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Appendix A

Low Heating Value Calculation

Assume that all calcium in both lignite and oil shale was in carbonate form.

Calcium presented in lignite	=	1.85 %
	=	1.85/40
	=	0.04625 %mole
Thus, C presented as CO_3	=	0.04625 %mole
	=	0.04625*12
	=	0.555 %
O presented as carbonate	=	0.04625*3
	=	0.13875 %mole
	=	0.13875*16
	=	2.22 %

From equation (5.1), low heating value of lignite =

8,080(41.05-0.555)/100 + 28,800{2.75-(26.30+2.22)/8}/100 + 2,500(1.6)/100 - 600{(9/8)*0.2408+0.1744} = 2,970 cal/gm

Low heating value of oil shale can be calculated in the similar manner.

Appendix B

Equivalent Fuel Feed Rate Calculation Based on Low Heating Value

Determine the feed rate for the mixture of oil shale to lignite weight ratio of 7:1.

The low heating value based feed rate

= the rate of thermal generation available from pure lignite combustion

= 5.814(kg/hr) * 2974(kcal/kg)

= 17,291 kcal/hr

Average heating value of 7:1 mixture

= {(oil shale fraction)(oil shale heating value) + (lignite fraction)(lignite heating value)}/ total fraction

= (7*1598 + 1*2970)/(7+1) = 1,770 kcal/kg

Thus, this mixture feed rate should be

17,291/1,770 = 9.769 kg/hr

Fuel mixtures of other proportions can be evaluated for the corresponding feed rates as the preceding procedure.

Appendix C

Stoichiometric Air Calculation

Referred to Table 5.1. Assume all Ca in the fuel is in the form of $CaCO_3$.

Ca in all oil shale = 4.35 weight %

Assume 100 kg oil shale basis.

Thus, Ca in oil shale = 4.35 kg

= 4.35/40

= 0.10875 kg-atom

C as CO_3 = 0.10875 kg-atom and

O as CO_3 = 0.10875*3

= 0.32625 kg-atom

Then, free C = 15.93/12 - 0.10875

= 1.21875 kg-atom

free O = 7.82/16 - 0.32625

= 0.1625 kg-atom

Oxygen required for reaction $C + O_2 \longrightarrow CO_2$

= 1.21875*2

= 2.4375 kg-atom

Oxygen required for reaction $H_2 + 1/2O_2 \longrightarrow H_2O$

= 1.82/2

= 0.91 kg-atom

Oxygen required for reaction $S + O_2 \longrightarrow SO_2$

= 0.67*2/32

= 0.041875 kg-atom

Thus, total O required = 2.4375 + 0.91 + 0.041875 - 0.1625

= 3.226875 kg-atom or

as O_2 = 1.6134375 kg-mole or

as air = 1.6134375*29

= 222.81 kg/100 kg oil shale

= 222.81/(100*1.295)

= 1.73 Nm^3/kg oil shale

Stoichiometric air for other fuel mixtures can be calculated in the same procedure.

Appendix D

Elutriation Rate Calculation

Performing sulfur balance around the reactor.

S in with fuel feed = S out with (ash+fly ash+flue gas)

$$F_F S_F = F_A S_A + F_E S_E + Q_G \rho_G c_{SO_2} M_S / M_{SO_2} \quad \text{or}$$

$$F_E = \frac{F_F S_F - F_A S_A - Q_G \rho_G c_{SO_2} M_S / M_{SO_2}}{S_E}$$

where F = mass flow rate, kg/hr

S = sulfur concentration, weight %

Q = dry basis volumetric flow rate, m^3/hr

ρ = density, kg/m^3

c = dry basis weight fraction

M = molecular weight

subscript .

F = fuel feed

A = ash

E = elutriated fly ash

G = flue gas

S = sulfur

SO_2 = sulfur dioxide

Take data from experiment number 10 shown in Table 6.1 for an example.

$$F_E = [\{8.904(3*0.0067 + 1*0.016)/4\} - 3.72(0.0144) - 67*1.217*19*10^{-6}*32/64]/0.037$$

$$= 0.704 \text{ kg/hr}$$

whereby the dry basis volumetric flow rate of flue gas was assumed to be equal to the fresh air feed rate, and the flue gas density was calculated from ideal gas law as follows:

$$PV = nRT$$

$$\rho_G = nM/V = PM/RT$$

where P = flue gas pressure of which is approximate to atmospheric

M = flue gas molecular weight of which is mole-averaged from three main gases, i.e. nitrogen, carbon dioxide, and oxygen

R = ideal gas constant

= $82.057*10^{-3}$ $(atm\text{-}m^3)/(kgmole\text{-}K)$

T = temperature of flue gas while analysing

= ambient temperature = 308 K

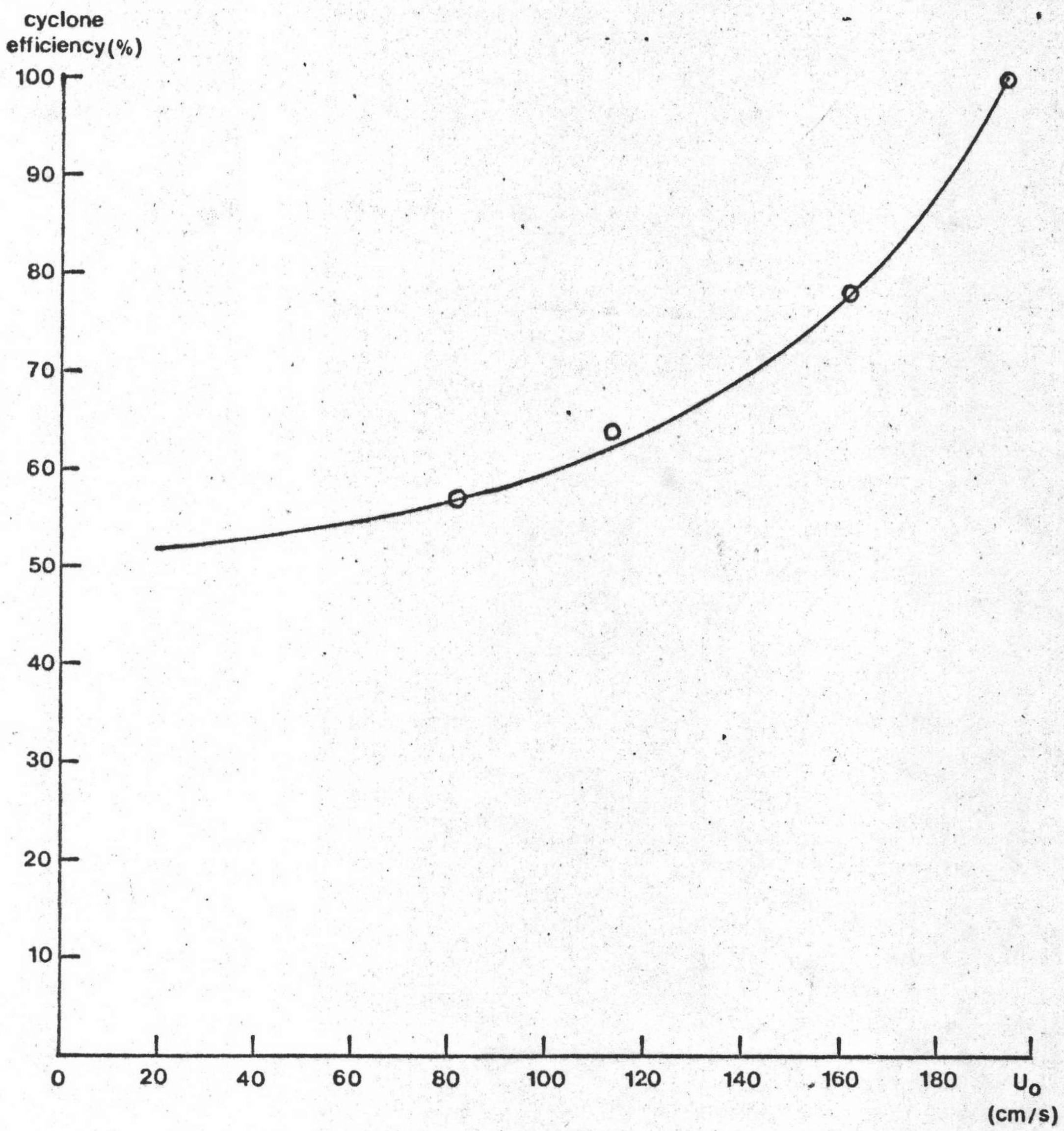
Thus, in the above-mentioned case,

$$\rho_G = \frac{1(atm)*(0.802*29 + 0.098*44 + 0.1*32)(kg/kgmole)}{82.057*10^{-3}(atm\text{-}m^3/kgmole\text{-}K)*308(K)}$$

$$= 1.217 \quad kg/m^3$$

Appendix E

Cyclones Efficiency as a Function of Superficial Gas Velocity



Note: The graph was obtained from experiments using lignite particles of smaller than 0.3 mm.

Appendix F

Comparision of Carbon Combustion Efficiency

of this Research with of the Prior Works

	Materials	L/CaM	Ca/S	d_p L (mm)	d_p CaM (mm)	HV (cal/gm)	Fuel Rate (kcal/hr)	u_{or} (cm/s)	u_{ob} (cm/s)	Q (m^3/hr)	EA (%)	A/F	T_b (^oC)	n_c	CO (ppm)	SO_2 (ppm)
This work	lignite and oil shale	1	2.2	2.59	2.61	2286	17,291	107	333	68	238	10.32	687	96.67	2597	21
Nattawut	lignite and limestone	1	12.0	2.41	.927		16,968	97	409	60	311	19.60	876	91.00	1307	64
This work	lignite and oil shale	1	2.2	2.59	2.61	2286	24,620	113	436	72	151	7.67	857	94.76	5186	30
Nattawut	lignite and limestone	1	12.0	2.41	.927		25,071	97	396	60	178	13.62	839	87.94	2246	52
This work	lignite and oil shale	1	2.2	2.59	1.44	2286	14,127	69	250	44	111	8.17	841	96.53	4044	468
Nattawut	lignite and limestone	1	12.0	2.41	.927		16,968	73	201	45	208	14.70	881	90.85	3514	65
Nattawut	lignite and limestone	1	12.0	2.41	.927		25,071	73	330	45	109	9.94	964	93.17	6366	68
This work	Mae Sot oil shale				2.61	1598	17,291	113		72	284	7.64	744	96.51		
Jayant	Mae Sot oil shale				2.29	2091	19,844	110		70	74	5.03	929	98.39		
This work	Mae Sot oil shale				1.44	1598	17,291	47		30	60	3.18	664	86.89		
Jayant	Mae Sot oil shale				1.15	1902	14,626	47		30	48	3.95	891	98.50		
This work	Mae Sot oil shale				1.44	1598	17,291	55		35	87	3.71	670	91.47		
Jayant	Mae Sot oil shale				1.15	1902	14,626	55		35	66	4.45	911	98.46		

L/CaM = weight lignite to calcium bearing material ratio.

Ca/S = calcium to sulfur mole ratio.

d_pL = lignite particles average diameter.

d_pCaM = average diameter of calcium bearing materials.

HV = heating value.

u_{or} = superficial gas velocity at room temperature.

u_{ob} = superficial gas velocity at bed temperature.

Q = gas volumetric flow rate at room temperature.

EA = excess air.

A/F = air to fuel mass ratio.

T_b = bed temperature.

n_c = carbon combustion efficiency.

Note: The experimental apparatus used in this work and by Nattawut was the same.

Experiments carried out by Jayant were done in a fluidized bed combustor having no in-bed and freeboard water tubes and the carbon combustion efficiencies were calculated based on the assumption of drained ash and fly ash composition equivalence.

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