MODELING OF HEAT TRANSFER PHENOMENA IN THE PROCESS OF COAL PYROLYSIS

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ABSTRACT

A steady state model of heat transfer phenomena coal pyrolisis in a batch reactor has been developed. The reactor was heated from the outside. The study was focussed on the heat transfer process in connection with the product distribution, especially on the tar product. Nusselt number had been choosen as the control number in the heat transfer process. From this study it is found that the highest tar product happened when the process temperature was 600 ^{0}C, the particle size was 6/8 mesh, and Nusselt Number was 253.887.

Keywords: *Coal pyrolisis, heat transfer, distribution, nusselt number*

INTRODUCTION

Technological development in the use of coal as a raw material is coal pyrolysis processes that produce otherproducts as a source of energy. Coal pyrolysis technology is based on thermal decomposition which produces tar and gas as the main products, while the resulting solids are the byproducts. With this pyrolysis process low-quality coal can be utilized. In general, Indonesian coal is of volatile bituminous coals with high content (30-50%) this suitable for use as raw material for tar (Ismail, S. and Machmud Hasjim, 1992).

Such as petroleum, coal pyrolysis fractionation tar from Indonesia produce fractions defined by the boiling point. Contained in fractions mild to severe in the fractionation of tar oil are hydrocarbons, oxygen compounds, nitrogen compounds and sulfur compounds. Such compounds can be used as solvents, pigments, liquid fuels and chemical industrial materials.

(Wender, I., L.A. Heredy, M.B. Neuworth, dan I.G.C. Dryden, 1981)

Basic classification of coal is generally in accordance with the ranking based on analysis of proximate and ultimate.

- Proximate analysis is to determine the carbon content (Fixed Carbon), Volatile Matter content, Ash content, Calorific value of coal and Water content.

Proximate analysis to evaluate the properties of the reactivity of ignition and combustion of coal, the classification of coal types.

- Ultimate analysis to determine the levels of the elements carbon, hydrogen, nitrogen and sulfur. Ultimate analysis is the minimum air requirements in order to burn completely, percentage of excess air, the concentration of exhaust gases including oxides of sulfur and nitrogen pollutants.

(Essenheigh, R.H., 1981)

Coal pyrolysis process is the separation of the solids content results in volatile materials by heating coal in which the factors that influence the pyrolysis products are the particle size and temperature pyrolysis, it is necessary to study heat transfer occurs in this pyrolysis reactor. Heat transfer system used is a heat transfer system walls heated, where the events of the displacement has been known that heat transfer could take place in three ways, which phenomena completely different from one another, namely: the phenomena of conduction (molecular), the phenomenon of convection (in flow) and the phenomena of radiation (in electromagnetic waves). In calculating the total heat transfer formula approach system held a packed bed by Balakrishnan.

(Balakrishnan, A.R. and David C.T. Pei, 1978)

The purpose of this research to study the heat transfer to the pyrolysis of coal, including conduction and convection heat transfer expressed in Nusselt number. By knowing the heat transfer to the coal pyrolysis process can assist in directing the kind of quantity and quality of the tar and gas as a feedstock for the chemical industry.

LEVELS OF COAL PYROLYSISMETHOD

Pyrolysis process of turning the complex into simpler substances by heating. Pyrolysis process causes thermal decomposition of coal to elemental carbon and other chemical components.

(Gibbind, J and Rafael Kandiyoti, 1989)

Pyrolysis process, there are two kinds:

a. Pyrolysis process without air and without the addition of chemicals to raw materials.

Pyrolysis process without air organic material, known as Destructive Distillation process which is defined as the decomposition of raw materials as a result of heating without contact with the air outside.

The result of the pyrolysis process can be divided into 3 types:

1. Solids: in the form of charcoal that are the residue of distillation.

2. Liquids: consisting of methanol, acetic acid, tar, acetone, and other substances in small quantities.

3. Substance gas: the distillation can not be condensed at room temperature, the gas that forms include CO, CO2, H2, CH4, etc. (Howard, J.B., 1981)

b. Pyrolysis process without air with the addition of chemicals to raw materials.

In principle pyrolysis method with the addition of chemicals to raw materials is similar to the process without the addition of chemicals material.

The chemicals used include calcium chloride, magnesium chloride, zinc chloride, phosphate acid and others. Tar buildup can be fractionated into fractions of light and heavy oil. Gas-condensable gas containing carbon dioxide, carbon mono oxide, hydrogen, methane and other hydrocarbons as the main constituent.

(Howard, J.B., 1981)

Pyrolysis process is a process of releasing volatile matter content (volatile matter) in a vacuum furnace with heat treatment.

Coal pyrolysis can be described in terms of multiple levels which is the development of a model proposed by Krevelen. (Krevelen, D.W., 1993)

I. Coking coal $\xrightarrow{k_1}$ metaplast
II. Metaplast $\xrightarrow{k_2}$ semi-coke + primary volatile
III.Semi-coke $\xrightarrow{k_3}$ coke + secondary gas
Where k1, k2, k3, is the reaction rate constants

Reaction I:

Coal is heated melting and disconnection will occur where the hydrogen bond is formed gas - gas lighter than break the bond that is very weak. Reaction I is polymerized reaction conditions where the presence of plastic formed unstable phase (Metaplast).

Reaction II:

This reaction is initiated by the formation and termination semicoke further bond which produces tar, gas and char. This process is called cracking where the tar and compound - non-aromatic compounds are released.

Reaction III:

Products formed in reaction II can react further where in the polymerization and condensation reaction occurs at semicoke namely the establishment of a secondary gas primarily CO and H2 gas, also the compacting back to form coke.

In reaction IIIis a reaction of secondary degasification.

(Krevelen, D.W., 1993)

Pyrolysis reaction mechanism of coal:

- Thermal decomposition phase
- Metaplast phase
- Volatile products phase
- Semi coke phase
- Coke phase
- Secondary gas phase

(Solomon, P.R., Michael A. Serio and Eric M. Suuberg, 1991)

HEAT TRANSFER PHENOMENA

Heat transfer in gas-solid can be used generally to describe a change in heat transfer include:

1. The convection heat transfer from the wall to the fluid.
2. The convection heat transfer from particles to the fluid.
3. The conduction heat transfer from the wall to the fluid.
4. The conduction heat transfer between the particles.
5. The radiation heat transfer

(Candra V. And Savery C.W., 1974)

The above heat transfer is depicted schematically in Figure 1, which can be explained as follows:

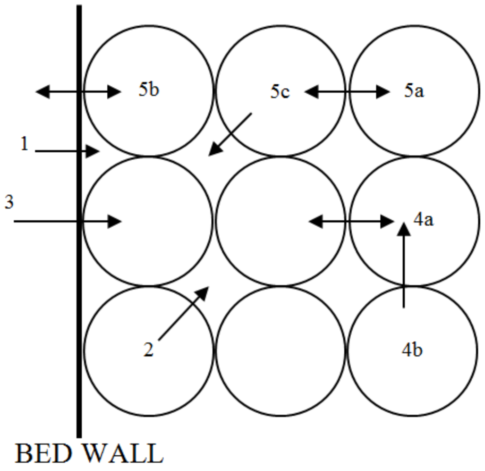

Figure 1. *Heat transfer phenomena in coal pyrolysis reactor*

Caption figure 1.
1. The convection heat transfer the fluid to the wall
2. The convection heat transfer the fluid to the particles
3. The conduction heat transfer the wall to the particles
4.a. The conduction heat transfer particles to particles radial direction
4.b. The conduction heat transfer particles to particles axial direction
5.a. The radiative heat transfers between particles
5.b. The radiative heat transfers between the wall and particles
5.c. The radiative heat transfers between the fluid and the particles
(Heeyoung Y., James Wei and Morton M. Denn, 1978)

Dimensionless number that is commonly used to describe the heat transfer is the Nusselt number.

$$Nu_t = h_t D_p / k_t \tag{1}$$

Differences in heat transfer occurs in a system will result in a change in total heat transfer. The method of heating the walls of the camp include: particle wall conduction heat transfer, heat transfer conduction radially and convection heat transfer to the fluid particles. So the total heat transfer can be expressed in Nusselt numbers were formulated as follows:

$$Nu_t = Nu_t + Nu_{tp} + (k_e^0/k_t) \quad (2)$$

Where Nu_{tp} is the convection heat transfer that can be expressed in the equation

$$Nu_{tp} = 0{,}016(Ar_m)^{0{,}25}\ (Re_p)^{0.5}\ (\phi_s)^{3{,}76} \quad (3)$$

Where: (ϕs) is the form factor of grains, Ar_m is the Archimedes number,

$$Ar_m = D_p^3\ g\ p_t\ (p_p - p_f)\ (1\text{-}\varepsilon)^2/\mu_f^2 \quad (4)$$

And $Re_p$is the particle Reynolds number,

$$Re_p = (D_p\ p_f^u)/\mu_f^2 \quad (5)$$

Nu_{fc} is the influence of fluid flow on the radial conduction heat transfer are defined as follows:

$$Nu_{fc} = 2{,}04 \times 10^5\ (P_c\, Cp_p/P_f\, CP_t)^{1/3} \quad (6)$$

$Ke^0$is effective with the fluid conductivity of immobility is expressed in the equation:

$$k_e/k_f = k_e/k_f + (\alpha\beta)\ P_{rf}Re_p \quad (7)$$

Price k_e^0/k_fcan be obtained from Figure 3. Where Re_{pm} is a modified particle Reynolds number is:

$$Re_{pm} = Re_p\ /\ (1 - \varepsilon) \quad (8)$$

Conduction Nusselt number is defined as follows:

$$Nu_{cd} = k_e^0/k_f \quad (9)$$

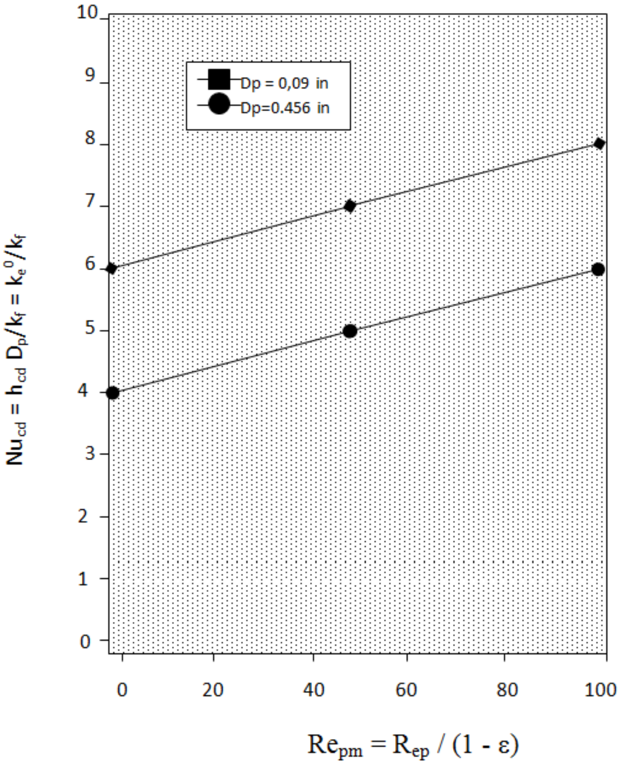

Figure 2. *Evaluation* k_e^0/k_f *use* Nu_{cd} *vs* Re_{pm}

(Bhattacharyya, D. and David C.T. Pei, 1974)

Influence biot modulus:

Biot modulus is obtained as a function of the Reynolds number using correlation approach:

$$Bi = 0{,}016\ (k_f/k_pa)\ (Ar_m)^{0{,}25}\ (Re_p)^{0{,}5} \tag{10}$$

Blot modulus is a variable that affects the conduction heat transfer coefficient, it can be used as information to plotNu_{cd} and Bi as a function of the number Reynold. (Balakrishnan, A.R. and David C.T. Pei, 1978)

METHODOLOGY

Parameters that do are temperature and particle size at constant pressure. Temperature variation 400 – 800°C with intervals of 100°C and particle size of 2/4 mesh, 6/8 mesh, 10/12 mesh at a pressure 0,1447 atm. Coal particles with bituminous coal classification (Kaltim Prima Coal) Technical specifications:

- Weight	:1 kg
- Shape factor	:0,63
- Density	:1350 kg/m^3
- Specific heat	:1,26 kj/kg K
- Thermal Conductivity	:0,26 J/m s K

METHODS

- Coal with a weight of 1 kg, in accordance with the desired size is inserted into the hopper.
- The reactor is heated to set the desired control is the core temperature of the reactor at 400°C, 500°C, 600°C, and 700°C.
- After the center of the reactor reached the desired temperature by 1 kg of coal could be included in the pyrolysis reactor.
- Set the condensor cooling water pump and regulate vacuum pump according to the pressure reactor.
- Obtained gas flowing through the condensor 1 accommodated in vacuum vest 1 is placed in the ice bath and the rest of the steam is passed through the condensor 2 to be accommodated in a vacuum vest 2 next accommodated in a vacuum vest 3, 4 and tar precipitator. Then the gas was supplied to the gas collector.
- After reaching the desired temperature, sampling is non-condensable gas of 150 ml after 15 minutes the desired temperature is reached and analyzed.
- The end of the pyrolysis can be shown with a wet vest meters that are not able to move anymore, then the operation is stopped.
- Measuring the final volume of pyrolysis.

ANALYSIS

- Analysis of the quantity of tar

Tar generated from each vacuum vest stored in one place and filtered to separate the water and tar, then measured the weight of water and the resulting tar.

(Richardson, F.W., 1975)

- Gas analyzer

Analyzing the gas by means of gas chromatography to determine thecomposition.

- Char analysis

Char with a way to analyze the proximate and ultimate.

(Seglin, L and Sidney A. Bresler, 1981)

RESULTS

Table 1. *Temperature 400°C*

Run	Particle diameter	Re_p	Pr_f	Ar_m
1	2/4 mesh	0,08183	1,93349	38928,465
2	6/8 mesh	0,03816	1,82487	5120,570
3	10/12 mesh	0,01251	1,80149	1118,648

Run	Particle diameter	Nu_{fp}	Nu_{fc}	Re_{pm}
1	2/4 mesh	0,01131	521,52	0,157365
2	6/8 mesh	0,00465	197,43	0,072000
3	10/12 mesh	0,00182	102,01	0,023167

Run	Particle diameter	Nu_{fp}	Nu_{fc}	Re_{pm}
1	2/4 mesh	5,453522	521,989	5632,4
2	6/8 mesh	5,0981461	197,897	5668,2
3	10/12 mesh	5,190486	102,476	3680,7

Table 2. *Temperature 500^{o}C*

Run	Particle diameter	Re_p	Pr_f	Ar_m
1	2/4 mesh	0,09015	1,95287	34240,396
2	6/8 mesh	0,04071	1,78765	3836,375
3	10/12 mesh	0,01694	1,78352	819,179

Run	Particle diameter	Nu_{fp}	Nu_{fc}	Re_{pm}
1	2/4 mesh	0,01150	532,296	0,173365
2	6/8 mesh	0,00447	206,515	0,076811
3	10/12 mesh	0,00196	124,785	0,031370

Run	Particle diameter	Nu_{fp}	Nu_{fc}	Re_{pm}
1	2/4 mesh	5,479103	532,734	6391,9
2	6/8 mesh	5,981559	206,981	6471,8
3	10/12mesh	5,190658	125,249	4550,7

Table 3. *Temperature 600^{o}C*

Run	Particle diameter	Re_p	Pr_f	Ar_m
1	2/4 mesh	0,09137	1,91381	22037,936
2	6/8 mesh	0,04101	1,77656	2986,305
3	10/12 mesh	0,01906	1,78198	627,816

Run	Particle diameter	Nu_{fp}	Nu_{fc}	Re_{pm}
1	2/4 mesh	0,01037	612,032	0,175720
2	6/8 mesh	0,00422	253,423	0,077375
3	10/12 mesh	0,00195	134,839	0,035290

Run	Particle diameter	Nu_{fp}	Nu_{fc}	Re_{pm}
1	2/4 mesh	5,479145	612,497	7150,8
2	6/8 mesh	5,981571	253,887	6664,3
3	10/12mesh	5,190741	135,303	5326,9

Table 4. *Temperature 700°C*

Run	Particle diameter	Re_p	Pr_f	Ar_m
1	2/4 mesh	0,10932	1,83724	18050,776
2	6/8 mesh	0,05359	1,72076	2445,648
3	10/12 mesh	0,02806	1,70962	525,627

Run	Particle diameter	Nu_{fp}	Nu_{fc}	Re_{pm}
1	2/4 mesh	0,01079	774,764	0,210228
2	6/8 mesh	0,00458	407,875	0,101122
3	10/12 mesh	0,00228	220,398	0,051966

Run	Particle diameter	Nu_{fp}	Nu_{fc}	Re_{pm}
1	2/4 mesh	5,479763	774,631	8977,8
2	6/8 mesh	5,982052	408,339	9627,6
3	10/12mesh	5,191092	220,862	8692,2

DISCUSSION

a. Nusselt number calculations obtained with the larger particle size and temperature pyrolysis, the price of the greater Nusselt number. The highest temperature tar products of pyrolysis 600°C and particle size 6/8 mesh, this is due to the higher temperature pyrolysis gas will occur secondary or non-condensable gas.
b. Biot Modulus calculations is obtained that the largerconduction Nusselt number the smaller the price Biot Modulus. The higher the temperature pyrolysis, conduction Nusselt number will be even greater, then the biot modulus smaller. The smaller the Biot Modulus will produce tar and gas are getting bigger.
c. Effect temperature and particle size of the product tar shows that the highest temperature tar products 600°C and particle size 6/8 mesh. If the temperature pyrolysis used is higher than 600°C there tar devolatilisation will be a secondary reaction in which tar devolatilization forming gas. Size the greater the contact area with the greater heat so volatile mater obtained greater and the results obtained by the greater tar.
d. Effect temperature and particle size of the product gas.
   Fluctuating gas obtained results, this was due to the results of pyrolysis time which the measurement gas products for each parameter should at the same time.

CONCLUSION

1. The heat transfer in the pyrolysis reactor is strongly influenced by the diameter of the coal particles and the pyrolysis temperature, the larger the diameter and the higher the temperature will result in greater heat

transfer. In this research we obtained good tar product on 6/8 mesh particle size and 600 ^{0}C temperature, so it need not be done by heating 600 ^{0}C because it will result in greater heat transfer means require big heat energy.

2. The calculation results obtained heat transfer rate in Nusselt numbers are not dimensionless, the higher the pyrolysis and the greater the particle diameter will increase the Nusselt number and Reynolds number.
3. In this experimentalthe most important role is the heat transfer of conduction between particles, conduction heat transfer depends on the physical properties of heat transfer in the particle.
4. In the pyrolysis process the amount and composition of pyrolysis depends on the process conditionspyrolysis temperature and particle size.
5. Based on experimental results adjusted for heat transfer it is necessary to note the same pyrolysis time of each parameter.

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