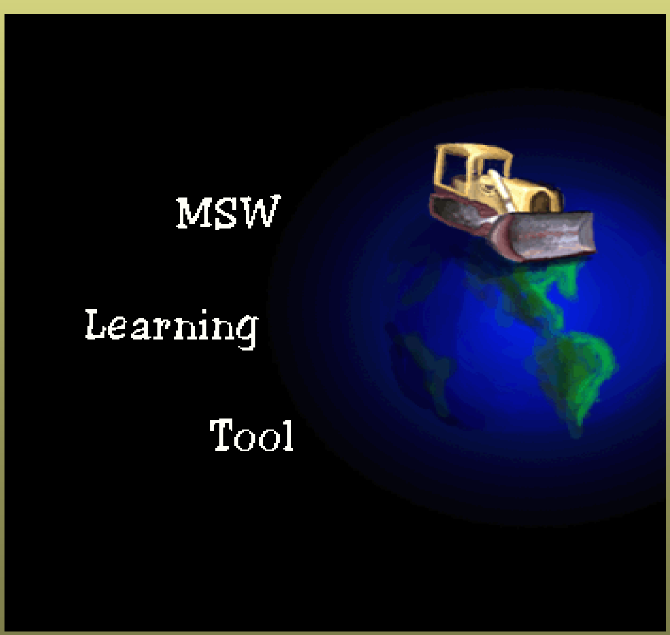
Incineration Exercise



Objectives

- Compute the composition of flue gas
- Compute the temperature of flue gas (a function of waste heat value and composition)
- Compute the amount of air required

Step 1: Waste Composition

- Determine the chemical composition (g), water content (g), and energy content

Step 1: Calculate chemical composition, water content, and energy content.											
Component	Composition	Moisture	Energy	Dry	--------------- Chemical Composition (dry basis) --------------						Energy
	(%, by weight)	Content	Content	Weight	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash	(Joules)
		(%, by weight)	(J/g)	(g)							
Food Waste	9	70	4645	2.7	1.296	0.173	1.015	0.070	0.011	0.135	41,802
Paper	34	6	16721	32.0	13.903	1.918	14.062	0.096	0.064	1.918	568,513
Cardboard	6	5	16256	5.7	2.508	0.336	2.542	0.017	0.011	0.285	97,539
Plastics	7	2	32513	6.9	4.116	0.494	1.564	0.000	0.000	0.686	227,591
Textiles	2	10	17418	1.8	0.990	0.119	0.562	0.083	0.003	0.045	34,835
Rubber	0.5	2	23224	0.5	0.382	0.049	0.000	0.010	0.000	0.049	11,612
Leather	0.5	10	17418	0.5	0.270	0.036	0.052	0.045	0.002	0.045	8,709
Yard Wastes	18.5	60	6503	7.4	3.537	0.444	2.812	0.252	0.022	0.333	120,298
Wood	2	20	18579	1.6	0.792	0.096	0.683	0.003	0.002	0.024	37,158
Glass	8	2	139	7.8	0.039	0.008	0.031	0.008	0.000	7.754	1,115
Tin Cans	6	3	697	5.8	0.262	0.035	0.250	0.006	0.000	5.267	4,180
Alumiinum	0.5	2	0	0.5	0.022	0.003	0.021	0.000	0.000	0.443	0
Other Metal	3	3	697	2.9	0.131	0.017	0.125	0.003	0.000	2.634	2,090
Dirt, ash, etc.	3	8	6967	2.8	0.726	0.083	0.055	0.014	0.006	1.877	20,901
sum:	100			78.8	28.97	3.81	23.78	0.61	0.12	21.49	1,176,343

Step 2 and 3: Determine the moles of Oxygen required

- Step 2: convert chemical composition and water content from g to g-mole using molecular weights
- Step 3: Determine the moles of oxygen required to combust the sample completely

C+02--->CO2
4H+02--->2H20
20--->02
2N--->N2
S+02--->SO2

Note: oxygen in the waste mass is released during the combustion process and decreases the oxygen required for stoichiometric combustion

Step 2 and 3:

Component	Weight (g)	Molecular Weight	Moles (g*mol)	Moles 02 req'd	
Carbon	28.97	12			C+02--->CO2
Hydrogen	3.81	1			4H+02--->2H20
Oxygen	23.78	16			2O -->O2
Nitrogen	0.61	14			2N--->N2
Sulfur	0.12	32.1			S+02--->SO2
Water	21.22	18			
Inerts (Ash)	21.49	n/a		0	
	100.00				
Oxygen for combustion of 100 g of MSW					g*mol

Step 2 and 3:						
Component	Weight	Molecular	Moles	Moles 02		
	(g)	Weight	(g*mol)	req'd		
Carbon	28.97	12	2.414	2.414	C+02--->CO2	
Hydrogen	3.81	1	3.810	0.95	4H+02--->2H20	
Oxygen	23.78	16	1.486	-0.743	2O -->O2	
Nitrogen	0.61	14	0.043	0	2N--->N2	
Sulfur	0.12	32.1	0.004	0.004	S+02--->SO2	
Water	21.22	18	1.179	0		
Inerts (Ash)	21.49	n/a		0		
	100.00					
Oxygen for combustion of 100 g of MSW				2.63	g*mol	

Step 4: Composition of Flue Gas

- Calculate the composition of gas produced by combustion of waste
- Be sure to add the water content in the waste sample to the water produced by combustion

Step 4					
Componen	Moles	Combustion		Combustion	
	(g*mol)	Pathway		Product	(g*mol)
Carbon		C+02--->CO2		CO2	
Hydrogen		4H+02--->2H20		H2O	
Oxygen					n/a
Nitrogen		2N --->N2		N2	
Sulfur		S+02--->SO2		SO2	
Water		H2O --->H20			

Step 4					
Component	Moles	Combustion		Combustion	
	(g*mol)	Pathway		Product	(g*mol)
Carbon	2.414	C+02--->CO2		CO2	2.414
Hydrogen	3.810	4H+02--->2H20		H2O	3.084
Oxygen	1.486				n/a
Nitrogen	0.043	2N --->N2		N2	0.022
Sulfur	0.004	S+02--->SO2		SO2	0.004
Water	1.179	H2O --->H20			5.524

Step 5: Calculate the Air Requirements

- Calculate the air supply required to provide the oxygen needed for stoichiometric combustion
- Moles of air required =

Required O_2 supply/O_2 mole fraction

Typical Air Composition (mole fractions)

Air Composition		
Component	mole fraction	
CO_2	0.0003	
N_2	0.7802	
O_2	0.2069	
H_2O	0.0126	

Moles of Air required per 100 g of waste		g*mol

Step 5

Moles of air = 2.63/0.2069

= 12.7 g-moles

Step 6: Composition of Air Supplied

- Calculate the moles of each gas component supplied in air using the air composition provided in Step 5

Step 6: Composition of supplied air		
	Component	Air supply
		(g*mol)
	CO2	
	N2	
	O2	
	H2O	
	SO2	
	sum:	12.70

Step 6: Composition of supplied air		
	Component	Air supply
		(g*mol)
	CO2	0.004
	N2	9.909
	O2	2.628
	H2O	0.160
	SO2	0.000
	sum:	12.70

Step 7: Determine the Composition of Flue Gas

- Stoichiometric (0% excess air) gas composition
- Add Step 4 results to Step 6 results
- Calculate in both moles and percent
- Sum moles to calculate total moles gas production

Step 7: Flue gas composition				
Combustio	--------- Moles of Flue Gas ---------			
Product	Combustion	Air Supply	Total	Percent
	Product Gas			
CO2				
H20				
O2				
N2				
SO2				
	5.52	10.07	15.60	100.0

Step 7: Flue gas composition				
Combustion	--------- Moles of Flue Gas ---------			
Product	Combustion	Air Supply	Total	Percent
	Product Gas			
CO2	2.41	0.00	2.42	15.50
H20	3.08	0.16	3.24	20.80
O2	0.00	0.00	0.00	0.00
N2	0.02	9.91	9.93	63.67
SO2	0.00	0.00	0.00	0.02
	5.52	10.07	15.60	100.00

Step 8: Calculate the Flue Gas Enthalpy

- Joules/g-mole is a function of temperature and compound, this function is complex, nonlinear
- We will calculate the enthalpy of the flue gas at various temperatures (1000, 1500, 2000, 2500^{o}F) using enthalpy data for individual gases and flue gas composition
- Total Joules/g-mole is a weighted average of all gases present

Required Enthalpy Data

Temp	CO2	H20	O2	N2
1000	23335	62529	16196	15606
1500	37655	73719	25565	24515
2000	52762	85702	35279	33721
2500	68600	98480	45325	43217

Step 8: Calculate flue gas enthalpy							
Temp, F	Btu/lb*mol		Temp	CO2	H20	O2	N2
1000			1000	23335	62529	16196	15606
1500			1500	37655	73719	25565	24515
2000	47477		2000	52762	85702	35279	33721
2500			2500	68600	98480	45325	43217

Step 8: Calculate flue gas enthalpy

Temp, F	Joules/g*mol	
1000	26561	
1500	36780	
2000	47477	
2500	58636	

Step 9: Convert Enthalpy in Gas to Heat Value of Waste

Joules/g waste = (Enthalpy in Joules/g-mole)*

moles of flue gas (from Step 7)/(100 g of waste)

Step 9: Convert enthalpy from Joules/g*mole to Joules/g waste

Temp, F	Joules/g waste			
1000				
1500				
2000	7405			
2500				

(47477 Joules/g-mole)(15.6 g-moles/100 g of waste)

= **7405 Joules/g waste**

Step 9: Convert enthalpy from Joules/g*mole to Joules/g waste				
Temp, F	Joules/g waste			
1000	4143			
1500	5737			
2000	7405			
2500	9146			

Step 10: Flue Gas Temperature

- Determination based on conservation of energy (Energy In = Energy Out - Losses)
- Knowing energy is transferred from waste to gas we can interpolate from Step 9 the temperature corresponding to the heat value of the waste

Step 10: Continued

- Calculate the temperature of the flue gas assuming no losses by using the energy content of the waste to interpolate between temperatures using information calculated in Step 9
- Calculate temperature of the flue gas assuming an efficiency of combustion

Step 10:				
Case A: No losses				
	Energy in flue gas		11763	J/g
	Temperature			F
Case B: 20% losses				
	Efficiency		80	%
	Energy in flue gas		9411	J/g
	Temperature			F

Step 10:				
Case A: No losses				
	Energy in flue gas		11763	J/g
	Temperature		3252	F
Case B: 20% losses				
	Efficiency		80	%
	Energy in flue gas		9411	J/g
	Temperature		2576	F

Excess Air Calculation

- Combustion is generally not done without excess air. Excess air is supplied to control temperature and increase mixing to ensure complete combustion

Excess Air Calculations - Step 11A

- Determine how many moles of air will be added:

(%EA/100)*(moles req'd for 0% EA (Step 5))

Step 11A - 25% Excess Air

12.7 g moles * 25/100 = 3.18 g moles

Excess Air Calculations -Step 11B

- Determine composition (g mole) of extra air supplied using air composition Step 5
- Add gas components from Step B to gas components (g moles) from Step 7 for 0% excess air
- Sum moles and convert to percentage composition

Step 11B - 25% Excess Air

Combustio	Base flue gas	Excess	Total	
Product	from 0% EA	Air		Percent
	g*mol	g*mol	g*mol	
CO2				
H20				
O2				
N2				
SO2				
sum:	15.60	3.18	18.77	100.0

Combustion	Base flue gas	Excess	Total	
Product	from 0% EA	Air		Percent
	g*mol	g*mol	g*mol	
CO_2	2.418	0.001	2.42	12.9
H20	3.244	0.040	3.28	17.5
O_2	0.000	0.657	0.66	3.5
N_2	9.931	2.477	12.41	66.1
SO_2	0.004	0.000	0.00	0.0
sum:	15.60	3.18	18.77	100.0

Excess Air Calculation - Step 11C

- Repeat Steps 8 through 10
- In Step 9, use the moles of gas calculated in Step 11B

Temp, F	Joules/g*mol		Temp	CO2	H20	O2	N2
1000			1000	23335	62529	16196	15606
1500			1500	37655	73719	25565	24515
2000			2000	52762	85702	35279	33721
2500			2500	68600	98480	45325	43217

Temp, F	Joules/g*mol
1000	24829
1500	34848
2000	45316
2500	56221

Temp, F	Joules/g waste
1000	
1500	
2000	
2500	

Temp, F	Joules/g waste
1000	4661
1500	6542
2000	8507
2500	10554

Case A: No losses				
	Energy in flue gas		11763	Joule/g
	Temperature			F
Case B: 20% loss				
	Efficiency		80	%
	Energy in flue gas		9411	Joules/g
	Temperature			F

Case A: No losses				
	Energy in flue gas		11763	Joules/g
	Temperature		2795	F
Case B: 20% loss				
	Efficiency		80	%
	Energy in flue gas		9411	Joules/g
	Temperature		2230	F

Repeat for 50%, 75%, and 100% Excess Air

50	**% Excess Air**							
	Extra air supplied:		6.35	g*mol				
Combustion	Base flue gas	Excess	Total					
Product	from 0% EA	Air		Percent				
	g*mol	g*mol	g*mol					
CO2	2.418	0.002	2.42	11.0				
H20	3.244	0.080	3.32	15.1				
O2	0.000	1.314	1.31	6.0				
N2	9.931	4.955	14.89	67.8				
SO2	0.004	0.000	0.00	0.0				
sum:	15.60	6.35	21.95	100.0				
Temp, F	Joules/g*mol		Temp	CO2	H20	O2	N2	
1000	23598		1000.00	23335	62529	16196	15606	
1500	33475		1500.00	37655	73719	25565	24515	
2000	43781		2000.00	52762	85702	35279	33721	
2500	54505		2500.00	68600	98480	45325	43217	
Temp, F	Jules/g waste							
1000	5179.2							
1500	7346.9							
2000	9608.8							
2500	11962.5							
Case A: No losses								
	Energy in flue gas		11763	Joules/g				
	Temperature		2476	F				
Case A: No losses								
	Efficiency		80	%				
	Energy in flue gas		9411	Joules/g				
	Temperature		1976	F				

75	**% Excess Air**							
	Extra air supplied:		9.53	g*mol				
Combustion	Base flue gas	Excess	Total					
Product	from 0% EA	Air		Percent				
	g*mol	g*mol	g*mol					
CO2	2.418	0.003	2.42	9.6				
H20	3.244	0.120	3.36	13.4				
O2	0.000	1.971	1.97	7.8				
N2	9.931	7.432	17.36	69.1				
SO2	0.004	0.000	0.00	0.0				
sum:	15.60	9.53	25.12	100.0				
Temp, F	Joules/g*mol		Temp	CO2	H20	O2	N2	
1000	22678		1000.00	23335	62529	16196	15606	
1500	32449		1500.00	37655	73719	25565	24515	
2000	42634		2000.00	52762	85702	35279	33721	
2500	53222		2500.00	68600	98480	45325	43217	
Temp, F	Btu/lb waste							
1000	5697.5							
1500	8152.0							
2000	10710.8							
2500	13370.9							
Case A: No losses								
	Energy in flue gas		11763	Joules/g				
	Temperature		2206	F				
Case A: No losses								
	Efficiency		80	%				
	Energy in flue gas		9411	Joules/g				
	Temperature		1756	F				

100	**% Excess Air**						
	Extra air supplied:		12.70	g*mol			
Combustion	Base flue gas	Excess	Total				
Product	from 0% EA	Air		Percent			
	g*mol	g*mol	g*mol				
CO2	2.418	0.004	2.42	8.6			
H20	3.244	0.160	3.40	12.0			
O2	0.000	2.628	2.63	9.3			
N2	9.931	9.909	19.84	70.1			
SO2	0.004	0.000	0.00	0.0			
sum:	15.60	12.70	28.30	100.0			
Temp, F	Joules/g*mol		Temp	CO2	H20	O2	N2
1000	21965		1000	23335	62529	16196	15606
1500	31653		1500	37655	73719	25565	24515
2000	41744		2000	52762	85702	35279	33721
2500	52227		2500	68600	98480	45325	43217
Temp, F	Joules/g						
1000	6215.7						
1500	8957.1						
2000	11812.7						
2500	14779.4						
Case A: No losses							
	Energy in flue gas		11763.43	Joules/g			
	Temperature		2011.84	F			
Case A: No losses							
	Efficiency		80.00	%			
	Energy in flue gas		9410.75	Joules/g			
	Temperature		1582.74	F			

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