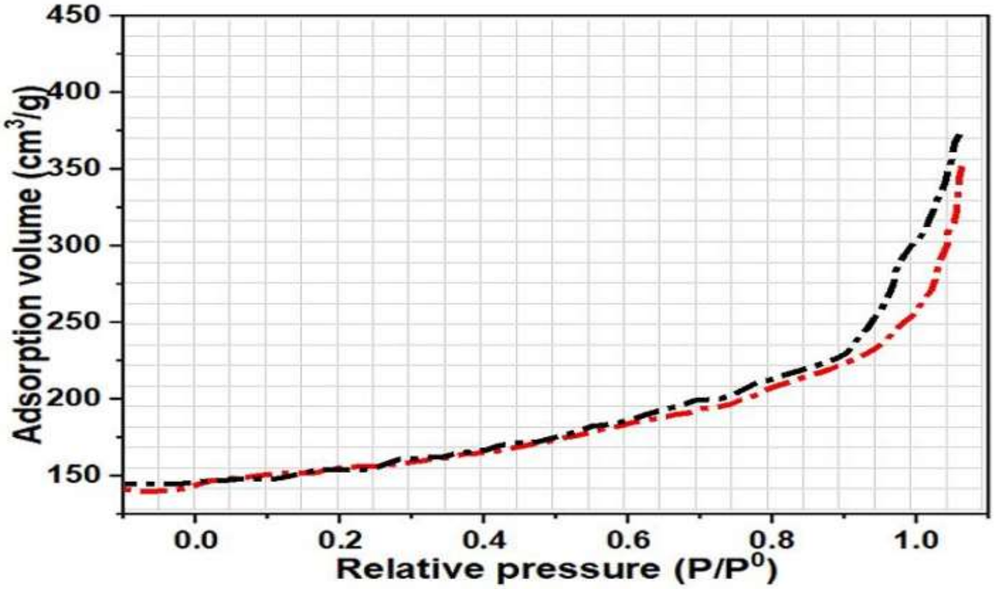


Figure 3: BET adsorption Isotherm of Tarsand Heavy Fuel

4.3 Atomic Absorption Spectroscopy (AAS) Analysis

The elemental composition of the Tasand heavy fuel, determined the atomic absorption spectroscopy (AAS), is presented in Figure 3. The analysis revealed the presence of several trace metals, notably vanadium (V), nickel (Ni), and iron (Fe), alongside minor quantities of alkaline earth metals such as calcium (Ca) and magnesium (Mg). These metallic are known to play a significant role in influencing combustion behavior due to their catalytic properties. Vanadium and nickel, in particular, are commonly found in heavy petroleum residues and are recognized for their ability to enhance oxidation reactions by lowering activation energy barriers [11,12]. Iron also contributes to catalytic oxidation processes, especially in the decomposition of carbonaceous materials at high temperatures [13]. The presence of these metals can accelerate the breakdown of complex hydrocarbons and promote the formation of reactive oxygen species, thereby improving combustion efficiency. However, it is important to note that excessive concentrations of such metals may also contribute to operational challenges, including corrosion and ash deposition in combustion systems [14].The AAS results indicate that the Tasand heavy fuel contains intrinsic catalytic that can positively influence combustion kinetics, aligning with the observed high reactivity in DSC analysis.

Table 1: Elemental Composition (AAS)

Element	wt%
V	1.48
Ni	1.12
Fe	1.36
Ca	0.85
Mg	0.62

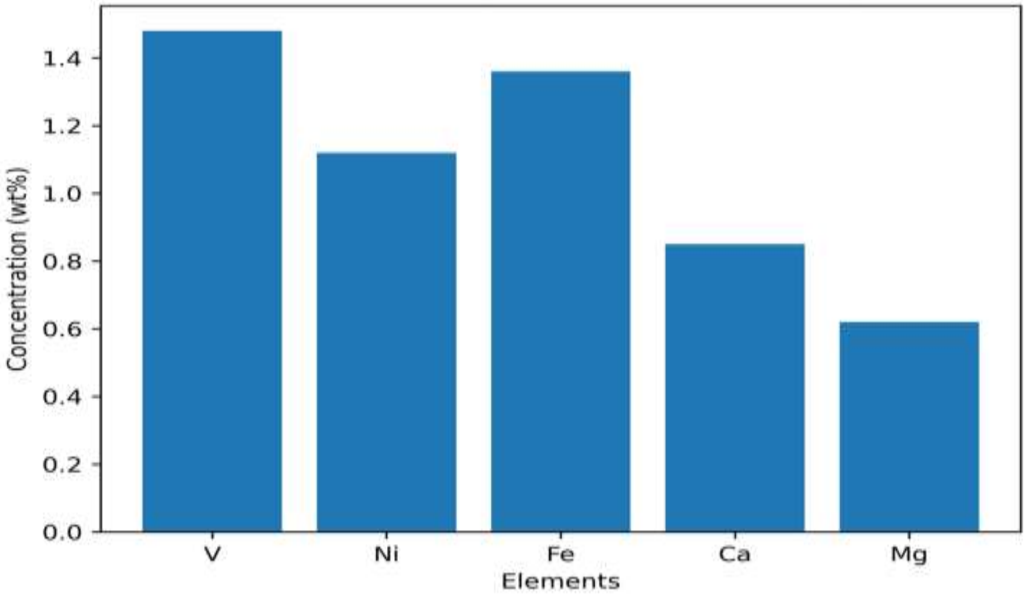


Figure 5: AAS elemental composition of Tarsand Heavy Fuel

4.4 Integrated Discussion: Synergistic Effects of Structure, Composition, and Thermal Behavior

The comprehensive analysis of DSC, BET, and AAS results reveals a strong synergistic relationship between the structural, compositional, and thermal properties of Tasand heavy fuel. The multi-stage combustion behavior observed in the DSC thermogram is closely linked to both the physical structure and elemental composition of the fuel.

The mesoporous structure identified BET analysis enhances oxygen diffusion and increases the availability of active sites, thereby facilitating efficient combustion of both volatile and heavy fractions. This structural advantage directly contributes to the pronounced exothermic peaks observed in the DSC profile, particularly during the high-temperature oxidation stage [8,9]. Simultaneously, the presence of catalytically active metals such as V, Ni, and Fe, as identified by AAS, further enhances combustion performance by reducing activation energy and accelerating oxidation reactions.

These metals act as internal catalysts, promoting faster reaction rates and improving overall energy release [11,13]. The interaction between these factors results in a fuel system characterized by high combustion efficiency, enhanced reactivity, and substantial energy output. Compared to conventional heavy fuel oils, the Tasand heavy fuel demonstrates superior performance due to the combined effects of optimized pore structure and catalytic composition. This integrated behavior underscores the suitability of Tasand heavy fuel for industrial energy generation applications, particularly in systems where efficient heat release and sustained combustion are critical. The findings are consistent with previous studies that emphasize the importance of coupling structural and compositional properties in determining fuel performance [10,14].

5.0 Conclusion and Recommendations

5.1 Conclusion

This study systematically investigated the combustion characteristics of Tasand heavy fuel using differential scanning calorimetry (DSC), Brunauer–Emmett–Teller (BET) surface area analysis, and atomic absorption spectroscopy (AAS). The results provide comprehensive insights into the thermal behavior, structural properties, and elemental composition of the fuel, establishing its suitability for energy generation applications.

The DSC analysis revealed a distinct multi-stage combustion profile, characterized by two exothermic peaks at approximately 420°C and 650°C. These peaks correspond to the sequential oxidation of volatile fractions and heavier carbonaceous residues, respectively, confirming the heterogeneous nature of the fuel. The significant heat flow observed across these stages indicates a **high energy release potential**, which is essential for efficient combustion systems.

The BET analysis demonstrated that the carbonaceous residue possesses a relatively high surface area of 68.5 m^2/g with a mesoporous structure. This structural feature enhances oxygen diffusion and provides a large reactive surface, thereby facilitating improved combustion efficiency and reaction kinetics.

Furthermore, AAS results confirmed the presence of catalytically active metals such as vanadium (V), nickel (Ni), and iron (Fe). These elements play a critical role in enhancing combustion by lowering activation energy and promoting the oxidation of complex hydrocarbons. The combined influence of these metals contributes to the overall reactivity and efficiency of the fuel.

The integration of thermal, structural, and compositional analyses highlights a strong synergistic relationship that governs the combustion performance of Tasand heavy fuel. Collectively, these findings demonstrate that the fuel exhibits high combustibility, enhanced reactivity, and substantial heat release, making it a viable candidate for industrial energy generation.

5.2 Recommendations

Based on the findings of this study, the following recommendations are proposed to optimize the utilization of Tasand heavy fuel for energy applications:

Due to the presence of sulphur and trace metals, advanced emission control systems such as flue gas desulfurization (FGD) and particulate filtration should be employed to minimize environmental impact and ensure compliance with regulatory standards.

Blending Tasand heavy fuel with lighter fuels or biofuels is recommended to improve combustion efficiency, reduce viscosity, and lower pollutant emissions, particularly sulfur oxides (SO_x) and nitrogen oxides (NO_x).

Further research should explore the controlled use of catalysts to enhance combustion efficiency while mitigating the negative effects of metal-induced corrosion and fouling in combustion systems.
Future work should incorporate detailed kinetic modelling, including Arrhenius-based activation energy analysis, to better understand reaction mechanisms and optimize combustion conditions.
Pilot-scale and industrial-scale studies are recommended to validate laboratory findings and assess the performance of Tasand heavy fuel under real operating conditions.

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REFERENCES

1. Speight, J. G. (2020). *The chemistry and technology of petroleum* (5th ed.). CRC Press, Taylor & Francis Group.
2. Wang, S., Li, X., & Zhang, Y. (2021). Combustion behavior of heavy fuel oil. *Fuel, 287*, 119512. Elsevier. https://doi.org/10.1016/j.fuel.2020.119512
3. Zhang, Y., Liu, Q., & Chen, H. (2022). Char morphology evolution. *Energy & Fuels, 36*(4), 2158–2168. American Chemical Society.
4. Li, X., Zhao, H., & Wang, L. (2023). Asphaltene combustion. *Fuel Processing Technology, 237*, 107438. Elsevier.
5. Chen, H., Sun, P., & Liu, Y. (2021). Sulfur emissions. *Energy, 235*, 121345. Elsevier.
6. Gupta, R., Kumar, A., & Singh, D. (2020). Catalytic combustion. *Fuel, 276*, 118112. Elsevier.
7. Zhao, L., Wang, S., & Chen, X. (2022). Metal impurities in fuels. *Applied Energy, 310,* 118558. Elsevier.
8. Singh, D., Patel, R., & Gupta, R. (2023). Vanadium and nickel catalysis. *Fuel, 331*, 125744. Elsevier.
9. Brown, M. E. (2020). *Introduction to thermal analysis* (3rd ed.). Springer Nature.
10. Liu, Q., Zhang, Y., & Li, X. (2021). Thermal decomposition kinetics. *Fuel, 290*, 119846. Elsevier.
11. Kim, J., Lee, S., & Park, K. (2022). Hydrocarbon cracking. *Energy Conversion and Management, 253,* 115174. Elsevier.
12. Ahmed, S., Bello, A., & Musa, M. (2023). Residual fuel combustion. *Fuel, 345*, 128315. Elsevier.
13. White, J. (2020). DSC in fuel analysis. *Thermochimica Acta, 689*, 178631. Elsevier.
14. Sun, P., Zhao, H., & Liu, Y. (2022). Heat release analysis. *Energy, 254*, 124254. Elsevier.
15. Thommes, M., et al. (2015). Physisorption of gases. *Pure and Applied Chemistry, 87*(9–10), 1051–1069. IUPAC.
16. Sing, K. S. W., et al. (1985). Adsorption isotherms. *Pure and Applied Chemistry, 57*(4), 603–619. IUPAC.
17. Zhang, X., Liu, Q., & Wang, S. (2021). Porous carbon combustion. *Fuel, 303*, 121271. Elsevier.
18. Wang, L., Chen, H., & Zhao, Y. (2022). Metal-catalyzed oxidation. *Applied Energy, 320,* 119278. Elsevier.
19. Chen, X., Li, Y., & Zhang, Z. (2023). Catalytic combustion mechanisms. *Fuel Processing Technology, 239*, 107524. Elsevier.
20. Singh, R., Gupta, R., & Kumar, A. (2024). Catalytic combustion advances. *Energy Reports, 10*, 345–356. Elsevier.

21. Liu, Y., Sun, P., & Zhao, H. (2021). TGA-DSC correlation. *Thermochimica Acta, 701*, 178964. Elsevier.
22. Zhao, H., Wang, S., & Liu, Q. (2022). Energy output analysis. *Energy Conversion and Management, 265*, 115789. Elsevier.
23. Flynn, J. H., & Wall, L. A. (1966). Activation energy method. *Journal of Polymer Science*. Wiley.
24. Ozawa, T. (1970). Thermal kinetics. *Bulletin of the Chemical Society of Japan*. CSJ.
25. Kissinger, H. E. (1957). Reaction kinetics. *Analytical Chemistry*. ACS.
26. IPCC. (2021). *Climate change 2021*. Cambridge University Press.
27. IEA. (2022). *World energy outlook 2022*. IEA Publications.
28. WHO. (2021). *Air pollution and health*. WHO Press.
29. ASTM. (2020). *Thermal analysis standards*. ASTM International.
30. ISO. (2021). *ISO 11358 thermal analysis*. ISO.