CHAPTER 6

PREDICTION OF POWER GENERATION BY MASS TRANSFER THEORY

6.1 Mass Transfer Theory

Wibulswas et al [6] gave a model of single fuel droplet combustion developed from Spalding model [7] as shown in Figure 6.1.

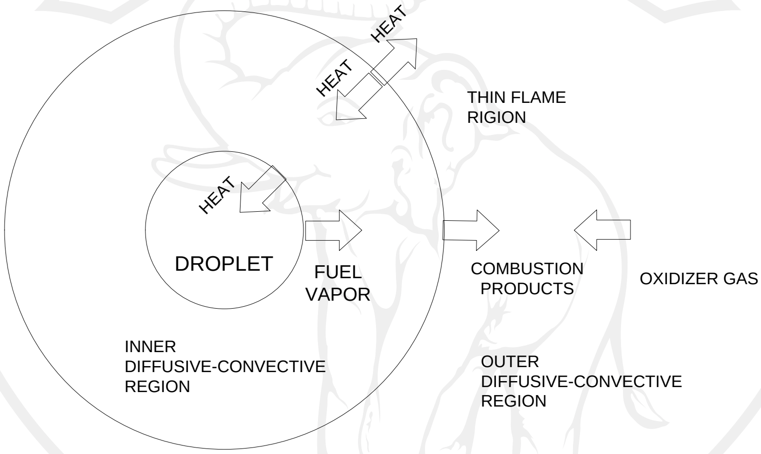

Figure 6.1 Combustion model of a single fuel droplet [6].

In combustion space, heat from surrounding hot air transfers into the fuel droplet by a temperature gradient and when the fuel temperature reaches the boiling point, evaporation of fuel occurs and there is fuel vapor around the droplet and combustion occurs in the neighborhood of the droplet.The model is simplified under a single-phase liquid droplet assumption. For emulsified oil, since the mixed fluid was in a form of water-in-oil droplet and this combustion still occurred at the surface which was oil thus the assumption on the single-phase droplet combustion could still remain.

The mass burning rate per unit area or mass transfer flux $\dot{m}''$ could be estimated from

$$\dot{m}'' = g\ln(1+B) \tag{6.1}$$

g is mass transfer conductance for the combustion of a fuel droplet in the air which could be calculated from

$$g = \left(\frac{\mu}{dSc}\right)(2+0.6Re^{0.5}\cdot Sc^{0.33})\ , \tag{6.2}$$

μ is absolute viscosity of bulk state, d is diameter of droplet, Sc is Schmidt number of fuel vapor in air and Re_D is Reynolds number of fuel droplet in the air.

The Schmidt number, Sc could be estimated by

$$Sc = 0.145M^{0.556}, \tag{6.3}$$

M is molecular mass of the fuel.

B is spalding mass transfer number which could be evaluated from

$$B = \frac{C_p(T_G-T_{BP})+m_{ox,G}\frac{H}{r}}{L+C_{p_{fu}}(T_{BP}-T_{fu})}, \tag{6.4}$$

C_p is specific heat of air, $C_{p_{fu}}$ is specific heat of liquid fuel ,T_G is bulk air temperature, T_{BP} is boiling point of liquid fuel, T_{fu} is temperature of the fuel, $m_{ox,G}$ is mass fraction of oxygen in the air, r is stoichiometric oxygen fuel ratio, L is heat of vaporization, and H is enthalpy of combustion of fuel.

During combustion, the combustion heat rate from the single fuel droplet could be

$$\dot{Q}_{single} = \frac{H(\pi d\mu)}{Sc}(2+0.6Re^{0.5}Sc^{0.33})\ln(1+B). \tag{6.5}$$

Since the droplet size is very small then

$$g \cong \frac{2\mu}{dSc}, \tag{6.6}$$

and

$$\dot{Q}_{single} = \frac{2H(\pi d\mu)}{Sc}\ln(1+B), \tag{6.7}$$

where H is heat of combustion or heating value of fuel.

If the combustion rate of the emulsified oil was obtained with the same droplet size, then the power ratio of the heat rate of the blended oil and that of the diesel oil generated by the engine could be set in a form of

$$\frac{P_{in,B}}{P_{in,D}} = \left(\frac{H_B}{H_D}\right)\left(\frac{Sc_D}{Sc_B}\right)\frac{\ln(1+B_B)}{\ln(1+B_D)}. \tag{6.8}$$

P_{in} is indicated power. Subscripts B and D refer to blended emulsified oil and diesel oil, respectively.

In practice, P_{in} could also be calculated by

$$P_{in} = \dot{m}_f H , \tag{6.9}$$

where $\dot{m_f}$ is fuel mass flow rate.

In a diesel engine, the output power or brake power is normally less than the total heat rate from the fuel. Wibulswas et alcommented a relation of $P_{bp} = kP_{in}/N^a$; k and a were constants, and N is engine speed. Since P_{bp} could be evaluated experimentally from a dynamometer then the values of k and a could be estimated by plotting the values of $log(P_{bp}/P_{in})$ versus $logN$. k is the intercept on the axis of $log(P_{bp}/P_{in})$ and a is the slope of the fitted curve.

When substitute $P_{in} = P_{bp}N^a/k$ into eqn (6.7) then

$$\frac{P_{bp,B}}{P_{bp,D}} = \left(\frac{H_B}{H_D}\right)\left(\frac{Sc_D}{Sc_B}\right)\frac{\ln(1+B_B)}{\ln(1+B_D)}\frac{({N^a}/{k})_D}{({N^a}/{k})_B}. \tag{6.10}$$

${P_{bp,B}}/{P_{bp,D}}$ is the ratio of the engine output power when the fuels are emulsified blended oil and diesel oil, respectively.

Eqn (6.10) is very useful. If the engine performance running with diesel oil is known, then the output power of the engine with emulsified blended oil could be evaluated directly.

6.2 Prediction of Power Generation

Figure 6.2 showed the engine efficiency with the engine speed when the emulsified oils with different compositions were undertaken. Then from $P_{bp} = kP_{in}/N^{a}$, the values of a and k for the emulsified oils in this study were

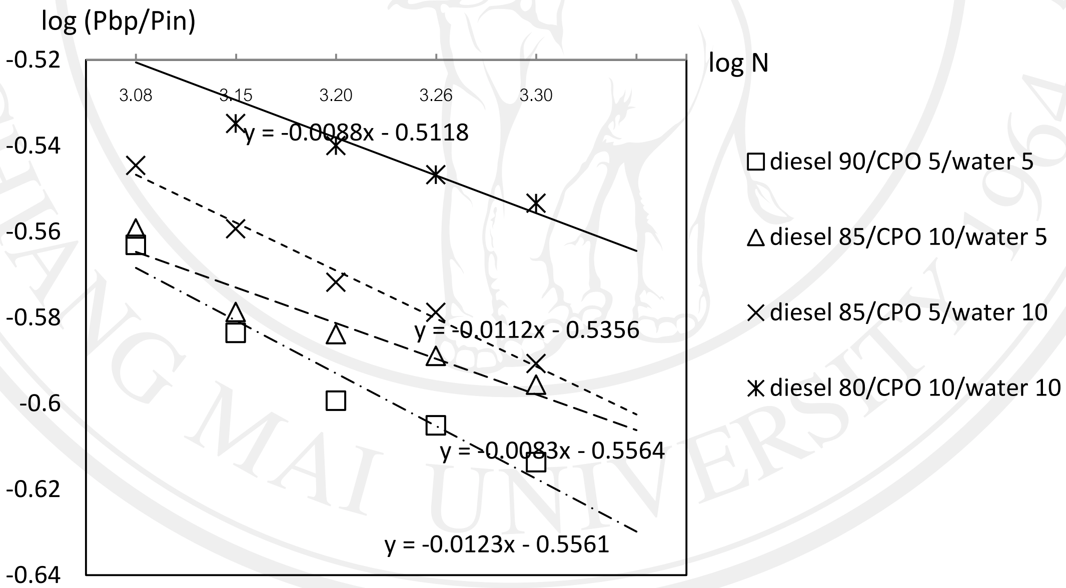

Figure 6.2 Engine efficiency versus engine speed with different compositions of emulsified fuels.

Diesel 90/CPO 5/water 5: a = 0.012, k = 0.573

Diesel 85/CPO 10/water 5: a = 0.083, k = 0.573

Diesel 85/CPO 5/water 10: a = 0.011, k = 0.585

Diesel 90/CPO 5/water 5: a = 0.009, k = 0.599

From eqn(6.10), the brake power of the engine for the emulsified oil was used as fuel could also be estimated when that of the diesel oil was prescribed. The results were shown in Figure 6.3. It could be seen that the results agreed well with the experimental data in Figure 6.4. The maximum errors were less than8 %.

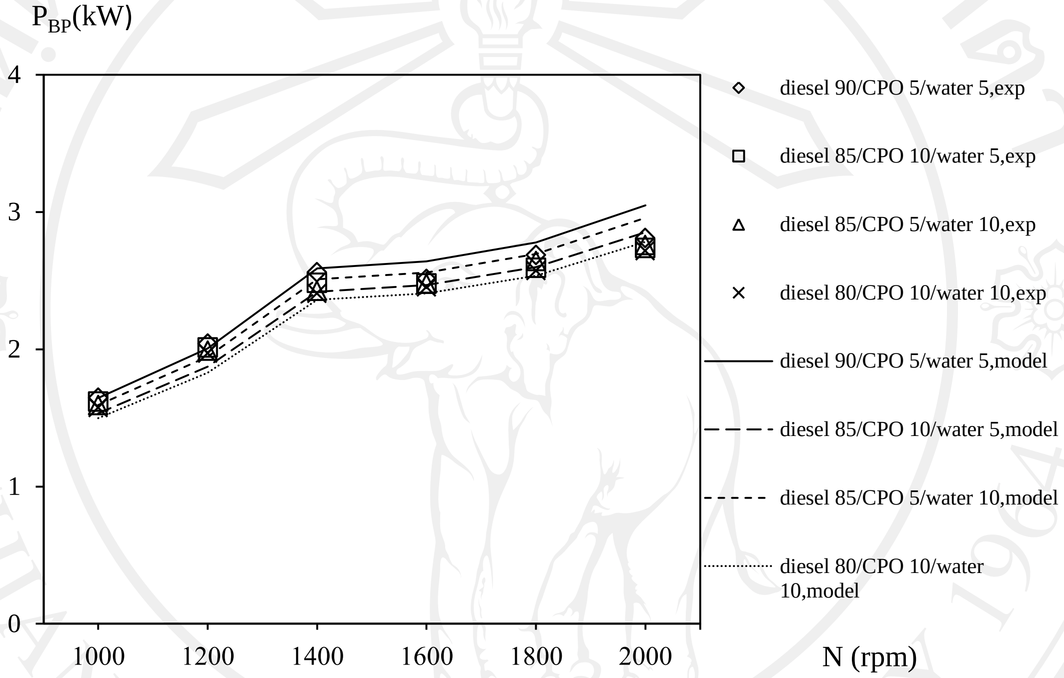

Figure 6.3 The simulated engine brake power when the emulsified oils were taken as fuel in the engine.

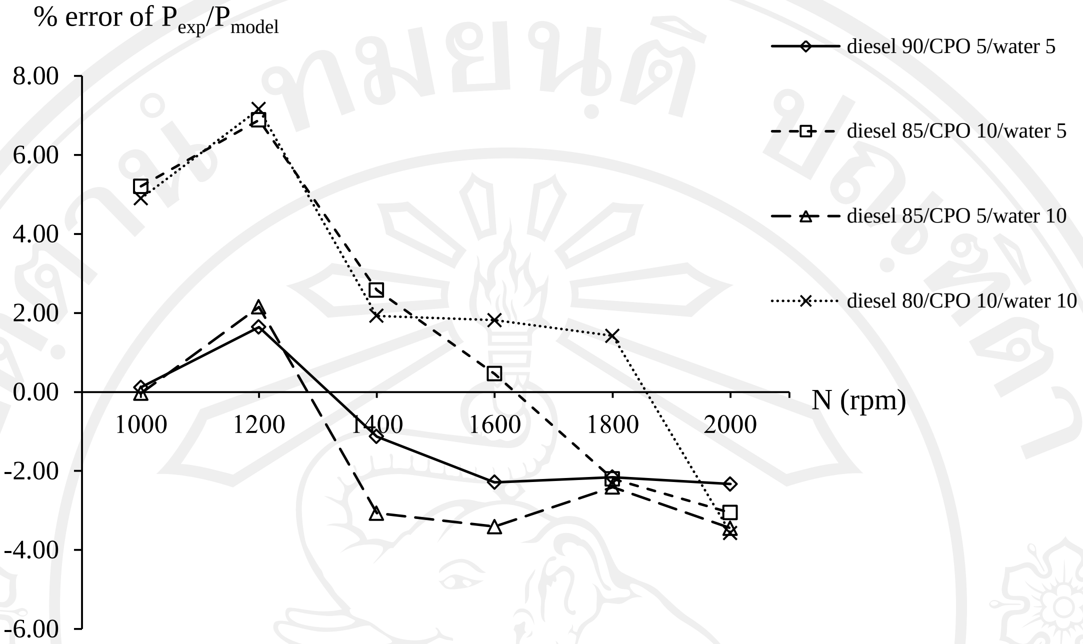

Figure 6.4 The maximum errors of engine brake power when the emulsified oils were taken as fuel in the engine.