THERMAL ANALYSIS OF THE BURN OF DIESEL OIL AND BIODIESEL IN A FLAME TUBE FURNACE

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Abstract. *The work consists in a theoretical and experimental study of the process of heat transfer in a flame tube furnace, where it was burned diesel oil and biodiesel from waste vegetable oil. It was studied the heat transfer rate in several sections along the furnace and each performance of the fuels was compared. The flow of heat from the burn of each fuel in the direction of the walls of the combustion chamber was evaluated at the same fuel injection pressure. The peak of heat transfer occurred around 45 cm far from the fuel injection nozzle in a 30.5 cm inner diameter combustion chamber. The diesel oil showed greater heat transfer rate in most parts exposed to the flame. In the region where the body of the flame is not present, the heat transfer of biodiesel becomes a little higher.*

Keywords*: furnace, flame tube, heat transfer, biodiesel and diesel oil.*

1. Introduction

Currently, it has been researched about reneweble fuels used in internal combustion engine. It can not be denied that the commotion, which is advertised in media today, has been achieved by researchers pledged to spread new knowledge and techniques of use of new fuels, which are used as an energy alternative better to the world. However, it is important to stand out that the fuels can and must be tested in diferent thermal machines already existing or developed to those objectives. An example are flame tube power boilers and aqua tube power boilers that runned by these kind of fuels. Recently, situations of rationing of electric energy has occurred in Brazil because energy sources are concentrate on few sources. An option to divercify these sources would be to construct a lot of thermal electric plants.

According to El-Mahallawy *et al.* (2003), there are numerous requeriments which must be considered when designing a flame tube furnace. The mainly ones include: wide stability limits, high combustion efficiency, high intensities of heat release, high heat transfer rates from flame, low emissions of pollutants and low noise.

2. Biodiesel

Fuels of vegetable origin are an alternative for the decrease of consumption of fossil fuels. Among several natural products fasteners of solar energy, glycerides or vegetable oils, constitute more promising renewable source to obtain liquid fuels. Although estimates of costs of production of vegetable oil are not so exciting in cases of the annual cultures, there are no doubts that perennial culture costs are smaller than costs of petroleum extraction. Another important focus is the integral application of gotten by-products in the several phases of industrial processes to obtaining oleaginous raw material. These by-products can be used for animal food, pharmaceutical industries, and direct use in power boilers. Besides, the renewable fuels can substitute partially or totally the lightest fractions of the petroleum (the gasoline, the diesel oil) and at the same time they bring social benefits as an increase of employment, today, one of the greatest national problems, (MIC-STI, 1985).

Technically, the biodiesel is defined as an alcohol ester of fatty acids obtained by transesterification reaction of any triglycerides (oils and vegetable fats or animal fats) with alcohol (methanol or etanol). The transesterification consists of a chemical reaction of a vegetable oil with an alcohol, which can be etanol or methanol, in the presence of an acid catalyst (HCl - hydrochloric acid) or basic catalyst (NaOH - sodium hydroxide or KOH - potassium hydroxide). As a result, it is obtained methyl or ethyl ester (biodiesel), according to the alcohol used, and glycerin. Therefore, the transesterification is nothing else that the separation of the glycerin of the vegetable oil (Meirelles, 2004).

3. Materials and Methods

The projected and built furnace is calorimetric type. To facilitate the construction and repairs and still, to provide use versatility, the furnace was projected and built in four same modules. The figure (1) shows the details of a module and of a calorimetric cell.

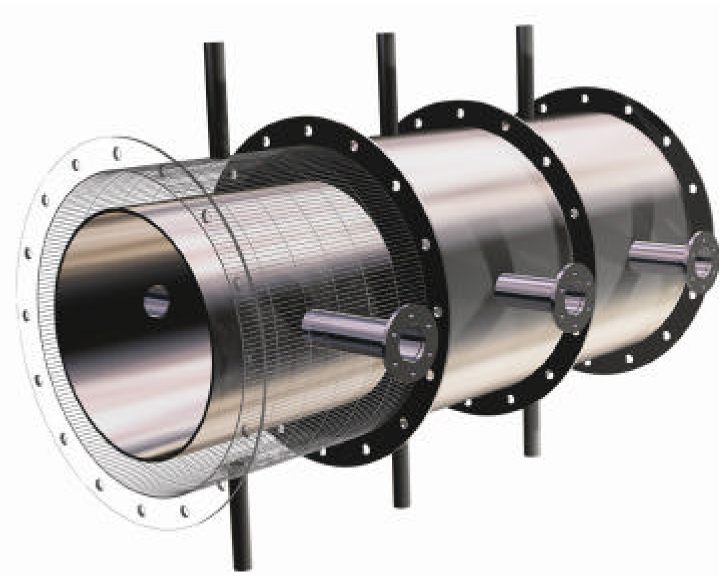

Figure 1. Illustrative Image of the Furnace Module.

Each module is 1 meter long and it is constituted by a central tube 305 mm in internal diameter, put upon by another tube 415 mm in internal diameter, forming a chamber of drainage of water 55 mm in thickness between the two tubes. The module, individually, is constituted by three 328mm-long calorimetric chambers, in other words, in each of them there are a pair of flanges at the extremities and two flanges that subdivide the external tube and the chamber of water, forming like this the three calorimetric chambers. The internal flanges were linked on the external face of the internal tube to promote stopping between the calorimetric chambers.

The burner was producted by *INCOETERMIC Ltda - Industry and Trade of Thermal Equipments*, and it is monobloc type for oil and gas (*Mod. SST 03 – D122 – UOP*) to 180,000 kcal. It is endowed with a motor WEG of 200 V, triphase, 2,39 A, 3.430 rpm and 0,55 kW; fan of *Sirocco* type and oil bomb Danfoss *Mod. BFP 21 L 5*. It can be observed, in the figure 2, the injector nozzle of the burner and where the air flow passes and forms the air-fuel mixture.

To the purpose of facilitating the understanding of the experimental set-up, in the figure (3) a schematic diagram is shown with its identified parts and its legends.

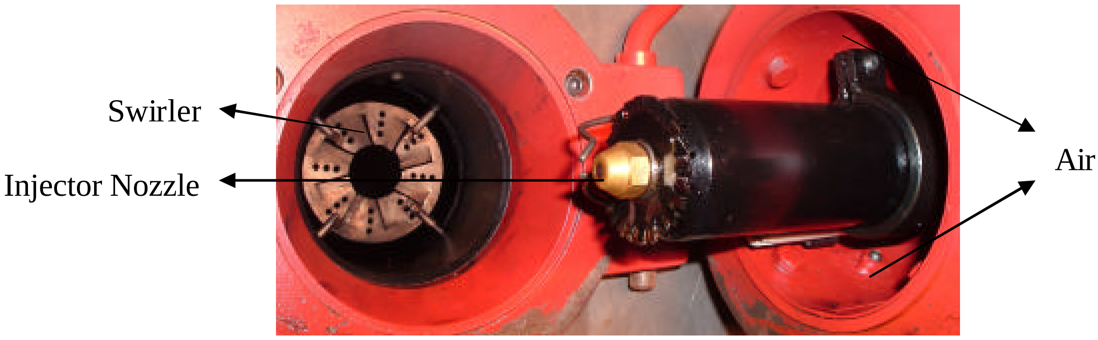

Figure 2. Injector Nozzle.

3.1. Thermal Analysis of a Calorimetric Cell

Capacity of water has to transport heat in each calorimetric cell of the furnace is determined by the following equation:

$$\dot{Q} = \dot{m} c_p \Delta T \tag{1}$$

Where: $\dot{Q}$ is the transport rate of heat by water [kW], $\dot{m}$ is the discharge of water through each cell [kg s^{-1}], c_p is 4.184 [kJ kg^{-1} ^{o}C^{-1}] (specific heat of the water at the constant pressure) and ΔT is the temperature difference between outlet and inlet of water [^{o}C].

Gunn and Horton (1989) and Gunn (1973) said heat transfer in the furnace happens mainly by radiation, where heat flow (heat per unit of area) is more intense. The pick of heat transfer rate, along the furnace, happens at a distance of the burner equivalent to square root of the furnace diameter (in meters), approximately.

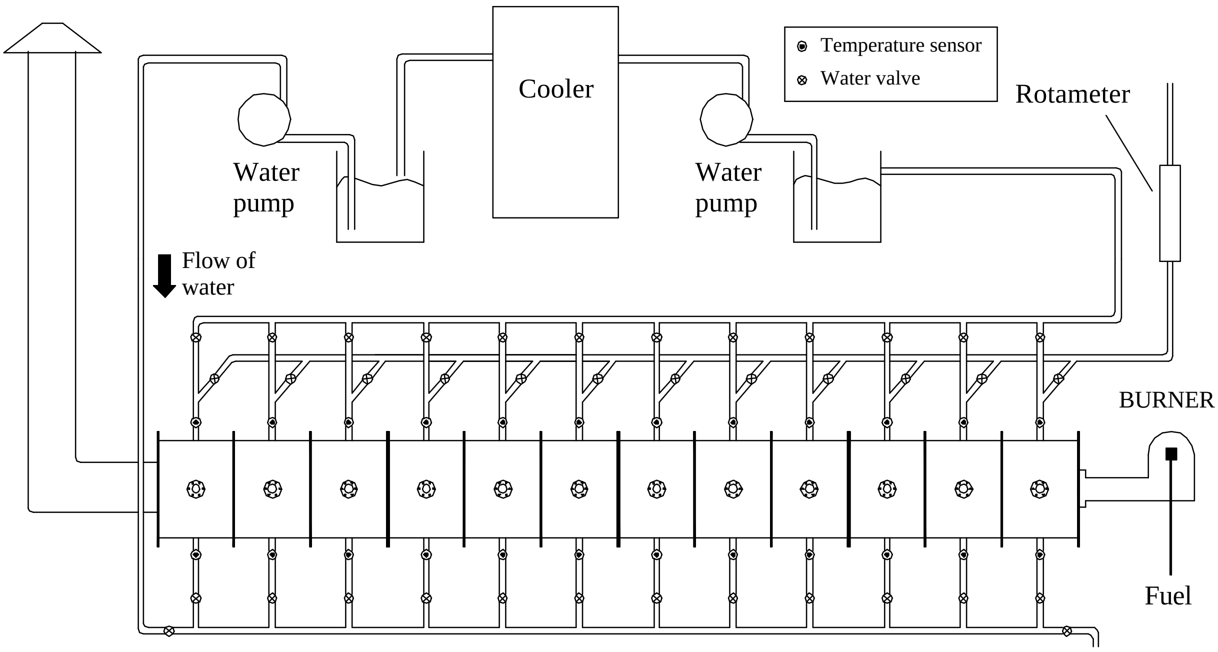

Figure 3. Schematic diagram of the experimental set-up.

Coefficient of average heat transfer of each calorimetric cell can be determined as:

$$h_m = \frac{\dot{Q}}{pDL\Delta T} = \frac{\dot{Q}}{pDL(T_p - T_\infty)} \qquad [kW\,m^{-2}\,{}^oC^{-1}] \tag{2}$$

The wall temperature (T_p) can be determined by interactive calculation that considers the temperature of saturation of the vapor in the work pressure, the thermal resistance through the walls of the furnace, the length, the internal and external diameter of the furnace and transferred heat.

$$T_p = T_{sat} + \frac{\dot{Q}_R}{2.pkL_f} ln\left(\frac{D_{ef}}{D_{if}}\right) \qquad [K] \tag{3}$$

Where: T_p is internal wall temperature of the furnace [K], T_{sat} is temperature of saturation of the water [K], $\dot{Q}_R$ is the heat transferred by radiation in the furnace [kW], k is the coefficient of thermal conductivity of the material of the furnace [kW m^{-1} K^{-1}] ($k_{steel} \cong 0.059$), L_f is length of the furnace [m], D_{ef} is external diameter of the furnace [m] and D_{if} is internal diameter of the furnace [m].

Through made calculations, it could be noticed that inside the furnace we have the flame temperature of the order to T_g = 2225.8 K and on the external side we have the water in the saturation temperature T_{sat} = 431.8 K. Considering the absurdity of the totality of the heat supplied by the fuel to be transferred in the furnace, it is observed that the temperature of the internal wall of the furnace is influenced more by the temperature of saturation of the water than by the flame temperature. It was noticed that the temperature of the foil of the furnace is of, at the most, 23.45 degrees superior to the saturation temperature. Therefore, it is reasonable to adopt as temperature of the internal wall of the furnace $T_p = T_{sat} + 20$; this avoids the tiresome interaction work. Knowing that in our study object the water does not boil, the relation that fallows becomes true:

$$T_p = T_{sat} + 10 \tag{4}$$

According to Özisik (1990), the temperature of the wall can be estimated by the average between the inlet temperature and the output temperature (this relation was also shown by Incropera and Dewitt, 1992). Therefore, to determinate the heat transfer coefficient of the calorietric cells, we will have:

$$T_P = \frac{T_e + T_s}{2} + 10 \tag{5}$$

$$T_\infty = T_e \tag{6}$$

Another form of determining the average heat transfer coefficient of each cell is using the correlation of Whitaker developed for drainage of gases and liquids, transverse to an isolated cylinder:

$$Nu_m = \frac{h_m D}{k} = (0{,}4\,Re^{0{,}5} + 0{,}06\,Re^{2/3})\,Pr^{0{,}4}\left(\frac{m_\infty}{m_p}\right)^{0{,}25} \tag{7}$$

Where:

$$Pr_{T^oC} \qquad 0{,}67 < Pr < 300 \tag{8}$$

$$m = n.r \qquad 0{,}25 < \frac{m_\infty}{m_p} < 5{,}2 \tag{9}$$

That agrees with experimental data around ± 25%.

The Number of Reynold for transverse drainage to an isolated circular cylinder is calculated through:

$$Re = \frac{U_{\infty} D}{n} \qquad 40 < Re < 105 \tag{10}$$

Where: U_{∞} is the speed of free current [m s^{-1}], D is the diameter of the cylinder [m] and n_c is the cinematic viscosity of the fluid [m^2 s^{-1}].

The speed of the free current can be calculated by law of the conservation of the applied mass to the tube of feeding of each colorimetric cell:

$$U_{\infty} = \frac{\dot{m}}{rA_t} \tag{11}$$

Where:
$$A_t = \frac{pd_t^2}{4} \tag{12}$$

According to study carried out by Santos and Souza (2004), in analysis done in an only calorimetric cell, it was observed that the transfer coefficient of calculated heat corresponds to obtained experimentally, being this inside of the zone of tolerance for the calculations.

3.2. Characteristics of the Fuels

In the table (1), it is observed the characteristics of the fuels used in the experiment, which were used to the calculation of the energy inserted in the furnace through the combustion.

Table 1. Characteristic of the Fuels: Diesel Oil and Biodiesel from waste vegetable oil.

Property	***Diesel Oil***	***Biodiesel***
Gross calorific values (kJ/kg)	44815	39622
Specific mass - 25 ^{o}C (kg/m^3)	857	872
Dynamic viscosity (cP)	4,826 (26,1 ^{o}C)	6,233 (25,6 ^{o}C)

4. Results

The experimental set-up was allowed to observe the heat transfer in the different cells along the furnace, this can be seen in the figure (4), where it is ploted the percentages of calorific energy transferred in each calorimetric cell in function of the energy introduced in the furnace. It is noticed in the cells in which the flame is present that the heat transfer of combustion of the diesel oil is higher than biodiesel. In the areas that the flame is not present, the biodiesel demonstrated better heat transfer in the cells 7 and 6, at the same injection pressure (7 kgf cm^{-2}).

In the figures (5.a) and (5.b), it is observed that at the same injection pressure (7 kgf cm^{-2}), the diesel oil flame has a more dispersed and shorter format than biodiesel flame, providing higher temperatures in the closest areas to the injector nozzle.

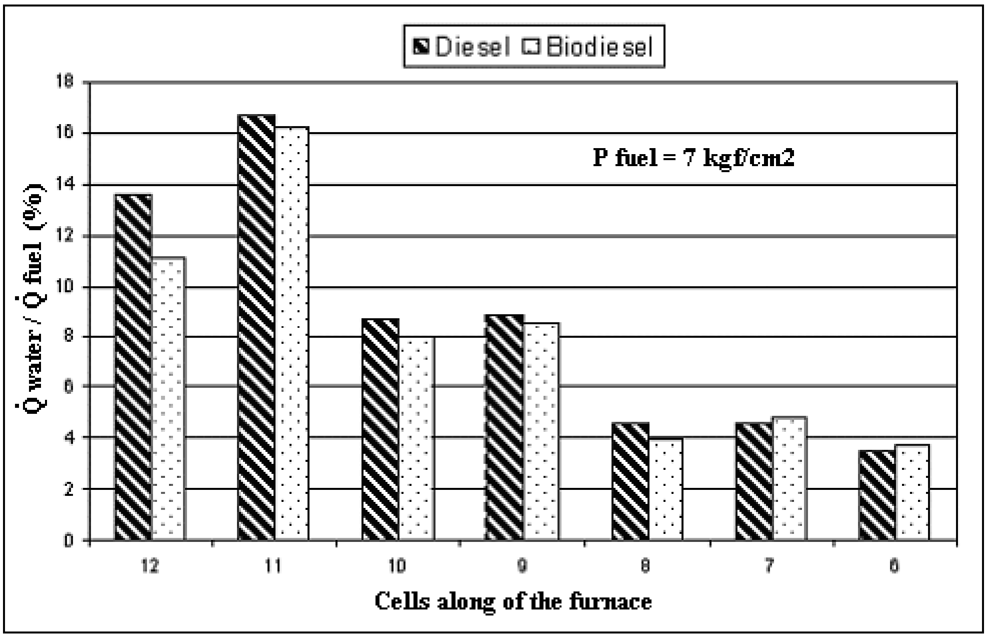

Figure 4. Heat Transfer in the Furnace.


(a)

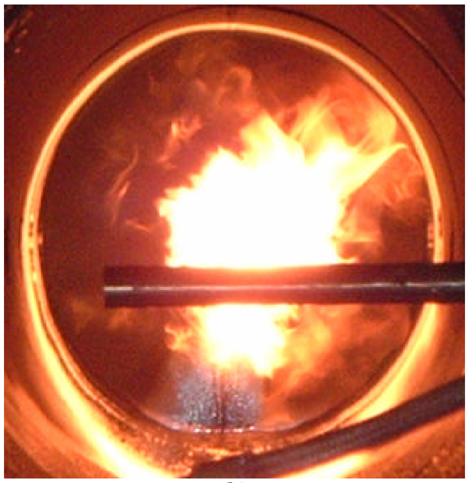
(b)

Figure 5. (a) Biodiesel Flame; (b) Diesel Oil Flame.

5. Conclusions

In the calorimeters 12 to 8, it was observed that the diesel oil provided larger heat transfer than biodiesel. In those calorimeters the heat transfer is predominantly by radiation due to the flame to be present in the calorimeters 12, 11 and at the beginning of the 10. The biodiesel presented larger heat transfer in the calorimeters 7 and 6. This happens because the exhaust gases of the biodiesel, which transfered less heat by radiation, arrive in these calorimeters with larger temperature than diesel oil gases, transferring more heat by convection.

It was verified that the differences in properties of the fuels had direct influence in the combustion of ones, and they influenced directly on flame temperatures.

Visually, it was verified that the diesel oil flame was formed in a closer area of the injector nozzle. It can also be observed, by sensitive analysis, that the burns of the biodiesel combustion, the products presented is less dark, less aggressive coloration and with softer smell than diesel oil. It confirms the smallest heat transfer by radiation in the furnace for biodiesel combustion. This is related with smallest presence of soot in the biodiesel flames than diesel oil.

In spite of smaller heat transfer by radiation in the furnace, the biodiesel can substitute the diesel oil in flame tube power biolers. It is advisable, however, that be made the monitorring of the temperature in the entrance of the chimney, based in this information, to control the injection of fuel in order to guarantee the same total output of power boiler (heat transfer in the furnace in the banks of tubes). It was also verified that the used burner did not present problems after substitution of the diesel oil, in spite of they possess different properties.

6. Acknowledgements

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7. References

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