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Combustion Profiles Of Asphaltene And Heavy Fuel Oils Derived From Tar Sand: A Review

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ABSTRACT

Asphaltenes are the heaviest and most polar part of crude oils, having complex molecular structures that are typically classified as a solubility class, soluble in light aromatics such as benzene and toluene but insoluble in paraffins. Because asphaltene is a constituent of crude oil with a high percentage of carbon, nitrogen, oxygen, and sulfur, its precipitation and agglomeration cause problems in oil recovery, production, and transportation. Because of its complicated molecular structure, its makeup has yet to be fully understood. Asphaltenes, which are solids, have or impart critical and frequently damaging fluid properties such as high viscosity, emulsion stability, low distillate yields, and inefficient phase separation. Asphaltene precipitation/deposition is influenced by a number of elements, including pressure, temperature, and the properties and amount of precipitants in the mixtures involved. This paper investigates the combustion characteristics of asphaltene and heavy fuel oils made from tar sand. It clarifies the intricacies of ignition, flame stability, and emissions during combustion by consolidating the body of previous knowledge. The knowledge gathered from this assessment is intended to direct future investigations toward improving the combustion process and reducing the negative environmental effects of using asphaltene and heavy fuel oils made from tar sand.

Keywords: Combustion, Asphaltene, Heavy Fuel Oils, Tar Sand

1. INTRODUCTION

Petroleum asphaltenes are complex organic compounds or polar macrocyclic molecules that are thought to be organized in stacked, multi-ring configurations. They contain a high concentration of nitrogen, oxygen, and sulfur atoms in addition to carbon and hydrogen atoms, as well as trace metals that form complexes with porphyrins inside the repeating unit [1]. They are defined as a solubility class of petroleum's heavy components that are insoluble in non-polar solvents like n-pentane and n-heptane [2] but soluble in aromatics like toluene [3].

These have been discovered to provide numerous difficulties, such as clogging wells and pipelines, blocking reservoirs, and fouling and stabilizing oil-water emulsions in the petroleum sector [4], [5]. Their solubility-based behavior includes the same chemicals from coal and bitumen, despite the fact that they are typically referred to as the heaviest fraction of petroleum. Numerous studies have examined the makeup of asphaltenes, and generally speaking, asphaltene macromolecules are thought to be made up of aliphatic side chains connected to aromatic moieties by C-C, C-O, and C-S bonds. However, a deeper understanding of asphaltenes' combustion and molecular structure can be a useful aid in gaining a better understanding of their behavior during conversion processes, as they have a significant impact on the physical and chemical properties of crude oils and related systems. [7]. Various methods have been put out to establish a "average structure" for asphaltenes. Asphaltene units were defined by the Archipelago Model 8 as a cluster of four to five layers of naphthene aromatic hydrocarbons made up of a series of molecules stacked in parallel planes. They also exhibit steric hindrances and deviations from planarity. This model is supported by NMR, FT-ICR MS, and thermal cracking methods 9. The island model 11 then explained that asphaltenes are made up of solitary aromatic hydrocarbons. They include cycloalkanes, branched-chain substituents, heteroatoms such as nitrogen in pyrrole and pyridine-like structures, and sulfur atoms in thiophene-like units. The oxygen atom is primarily associated with phenolic compounds or ethers with aliphatic substituent. Vanadium and nickel are connected with porphyrins in much lesser levels. Recently, additional studies have supported the concept of a macromolecule, which is consistent with the existence of both types of models. The ratios of the archipelago and island constructions varied depending on the asphaltene origin [9].

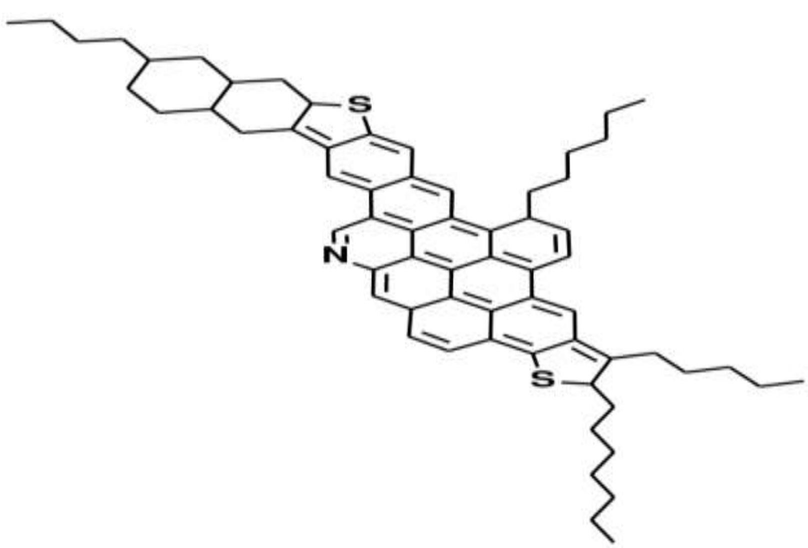

Figure 1: The deduced chemical structure of the asphaltene molecule [10].

The archipelago model is mostly derived using X-ray diffraction (XRD). It is a non-destructive technique used to assess the carbon stacking structure of carbon compounds such as asphaltenes. The proposed model structures are useful for identifying changes that occur during transformation processes such as pyrolysis, thermal cracking, and catalytic hydrogenation[12]. Despite their common structure, asphaltenes are complicated combinations. Pyrolysis, a thermal approach that looks to be an alternate means to produce smaller molecules from macromolecule complex mixtures, can simply be used to convert asphaltene. Pyrolysis transforms the asphaltene mixture into a simpler blend of raw ingredients, hence easing the separation processes [13].

2. AGGREGATION AND PRECIPITATION

Asphaltenes clump in crude oil, producing clusters; this aggregation can lead to asphaltene precipitation under certain conditions, causing equipment fouling and pipeline clogs in the oil sector [14]. Asphaltene precipitation is one of the most difficult difficulties in oil production and processing [15]. Asphaltene precipitation and deposition have a deleterious impact on the functioning of industrial systems, both upstream and downstream. Asphaltene precipitation and deposition can cause pore throat obstruction, altered reservoir wettability, and a decrease in reservoir permeability, among other negative outcomes. Asphaltene is thus a solid component of crude oil with an extremely high molecular weight; this is the primary reason why it is extremely problematic, as it can form dense flocculations and deposits in reservoirs, wellbores, and transportation pipelines, causing severe operational and production problems [3].

3. IMPACTS OF ASPHALTENE ON REFINING PROCESSES

3.1 Coking is a carbon rejection process that converts heavier residues with high sulfur content at the bottom of the Vacuum Distillation Unit (VDU) into lower molecular fractions such as gases, naphtha, light gas oil (LGO), heavy gas oil (HGO), and solid petroleum coke or pet coke. Asphaltenes help to make coke, a solid carbonaceous substance. Coke production can occur in reaction zones and on catalysts, lowering refining process efficiency [17].

3.2 Viscosity increase: Asphaltenes increase the total viscosity of crude oil, making it more difficult to handle, and this viscosity increase can affect pump and pipeline efficiency. According to Mohammed and Linus [15], asphaltenes pose additional obstacles to fluid flow by affecting not only fluid viscosity and density, but also stabilizing oil-water emulsions. Furthermore, Mansour et al. [18] discovered that asphaltenes are not soluble in the distillate portion of crude oil, but they do dissolve to variable degrees when linked with resins. Crude oil with a higher percentage of asphaltene is usually more viscous, which could be due to the stronger attraction and aggregation of asphaltene particles, specifically, for the heavy or extra-heavy crude oil [18].

4. HEAVY FUEL OIL

Heavy fuel oil (HFO) is an economically advantageous, tar-like, low-grade fuel used to move marine engines, fire industrial blast furnaces, and generate electricity in utility boilers due to its low cost, availability, and high energy density. HFO is distinguished by its high viscosity, molecular weight, asphaltene concentration, and rich compositional diversity, which includes several thousand distinct molecules and functional groups. HFO comprises polycyclic sulfur and aromatic hydrocarbons, as well as heavy metals such as vanadium and nickel, which damage metal components in engines and gas turbines [19]. Bunker C and vacuum residue are examples of heavy fuel oils that are frequently used as transport fuels, such as in large marine engines, and as fuel for industrial boilers and power generation. Together with related poly-nuclear aromatic hydrocarbons (PAH), carbonaceous particulate emissions from burning these fuels produce fine soot (also known as black carbon, or BC). These fossil fuels' greenhouse gas emissions are continuously deteriorating the planet, contributing to global warming and other issues related to pollutant emissions [20].

5. COMBUSTION OF ASPHALTENE AND HEAVY FUEL OILS

Hydrocarbons found in asphaltene and heavy fuel oils (HFO), which are made from tar sand, undergo oxidation during combustion. These hydrocarbons react with oxygen during combustion, releasing heat energy and generating water (H_2O) and carbon dioxide (CO_2) as byproducts [20]. However, because of its detrimental effects on the environment, which are mostly caused by the emissions of sulfur oxides and cenospheres, the usage of HFO is confronted with numerous difficulties. Furthermore, because of its high sulfur content, HFO has detrimental corrosive effects on the machinery utilized in power generation systems. Biodiesels encourage more thorough combustion than traditional diesel fuels, which successfully lowers emissions of smoke, carbon monoxide (CO), and particulate matter (PM) [21], [22]. These factors have caused a sharp decline in the usage of HFO as an energy source since it peaked in the late 1970s [14]. Compared to light fuel oils, HFO's low carbon efficiency results in noticeably larger emissions of pollutants into the environment. [23]

6. POLLUTANT FORMATION IN COMBUSTION PROCEDURE

In their paper Reduction of Air Pollution by Combustion Processes, Aurel and Stefania described the sources of combustion, which primarily include boilers, furnaces, and gas turbines, as well as mobile sources, which include transportation vehicles, whose internal combustion engines burn diesel and spark ignition engines burn gasoline. Additionally, [24] said that in fuel combustion processes, full combustion with the least amount of air surplus results in the exclusive creation of CO_2, H_2O, SO_2, and N_2 gases, which releases the most energy. On the other hand, incomplete combustion produces toxic substances for both the environment and people, including as particulate matter, CO, NO_x, SO_2, and VOCs.

7. MONITORING EMISSIONS AND REDUCING POLLUTION IN COMBUSTION PROCESSES

The purpose of an emission monitoring and control system is to monitor and regulate the emissions of greenhouse gases and other pollutants from industrial facilities or operations. Sensors, analyzers, and data gathering devices are used to track the amount and kind of emissions generated. In order to ensure sustainable and ethical operations, EMCS is an essential instrument for industries to monitor and manage their environmental impact. Environmental degradation is a result of industries' rapid development. The primary cause of environmental deterioration is modern technology in all domains. One of the hardest things to do for environmental protection is to control industrial pollution [25].

7.1 FLUE GAS TREATMENT

The method and technology used to eliminate contaminants and dangerous materials from exhaust gases generated during combustion in industrial operations or power production are referred to as flue gas treatment. Among the technologies used to remediate flue gases are [26].

7.1.1. Selective non-catalytic reduction (SNCR): This technique lowers the emissions of nitrogen oxide in traditional power plants that burn coal, trash, and biomass. In order to react with the nitrogen oxides produced during combustion, ammonia or urea is injected into the boiler's firebox at a temperature between 1,400 and 2,000 ºF (760 and 1090 ºF). Molecular nitrogen (N_2), carbon dioxide (CO_2), and water (H_2O) [27] are the end products of the chemical process without the aid of a catalyst.

7.1.2 Selective Catalytic Reduction (SCR): This process uses a catalyst to convert nitrogen oxides into diatomic nitrogen (N_2) and water. A stream of flue gas is treated with a reductant, usually anhydrous ammonia (NH_4OH) or urea (CO $(NH_2)_2$) solution, and then reacts with a catalyst. When urea is used, the process produces nitrogen and carbon dioxide as it nears completion. The method employs a catalyst to promote the reaction of nitrogen oxides (NO_x) with ammonia (NH_3) to produce nitrogen (N_2) and water (H_2O), lowering the amount of NO_x released into the atmosphere.[27]

7.2 PARTICULATE MATTER CONTROL:

Particulate matter produced by incomplete combustion includes microscopic solid particles and liquid droplets, which contribute to air pollution. Particulate matter (PM) control is critical in companies and power plants to reduce fine particle emissions into the environment, which can have a negative impact on air quality and human health [28]. The reduction of this PM includes:

7.2.1. Electrostatic Precipitators (ESPs): Remove particulate debris from the gas stream by generating a large voltage drop between electrodes. A gas stream carrying particles runs into the ESP and between sets of huge plate electrodes; gas molecules are ionized, and the resultant ions cling to the particles, causing the particles to charge. The charged particles are attracted and collected on the oppositely charged plates, while the clean gas flows through the device [28].

7.2.2. Wet Scrubbers: These systems use liquid (often water or alkaline solutions) to absorb and neutralize acidic pollutants such as SO_2. It manages combustible or explosive dust, cools gasses, and neutralizes acid mists and vapors (Cooper and Alley, 2002). The cleaned gas is then expelled into the atmosphere [26].

7.2.3. Dry Scrubbers: These function similarly to other scrubbers. The device sprays a collection of dry reagents into an exhaust stream; the chemicals react differently depending on the substance being removed. Some of these materials eliminate dangerous contaminants in the stream through a chemical reaction, while others induce a material to react and transform into a different substance. Dry scrubbers employ a dry sorbent or powder to react with and neutralize contaminants. The treated gas is subsequently filtered and discharged into the atmosphere [26].

8. GOVERNMENT REGULATIONS AND INCENTIVES

In Nigeria, air pollution can be reduced by increasing access to clean household energy, such as cleaner cook stoves and solar illumination. There are additional potential in transportation, the oil and gas industry, agriculture, and improving municipal solid waste management[29]. Stringent environmental rules frequently force industries to embrace cleaner technology, which influence combustion practices. Incentives, such as tax breaks or subsidies for cleaner combustion processes, encourage businesses to invest in environmentally friendly practices. Balancing regulatory compliance with economic incentives is critical for promoting sustainable combustion methods in the asphaltene industry and aligning industrial activities with broader environmental objectives.

9. CONCLUSION

After evaluating several approaches and their findings in the literature (2010-2023), I conclude that researching the combustion profiles of asphaltene and heavy fuel oils powered by tar sand provides useful insights into their thermal behavior, emissions, and potential environmental impact. This paper advances our understanding of energy production from unusual sources, allowing for the creation of more efficient and ecologically friendly combustion processes. Further research in this area can help to improve combustion technology and promote responsible energy development. HFOs are also challenging to handle using standard containment and recovery procedures, due to their high viscosity, which inhibits transit and pumping.

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