LAMPIRAN I
DATA PENGAMATAN

1. Data Komposisi Bahan Bakar

Jenis Bahan Bakar : *Liquiefied Petroleum Gas*

Komposisi dalam %vol : (ASTM: D-1946)

Tabel. Komposisi Bahan Bakar LPG

Komposisi	**%**
C_2H_6	0.8
C_3H_8	1.2
C_4H_{10}	97.1
C_5H_{12}	0.894
H_2S	0.001
H_2O	0.005
Total	**100**

Sumber: *Pertamina RU-3*,2017

Densitas : 1.49 gr/L

Waktu Operasi : 1 jam = 60 menit

Konsumsi Bahan Bakar : 2.7 Kg/menit

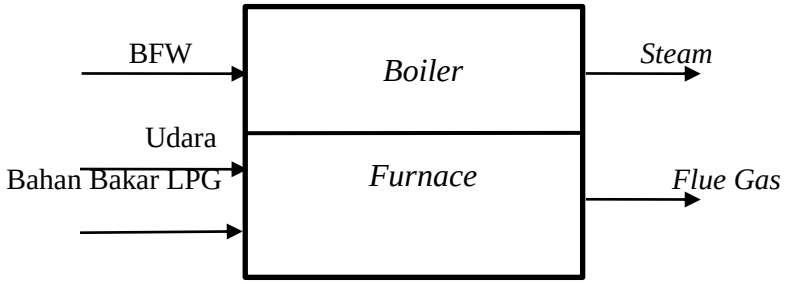
2. Analisa *Dry Flue Gas*

Alat Ukur : Gas *Analyzer*

Tabel. Komposisi *Dry Flue Gas*

Komposisi	**%**
CO_2	13.744
O_2	0.46
N_2	85.796
Total	**100**

LAMPIRAN II
PERHITUNGAN



Gambar. Blog Diagram Neraca Massa

A. Menghitung Neraca Massa

1. Menghitung Berat Molekul Rata - rata pada Bahan Bakar LPG

Basis = 1 Kmol

Flow Bahan Bakar = 2.7 kg/kmol

Tabel. Komponen Bahan Bakar

Komponen	%Vol	Fraksi Mol	BM	Kg
C_2H_6	0.8	0.008	30	0.24
C_3H_8	1.2	0.012	44	0.528
C_4H_{10}	97.1	0.971	58	56.318
C_5H_{12}	0.894	0.00894	72	0.6437
H_2S	0.001	0.00001	34	0.0003
H_2O	0.005	0.00005	18	0.0009
Total	**100**	**1**	**256**	**57.7309**

$$\text{BM Campuran} = \frac{\text{Total Massa}}{\text{Mol}}$$

$$= \frac{57.7309 \quad \text{kg}}{1 \text{ Kmol}}$$

$$= 57.73092 \quad \text{kg/kmol}$$

2. Menghitung mol setiap komponen

$$\text{Kmol Bahan Bakar} = \frac{\text{Kg Bahan Bakar}}{\text{BM Campuran}}$$

$$= \frac{2.7 \text{ kg}}{57.7309 \text{ kg/kmol}}$$

$$= 0.0468 \text{ kmol}$$

$$= 46.7687 \text{ mol}$$

Tabel. Komponen Bahan Bakar

Komponen	%Vol	Mol	BM	gr
C_2H_6	0.8	0.3741	30	11.2245
C_3H_8	1.2	0.5612	44	24.6939
C_4H_{10}	97.1	45.4124	58	2633.9196
C_5H_{12}	0.894	0.4181	72	30.1041
H_2S	0.001	0.0005	34	0.0159
H_2O	0.005	0.0023	18	0.0421
Total	**100**	**46.7687**	**256**	**2700**

3. Menghitung O_2 Teoritis

Reaksi stokiometri pembakaran gas pada ruangbakar

a.Etana

$$\underset{0.3741}{C_2H_6} + \underset{1.3095}{3.5\ O_2} \longrightarrow \underset{0.7483}{2\ CO_2} + \underset{1.1224}{3\ H_2O}$$

b.Propana

$$\underset{0.5612}{C_3H_8} + \underset{2.8061}{5\ O_2} \longrightarrow \underset{1.6837}{3\ CO_2} + \underset{2.2449}{4\ H_2O}$$

c.Butan

$$\underset{45.412}{C_4H_{10}} + \underset{295.1806}{6.5\ O_2} \longrightarrow \underset{181.649}{4\ CO_2} + \underset{227.06}{5\ H_2O}$$

d.Pentana

$$\underset{0.4181}{C_5H_{12}} + \underset{3.344897}{8\ O_2} \longrightarrow \underset{2.0906}{5\ CO_2} + \underset{2.5087}{6\ H_2O}$$

Tabel. Mol dari hasil reaksi stokiometri

Komponen	Mol		
	O_2	**CO_2**	**H_2O**
C_2H_6	1.3095	0.7483	1.1224
C_3H_8	2.8061	1.6837	2.2449
C_4H_{10}	295.1806	181.6496	227.0620
C_5H_{12}	3.3449	2.0906	2.5087
Total	**302.6412**	**186.1722**	**232.9381**

O_2Teoritis = 302.6412 mol

Udara teoritis = $\frac{100}{21}$ x O_2 teoritis

= $\frac{100}{21}$ x 302.6412 mol

= 1441.1485 mol

= 41793.3064 gr

= 41.79331 kg

4. Menghitung komposisi *dry flue gas*

AFR Teoritis = $\frac{\text{massa udara}}{\text{massa bahan bakar}}$

= $\frac{41.7933}{2.7}$

= 15.4790

AFR Aktual = 16:01

Udara Suplai = kg/kg bahan bakar x massa bahan bakar

= 16 x 2.7 kg

= 43.20 kg

= 1.4897 kmol

= 1489.655 mol

O_2 dari udara = 0.21 x udara suplai

= 0.21 x 1489.65 mol

= 312.8276 mol

O_2 sisa keluar stackgas = O_2 dari udara - O_2 teoritis

= 312.827 - 302.641 mol

= 10.1864

N_2 keluar dari stackgas = 0.79 x udara suplai

= 0.79 x 1489.655 mol

= 1176.8276

$$\% \text{ Udara Excess} = \frac{\text{udara suplai - udara teoritis}}{\text{udara suplai}} \times 100\ \%$$

$$= \frac{43.2 - 41.79}{43.2} \times 100\ \%$$

= 0.0326 x 100 %

= 3.2562 %

Tabel. Komposisi *Flue Gas*

Komponen	mol	kg
CO_2 flue gas	186.1722	8.1916
H_2O	232.9381	4.1929
O_2 sisa	10.1864	0.3260
N_2	1176.8276	32.9512
Total	**1606.1242**	**45.6616**

5. Menghitung komposisi *wet flue gas*

T udara bola kering = 50 ^oC

T udara bola basah = 30 ^oC

Humidity = 0.08 mol H_2O/mol udarakering

(sumber: Hougen Hal 100)

H_2Odariudara = H x udarasupla

= 0.08 x 1489.65 mol

= 119.1724 mol

Total H_2O keluar stackgas = H_2Oteori + H_2O dariudara

= 232.9381 + 119.17241 mol

= 352.110

Tabel. Komposisi *Wet Flue Gas*

Komponen	mol	kg
CO_2 flue gas	186.1722	8.1916
H_2O	352.1105	6.3380
O_2 sisa	10.1864	0.3260
N_2	1176.8276	32.9512
Total	**1725.2966**	**47.8067**

Tabel. Neraca Massa pada *Furnace*

Komponen	Input (kg)	Output (kg)
Bahan Bakar	2.7	
O_2	10.01048	0.3260
H_2O	2.1451	4.1929
CO_2		8.1916
N_2	32.9512	32.9512
Total	**45.6616**	**45.6616**

6. Neraca massa seputar *Boiler Furnace*

Tabel. Neraca Massa seputar *Boiler Furnace*

Komponen	Input (kg)	Output (kg)
Bahan Bakar	2.7	
O_2	10.0105	0.3260
H_2O	2.1451	4.1929
N_2	32.9512	32.9512
CO_2		8.1916
BFW	20	
Steam		17
Blowdown		3
Total	**65.6616**	**65.6616**

ANALISA THERMAL SEPUTAR *BOILER FURNACE*

Data :

1	.Temperatur Udara	=	50	^{o}C
2	.Temperatur Bahan Bakar	=	28	^{o}C
3	.Temperatur Air Masuk	=	28	^{o}C
4	.Temperatur *flue gas*	=	10 0	^{o}C
5	.Temperatur *Reference*	=	28	^{o}C
6	.Temperatur dinding *furnace*	=	85	^{o}C
7	.Tekanan *Steam*	=	10	Bar
8	.Temperatur *Steam*	=	189.7	^{o}C

B. Menghitung Neraca Energi

Data Operasi : 1 Jam

T ref = 28 ^{o}C

T udara = 50 ^{o}C

1. Menghitung Entalpi *Liquefied Petroleum Gas*

Tref = 28 ^{o}C

T_{LPG} = 28 ^{o}C

Q_{LPG} = n x Cp (T_{LPG} - Tref)

Maka, Q = 0Kcal

2. Menghitung *Heaving Value* LPG

massa $_{LPG}$ = 2.7 kg

HHV_{LPG} = 11920.799 Kcal/kg

Heaving Value $_{LPG}$ = m_{LPG} x HHV_{LPG}

= 2.7 x 11920.799 Kcal/kg

= 32186.157 Kcal

3. Menghitung Entalpi *Heat* Udara

n udara = 1.489 / 7 kmol

Temperatur referensi = 28 ^{o}C = 301 K

Temperatur udara = 50 ^{o}C = 323 K

Dari tab.17 Hougen hal 255 diperoleh a = 6.386

0
b = 0.002
c = -0.0000002656

Cp = $a + bT + cT^2$ (eq. 21Hougen hal253)

= $a + \frac{b}{2}(T_2 + T_1) + \frac{c}{3}(T_2^2 + T_2 T_1 + T_1^2)$ (eq. 2 Hougen hal 258)

Cp udara = $6.3860 + \frac{0.002}{2} 624\ K + \frac{-0.00000026}{3} 3E{+}05\ K$

= 6.9099 Kcal/kmol.k

Q = n udara x Cp udara (Tudara - Tref)
= 1.4897 kmol x 6.909 kcal/kmol.K
= 10.2933 Kcal

Laten heat H_2O

T = 100 ^oC

maka nilai Hfg = 2257 kj/kg (Moran, Fundamentals of Engineering Thermodynamics)
= 2257 kj/kg x 0.2 kkal/kj
= 542 kcal/kg

Maka *Laten Heat* udara,

Q = m x $H_{fg\ udara}$
= 2.15 kg x 541.7 kcal/kg
= 1161.959 Kcal

4. Menghitung Entalpi *Boiler Feed Water* (BFW)

$T_{air\ masuk}$ = 28 C

hf_{BWF} = 117 Kj/kg
= 27.9Kj/kg

Q = m x $H_{fg\ BFW}$
= 20.00 kg x 27.94 kcal/kg
= 558.8994 Kcal

5. Entalpi *Saturated Steam*

m_{steam} = 17 kg

T_{steam} = 190 C

h_f = 669.43 Kcal/kg

Maka,

Q_{Steam} = m x h_f
= 17 kg x 669.4 Kcal/kg
= 11380.31 Kcal

6. Menghitung entalpi pada *flue gas*

$T_{flue\ gas}$ = 100 ^oC

Cp CO_2 = 9.25 Cal/grmol^oC (Sumber:*Hougen*, hal216)

Q_{CO2} = n Cp (T_2-T_1)
= 186.1722 gmolx 9.2 Cal/grmol C x (100-28)
= 123990.6852 Cal

Cp O_2 = 7.06 Cal/grmol^oC (Sumber:*Hougen*, hal216)

Q_{CO2} = n Cp (T_2-T_1)
= 10.1864 gmolx 7.1 Cal/grmol C x (100-28)
= 5177.950848 Cal

Cp N_2 = 6.67 Cal/grmol^oC (Sumber:*Hougen*, hal216)

Q_{CO2} = n Cp (T_2-T_1)
= 1176.828 gmolx 6.7 Cal/grmol C x (100-28)
= 565159.6866 Cal

Maka,

Total *Fluegas* = CO_2 + Cp O_2 + Cp N_2
= 123990.6852 + 5177.951 + 565159.69 cal
= 694328.3227 cal
= 694.3283227 Kcal

7. Menghitung Entalpi Uap Air dalam *Flue Gas*

Panas laten H_2O dari udara dan reaksi pembakaran LPG

λ pd 100 ^oC = 671 ^oR adalah = 1751 Btu/lb

λ = 970.1 Btu/lb (Moran, Fundamentals of Engineering Thermodynamics)
= 970.1 Btu/lb x (1 Kj/kg / 0,424992 Btu/lb)
= 2282. kj/kg
= 2282. kj/kg x 0.2 kkal/kj
= 547.8 kcal/kg

Entalpi uap air dlm flue gas = massa H_2O dlm flue gas x λ
= 2.145 x 547.8 kcal/kg
= 1175.1431 kcal

8. Entalpi dari *Blowdown*

m *blowdown* = 3
T *blowdown* = 120 ^oC
Maka hf = 503.71 kj/kg
Q*blowdown* = m *blowdown* x 503.71 kj/kg
= 3 x 503.71 kj/kg
= 1511.1 kj
= 1511.1 kj x 0.2 kkal/kj
= 363 kcal

9. Menghitung *Heat Loss* radiasi permukaan *Furnace*

ε = 0.78
σ = 5.67×10^{-8} W/m^2K (Sumber,*Holman*. Hal 351)
A = 2.678 m^2
Ts = 85 ^oC = 358 K
T_{ref} = 28 ^oC = 301 K

$$Q = \varepsilon \cdot \Sigma \cdot A_{boiler} ((Ts^4)/1000 - (Tref^4)/1000)$$

$$= 0.78 \times 5.67 \times 10^{-8} \times 3.372 \times \left[\frac{(358)^4}{1000}\right] - \left[\frac{(301)^4}{1000}\right]$$

= 1.2255 W/1000 (3600)
= 4.4117 Kj/jam x 0.24 Kcal/Kj
= 1.05881 Kcal/jam

10. Menghitung *Heat Loss* Konveksi dari permukaan *Furnace*

$T_{dinding\ luar}$ = 85 C 358 K
Tref = 28 C 301 K
ΔT = 57 C 330 K
Panjang = 100 cm = 1 m
Lebar = 58 cm = 0.6 m
Tinggi = 70 cm = 0.7 m

A luas = 2 (p. L + p.t + L.t)

= 2 x 0.58 + 0.7 + 0.4

= 3.3720 m^2

$$h = 1.42 \left(\frac{\Delta T}{L} \right)^{1/4.}$$ (Sumber:J.P.Holman Hal.315)

$$= 1.42 \left(\frac{57}{1} \right)^{1/4.}$$

= 3.9017 $W/m^{2o}C$

Q = h x A x ΔT (Sumber:J.P.HolmanHal.315)

= 3.9017 W/m^2C x 3.372 m^2 x 57

= 749.93 J/s/1000(3600)

= 2699.7 Kj/jam

= 2699.7 Kj/jam x 0.2 kkal/kj

= 647.94 kkal/jam

Tabel. Neraca Energi seputar *Boiler Furnace*

Komponen	Input (Kcal)	%	Output (Kcal)	%
Entalpi LPG	0.0000	0.00		
Heating Value LPG	32186.1573	94.90		
Entalpi *Boiler Feed Water*	558.8994	0.90		
Entalpi udara kering	10.2933	0.03		
Laten heat H_2O udara	1161.9596	3.43		
Panas Penguapan H_2O			1175.1431	3.46
Entalpi *Steam*			11380.3100	33.5
Entalpi *Flue Gas*			694.3283	2.05
Entalpi *Blowdown*			362.6712	1.07
Heat Loss Radiasi			1.0588	0.00
Heat Loss Konveksi			647.9377	1.91
Heat Loss akumulasi dalam sistem			19655.8606	57.9
Total	**33917.3097**	**100**	**33917.3097**	**100**

$$\text{Efisiensi} = \frac{\text{Entalpi Steam}}{HV_{LPG}} \times 100\ \%$$

$$= \frac{11380.31}{32186.1573} \times 100\ \%$$

$$= 0.35358 \times 100\ \%$$

$$= 35.36\ \%$$

$$\text{SFC} = \frac{\text{massa bahan bakar}}{\text{Massa } \textit{steam}}$$

$$= \frac{2.7}{17}$$

$$= 0.1588 \text{ Kcal/Kg}$$