CHAPTER 4

MASS TRANSFER MODEL FOR SINGLE DROPLET COMBUSTION

In this chapter, experimental study on single droplet combustion of emulsified oil with various compositions was carried out. The mass transfer model described in Chapter 2 was also used to evaluate the fuel combustion rate and the experimental data were used to verify the model.

4.1 Mass Transfer Theory

When combustion of a fuel droplet burns in an oxidizing atmosphere, the temperature of the liquid may change during this burning process. In combustion chamber, liquid fuels are injected into the combustion space in the form of droplets. The size of the combustion chamber is in part dependent on the time taken for vaporization and burning. The burning rate and time depend upon the heat of combustion of the fuel; its volatility, its oxygen requirement, the oxygen concentration of the fuel and so on. Spalding [7] proposed a model for evaluating mass transfer of fuel during combustion

$$m'' = g \ln(1+B), \tag{4.1}$$

For a droplet which was assumed to be spherically-symmetrical, quasi-steady conditions prevail in the gas, the distances between the droplets are much larger than the droplet diameters and the chemical-kinetic constants are such as to allow neither fuel vapor nor oxygen to penetrate the reaction zone in significant amounts [7], g could be calculated by

$$g = \left(\frac{\mu}{d \cdot Sc}\right)\left(2 + 0.6Re^{0.5} \cdot Sc^{0.33}\right), \tag{4.2}$$

B is Spalding transfer number in case of combustion process it could be calculated from

$$B = \frac{C_p(T_G - T_{BP}) + m_{ox,G}\frac{H}{r}}{L + C_{p_{fu}}(T_{BP} - T_{fu})}, \tag{4.3}$$

The details to evaluate each term were explained in Chapter 2. The model is simplified under a single-phase liquid droplet assumption. For emulsified oil, the water content inside the droplet is transformed into water vapor, anyhow, since the droplet is very fine then the single-phase liquid droplet assumption still remains.

4.2 Experiment for Single droplet combustion

Experimental setup for single droplet fuel combustion was shown in Figure 4.1. There was a brass sphere (1) having a diameter of 50 mm as shown in Figure 4.2, an oil supply vessel (2), a glass cylinder vessel (3) with a constant head control, a blower (4) to supply air passing through the sphere at a constant speed and a Bunsen burner (5). The oil from vessel (3) was fed through a copper tube to the brass sphere (1) contained in a small tunnel. The flow rate was controlled to get a thin film of oil on the sphere surface and during burning the combustion could occur continuously. The details of the components were shown in Figures 4.2 – 4.5. The air speed was controlled at 3 m/s. The sphere surface temperature, the air temperature and the fuel consumption were recorded. The diesel oil and the emulsion of diesel/CPO/water with various compositions were tested.

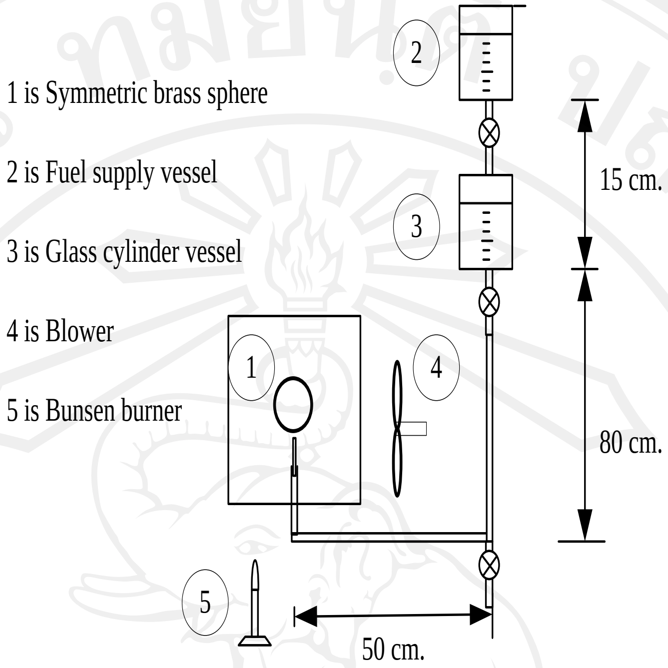

Figure 4.1 Experimental setup for testing single droplet combustion.

Figure 4.2 The brass sphere of 5 mm diameter.

Figure 4.3 The Bunsen burner.

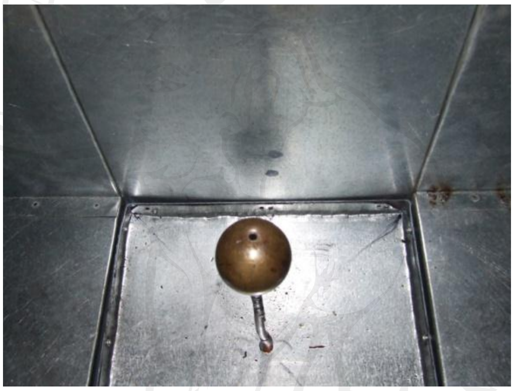

Figure 4.4 Fixing the sphere with the oil feeding tube.

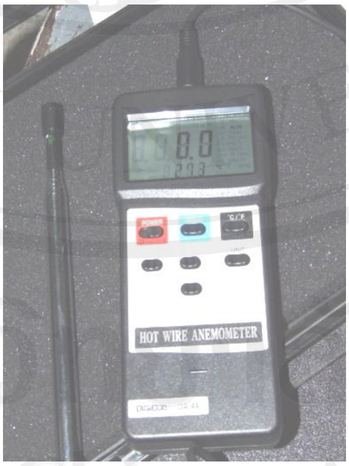

Figure 4.5 Hot wire anemometers for measuring air speed.

4.3 Results

In the experiment, control of thin film of oil on the sphere surface was rather difficult. The data were recorded when the combustion occurred continuously. The measured fuel consumption rates were compared with those predicted from the mass transfer model. The results were shown in Table 4.1.

It could be seen that the diesel oil could be burnt easily compared with the diesel oil blended with palm oil then the combustion rate of the fuel was highest for the pure diesel oil. When there was water blended in the oil, the continuous firing was more difficult with the composition of water since some part of combustion heat was used to evaporate water in the fuel.

It could be noted that the predicted fuel consumption rate from the mass transfer model agreed well with those from the experimental data. The maximum error was less than 7 %.

The difference between the combustion rates from experiments compare with predicted from mass transfer theory, because unknown the exact physics of the Schmidt number of water vapor in the air and the flow of oil drops during the experiment.

Table 4.1 Mass transfer rate of fuel for single droplet combustion.

Fuel	Mass transfer rate from experiment (g/s)	Mass transfer rate from theory (g/s)	error (%)
diesel	0.136	0.140	2.58
diesel/water (98/2)	0.131	0.139	5.63
diesel/water (96/4)	0.130	0.135	3.47
diesel/water (94/6)	0.127	0.136	6.34
diesel/water (92/8)	0.125	0.133	6.02
diesel/water (90/10)	0.124	0.132	6.15
diesel/palm (95/5)	0.135	0.136	1.07
diesel/palm/water (93/5/2)	0.129	0.136	4.97
diesel/palm/water (91/5/4)	0.128	0.135	5.13
diesel/palm/water (89/5/6)	0.126	0.134	5.90
diesel/palm/water (87/5/8)	0.125	0.134	6.59
diesel/palm/water (85/5/10)	0.124	0.133	6.55
diesel/palm (90/10)	0.133	0.130	-2.50
diesel/palm/water (88/10/2)	0.126	0.129	2.26
diesel/palm/water (86/10/4)	0.123	0.128	3.90
diesel/palm/water (84/10/6)	0.123	0.128	4.07
diesel/palm/water (82/10/8)	0.122	0.128	5.23
diesel/palm/water (80/10/10)	0.122	0.128	5.03
diesel/palm (90/15)	0.130	0.128	-1.813
diesel/palm/water (83/15/2)	0.129	0.127	-1.66
diesel/palm/water (81/15/4)	0.127	0.126	-0.79
diesel/palm/water (79/15/6)	0.124	0.126	1.78
diesel/palm/water (77/15/8)	0.122	0.127	3.76
diesel/palm/water (75/15/10)	0.121	0.127	4.38