SPRAYS OF BIOMASS PYROLYSIS OIL EMULSIONS: MODELLING AND EXPERIMENTAL INVESTIGATION. PRELIMINARY RESULTS ON MODELLING.

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ABSTRACT: Emulsions of biomass pyrolysis oils (POs) and Light Fuel Oil (LFO)/Diesel fuel have been developed in the past years with the aim of facilitating the use of this renewable fuel for both heat and power&heat applications. Some basic fuel properties, such as viscosity or ignition delay, are significantly different between emulsions and pure PO. The understanding of the injection of PO/LFO emulsion is a key issue to optimise the combustion of this fuel. The present work is a preliminary step towards the investigation of PO/LFO emulsion atomization with commercially available nozzles that are commonly used in standard small-scale boilers. A correlation model is derived from existing models for other fuels in order to estimate the most relevant parameters of the spray: model output will then be validated by measurements in an experimental device.

An experimental unit has therefore been designed for testing injection of PO/LFO emulsion and comparing the emulsion behaviour with pure LFO and Diesel oil. Laser scattering techniques will be used to investigate standard nozzles. The experimental and numerical research work will make available a more detailed insight into the atomisation of emulsions.

Keywords: flash pyrolysis, emulsions, atomization

1 INTRODUCTION

The use of liquids from biomass flash pyrolysis processes (PO, Pyrolysis Oils) presents some difficulties due to the peculiar characteristics of these fuels, such as high viscosity, acidity, sensitivity to high temperatures and to heating/cooling cycles, possible polymerization, carbonization or cocking in injectors, ignition delay, and other aspects. Storage is also an important issue to be taken into account, as the fuel physico-chemical properties can significantly change during the period ranging from production to utilization. For instance, phase separation can quickly occur: this aspect depends on a number of factors, such as the specific pyrolysis process, the feedstock type, and the storage temperatures, etc. Methanol (or other alcohols) is often added to POs, so to facilitate their use and slow down the aging process. However, both technical (such as fuel flash point change) and economical aspects have to be carefully considered in adding ethanol to pyrolysis liquids.

Among the motivations behind the production of emulsions from flash pyrolysis liquids and Light Fuel Oils (LFOs), the improved stability and reduced aging effect was one of the main driving factors.

Today, with improved production processes and increased stability of POs, the interest in emulsion production is mainly due to the improved characteristics of the fuel (as regards ignition, for instance) and easier handling and use.

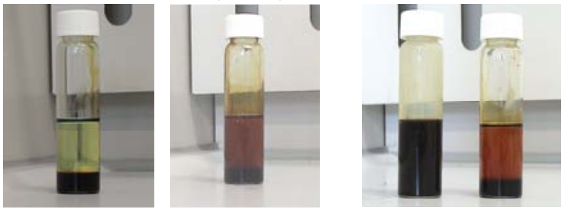
2 PO/LFO EMULSIONS

Emulsions are constituted at least by two immiscible fluids and a surface-active agent, which is able to stabilize the dispersed phase in the form of droplets, whose dimensions typically range from 300-400 nanometers to about 10 micrometers (figure 1). Since it affects most of the properties of emulsions (stability, viscosity, etc.), droplet size distribution is of particular importance.

When an emulsion is prepared, the choice of the emulsification method and the selection of the most appropriate surfactant represent the key-factors in obtaining a stable dispersion.

In the case of PO/LFO emulsions, their preparation and stability is of particular interest because they are expected to offer the following advantages (compared to pure PO use):

- Easier ignition
- Easier transportation, handling and storage
- Lower viscosity
- Improved stability against aging


Light Fuel Oil (LFO) and Pyrolysis Oil (PO) are not miscible.

Diesel Oil and PO mixture immediately after the emulsification process with no use of surfactants. The separation has already taken place.

Diesel Oil and PO mixtures immediately after the emulsification process with the use of an appropriate surfactant (on the left) and without any surfactant (on the right).

Figure 1: Emulsions of PO and LFO

As shown in the next figure, which describes a single droplet combustion test, the use of emulsion instead of pure PO significantly reduces the ignition time, which is a very important aspect in combustion devices [1].

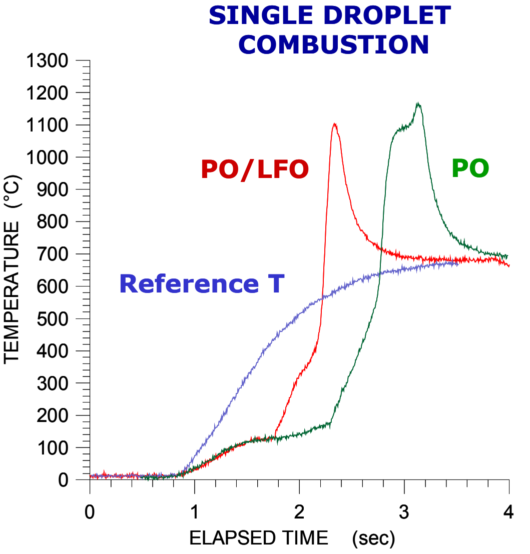


Figure 2: Emulsion and pure PO single droplet combustion

3 EMULSION PRODUCTION

PO/LFO (PO/Diesel) emulsions have been produced in a wide range during the recent years [2-5]. In this work, the emulsification process has been carried out by separately heating PO and Diesel Oil up to the emulsification temperature [6]. The proper surfactant (chosen among a large number of non-ionic surface-active molecules) was dissolved into the Diesel oil, and then PO was added to this solution. The mixture, still at the emulsification temperature, was then fed to the emulsification head (which acts similarly to a centrifugal pump), where strong shear stress and fluid accelerations take place, producing a fine dispersion of PO in Diesel Oil (figure 3). Finally, the emulsion was cooled down to room temperature.

Stability of the emulsion was investigated by following the evolution of the droplet size distribution against aging. Tests were carried out both at room temperature and in accelerated-aging conditions. This was done by storing the emulsion at 65ºC, for a defined amount of time.

Droplet size distribution was investigated by means of optical microscopy and FOQELS (Fiber Optic Quasi Elastic Light Scattering) analysis. Results demonstrates that stable emulsions have been produced with various POs (produced by VTT and FORTUM) at both lab and greater (~50 l/h) scale [6].

Emulsions have been then tested in small scale pumps for domestic boilers [5], according to the COMBIO project activity plan (figure 4).

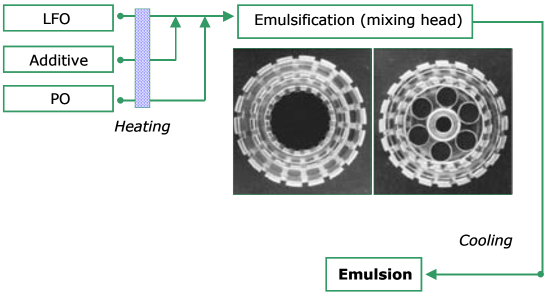


Figure 3: Basic procedure for emulsion production

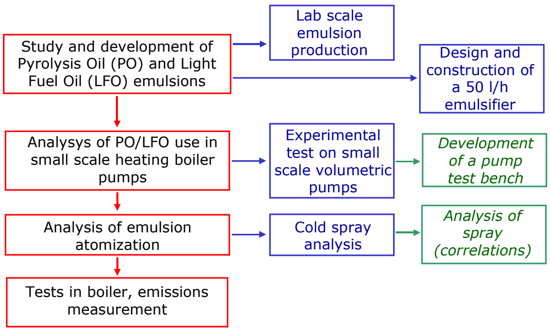


Figure 4: COMBIO project activities on emulsion investigation

4 SPRAY INVESTIGATION: DESIGN OF THE EXPERIMENTAL DEVICE AND CORRELATION MODEL

As regards fuel spray, an experimental unit has been designed for testing injection of PO/LFO emulsion and comparing the emulsion behaviour with pure LFO.

Laser scattering techniques will be used to investigate standard nozzles: it will be the first time that these optical systems are applied to PO/LFO emulsions.

A scheme showing the layout of the fuel atomization experimental device is given in the next figure.

Results from experimental work will then be available for tuning a correlation model for PO/LFO emulsion sprays.

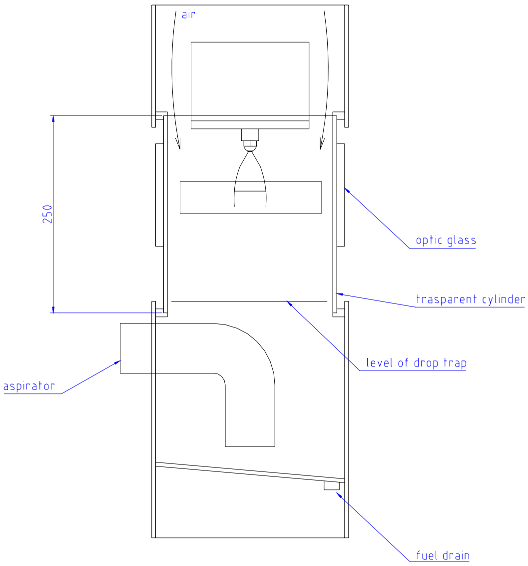


Figure 5: Design of the experimental device

In the field of pyrolysis liquids spray, a recent work by Garcia-Perez et al [7] has investigated and published results on Delevan nozzles:

- A type (hollow-cone), $FN = 5.51 \cdot 10^{-8} m^2$, 70°;
- W type (all –purpose), $FN = 5.51 \cdot 10^{-8} m^2$, 70°.

PO (80 °C temperature), Heating Oil (40 °C and 25 °C), water (60°C and 25°C) were studied.

A correlation was proposed to determine the Sauter Mean Diameter and the droplet distribution. Experimental validation of the correlation was carried out.

Based on this data, the following correlation can be developed (*correlazione empirica-empirical correlation*): then

$$SMD = 124.3 \cdot FN^{-0.387} \cdot \Delta P^{-0.419} \cdot \upsilon^{0.164} \quad \text{(A)}$$

in which pressure P is expressed in Pa, FN is the Flow Number (m^2) and ν is the kinematik viscosity (m^2/s).

However, also the surface tension plays an important role in fuel atomisation: a further correlation has therefore been developed taking into account this further aspect (*correlazione empirica con tensione superficiale-empirical correlation with surface tension*):

$$SMD = 599.2 \cdot FN^{-0.393} \cdot \Delta P^{-0.418} \cdot \upsilon^{0.251} \cdot \sigma^{0.277} \quad \text{(B)}$$

where σ, surface tension, is expressed as N/m.

In the following figures these correlations are used to calculate SMD versus pressure for different fluids, and the obtained curves compared with experimental data from literature.

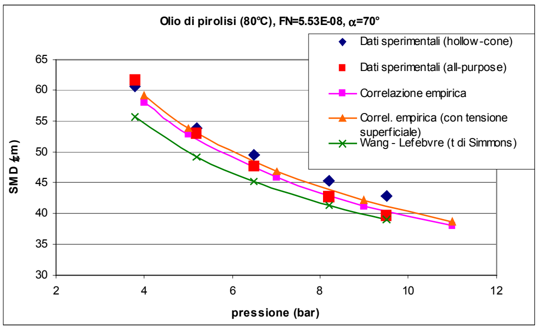


Figure 6: Pyrolysis oil, 80 °C.

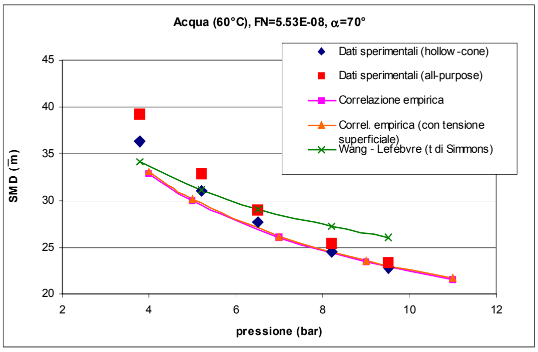


Figure 7: Water, 60 °C.

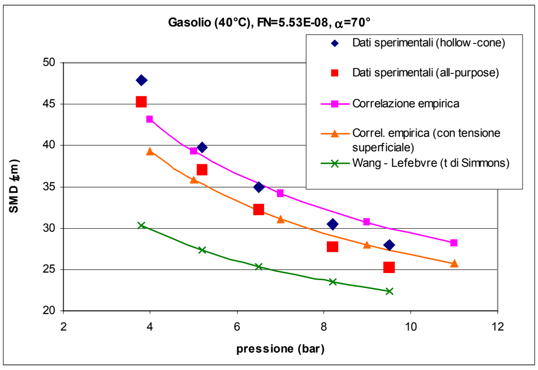


Figure 8: Light Fuel Oil, 60 °C.

The maximum error in predicting the SMD is 13 %, keeping constant FN = 5.53 E-8 (Flow Number) and α = 70° (spray angle). Similar results have been obtained considering different injectors having FN = 3.69 E-8 and FN = 7.36 E-8. Results for the intermediate nozzle (FN = 5.53 E-8) shows the lowest maximum error.

Similarly, the correlation has been applied to estimate the SMD for PO/LFO emulsions. 10 % w/w PO in LFO has been assumed. In the following graph, results for PO at 80°C and 40 °C are compared to Wang Lefebvre correlation.

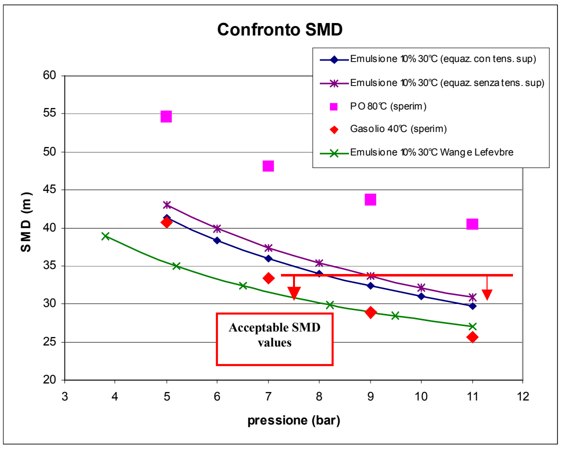


Figure 8: PO/LFO emulsions (30°C) , PO (80 °C), LFO (40°C).

As shown in the graph, according to both the Wang Lefebvre correlation and the others here proposed, it should be possible to obtain spray droplets of less than 35 µm with 10 % w/w emulsions with feeding pressures around 8÷10 bar. This size is quite close to standard operation of LFO burners.

However, in order to achieve this droplet size a slight pressure increase is necessary, compared to LFO fuel (7 bar). This will generate a slight increase in thermal power input. As an alternative, a slight fuel (emulsion) preheating can be applied, so to reduce further the fuel viscosity.

These estimates will then be compared to experimental results that will be obtained in the following activities.

5 CONCLUSIONS AND FUTURE WORK

Emulsions of PO/LFO have been obtained at both lab-scale and larger (50 l/h) scale. A spray rig has been designed and is currently under construction, with the aim of carrying out an experimental investigation of the most relevant spray parameters.

A correlation model has been defined and compared with data available on literature for pure PO, LFO and water. It has then been used to estimate characteristics of PO-/LFO spray: a further validation of the proposed correlation will then be carried out by using the spray rig.

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