

BAB 1V

NERACA MASSA DAN NERACA PANAS

4.1. Neraca Massa

a) Perhitungan Neraca Massa

Kapasitas pabrik per tahun = 16.000 ton/tahun

Waktu operasi satu tahun = 330 hari

Kapasitas pabrik per jam = $16.000 \frac{\text{ton}}{\text{tahun}} \times \frac{1.000 \text{ kg}}{1 \text{ ton}} \times \frac{1 \text{ tahun}}{330 \text{ hari}} \times \frac{1 \text{ hari}}{24 \text{ jam}}$
= 2020,2020 kg/jam

Kadar H₃BO₃ dipasaran = min 99,5% (Nippon Denko Co., Ltd., 2018)

Massa MgSO₄·7H₂O = $\frac{99,5}{100} \times 2020,2020 \text{ kg}$ = 2010,1010 kg/jam

Impuritas = $\frac{0,5}{100} \times 2020,2020 \text{ kg}$ = 10,1010 kg/jam
= 2020,2020 kg/jam

Komposisi umpan masuk :

Na₂B₄O₇·10H₂O = 99,5% berat

CO₂ = 0,2% berat

SO₄ = 0,2% berat

Cl = 0,03% berat

Fe = 0,07% berat

= 100% berat

(Zhengzhou P&B Chemical Ltd., 2018)

H₂SO₄ = 98% berat

Cl = 0,001% berat

NO₃ = 0,0005% berat

Fe = 0,005% berat

Pb = 0,005% berat

H₂O = 1,9885% berat

= 100% berat

(PT Petrokimia Gresik, 2015)

$$\begin{aligned}
 \text{Umpan basis} &= 100 \text{ kmol/jam H}_2\text{SO}_4 + \text{impuritas} = 9649,0449 \text{ kg/jam} \\
 \text{Produk basis} &= 23.739,3617 \quad \text{kg/jam} \\
 \text{Produk sebenarnya} &= 2.020,2020 \quad \text{kg/jam} \\
 \text{Faktor koreksi} &= \frac{\text{produksebenarnya}}{\text{produkbasis}} \\
 &= \frac{2020,2020}{23739,3617} = 0,0851
 \end{aligned}$$

Komposisi umpan masuk :

Komposisi umpan $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$

$$\begin{aligned}
 \text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O} &= \text{massa} \times \text{faktor koreksi} \\
 &= 38.332,5744 \times 0,0851 = 3.262,0736 \text{ kg/jam} \\
 \text{CO}_2 &= \text{massa} \times \text{faktor koreksi} \\
 &= 8,8916 \times 0,0851 = 0,7576 \text{ kg/jam} \\
 \text{SO}_4 &= \text{massa} \times \text{faktor koreksi} \\
 &= 19,4076 \times 0,0851 = 1,6516 \text{ kg/jam} \\
 \text{Cl} &= \text{massa} \times \text{faktor koreksi} \\
 &= 1,0758 \times 0,0851 = 0,0916 \text{ kg/jam} \\
 \text{Fe} &= \text{massa} \times \text{faktor koreksi} \\
 &= 3,9599 \times 0,0851 = 0,3370 \text{ kg/jam} \\
 &= 3.264,9103 \text{ kg/jam}
 \end{aligned}$$

Komposisi umpan H_2O Pelarut

$$\begin{aligned}
 \text{H}_2\text{O} &= \text{massa} \times \text{faktor koreksi} \\
 &= 9.053,8330 \times 0,0851 = 770,4745 \text{ kg/jam}
 \end{aligned}$$

Komposisi umpan H_2SO_4

$$\begin{aligned}
 \text{H}_2\text{SO}_4 &= \text{massa} \times \text{faktor koreksi} \\
 &= 9.611,84 \times 0,0851 = 817,9604 \text{ kg/jam} \\
 \text{Cl} &= \text{massa} \times \text{faktor koreksi} \\
 &= 0,0355 \times 0,0851 = 0,003 \text{ kg/jam} \\
 \text{NO}_3 &= \text{massa} \times \text{faktor koreksi} \\
 &= 0,0310 \times 0,0851 = 0,0026 \text{ kg/jam}
 \end{aligned}$$

Fe	= massa x faktor koreksi		
	= 0,28 x 0,0851	= 0,0238	kg/jam
Pb	= massa x faktor koreksi		
	= 1,035 x 0,0851	= 0,0881	kg/jam
H ₂ O	= massa x faktor koreksi		
	= 35,8234 x 0,0851	= 3,0485	kg/jam
		<hr/>	
		= 821,1265	kg/jam

MIXER

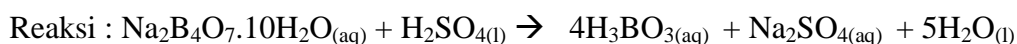
Fungsi : Mencampurkan boraks dengan air.

Tabel 4.1.1. Neraca Massa Mixer

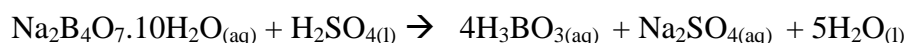
Komponen	Input (kg/jam)		Output (kg/jam)
	Arus 1	Arus 2	Arus 3
Na ₂ B ₄ O ₇ .10H ₂ O	3262,0736	-	3262,0736
CO ₂	0,7567	-	0,7567
SO ₄	1,6516	-	1,6516
Cl	0,0916	-	0,0916
Fe	0,3370	-	0,3370
H ₂ O	-	770,4745	770,4745
Sub Total	3264,9103	770,4745	4035,3848
Total	4035,3848	4035,3848	4035,3848

REAKTOR

Fungsi : Mereaksikan boraks dengan asam sulfat



Konversi = 99% (US Patent No. 4,156,654)



M : 8,5536 kmol 8,3397 kmol

R : 8,2563 kmol 8,2563 kmol 33,0253 kmol 8,2563 kmol 41,2816 kmol

A : 0,2972 kmol 0,0834 kmol 33,0253 kmol 8,2563 kmol 41,2816 kmol

Tabel 4.1.2. Neraca Massa Reaktor

Komponen	Input (kg/jam)		Output (kg/jam)	
	Arus 3	Arus 4	Arus 5	Arus 6
Na ₂ B ₄ O ₇ ·10H ₂ O	3262,0736	-	-	113,3571
H ₂ SO ₄	-	817,9604	-	8,1796
H ₂ O	770,4745	3,0485	-	1517,2235
H ₃ BO ₃	-	-	-	2041,9885
Na ₂ SO ₄	-	-	-	1172,7291
SO ₄	1,6516	-	-	1,6516
Fe	0,3370	0,0238	-	0,3608
Pb	-	0,0881	-	0,0881
CO ₂	0,7567	-	0,7567	-
NO ₃	-	0,0026	0,0026	-
Cl	0,0916	0,0030	0,0946	-
Sub Total	4035,3848	821,1265	0,8539	4855,5782
Total	4856,4321		4856,4321	

CENTRIFUGE - 01

Fungsi : Memisahkan kristal Na_2SO_4 dengan larutan H_3BO_3 .

Tabel 4.1.3. Neraca Massa Centrifuge - 01

Komponen	Input (kg/jam)		Output (kg/jam)
	Arus 6	Arus 7	Arus 10
$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	113,3571	-	113,3571
H_2SO_4	8,1796	-	8,1796
H_2O	1517,2235	15,1722	1502,0512
H_3BO_3	2041,9885	-	2041,9885
Na_2SO_4	1172,7291	1172,7291	-
SO_4	1,6516	-	1,6516
Fe	0,3608	0,3608	-
Pb	0,0881	0,0881	-
Sub Total	4855,5782	1188,3502	3667,2280
Total	4855,5782		4855,5782

ROTARY DRYER - 01

Fungsi : Mengeringkan kristal Na_2SO_4 dengan udara panas.

Tabel 4.1.4. Neraca Massa Rotary Dryer - 01

Komponen	Input (kg/jam)	Output (kg/jam)	
	Arus 7	Arus 8	Arus 9
Na_2SO_4	1172,7291	11,7273	1161,0018
H_2O	15,1722	13,6550	1,5172
Fe	0,3608	-	0,3608
Pb	0,0881	-	0,0881
Sub Total	1188,3502	25,3823	1162,9679
Total	1188,3502		1188,3502

CYCLONE - 01

Fungsi : Menangkap padatan Na₂SO₄ yang terikut oleh udara panas.

Tabel 4.1.5. Neraca Massa Cyclone - 01

Komponen	Input (kg/jam)		Output (kg/jam)	
	Arus 8	Arus 16	Arus 17	Arus 17
Na ₂ SO ₄	11,7273	0,1173	11,6100	-
H ₂ O	13,6550	13,6550	-	-
Sub Total	25,3823	13,7723	11,6100	-
Total	25,2823	25,2823		

BELT CONVEYOR - 01

Fungsi : Mendinginkan kristal Na₂SO₄ sampai suhu kamar.

Tabel 4.1.6. Neraca Massa Belt Conveyor - 01

Komponen	Input (kg/jam)		Output (kg/jam)	
	Arus 9	Arus 17	Arus 20	Arus 20
Na ₂ SO ₄	1161,0018	11,6100	1172,6118	-
H ₂ O	1,5172	-	1,5172	-
Fe	0,3608	-	0,3608	-
Pb	0,0881	-	0,0881	-
Sub Total	1162,9679	11,6100	1174,5779	-
Total	1174,5779	1174,5779		

CRYSTALLIZER

Fungsi : Kristalisasi larutan H_3BO_3 menjadi kristal H_3BO_3 .

Tabel 4.1.7. Neraca Massa Crystallizer

Komponen	Input (kg/jam)	Output (kg/jam)
	Arus 10	Arus 11
$Na_2B_4O_7 \cdot 10H_2O$	113,3571	113,3571
H_2SO_4	8,1796	8,1796
H_2O	1502,0512	1502,0512
H_3BO_3 (aq)	2041,9885	1,3804
H_3BO_3 (s)	-	2040,608101
SO_4	1,6516	1,6516
Total	3667,2280	3667,2280

CENTRIFUGE - 02

Fungsi : Memisahkan kristal H_3BO_3 dengan *Mother liquor*.

Tabel 4.1.8. Neraca Massa Centrifuge - 02

Komponen	Input (kg/jam)	Output (kg/jam)	
	Arus 11	Arus 12	Arus 13
$Na_2B_4O_7 \cdot 10H_2O$	113,3571	-	113,3571
H_2SO_4	8,1796	-	8,1796
H_2O	1502,0512	15,0205	1487,0307
H_3BO_3 (aq)	1,3804	-	1,3804
H_3BO_3 (s)	2040,608101	2040,6081	-
SO_4	1,6516	1,6516	-
Sub Total	3667,2280	2057,2802	1609,9478
Total	3667,2280	3667,2280	

ROTARY DRYER - 02

Fungsi : Mengeringkan kristal H_3BO_3 dengan udara panas.

Tabel 4.1.9. Neraca Massa Rotary Dryer - 02

Komponen	Input (kg/jam)	Output (kg/jam)	
	Arus 11	Arus 13	Arus 14
H_3BO_3 (s)	2040,6081	20,4061	2020,2020
H_2O	15,0205	13,5185	1,5021
SO_4	1,6516	0,0165	1,6351
Sub Total	2057,2802	33,9411	2023,3391
Total	2057,2802	2057,2802	

CYCLONE - 02

Fungsi : Menangkap padatan H_3BO_3 yang terikut oleh udara panas.

Tabel 4.1.10. Neraca Massa Cyclone - 02

Komponen	Input (kg/jam)	Output (kg/jam)	
	Arus 14	Arus 18	Arus 19
H_3BO_3 (s)	13,5185	13,5185	-
H_2O	20,4061	0,2041	20,2020
SO_4	0,0165	0,0002	0,0164
Sub Total	33,9411	13,7227	20,2184
Total	33,9411	33,9411	

BELT CONVEYOR - 02

Fungsi : Mendinginkan kristal H_3BO_3 sampai suhu kamar.

Tabel 4.1.11. Neraca Massa Belt Conveyor - 02

Komponen	Input (kg/jam)		Output (kg/jam)
	Arus 15	Arus 19	Arus 21
H_3BO_3 (s)	2020,2020	20,2020	2040,4040
H_2O	1,5021	-	1,5021
SO_4	1,6351	0,0164	1,6514
Sub Total	2023,3391	20,2184	2043,5575
Total	2043,5575		2043,5575

4.2. Neraca Panas

Basis perhitungan : 1 jam operasi

Suhu referensi : 298,15 K

Satuan Panas (energi) : kJ

Satuan Cp : J/mol.K

Tekanan : atm

Kapasitas panas bahan dipengaruhi suhu, $C_p = f(T)$ mengikuti persamaan :

$$C_p = A + BT + CT^2 + DT^3 + ET^4$$

Dalam bentuk integral:

$$\int C_p dT = A(T - 298,15) + \frac{B}{2}(T^2 - 298,15^2) + \frac{C}{3}(T^3 - 298,15^3) + \frac{D}{4}(T^4 - 298,15^4) + \frac{E}{5}(T^5 - 298,15^5)$$

Keterangan:

C_p = Kapasitas panas (J/mol.K)

A,B,C,D,E = Koefisien regresi komponen

Data-data konstanta kapasitas panas masing-masing komponen dalam berbagai wujud:

Tabel 4.2.1. Konstanta Kapasitas Panas

Komponen	A	B	C	D	E
CO ₂ (g)	27,437	4,23E-02	-1,95E-05	3,99E-09	-2,98E-13
H ₂ O (g)	33,933	-8,41E-03	2,99E-05	-1,78E-08	3,69E-12
Cl (l)	8				
NO ₃ (l)	26				
SO ₄ (l)	31,4				
H ₂ O (l)	92,053	-3,99E-02	-2,11E-04	5,34E-07	
H ₂ SO ₄ (l)	26,004	7,03E-01	-1,38E-03	1,03E-06	
Fe (s)	26,748	-1,53E-02	3,84E-05		
H ₃ BO ₃ (s)	21,6				
H ₃ BO ₃ (aq)	75,571	8,63E-02	-1,17E-04		
Na ₂ B ₄ O ₇ .10H ₂ O (s)	147				
Na ₂ SO ₄ (s)	12,202	5,81E-01	-6,06E-04		
Pb (s)	23,167	1,15E-02	-2,04E-06		
CO ₂ (g)	27,437	4,23E-02	-1,95E-05	3,99E-09	-2,98E-13

(Sumber : Yaws, 1999; Himmelblau, 1989)

Tabel 4.2.2. Data Kapasitas Panas Masing-Masing Komponen

Komponen	Cp (J/mol), 298,15	Cp (J/mol), 303,15	Cp (J/mol), 313,15	Cp (J/mol), 373,15	Cp (J/mol), 393,15	Cp (J/mol), 300.7515	Cp (J/mol), 300,15	Cp (J/mol), 323,15	Cp (J/mol), 423,15
CO ₂ (g)	9896	10089	10476	12864	13684	9996	9973	10866	14936
H ₂ O (g)	9974	10142	10479	12513	13196	10061	10041	10816	14227
Cl (l)	2385	2425	2505	2985	3145	2406	2401	2585	3385
NO ₃ (l)	7752	7882	8142	9702	10222	7820	7804	8402	11002
SO ₄ (l)	9362	9519	9833	11717	12345	9444	9425	10147	13287
H ₂ O (l)	24862	25239	25993	30505	32022	25058	25013	26745	34331
H ₂ SO ₄ (l)	28818	29519	30934	39688	42693	29182	29098	32362	47270
Fe (s)	7632	7760	8017	9578	10108	7699	7684	8275	10915
H ₃ BO ₃ (s)	6440	6548	6764	8060	8492	6496	6483	6980	9140
H ₃ BO ₃ (aq)	25334	25788	26699	32180	34008	25570	25516	27611	36746
Na ₂ B ₄ O ₇ .10H ₂ O (s)	43828	44563	46033	54853	57793	44210	44122	47503	62203
Na ₂ SO ₄ (s)	24120	24781	26119	34525	37443	24464	24384	27477	41896
Pb (s)	7404	7536	7801	9415	9961	7472	7457	8068	10788

MIXER

Fungsi : Mencampurkan boraks dengan air.

Tabel 4.2.3. Neraca Panas Mixer

Komponen	Input (kJ/jam)		Output (kJ/jam)
	Arus 1	Arus 2	Arus 3
Na ₂ B ₄ O ₇ ·10H ₂ O	6286,8712	-	3271,1012
CO ₂	3,3095	-	1,7202
SO ₄	2,6993	-	1,4045
Cl	0,1032	-	0,0537
Fe	0,7705	-	0,4007
H ₂ O	-	16144,2738	8402,8871
Panas pelarutan	73163,4957	-	-
Panas yang dikeluarkan			83923,9557
Total	95601,5232		95601,5232

HEATER-01

Fungsi : Memanaskan larutan keluaran mixer sampai suhu 100 °C.

Tabel 4.2.4. Neraca Panas Heater-01

Komponen	Input (kJ/jam)	Output (kJ/jam)
Na ₂ B ₄ O ₇ .10H ₂ O	3271,1012	94303,0680
CO ₂	1,7202	51,0337
SO ₄	1,4045	40,4897
Cl	0,0537	1,5474
Fe	0,4007	11,7091
H ₂ O	8402,8871	241340,5005
Q loss	-	17056,3569
Beban pemanas	341127,1379	-
Total	352804,7054	352804,7054

HEATER-02

Fungsi : Memanaskan H₂SO₄ sampai suhu 100 °C.

Tabel 4.2.5. Neraca Panas Heater-02

Komponen	Input (kJ/jam)	Output (kJ/jam)
H ₂ SO ₄	5851,6351	90653,0729
Cl	0,0034	0,0511
NO ₃	0,0055	0,0830
Fe	0,0545	0,8279
Pb	0,0563	0,8559
H ₂ O	63,8782	954,9142
Q loss	-	4510,2196
Beban pemanas	90204,39152	-
Total	96120,0246	96120,0246

REAKTOR

Fungsi : Mereaksikan boraks dengan asam sulfat.

Tabel 4.2.6. Neraca Panas Reaktor

Komponen	Input (kJ/jam)		Output (kJ/jam)	
	Arus 3	Arus 4	Arus 5	Arus 6
Na ₂ B ₄ O ₇ .10H ₂ O	94303,0680	-	-	3277,0316
H ₂ SO ₄	-	90653,0729	-	906,5307
H ₂ O	241340,5005	954,9142	-	475249,3328
H ₃ BO ₃	-	-	-	226095,3141
Na ₂ SO ₄	-	-	-	85905,1604
SO ₄	40,4897	-	-	40,4897
Fe	11,7091	0,8279	-	12,5370
Pb	-	0,8559	-	0,8559
CO ₂	51,0337	-	51,0337	-
NO ₃	-	0,0830	0,0830	-
Cl	1,5474	0,0511	1,5984	-
Panas reaksi	-	-	-	143,6967
Beban Pendingin	364272,7956	-	-	-
Sub Total	335748,3485	91609,8050	52,7151	791487,2524
Total	791630,9490		791630,9490	

ROTARY DRYER - 01

Fungsi : Mengeringkan kristal Na_2SO_4 dengan udara panas.

Tabel 4.2.7. Neraca Panas Rotary Dryer - 01

Komponen	Input (kJ/jam)		Output (kJ/jam)	
	Arus 7	Arus 8	Arus 9	
Na_2SO_4	85905,1604	1099,9753	108897,5551	
H_2O	4752,4933	9735,3529	603,0152	
Fe	12,5370	-	15,9532	
Pb	0,8559	-	1,0882	
Beban pemanas	29681,8932	-	-	
Sub Total	90671,0467	10835,3282	109517,6118	
Total	120352,94	120352,94		

BELT CONVEYOR - 01

Fungsi : Mendinginkan kristal Na_2SO_4 sampai suhu kamar.

Tabel 4.2.8. Neraca Panas Belt Conveyor - 01

Komponen	Input (kJ/jam)		Output (kJ/jam)	
	Arus 9	Arus 17	Arus 20	Q Lepas
Na_2SO_4	108897,5551	1088,9756	5455,7220	-
H_2O	603,0152	-	31,7914	-
Fe	15,9532	-	0,8250	-
Pb	1,0882	-	0,0563	-
Sub Total	109517,6118	1088,9756	5488,3947	105118,1926
Total	110606,5873	110606,5873		

COOLER

Fungsi : Menurunkan suhu larutan asam borat sampai suhu 50 °C

Tabel 4.2.9. Neraca Panas Cooler

Komponen	Input (kJ/jam)	Output (kJ/jam)
Na ₂ B ₄ O ₇ .10H ₂ O	3277,0316	1092,3439
H ₂ SO ₄	906,5307	295,5867
H ₂ O	470496,8395	156999,6499
H ₃ BO ₃	226095,3141	75189,1636
SO ₄	40,4897	13,4966
Beban Pendingin	-	467225,9650
Sub Total	700816,2057	233590,2407
Total	700816,2057	700816,2057

CRYSTALLIZER

Fungsi : Kristalisasi larutan H₃BO₃ menjadi kristal H₃BO₃.

Tabel 4.2.10. Neraca Panas Crystallizer

Komponen	Input (kJ/jam)	Output (kJ/jam)
	Arus 10	Arus 11
Na ₂ B ₄ O ₇ .10H ₂ O	1092,3439	655,4063
H ₂ SO ₄	295,5867	176,4683
H ₂ O	156999,6499	94298,2500
H ₃ BO ₃ (aq)	75189,1636	30,4753
H ₃ BO ₃ (s)	-	10692,9699
SO ₄	13,4966	8,0979
Panas kristalisasi	746155,4429	-
Beban Pendingin	-	873884,0157
Sub Total	979745,6836	105861,6679
Total	979745,6836	979745,6836

ROTARY DRYER - 02

Fungsi : Meringkakan kristal H_3BO_3 dengan udara panas.

Tabel 4.2.11. Neraca Panas Rotary Dryer - 02

Komponen	Input (kJ/jam)		Output (kJ/jam)	
	Arus 11	Arus 13	Arus 14	
H_3BO_3 (s)	10692,9699	534,6485	52930,2012	
H_2O	942,9825	1905,3949	470,4968	
SO_4	8,0979	0,4049	40,0848	
Beban pemanas	44237,1808	-	-	
Sub Total	11644,0504	2440,4483	53440,7829	
Total	55881,2312		55881,2312	

BELT CONVEYOR - 02

Fungsi : Mendinginkan kristal H_3BO_3 sampai suhu kamar.

Tabel 4.2.12. Neraca Panas Belt Conveyor - 02

Komponen	Input (kJ/jam)		Output (kJ/jam)	
	Arus 15	Arus 19	Arus 21	Q Lepas
H_3BO_3 (s)	52930,2012	529,3020	15003,0554	-
H_2O	470,4968	-	31,4735	-
SO_4	40,0848	0,4008	2,6990	-
Sub Total	53440,7829	529,7029	15037,2280	38933,2578
Total	53970,4858		53970,4858	