APPENDIKS B
PERHITUNGAN NERACA PANAS

A. Perhitungan Kebutuhan Bahan Baku Secara Teori

Kapasitas direncanakan = 100000 ton/tahun

$$= 100000 \frac{\text{ton}}{\text{tahun}} \times \frac{1 \text{ tahun}}{330 \text{ hari}} \times \frac{1 \text{ hari}}{24 \text{ jam}}$$

= 12,626 ton/jam

= 12626,263 kg/jam

Jumlah hari kerja = 1 tahun = 330 hari

Jumlah waktu kerja per hari = 1 hari = 24 jam

Basis = 10212,918 kg/jam CaO

Kapasitas Panas

Komponen	**form**	Cp	**a**	**b**	**c**	**d**
CaO	2	kal/gmol K	10,000	0,0048	-108000	0
SiO_2	2	kal/gmol K	10,870	0,0087	-241200	0
MgO	2	kal/gmol K	10,860	0,0012	-208700	0
C	2	kal/gmol K	2,673	0,0026	-116900	0
S	2	kal/gmol K	3,630	0,0064	0	0
Al_2O_3	2	kal/gmol K	22,080	0,0090	-522500	0
Fe_2O_3	2	kal/gmol K	24,720	0,0160	-423400	0
P	2	kal/gmol K	5,500	0,0000	0	0
$Ca(OH)_2$	2	kal/gmol K	21,4	0,0000	0	0
$H_2O_{(l)}$	1	J/gmol K	18,2964	0,4721	-0,0013	1,314E-06
$H_2O_{(g)}$	1	J/gmol C	33,46	0,0069	7,6E-06	-3,593E-09
Udara	1	J/gmol K	28,09	0,00197	4,8E-06	-1,965E-09

Panas Pembentukan

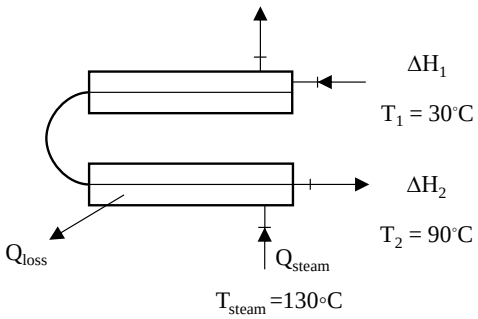
Komponen	**BM kg/kmol**	**∆Hf kJ/gmol**
CaO	56,08	-635,6
$H_2O_{(l)}$	18,02	-285,84
$Ca(OH)_2$	74,10	-986,56

(Perry, J. H., 8th edition Tabel 2.194; $Cp = a + bT + cT^{-2}$)

(D. M.,7th Edition. App.E: $Cp_1 = a + bT + cT^2 + dT^3$, $Cp_2 = a + bT + cT^{-2}$)

1. Heater Air Proses (E-116)

Fungsi : Menaikkan suhu air sebelum masuk reaktor dari 30 C sampai 90 °C



Neraca Panas Total : ΔH_1 + Q steam = ΔH_2 + Q loss

Keterangan :

ΔH_1 = panas air proses masuk

ΔH_2 = panas air proses keluar

Q_{steam} = panas steam

Q_{loss} = panas yang hilang

Data

Suhu referensi = 25 °C = 298,15 K

Suhu H_2O masuk = 30 °C = 303,15 K

Suhu H_2O keluar = 90 °C = 363,15 K

Suhu steam = 130 °C = 403,15 K

Menghitung Panas Air Masuk (ΔH_1)

Komponen	**BM kg/kmol**	**massa kg/jam**	**$\int CpdT$ kkal/kmol**	**ΔH_1 kkal/jam**
$H_2O_{(l)}$	18,02	6215,507	89,4151	30841,286

Menghitung Panas Steam

λs = 2173,600 kJ/kg *(Van Ness 8th edition, Tabel E.1 hal 686)*

= 2173,600 × 0,239

= 519,490 kkal/kg

Q_{steam} = m × λs

= m × 519,490

= 519,490 m kkal/kg

Menghitung Panas Air Keluar (ΔH_2)

Komponen	BM kg/kmol	massa kg/jam	$\int CpdT$ kkal/kmol	$\Delta H2$ kkal/jam
$H_2O_{(l)}$	18,02	6215,507	1171,1846	403968,181

Menghitung Panas yang hilang

Q_{loss} = 5% × panas masuk
= 5% × (ΔH_1 + Q_{steam})
= 5% × (30841,286 + 519,4904 m)
= 1542,0643 + 25,975 m

Neraca Panas Total

ΔH_1 + Q_{steam} = ΔH_2 + Q_{loss}
30841,286 + 519,490 m = 403968,181 + 1542,064 + 25,975 m
493,51588 m = 374668,959
m = 759,183 kg/jam

Maka massa steam yang dibutuhkan adala 759,183 kg/jam

Menghitung panas steam yang dibutuhkan

Q_{steam} = 519,490 × m
= 519,490 × 759,183
= 394388,378 kkal/jam

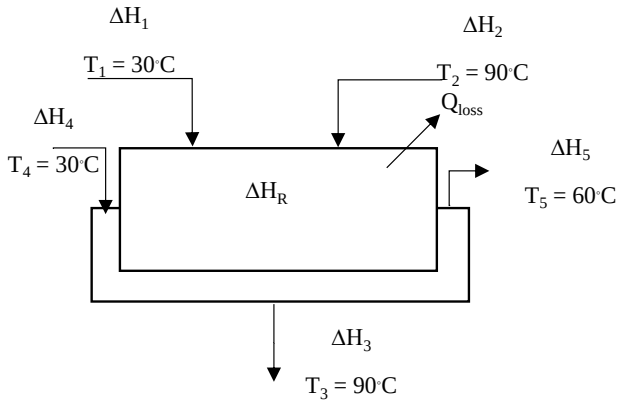
Menghitung panas yang hilang

Q_{loss} = 1542,064 + 25,975 m
= 1542,064 + 19719,419
= 21261,483 kkal/jam

Neraca Panas pada Heater H_2O			
Masuk (kkal/jam)		**Keluar (kkal/jam)**	
ΔH_1	30841,286	ΔH_2	403968,181
Q_{steam}	394388,378	Q_{loss}	21261,483
Total	**425229,664**	**Total**	**425229,664**

2. Reaktor (R-110)

Fungsi Mereaksikan CaO dengan air



Neraca panas total

$\Delta H_1 + \Delta H_2 + \Delta H_R + \Delta H_4 = \Delta H_3 + \Delta H_5 + Q_{loss}$

$\Delta H_1 + \Delta H_2 + \Delta H_R = \Delta H_3 + \Delta H_5 - \Delta H_4 + Q_{loss}$

$\Delta H_1 + \Delta H_3 + \Delta H_R = \Delta H_3 + Q_{serap} + Q_{loss}$

Keterangan:

ΔH_1 = panas bahan masuk

ΔH_2 = panas air proses masuk

ΔH_3 = panas bahan keluar

ΔH_R = panas reaksi

ΔH_4 = panas air pendingin masuk

ΔH_5 = panas air pendingin yang keluar

Q_{loss} = panas yang hilang

Data

Suhu referensi	=	25	°C =	298,15	K
Suhu Bahan masuk	=	30	°C =	303,15	K
Suhu Bahan keluar	=	90	°C =	363,15	K
Suhu air pendingin masuk	=	30	°C =	303,15	K
Suhu air pendingin keluar	=	60	°C =	333,15	K

Menghitung Panas Bahan Masuk (ΔH_1)

Komponen	**BM kg/kmol**	**massa kg/jam**	**$\int CpdT$ kkal/kmol**	**ΔH_1 kkal/jam**
CaO	56,08	9671,633	51,3012326	8847,480232
SiO_2	60,08	66,384	54,1032699	59,78011871
MgO	40,3	153,194	44,5542273	169,3655028
C	12,01	30,639	10,8321651	27,63397388

S	32,07	5,106	27,7708	4,421903512
Al_2O_3	101,94	91,916	94,9812588	85,64176871
Fe_2O_3	159,69	91,916	124,289888	71,54024291
P	30,98	102,129	27,5	90,65695067
Jumlah				9356,520693

Menghitung Panas Bahan keluar ($\Delta\overline{H_2}$)

Komponen	**BM kg/kmol**	**massa kg/jam**	**$\int CpdT$ kkal/kmol**	**ΔH_2 kkal/jam**
H_2O	18,02	6215,507	1171,1846	403968,181

Menghitung Panas Bahan Masuk (ΔH_3)

Komponen	**BM kg/kmol**	**massa kg/jam**	**$\int CpdT$ kkal/kmol**	**ΔH_3 kkal/jam**
CaO	56,08	386,865	689,1865	4754,321
SiO_2	60,08	66,384	748,9901	827,579
MgO	40,3	153,194	606,3366	2304,888
C	12,01	30,639	159,8112	407,695
S	32,07	5,106	373,5004	59,472
Al_2O_3	101,94	91,916	1314,3328	1185,095
Fe_2O_3	159,69	91,916	1697,3545	976,983
P	30,98	102,129	357,5000	1178,540
$Ca(OH)_2$	74,1	12268,211	1391,0000	230297,999
H_2O	18,02	3232,064	1171,1846	210063,454
Jumlah				452056,026

Menghitung Panas Pembentukan

Reaktan

Komponen	**kmol**	**kJ/gmol**	**kkal/gmol**	**kkal/kmol**	**ΔHf**
CaO	165,563	-635,600	-151,9084	-151908,4	-25150395,75
$H_2O_{(l)}$	165,563	-285,840	-68,31576	-68315,76	-11310555,57
Jumlah					-36460951,32

Produk

$Ca(OH)_2$	165,563	-986,56	-235,78784	-235787,84	-39037719,37

$\Delta H_{rxn} = \Delta Hf_{produk} - \Delta Hf_{reaktan}$

$= -39037719,373 - -36460951,325$

$= -2576768,048$

$\Delta H_R = \Delta H_{produk} - \Delta H_{reaktan} + \Delta H_{rxn}$
$= \Delta H_3 - (\Delta H_1 + \Delta H_2) + \Delta H_{rxn}$
$= 452056,026 - (9356,521 + 403968,181) + -2576768,048$
$\Delta H_R = -2538036,723$ reaksi eksotermik

Menghitung Panas yang Hilang
Qloss = 5% × Panas masuk
$= 5\% \times (\Delta H_1 + \Delta H_2 + \Delta H_R)$
$= 5\% \times 2951361,425$
$= 147568,071$ kkal/jam

Neraca panas total
$\Delta H_1 + \Delta H_2 + \Delta H_R + \Delta H_4 = \Delta H_3 + \Delta H_5 + Q_{loss}$
$\Delta H_1 + \Delta H_2 + \Delta H_R = \Delta H_3 + \Delta H_5 - \Delta H_4 + Q_{loss}$
$\Delta H_1 + \Delta H_3 + \Delta H_R = \Delta H_3 + Q_{serap} + Q_{loss}$
$9356,521 + 403968,18 + 2538036,723 = 452056,03 + Q_{serap} + 147568,071$
$Q_{serap} = 2351737,327$ kkal/jam

Menghitung Panas Air Pendingin Masuk (ΔH_4)

Komponen	**BM**	$\int$**CpdT**	
	kg/kmol	**kkal/kmol**	**kkal/kg**
H_2O	18,02	89,4151	4,962

$Q = m \times \int CpdT$
$= m \times 4,962$
$= 4,962 \quad m$

Menghitung Panas Air Pendingin Masuk (ΔH_5)

Komponen	**BM**	$\int$**CpdT**	
	kg/kmol	**kkal/kmol**	**kkal/kg**
H_2O	18,02	628,4248	34,874

$\Delta H_5 = m \times \int CpdT$
$= m \times 34,874$
$= 34,874 \quad m$

$Q_{serap} = \Delta H_5 - \Delta H_4$
$2351737,327 = 34,874 \quad m - 4,962 \quad m$
$2351737,327 = 29,912 \quad m$
$m = 78622,528$ kg/jam

kebutuhan air pendingin = 78622,53 kg/jam

maka,

ΔH_4 = 4,962 × m
= 390124,201 kkal/jam

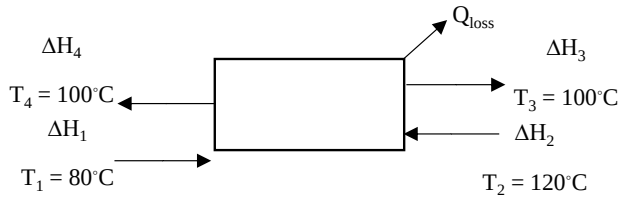
ΔH_5 = 34,874 × m
= 2741861,528 kkal/jam

Q_{serap} = 2351737,327 kkal/jam

Neraca Panas pada Reaktor			
Masuk (kkal/jam)		**Keluar (kkal/jam)**	
ΔH_1	9356,521	ΔH_3	452056,026
ΔH_2	403968,181	Q_{serap}	2351737,327
ΔH_R	2538036,723	Q_{loss}	147568,071
Total	**2951361,425**	**Total**	**2951361,425**

3. Rotary Dryer (B-120)

Mengurangi kadar air yang terkandung dalam produk $Ca(OH)_2$



Neraca Panas Total

$\Delta H_1 + \Delta H_2 = \Delta H_3 + \Delta H_4 + Q_{loss}$

Keterangan:

ΔH_1 = panas bahan masuk rotary dryer

ΔH_2 = panas udara masuk rotary dryer

ΔH_3 = panas bahan keluar rotary dryer

ΔH_4 = panas udara keluar rotary dryer

Q_{loss} = panas yang hilang

Data

Suhu referensi	=	25	°C =	298,15	K
Suhu Bahan masuk	=	80	°C =	353,15	K
Suhu Bahan keluar	=	100	°C =	373,15	K
Suhu udara masuk	=	120	°C =	393,15	K
Suhu udara keluar	=	100	°C =	373,15	K

Menghitung Panas Bahan Masuk (ΔH_1)

Komponen	**BM kg/kmol**	**massa kg/jam**	**$\int CpdT$ kkal/kmol**	**$\Delta H1$ kkal/jam**
CaO	56,08	386,865	493,718	3405,894
SiO2	60,08	66,384	472,097	521,632
MgO	40,3	153,194	488,317	1856,255
C	12,01	30,639	86,023	219,454
S	32,07	5,106	199,826	31,818
Al2O3	101,94	91,916	941,714	849,116
Fe2O3	159,69	91,916	1138,875	655,527
P	30,98	102,129	302,500	997,226
$Ca(OH)_2$	74,1	12268,211	1177,000	194867,537
H2O	18,02	3232,064	989,853	177539,924
Jumlah				380944,383

Menghitung Panas Udara Masuk (ΔH_2)

Komponen	**BM kg/kmol**	**$\int CpdT$**	
		kkal/kmol	**kkal/kg**
Udara	29	664,4275	22,9113

$\Delta H_2 = m \times \int CpdT$

$= m \times 22,911$

$= 22,911 \; m$

Menghitung Panas Bahan Keluar (ΔH_3)

Komponen	**BM kg/kmol**	**massa kg/jam**	**$\int CpdT$ kkal/kmol**	**ΔH_3 kkal/jam**
CaO	56,08	379,128	677,376	4579,388
SiO_2	60,08	65,056	652,977	707,061
MgO	40,3	150,130	673,854	2510,314
C	12,01	30,026	121,767	304,429
S	32,07	5,004	272,490	42,520
Al_2O_3	101,94	90,078	1304,104	1152,354
Fe_2O_3	159,69	90,078	1569,175	885,140
P	30,98	100,087	412,500	1332,657
$Ca(OH)_2$	74,1	12022,847	1605,000	260413,891
H_2O	18,02	99,721	1352,967	7487,163
Jumlah				279414,917

Menghitung Panas Udara Keluar

Komponen	BM kg/kmol	∫CpdT	
		kkal/kmol	kkal/kg
Udara	29	523,7188	18,0593

ΔH_4 Udara = m × ∫CpdT
= m × 18,059
= 18,0593 m

Panas bahan menuju cyclone

Komponen	BM kg/kmol	massa kg/jam	∫CpdT kkal/kmol	ΔH4 kkal/jam
CaO	56,08	7,737	677,376	93,457
SiO_2	60,08	1,328	652,977	14,430
MgO	40,3	3,064	673,854	51,231
C	12,01	0,613	121,767	6,213
S	32,07	0,102	272,490	0,868
Al_2O_3	101,94	1,838	1304,104	23,517
Fe_2O_3	159,69	1,838	1569,175	18,064
P	30,98	2,043	412,500	27,197
$Ca(OH)_2$	74,1	245,364	1605,000	5314,569
H_2O	18,02	3132,343	608,053	105695,408
Jumlah				111244,954

ΔH_4 total = ΔH_4 Bahan Cyclone + ΔH_4 Udara
ΔH_4 total = 111245 + 18,059 m

Panas Yang hilang
Q_{loss} = 5% × panas masuk
= 5% × ($\Delta H_1 + \Delta H_2$)
= 5% × 380944,383 + 22,911 m
= 19047,219 + 1,146 m

Neraca Panas Total
$\Delta H_1 + \Delta H_2 = \Delta H_3 + \Delta H_4 + Q_{loss}$
380944,383 + 22,9 m = 279414,917 + 111244,954 + 18,059 m
+ 19047,219 + 1,146 m
3,706 m = 28762,708
m = 7760,2 kg/jam

Kebutuhan udara untuk rotary dryer adalah = 7760,2 kg/jam

$\Delta H_2 = m \times \int CpdT$

$\Delta H_2 = 22{,}911292 \times m$

$= 22{,}911292 \times 7760{,}1595$

$= 177795{,}28$ kkal/jam

ΔH_4 total = ΔH_4 Bahan Cyclone + ΔH_4 Udara

ΔH_4 total = $111244{,}95 + 18{,}0593\ m$

$= 111244{,}95 + 140143$

$= 251387{,}77$ kkal/jam

$Q_{loss} = 19047{,}219 + 1{,}14556\ m$

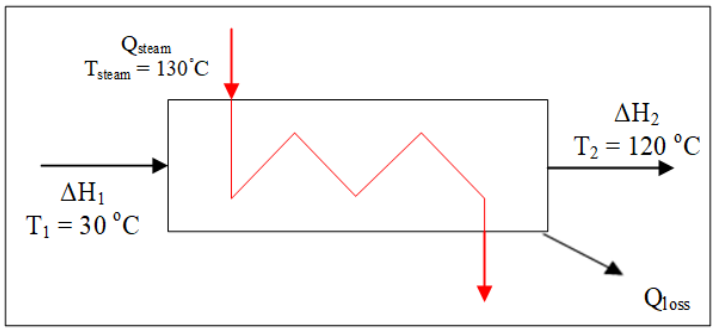
$= 19047{,}219 + 8889{,}7642$

$= 27936{,}983$ kkal/jam

Neraca Panas pada Rotary Dryer (B-120)			
Masuk (kkal/jam)		**Keluar (kkal/jam)**	
ΔH1	380944,383	ΔH3	279414,917
ΔH2	177795,28	ΔH4	251387,77
		Qloss	27936,983
Total	**558739,667**	**Total**	**558739,667**

4. Heater Udara (E-123)

Fungsi : Meningkatkan suhu udara sebelum masuk ke rotary dryer



Neraca Panas Total

$\Delta H_1 + Q_{steam} = \Delta H_2 + Q_{loss}$

Keterangan:

ΔH_1 = panas udara masuk heater

ΔH_2 = panas udara keluar heater

Q_{steam} = panas steam

Q_{loss} = panas yang hilang

Data

Suhu referensi	=	25	°C =	298,15	K
Suhu Steam	=	130	°C =	403,15	K
Suhu udara masuk	=	30	°C =	303,15	K
Suhu udara keluar	=	120	°C =	393,15	K

Menghitung Panas yang terkandung dalam udara masuk (ΔH_1)

Komponen	**BM kg/kmol**	**massa kg/jam**	**$\int CpdT$ kkal/kmol**	**ΔH_1 kkal/jam**
Udara	29	7760,159	34,7281	9292,950

Menghitung Panas Steam (Q_{steam})

λs = 2173,6 kJ/kg *(Van Ness 8th edition, Tabel E.1 hal 686)*

= 2173,6 × 0,239

= 519,4904 kkal/kg

Q_{steam} = m × λs

= m × 519,4904

= 519,490 m kkal/kg

Menghitung panas yang terkandung dalam udara keluar (ΔH_2)

Komponen	**BM kg/kmol**	**massa kg/jam**	**$\int CpdT$ kkal/kmol**	**ΔH_2 kkal/jam**
Udara	29	7760,159	664,427	177795,28

Q_{loss} = panas yang hilang

Q_{loss} = 5% × panas masuk

= 5% × (ΔH_1 + Q_{steam})

= 5% × (9292,950 + 519,490 m)

= 464,647 + 25,975 m

Neraca Panas Total

ΔH_1 + Q_{steam} = ΔH_2 + Q_{loss}

9292,950 + 519,490 m = 177795,28 + 464,647 + 25,975 m

493,516 m = 168966,98

m = 342,37 kg/jam

Q_{steam} = 519,490 m

= 177859,98 kkal/jam

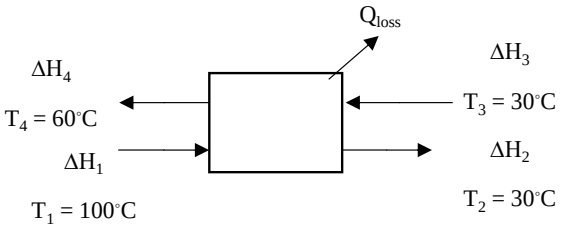
Q_{loss} = 464,647 + 25,975 m

= 9357,647 kkal/jam

Neraca Panas pada Heater Udara			
Masuk (kkal/jam)		Keluar (kkal/jam)	
ΔH1	9292,950	ΔH2	177795,28
Q steam	177859,98	Qloss	9357,647
Total	**187152,93**	**Total**	**187152,93**

5. Cooling Conveyor (J-132)

Fungsi : menurunkan suhu produk $Ca(OH)_2$ dan mengangkut menuju bin produk $Ca(OH)_2$



Neraca Panas = $\Delta H_1 + \Delta H_3 = \Delta H_2 + \Delta H_4 + Q_{loss}$

Keterangan:

ΔH1 = panas bahan masuk
ΔH2 = panas bahan keluar
ΔH3 = panas udara masuk
ΔH4 = panas udara keluar
Qloss = panas yang hilang

Data

Suhu referensi	=	25	°C =	298,15	K
Suhu Bahan masuk	=	100	°C =	373,15	K
Suhu Bahan keluar	=	30	°C =	303,15	K
Suhu udara masuk	=	30	°C =	303,15	K
Suhu udara keluar	=	60	°C =	333,15	K

Menghitung panas bahan masuk (ΔH_1)

Komponen	**BM kg/kmol**	**massa kg/jam**	**$\int CpdT$ kkal/kmol**	**ΔH_1 kkal/jam**
CaO	56,08	379,128	677,376	4579,388
SiO2	60,08	65,056	652,977	707,061
MgO	40,3	150,130	673,854	2510,314
C	12,01	30,026	121,767	304,429
S	32,07	5,004	272,490	42,520
Al2O3	101,94	90,078	1304,104	1152,354

Fe2O3	159,69	90,078	1569,175	885,140
P	30,98	100,087	412,500	1332,657
$Ca(OH)_2$	74,1	12022,847	1605,000	260413,891
H2O	18,02	99,721	608,053	3364,897
Jumlah				275292,651

Menghitung panas bahan keluar (ΔH_2)

Komponen	**BM** **kg/kmol**	**massa** **kg/jam**	**$\int CpdT$** **kkal/kmol**	**ΔH_2** **kkal/jam**
CaO	56,08	379,128	44,038	297,716
SiO2	60,08	65,056	41,029	44,427
MgO	40,3	150,130	42,758	159,286
C	12,01	30,026	6,905	17,262
S	32,07	5,004	18,166	2,835
Al2O3	101,94	90,078	81,518	72,032
Fe2O3	159,69	90,078	100,218	56,531
P	30,98	100,087	27,500	88,844
$Ca(OH)_2$	74,1	12022,847	107,000	17360,926
H2O	18,02	99,721	374,122	2070,346
Jumlah				20170,205

Menghitung panas udara masuk (ΔH_3)

Komponen	**BM** **kg/kmol**	**$\int CpdT$**	
		kkal/kmol	**kkal/kg**
Udara	29	34,7281	1,198

ΔH_3 Udara = m × $\int$CpdT
= m × 1,198
= 1,19752 m

Menghitung panas udara keluar (ΔH_4)

Komponen	**BM** **kg/kmol**	**$\int CpdT$**	
		kkal/kmol	**kkal/kg**
Udara	29	243,6465	8,4016

ΔH_4 Udara = m × $\int$CpdT
= m × 8,4016
= 8,4016 m

Panas Yang hilang

Q loss = 5% × panas masuk
= 5% × (ΔH_1 + ΔH_3)
= 5% × 275292,651 + 8,402 m
= 13764,633 + 8,402 m

Neraca Panas Total

$\Delta H_1 + \Delta H_3 = \Delta H_2 + \Delta H_4 + Q_{loss}$

275292,65 + 1,198 m = 20170,205 + 8,402 m

+ 8 m + 13764,6325

15,606 m = 241357,81

m = 15466,015 kg/jam

Menghitung panas udara masuk (ΔH3)

ΔH3 = panas udara masuk rotary dryer

Udara = m × ∫CpdT

= 15466,015 × 1,198

= 18520,87

Menghitung panas udara masuk (ΔH4)

ΔH4 = panas udara masuk rotary dryer

Udara = m × ∫CpdT

= 15466,015 × 8,4016

= 129939,3417

Panas Yang hilang

Q loss = 13764,6325 + 8,4016 m

= 13764,6325 + 8,4016 × 15466,0151

= 13764,6325 + 129939,34

= 143703,9743

Neraca Panas pada Cooling Conveyor			
Masuk (kkal/jam)		**Keluar (kkal/jam)**	
ΔH_1	275292,651	ΔH_2	20170,205
ΔH_3	18520,870	ΔH_4	129939,342
		Q_{loss}	143703,974
Total	**293813,521**	**Total**	**293813,521**