Synergistic utilization of heavy fraction of tire pyrolysis oil and heavy fuel oil in thermal conversion processes

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Abstract

Insights into the characteristic behavior of residual fuel oils needing urgent attention are obtained at conditions representative of relevant thermal conversion processes such as gasification and combustion. To that end, the heavy fraction of tire pyrolysis oil and heavy fuel oil (as representatives of alternative and conventional residual fuels, respectively) are experimentally investigated via isolated droplet method in neat and blended form.

Body

In recent times, the pyrolysis of waste tires has been an object of significant research efforts, since the disposal of these residues poses a first order environmental problem. Tire pyrolysis oil (TPO) so obtained can be distilled to provide valuable petrochemicals such as BTEX and carbon black oil [1]. Alternatively, it can also be distilled into various fractions such as light, low-middle, high-middle, and heavy fractions which have physico-chemical properties comparable to those of petroleum fractions such as gasoline, diesel, distillate marine fuels and bitumen, respectively [2]. Thus clearly suggesting TPO's potential in defossilizing existing combustion devices, either alone or as blends.

On the other hand, as global crude oil consumption continues, the distillation process keeps yielding a residual - heavy fuel oil (HFO). Due to its low cost and high calorific value, HFO is widely utilized in marine and industrial sectors regardless of exhibiting complex evaporation and combustion features such as micro-explosions (MXs) and the formation of large cenospheres requiring long consumption times [3]. The heavy fraction of TPO resembles HFO, physico-chemically [2] as well as in terms of economic value. Hence, for the first time, the less studied heavy fraction of TPO obtained at the bottom of the atmospheric distillation tower operating at 220 °C in the Instituto de Carboquimica (CSIC-ICB, Zaragoza) is investigated in neat as well as in blended form with an industrial sample of HFO having low asphaltene content. Both fuels were found to have similar elemental composition of CHNS, however, GC-MS analysis revealed that TPO was rich in cyclic aromatics with 42.5% wt. of PAHs. While they had similar densities, their viscosities were markedly different; 1349 mPas and 8.2 mPas for HFO and TPO, respectively at 40 °C. HFO was blended with three TPO concentrations: 10% (TPO10), 25% (TPO25) and 50% (TPO50) by wt., resulting in perfectly miscible blends without any co-solvents.

The utilization of these residual fuels/blends in thermal applications requires a dense spray of fine droplets and hence, single droplet studies are widely employed to extract relevant behaviors under strictly controlled conditions. However, for TPO, only a few works such as [4-6] have reported intrinsic characteristics of light fraction / aromatic rich droplets of TPO. Besides, these works do not address the characterization of the coke residue generated from TPO, although clearly reported to occur in [4]. Therefore, the suspended droplet method is adopted to characterize the entire history of TPO and HFO/TPO droplets, encompassing the liquid and solid consumption stages as well as the cenosphere morphology at flame-like ambient conditions. In this technique, an isolated droplet of initial size d_0~500 µm is suspended at the cross-junction of two thin SiC fiber (d_f~15 µm) and is placed underneath a McKenna flat flame burner operating with premixed CH_4+Air+O_2, where the droplet evaporates/burns within its hot flue gases. Two optical devices placed perpendicular to each other record the temporal evolution of droplet and its envelope flame (if any) using high-speed shadowgraphy technique (2500 fps) and CH* self-emission with high sensitivity camera, respectively. The images obtained are later post-processed using MATLAB®. The ambient conditions at the droplet location from this arrangement are measured and found to be: droplet Re ~ 0.5, gas temperature of 1336±50 K and 1408±20 K during liquid and solid consumption phases, respectively. A detailed description of the facility can be found elsewhere [3].

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Figure 1 shows the normalized size history of droplets (liquid stage) when exposed to oxygen-free hot gases. Firstly, it is clear that similar to HFO [3], neat TPO droplets also exhibit a two-staged behavior: (i) steady heat-up and (ii) disruptive behavior with multiple MXs. Some of the representative droplet events are also shown in Fig. 1. Repeated tests with TPO showed that it exhibits two different modes. In mode I, the fluctuating behavior is delayed, and it begins after droplet swelling to ~1.5d_0. Whereas, in mode II, prolonged sequences of MXs and puffing with large child droplets occur, leading to ~10% shorter liquid conversion time. Lastly, the droplet for all the tested fuels undergoes pyrolysis+polymerization which results in a solid residue [3]. Here, an abrupt expansion of droplet shell occurs which later collapses; see at 3.9 s/mm^2 for HFO and at 2.6 (I) and 2.9 (II) s/mm^2 for TPO. Interestingly, the effect of TPO blending reduces HFO liquid lifetime by ~12% (for all ratios). The morphology of cenospheres is observed using SEM and is shown in Fig.1. HFO cenospheres are hollow shells with large blowholes (50-60 µm), few small pores (4-5 µm), smooth interior and exterior surface and thick walls (~26 µm). On the other hand, TPO cokes are elongated with their shells packed closely around the fiber junction. The strong MXs experienced by TPO droplets results in spongelike, and thin walls (~10 µm). Moreover, soot deposits are found in TPO cokes which concur with their high PAH content.

The consumption of cenospheres occurred in 5% O_2 co-flow. Figure 2 shows its size history during this period from the instance it was formed. As discussed in [3], HFO cokes showed a prolonged constant diameter burning zone due to higher carbon mass in the thick walls. On the contrary, TPO cokes burnt faster as the porous walls permitted rapid diffusion of oxygen causing it to burn in the mixed regime. The effect of TPO addition on HFO coke burning was more substantial than in its liquid stage. For TPO25 and TPO50, the solid-to-liquid consumption ratio reduced by ~20% and ~30%, respectively. This could be attributed to the increase in porosity of coke walls by the volatile content of TPO.

Conclusion

A comprehensive investigation has been carried out of novel fuels: heavy fraction TPO and its blends with HFO. Comparative assessment between them shows their characteristic resemblance in addition to their physico-chemical properties. Besides, the positive effects of TPO blending support the viability of an alternative to utilize two residual fuels synergistically for energy and waste reduction purposes.

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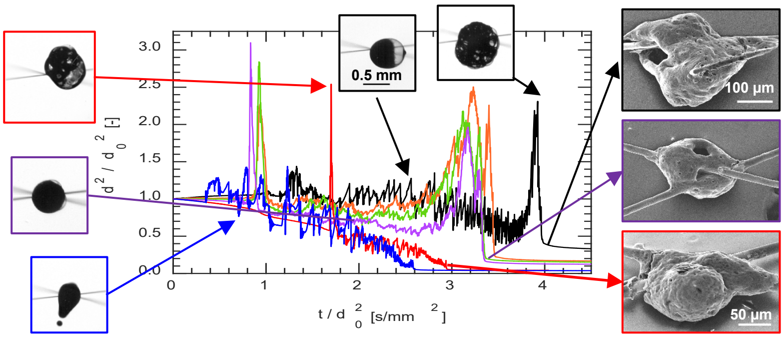

Fig. 1 Evolution of normalized droplet size during evaporation in 0%O_2. along with typical disruptive events and cenosphere images from SEM (legend in Fig. 2).

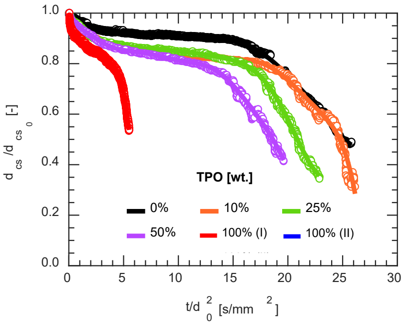

Fig. 2 Normalized size history of oxidizing cenosphere in a hot co-flow with 5% O_2.