DAFTAR PUSTAKA

Aries. R.S., and Newton, R.D., 1954, " *Chemical Engineering Cost Estimation* ", Mc GrawHill Book Co. Inc, New York

Brown, G.G., and Foust, A.S., 1961, " *Unit Operation* ", John Wiley and Sons. New York

Brownell, L.E., and Young, E.H., 1959, " *Process Equipment Design*", Wiley Eastern Limited, New Delhi

Clark, J.W., Viessman,W., and Hammer,M.J., 1977, " *Water Suplay and Polutan Controll*", Harper International Edition, New York

Coulson, J.M., and Richardson ,J.F., 1989, " *An Introduction to Chemical Engineering Design*", Pergamon Press, New York

Faith, W.L., and Keyes, D.B., 1955, *Industrial chemical*, John Wiley and Sons, Inc., New York

Kirk,R.E., and Othmer, D.F., 1977, " *Encyclopedia of Chemical Technology*",3 ed.,Vol 1, John Wiley and Sons, New York

Kern,D.Q., 1965," *Process Heat Transfer*", Mc Graw Hill International Book Co., Singapore

Laidler, K.J., 1965," *Chemical Kinetics*", 2 ed., Tata Mc Graw Hill Publising Company LTD., New Delhi

Levenspiel, O.,1972,"*Chemical Reaction Engineering* ",2 ed.,John Wiley and Sons, Inc., New York

Mc Cabe, W.L., Smith, J.C., and Harriot, P., 1985, " *Unit Operation of Chemical Engineering* ", 4th ed, Mc GrawHill Book Co. Singapore

Perry , R.H., and Green, D.W.,1984," *Chemical Engineers Handbook* ", Mc Graw Hill Book, New York

Peters, M.S., and Timmerhouse, K.D., 1981, " *Plant Design Economic's for Chemical engineering's* ", 4th ed, Mc GrawHill Book Co. Ltd., New York

Rase, F.H., and Barrow, M.H.,1957," *Project Engineering of Proses Plant* ", John Wiley and Sons , Inc., New York

Smith, J.M., 1973, " *Chemical Engineering Kinetic's* ", 3rd ed, Mc GrawHill Book Kogakusha, Tokyo

Smith, J.M., and Van Ness, H.C., " *Introduction to Chemical Engineering Thermodinamic's* ", 2nd ed, Mc GrawHill Book Co. Ltd., New York

Treyball, R.E., 1984," *Mass Transfer Operation*", 3 ed., John wiley and Sons, Inc., New York

Ulrich, G.D., 1984, " *A Guide to Chemical engineering Process Design and Economic's* ", John Wiley and Sons. Inc., New York

Wallas, Stenley, M., 1991, " *Chemical Process Equiment Selection and Design* ", Mc GrawHill Book Co., Tokyo

REAKTOR

Fungsi : Mereaksikan CH_3OH dengan HCl menjadi CH_3Cl dan H_2O dengan konversi CH_3OH 95 %.

Jenis : Fixed bed multitubular reaktor dilengkapi dengan pendingin

Fasa : Gas

Suhu : 623 K pada umpan.

Tekanan : 1,30 atm

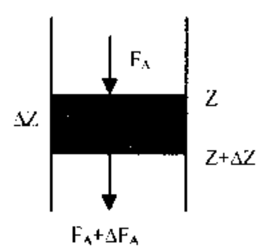
Operasi : Nonadiabatis nonisotermal

Katalis : alumina gel

PENYUSUNAN MODEL MATEMATIS

1. Neraca Massa pada Reaktor

Penyusunan neraca massa dibuat pada elemen volume di sebuah pipa dalam reaktor. Dalam hal ini diasumsikan tidak ada distribusi komposisi arah radial, sehingga arah axial saja yang ditinjau (karena L/D >>)



Gambar 1. Neraca Massa pada Elemen Volume

Reaksi yang terjadi adalah sebagai berikut :

$CH_3OH + HCl \rightleftharpoons CH_3Cl + H_2O$ ....(1)

Neraca massa CH_3OH di elemen volume pada steady state

$F_{Ainput} - F_{Aoutput} - F_{Areaction} = 0$

$F_A\big|_Z - F_A\big|_{Z+\Delta Z} - (-r_A).\rho_b.\pi D_i^2/4.Nt.\Delta Z = 0$

bila persamaan di atas dibagi dengan ΔZ menjadi :

$$\frac{F_A\big|_Z - F_A\big|_{Z+\Delta Z} - (-r_A).\rho_b.\pi D_i^2/4.Nt.\Delta Z = 0}{\Delta Z}$$

$$\frac{F_A\big|_{Z+\Delta Z} - F_A\big|_Z}{\Delta Z} = -(-r_A).\rho_b.\pi D_i^2/4.Nt$$

$$\text{limit}\ \frac{F_A\big|_{Z+\Delta Z} - F_A\big|_Z}{\Delta Z} = -(-r_A).\rho_b.\pi D_i^2/4.Nt$$

$\Delta Z \rightarrow 0$

diperoleh :

$$\frac{dF_A}{dZ} = \frac{-(-r_A).\rho_b.\pi D_i^2.Nt}{4}$$

$$F_A = F_{A0}(1 - x_A)$$

maka :

$$\frac{dx_A}{dZ} = (-r_A).\rho_b.\pi D_i^2.\frac{Nt}{4.F_{A0}}$$ ....(2)

dengan :

Nt : jumlah tube

D_i : diameter dalam tube, m

F_A : Flowrate CH_3OH, kmol/j

x_A : konversi CH_3OH menjadi CH_3Cl

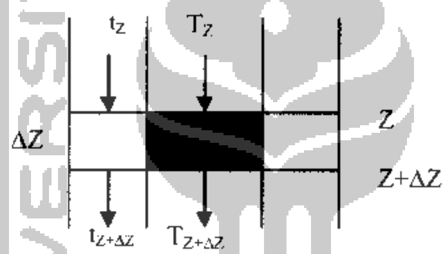
ρ_b : bulk density katalisator, kg/m^3

$(-r_A)$: kecepatan reaksi (1)

2. Neraca Panas pada Reaktor

Perbedaan suhu arah radial dalam tube dianggap tidak ada sehingga dapat disusun persamaan steady state sebagai berikut :

Arah aliran media pendingin searah dengan arah aliran gas dalam reaktor (*Co current*) yaitu sama sama dari atas, hal ini dimaksudkan agar suhu pendingin keluar cukup tinggi sehingga dapat dimanfaatkan sebagai pemanas umpan reaktor dan agar dapat diperoleh profil suhu yang baik dan mudah dikontrol.



Gambar 2. Neraca Panas pada Elemen Volume

Neraca panas dalam pipa steady state:

R.O.H in – R.O.H out + R.O.H generated – R.O.H transferred =0

$$\sum F_i.Cp_i(T-298)\Big|_Z - \sum F_i.Cp_i(T-298)\Big|_{Z+\Delta Z} + F_{A0}.\Delta x_A.\Delta H_R - UD.\pi.D_0.\Delta Z.Nt.(T-t) = 0$$

bila persamaan di atas dibagi dengan ΔZ menjadi :

$$\frac{\sum F_i.Cp_i(T-298)\Big|_Z - \sum F_i.Cp_i(T-298)\Big|_{Z+\Delta Z} - F_{A0}.\Delta x_A.\Delta H_R - UD.\pi.D_0.\Delta Z.Nt.(T-t) = 0}{\Delta Z}$$

$$\lim_{\Delta Z \to 0} \frac{\sum F_i.Cp_i(T-298)\Big|_{Z+\Delta Z} - \sum F_i.Cp_i(T-298)\Big|_Z}{\Delta Z} = F_{A0}.\frac{\Delta x_A}{\Delta Z}.\Delta H_R - UD.\pi.D_0.Nt.(T-t)$$

$$\sum F_i.Cp_i\frac{dT}{dZ} = F_{A0}.\frac{\Delta x_A}{\Delta Z}.\Delta H_R - UD.\pi.D_0.Nt.(T-t)$$

$$\frac{dT}{dZ} = \frac{F_{A0}.\frac{dx_A}{dZ}.\Delta H_R - UD.\pi.D_0.Nt.(T-t)}{\sum F_i.CP_i} \qquad \text{..........(3)}$$

dengan :

D_0 = diameter luar tube, m

Cp = kapasitas panas gas, kJ/kmol.K

T = suhu gas, K

t = suhu pendingin, K

ΔHR = panas reaksi, kJ/k.mol

Neraca panas pendingin pada steady state:

R.O.H in – R.O H out + R.O.H Transferred =0

$$Mc.Cpc.(t-298)\Big|_{Z} - Mc.Cpc.(t-298)\Big|_{Z+\Delta Z} + UD.\pi.D_0.\Delta Z.Nt.(T-t) = 0$$

bila dibagi dengan ΔZ diperoleh:

$$\frac{Mc.Cpc.(t-298)\Big|_{Z} - Mc.Cpc.(t-298)\Big|_{Z+\Delta Z} + UD.\pi.D_0.\Delta Z.Nt.(T-t) = 0}{\Delta Z}$$

$$\text{limit} \frac{Mc.Cpc.(t-298)\Big|_{Z+\Delta Z} - Mc.Cpc.(t-298)\Big|_{Z}}{\Delta Z} = UD.\pi.D_0.Nt.(T-t)$$

$$Mc.Cpc.\frac{dt}{dZ} = UD.\pi.D_0.Nt.(T-t)$$

$$\frac{dt}{dZ} = \frac{UD.\pi.D_0..Nt.(T-t)}{Mc.Cpc} \quad \text{.....................(4)}$$

dengan :

Mc = kecepatan alir pendingin, kg/j

Cpc = kapasitas panas pendingin, kJ/kg.K

3. Penurunan Tekanan dalam Bed Katalisator

Penurunan tekanan dalam pipa yang berisi butir-butir katalisator dapat dipakai persamaan *Ergum* (*Perry and Green, 6th hal 4-37 1984*).

$$\frac{-dP}{dZ} = \left[\frac{150(1-\varepsilon)\mu}{Dp} + 1{,}756 \right] \frac{(1-\varepsilon)G}{\varepsilon^{3} Dp.\rho.gc}$$

keterangan :

P = Tekanan, N/m ^{2}

G = Fluks massa gas (kg/s.m ^{2})

μ = Viskositas fluida, kg/m.det

ρ = Densitas fluida, kg/m ^{3}

Dp = Diameter katalisato r. m

gc = Faktor konversi satuan = 1 pd sistem SI

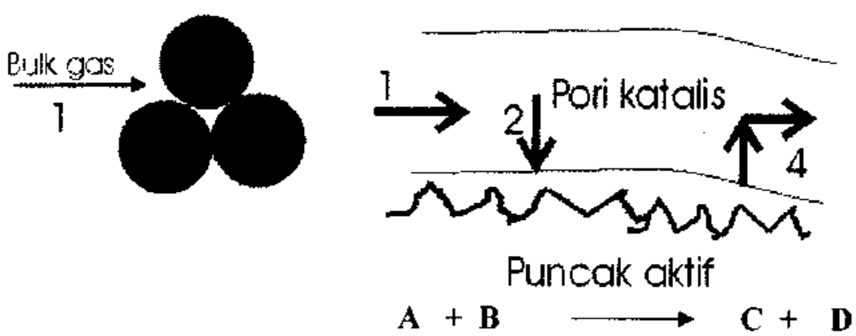
KINETIKA REAKSI

Persamaan reaksi :

$$CH_3OH + HCl \underset{k_2}{\overset{k_1}{\rightleftharpoons}} CH_3Cl + H_2O$$

Mekanisme reaksi yang terjadi adalah (*Levenspiel, 1972*):

1. Transfer massa dari bulk gas ke permukaan luar katalisator diikuti difusi gas melalui pori katalisator
2. Proses adsorbsi gas dari permukaan katalisator ke puncak aktif katalisator
3. Reaksi di puncak aktif katalisator
4. Desorbsi gas hasil reaksi



Gambar 3. Mekanisme Reaksi

Asumsi:

Turbulensi gas cukup tinggi, dan katalisator cukup porous sehingga internal dan eksternal diffusion dapat diabaikan karena berjalan sangat cepat, sehingga langkah 1 tidak mengontrol sistem.

Katalisator memiliki luas permukaan transfer massa yang tinggi, yaitu 100 - 300 m^2/gram (*US Patent 5,041,406*). Sehingga proses adsorbsi ke gas ke puncak aktif katalisator dan proses desorbsi gas hasil keluar dari katalisator akan berjalan dengan cepat. Sehingga langkah 2 dan langkah 4 tidak mengontrol proses secara keseluruhan. Sehingga yang akan mengontrol kecepatan reaksi secara keseluruhan adalah reaksi kimia yang terjadi di puncak aktif katalisator.

Penentuan Panas Reaksi ($\Delta H_{R\ 298}$)

Tabel 1. Nilai ΔH^of dan ΔG^of (*Coulson and Richardson, 1989*)

Senyawa	ΔH^of (kJ/mol)	ΔG^of (kJ/mol)
HCl	-92,36	-95,33
CH_3Cl	-86,37	-62,93
CH_3OH	-201,90	-162,62
H_2O	-242,00	-228,77

Sehingga perubahan energi pembentukan :

$$\Delta H_{R\,298} = \sum \Delta Hf_{produk} - \sum \Delta Hf_{reaktan}$$
$$= (-242,00 + -86,37 - (-92,36 + -201,90)$$
$$= -34,11 \text{ kJ/mol (reaksi eksotermis)}$$

Perubahan energi bebas Gibbs reaksi

$$\Delta G_R = \sum \Delta Gf_{produk} - \sum \Delta Gf_{reaktan}$$
$$= -228,77 - 62,93 - (-95,33 + -162.62)$$
$$= -33.75 \text{ kJ/mol}$$

Penentuan nilai konstanta keseimbangan reaksi, K

(*Perry and Green, 1984*)

$$\Delta G_R = -R.T.\ln K$$

$$K = \exp\left[\frac{33.750}{1,987.(4,18).T}\right]$$

pada suhu 350 $^{\circ}C$ nilai k :

$$K = \frac{k_1}{k_2} = \exp\left[\frac{33.750}{1,987.(4,18).(350+273)}\right] = 680,25$$

sehingga $k_1 >> k_2$ atau ***reaksi berjalan searak ke kanan***

Sehingga persamaan reaksi di atas dapat di tuliskan :

$$CH_3OH + HCl \xrightarrow{k} CH_3Cl + H_2O \quad ....(5)$$

Persamaan Kecepatan Reaksi ($-r_A$) dan Konstanta Kecepatan Reaksi (k)

Persamaan kecepatan reaksi :

Data yang diperoleh (*US Patent 5,041,406*) Example 1 :

Diameter pipa = 14 mm = 1,4 cm

Volume katalisator = 6 cm^3

Tekanan total (Pt) = 20 psig = 1,36 atm.

Space velocity = 2.300 1/jam.

Diameter katalis = 2 mm

Porositas tumpukan katalisator ε = 0,384 (*Brown, 1950*)

Ratio umpan (M) $= \frac{\text{mol HCl}}{\text{mol } CH_3OH} = 1,4$

Hasil konversi yang didapatkan:

Tabel 2. Nilai konversi metanol

Suhu Reaksi, ^{O}C	Konversi metanol, X_A
300	0,955
400	0,974

Reaksi yang terjadi :

$CH_3OH + HCl \longrightarrow CH_3Cl + H_2O$ $\quad - \Delta Hr = - 34,11$ kJ/ mol

Atau :

$A + B \longrightarrow C + D$

Kecepatan reaksi diasumsikan merupakan reaksi elementer sehingga mengikuti orde 1 terhadap metanol dan orde 1 terhadap HCl (*Levenspiel, 1972*) :

$$-(r_A) = \frac{-dn_A}{W_{kat}.dt} = k.\ P_A.P_B$$

Dengan :

W_{kat} = berat katalisator

P_A = Tekanan parsial methanol $= P_{A0} . (1 - x)$ atm

P_B = Tekanan parsial HCl $= P_{B0} - P_{A0}.x$, atm

Misalkan umpan masuk metanol = a mol/jam

Maka umpan masuk HCl = M. a = 1,4. a mol/j

Mol umpan total = a + 1,4 a = 2,4 .a mol/j

$$P_{A0} = \frac{a}{2,4a}.Pt = 0,417\ Pt = 0,417.\ (1,36\ atm) = 0.567\ atm$$

$$P_{B0} = 1,4.(0,567\ atm) = 0,794\ atm.$$

$$P_A = \frac{n_A.R.T}{V} \rightarrow V = 6\,cm^3.\varepsilon$$

ε = porositas bed = 0,384

V = 6.(0,384) = 2,304 cm^3

sehingga :

$$n_{A0} = \frac{P_{A0}.V}{R.T}$$

R = 0,08206 L.atm/mol.K

T = suhu dalam K

$$n_{A0} = \frac{0{,}567\,atm(2{,}304\,\text{cm}^3).\dfrac{1L}{1000\,\text{cm}^3}}{0{,}08206\,L.atm/(mol.K)(T,K)} = \frac{0{,}016}{T}\,mol$$

sehingga :

$$-\frac{dn_A}{dt} = -n_{A0}\frac{d(1-x)}{dt} = k.P_{A0}\,.(1-x)(P_{B0} - P_{A0}x).W_{kat}$$

$$-\frac{dn_A}{dt} = -n_{A0}\frac{d(1-x)}{dt} = k.P_{A0}^{\;2}.(1-x)(\frac{P_{B0}}{P_{A0}} - x).W_{kat}$$

$$\frac{dx}{dt} = k\frac{P_{A0}^{\;2}(1-x)(\dfrac{P_{B0}}{P_{A0}} - x)}{n_{A0}}W_{kat}$$

$$\frac{dx.}{(1-x)(\dfrac{P_{B0}}{P_{A0}} - x)} = \frac{P_{A0}^{\;2}}{n_{A0}}.k.W_{kat}dt$$

waktu tinggal, t dapat dihitung dengan *space velocity*

$$t = \frac{1}{SV} = \frac{1}{2300}\,jam.\frac{3600\,\text{det}}{\text{jam}} = 1{,}57\ \text{detik}$$

Perhitungan berat katalisator dipakai :

$\rho_{true} = 3{,}98$ g/cc (Brown,1950)

untuk 1 gram volume padatan $= \dfrac{1}{3{,}98} = 0{,}251$ cc

Volume ruang kosong = 0,384.(0,251) = 0,0965 cc

Volume total = 0,251 + 0,0965 = 0,348 cc

$$\rho_{bulk} = \frac{1}{0{,}348} = 2{,}87 \text{ g/cc}$$

Berat katalis digunakan, W = 6 cc.(2,87 g/cc) = 17,25 gram

Persamaan differensial di atas dapat dipecah sebagai berikut :

$$\frac{A}{(1-x)} + \frac{B}{(\frac{P_{B0}}{P_{A0}} - x)} = \frac{1}{(1-x)(\frac{P_{B0}}{P_{A0}} - x)} = \frac{A(\frac{P_{B0}}{P_{A0}} - x) + B(1-x)}{(1-x)(\frac{P_{B0}}{P_{A0}} - x)}$$

$$\frac{P_{B0}}{P_{A0}} A - Ax - Bx + B = 1$$

$$\frac{P_{B0}}{P_{A0}} A + B = 1$$

$$A + B = 0$$

Diperoleh :

$$\left(\frac{P_{B0}}{P_{A0}}-1\right)A = 1 \rightarrow A = \frac{1}{\left(\frac{P_{B0}}{P_{A0}}-1\right)}$$

$$B = -\frac{1}{\left(\frac{P_{B0}}{P_{A0}}-1\right)}$$

Persamaan di atas menjadi :

$$\frac{1}{\left(\frac{P_{B0}}{P_{A0}}-1\right)}\int_0^{XA}\frac{1}{(1-x)}dx - \frac{1}{\left(\frac{P_{B0}}{P_{A0}}-1\right)}\int_0^{XA}\frac{1}{(\frac{P_{B0}}{P_{A0}}-x)}dx = \frac{\int_0^t k.P_{A0}^{\ 2}.W_{kat}.dt}{n_{A0}}$$

$$\frac{1}{\left(\frac{P_{B0}}{P_{A0}}-1\right)}\ln\left[\frac{\frac{P_{B0}}{P_{A0}}-x}{1-x}\right]_0^{XA} = k.\frac{P_{A0}^{\ 2}}{n_{A0}}t.W_{kat} \quad \text{.......(6)}$$

$$\frac{P_{B0}}{P_{A0}} = 1{,}4 \rightarrow \frac{1}{\left(\frac{P_{B0}}{P_{A0}}-1\right)} = 2{,}5$$

untuk Suhu, $T = 300\ ^{o}C, X_A = 0{,}995$ $\quad n_{A0} = \frac{0{,}016}{(300+273)} = 2{,}8.10^{-5}\ mol$

$$k\frac{P_{A0}^{\ 2}}{n_{A0}}.t.W_{kat} = k\frac{.(0{,}567)^2(1{,}57).W_{kat}}{2{,}8.10^{-5}} = 18.076.k.W_{kat}$$

$$2{,}5\left\{\ln\left[\frac{1{,}4-0{,}995}{1-0{,}995}\right] - \ln\left[\frac{1{,}4-0}{1-0}\right]\right\} = 18.076.k.W_{kat}$$

$$4{,}887 = 18.076.k.W_{kat}$$

$k.W_{kat} = 0{,}00027$ mol/(atm^2.det) dengan katalis 17,25 gram

maka :

$$k = \frac{0{,}00027}{17{,}25} = 1{,}57.10^{-5} \quad \text{mol/(atm}^2\text{.det.gkat)}$$

$$\text{Untuk Suhu, T} = 400\ ^{O}C, X_A = 0{,}974 \qquad n_{A0} = \frac{0{,}016}{(400+273)} = 2{,}37.10^{-5}\ mol$$

$$2.5\left\{\ln\left[\frac{1{,}4-0{,}974}{1-0{,}974}\right] - \ln\left[\frac{1{,}4-0}{1-0}\right]\right\} = \frac{(0{,}567)^2(1{,}57)}{2{,}37.10^{-5}}.k.W_{kat}$$

$$6{,}15 = 21.230{,}5.k.W_{kat}$$

$$k.W_{kat} = 0{,}00029 \text{ mol/(atm}^2\text{.det)}, \rightarrow k = \frac{0{,}00029}{17{,}25} = 1.68.10^{-5} \text{ (mol/atm}^2\text{.gkat.det)}$$

Sehingga bisa diperoleh data :

Tabel 3. Nilai konstanta kecepatan reaksi

Suhu, K	Nilai k, (mol/ (atm^2.det.gkat)
573	$1{,}57.10^{-5}$
673	$1{,}68.10^{-5}$

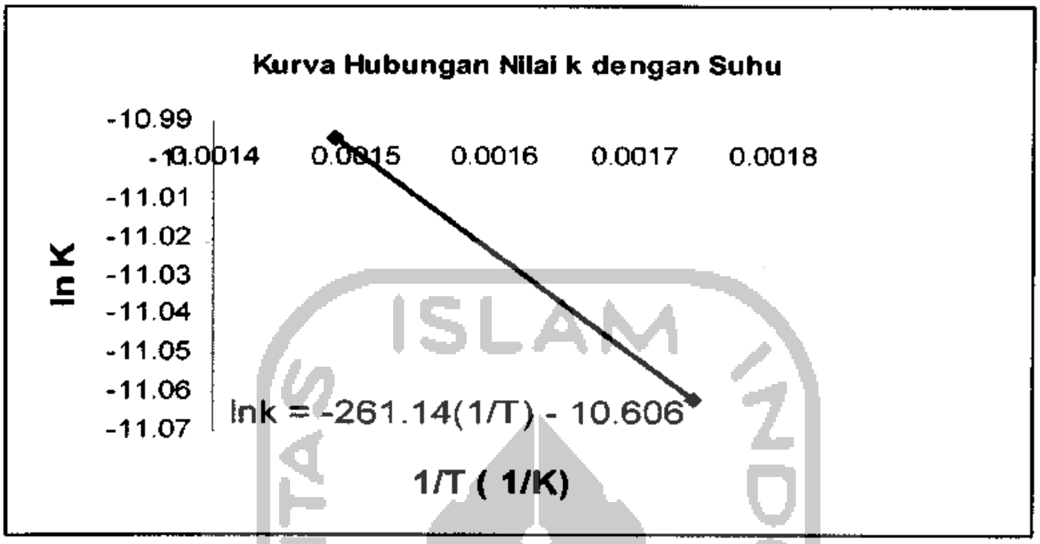
Persamaan umum nilai konstanta kecepatan reaksi adalah mengikuti persamaan *Arrhenius* sebagai berikut :

$$k = A.e^{\frac{-E}{RT}}$$

bila di logaritmakan :

$$\ln k = \ln A - \frac{E}{R}.\frac{1}{T}$$

dapat dibuat garis lurus dengan slope $\frac{-E}{R}$ *dan* intercep*t* ln A



Gambar 4. Grafik hubungan nilai k dengan suhu

Diperoleh nilai ln A = -10,606 sehingga A = exp(-10,606) = 2,48.10^{-5}

Nilai $\frac{-E}{R} = -261,14$, E = 261,14 (1,987) =518,8 kal/mol

Sehingga nilai k:

$$k = 2,48.10^{-5}.\exp\left[\frac{-261,14}{T}\right] \frac{\text{mol}}{\text{atm}^2.\text{gkat.det}} \qquad \ldots\ldots(7a)$$

$$k = 2,48.10^{-5}.\exp\left[\frac{-261,14}{T}\right] \frac{\text{mol}}{\text{atm}^2.\text{gkat.det}} 3600\frac{\text{det}}{jam}$$

Sehingga diperoleh nilai konstanta kecepatan reaksi, k :

$$k = 0,0892.\exp\left[\frac{-261,14}{T}\right] \frac{\text{kgmol}}{\text{atm}^2.\text{kgkat.jam}} \qquad \ldots\ldots(7b)$$

Sehingga persamaan kecepatan reaksi :

$$(-r_A) = 0,0892.\exp\left[\frac{-261,14}{T}\right] \frac{\text{kgmol}}{\text{atm}^2.\text{kgkat.jam}} .P_A.P_B(atm)^2$$

$$(-r_A) = 0,0892.\exp\left[\frac{-261,14}{T}\right] .P_A.P_B \frac{\text{kgmol}}{\text{kgkat.jam}} \qquad \ldots\ldots(8)$$

dengan:

$$P_A = \frac{n_A}{n_t} P_t = \frac{n_{A0}(1-x)}{n_t} P_t$$

$$P_B = \frac{n_B}{n_t} P_t = \frac{n_{B0} - n_{A0}.x}{n_t} P_t$$

n_A = mol A dalam campuran gas, kmol/jam

n_{A0} = mol A pada umpan, kmol/jam

n_B = mol B dalam campuran gas, kmol/jam

n_{B0} = mol B pada umpan, kmol/jam

T = suhu absolut, K

P_A, P_B = tekanan parsial methanol dan HCl, atm

P_t = Tekanan sistem total, atm

NERACA MASSA REAKTOR

	CH_3OH +	HCl →	CH_3Cl +	H_2O
Awal	106,68	103,12	18,40	368,47
Reaksi	106,68 x	106,68 x	106,68 x	106,68 x
Keluar	106,68(1-x)	103,12-106,68 x	18,40+106,68x	368,47+106,68 x

Tabel 4. Persamaan neraca massa fungsi konversi CH_3OH

Senyawa	Input, x = 0, kmol/j	Output, kmol/j	Output x = 0,95, kmol/j
HCl	103,12	103,12-106,68 x	1,77
CH_3Cl	18,40	18,40+106,68 x	119,75
CH_3OH	106,68	106,68 (1-x)	5,33
H_2O	368,47	368,47+106,68 x	469,82

Diperoleh:.

Tabel 5. Neraca massa reaktor

Senyawa	Input, kg/j	Output, kg/j
HCl	3764,02	64,60
CH_3Cl	929,35	6047,72
CH_3OH	3413,93	170,61
H_2O	6632,48	8456,85
Total	**14739,78**	**14739,78**

SIFAT FISIS GAS

1. Kapasitas panas komponen(Cp), kJ/kmol.K

   (*Coulson and Richardson, 1989*)

   $CP_G(I) = a(i) + b(i) . T + c(i) . T^2 + d(i). T^3$ ....(9)

Tabel 6. Kapasitas panas gas

Senyawa	a	$b.10^3$	$c10^5$	$d.10^9$
HCl	30,291	-7,201	1,246	-3,097
CH_3Cl	13,875	10,140	-3,888	2,566
CH_3OH	21,152	70,920	2,587	-25,810
H_2O	32,243	1,923	1,055	-3,596

2. Viskositas gas

   (metode *Thodos and Coworker , Perry and Green, 1984*)

   $\eta\varepsilon = 4{,}61o\ Tr^{0{,}618} - 2{,}04\ EXP(-0{,}449. Tr) + 1{,}94\ EXP(-4{,}058. Tr) + 0{,}1$

   $\varepsilon = Tc^{1/6} (BM)^{0.5} Pc^{-2/3}$

   Tr = T/Tc

   Tc = suhu kritis, K

   Pc = tekanan kritis, atm

η = viskositas, μP

Tabel 7. Kondisi kritis gas (*Coulson and Richardson, 1989*)

Senyawa	Tc, K	Pc, atm
HCl	363,2	85,5
CH_3Cl	416,3	66,8
CH_3OH	512,6	81,0
H_2O	647,3	220,5

3. Densitas, kg/m^3 (*Coulson and Richardson, 1989*)

   ρ = (BM / 22,415) . (273 / T) . P

4. Konduktivitas gas, W/m.K

   digunakan metode *Eucker, 1911* (*Coulson and Richardson, 1989*)

   k = μ (Cp + 10,4 / BM)

   μ = viskositas, cP

   Cp = kapasitas panas, kJ/kg.K

Data pendingin

Pendingin dowterm A cair pada 5 atm dengan sifat (*Perry and Green , 1984*):

Dipakai tekanan pendingin 5 atm karena titik didih dowterm A pada tekanan ini 670 K sehingga dalam reaktor fasa dowterm A dapat dipertahankan tetap cair

- kapasitas panas 2,63 kJ/kg.K
- densitas 680 kg/ m^3
- viskositas 0,5 kg/m.j
- konduktivitas 0,943 kJ/m.j.K

Menghitung Panas Reaksi

$$\Delta H_{R,T} = \Delta H_{R,298} + \int_{298}^{T} \Delta Cp_1 . dT$$

$$\Delta H_{R,298} = -33.41\ kJ / kmol$$

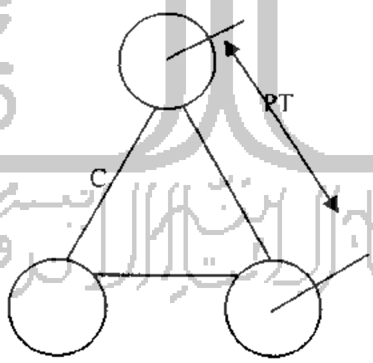
Pipa Reaktor (*Perry and Green, 1984*):

Pipa yang di pakai adalah NS = 4, schedule 40 (cukup baik untuk tekanan atmosferis)

Diameter dalam pipa (ID) = 4,026 in

Diameter luar pipa (OD) = 4,50 in

Pipa-pipa disusun triangular pitch (dalam luas periperal sama, jumlah pipa lebih banyak):



Gambar 5. Susunan Pipa dalam Reaktor

dengan :

PT = jarak 2 pusat pipa

= 1,25 OD

C = PT- OD (clearence)

Diameter shell dibutuhkan, Ds :

Ds = OD .(Nt / 0,319)$^{0.4668}$. (*Coulson and Richardson, 1989*)

Perkiraan Jumlah Pipa

Karena fluida (gas) melewati tumpukan katalisator maka jumlah pipa diperkirakan sedemikian rupa sehingga Re > 100 syarat turbulen. (*Perry and Green,1984*):

$$G = \frac{4.Wt}{\pi\ Di^2\ Nt}$$

$$Re = \frac{G.Dp}{\mu}$$

keterangan:

C = jarak 2 pipa (clearance), m

PT = jarak 2 pusat pipa (pitch), m

Dp = diameter partikel dalam pipa, m

Do = diameter luar pipa, m

Di = diameter dalam pipa, m

μ = viskositas campuran gas, kg/m.j

Nt = jumlah pipa dalam reaktor

G = fluks massa gas tiap pipa, $kg/m^2/j$

Wt = massa gas total masuk reaktor, kg/j

Re = bilangan Reynold

Jumlah pendingin

Jumlah pendingin dibutuhkan (Wc) ditentukan dengan cara coba-coba sehingga diperoleh distribusi suhu yang baik dalam reaktor, yaitu :

- Tidak terjadi hot spot pada katalis (yaitu suhu yang sangat tinggi pada bagian katalis tertentu yang dapat menyebabkan katalisator cepat rusak.

$$Gs = \frac{Wc}{As}$$

$$As = \frac{Ds.C.B}{PT}$$

dengan:

Gs = fluks massa pendingin, $kg/j/m^2$

Wc = laju alir massa pendingin kg/j

As = luas penampang aliran pendingin, m^2

Ds = diameter shell, m

C = clearance, jarak 2 pipa, m

B = jarak antara baffle (baffle space), m

PT = jarak pusat 2 pipa (pitch), m

Koefisien Perpindahan Panas Overall (Ud)

Koefisien perpindahan panas keseluruhan (Ud) dapat ditentukan berdasarkan persamaan-persamaan berikut (*Kern,1954*):

Tahanan overall dari perpindahan panas = $\sum R$

$$\sum R = \frac{1}{hi} + \frac{1}{ho} + \frac{Lm}{Km}$$

Apabila hi dan ho dinyatakan pada transfer panas yang sama maka hi dinyatakan dengan luas transfer bagian luar sehingga:

$$hio = hi\frac{Di}{Do}$$

Apabila tahanan dinding pipa (Lm/Km) diabaikan (dinding relatif tipis) maka:

$$\sum R = \frac{1}{hio} + \frac{1}{ho}$$

Tahanan overall ini merupakan kebalikan dari koefisien transfer panas dalam keadaan bersih (*clean overall coefficient*)

$$\sum R = \frac{1}{Uc} = \frac{1}{hio} + \frac{1}{ho}$$

maka :

$$Uc = \frac{hio.ho}{hio + ho}$$

Dalam keadaan terpakai maka clean overall coefficient (Uc) ini perlu ditambah dengan tahanan pengotor Rd (falling faktor). Sehingga koefisien transfer panas dalam keadaan terpakai (Ud) dapat dihitung:

$$\frac{1}{Ud} = \frac{1}{Uc} + Rd$$

$$Ud = \frac{Uc}{1 + Uc.Rd}$$

dari tabel. 12 (*Kern, 1954*) diperoleh harga Rd sebagai berikut:

Rd = Rd uap organic

Rd = 0,0003 J $Ft^2\ ^0F/Btu$

Koefisien transfer panas dinding pipa bagian dalam digunakan rumus 6.2 (*Kern, 1954*):

$$\frac{hi\,D}{k} = 0{,}027\left[\frac{D.G}{\mu}\right]^{0,8}\left[\frac{Cp.\mu}{k}\right]^{1/3}$$

Harga koefisien transfer panas ini harus dikoreksi untuk pipa berisi padatan katalis. Hubungan perbandingan diameter partikel dengan diameter pipa (Dp/Di) terhadap perbandingan hi pipa berisi partikel dengan pipa kosong (hw/h) di teliti oleh *Colburn* (*Smith, J.M., hal 571, 1977*)

Tabel 8. Hubungan perbandingan (Dp/Di) terhadap (hw/h)

Dp/Di	0,05	0,10	0,15	0,20	0,25	0,30
hw/h	5,5	7	7,8	7,5	7,0	6,6

$$\frac{Dp}{Di} = \frac{\text{diameter katalis}}{\text{diameter dalam pipa}}$$

$$= \frac{2}{25{,}4.0{,}957}$$

$$= 0{,}082$$

dari tabel untuk Dp/Di = 0,082, maka hw/h= 6,5 sehingga hi berkatalis

$$hi = (6{,}5)0{,}027\left[\frac{kg}{Di}\right]\left[\frac{Di.G}{\mu\mu}\right]^{0,8}\left[\frac{Cp.\mu}{kg}\right]^{1/3}$$

sedangkan koefisien transfer panas dalam shell untuk aliran tur bulen dipakai persamaan hal. 137 (Kern, 1954) :

$$ho = 0{,}36\left[\frac{kc}{De}\right]\left[\frac{De.Gs}{\mu\mu c}\right]^{0.55}\left[\frac{Cpc.\mu c}{kc}\right]^{1/3}$$

dengan diameter ekivalen (De) adalah :

$$De = \frac{4\left[\frac{1}{2}PT.(0{,}86)P\,T - \frac{1}{2}\pi Do^2/4\right]}{\frac{1}{2}\pi Do}$$

keterangan:

G,Gs = fluks massa gas dan pendingin, $kg/m^2/j$

Kc, kg = konduktivitas panas pendingin dan gas, kJ/m/j.K

μ,μc = viskositas gas dan pendingin, kg/m/j

Di,De,Do = diameter dalam pipa, ekivalen dan diameter luar, m

Hio, ho = koefisien transfer panas dinding dalam dan luar pipa, $kJ/m^2/j/K$

Rd = fouling faktor

Ud, Uc = koefisien transfer panas overall keadaan terpakai dan bersih $kJ/m^2/j/K$

Persamaan diferensial simultan yang diperoleh dari neraca massa dan neraca panas di atas dapat diselesaikan dengan metode runge kutta order 4 dengan batas :

Z = 0 X = 0 T = 623 K P = 1,30 atm t = 583 K

Dengan inkrement panjang ΔZ digunakan 0,01 m, dan diselesaikan dengan program komputer

MECHANICAL DESIGN REAKTOR

Menghitung tebal shell (dinding reaktor)

Bahan yang dipilih untuk dinding reaktor adalah Stainlessteel AISI 316 *(Coulson and Richardson, 1989)*

$$Ts = \frac{P_i . D_i}{2f\ E - p_i} + C$$

E = joint efficiency , max) = 0,85

C = corrotion allowance = 2 mm

f = maximum design stress, N/mm

p_i = design Pressure , N/mm

D_i = diameter reaktor, mm

Ts = tebal shell, mm

Menghitung tebal head (torisperical dished head head)

(*Coulson and Richardson, 1989*)

$$Th = \frac{P_i\ D_i}{2\ f\ E - 0{,}2\ P} + C$$

$$\text{Volume head} = 0{,}000076\,[\text{ID head}]^3\ ft^3$$

Dari tabel 5 - 11 (Brownell and Young, 1954) dipakai safety factor (Sf = 1,5 in) diambil Sf = 1,5 in, OD head = ID head + 2 Tebal head

Inside depth of dish $b = \frac{\text{ID head}}{4}$

Tinggi total head = b + Sf + Th

Tebal penyangga tumpukan katalisator

Persamaan : $T = \frac{P\ D}{4\ f} + C$ persamaan 3.1.3 (*Brownell and Young, 1954*)

D = Diameter dalam pipa, in

P = (Tekanan sistem + Wkat / At), psi

Wkat = Beban karena katalisator, lbf

At = luas penyangga , in^2

C = corrosion allowance = 0,125 in

F = maximum design stress, psi

Perhitungan plate penyangga pipa

berat pipa = 2,17 lb/ft (*Perry and Green, 1984*)

BB1 = Wkat . 9,81 / 3,14 D_S^2 / 4 / NT

BB2 = P_{T0} . 101300

BB3 = 2,17 . 0, 4355 / 0,3048 . Z . 9,81 / (3,14 . $D_S^{\ 2}$ / 4)

BB = (BB1 + BB2 + BB3) / 1000000!

TPP = (BB . D_I . 1,1 / (4 . f) + C / 25,4

TPP = tebal penyangga katalis, in

D_I = diameter dalam pipa, mm

BB1 = beban karena katalisator, N/m^2

BB2 = beban karena tekanan, N/m^2

BB3 = beban karena pipa, N/m^2

BB = total beban, N/mm ^{2}

P_{T0} = tekanan sistem, atm

Wkat = berat katalis, kg

Baffle

Baffle spacing

Dari *Kern, 1954., " Process Heat Transfer", hal 129*

Baffle spacing = (0,2 s/d 1) ID shell

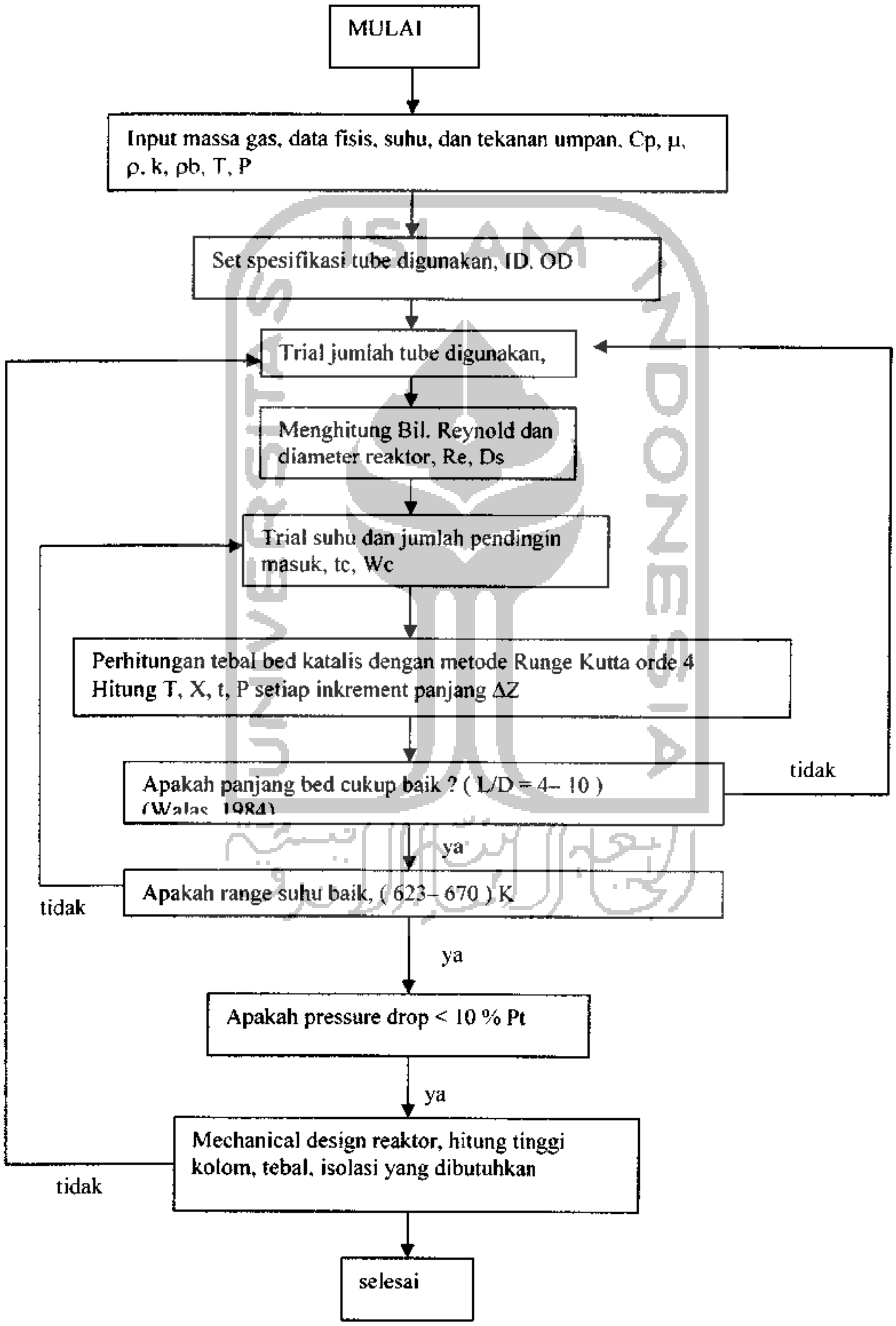
Diambil = 0,5 x ID shell

Baffle segmental

Dari *Perry and Green, 1954* :

Baffle segmental = 0,75 x ID shell

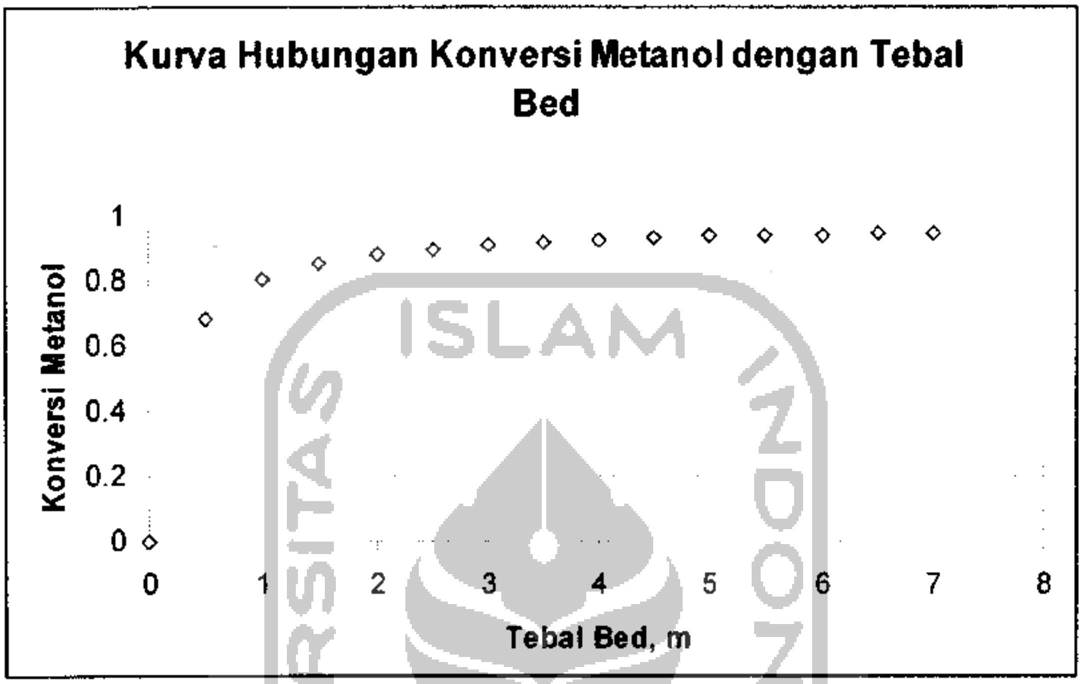
Perhitungan persamaan-persamaan di atas dilakukan dengan program komputer.



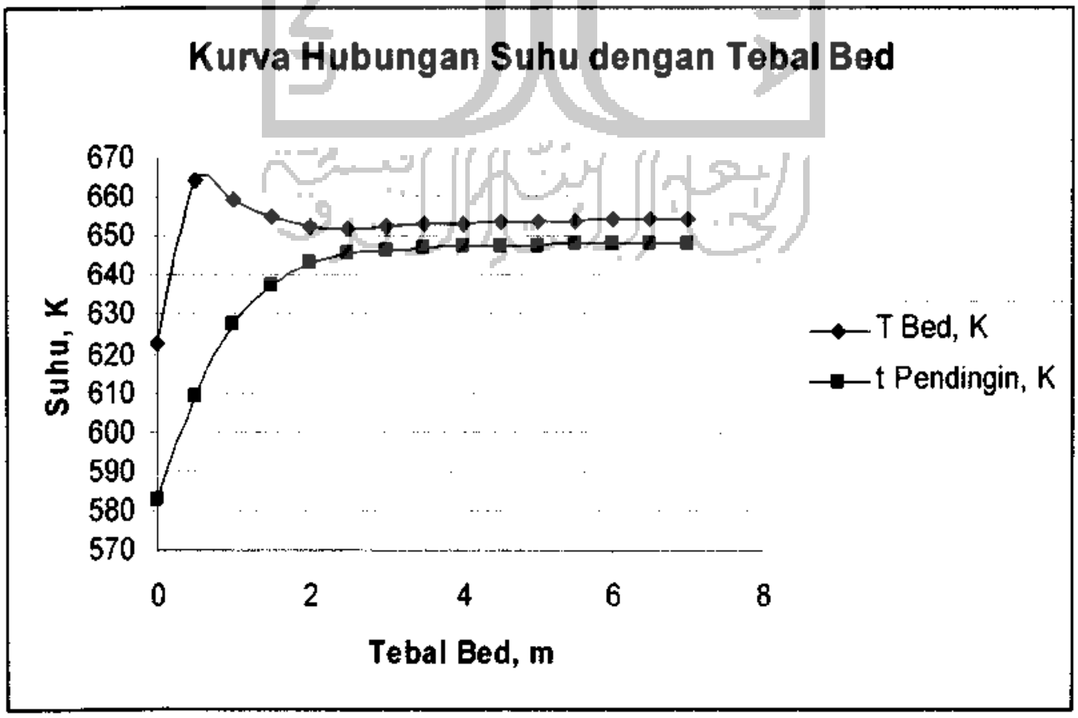
Gambar 6. Algoritma perhitungan reaktor

RESUME REAKTOR

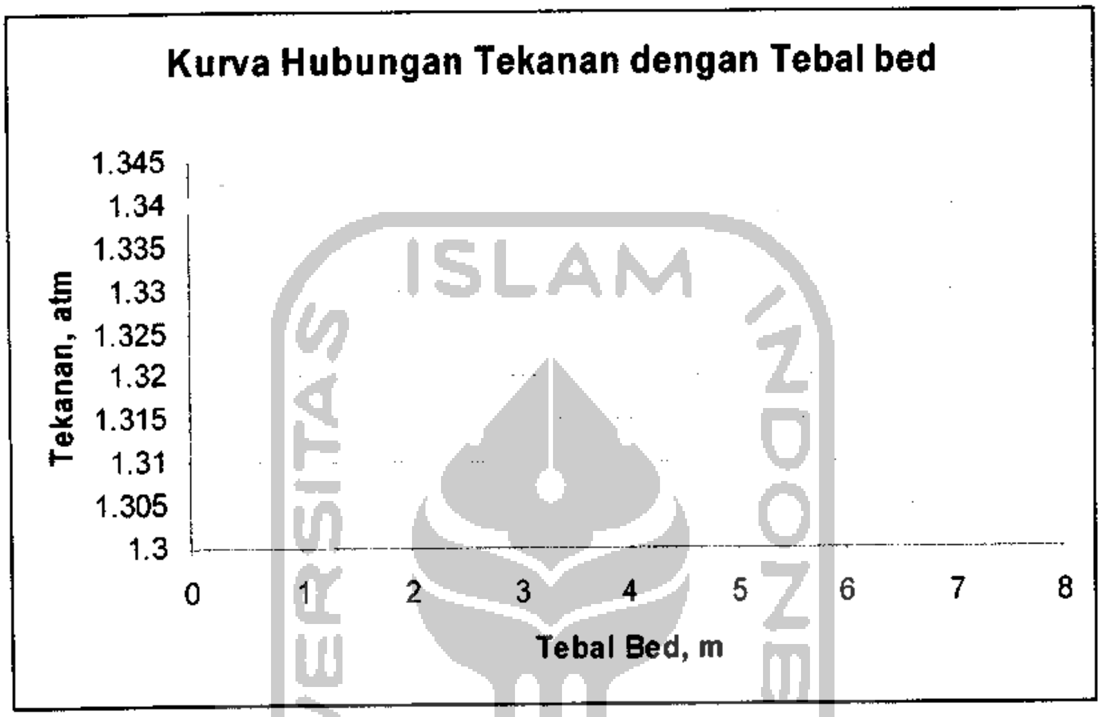
Fungsi	:	Mereaksikan CH_3OH dengan HCl menjadi CH_3Cl dan H_2O dengan konversi CH_3OH 95 %.
Jenis	:	Fixed bed multitubular reaktor.
Fasa	:	Gas
Suhu	:	623 – 654.4678 K
Tekanan	:	1,30 atm
Operasi	:	Nonadiabatis nonisotermal
Katalis	:	Alumina gel berukuran 2,0 mm sebanyak 63.673,42 kg.
Jumlah alat	:	1 buah
Dimensi kolom	:	Diameter kolom 3,4 m Tinggi kolom 8.84 m Tinggi bed katalisator 7,02 m Tebal shell dan head 3 /16 in (4,76 mm)
Bahan	:	Stainlessteel AISI 316
Spesifikasi tube	:	Diameter dalam pipa (ID) = 4,026 in Diameter luar pipa (OD) = 4,50 in NS 4 in Stainlessteel AISI 316 Jumlah 450 tube
Isolasi	:	Magnesia setebal 3 in (7,62 cm)
Pendingin	:	Dowterm A cair sebanyak 7.000 kg/j Suhu 583 – 648,4951 K Tekanan 5 atm



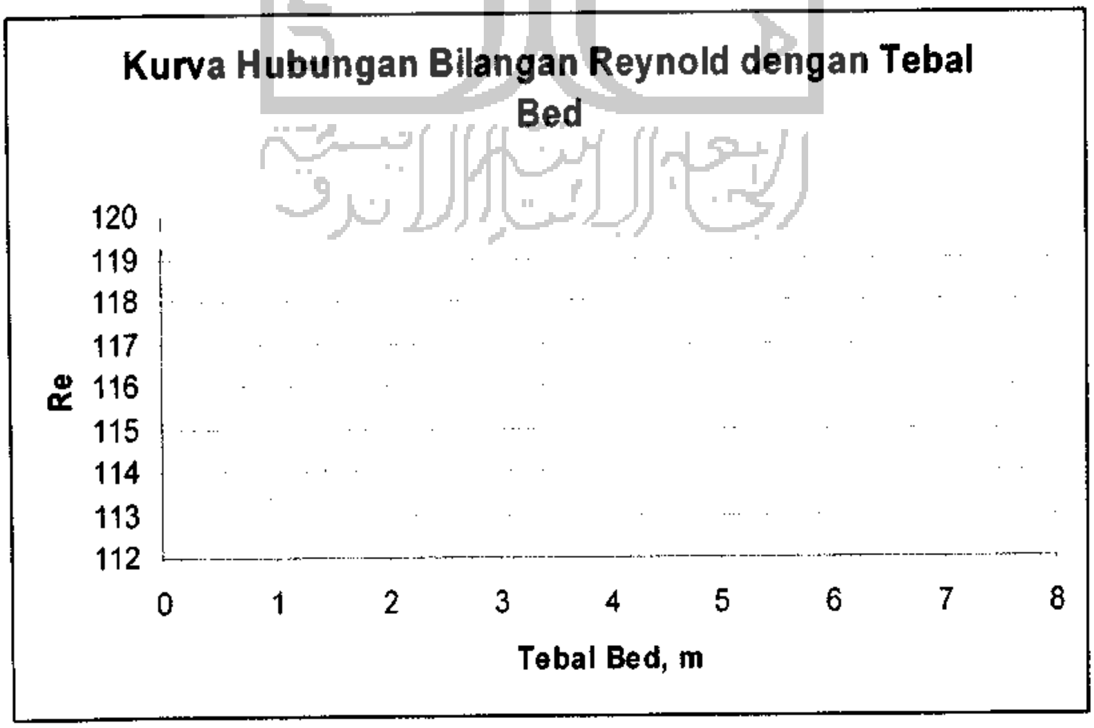
Gambar 7. Grafik hubungan konversi CH_3OH dengan tebal bed



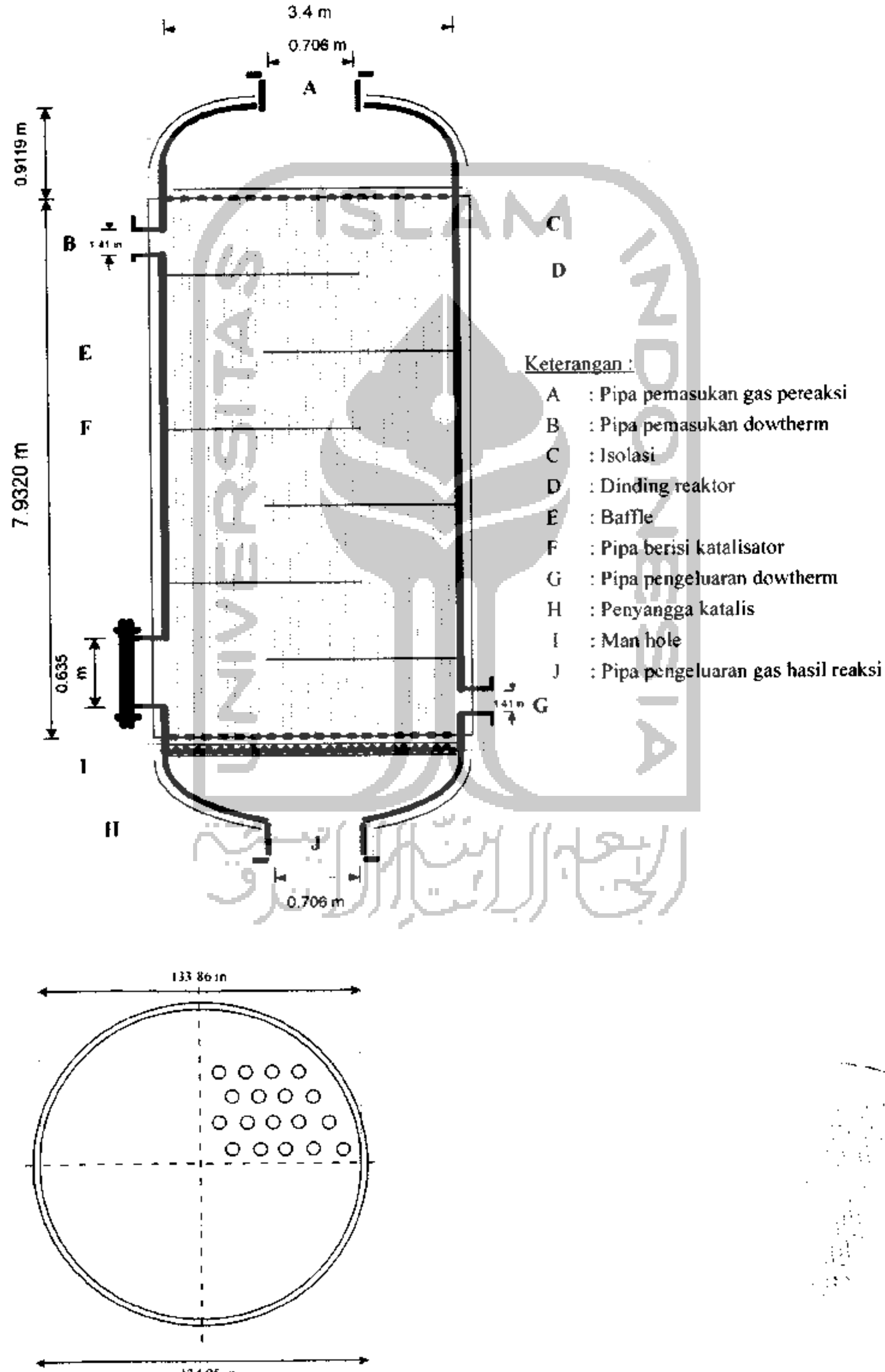
Gambar 8. Grafik hubungan suhu dengan tebal bed



Gambar 9. Grafik hubungan tekanan dengan tebal bed



Gambar 10. Grafik hubungan bilangan reynold dengan tebal bed



Gambar 11. Skema reaktor fixed bed multitube

Source Code Program Q Basic

```
PRINT "                    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%"
PRINT "                    %  PERANCANGAN REAKTOR MULTITUBE 01 %"
PRINT "                    %      PABRIK METHYL CHLORIDE       %"
PRINT "                    %        KAP. 40.000 TON/TH         %"
PRINT "                    %                                   %"
PRINT "                    %                                   %"
PRINT "                    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%"
PRINT : PRINT
PRINT " KETERANGAN:"
N = 4
DELZ = .01
DIM BM(N), MASSA(N), MOL(N), CPA(N), CPB(N), CPC(N), CPD(N),
PCRIT(N), TCRIT(N), MOLO(N)
DIM MIU(N), VISA(N), VISB(N), PRES(N)
M = 3000: mp = 10
DIM X(M + 1), T(M + 1), TC(M + 1), Z(M + 1), DELP(M + 1), P(M + 1),
RE(M + 1), RA(M + 1)
PRINT : PRINT
PRINT
PRINT " 1. HCL   2. CH3CL   3. CH3OH   4. H2O  "
PRINT
PRINT " PENDINGIN ADALAH DOWTERM A CAIR PADA 5 ATM"
PRINT
'INPUT BERAT MOLEKUL
FOR I = 1 TO N
READ BM(I)
NEXT I
```

```
DATA 36.5,50.5,32,18
'MASSA MASUK
MASSA = 0: MOL = 0
FOR I = 1 TO N
READ MASSA(I)
MASSA = MASSA + MASSA(I)
MOL(I) = MASSA(I) / BM(I)
MOL = MOL + MOL(I)
NEXT I
MOLTTL = MOL
BMR = MASSA / MOLTTL
DATA 3764.0169,929.3493,3413.9310,6632.4820
PRINT "  TOTAL MASSA MASUK              ="; MASSA; "KG/J"
'DATA KAPASITAS PANAS GAS, COULSON, 1989
FOR I = 1 TO N
READ CPA(I), CPB(I), CPC(I), CPD(I)
NEXT I
DATA 30.291,-7.201E-3,1.246E-5,-3.097E-9
DATA 13.875,1.014E-2,-3.888E-5,2.566E-9
DATA 21.152,7.092E-2,2.587E-5,-2.581E-8
DATA 32.243,1.9235E-3,1.055E-5,-3.596E-9
'INPUT KONDISI KRITIS, COULSON 1989
 FOR I = 1 TO N
 READ TCRIT(I), PCRIT(I)
 NEXT I
 DATA 363.2,85.5,416.3,66.8,512.6,81.0,647.3,220.5
' BERAT MOLEKUL RERATA
BMR = MASSA / MOL
```

```
DP = 2 / 1000
TC0 - 583
T0 = 350 + 273
PT0 = 1.3
TDEN = 249 / 62.5 * 1000
E = .384: VOL - (1 / TDEN) / (1 - E)
RHOB = 1 / VOL
PRINT
PRINT "  DATA KATALISATOR"
PRINT
PRINT "  JENIS KATALIS                          - ALUMINA GEL"
PRINT "  DIAMETER BUTIR                         ="; DP; "m"
PRINT "  TRUE DENSITY KATALIS                   ="; TDEN; "KG/M3"
PRINT "  BULK DENSITY                           ="; RHOB; "kg/m3"
PRINT "  POROSITY                               ="; E
PRINT "  BENTUK                                 = BOLA"
PRINT "          KONDISI REAKTOR"
PRINT
CPC = 2.63
PRINT "   SUHU UMPAN MASUK                       ="; T0; "K"
PRINT "   SUHU PENDINGIN MASUK                   ="; TC0; "K"
PRINT "   TEKANAN UMPAN REAKTOR                  ="; PT0; "atm"
MC = 7000
PRINT "   JUMLAH PENDINGIN DIGUNAKAN             -"; MC; "Kg/J"
PRINT "   INCREMENT PANJANG  DIGUNAKAN           ="; DELZ; "m"
PRINT
PRINT "   BERHENTI DULU YA........"
DO
```

```
LOOP WHILE INKEYS = ""
PRINT
' PENENTUAN JUMLAH TUBE
P = PT0
PRINT
PRINT
'SPESIFIKASI TUBE
PRINT "  DIGUNAKAN PIPA NS = 4   OD=4.5 IN DAN ID = 4.026 IN"
PRINT " bahan STAINLESTEEL AISI 316 "
ID = 4.026 * 2.54 / 100
OD = 4.5 * 2.54 / 100
PRINT
PRINT "  DIAMETER DALAM TUBE                    ="; ID; "m"
PRINT "  DIAMETER LUAR TUBE                     ="; OD; "m"
' Trial jumlah tube digunakan, Nt
Nt = 450
AREA = 3.14159 / 4 * ID ^ 2 * Nt
AT = AREA / Nt
PRINT "  JUMLAH TUBE DIPAKAI                    ="; Nt; "TUBE"
PRINT "  LUAS AREA ALIR                         ="; AREA; "m2"
T = T0
RHOG = BMR / 22.14 * P * 273 / (T)
GOSUB VISKO
G = MASSA / AREA / 3600
RE = MASSA / AREA * DP / MIU
PT = 1.25 * OD
PRINT "  REYNOLD NUMBER                         ="; RE
PRINT "  TRIANGULAR PITCH                       ="; PT; "m"
```

```
DS = OD * (Nt / .319) ^ (1 / 2.142)
'COULSON, 1989 P.523
PRINT "  DIAMETER SHELL TERHITUNG               ="; DS; "m"
PRINT
DS = 3.4
PRINT "  digunakan diameter shell               ="; DS; " M"
PRINT
PRINT "  D PARTIKEL / D TUBE                    ="; DP / TD
PRINT
PRINT "  FAKTOR KOREKSI HIO  = 6.5"
PRINT
' ANALISIS TOTAL
MOP = 0
FOR I = 1 TO N
MOLO(I) = MOL(I)
MOP = MOP + MOL(I)
NEXT I
FOR I = 1 TO N
PRES(I) = MOL(I) / MOP * PTO
PRES = PRES + PRES(I)
NEXT I
PRINT
PRINT
PRINT " TEKANAN PARSIAL HCL MASUK   ="; PRES(1); "atm"
PRINT " TEKANAN PARSIAL CH3CL MASUK ="; PRES(2); "atm"
PRINT " TEKANAN PARSIAL CH3OH MASUK ="; PRES(3); "atm"
PRINT " TEKANAN PARSIAL H2O MASUK   ="; PRES(4); "atm"
PRINT "____________________________________________ +"
```

```
PRINT " tekanan total umpan          ="; PRES; "atm"
PRINT : PRINT : PRINT
MC = MC
P = PT0: TMAX = T0: TMIN = T0
duit = 0
UDT = 0
' PERANCANGAN TEBAL BED KATALIS
' METODE RUNGE KUTTA TINGKAT 4
T(0) = T0: TC(0) = TC0: Z(0) = 0: X(0) = 0: DELP(0) = 0: P(0) = P
RE(0) = RE
FOR J = 0 TO M - 1
IF X(J) > .95 THEN GOTO HELL
Z = Z(J): X = X(J): T = T(J): TC = TC(J): DELP = DELP(J)
GOSUB RUNGE
R11 = R1 * DELZ: R21 = R2 * DELZ: R31 = R3 * DELZ: R41 = R4 * DELZ
Z = Z(J) + DELZ / 2: X = X(J) + R11 / 2: T = T(J) + R21 / 2: TC =
TC(J) + R31 / 2
DELP = DELP(J) + R41 / 2
GOSUB RUNGE
R12 = R1 * DELZ: R22 = R2 * DELZ: R32 = R3 * DELZ: R42 = R4 * DELZ
Z = Z(J) + DELZ / 2: X = X(J) + R12 / 2: T = T(J) + R22 / 2: TC =
TC(J) + R32 / 2
DELP = DELP(J) + R42 / 2
GOSUB RUNGE
R13 = R1 * DELZ: R23 = R2 * DELZ: R33 = R3 * DELZ: R43 = R4 * DELZ
Z = Z(J) + DELZ: X = X(J) + R13: T = T(J) + R23: TC = TC(J) + R33
DELP = DELP(J) + R43
GOSUB RUNGE
```

```
R14 = R1 * DELZ: R24 = R2 * DELZ: R34 = R3 * DELZ: R44 = R4 * DELZ
Z(J + 1) = Z(J) + DELZ
X(J + 1) = X(J) + (R11 + 2 * R12 + 2 * R13 + R14) / 6
T(J + 1) = T(J) + (R21 + 2 * R22 + 2 * R23 + R24) / 6
TC(J + 1) = TC(J) + (R31 + 2 * R32 + 2 * R33 + R34) / 6
DELP(J + 1) = DELP(J) - (R41 - 2 * R42 + 2 * R43 + R44) / 6
RE(J + 1) = MASSA / AREA * DP / MIU
RA(J) = RP1
duit = duit + 1
UDT = UDT + UD
P(J + 1) = P
IF TMAX < T THEN TMAX = T
IF T < TMIN THEN TMIN = T
X = X(J + 1)
NEXT J
HELL:
' PRINT#1, HASIL PERHITUNGAN
PRINT : PRINT
PRINT "              HASIL PERHITUNGAN  BED KATALIS"
PRINT "              %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%"
PRINT
PRINT                                                              "
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%"
PRINT "  %  Z, m  % KONV,x %T BED,K % t PEND,K % P,atm  %   RE  %
rA,KMOL/J/KGKAT %"
```

```
PRINT                                                                      "
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%"
HAN$ - "   % ##.### % #.#### % ###.## % ###.##    % ##.### %####.# %
##.#######        %"
FOR J = 0 TO duit STEP 5 * mp
PRINT USING HAN$; Z(J); X(J); T(J); TC(J); P(J); RE(J); RA(J)
NEXT J
PRINT                                                                      "
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%"
SLEEP
MASSA = 0
FOR I = 1 TO N
MASSA(I) = BM(I) * MOL(I)
MASSA = MASSA + MASSA(I)
NEXT I
PRINT : PRINT
PRINT "                      NERACA MASSA  HASIL REAKTOR"
PRINT "                      %%%%%%%%%%%%%%%%%%%%%%%%%%%%"
PRINT : PRINT
PRINT                                                                      "
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%"
PRINT "    %    SENY    %   MASUK, KGMOL/J   % KELUAR, KGMOL/J %
KEL.KG/J  %"
PRINT                                                                      "
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%"
```

```
RAT$ = "     %    #         %     #######.######  %  ######.#######  %
########.## %"
FOR I = 1 TO N
PRINT USING RAT$; I; MOLO(I); MOL(I); MASSA(I)
NEXT I
PRINT                                                              "
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%"
PRINT
PRINT : PRINT
PRINT
PRINT
PRINT " TEKANAN PARSIAL HCL KELUAR      ="; PA; "atm"
PRINT " TEKANAN PARSIAL CH3CL KELUAR    ="; PC; "atm"
PRINT " TEKANAN PARSIAL CH3OH KELUAR    ="; PB; "atm"
PRINT " TEKANAN PARSIAL H2O  KELUAR     ="; PD; "atm"
PRINT "______________________________________________ +"
PRES = PA + PB + PC + PD
PRINT " TEKANAN TOTAL  KELUAR           ="; PRES; "atm"
PRINT : PRINT
PRINT
PRINT " TOTAL MASSA KELUAR                         ="; MASSA; "KG/J"
PRINT
SLEEP
TCOUT = TC
PRINT
PRINT "       SUHU HASIL KELUAR                    ="; T; "K"
PRINT "       KONVERSI KELUAR                      ="; X
PRINT "       SUHU PENDINGIN MASUK                 ="; TCO; "K"
```

```
PRINT "         SUHU PENDINGIN KELUAR              ="; TC; "K"
PRINT "         TEKANAN KELUAR REAKTOR             ="; P; "atm"
PRINT "         PRESSURE DROP DI TUBE              ="; DELP; "atm"
PRINT "         TINGGI TUMPUKAN KATALIS            ="; Z; "m"
PRINT "         SUHU MAXIMUM                       ="; TMAX; "K"
PRINT "         SUHU MINIMUM                       ="; TMIN; "K"
TCRAT = (TCC * TC) ^ .5
PRINT "         SUHU PENDINGIN RERATA              ="; TCRAT; "K"
TC = TCRAT
GOSUB RUNGE
BSP = DS * .5
PRINT "         REYNOLD DI SHELL                   ="; RES
PRINT "         BAFFLE SPACING                     ="; BSP; "m"
PRINT "           UD RATA-RATA                         ="; UDT / duit;
"KJ/m2.j.K"
PRINT
SLEEP
PRINT "  FIG 12.30 (COULSON,1989) Jf = 0.09"
JF = .09
VCC = GS / RHOC / 3600
DELPS = 8 * JF * (DS / DE) * (Z / DS * .5) * RHOC * VCC ^ 2 / 2 /
101300
PRINT "         PRESSURE DROP DI SHELL             ="; DELPS; "atm"
PRINT "  pressure drop di shell acceptable"
WKAT = RHOB * AT * Nt * Z
PRINT "         TOTAL KATALISATOR DIPERLUKAN       ="; WKAT; "kg"
SLEEP
PRINT
```

```
PRINT "    MECHANICAL DESIGN REAKTOR"
PRINT "    %%%%%%%%%%%%%%%%%%%%%%%%%%%"
PRINT : PRINT
PRINT "    MENENTUKAN TEBAL SHELL"
PRINT
PI = 1.1 * 1.4 * 101300 / 1000000!
DI = DS * 1000
PRINT "    BAHAN REAKTOR  stainlessteel AISI 316"
PRINT "    pada T MAX  f = 120 N/mm2"
F = 120
JE = .85
PRINT "    JOINT EFFICIENCY                    ="; JE
CA = 2
PRINT "    CORROSION ALLOWANCE                 ="; CA; "mm"
TS = (PI * DI / (2 * JE * F - PI) + CA) / 25.4
PRINT "    TEBAL SHELL MINIMUM                 ="; TS; "INC"
PRINT "    diambil tebal plate standard 3/16 in "
PRINT
PRINT "    MENENTUKAN TEBAL HEAD"
PRINT
PRINT "    JENIS TORISPERICAL DISHED HEAD"
TH = (PI * DI / (2 * JE * F - .2 * PI) + CA) / 25.4
PRINT "    TEBAL HEAD MINIMUM                  ="; TH; "INC"
PRINT "    diambil tebal plate standard 3/16 in"
TH = 15 / 16 * 2.54 / 100
PRINT "    BERDASAR TABEL 5-11 BROWNELL AND YOUNG DIAMBIL sf=1,5 IN"
SF = 1.5 * 2.54 / 100
ODHEAD = DS + 2 * TH
```

```
PRINT "    DIAMETER LUAR HEAD                    ="; ODHEAD; "m"
DISH = DS / 4
PRINT "    INSIDE DEPT OF DISH                   ="; DISH; "m"
HH = DISH + SF + TH
PRINT "    TINGGI TOTAL HEAD                     ="; HH; "m"
PRINT "    TINGGI TOTAL REAKTOR TERMASUK HEAD    ="; Z + 2 * HH; "m"
VH = .000076 * (DS * 100 / 2.54) ^ 3 * .02832
PRINT "    VOLUME HEAD                           ="; VH; "m3"
PRINT : PRINT
SLEEP
PRINT : PRINT
PRINT "    TEBAL PENYANGGA KATALISATOR"
PRINT
BEBAN = WKAT * 9.81 / (AT * Nt)
PRINT "    BEBAN PENYANGGA KRN KATALIS      ="; BEBAN; "N/m2"
BEBAN = BEBAN + 15 * 101300
BEBAN = BEBAN / 1000000!
PRINT "    BEBAN TOTAL PENYANGGA KATALIS    ="; BEBAN; "N/mm2"
TPK = (BEBAN * 1.1 * ID * 1000 / Nt / (4 * F) + CA) / 25.4
PRINT "    TEBAL PENYANGGA KATALISATOR MIN  ="; TPK; "INC"
PRINT "    diambil tebal plate standard 3/16 in"
PRINT : PRINT
PRINT
SLEEP
PRINT
PRINT "    TEBAL PENYANGGA PIPA"
PRINT "    berat pipa  = 2.17 lb/ft ( PERRY,1984)"
BB1 = WKAT * 9.81 / (3.14159 * DS ^ 2 / 4)
```

```
BB2 = PTO * 101300

BB3 = 2.17 * .4355 / .3048 * Z * 9.81 * Nt/ (3.14159 * DS ^ 2 / 4)

PRINT "    BEBAN KARENA KATALIS               ="; BB1; "N/m2"

PRINT "    BEBAN KARENA TEKANAN               ="; BB2; "N/m2"

PRINT "    BEBAN KARENA PIPA                  ="; BB3; "N/m2"

BB = (BB1 + BB2 + BB3) / 1000000!

TPP = (BB * DI * 1.1 / (4 * F) + CA) / 25.4

PRINT "    TEBAL PENYANGGA PIPA MINIMUM      ="; TPP; "INCH"

PRINT "    diambil tebal plate standard 4/16 in"

PRINT : PRINT

SLEEP

PRINT "     PIPA PEMASUKAN DAN PENGELUARAN"

PRINT

AT1 = MASSA / 3600 / 30 / RHOG1

DOPT = (282 * (MASSA / 3600) ^ .52 * RHOG ^ -.37) / 25.4

PRINT " DIAMETER PIPA PEMASUKAN TERHITUNG    ="; DOPT; "INCH"

DOPT = (282 * (MASSA / 3600) ^ .52 * RHOG ^ -.37) / 25.4

PRINT " DIAMETER PIPA PENGELUARAN TERHIT     ="; DOPT; "INCH"

DOPT = (282 * (MC / 3600) ^ .52 * RHOC ^ -.37) / 25.4

PRINT "     DIAMETER PIPA COOLER TERHITUNG ="; DOPT; "INCH"

BS = .75 * DS

PRINT "     BAFFLE SEGMENTAL                    ="; BS; "m"

MH = 25 * 2.54 / 100

PRINT "     MANHOLE                             ="; MH; "m"

SLEEP

PRINT

PRINT "     TEBAL ISOLASI DAN HEATLOST"

PRINT "     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%"
```

```
PRINT
'PERHITUNGAN TEBAL ISOLASI SHELL
PRINT "   BAHAN ISOLASI MAGNESIA "
KSS = .05: TS = TH
TI = TCOUT
E = .95
THO = 5.67E-08
KL = 25.8 * 1.7073
DELTP = 2
TU = 305
PRINT "  SUHU UDARA LUAR                    ="; TU; "K"
PRINT : PRINT
PRINT                                                                      "
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%"
PRINT "         %  TP     %   HC    %  Hr    %  Q/A  %  TIP  %   XSS,m
% "
PRINT                                                                      "
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%"
MEA$ = "            % ###    % ##.###  % ##.###  % ####.#  % ###.##%
#.#####  %"
TP = 328
Hr = (E * THO * (TP ^ 4 - TU ^ 4)) / (TP - TU)
HC = .73 * (TP - TU) ^ .33
Q = (Hr + HC) * (TP - TU)
TIP = TI - (Q * TS / KL)
XIS = KSS * (TIP - TP) / Q
PRINT USING MEA$; TP; HC; Hr; Q; TIP; XIS
```

```
PRINT                                                              "
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%"
PRINT
SLEEP
PRINT
XIS = 2.54 * 3 / 100: TIP = 679.26: TP = 328: X = XIS
QLS = KSS / XIS * (TIP - TP) * 3.14159 * Z * (ODHEAD + 2 * XIS) *
3.6
PRINT : PRINT
PRINT "          TEBAL ISOLASI SHELL DIAMBIL          ="; 3; "IN"
PRINT "          SUHU PERMUKAAN SHELL                 ="; TP; "K"
PRINT "          PANAS HILANG DI SHELL                ="; QLS; "KJ/J"
PRINT : PRINT
D = DS + 2 * (X + TS)
A = 3.14159 * (ODHEAD + 2 * XIS) ^ 2 / 2
QL = 2 * KSS / XIS * (TIP - TP) * A * 3.6
PRINT : PRINT
PRINT "          TOTAL HEAT LOSS DI HEAD             ="; QL; "KJ/J"
PRINT "           TOTAL HEATLOSS                          ="; QL + QLS;
"kJ/J"
PRINT
SLEEP
PRINT
END
RUNGE:
MOL(1) = MOLO(1) - MOLO(3) * X
MOL(3) = MOLO(3) * (1 - X)
MOL(2) = MOLO(2) + MOLO(3) * X
```

```
MOL(4) = MOL0(4) + MOL0(3) * X
MOLT = 0
FOR I = 1 TO N
MOLT = MOLT + MOL(I)
NEXT I
BMR = MASSA / MOLT
P = MOLT / MOLTTL * PT0 - DELP
PA = MOL(3) / MOLT * P
PB = MOL(1) / MOLT * P
PC = MOL(2) / MOLT * P
PD = MOL(4) / MOLT * P
GOSUB CPNAS
GOSUB VISKO
CP = SIGCP / MOLT
GOSUB KONDUK
GOSUB DELHR
HI = K / ID * 6.5 * .027 * (ID * G * 3600 / MIU) ^ .8 * (CP / BMR *
MIU / K) ^ .3333
HIO = HI * ID / OD
' SHELL SIDE
DE = 1.1 / OD * (PT ^ 2 - .917 * OD ^ 2)
RHOC = 680
MIUC = .4
ASHELL = (PT - OD) * DS * .5 * DS / PT
GS = MC / ASHELL
RES = DE * GS / MIUC
KC = .943
```

```
HO = .36 * (KC / DE) * (DE * GS / MIUC) ^ .55 * (CPC * MIUC / KC) ^
.333
UC = HIO * HO / (HIC + HO)
DU = 1 / UC + (.0003) / 3.6
UD = 1 / DU
' KECEPATAN REAKSI
KR = .0892 * EXP(-261.14 / T)
RP1 = KR * PB * PA
RP = RP1 * AT * Nt * RHOB * 1000 / 62.4
R1 = RP / MOLO(3)
TRANSFER = UD * 3.14159 * OD * Nt * (T - TC)
R2 = (-TRANSFER + MOLO(3) * R1 * DELHR1)
R2 = R2 / SIGCP
R3 = UD * 3.14159 * OD * Nt * (T - TC) / (MC * CPC)
RHOG = BMR / 22.14 * P * 273 / (T)
IF X = 0 THEN RHOG1 = RHOG
IF X > .95 THEN RHOG2 = RHOG
DEN = RHOG * 62.4 / 1000
VIS = MIU / 3600 / 3.6
FLUX = G / 3600 / .4535
PAN = DP * 3.208
GC = 32.2
RT = (150 * (1 - E) * VIS / PAN + 1.75 * FLUX) * (1 - E) / E ^ 3 *
FLUX / PAN / DEN / GC
R4 = RT / 14.7
RETURN
CPNAS:
'PERHITUNGAN KAPASITAS PANAS kj/j
```

```
SIGCP = 0
FOR I - 1 TO N
CP = CPA(I) + CPB(I) * T + CPC(I) * T ^ 2 + CPD(I) * T ^ 3
SIGCP = SIGCP + MOL(I) * CP
NEXT I
RETURN
DELHR:
DELHR0 = 34.11
TREF = 298
DELHR1 = 0: DELHR2 = 0
'perhitungan DELHR kj/kmol
DELHR1 = 1000 * DELHR0 + (CPA(2) + CPA(4) - CPA(3) - CPA(1)) * (T -
298)
DELHR1 = DELHR1 + (CPB(2) + CPB(4) - CPB(3) - CPB(1)) / 2 * (T ^ 2 -
298 ^ 2)
DELHR1 = DELHR1 + (CPC(2) + CPC(4) - CPC(3) - CPC(1)) / 3 * (T ^ 3 -
298 ^ 3)
DELHR1 = DELHR1 + (CPD(2) + CPD(4) - CPD(3) - CPD(1)) / 4 * (T ^ 4 -
298 ^ 4)
RETURN
KONDUK:
'KONDUKTIVITAS GAS ( KJ / M.JAM)
K = 4.18 / 1.163 * MIU / 3.6 * (CP / BMR + 10.4 / BMR)
RETURN
VISKO:
' PERHITUNGAN VISKOSITAS GAS ( kg/m.j)
MIU = 0
FOR I = 1 TO N
```

```
TR = T / TCRIT(I)

EPSI = TCRIT(I) ^ (1 / 6) * BM(I) ^ -.5 * PCRIT(I) ^ (-2 / 3)

MIUL = 4.61 * TR ^ .618 - 2.04 * EXP(-.449 * TR) + 1.94 * EXP(-4.058

* TR) + .1

MIUL = MIUL / EPSI

MIUL = MIUL * .0001 * 3.61

MIU = MIU + MASSA(I) / MASSA / MIUL

NEXT I

MIU = 1 / MIU

RETURN
```

Output Program

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  PERANCANGAN REAKTOR MULTITUBE 01 %
%       PABRIK METHYL CHLORIDE        %
%         KAP. 40.000 TON/TH          %
%                                     %
%                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

KETERANGAN:
1. HCL    2. CH3CL    3. CH3OH    4. H2O
PENDINGIN ADALAH DOWTERM A CAIR PADA 5 ATM
 TOTAL MASSA MASUK              = 14739.78 KG/J
 DATA KATALISATOR
 JENIS KATALIS                        = ALUMINA GEL
 DIAMETER BUTIR                       = .002 m
 TRUE DENSITY KATALIS                 = 3984 KG/M3
 BULK DENSITY                         = 2454.144 kg/m3
 POROSITY                             = .384
 BENTUK                               =  BOLA
  KONDISI REAKTOR
  SUHU UMPAN MASUK                     = 623 K
  SUHU PENDINGIN MASUK                 = 583 K
  TEKANAN UMPAN REAKTOR                = 1.3 atm
  JUMLAH PENDINGIN DIGUNAKAN           = 7000 Kg/J
  INCREMENT PANJANG  DIGUNAKAN         = .01 m
  BERHENTI DULU YA........
```

DIGUNAKAN PIPA NS = 4   OD=4.5 IN DAN ID = 4.026 IN

bahan STAINLESTEEL AISI 316

DIAMETER DALAM TUBE = .1022604 m

DIAMETER LUAR TUBE = .1143 m

JUMLAH TUBE DIPAKAI = 450 TUBE

LUAS AREA ALIR = 3.695873 m2

REYNOLD NUMBER = 119.5325

TRIANGULAR PITCH = .142875 m

DIAMETER SHELL TERHITUNG = 3.375705 m

digunakan diameter shell = 3.4 M

D PARTIKEL / D TUBE = 1.955791E-02

FAKTOR KOREKSI HIO = 6.5

TEKANAN PARSIAL HCL MASUK = .2315899 atm

TEKANAN PARSIAL CH3CL MASUK = .0413284 atm

TEKANAN PARSIAL CH3OH MASUK = .2395884 atm

TEKANAN PARSIAL H2O MASUK = .8274934 atm

+

---

tekanan total umpan = 1.34 atm

HASIL PERHITUNGAN BED KATALIS

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%

%%%%%%

% Z, m % KONV,x %T BED,K % t PEND,K % P,atm % RE %

rA,KMOL/J/KGKAT %

0.000	0.0000	623.00	583.00	1.340	119.5	0.0029864
0.500	0.6849	664.28	609.28	1.338	112.7	0.0002972
1.000	0.8071	659.49	627.51	1.335	113.5	0.0001035
1.500	0.8578	655.11	637.59	1.333	114.1	0.0000520
2.000	0.8855	652.74	643.08	1.330	114.5	0.0000311
2.500	0.9029	651.88	645.89	1.328	114.7	0.0000207
3.000	0.9149	652.54	646.55	1.325	114.6	0.0000147
3.500	0.9236	653.02	647.03	1.323	114.5	0.0000109
4.000	0.9301	653.38	647.40	1.320	114.4	0.0000084
4.500	0.9353	653.67	647.68	1.318	114.4	0.0000067
5.000	0.9394	653.88	647.92	1.315	114.3	0.0000054
5.500	0.9428	654.08	648.09	1.313	114.3	0.0000045

```
%   6.000 % 0.9456 % 654.23 % 648.25   %  1.310 % 114.3 %  0.0000037
%
%   6.500 % 0.9479 % 654.37 % 648.37   %  1.308 % 114.3 %  0.0000032
%
%   7.000 % 0.9500 % 654.46 % 648.49   %  1.305 % 114.3 %  0.0000027
%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

                    NERACA MASSA  HASIL REAKTOR
                    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%

   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   %   SENY   %  MASUK, KGMOL/J  % KELUAR, KGMOL/J %  KEL.KG/J  %
   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   %   1      %     103.123749 %     1.7699482 %        64.60 %
   %   2      %      18.402956 %   119.7567596 %      6047.72 %
   %   3      %     106.685341 %     5.3315401 %       170.61 %
   %   4      %     368.471222 %   469.8250122 %      8456.85 %
   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


  TEKANAN PARSIAL HCL KELUAR      - 1.166055E-02 atm
  TEKANAN PARSIAL CH3CL KELUAR    = .2619185 atm
  TEKANAN PARSIAL CH3OH KELUAR    = 3.871032E-03 atm
  TEKANAN PARSIAL H2O  KELUAR     = 1.027548 atm
 _______________________________________________ +
  TEKANAN TOTAL  KELUAR           = 1.304999 atm
```

TOTAL MASSA KELUAR	- 14739.78 KG/J
SUHU HASIL KELUAR	= 654.4678 K
KONVERSI KELUAR	= .9500256
SUHU PENDINGIN MASUK	- 583 K
SUHU PENDINGIN KELUAR	- 648.4951 K
TEKANAN KELUAR REAKTOR	= 1.304999 atm
PRESSURE DROP DI TUBE	= 3.500158E-02 atm
TINGGI TUMPUKAN KATALIS	= 7.020066 m
SUHU MAXIMUM	= 664.3224 K
SUHU MINIMUM	= 623 K
SUHU PENDINGIN RERATA	= 614.8761 K
REYNOLD DI SHELL	= 1228.614
BAFFLE SPACING	- 1.7 m
UD RATA-RATA	- 49.93139 KJ/m2.j.K

FIG 12.30 (COULSON,1989) Jf = 0.09

PRESSURE DROP DI SHELL = 6.394926E-07 atm

pressure drop di shell acceptable

TOTAL KATALISATOR DIPERLUKAN = 63673.42 kg

MECHANICAL DESIGN REAKTOR

%%%%%%%%%%%%%%%%%%%%%%%%%%

MENENTUKAN TEBAL SHELL

BAHAN REAKTOR stainlessteel AISI 316

pada T MAX f = 120 N/mm2

JOINT EFFICIENCY = .85

CORROSION ALLOWANCE = 2 mm

TEBAL SHELL MINIMUM = .181182 INC

diambil tebal plate standard 3/16 in

MENENTUKAN TEBAL HEAD

JENIS TORISPERICAL DISHED HEAD

TEBAL HEAD MINIMUM = .1811193 INC

diambil tebal plate standard 3/16 in

BERDASAR TABEL 5-11 BROWNELL AND YOUNG DIAMBIL sf=1,5 IN

DIAMETER LUAR HEAD = 3.447625 m

INSIDE DEPT OF DISH = .85 m

TINGGI TOTAL HEAD = .9119125 m

TINGGI TOTAL REAKTOR TERMASUK HEAD = 8.843891 m

VOLUME HEAD = 5.162291 m3

TEBAL PENYANGGA KATALISATOR

BEBAN PENYANGGA KRN KATALIS = 169009.2 N/m2

BEBAN TOTAL PENYANGGA KATALIS = 1.688509 N/mm2

TEBAL PENYANGGA KATALISATOR MIN = 7.877478E-02 INC

diambil tebal plate standard 3/16 in

TEBAL PENYANGGA PIPA

berat pipa = 2.17 lb/ft (PERRY,1984)

BEBAN KARENA KATALIS = 68798.63 N/m2

BEBAN KARENA TEKANAN = 135742 N/m2

BEBAN KARENA PIPA = 10582.99 N/m2

TEBAL PENYANGGA PIPA MINIMUM = .1447312 INCH

diambil tebal plate standard 4/16 in

PIPA PEMASUKAN DAN PENGELUARAN

DIAMETER PIPA PEMASUKAN TERHITUNG = 27.78916 INCH

DIAMETER PIPA PENGELUARAN TERHIT = 27.78916 INCH

DIAMETER PIPA COOLER TERHITUNG = 1.404626 INCH

BAFFLE SEGMENTAL = 2.55 m

MANHOLE = .635 m

TEBAL ISOLASI DAN HEATLOST

%%%%%%%%%%%%%%%%%%%%%%%%%%%

BAHAN ISOLASI MAGNESIA

SUHU UDARA LUAR = 305 K

TP	HC	Hr	Q/A	TIP	XSS,m
328	2.054	6.840	204.6	648.38	0.07831

TEBAL ISOLASI SHELL DIAMBIL	= 3 IN
SUHU PERMUKAAN SHELL	= 328 K
PANAS HILANG DI SHELL	= 65878.31 KJ/J
TOTAL HEAT LOSS DI HEAD	= 33783.67 KJ/J
TOTAL HEATLOSS	= 99661.98 kj/j