ANNEX 4. 大気汚染に関する計算書

Calculation for Air Pollution in Environment Problem

Type-A So 1% Chimney 80 m

1. Fuel Consumption

Basic Specification	Abbreviation	Unit	Applying value of this project
1. Output at Generator end	Po	MW	120
2. Power plant thermal efficiency	ηp	%	25
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption	Fo	T/H	

$$Fo = \frac{Po \times 860 \times \frac{\alpha}{100}}{\frac{\eta p}{100} \times Hh'}$$ 38.6 T/H

2. Combustion Gas Volume

Basic Specification			
1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl'	Hl'	kcal/kg	
$Hl' = Hh' - 6\ (9 \times ho')$			10,025
° Excess air ratio m	m	-	
$m = \frac{21}{21 - O_2}$			1.24
° Combustion Gas Volume			
. Theorethical air volume	Ao'	Nm^3/kg-fuel	
$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$			
. Theorethical combustion gas volume	Go'	Nm^3/kg-fuel	
$Go' = 1.11 \times Hl' \times 10^{-3}$			11.13

. Actual combustion gas volume	G		
at Wet gas condition	G'w		
$G'w = Go' + (m-1)Ao'$			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18}(9 \times ho + W')$			12.25

3. Flue Gas Volume at Boiler End	Qb	Nm^3/H	
at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	527×10^3
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	473×10^3

4. Effective Height of Chimney

(apply equation of Bosanquet)

<u>Basic Condition</u>

1. Flue gas volume	QwB	Nm^3/H	527×10^3
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	80

Calculation of effective chimney height

. exhaust gas volume	Qt	m^3/s	162

$$= \frac{Qw\beta \times (273 + ta)}{3{,}600 \times 273}$$

. exhaust gas velocity at chimney nozzle	Vg	m/s	60

$$= \frac{Qw \times (273 + tg)}{3{,}600 \times 273 \times \frac{\pi}{4} D^2}$$

. Raising height of flue gas by flue gas energy (momentum)	Hm	m	
$= \frac{4.77}{1 + \frac{0.43 \times U}{Vg}} \times \frac{\sqrt{Qt \times Vg}}{U}$			
$= \frac{0.795 \sqrt{Qt \times Vg}}{1 + \frac{2.58}{Vg}}$			47
. Raising height of flue gas by temperature difference between flue gas and ambient	Ht	m	
$= 6.37 \times g \times \frac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \frac{2}{J} - 2)$			56.3
$= 1.91 \times 10^{-3} \times Qt\ (tg-ta) \times (2.3 \log J + \frac{1}{J} - 1)$			
$J = \frac{U_2}{\sqrt{Qt \times Vg}} \times 0.43\sqrt{\frac{(273 + to)}{g(d\theta/dz)}} - 0.28 \frac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$			
$= \frac{1}{\sqrt{Qt \times Vg}} (1{,}498 - \frac{312 \times Vg}{tg - ta}) + 1$			14.4
. Effective height of chimney	He	m	165
$= Ho + 0.65\ (Hm + Ht)$			

5. Calculation of air polutant

Basic Specification

1. Fuel consumption	Fo	T/H	38.6
2. Sulphur component	So	%	1.0
3. Flue gas volume at dry state	QdB	Nm^3/H	473×10^3
4. Effective height of chimney	He	m	165
5. O_2 content in flue gas	O_2	%	4.0
Calculation of SO_x emission			
° SO_x volume at boiler end	q'	Nm^3/H	270.2
= 7 (Fo x So)			
° SO_x density at chimney nozzle	qc	ppm	570
$= \frac{q'}{QdB} \times 10^6$			

6. Maximum SO_x Landing Density and Distance

6-1 Maximum SO_x landing density (apply equation of Sutton) $= 1.72 \times \frac{q'}{Hc^2}$	Cmax	ppm	0.017
6-2 Maximum SO_x landing distance (apply equation of Sutton) $= 20.8 \times He^{1.143} \times 10^{-3}$	Xmax	km	7.1

Calculation for Air Pollution in Environment Problem

Type-A So 1% Chimney 100 m

1. Fuel Consumption

Basic Specification	Abbreviation/Unit		Applying value of this project
1. Output at Generator end	Po	MW	120
2. Power plant thermal efficiency	ηp	%	25
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption	Fo	T/H	
$Fo = \dfrac{Po \times 860 \times \dfrac{\alpha}{100}}{\dfrac{\eta p}{100} \times Hh'}$			38.6 T/H

2. Combustion Gas Volume

Basic Specification

1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl'	Hl'	kcal/kg	
$Hl' = Hh' - 6\ (9 \times ho')$			10,025
° Excess air ratio m	m	-	
$m = \dfrac{21}{21 - O_2}$			1.24
° Combustion Gas Volume			
. Theorethical air volume	Ao'	Nm^3/kg-fuel	
$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$			
. Theorethical combustion gas volume	Go'	Nm^3/kg-fuel	
$Go' = 1.11 \times Hl' \times 10^{-3}$			11.13

. Actual combustion gas volume	G		
at Wet gas condition	G'w		
G'w = Go' + (m-1)Ao'			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18} (9 \times ho + W')$			12.25
3. Flue Gas Volume at Boiler End	Qb	Nm^3/H	
at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	527×10^3
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	473×10^3

4. Effective Height of Chimney

(apply equation of Bosanquet)

<u>Basic Condition</u>

1. Flue gas volume	QwB	Nm^3/H	527×10^3
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	100
Calculation of effective chimney height			
. exhaust gas volume	Qt	m^3/s	162
$= \frac{Qw\beta \times (273 + ta)}{3,600 \times 273}$			
. exhaust gas velocity at chimney nozzle	Vg	m/s	60
$= \frac{Qw \times (273 + tg)}{3,600 \times 273 \times \frac{\pi}{4} D^2}$			

. Raising height of flue gas by flue gas energy (momentum)	Hm	m	
$= \dfrac{4.77}{1 + \dfrac{0.43 \times U}{Vg}} \times \dfrac{\sqrt{Qt \times Vg}}{U}$			
$= \dfrac{0.795\sqrt{Qt \times Vg}}{1 + \dfrac{2.58}{Vg}}$			75
. Raising height of flue gas by temperature difference between flue gas and ambient	Ht	m	
$= 6.37 \times g \times \dfrac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \dfrac{2}{J} - 2)$			56.3
$= 1.91 \times 10^{-3} \times Qt\ (tg-ta) \times (2.3\ \log J + \dfrac{1}{J} - 1)$			
$J = \dfrac{U_2}{\sqrt{Qt \times Vg}} \times 0.43\sqrt{\dfrac{(273 + to)}{g(d\theta/dz)}} - 0.28\ \dfrac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$			
$= \dfrac{1}{\sqrt{Qt \times Vg}}\ (1{,}498 - \dfrac{312 \times Vg}{tg - ta}) + 1$			14.4
. Effective height of chimney	He	m	
= Ho + 0.65 (Hm + Ht)			185

5. Calculation of air polutant

Basic Specification

1. Fuel consumption	Fo	T/H	38.6
2. Sulphur component	So	%	1.0
3. Flue gas volume at dry state	QdB	Nm^3/H	473×10^3
4. Effective height of chimney	He	m	185
5. O_2 content in flue gas	O_2	%	4.0

Calculation of SO_x emission

° SO_x volume at boiler end	q'	Nm^3/H	270.2
= 7 (Fo x So)			
° SO_x density at chimney nozzle	qc	ppm	570
$= \dfrac{q'}{QdB} \times 10^6$			

6. Maximum SO_x Landing Density and Distance

6-1 Maximum SO_x landing density (apply equation of Sutton)	Cmax	ppm	0.014
$= 1.72 \times \frac{q'}{Hc^2}$			
6-2 Maximum SO_x landing distance (apply equation of Sutton)	Xmax	km	8.1
$= 20.8 \times He^{1.143} \times 10^{-3}$			

Calculation for Air Pollution in Environment Problem

Type-A So 1% Chimney 120 m

1. Fuel Consumption

Basic Specification	Abbreviation/Unit		Applying value of this project
1. Output at Generator end	Po	MW	120
2. Power plant thermal efficiency	ηp	%	25
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption	Fo	T/H	

$$Fo = \frac{Po \times 860 \times \frac{\alpha}{100}}{\frac{\eta p}{100} \times Hh'}$$ 38.6 T/H

2. Combustion Gas Volume

Basic Specification			
1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl'	Hl'	kcal/kg	
Hl' = Hh' - 6 (9 x ho')			10,025
° Excess air ratio m	m	-	
$m = \frac{21}{21 - O_2}$			1.24
° Combustion Gas Volume			
. Theorethical air volume	Ao'	Nm^3/kg-fuel	
$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$			
. Theorethical combustion gas volume	Go'	Nm^3/kg-fuel	
$Go' = 1.11 \times Hl' \times 10^{-3}$			11.13

. Actual combustion gas volume	G		
at Wet gas condition	G'w		
$G'w = Go' + (m-1)Ao'$			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18}(9 \times ho + W')$			12.25

3\. Flue Gas Volume at Boiler End — Qb — Nm^3/H

at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	527×10^3
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	473×10^3

4\. Effective Height of Chimney

(apply equation of Bosanquet)

<u>Basic Condition</u>

1. Flue gas volume	QwB	Nm^3/H	527×10^3
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	120

Calculation of effective chimney height

. exhaust gas volume	Qt	m^3/s	162
$= \frac{Qw \times (273 + ta)}{3{,}600 \times 273}$			
. exhaust gas velocity at chimney nozzle	Vg	m/s	60
$= \frac{QwB \times (273 + tg)}{3{,}600 \times 273 \times \frac{\pi}{4} D^2}$			

. Raising height of flue gas by flue gas energy (momentum)	Hm	m	
$= \dfrac{4.77}{1 + \dfrac{0.43 \times U}{Vg}} \times \dfrac{\sqrt{Qt \times Vg}}{U}$			
$= \dfrac{0.795\sqrt{Qt \times Vg}}{1 + \dfrac{2.58}{Vg}}$			75
. Raising height of flue gas by temperature difference between flue gas and ambient	Ht	m	
$= 6.37 \times g \times \dfrac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \dfrac{2}{J} - 2)$			56.3
$= 1.91 \times 10^{-3} \times Qt\ (tg-ta) \times (2.3\ \log J + \dfrac{1}{J} - 1)$			
$J = \dfrac{U_2}{\sqrt{Qt \times Vg}} \times 0.43\sqrt{\dfrac{(273 + to)}{g(d\theta/dz)}} - 0.28\ \dfrac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$			
$= \dfrac{1}{\sqrt{Qt \times Vg}}\ (1{,}498 - \dfrac{312 \times Vg}{tg - ta}) + 1$			14.4
. Effective height of chimney	He	m	
$= Ho + 0.65\ (Hm + Ht)$			205

5. Calculation of air polutant

Basic Specification

1. Fuel consumption	Fo	T/H	38.6
2. Sulphur component	So	%	1.0
3. Flue gas volume at dry state	QdB	Nm^3/H	473×10^3
4. Effective height of chimney	He	m	205
5. O_2 content in flue gas	O_2	%	4.0

Calculation of SO_x emission

° SO_x volume at boiler end	q'	Nm^3/H	270.2
$= 7\ (Fo \times So)$			
° SO_x density at chimney nozzle	qc	ppm	570
$= \dfrac{q'}{QdB} \times 10^6$			

6. Maximum SO_x Landing Density and Distance

6-1	Maximum SO_x landing density (apply equation of Sutton)	Cmax	ppm	0.011
	$= 1.72 \times \frac{q'}{Hc^2}$			
6-2	Maximum SO_x landing distance (apply equation of Sutton)	Xmax	km	9.1
	$= 20.8 \times He^{1.143} \times 10^{-3}$			

Calculation for Air Pollution in Environment Problem

Type-F So 1% Chimney 80 m

1. Fuel Consumption

Basic Specification	Abbreviation	Unit	Applying value of this project
1. Output at Generator end	Po	MW	60
2. Power plant thermal efficiency	ηp	%	19
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption — Fo — T/H

$$Fo = \frac{Po \times 860 \times \frac{\alpha}{100}}{\frac{\eta p}{100} \times Hh'}$$ 25.4 T/H

2. Combustion Gas Volume

Basic Specification	Abbreviation	Unit	Applying value of this project
1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl' — Hl' — kcal/kg

$Hl' = Hh' - 6\ (9 \times ho')$ 10,025

° Excess air ratio m — m — -

$$m = \frac{21}{21 - O_2}$$ 1.24

° Combustion Gas Volume

. Theorethical air volume — Ao' — Nm^3/kg-fuel

$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$

. Theorethical combustion gas volume — Go' — Nm^3/kg-fuel

$Go' = 1.11 \times Hl' \times 10^{-3}$ 11.13

. Actual combustion gas volume	G		
at Wet gas condition	G'w		
$G'w = Go' + (m-1)Ao'$			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18}(9 \times ho + W')$			12.25
3. Flue Gas Volume at Boiler End	Qb	Nm^3/H	
at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	347×10^3
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	311×10^3

4. Effective Height of Chimney

(apply equation of Bosanquet)

Basic Condition

1. Flue gas volume	QwB	Nm^3/H	347×10^3
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	80
Calculation of effective chimney height			
. exhaust gas volume	Qt	m^3/s	107
$= \frac{QwB \times (273 + ta)}{3,600 \times 273}$			
. exhaust gas velocity at chimney nozzle	Vg	m/s	39
$= \frac{Qw \times (273 + tg)}{3,600 \times 273 \times \frac{\pi}{4} D^2}$			

. Raising height of flue gas by flue gas energy (momentum)	Hm	m	
$= \dfrac{4.77}{1 + \dfrac{0.43 \times U}{Vg}} \times \dfrac{\sqrt{Qt \times Vg}}{U}$			
$= \dfrac{0.795\sqrt{Qt \times Vg}}{1 + \dfrac{2.58}{Vg}}$			48
. Raising height of flue gas by temperature difference between flue gas and ambient	Ht	m	
$= 6.37 \times g \times \dfrac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \dfrac{2}{J} - 2)$			46.1
$= 1.91 \times 10^{-3} \times Qt\ (tg - ta) \times (2.3 \log J + \dfrac{1}{J} - 1)$			
$J = \dfrac{U_2}{\sqrt{Qt \times Vg}} \times 0.43\sqrt{\dfrac{(273 + to)}{g(d\theta/dz)}} - 0.28\,\dfrac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$			
$= \dfrac{1}{\sqrt{Qt \times Vg}}\ (1{,}498 - \dfrac{312 \times Vg}{tg - ta}) + 1$			22.4
. Effective height of chimney	He	m	
$= Ho + 0.65\ (Hm + Ht)$			141

5. Calculation of air polutant

Basic Specification

1. Fuel consumption	Fo	T/H	25.4
2. Sulphur component	So	%	1.0
3. Flue gas volume at dry state	QdB	Nm^3/H	311×10^3
4. Effective height of chimney	He	m	141
5. O_2 content in flue gas	O_2	%	4.0

Calculation of SO_x emission

° SO_x volume at boiler end	q'	Nm^3/H	177.8
$= 7\ (Fo \times So)$			
° SO_x density at chimney nozzle	qc	ppm	570
$= \dfrac{q'}{QdB} \times 10^6$			

6. Maximum SO_x Landing Density and Distance

6-1	Maximum SO_x landing density (apply equation of Sutton) $= 1.72 \times \frac{q'}{Hc^2}$	Cmax	ppm	0.015
6-2	Maximum SO_x landing distance (apply equation of Sutton) $= 20.8 \times He^{1.143} \times 10^{-3}$	Xmax	km	6.0

Calculation for Air Pollution in Environment Problem

Type-F So 1% Chimney 100 m

1. Fuel Consumption

Basic Specification	Abbreviation/Unit		Applying value of this project
1. Output at Generator end	Po	MW	60
2. Power plant thermal efficiency	ηp	%	19
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption — Fo — T/H

$$Fo = \frac{Po \times 860 \times \frac{\alpha}{100}}{\frac{\eta p}{100} \times Hh'}$$ 25.4 T/H

2. Combustion Gas Volume

Basic Specification			
1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl' — Hl' — kcal/kg

$Hl' = Hh' - 6\ (9 \times ho')$ 10,025

° Excess air ratio m — m — ~

$$m = \frac{21}{21 - O_2}$$ 1.24

° Combustion Gas Volume

. Theorethical air volume — Ao' — Nm^3/kg-fuel

$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$

. Theorethical combustion gas volume — Go' — Nm^3/kg-fuel

$Go' = 1.11 \times Hl' \times 10^{-3}$ 11.13

. Actual combustion gas volume	G		
at Wet gas condition	G'w		
$G'w = Go' + (m-1)Ao'$			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18}(9 \times ho + W')$			12.25
3. Flue Gas Volume at Boiler End	Qb	Nm^3/H	
at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	347×10^3
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	311×10^3
4. Effective Height of Chimney			
(apply equation of Bosanquet)			
Basic Condition			
1. Flue gas volume	QwB	Nm^3/H	347×10^3
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	100
Calculation of effective chimney height			
. exhaust gas volume	Qt	m^3/s	107
$= \frac{QwB \times (273 + ta)}{3{,}600 \times 273}$			
. exhaust gas velocity at chimney nozzle	Vg	m/s	39
$= \frac{Qw \times (273 + tg)}{3{,}600 \times 273 \times \frac{\pi}{4} D^2}$			

. Raising height of flue gas by flue gas energy (momentum)	Hm	m	
$= \frac{4.77}{1 + \frac{0.43 \times U}{Vg}} \times \frac{\sqrt{Qt \times Vg}}{U}$			
$= \frac{0.795\sqrt{Qt \times Vg}}{1 + \frac{2.58}{Vg}}$			48
. Raising height of flue gas by temperature difference between flue gas and ambient	Ht	m	
$= 6.37 \times g \times \frac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \frac{2}{J} - 2)$			46.1
$= 1.91 \times 10^{-3} \times Qt\ (tg-ta) \times (2.3\ \log J + \frac{1}{J} - 1)$			
$J = \frac{U_2}{\sqrt{Qt \times Vg}} \times 0.43\sqrt{\frac{(273 + to)}{g(d\theta/dz)}} - 0.28\ \frac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$			
$= \frac{1}{\sqrt{Qt \times Vg}} (1{,}498 - \frac{312 \times Vg}{tg - ta}) + 1$			22.4
. Effective height of chimney	He	m	
= Ho + 0.65 (Hm + Ht)			161

5. Calculation of air polutant

<u>Basic Specification</u>

1. Fuel consumption	Fo	T/H	25.4
2. Sulphur component	So	%	1.0
3. Flue gas volume at dry state	QdB	Nm^3/H	311×10^3
4. Effective height of chimney	He	m	161
5. O_2 content in flue gas	O_2	%	4.0

Calculation of SO_x emission

° SO_x volume at boiler end	q'	Nm^3/H	177.8
= 7 (Fo x So)			
° SO_x density at chimney nozzle	qc	ppm	570
$= \frac{q'}{QdB} \times 10^6$			

6. Maximum SO_x Landing Density and Distance

6-1 Maximum SO_x landing density (apply equation of Sutton)	Cmax	ppm	0.012

$$= 1.72 \times \frac{q'}{Hc^2}$$

6-2 Maximum SO_x landing distance (apply equation of Sutton)	Xmax	km	6.9

$$= 20.8 \times He^{1.143} \times 10^{-3}$$

Calculation for Air Pollution in Environment Problem

Type-F So 1% Chimney 120 m

1. Fuel Consumption

Basic Specification	Abbreviation/Unit		Applying value of this project
1. Output at Generator end	Po	MW	60
2. Power plant thermal efficiency	ηp	%	19
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption	Fo	T/H	
$Fo = \dfrac{Po \times 860 \times \dfrac{\alpha}{100}}{\dfrac{\eta p}{100} \times Hh'}$			25.4 T/H

2. Combustion Gas Volume

Basic Specification			
1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl'	Hl'	kcal/kg	
$Hl' = Hh' - 6 (9 \times ho')$			10,025
° Excess air ratio m	m	-	
$m = \dfrac{21}{21 - O_2}$			1.24
° Combustion Gas Volume			
. Theorethical air volume	Ao'	Nm^3/kg-fuel	
$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$			
. Theorethical combustion gas volume	Go'	Nm^3/kg-fuel	
$Go' = 1.11 \times Hl' \times 10^{-3}$			11.13

. Actual combustion gas volume	G		
at Wet gas condition	G'w		
$G'w = Go' + (m-1)Ao'$			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18}(9 \times ho + W')$			12.25
3. Flue Gas Volume at Boiler End	Qb	Nm^3/H	
at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	347×10^3
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	311×10^3
4. Effective Height of Chimney			
(apply equation of Bosanquet)			
Basic Condition			
1. Flue gas volume	QwB	Nm^3/H	347×10^3
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	120
Calculation of effective chimney height			
. exhaust gas volume	Qt	m^3/s	107
$= \frac{Qw \times (273 + ta)}{3,600 \times 273}$			
. exhaust gas velocity at chimney nozzle	Vg	m/s	39
$= \frac{QwB \times (273 + tg)}{3,600 \times 273 \times \frac{\pi}{4} D^2}$			

. Raising height of flue gas by flue gas energy (momentum) | Hm | m |

$$= \frac{4.77}{1 + \frac{0.43 \times U}{Vg}} \times \frac{\sqrt{Qt \times Vg}}{U}$$

$$= \frac{0.795\sqrt{Qt \times Vg}}{1 + \frac{2.58}{Vg}}$$ 48

. Raising height of flue gas by temperature difference between flue gas and ambient | Ht | m |

$$= 6.37 \times g \times \frac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \frac{2}{J} - 2)$$ 46.1

$$= 1.91 \times 10^{-3} \times Qt\ (tg-ta) \times (2.3\ \log J + \frac{1}{J} - 1)$$

$$J = \frac{U_2}{\sqrt{Qt \times Vg}} \times \ 0.43\sqrt{\frac{(273 + to)}{g(d\theta/dz)}}$$

$$- 0.28\ \frac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$$

$$= \frac{1}{\sqrt{Qt \times Vg}}\ (1{,}498 - \frac{312 \times Vg}{tg - ta}) + 1$$ 22.4

. Effective height of chimney | He | m |

= Ho + 0.65 (Hm + Ht) 181

5. Calculation of air polutant

Basic Specification

1. Fuel consumption	Fo	T/H	25.4
2. Sulphur component	So	%	1.0
3. Flue gas volume at dry state	QdB	Nm^3/H	311×10^3
4. Effective height of chimney	He	m	181
5. O_2 content in flue gas	O_2	%	4.0

Calculation of SO_x emission

° SO_x volume at boiler end | q' | Nm^3/H | 177.8

= 7 (Fo x So)

° SO_x density at chimney nozzle | qc | ppm | 570

$$= \frac{q'}{QdB} \times 10^6$$

6. Maximum SO_x Landing Density and Distance

6-1	Maximum SO_x landing density (apply equation of Sutton) $= 1.72 \times \frac{q'}{Hc^2}$	Cmax	ppm	0.009
6-2	Maximum SO_x landing distance (apply equation of Sutton) $= 20.8 \times He^{1.143} \times 10^{-3}$	Xmax	km	7.9

Calculation for Air Pollution in Environment Problem

Type-A So 1.6% Chimney 80 m

1. Fuel Consumption

Basic Specification	Abbreviation	Unit	Applying value of this project
1. Output at Generator end	Po	MW	120
2. Power plant thermal efficiency	ηp	%	25
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption — Fo — T/H

$$Fo = \frac{Po \times 860 \times \frac{\alpha}{100}}{\frac{\eta p}{100} \times Hh'}$$ 38.6 T/H

2. Combustion Gas Volume

Basic Specification	Abbreviation	Unit	Applying value of this project
1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl' — Hl' — kcal/kg

$Hl' = Hh' - 6\ (9 \times ho')$ 10,025

° Excess air ratio m — m — -

$$m = \frac{21}{21 - O_2}$$ 1.24

° Combustion Gas Volume

. Theorethical air volume — Ao' — Nm^3/kg-fuel

$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$

. Theorethical combustion gas volume — Go' — Nm^3/kg-fuel

$Go' = 1.11 \times Hl' \times 10^{-3}$ 11.13

. Actual combustion gas volume — G

at Wet gas condition	G'w		
$G'w = Go' + (m-1)Ao'$			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18}(9 \times ho + W')$			12.25

3. Flue Gas Volume at Boiler End — Qb — Nm^3/H

at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	527×10^3
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	473×10^3

4. Effective Height of Chimney

(apply equation of Bosanquet)

Basic Condition

1. Flue gas volume	QwB	Nm^3/H	527×10^3
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	80

Calculation of effective chimney height

. exhaust gas volume	Qt	m^3/s	162
$= \frac{QwB \times (273 + ta)}{3,600 \times 273}$			
. exhaust gas velocity at chimney nozzle	Vg	m/s	60
$= \frac{Qw \times (273 + tg)}{3,600 \times 273 \times \frac{\pi}{4} D^2}$			

. Raising height of flue gas by flue gas energy (momentum)	Hm	m	

$$= \frac{4.77}{1 + \frac{0.43 \times U}{Vg}} \times \frac{\sqrt{Qt \times Vg}}{U}$$

$$= \frac{0.795\sqrt{Qt \times Vg}}{1 + \frac{2.58}{Vg}}$$ 75

. Raising height of flue gas by temperature difference between flue gas and ambient	Ht	m	

$$= 6.37 \times g \times \frac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \frac{2}{J} - 2)$$ 56.3

$$= 1.91 \times 10^{-3} \times Qt\ (tg - ta) \times (2.3\ \log J + \frac{1}{J} - 1)$$

$$J = \frac{U_2}{\sqrt{Qt \times Vg}} \times \ 0.43\sqrt{\frac{(273 + to)}{g(d\theta/dz)}}$$

$$- 0.28\ \frac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$$

$$= \frac{1}{\sqrt{Qt \times Vg}}\ (1{,}498 - \frac{312 \times Vg}{tg - ta}) + 1$$ 14.4

. Effective height of chimney	He	m	
= Ho + 0.65 (Hm + Ht)			165

5. Calculation of air polutant

Basic Specification

1. Fuel consumption	Fo	T/H	38.6
2. Sulphur component	So	%	1.6
3. Flue gas volume at dry state	QdB	Nm^3/H	473×10^3
4. Effective height of chimney	He	m	165
5. O_2 content in flue gas	O_2	%	4.0

Calculation of SO_x emission

° SO_x volume at boiler end	q'	Nm^3/H	432.3
= 7 (Fo x So)			
° SO_x density at chimney nozzle	qc	ppm	914

$$= \frac{q'}{QdB} \times 10^6$$

6. Maximum SO_x Landing Density and Distance

6-1	Maximum SO_x landing density (apply equation of Sutton)	Cmax	ppm	0.027

$$= 1.72 \times \frac{q'}{Hc^2}$$

6-2	Maximum SO_x landing distance (apply equation of Sutton)	Xmax	km	7.1

$$= 20.8 \times He^{1.143} \times 10^{-3}$$

Calculation for Air Pollution in Environment Problem

Type-A So 1.6% Chimney 100 m

1. Fuel Consumption

Basic Specification	Abbreviation/Unit		Applying value of this project
1. Output at Generator end	Po	MW	120
2. Power plant thermal efficiency	ηp	%	25
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption	Fo	T/H	

$$Fo = \frac{Po \times 860 \times \frac{\alpha}{100}}{\frac{\eta p}{100} \times Hh'}$$ 38.6 T/H

2. Combustion Gas Volume

Basic Specification			
1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl'	Hl'	kcal/kg	
Hl' = Hh' − 6 (9 x ho')			10,025
° Excess air ratio m	m	–	
$m = \frac{21}{21 - O_2}$			1.24
° Combustion Gas Volume			
. Theorethical air volume	Ao'	Nm^3/kg-fuel	
$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$			
. Theorethical combustion gas volume	Go'	Nm^3/kg-fuel	
$Go' = 1.11 \times Hl' \times 10^{-3}$			11.13

. Actual combustion gas volume	G		
at Wet gas condition	G'w		
$G'w = Go' + (m-1)Ao'$			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18}(9 \times ho + W')$			12.25
3. Flue Gas Volume at Boiler End	Qb	Nm^3/H	
at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	527×10^3
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	473×10^3
4. Effective Height of Chimney			
(apply equation of Bosanquet)			
Basic Condition			
1. Flue gas volume	QwB	Nm^3/H	527×10^3
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	100
Calculation of effective chimney height			
. exhaust gas volume	Qt	m^3/s	162
$= \frac{Qw \times (273 + ta)}{3{,}600 \times 273}$			
. exhaust gas velocity at chimney nozzle	Vg	m/s	60
$= \frac{QwB \times (273 + tg)}{3{,}600 \times 273 \times \frac{\pi}{4} D^2}$			

• Raising height of flue gas by flue gas energy (momentum)	Hm	m	
$= \frac{4.77}{1 + \frac{0.43 \times U}{Vg}} \times \frac{\sqrt{Qt \times Vg}}{U}$			
$= \frac{0.795\sqrt{Qt \times Vg}}{1 + \frac{2.58}{Vg}}$			75
• Raising height of flue gas by temperature difference between flue gas and ambient	Ht	m	
$= 6.37 \times g \times \frac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \frac{2}{J} - 2)$			56.3
$= 1.91 \times 10^{-3} \times Qt\ (tg - ta) \times (2.3 \log J + \frac{1}{J} - 1)$			
$J = \frac{U_2}{\sqrt{Qt \times Vg}} \times 0.43\sqrt{\frac{(273 + to)}{g(d\theta/dz)}}$			
$- 0.28 \frac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$			
$= \frac{1}{\sqrt{Qt \times Vg}} (1{,}498 - \frac{312 \times Vg}{tg - ta}) + 1$			14.4
• Effective height of chimney	He	m	
$= Ho + 0.65\ (Hm + Ht)$			185

5. Calculation of air polutant

<u>Basic Specification</u>

1. Fuel consumption	Fo	T/H	38.6
2. Sulphur component	So	%	1.6
3. Flue gas volume at dry state	QdB	Nm^3/H	473×10^3
4. Effective height of chimney	He	m	185
5. O_2 content in flue gas	O_2	%	4.0
Calculation of SO_x emission			
° SO_x volume at boiler end	q'	Nm^3/H	432.3
$= 7\ (Fo \times So)$			
° SO_x density at chimney nozzle	qc	ppm	914
$= \frac{q'}{QdB} \times 10^6$			

6. Maximum SO_x Landing Density and Distance

6-1 Maximum SO_x landing density (apply equation of Sutton) $= 1.72 \times \frac{q'}{Hc^2}$	Cmax	ppm	0.022
6-2 Maximum SO_x landing distance (apply equation of Sutton) $= 20.8 \times He^{1.143} \times 10^{-3}$	Xmax	km	8.1

Calculation for Air Pollution in Environment Problem

Type-A So 1.6% Chimney 120 m

1. Fuel Consumption

Basic Specification	Abbreviation/Unit		Applying value of this project
1. Output at Generator end	Po	MW	120
2. Power plant thermal efficiency	ηp	%	25
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption	Fo	T/H	

$$Fo = \frac{Po \times 860 \times \frac{\alpha}{100}}{\frac{\eta p}{100} \times Hh'}$$

38.6 T/H

2. Combustion Gas Volume

Basic Specification			
1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl'	Hl'	kcal/kg	
$Hl' = Hh' - 6\ (9 \times ho')$			10,025
° Excess air ratio m	m	–	
$m = \frac{21}{21 - O_2}$			1.24

° Combustion Gas Volume

. Theorethical air volume	Ao'	Nm^3/kg-fuel	
$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$			
. Theorethical combustion gas volume	Go'	Nm^3/kg-fuel	
$Go' = 1.11 \times Hl' \times 10^{-3}$			11.13

. Actual combustion gas volume	G		
at Wet gas condition	G'w		
$G'w = Go' + (m-1)Ao'$			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18}(9 \times ho + W')$			12.25
3. Flue Gas Volume at Boiler End	Qb	Nm^3/H	
at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	527×10^3
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	473×10^3
4. Effective Height of Chimney			
(apply equation of Bosanquet)			
Basic Condition			
1. Flue gas volume	QwB	Nm^3/H	527×10^3
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	120
Calculation of effective chimney height			
. exhaust gas volume	Qt	m^3/s	162
$= \frac{Qw \times (273 + ta)}{3{,}600 \times 273}$			
. exhaust gas velocity at chimney nozzle	Vg	m/s	60
$= \frac{Q_{wB} \times (273 + tg)}{3{,}600 \times 273 \times \frac{\pi}{4} D^2}$			

. Raising height of flue gas by flue gas energy (momentum) | Hm | m |

$$= \frac{4.77}{1 + \frac{0.43 \times U}{Vg}} \times \frac{\sqrt{Qt \times Vg}}{U}$$

$$= \frac{0.795\sqrt{Qt \times Vg}}{1 + \frac{2.58}{Vg}}$$ 75

. Raising height of flue gas by temperature difference between flue gas and ambient | Ht | m

$$= 6.37 \times g \times \frac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \frac{2}{J} - 2)$$ 56.3

$$= 1.91 \times 10^{-3} \times Qt\ (tg-ta) \times (2.3\ \log J + \frac{1}{J} - 1)$$

$$J = \frac{U_2}{\sqrt{Qt \times Vg}} \times 0.43\sqrt{\frac{(273 + to)}{g(d\theta/dz)}}$$

$$- 0.28\ \frac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$$

$$= \frac{1}{\sqrt{Qt \times Vg}}\ (1{,}498 - \frac{312 \times Vg}{tg - ta}) + 1$$ 14.4

. Effective height of chimney | He | m

= Ho + 0.65 (Hm + Ht) 205

5. Calculation of air polutant

Basic Specification

1. Fuel consumption	Fo	T/H	38.6
2. Sulphur component	So	%	1.6
3. Flue gas volume at dry state	QdB	Nm^3/H	473×10^3
4. Effective height of chimney	He	m	205
5. O_2 content in flue gas	O_2	%	4.0

Calculation of SO_x emission

° SO_x volume at boiler end | q' | Nm^3/H | 432.3

= 7 (Fo x So)

° SO_x density at chimney nozzle | qc | ppm | 914

$$= \frac{q'}{QdB} \times 10^6$$

6. Maximum SO_x Landing Density and Distance

6-1 Maximum SO_x landing density (apply equation of Sutton) $= 1.72 \times \frac{q'}{He^2}$	Cmax	ppm	0.018
6-2 Maximum SO_x landing distance (apply equation of Sutton) $= 20.8 \times He^{1.143} \times 10^{-3}$	Xmax	km	9.1

<u>Calculation for Air Pollution in Environment Problem</u>

<u>Type-F So 1.6% Chimney 80 m</u>

1. Fuel Consumption

Basic Specification	Abbreviation	Unit	Applying value of this project
1. Output at Generator end	Po	MW	60
2. Power plant thermal efficiency	ηp	%	19
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption	Fo	T/H	
$Fo = \dfrac{Po \times 860 \times \dfrac{\vartheta}{100}}{\dfrac{\eta p}{100} \times Hh'}$			25.4 T/H

2. Combustion Gas Volume

Basic Specification			
1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl'	Hl'	kcal/kg	
$Hl' = Hh' - 6\ (9 \times ho')$			10,025
° Excess air ratio m	m	-	
$m = \dfrac{21}{21 - O_2}$			1.24
° Combustion Gas Volume			
. Theorethical air volume	Ao'	Nm^3/kg-fuel	
$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$			
. Theorethical combustion gas volume	Go'	Nm^3/kg-fuel	
$Go' = 1.11 \times Hl' \times 10^{-3}$			11.13

. Actual combustion gas volume	G		
at Wet gas condition	G'w		
$G'w = Go' + (m-1)Ao'$			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18}(9 \times ho + W')$			12.25

3. Flue Gas Volume at Boiler End — Qb — Nm^3/H

at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	$347x10^3$
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	$311x10^3$

4. Effective Height of Chimney

(apply equation of Bosanquet)

<u>Basic Condition</u>

1. Flue gas volume	QwB	Nm^3/H	$347x10^3$
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	80

Calculation of effective chimney height

. exhaust gas volume	Qt	m^3/s	107
$= \frac{Qw \times (273 + ta)}{3,600 \times 273}$			
. exhaust gas velocity at chimney nozzle	Vg	m/s	39
$= \frac{QwB \times (273 + tg)}{3,600 \times 273 \times \frac{\pi}{4} D^2}$			

. Raising height of flue gas by flue gas energy (momentum)	Hm	m	
$= \dfrac{4.77}{1 + \dfrac{0.43 \times U}{Vg}} \times \dfrac{\sqrt{Qt \times Vg}}{U}$			
$= \dfrac{0.795\sqrt{Qt \times Vg}}{1 + \dfrac{2.58}{Vg}}$			48
. Raising height of flue gas by temperature difference between flue gas and ambient	Ht	m	
$= 6.37 \times g \times \dfrac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \dfrac{2}{J} - 2)$			46.1
$= 1.91 \times 10^{-3} \times Qt\ (tg-ta) \times (2.3\ \log J + \dfrac{1}{J} - 1)$			
$J = \dfrac{U_2}{\sqrt{Qt \times Vg}} \times 0.43\sqrt{\dfrac{(273 + to)}{g(d\theta/dz)}} - 0.28\,\dfrac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$			
$= \dfrac{1}{\sqrt{Qt \times Vg}}\,(1{,}498 - \dfrac{312 \times Vg}{tg - ta}) + 1$			22.4
. Effective height of chimney	He	m	
$= Ho + 0.65\ (Hm + Ht)$			141

5. Calculation of air polutant

Basic Specification

1. Fuel consumption	Fo	T/H	25.4
2. Sulphur component	So	%	1.6
3. Flue gas volume at dry state	QdB	Nm^3/H	473×10^3
4. Effective height of chimney	He	m	141
5. O_2 content in flue gas	O_2	%	4.0

Calculation of SO_x emission

° SO_x volume at boiler end	q'	Nm^3/H	284.5
$= 7\ (Fo \times So)$			
° SO_x density at chimney nozzle	qc	ppm	601
$= \dfrac{q'}{QdB} \times 10^6$			

6. Maximum SO_x Landing Density and Distance

6-1 Maximum SO_x landing density (apply equation of Sutton) $= 1.72 \times \frac{q'}{Hc^2}$	Cmax	ppm	0.025
6-2 Maximum SO_x landing distance (apply equation of Sutton) $= 20.8 \times He^{1.143} \times 10^{-3}$	Xmax	km	6.0

Calculation for Air Pollution in Environment Problem

Type-F So 1.6% Chimney 100 m

1. Fuel Consumption

Basic Specification	Abbreviation/Unit		Applying value of this project
1. Output at Generator end	Po	MW	60
2. Power plant thermal efficiency	ηp	%	19
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption	Fo	T/H	
$Fo = \dfrac{Po \times 860 \times \frac{\alpha}{100}}{\frac{\eta p}{100} \times Hh'}$			25.4 T/H

2. Combustion Gas Volume

Basic Specification			
1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl'	Hl'	kcal/kg	
$Hl' = Hh' - 6\ (9 \times ho')$			10,025
° Excess air ratio m	m	–	
$m = \dfrac{21}{21 - O_2}$			1.24
° Combustion Gas Volume			
. Theorethical air volume	Ao'	Nm^3/kg-fuel	
$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$			
. Theorethical combustion gas volume	Go'	Nm^3/kg-fuel	
$Go' = 1.11 \times Hl' \times 10^{-3}$			11.13

. Actual combustion gas volume	G		
at Wet gas condition	G'w		
$G'w = Go' + (m-1)Ao'$			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18} (9 \times ho + W')$			12.25
3. Flue Gas Volume at Boiler End	Qb	Nm^3/H	
at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	347×10^3
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	311×10^3
4. Effective Height of Chimney			
(apply equation of Bosanquet)			
Basic Condition			
1. Flue gas volume	QwB	Nm^3/H	347×10^3
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	100
Calculation of effective chimney height			
. exhaust gas volume	Qt	m^3/s	107
$= \frac{Qw \times (273 + ta)}{3,600 \times 273}$			
. exhaust gas velocity at chimney nozzle	Vg	m/s	39
$= \frac{Qw \times (273 + tg)}{3,600 \times 273 \times \frac{\pi}{4} D^2}$			

. Raising height of flue gas by flue gas energy (momentum)	Hm	m	
$= \dfrac{4.77}{1 + \dfrac{0.43 \times U}{Vg}} \times \dfrac{\sqrt{Qt \times Vg}}{U}$			
$= \dfrac{0.795\sqrt{Qt \times Vg}}{1 + \dfrac{2.58}{Vg}}$			48
. Raising height of flue gas by temperature difference between flue gas and ambient	Ht	m	
$= 6.37 \times g \times \dfrac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \dfrac{2}{J} - 2)$			46.1
$= 1.91 \times 10^{-3} \times Qt\ (tg-ta) \times (2.3\ \log J + \dfrac{1}{J} - 1)$			
$J = \dfrac{U_2}{\sqrt{Qt \times Vg}} \times\ 0.43\sqrt{\dfrac{(273 + to)}{g(d\theta/dz)}}$			
$- 0.28\ \dfrac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$			
$= \dfrac{1}{\sqrt{Qt \times Vg}}\ (1{,}498 - \dfrac{312 \times Vg}{tg - ta}) + 1$			22.4
. Effective height of chimney	He	m	
= Ho + 0.65 (Hm + Ht)			161

5. Calculation of air polutant

<u>Basic Specification</u>

1. Fuel consumption	Fo	T/H	25.4
2. Sulphur component	So	%	1.6
3. Flue gas volume at dry state	QdB	Nm^3/H	473×10^3
4. Effective height of chimney	He	m	161
5. O_2 content in flue gas	O_2	%	4.0
Calculation of SO_x emission			
° SO_x volume at boiler end	q'	Nm^3/H	284.5
= 7 (Fo x So)			
° SO_x density at chimney nozzle	qc	ppm	601
$= \dfrac{q'}{QdB} \times 10^6$			

6. Maximum SO_x Landing Density and Distance

6-1 Maximum SO_x landing density (apply equation of Sutton) $= 1.72 \times \frac{q'}{Hc^2}$	Cmax	ppm	0.019
6-2 Maximum SO_x landing distance (apply equation of Sutton) $= 20.8 \times He^{1.143} \times 10^{-3}$	Xmax	km	6.9

Calculation for Air Pollution in Environment Problem

Type-F So 1.6% Chimney 120 m

1. Fuel Consumption

Basic Specification	Abbreviation/Unit		Applying value of this project
1. Output at Generator end	Po	MW	60
2. Power plant thermal efficiency	ηp	%	19
3. Fuel combustion ratio		%	100
4. High heat value of fuel	Hh'	kcal/kg	10,700

Calculation Form

° Fuel consumption	Fo	T/H	
$Fo = \dfrac{Po \times 860 \times \frac{\alpha}{100}}{\frac{\eta p}{100} \times Hh'}$			25.4 T/H

2. Combustion Gas Volume

Basic Specification	Abbreviation/Unit		Applying value of this project
1. Hydrogen	ho'	%	12.5
2. High heat value of fuel	Hh'	kcal/kg	10,700
3. O_2 content in flue gas	O_2	%	4.0

Calculation Form

° Low heat value of Fuel Hl'	Hl'	kcal/kg	
$Hl' = Hh' - 6\ (9 \times ho)$			10,025
° Excess air ratio m	m	-	
$m = \dfrac{21}{21 - O_2}$			1.24
° Combustion Gas Volume			
. Theorethical air volume	Ao'	Nm^3/kg-fuel	
$Ao' = 0.85 \times Hl' \times 10^{-3} + 2.0$			
. Theorethical combustion gas volume	Go'	Nm^3/kg-fuel	
$Go' = 1.11 \times Hl' \times 10^{-3}$			11.13

. Actual combustion gas volume	G		
at Wet gas condition	G'w		
$G'w = Go' + (m-1)Ao'$			13.65
at Dry gas condition	G'd		
$G'd = Gw' - \frac{0.224}{18} (9 \times ho + W')$			12.25

3. Flue Gas Volume at Boiler End

	Qb	Nm^3/H	
at wet condition			
$QwB = (Fo \times G'w) \times 10^3$	QwB	Nm^3/H	$347x10^3$
at dry condition			
$QdB = (Io \times G'd) \times 10^3$	QdB	Nm^3/H	$311x10^3$

4. Effective Height of Chimney

(apply equation of Bosanquet)

Basic Condition

1. Flue gas volume	QwB	Nm^3/H	$347x10^3$
2. Ambient temperature	ta	°C	30
3. Flue gas temperature	tg	°C	135
4. Diameter of Chimney	D	m	2.16
5. Wind velocity	U	m/s	6
6. Temperature reducing rate	$d\theta/dz$	°C/m	0.0033
7. Design height of chimney	Ho	m	120

Calculation of effective chimney height

. exhaust gas volume	Qt	m^3/s	107
$= \frac{Qw \times (273 + ta)}{3,600 \times 273}$			
. exhaust gas velocity at chimney nozzle	Vg	m/s	39
$= \frac{Qw \times (273 + tg)}{3,600 \times 273 \times \frac{\pi}{4} D^2}$			

- Raising height of flue gas by flue gas energy (momentum) — Hm — m

$$= \frac{4.77}{1 + \frac{0.43 \times U}{Vg}} \times \frac{\sqrt{Qt \times Vg}}{U}$$

$$= \frac{0.795\sqrt{Qt \times Vg}}{1 + \frac{2.58}{Vg}}$$ — 48

- Raising height of flue gas by temperature difference between flue gas and ambient — Ht — m

$$= 6.37 \times g \times \frac{Qt\ (tg - ta)}{U^3\ (273 + ta)} \times (LnJ^2 + \frac{2}{J} - 2)$$ — 46.1

$$= 1.91 \times 10^{-3} \times Qt\ (tg-ta) \times (2.3 \log J + \frac{1}{J} - 1)$$

$$J = \frac{U_2}{\sqrt{Qt \times Vg}} \times 0.43\sqrt{\frac{(273 + to)}{g(d\theta/dz)}}$$

$$- 0.28\ \frac{Vg\ (273 + ta)}{g\ (tg - ta)} + 1$$

$$= \frac{1}{\sqrt{Qt \times Vg}} (1{,}498 - \frac{312 \times Vg}{tg - ta}) + 1$$ — 22.4

- Effective height of chimney — He — m

$$= Ho + 0.65\ (Hm + Ht)$$ — 181

5. Calculation of air polutant

<u>Basic Specification</u>

1. Fuel consumption	Fo	T/H	25.4
2. Sulphur component	So	%	1.6
3. Flue gas volume at dry state	QdB	Nm^3/H	473×10^3
4. Effective height of chimney	He	m	181
5. O_2 content in flue gas	O_2	%	4.0

Calculation of SO_x emission

° SO_x volume at boiler end — q' — Nm^3/H — 284.5

$$= 7\ (Fo \times So)$$

° SO_x density at chimney nozzle — qc — ppm — 601

$$= \frac{q'}{QdB} \times 10^6$$

6. Maximum SO_x Landing Density and Distance

6-1	Maximum SO_x landing density (apply equation of Sutton) $= 1.72 \times \frac{q'}{Hc^2}$	Cmax	ppm	0.015
6-2	Maximum SO_x landing distance (apply equation of Sutton) $= 20.8 \times He^{1.143} \times 10^{-3}$	Xmax	km	7.9

ANNEX 5. ガスタービンに適用可能な燃料の検討

ANNEX 5

ガスタービンに適用可能な燃料の検討

ガスタービンに適用する燃料は、一般にガスFuelとLiquid Fuel が使用される。燃料は、１種類のケースもあるが、Multi fuelのケースもある。このClauseでは、Gss fuel, distilary fuel, Heavy oil fuelの３種類のFuelが、機器の設計と、運転中に燃料切替により与える影響をスタディしたものである。

Gas Turbine — Application of multi fuel.

Case - one

(1) Fuel distilary - Gas fuel are available.

(2) Type of combustion chamber	respective Type at proven design
(3) Operation mode	Fuel change are available on load condition

Case - two

(1) Fuel distilary- Heavy oil OK

(2) Type of combustion chamber	respective type at proven design
(3) Operation mode	Fuel change over are available on load condition

Case - three

(1) Fuel Gas - Heavy oil are available

(2) Type of combustion chamber	respective type at proven design
(3) Operation mode	Fuel change over are available on load condition

Case - four

(1) Fuel Gas - distilary - Heavy Fuel

(2) Type of combustion chamber	respective type peculiar design
(3) Operation mode	Fuel change over are available on load condition

ANNEX 6　軽負荷時における発電所の運転

ANNEX 6　軽負荷時における発電所の運転

Barka P.S. (740MW) の運開により、1989年のMEWの発電所の出力規模は、1,008MW から1,748MW に、発電機台数は30台から40台に増加する。これらの発電機は季節的或いは時間的な負荷変動に対応して、供給信頼度の高い運転を行う必要がある。MEWの Capital area及びBatinah coast areaの電力及び水の需要を満たし、かつ運転中の発電機が万一の事故により系統から脱落した場合でも系統の周波数低下を極力小さくする様な発電機の運転方法を検討した。

検討期間は1988～1992年とし、各年の6月（最大需要時）及び2月（最低需要時）の2断面を対象にした。

検討の前提条件を次の通りに設定した。

(1) 1989年4月にCapital areaとBatinah coast areaの電力系統は単一系統を構成する。

(2) Capital areaとBatinah coast areaは原則としてそれぞれの系統で需給バランスを保つことにする。

(3) Barka P.S.は1988年7月に 1.2号機が運開される予定であるが、1988年6月のピーク需要をこれらの発電機の試運転による電力で賄うことにする。

(4) 原則として、大容量発電機の単機出力は、総需要の10%以下に制限する。但し、Rusail P.S. 及びBarka P.S.の発電機出力は40MW（定格の約50%）迄減少させる。

(5) 軽負荷時には、大容量機による負荷の分担を出来るだけ少なくする。但し、電力系統の信頼度上から、各発電所とも最低一台は発電機を並列しておく。

(6) 造水設備を付属している発電機は、水の需要に合わせて運転する。

(7) 需給調整は原則として、下記の方法による。

1) 軽負荷時にRusail及びBarka P.S.の発電機出力を40MW迄制限している場合は、Ghuburah P.S. の27.5MW及び17.5MWで需給調整を行う。

2) Rusail 及びBarka の発電機出力を40MW以上で運転出来る需要規模では、Rusailの発電機で需給調整を行う。

3) 夏期は30MW以上、冬期は10MW以上のガスタービン発電機をガバナフリー運転する。

各変電所の最大需要（6月）と最低需要（2月）をTable 1 とTable 2 に示す。

Table 1 及びTable 2 の需要を満たす各発電所の発電機出力を求めるとTable 3 に示すようになる。

各発電所がTable 3 のような運転をすれば電力需要と共に水需要についても条件を満足

することが出来る。

但し、Table 3 に示した各発電機の出力は単なる一例であり、実施に当たっては発電機の性能，運転経費及び系統条件（電圧維持，送電損失，需要分布）を更に検討する必要がある。

最低需要時において万一最大出力の発電機がトリップした場合、周波数は1989年には、47.52 Hz迄低下するが、その後需要の延びと共に低下する割合は序々に減って来て、1993年以降の周波数低下値は運転許容限界の 1.5Hz以内に抑えられる。

1989年から1992年におけるオフピーク時には、1台当りの発電機出力を抑制するだけでは周波数低下を許容範囲（48.5Hz）に維持出来ないので、周波数低下リレーにより部分的な負荷遮断を実施し、系統の需給バランスを維持し、周波数低下を防ぐものとする。

Table 1 Demand Forecast at Each Substation in June

(MW)

Substations \ Year	Peak Load (100%)								Minimum Load (53.5%)								Remarks
	1988	1989	1990	1991	1992	1993	1994	1995	1988	1989	1990	1991	1992	1993	1994	1995	
Al Falaj	84	94	105	114	122	129	136	143	45	50	56	61	65	69	73	77	
Wadi Khabir	84	94	105	114	122	129	136	143	45	50	56	61	65	69	73	77	
Wadi Adai	83	94	104	114	121	129	135	143	44	50	56	61	65	69	72	77	
Qaboos	76	81	95	110	120	131	136	141	41	43	51	59	64	70	73	75	
Khuwair	50	65	85	105	120	131	136	141	27	35	45	56	64	70	73	75	
Ghubrah	89	96	103	110	115	120	125	130	48	51	55	59	62	64	67	70	
Air Port Heights	40	80	95	110	117	124	132	141	21	43	51	59	63	66	71	75	
Rusail	187	191	196	203	211	220	228	237	100	102	105	109	113	118	122	127	
Seeb Palace	48	50	53	56	59	62	65	69	26	27	28	30	32	33	35	37	
Barka	40	46	50	55	61	68	76	84	21	25	27	29	33	36	41	45	
Musanna	17	19	22	25	29	33	38	44	9	10	12	13	16	18	20	24	
Rustaq	21	24	27	32	36	42	48	55	11	13	14	17	19	22	26	29	
Suwaiq	21	24	28	32	37	42	49	56	11	13	15	17	20	22	26	30	
Khabourah	13	16	18	20	24	27	31	36	7	9	10	11	13	14	17	19	
Saham	23	27	32	37	43	49	56	65	12	14	17	20	23	26	30	35	
Sohar	30	37	44	50	57	66	76	87	16	20	24	27	30	35	41	47	
Shinas	8	10	11	13	15	17	20	23	4	5	6	7	8	9	11	12	
Copper Mine	17	17	17	17	17	17	17	17	9	9	9	9	9	9	9	9	
Buraimi	56	66	75	83	95	106	116	131	30	35	40	44	51	57	62	70	
Ibri	44	52	61	68	78	87	96	109	24	28	33	36	42	47	51	58	
Capital Area	840	958	1,068	1,180	1,270	1,360	1,440	1,527	449	512	571	631	681	726	772	818	(Including Musanna, Rustaq, Suwaiq)
Batinah Area	191	225	258	288	329	369	412	468	102	120	139	154	176	197	221	250	
Grand Total	1,031	1,183	1,326	1,468	1,599	1,729	1,852	1,995	551	632	710	785	857	923	993	1,068	

Table 2 Demand Forecast at Each Substation in February

(MW)

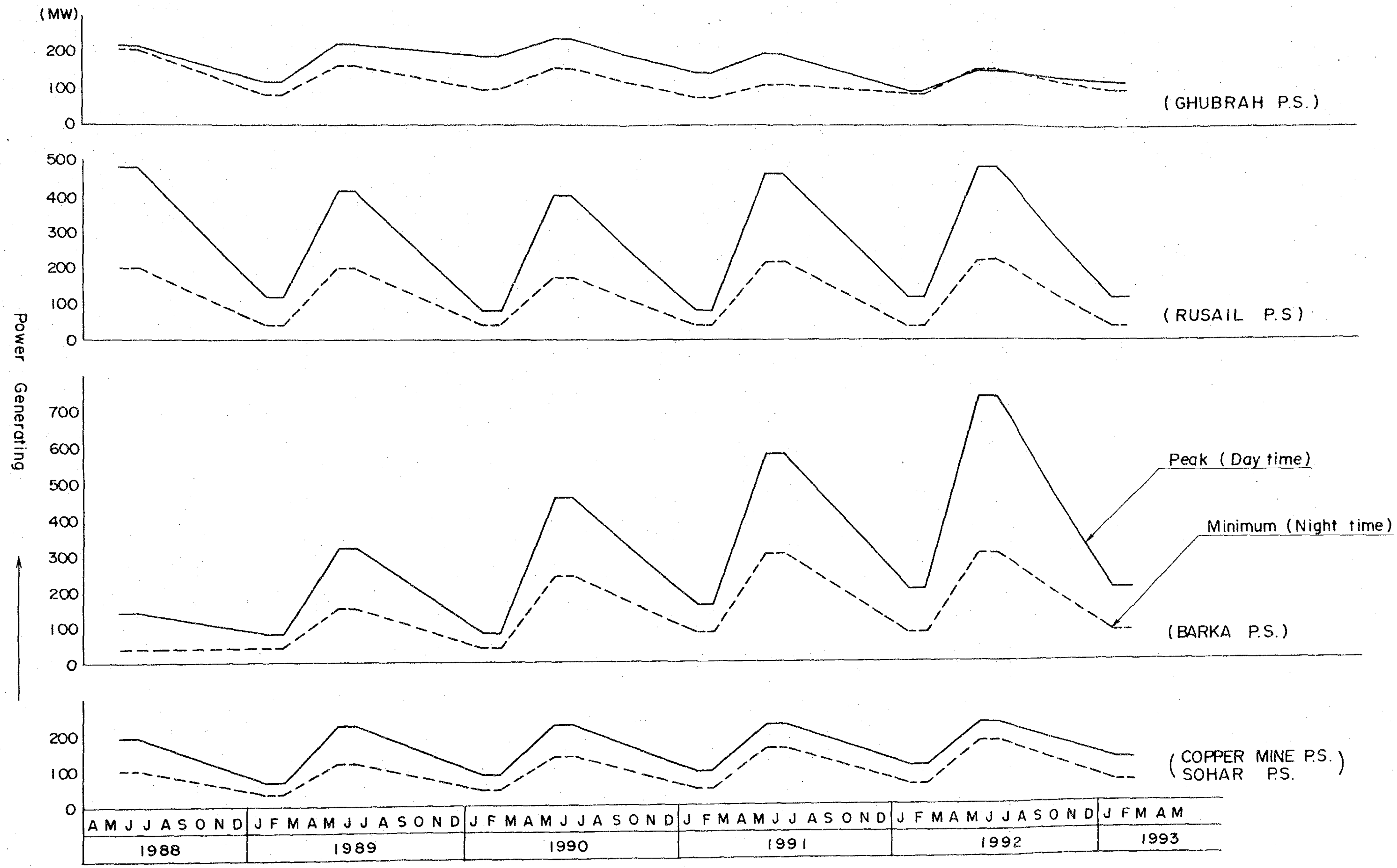
Year / Substations	Peak Load (32.8%)								Minimum Load (16.5%)								Remarks
	1988	1989	1990	1991	1992	1993	1994	1995	1988	1989	1990	1991	1992	1993	1994	1995	
Al Falaj	28	31	34	37	40	42	45	47	14	16	17	19	20	21	23	24	
Wadi Khabir	28	31	34	37	40	42	45	47	14	16	17	19	20	21	22	24	
Wadi Adai	27	31	34	37	40	42	44	47	14	15	17	19	20	21	22	23	
Qaboos	25	27	31	36	39	43	45	46	12	13	16	18	20	22	22	23	
Khuwair	16	21	28	34	39	43	45	46	8	11	14	17	20	22	22	23	
Ghubrah	29	31	34	36	38	40	41	43	15	16	17	18	19	20	21	21	
Air Port Heights	13	26	31	36	38	41	43	46	7	13	16	18	19	20	22	23	
Rusail	61	63	64	67	69	72	75	78	31	31	32	33	35	36	38	39	
Seeb Palace	16	16	17	18	19	20	21	23	7	8	9	9	10	10	11	11	
Barka	13	15	16	18	20	22	25	28	7	8	8	9	10	11	13	14	
Musanna	5	6	7	8	10	11	12	14	3	3	4	4	5	5	6	7	
Rustaq	7	8	9	11	12	14	16	18	4	4	5	5	6	7	8	9	
Suwaiq	7	8	9	11	12	14	16	18	4	4	5	5	6	7	8	9	
Khabourah	4	5	6	7	8	9	10	12	2	3	3	3	4	4	5	6	
Saham	7	9	10	12	14	16	18	21	4	4	5	6	7	8	9	11	
Sohar	10	12	14	16	19	22	25	29	5	6	7	8	9	11	13	14	
Shinas	3	3	4	4	5	6	7	8	1	2	2	2	2	3	3	4	
Copper Mine	6	6	6	6	6	6	6	6	3	3	3	3	3	3	3	3	
Buraimi	18	22	25	27	31	35	38	43	9	11	12	14	16	17	19	22	
Ibri	14	17	20	22	26	29	31	36	7	9	10	11	13	14	16	18	
Capital Area	275	314 (319)	348	386	416	446	473	501	140	158 (161)	177	193	210	223	238	250	(Including Musanna, Rustaq, Suwaiq)
Batinah Area	62	74 (69)	85	94	109	123	135	155	31	38 (35)	42	47	54	60	68	78	( ): Khabourah
Grand Total	337	388	433	480	525	569	608	656	171	196	219	240	264	283	306	328	

Table 3 Power Generation Program

(MW)

P.S.	No.	Unit	Capacity	1988 Jun.		1989 Feb.		1989 Jun.		1990 Feb.		1990 Jun.		1991 Feb.		1991 Jun.		1992 Feb.		1992 Jun.		1993 Feb.		Remarks
				Peak	Min.	Peak	Min.	Peak	Min.	Peak	Min.	Peak	Min.	Peak	Min.	Peak	Min.	Peak	Min.	Peak	Min.	Peak	Min.	
Demand (Capital)				840	449	319	161	958	512	348	177	1,068	571	386	193	1,180	631	416	210	1,270	681	446	223	
GHUBRAH (285 MW)	1	Steam	50 MW	50	50	40	40	50	50	40	40	50	50	40	40	50	50	40	40	50	50	40	40	
	1	Gas	17.5	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	Except steam 7.5 MW x 3
	2	"	"	17	17	17		17	17	17	17	17	17	17		17	17	17	17	17	17	17		
	3	"	"	17	17			17	17	17		17	17	17		17				17	17			
	4	"	"	17	17			17	17	17		17		17		17								
	5	"	"	17	17			17	17	17		17		17		17								
	6	"	"	17	17			17		17		17				17								
	7	"	"	17	17			17				*17				10								* to Batinah
	8	"	"									*16				10								
	9	"	"																					
	1	Gas	27.5	27	20	27	24	27	27	27	23	27	27	21	16	27	27	22	16	27	27	27	27	
	2	"	"	24	20	18		27		19		27	27							*24	27	25	19	
		Total		220	209	119	81	223	162	188	97	239	155	146	73	199	111	96	90	152	155	126	103	
RUSAIL (498 MW)	1	Gas	83 MW	80	40	40	40	83	50	40	40	83	60	40	40	83	60	40	40	83	60	40	40	
	2	"	"	80	40	40		83	50	40		83	60	40		83	60	40		83	60	40		
	3	"	"	80	40	40		83	50			83	56			83	60	40		83	60	40		
	4	"	"	80	40			83	50			83				83	40			83	46			
	5	"	"	80	40			83				70				69				83				
	6	"	"	80												*63				67				
		Total		480	200	120	40	415	200	80	40	402	176	80	40	464	220	120	40	482	226	120	40	
BARKA (740 MW)	1	Gas	80 MW	70	40	40	40	80	50	40	40	80	60	40		80	60	40		80	60	40		
	2	"	"	70		40		80	50	40		80	60	40		80		40		80	60	40		
	3	"	"					80	50			80				80				80				
	4	"	"					80				80				80				80				
	5	"	"																	*80				
	1	Steam	80									80	60			80	60			80		40		
	2	"	"																	80				
	1	"	60									60	60	40	40	60	60	40	40	60	60	40	40	
	2	"	"											40	40	60	60	40	40	60	60	40	40	
	3	"	"													60	60			60	60			
		Total		140	40	80	40	320	150	80	40	460	240	160	80	580	300	200	80	740	300	200	80	
Demand (Batinah)				191	102	69	35	225	120	85	42	258	139	94	47	288	154	109	54	329	176	123	60	
COPPER MINE (165 MW)	1	Gas	17 MW	17	17	17	10	17	15			17	17	17		17	10	11		17	17	17		
	2	"	"	17		12	10	17	15			17	17	17		17		11		17	17			
	3	"	"	13				17				17				17				17				
	1	"	27	27	25	20		27		25		27	27			27	27	27		27	27	23		
	2	"	"	27				27				27	18			27	27			27	27	23		
	1	"	30	30	30			30	30	30	21	30		30	23	30	30	30	27	30	28	30	30	
	2	"	"					30				30				30				30				
SOHAR (60 MW)	1	Gas	30 MW	30	30	20	15	30	30	30	21	30	30	30	24	30	30	30	27	30	30	30	30	
	2	"	"	30				30	30			30	30			30	30			30	30			
		Total		191	102	69	35	225	120	85	42	225	139	94	47	225	154	109	54	225	176	123	60	
Frequency Drop (HZ)	Largest generator unit drops			49.05	49.11	48.75	47.52	49.30	49.21	49.08	48.17	49.37	49.15	49.17	48.33	49.43	49.24	49.24	48.48	49.48	49.30	49.30	48.59	
	120 MW drops in June			48.57	47.33			48.99	48.10			49.10	48.31			49.18	48.47			49.25	48.60			reference value
	60 MW drops in February					48.12	46.27			48.61	47.26			48.75	47.50			48.86	47.73			48.95	47.88	

Fig. 1 POWER GENERATION PROGRAM



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