BAB 1V
NERACA MASSA DAN NERACA PANAS

4.1. Neraca Massa

a) Perhitungan Neraca Massa

Kapasitas pabrik per tahun = 12.000 ton/tahun

Waktu operasi satun tahun = 330 hari

Kapasitas pabrik per jam $=12.000\,\frac{ton}{tahun}\times\frac{1.000\,kg}{1\,ton}\times\frac{1\,tahun}{330\,hari}\times\frac{1\,hari}{24\,jam}$

= 1515,1515 kg/jam

Kadar H_3BO_3 dipasaran = min 99,5% (Nippon Denko Co., Ltd., 2018)

Massa $MgSO_4.7H_2O$ = $\frac{99,5}{100}$ x 1515,1515 kg = 1507,5757 kg/jam

Impuritas = $\frac{0,5}{100}$x 1515,1515 kg = 7,5757 kg/jam

= 1515,1515 kg/jam

Komposisi umpan masuk :

$Na_2B_4O_7.10H_2O$	= 99,5%	berat
CO_2	= 0,2%	berat
SO_4	= 0,2%	berat
Cl	= 0,03%	berat
Fe	= 0,07%	berat
	= 100%	berat

(Zhengzhou P&B Chemical Ltd., 2018)

H_2SO_4	= 98%	berat
Cl	= 0,001%	berat
NO_3	= 0,0005%	berat
Fe	= 0,005%	berat
Pb	= 0,005%	berat
H_2O	= 1,9885%	berat
	= 100%	berat

(PT Petrokimia Gresik, 2015)

Umpan basis = 100 kmol/jam

Produk Basis = 23976, 7553 kg/jam

Produk Sebenarnya = 1532, 6681 kg/jam

Faktor koreksi $= \frac{\text{produk sebenarnya}}{\text{produk basis}}$

$= \frac{1532,6681}{23976,75531} = 0,0639$

MIXER-01

Fungsi : Mencampurkan boraks dengan air.

Tabel 4.1.1. Neraca Massa Mixer-01

Komponen	**Input (kg/jam)**		**Output (kg/jam)**
	Arus 1	**Arus 2**	**Arus 3**
$Na_2B_4O_7.10H_2O$	2446,5552	-	2446,5552
CO_2	0,5675	-	0,5675
SO_4	1,2387	-	1,2387
Cl	0,0687	-	0,0687
Fe	0,2527	-	0,2527
H_2O	-	577,8558	577,8558
Sub Total	2448,6828	577,8558	3026,5386
Total	**3026,5386**		**3026,5386**

REAKTOR-01

Fungsi : Mereaksikan boraks dengan asam sulfat

Reaksi : $Na_2B_4O_7.10H_2O_{(aq)} + H_2SO_{4(l)} \rightarrow 4H_3BO_{3(aq)} + Na_2SO_{4(aq)} + 5H_2O_{(l)}$

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

$Na_2B_4O_7.10H_2O_{(aq)} + H_2SO_{4(l)} \rightarrow 4H_3BO_{3(aq)} + Na_2SO_{4(aq)} + 5H_2O_{(l)}$

M	: 6,4152 kmol	6,2548 kmol			
R	: 6,1922 kmol	6,1922 kmol	24,7690 kmol	6,1922 kmol	30,9612 kmol
A	: 0,2229 kmol	0,0625 kmol	24,7690 kmol	6,1922 kmol	30,9612 kmol

Tabel 4.1.2. Neraca Massa Reaktor-01

Komponen	Input (kg/jam)		Output (kg/jam)	
	Arus 3	**Arus 4**	**Arus 5**	**Arus 6**
$Na_2B_4O_7.10H_2O$	2446,5552	-	-	85,0178
H_2SO_4	0,0000	613,4703	-	6,1347
H_2O	577,8558	2,2864	-	1137,9176
H_3BO_3	-	-	-	1531,4914
Na_2SO_4	-	-	-	879,5468
SO_4	1,2387	-	-	1,2387
Fe	0,2527	0,0179	-	0,2706
Pb	0,0000	0,0661	-	0,0661
CO_2	0,5675	-	0,5675	-
NO_3	-	0,0020	0,0020	-
Cl	0,0687	0,0023	0,0709	-
Sub Total	3026,5386	615,8449	0,6404	3641,6836
Total	**3642,3835**		**3642,3241**	

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
$Na_2B_4O_7.10H_2O$	1531,4914	-	1531,4914
H_2SO_4	85,0178	-	85,0178
H_2O	879,5468	11,3792	-
H_3BO_3	6,1347	-	6,1347
Na_2SO_4	0,2706	879,5468	-
SO_4	0,0661	0,0661	-
Fe	1,2387	0,2706	1,2387
Pb	0,0661	0,0661	1126,5384
Sub Total	3641,6836	891,26266	2750,4210
Total	3641,6836		3641,6836

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	879,5468	8,7955	870,7513
H_2O	11,3792	10,2413	1,1379
Fe	0,2706	-	0,2706
Pb	0,0661	-	0,0661
Sub Total	891,2627	19,0367	872,2259
Total	891,2627	891,2627	

CYCLONE - 01

Fungsi : Menangkap padatan Na_2SO_4 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**
Na_2SO_4	8,7955	0,0880	8,7075
H_2O	10,2413	10,2413	-
Sub Total	19,0367	10,3292	8,7075
Total	19,0367	19,0367	

BELT CONVEYOR - 01

Fungsi : Mendinginkan kristal Na_2SO_4 sampai suhu kamar.

Tabel 4.1.6. Neraca Massa Cooling Conveyor - 01

Komponen	Input (kg/jam)		Output (kg/jam)
	Arus 9	**Arus 17**	**Arus 20**
Na_2SO_4	870,7513	8,7075	879,4589
H_2O	1,1379	-	1,1379
Fe	0,2706	-	0,2706
Pb	0,0661	-	0,0661
Sub Total	872,2259	8,7075	880,9334
Total	880,9334		880,9334

CRYSTALLIZER-01

Fungsi : Kristalisasi larutan H_3BO_3 menjadi kristal H_3BO_3.

Tabel 4.1.7. Neraca Massa Crystallizer-01

Komponen	Input (kg/jam)	Output (kg/jam)
	Arus 10	Arus 11
$Na_2B_4O_7.10H_2O$	85,0178	85,0178
H_2SO_4	6,1347	6,1347
H_2O	1531,4914	1,0353
H_3BO_3 (aq)	0	1530,4561
H_3BO_3 (s)	1126,5384	1126,5384
SO_4	1,2387	1,2387
Total	2750,4210	2750,4210

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
$Na_2B_4O_7.10H_2O$	85,0178	-	85,0178
H_2SO_4	6,1347	-	6,1347
H_2O	1,0353	11,2654	1115,2730
H_3BO_3 (aq)	1530,4561	1530,4561	-
H_3BO_3 (s)	1126,5384		1,0353
SO_4	1,2387	1,2387	-
Sub Total	2750,4210	1542,9601	1207,4608
Total	2750,4210	2750,4210	

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 12	**Arus 14**	**Arus 15**
H_3BO_3 (s)	1530,4561	15,3046	1515,1515
H_2O	11,2654	10,1388	1,1265
SO_4	1,2387	0,0124	1,2263
Sub Total	1542,9601	25,4558	1517,5043
Total	1542,9601	1542,9601	

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)	10,1388	0,1530	15,1515
H_2O	15,3046	10,1388	-
SO_4	0,0124	0,0001	0,0123
Sub Total	25,4558	10,2920	15,1638
Total	25,4558	25,4558	

BELT CONVEYOR - 02

Fungsi : Mendinginkan kristal H_3BO_3 sampai suhu kamar.

Tabel 4.1.11. Neraca Massa Cooling Conveyor - 02

Komponen	Input (kg/jam)		Output (kg/jam)
	Arus 15	Arus 19	Arus 21
H_3BO_3 (s)	1515,1515	15,1515	1530,3030
H_2O	1,1265	-	1,1265
SO_4	1,2263	0,0123	1,2386
Sub Total	1517,5043	15,1638	1532,6681
Total	1532,6681		

4.2. Neraca Panas

Basis perhitungan : 1 jam operasi

Suhu referensi : 298 K

Satuan Panas (energi) : KJ

Satuan Cp : J/mol K

Tekanan : atm

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

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

Dalam bentuk integral:

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

Keterangan:

Cp = Kapasitas panas (J/kmol 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_2O (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_2O (l)	92,053	-3,99E-02	-2,11E-04	5,34E-07	
H_2SO_4 (l)	26,004	7,03E-01	-1,38E-03	1,03E-06	
Fe (s)	26,748	-1,53E-02	3,84E-05		
H_3BO_3 (s)	21,6				
H_3BO_3 (aq)	75,571	8,63E-02	-1,17E-04		
$Na_2B_4O_7.10H_2O$ (s)	147				
Na_2SO_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), 298,15K	Cp (J/mol), 303,15 K	Cp (J/mol), 313,15 K	Cp (J/mol), 373,15K	Cp (J/mol), 393,15 K	Cp (J/mol), 300,15 K	Cp (J/mol), 323,15 K	Cp (J/mol), 343,15 K	Cp (J/mol), 300,66 K
$Na_2B_4O_7.10H_2O$ (l)	4,3828,E+04	4,4563,E+04	4,6033,E+04	5,4853,E+04	5,7793,E+04	4,4122,E+04	4,7503,E+04	5,0443,E+04	4,4198,E+04
CO_2 (g)	9,8961,E+03	1,0089,E+04	1,0476,E+04	1,2864,E+04	1,3684,E+04	9,9730,E+03	1,0866,E+04	1,1657,E+04	9,9928,E+03
SO_4 (l)	9,3619,E+03	9,5189,E+03	9,8329,E+03	1,1717,E+04	1,2345,E+04	9,4247,E+03	1,0147,E+04	1,0775,E+04	9,4408,E+03
Cl (l)	2,3852,E+03	2,4252,E+03	2,5052,E+03	2,9852,E+03	3,1452,E+03	2,4012,E+03	2,5852,E+03	2,7452,E+03	2,4053,E+03
Fe (s)	7,6324,E+03	7,7605,E+03	8,0172,E+03	9,5783,E+03	1,0108,E+04	7,6836,E+03	8,2747,E+03	8,7927,E+03	7,6968,E+03
H_2O (l)	2,4862,E+04	2,5239,E+04	2,5993,E+04	3,0505,E+04	3,2022,E+04	2,5013,E+04	2,6745,E+04	2,8247,E+04	2,5052,E+04
H_2SO_4 (l)	2,8818,E+04	2,9519,E+04	3,0934,E+04	3,9688,E+04	4,2693,E+04	2,9098,E+04	3,2362,E+04	3,5257,E+04	2,9170,E+04
Pb (s)	7,4037,E+	7,5360,E	7,8014,E+	9,4152,E+	9,9612,E+	7,4565,E+	8,0678,E+	8,6037,E+	7,4701,E+

	03	+03	03	03	03	03	03	03	03
NO_3 (l)	7,7519,E+03	7,8819,E+03	8,1419,E+03	9,7019,E+03	1,0222,E+04	7,8039,E+03	8,4019,E+03	8,9219,E+03	7,8172,E+03
H_3BO_3 (aq)	2,5334,E+04	2,5788,E+04	2,6699,E+04	3,2180,E+04	3,4008,E+04	2,5516,E+04	2,7611,E+04	2,9437,E+04	2,5562,E+04
Na_2SO_4 (s)	2,4120,E+04	2,4781,E+04	2,6119,E+04	3,4525,E+04	3,7443,E+04	2,4384,E+04	2,7477,E+04	3,0248,E+04	2,4452,E+04
H_2O (g)	9,9737,E+03	1,0142,E+04	1,0479,E+04	1,2513,E+04	1,3196,E+04	1,0041,E+04	1,0816,E+04	1,1493,E+04	1,0058,E+04
H_3BO_3 (s)	6,4400,E+03	6,5480,E+03	6,7640,E+03						

MIXER-01

Fungsi : Mencampurkan boraks dengan air.

Tabel 4.2.3. Neraca Panas Mixer-01

Komponen	**Input (kJ/jam)**		**Output (kJ/jam)**
	Arus 1	**Arus 2**	**Arus 3**
$Na_2B_4O_7.10H_2O$	4715,1534	0,0000	2453,6469
CO_2	2,4821	0,0000	1,2903
SO_4	2,0245	0,0000	1,0535
Cl	0,0774	0,0000	0,0403
Fe	0,5779	0,0000	0,3006
H_2O	0,0000	12108,2054	6302,9895
Sub Total	16828,5206		8759,3211
Panas yang dikeluarkan			8069,1995
Total	**16828,5206**		**16828,5206**

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)
$Na_2B_4O_7.10H_2O$	2453,6469	70727,3010
CO_2	1,2903	38,2753
SO_4	1,0535	30,3673
Cl	0,0403	1,1605
Fe	0,3006	8,7818
H_2O	6302,9895	181005,3754
Sub total	8759,3211	251811,2613
Q loss		12792,2074
Beban Pemanas	255844,1476	
TOTAL	264603,4687	264603,4687

HEATER-02

Fungsi : Memanaskan H_2SO_4 sampai suhu 100 °C.

Tabel 4.2.5. Neraca Panas Heater-02

Komponen	Masuk (kJ/jam)	Keluar (kJ/jam)
H_2SO_4	4388,7263	67989,8047
Cl	0,0026	0,0383
NO_3	0,0041	0,0622
Fe	0,0409	0,6210
Pb	0,0422	0,6419
H_2O	47,9086	716,1856
Sub total	4436,7248	68707,3537
Q loss		3382,664682
Beban Pemanas	67653,29364	
Total	72090,0184	72090,0184

REAKTOR-01

Fungsi : Mereaksikan boraks dengan asam sulfat.

Tabel 4.2.6. Neraca Panas Reaktor-01

Komponen	**Masuk (kJ/jam)**		**Keluar (kJ/jam)**	
	Arus 3	Arus 4	Arus 5	Arus 6
$Na_2B_4O_7.10H_2O$	70727,3010	0,0000	0,0000	2457,7737
H_2SO_4	0,0000	67989,8047	0,0000	679,8980
H_2O	181005,3754	716,1856	0,0000	356436,9996
H_3BO_3	0,0000	0,0000	0,0000	169571,4855
Na_2SO_4	0,0000	0,0000	0,0000	64428,8703
SO_4	30,3673	0,0000	0,0000	30,3673
Fe	8,7818	0,6210	0,0000	9,4028
Pb	0,0000	0,6419	0,0000	0,6419
CO_2	38,2753	0,0000	38,2753	0,0000
NO_3	0,0000	0,0622	0,0622	0,0000
Cl	1,1605	0,0383	1,1988	0,0000
Panas reaksi			107,7725117	
Beban pendingin	273204,5967			
Sub Total	251811,2613	68707,3537	39,5364	593615,4393
Total	593723,2118		593723,2118	

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	64448,4927	824,9815	81673,1663
H_2O	3565,4150	7301,5147	452,2614
Fe	9,4056	-	11,9649
Pb	0,6421	-	0,8162
Beban pemanas	22240,7496	-	-
Sub Total	90264,7050	8126,4961	82138,2088
Total	90264,7050	90264,7050	

BELT CONVEYOR - 01

Fungsi : Mendinginkan kristal Na_2SO_4 sampai suhu kamar.

Tabel 4.2.8. Neraca Panas Cooling Conveyor - 01

KOMPONEN	Q MASUK (kJ/jam)		Q KELUAR (kJ/jam)	
	ARUS 9	ARUS 17	ARUS 20	Q LEPAS
Na_2SO_4	81673,1663	816,7317	4091,7915	
H_2O	452,2614		23,8436	
Fe	11,9649		0,6187	
Pb	0,8162		0,0422	
SUB TOTAL	82138,2088	816,7317	4116,2960	78838,6445
TOTAL	82954,9405		82954,9405	

COOLER-01

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

Tabel 4.2.9. Neraca Panas Cooler-01

KOMPONEN	Q MASUK (kJ/jam)	Q KELUAR (kJ/jam)
$Na_2B_4O_7.10H_2O$	2457,7737	819,2579
H_2SO_4	679,8980	221,6900
H_2O	352872,6296	117749,7374
H_3BO_3	169571,4855	56391,8727
SO_4	30,3673	10,1224
SUB TOTAL	525612,1542	175192,6805
BEBAN PENDINGIN		350419,4737
TOTAL	525612,1542	525612,1542

CRYSTALLIZER-01

Fungsi : Kristalisasi larutan H_3BO_3 menjadi kristal H_3BO_3.

Tabel 4.2.10. Neraca Panas Crystallizer-01

KOMPONEN	Q MASUK (kJ/jam)	Q KELUAR (kJ/jam)
$Na_2B_4O_7.10H_2O$	819,2579	491,5547
H_2SO_4	221,6900	132,3512
H_2O	117749,7374	70723,6875
H_3BO_3 (aq)	56391,8727	22,8565
H_3BO_3 (s)	0,0000	8019,7275
SO4	10,1224	6,0735
SUB TOTAL	734809,2627	79396,2509
BEBAN PENDINGIN		655413,0118
TOTAL	734809,2627	734809,2627

ROTARY DRYER - 02

Fungsi : Mengeringkan kristal H_3BO_3 dengan udara panas.

Tabel 4.2.11. Neraca Panas Rotary Dryer - 02

Komponen	Input (kJ/jam)	Output (kJ/jam)	
	Arus 12	Arus 14	Arus 15
H_3BO_3 (s)	8019,7275	400,9864	39697,6509
H_2O	707,2369	1429,0461	352,8726
SO_4	6,0735	0,3037	30,0636
Beban pemanas	33177,8856	-	-
Sub Total	41910,9234	1830,3362	40080,5872
Total	41910,9234	41910,9234	

BELT CONVEYOR - 02

Fungsi : Mendinginkan kristal H_3BO_3 sampai suhu kamar.

Tabel 4.2.12. Neraca Panas Cooling Conveyor - 02

Komponen	Input (kJ/jam)		Output (kJ/jam)	
	Arus 15	Arus 19	Arus 21	Q Lepas
H_3BO_3 (s)	39697,6509	396,9765	11252,2916	
H_2O	352,8726	0,0000	23,6051	
SO_4	30,0636	0,3006	2,0042	
Sub Total	40080,5872	397,2771	11277,9009	158545,2428
Total	40477,8643		40477,8643	