Thermal Equipments

List of Problems

1. A container holds a gaseous mixture comprised of 30% CO_2, 5% CO, 5% H_2O, 50% N_2 and 10% O_2. Calculate:

   (a) the partial pressure of each component considering a total pressure equal to 2 atm;

   (b) the partial volume of each component considering a total volume equal to $0.3\,\mathrm{m}^3$.

[illegible]

2. The exhaust to the atmosphere from an incinerator shows a CO stream with a partial pressure of 0.19 mm Hg. Determine the CO molar fraction in ppm.

3. Determine the sensible heat content of 68 kg of carbon dioxide at 1200 °C relative to 15 °C. How much heat must be removed to drop the temperature to 300 °C?

4. Calculate the heat (enthalpy) of combustion at 25 °C and 1 atm for the following fuels:
   (a) ethyl alcohol (C_2H_5OH);
   (b) chloroform ($CHCl_3$).

5. Determine the higher and lower heating value of ethanol (C_2H_5OH).

[illegible]

6. Ethyl alcohol (C_2H_5OH) burns with air. The product gas is analyzed and the laboratory gives only the following percentages on a dry molar basis: 6.9% CO_2, 1.4% CO and 0.5% C_2H_5OH. Assuming the

remaining components consist of O_2 and N_2 determine:

(a) molar fraction of O_2 and N_2 on a dry and wet basis;

(b) percent of excess air.

7. Sludge containing mercury is burned in an incinerator (mercury feed rate $4.2\,\text{kg.h}^{-1}$). The resulting $260\,^\circ\text{C}$ product gas ($18 \times 10^4\,\text{kg.h}^{-1}$, $M = 32\,\text{kg.kmol}^{-1}$) is quenched with water to a temperature of $65.0\,^\circ\text{C}$. The resulting stream is filtered to remove all particles. What happens to the mercury? Assume the process pressure is $1\,\text{atm}$ and that the vapor pressure of Hg at $65.0\,^\circ\text{C}$ is $3.4 \times 10^{-4}\,\text{atm}$.

[illegible]

8. **(Problem solved in theoretical classes.)** 1.0×10^4 kg/day of a spent absorbent containing 92% carbon, 6% ash and 2% moisture is to be burned completely to generate carbon dioxide for process use. The exit temperature of the incinerator is 1000 °C.
   (a) Determine the production rate of carbon dioxide on a molar basis ($\text{kmol}_{CO_2}.\text{min}^{-1}$);
   (b) Determine the production rate of carbon dioxide on a mass basis (expressed in $\text{kg}_{CO_2}.\text{min}^{-1}$);
   (c) Determine the volumetric production rate of carbon dioxide (expressed in $\text{m}^3_{CO_2}/\text{min}$) at a pressure of 1.04 atm.

[illegible]

9. Flue gases from the combustion of 14.34 kg of graphite (essentially pure carbon) with oxygen are at a temperature of 1000 °C and a pressure of 1.04 atm.

   (a) Determine the volume (in cubic meters) of the CO_2 produced;

   (b) Determine the density of the CO_2 produced.

10. The inlet gas to a spray tower is at 900 °C. The gas is piped through a 1 m inside diameter duct at $8\,m.s^{-1}$ to the spray tower. The scrubber cools the gas to 260 °C. In order to maintain the velocity of $8\,m.s^{-1}$ at the outlet section of the unit determine the duct diameter. Neglect the pressure across the spray tower and any moisture considerations.

11. Data from an incinerator indicate a volumetric flow rate of $5\,m^3.s^{-1}$ (15.6 °C, 1 atm). If the operating temperature and pressure of the unit are 1060 °C and 1 atm, respectively, calculate the actual flow rate in $m^{-3}.s^{\cdot 1}$.

12. The carbon monoxide concentration in a flue gas stream with 10 vol% moisture at 500 °C and 1.05 atm is measured at 88.86 parts per million (ppm) by volume (ppmv). Does this meet the regulatory limit of $100\,mg.Nm^{-3}$ established by the regulation on a dry basis at 0 °C and 1 atm?

13. **(Problem solved in theoretical classes.)** A sample of 76 mg of particulate matter is collected in the course of sampling 2.35 m^3 of flue gas at 68 °C and 1.03 atm. The flue gas contains 12.5% moisture. An Orsat (dry basis) analysis of the gases shows 10.03% oxygen and 10.20% carbon dioxide. The air pollution code emission limit is 60 $mg.Nm^{-3}$ corrected to 7% oxygen. The emission code defines "normal cubic meter - Nm^{-3}" as the volume computed at 0 °C and 1.0 atm.

(a) Is the source in conformance with the code?

(b) What if the code referenced a correction of 12% carbon dioxide. Would the source be in conformance with the code?

(c) What if the code referenced a correction of 50% excess air. Would the source be in conformance with the code?

14. An incinerator design which has been successfully used in Houston, TX, (0 m above mean sea level), is to be used in Albuquerque, NM (1600 m above mean sea level). To ensure proper performance of the incinerator, it is necessary to correct for the change in the altitude since the density of the combustion air will decrease. Assume $p = 1\,\text{atm}$, $T = 16\,^{\circ}\text{C}$ and $\rho = 1.211\,\text{kg.m}^{-3}$ in Houston.

    (a) Calculate the theoretical air requirements in $\text{m}^3.\text{s}^{-1}$ to burn $4.5 \times 10^4\,\text{kg/day}$ of chlorobenzene (C_6H_5Cl) in Houston. Assume for the incineration of chlorobenzene the following stoichiometric reaction:

    $$C_6H_5Cl + 7O_2 + 26.3N_2 \rightarrow 6CO_2 + HCl + 2H_2O + 26.3N_2$$

    (b) Calculate the required air flow rate ($\text{m}^3.\text{s}^{-1}$) to achieve complete combustion of $4.5 \times 10^4\,\text{kg/day}$ of chlorobenzene in Albuquerque. Assume the pressure and temperature in Albuquerque equal to 0.82 atm and $5\,^{\circ}\text{C}$, respectively.

    (c) Calculate the allowable particulate concentration (g.m^{-3}) in Albuquerque which corresponds to $0.183\,\text{g.m}^{-3}$ in Houston. The allowable particulate concentration in Albuquerque should be calculated based on the same total mass of particulates.

15. A compliance stack test of an incinerator yields the results below. Determine whether the incinerator meets the state particulate standard of 0.114 g.m^{-3} at standard conditions (T_{ref} = 28 °C and p_{ref} = 1 atm) and on a dry basis. Estimate the amount of particulate matter escaping the stack, and indicate the molecular weight of the stack gas. Use standard conditions of temperature and pressure (28 °C and 1 atm, respectively)

Volume sampled (dry basis)	1 m^3	Moisture in the stack gas	7 vol%
Diameter of stack	0.6 m	O_2 in stack gas (dry basis)	7 vol%
Pressure of stack gas	26.9 in Hg	CO_2 in stack gas (dry basis)	14 vol%
Stack gas temperature	60 °C	N_2 in stack gas (dry basis)	79 vol%
Mass of particulate collected	0.16 g	Pitot tube factor (k)	0.85

Pitot tube measurements made at eight points across the diameter of the stack provided values of: 0.3, 0.35, 0.4, 0.5, 0.5, 0.4, 0.3, and 0.3 in H_2O. Use the following equations for S-type pitot tube velocity, v [m.s^{-1}], measurements:

$$v = k\sqrt{2gH} = k\sqrt{2g\frac{\rho_1}{\rho_2}\,(0.0254)\,h}$$

where, g is the gravitational acceleration (= 9.81 m.s^{-2}), H is the fluid velocity head [in H_2O], ρ_1 is the density of manometer fluid (= 1000 kg.m^{-3}), ρ_2 is the density of flue gas (= 1.084 kg.m^{-3}) and h is the mean pitot tube reading [in H_2O].

16. A coal process unit waste, containing carbon and free water, is being incinerated. The flue gas leaving the incinerator is at a temperature of 230 °C following a waste heat recovery unit and contains a particulate loading of $0.137\,\mathrm{g.m^{-3}}$. The flue gas analysis shows the following composition:

Component	Volume Percent
O_2 in stack gas	12.5
CO_2 in stack gas	12.5
N_2 in stack gas	50.0
H_2O in stack gas	25.0

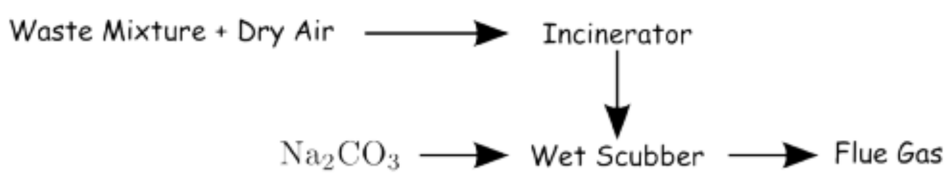
Determine the outlet particulate loading based on a dry basis corrected to 50% of excess air. Is the process in compliance with the particulate emission limit of $0.183\,\mathrm{g.m^{-3}}$. Consider the reference, standard conditions employed in the United Sates to report stack gas flows (1 atm and $20\,^\circ$C).

[illegible]

17. A waste mixture to be incinerated in a liquid injection incinerator has the following composition per 1 kg of waste:

Component	**Mass**
H	0.109 kg
O	0.102 kg
water	0.022 kg
C	0.732 kg
Cl	0.035 kg

The incineration system is configured as shown below:



(a) If dry air is used for combustion, how many kilograms of water will be present in the flue gas, before the scrubber, per kilogram of waste? Consider the production of hydrogen chloride (HCl) through the reaction:

$$Cl + \frac{1}{2}H_2 \rightarrow HCl$$

(b) For the same waste mixture, calculate the stoichiometric volume of oxygen (at normal conditions - 0 °C and 1 atm) required per kilogram of waste.

(c) Soda ash (Na_2CO_3) is used in a wet scrubber to neutralize the hydrogen chloride (HCl) produced during combustion. How many kmoles of soda ash are needed per kilogram of waste for exact neutralization?

18. The Chinese literature reports the heating value of a municipal refuse from the Beijing area as 1800 kcal.kg^{-1} (as fired). The moisture content of the waste was 37 wt% and the hydrogen content of the waste (on a dry basis) was 3.69 wt%. How do these data suggest that the heating value of the Chinese waste compares with waste burned in New York City, which is often reported to have a heating value of about 3500 kcal.kg^{-1}.

19. **(Problem solved in theoretical classes.)** Calculate the air requirement and products of combustion when burning at 30% excess air, 75 kg/h of a waste liquid having the ultimate analysis: 12.2% moisture, 71.0% carbon, 9.2% hydrogen, 3.4% sulfur, 2.1% oxygen, 0.6% nitrogen and 1.5% ash. The combustion air is at 15 °C and has 70% relative humidity.

20. **(Problem solved in theoretical classes.)** The flue gas from a waste incinerator burning a waste believed to have little nitrogen or oxygen has an Orsat analysis (using alkaline CO_2 absorbent) of 12.3% CO_2, 5.1% O_2 and the rest nitrogen and inerts. From these data calculate:
    (a) The weight ratio of hydrogen to carbon in the waste;
    (b) The percentage of carbon and hydrogen in the dry waste;
    (c) The weight ratio between the dry air used and the dry waste;
    (d) The percentage of excess air used;
    (e) The moles of exhaust gas discharged from the unit per kilogram of dry waste burned.

21. **(Problem solved in theoretical classes.)** A waste sludge is to be burned in a well-insulated combustion chamber followed by a waste heat boiler. The sludge has the following composition:

Component	Weight Percent
Benzene	70.0
Carbon (coke)	8.2
Ash	9.3
Moisture	12.5

The initial concept proposed is to burn the waste using only 10% excess air (available preheated to 300 °C) to maximize the heat recovered from the flue gases.

(a) Assuming 5% heat loss from both the combustion chamber and the boiler and neglecting dissociation, at what temperature will the flue gases enter the boiler?

(b) At a burning rate of 1100 kg.h^{-1}, what will be the streaming rate if the stack temperature is 180 °C and the boiler stream is saturated at 15.8 atm?

Boiler feedwater is the saturated liquid at 100 °C. Ambient humidity is 0.008 kg.kg^{-1}dry gas. A diagram of the process is given in Figure 1.

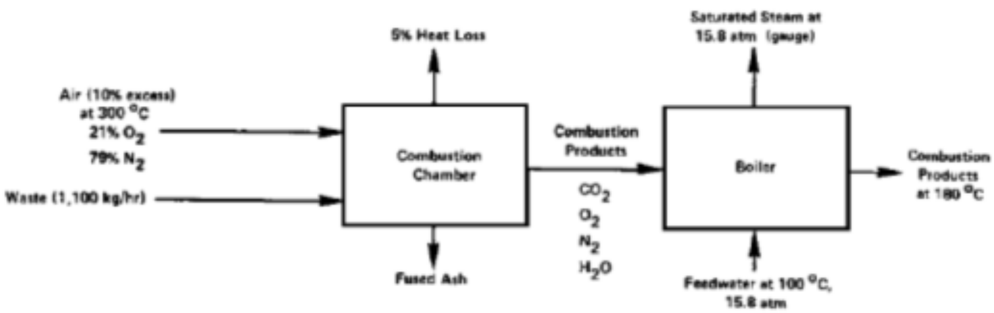


Figura 1: Process flowsheet.

22. Develop the general relationship for K_p as a function of temperature and calculate K_p at a temperature of 1000 °C for the water-gas shift reaction:

$$CO + H_2O\,(g) \rightarrow H_2 + CO_2 \tag{105}$$

23. For the combustion chamber conditions of Problem 21, what is the emission rate of thermal NO due to the reaction $\frac{1}{2}N_2 + \frac{1}{2}O_2 \rightarrow NO$? If this result indicates that NO emissions are excessive, one approach to control would involve recycling of stack gas at 180 °C to dilute and cool the combustion chamber off-gas to 1000 °C. What is the flow rate of the recycle stream and the resulting NO emission rate?

24. $470\,m^3.min^{-1}$ of a waste gas stream from a carbon char reactivation furnace is produced at $300\,°C$. Its composition is as follows:

Component	**Mol Percent**
N_2	78.17
CO_2	18.71
CO	2.08
O_2	1.04
Total	100.00

The waste gas will be mixed with the flue gas from an atmospheric natural gas (methane) combustor operating at 50% excess air in a 'fume incinerator' or afterburner. If CO combustion is assumed not to begin until the two gas streams are intimately mixed, plot the required residence time to reduce the CO concentration to 10 ppm (neglecting dilution effects) against the mixed-gas temperature. Note that residence time is directly related to the incinerator volume (capital cost) and mixed-gas temperature to methane consumption rate (operating cost). For ease in computation, assume that the heat capacity of the two gas streams is constant, identical and equal to about $8\,kcal.kmol^{-1}.°C^{-1}$. Neglect heat release from CO combustion. The datum for sensible heat content is $15.5\,°C$. The system is shown in Figure 2.

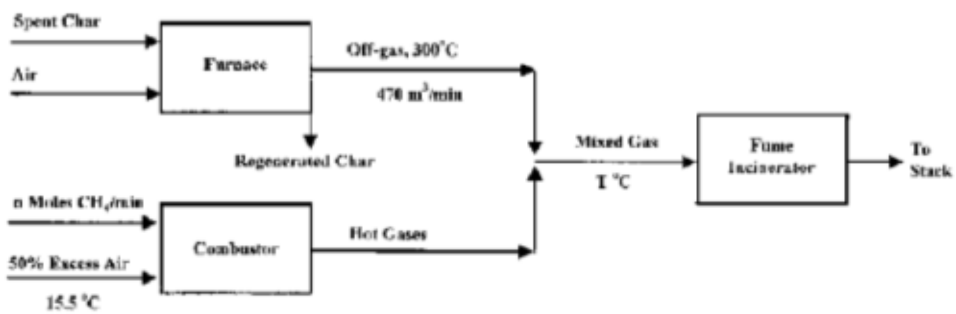
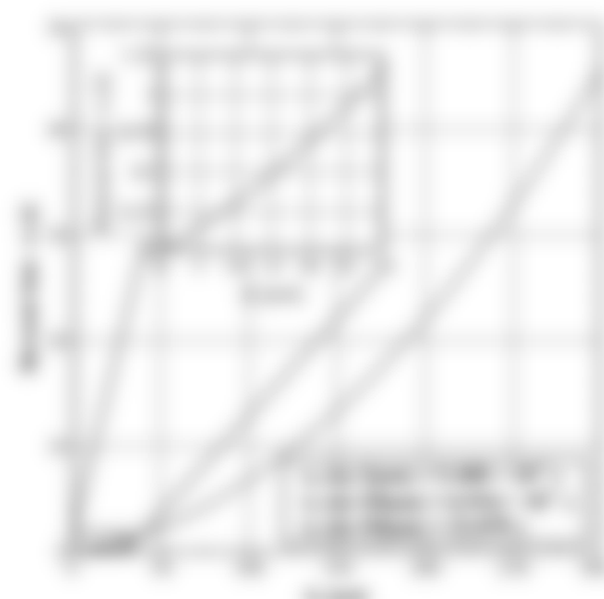


Figura 2: Process flowsheet.

25. The combustion of benzene and other unsaturated ring compounds is known to often result in the formation of soot. If soot is formed at 1400 °C in Problem 23 what are the burnout times for 2, 20 and 30 μm soot particles?



26. A gas stream containing organic vapors must be processed in a natural gas-fired afterburner to achieve at least 99% destruction of acrylonitrile (AN). AN is believed to be the most toxic and the most difficult to incinerate of the compounds present in the off-gas stream. It has been suggested that an afterburner operating at a temperature of 850 °C, with an oxygen partial pressure (p_{O_2}) equal to 0.13 atm and with a mean residence time of 0.3 s achieves this objective. Is this correct?

[illegible]

27. Using the method of Shebeko, estimate the flashpoint of methyl ethyl ketone (MEK). Compare the estimated value to the literature value of $-1.1\,^{\circ}\mathrm{C}$.

28. A waste incinerator is burning an aqueous slurry of soot (carbon) with the production of a small amount of fly ash. The waste is 70% water by mass and is burned with 0% excess air. The flue gas generated contains 85 mg of particulates in each $1\,\mathrm{m}^3$ at $300\,^{\circ}\mathrm{C}$. Consider the standard temperature equal to $15.6\,^{\circ}\mathrm{C}$ and assume that when the flue gas passes through a waste heat boiler no water condensation occurs. Calculate the particulate concentration in the flue gas in:

    (a) $\mathrm{mg.am^{-3}}$ ($\mathrm{am^3}$ - actual cubic meters);

    (b) $\mathrm{mg.sm^{-3}}$ ($\mathrm{sm^3}$ - standard cubic meters);

    (c) $\mathrm{mg.dsm^{-3}}$ ($\mathrm{dsm^3}$ - dry standard cubic meters)

    (d) $\mathrm{mg.dsm^{-3}}$ corrected to 50% EA (EA - excess air).

    If the regulations require that particulate emissions be less than $10\,\mathrm{mg.dsm^{-3}}$ corrected to 50% EA, is this incinerator in compliance or must additional particulate control measures be taken?

29. A company is planning to burn $100\,\mathrm{mol.h^{-1}}$ of a waste composed by 90 mol% C_6H_5Cl and 10 mol% CH_2Cl_2 at 100% EA (EA - excess air). Ambient temperature, relative humidity and pressure are $21\,^{\circ}\mathrm{C}$, 65% and 1 atm, respectively. Standard conditions are $20\,^{\circ}\mathrm{C}$ and 1 atm.

    (a) What is the mole fraction of HCl in the flue gas if all the Cl from C_6H_5Cl and CH_2Cl_2 reacts to form HCl, according to the following stoichiometric reactions:

    $$\mathrm{C_6H_5Cl + 7\,(O_2 + 3.76N_2) \rightarrow 6CO_2 + 2H_2O + HCl + 7 \times 3.76N_2}$$

    $$\mathrm{CH_2Cl_2 + (O_2 + 3.76N_2) \rightarrow CO_2 + 2HCl + 3.76N_2}$$

    (b) Considering that 5 wt.% of chlorinated organics (C_6H_5Cl and CH_2Cl_2) combusted originate particulate material determine the outlet particulate loading based on a dry basis corrected to 50% of excess air.

30. An incineration unit burns a specific amount of municipal solid waste (MSW) with the following ultimate analysis: 30% C, 7% H_2, 1% S, 1% N_2, 15% O_2, 32% H_2O and 14% Ash. The waste is burned at 20% excess air. Dry air, preheated to 450 °C is used for combustion. Flue gases leave the incinerator at 600 °C. Consider for air a specific heat equal to 7.2 kcal.kmol^{-1}.K^{-1}. The water vaporization enthalpy at 25 °C corresponds to 2440 kJ.kg^{-1}. Perform an energy balance on the incineration unit and determine the generated steam considering $p = 10\,\text{bar}$, $T_{sat} = 179.9\,°\text{C}$, $h_{fg} = 2015\,\text{kJ.kg}^{-1}$ and $T_{water,in} = 100\,°\text{C}$. Consider 100 kg of waste as a basis for the calculation. Mention all the underlying assumptions.

31. An incinerator burns at atmospheric pressure a residue composed by hydrocarbons, sulfur (S) and chlorine (Cl). For specific exhaust gas temperature values condensation of sulfuric acid, hydrochloric acid (HCl) nitric acid (HNO_3) may occur. Determine the minimum temperature of the exhaust gas stream to avoid corrosion at low temperatures. The exhaust gas composition is given in the table that follows:

k	X_k[%]
CO_2	20
H_2O (g)	25
N_2	48
SO_3 (g)	0.01
HNO_3 (g)	0.003
HCl (g)	0.001

32. An incinerator rated at 22 MW heat input is to destroy $3 \times 10^3\,\text{kg.h}^{-1}$ of sludge initially at 15.6 °C using natural gas. The sludge contains 40% free water, 30% C, 6% H, 2% Cl, 8% O, 4% N and 10% inerts (by mass). The LHV of the sludge is 2300 kJ.kg^{-1}. Flue gases leave the primary combustion chamber at 1100 °C and there is no secondary combustion unit. Neglect heat losses, assume complete combustion and consider stoichiometric air is supplied at 15.6 °C. Use a specific heat of 3.5 kJ.kg^{-1}.K^{-1} for the inert fraction of the waste.

    (a) Determine the required volumetric flow rate at normal conditions of natural gas (assume CH_4) of 50000 kJ.kg^{-1} lower heating value.

    (b) Is the incinerator properly sized to handle the heat load considered?

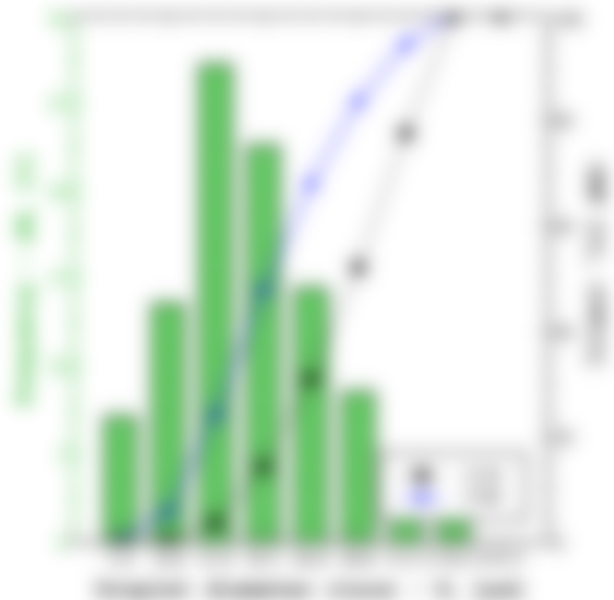
    (c) Determine the composition of the exhaust gas.

33. Natural gas at 15 °C (methane with a flame temperature of 2170 K) is to be burned in air from a port 4 cm in diameter at a velocity of $3\,m.s^{-1}$. The furnace is 8 m wide. Flame impingement has been a problem at other plants and the plant engineer suggests cutting back on the fuel flow by up to 20% to reduce flame length. Will this work? What will?

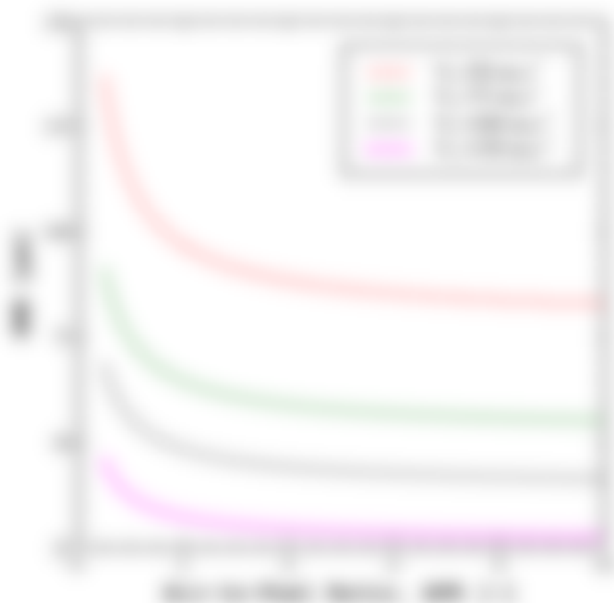
34. The following droplet size data have been obtained experimentally:

Size - [μm]	**Count**
0-10	80
11-25	150
26-40	300
41-60	250
61-75	160
76-100	95
101-130	50
131-170	20
171-220	0
0-220	1105

Determine the droplet size distribution, cumulative number and volume fraction distributions. Determine the most probable diameter, the median diameter and mean diameter, the volume median and volume mean diameters and the Sauter mean diameter (SMD).



35. Compute and plot the SMD for a kerosene spray from a pre-filming air-blast nozzle over a range of air flow to liquid fuel flow ratios from 1 to 10. The air is at the reference standard temperature and pressure. Consider 4 different values for the air velocity: 50, 75, 100 and 125 $m.s^{-1}$. The discharge orifice diameter is equal to 36 mm. Consider the SMD semi-empirical correlation of Rizkalla and Lefebvre with constants tuned by Jasuja.



36. An incinerator furnace has a mean gas residence time of 0.1 s. Considering that the furnace temperature is constant and equal to 1000 °C. Determine the maximum allowed size of n-heptane (C_7H_{16}) droplets if they have to be totally consumed: a) by vaporization alone; b) by vaporization followed by combustion before they exit from the furnace.

37. Consider a 500-μm-diameter liquid n-hexane (C_6H_{14}) droplet evaporating in hot, stagnant nitrogen at 1 atm. The N_2 temperature is 850 K. Determine the lifetime of the n-hexane droplet, assuming the droplet temperature is at its boiling point.

38. Consider the combustion of an n-heptane (C_7H_{16}) droplet with a diameter equal to 100 μm. Determine the lifetime of the burning droplet considering that the droplet is at its boiling point and $P = 1$ atm and $T_\infty = 300$ K.

39. A liquid residue with a mass flow rate equal to 0.01 kg.s^{-1} is to be atomized at room temperature. The liquid properties for three temperatures are given below:

	Density, ρ_l [kg.m^{-3}]	Surface tension, σ [N.m^{-1}]	Viscosity, μ_l [Pa.s]
$T = 20$ °C	988	26.0×10^{-3}	0.75
$T = 75$ °C	920	42.4×10^{-3}	0.15
$T = 90$ °C	890	46.4×10^{-3}	0.08

A pressure atomizer will be used. For isothermal atomization ($p = 1.013 \times 10^5$ N.m^{-2} and $T = 20$ °C) the following data is supplied by the atomizer manufacturer:

- Discharge orifice diameter (d_0): 1.00 mm
- Injection pressure differential across the nozzle (Δp_L): 20 bar to 35 bar
- Half spray angle (θ): 45°

(a) Determine the Sauter Mean Diameter (SMD) considering $\Delta p_L = 20$ bar.

(b) Suggest several operational measures to optimize the SMD.

40. **(Problem solved in theoretical classes.)** Using the complex Dulong equation, estimate the heating value of a waste with the following composition: 45.85% organic carbon, 0.83% inorganic carbon, 6.61% hydrogen, 35.94% oxygen, 1.03% nitrogen, 0.1% sulfur, and 9.64% ash.

41. **(Problem solved in theoretical classes.)** Estimate the theoretical air requirement and the heating value for methane. Also, estimate the theoretical air requirement for a waste of unknown composition that, from bomb calorimeter, has a heating value of 2900 kcal.kg^{-1}.

42. A liquid fuel is to be burned in an incinerator. The fuel has the following properties:

- Density (75 °): 988 kg.m^{-3}
- Superficial tension (20 °C): 28.4×10^{-3} N.m^{-1}
- Viscosity (75 °): 0.112 Pa.s
- Specific heat at constant pressure: 0.45 cal.g^{-1}.°C^{-1}
- Boiling temperature: 200 °C
- Latent heat: 90 cal.g^{-1}
- Heat of combustion: 715 cal.g^{-1}
- Thermal diffusivity of the liquid's vapor: 4×10^{-4} cm^2.s^{-1}

The company that rules the incinerator has the possibility to choose one of three possible burners to process the fuel. The three burners were tested for liquid atomization by the corresponding manufactures under isothermal conditions at $p = 1.013 \times 10^5$ Pa and $T = 25$ °C:

- Pressure atomizer
  - Discharge orifice diameter: 0.50 mm
  - Injection pressure differential across the nozzle: 45 bar
  - Mass flow rate: 0.01 $kg.s^{-1}$
  - Half spray angle: 45°
- Pre-filming atomizer
  - Air velocity: 60 $m.s^{-1}$
  - Air/Fuel Ratio (AFR): 4
  - Mass flow rate: 0.01 $kg.s^{-1}$
- Plain-jet atomizer
  - Air velocity: 60 $m.s^{-1}$
  - Air/Fuel Ratio (AFR): 4
  - Discharge orifice diameter: 2.0 mm
  - Mass flow rate: 0.01 $kg.s^{-1}$

(a) Select the most adequate burner, justifying the underlying assumptions and stating the deviations in relation to the reality.

(b) The incinerator has a cylindrical shape with a vertical downward flame. Atmospheric air at the conditions stated before is considered. The air/fuel ratio is equal to 2.5. Consider the combustion products at a constant temperature of 1300 °C and with $C_p = 0.31\,\text{cal.g}^{-1}.°\text{C}^{-1}$ and $\rho = 0.2\,\text{g.cm}^{-3}$. Find the minimum incinerator height required for the three atomizers. Verify if the spray droplets are burned.

43. An incinerator receives municipal wastes from three neighboring districts. The municipal refuse is collected in the three districts after waste separation by citizens for recycling. The average composition of the MSW as well as the daily received amounts are presented in the table that follows. The composition of the MSW was analyzed at the production site ("as generated").

	District A		District B		District C	
Quantity (ton/dia)	240		144		96	
Component	As generated [% mass]	Moisture at gen. [% mass]	As gen. [% mass]	Moist. [% mass]	As gen. [% mass]	Moist. [% mass]
Cans/wire	1.0	2.0	3.0	2.0	2.0	2.0
Paper	24.0	8.0	22.0	8.0	23.0	8.0
Plastics	8.0	1.0	3.0	1.0	10.0	1.0
Leather/Rubber	3.0	2.0	1.0	2.0	2.0	2.0
Textiles	5.0	10.0	5.0	10.0	5.0	10.0
Wood (sawdust/limbs)	5.0	15.0	15.0	15.0	3.0	15.0
Food waste	48.0	90.0	38.0	90.0	38.0	90.0
Yard waste	3.0	50.0	10.0	50.0	14.0	50.0
Broken glass	1.0	2.0	1.0	2.0	1.0	2.0
Miscellaneous	2.0	2.0	2.0	2.0	2.0	2.0
Total	100.0	–	100.0	–	100	–

The MSW plant layout with the pre-treatment system is represented in Figure 3. The pre-treatment stage has a capacity much larger than that of the incinerator and operate always with a mixed charge at the proportion of the weight of residuals received from the three districts (according to the level of waste in the MSW storage pit). The trommel eliminates glass and metal with an efficiency of 80%. Assume that the remaining material categories are not eliminated by the trommel. The hammermill and shear shredder have a double function of decreasing the components size and enhance the homogenization level. Consider no moisture transfer between waste components during all stages of the waste flux (from the production site to the incinerator).

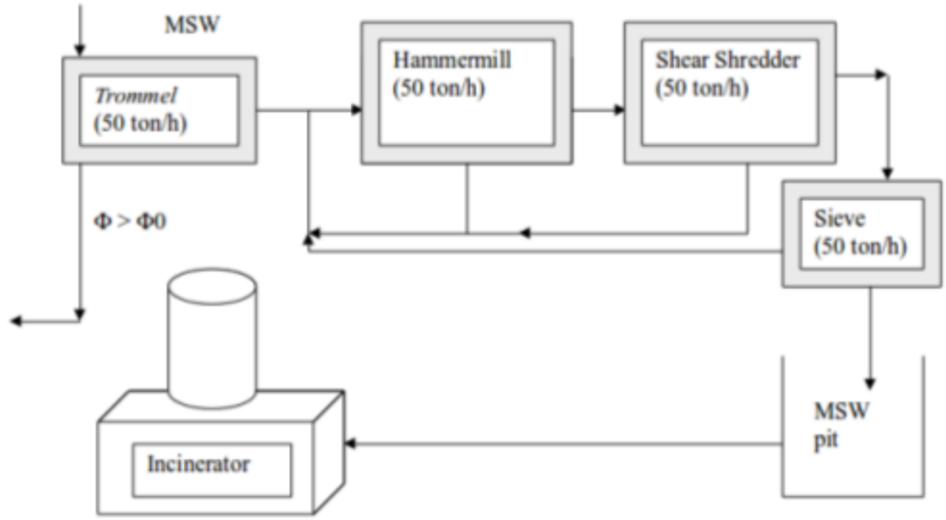


Figura 3: Plant layout.

Component, k	% dry ($Y_{k,db}$ [%])	Ashes	C	H_2	O_2	S	N_2
Cans/Wire	12.10	10.00	1.00	0.90	0.10	0.00	0.10
Paper	46.00	3.00	23.00	2.80	17.00	0.10	0.10
Plastics	2.50	1.00	1.00	0.10	0.10	0.10	0.20
Leather/Rubber	3.30	0.50	2.00	0.50	0.20	0.00	0.10
Textiles	2.50	0.10	1.50	0.10	0.30	0.00	0.50
Wood (sawdust/limbs)	1.70	0.10	1.20	0.20	0.20	0.00	0.00
Food waste	7.80	1.20	5.00	0.30	0.90	0.10	0.30
Yard waste	8.40	0.60	6.00	0.60	0.80	0.10	0.30
Broken glass	13.20	13.00	0.10	0.10	0.00	0.00	0.00
Miscellaneous	2.50	1.50	0.50	0.10	0.30	0.00	0.10
Total	100.00	31.00	41.30	5.70	19.90	0.40	1.70

Tabela 1: Ultimate analysis on a dry basis of the average waste mixture [kg/100kg$_{\text{MSW}}$].

(a) Build up the components table (average mass percentage composition, both on wet and dry basis) of the waste in the pit that feeds the incinerator.

(b) Characterize chemically (ultimate analysis on a dry basis) the solid fuel burnt in the incinerator, justifying the approaches done. Use Table 1 as reference.

(c) Determine the ultimate analysis (wet basis) of the solid fuel.

(d) Perform a mass balance to the incinerator, determining the stoichiometric air requirement and the mass composition of combustion products (CO_2, H_2O, SO_2, N_2 and ashes) using as basis 100 kg of MSW.

44. The MSW from a city without a separate waste collection system is to be burnt in an incinerator. The average composition of the waste of the city analyzed at the production site ("as generated") is presented in the next table.

Category	As generated [% mass]	Moisture at generation [% mass]
Metal	5.0	2.0
Paper	20.0	8.0
Plastics	10.0	2.0
Leather/Rubber	3.0	2.0
Textiles	2.0	10.0
Wood	5.0	15.0
Food waste	40.0	90.0
Yard waste	10.0	50.0
Glass	3.0	2.0
Miscellaneous	2.0	2.0
Total	100	-

(a) Characterize chemically (ultimate analysis on a wet basis) the fuel to be burned in the incinerator.

(b) Perform a mass balance to the incinerator and determine the stoichiometric air required and the composition of the combustion products. Assume complete reactions.

(c) Considering an excess air (EA) equal to 200% determine the composition of the combustion products. Assume complete reactions.

(d) On a mass basis consider the ash composed by 45.22% SiO_2, 22.02% Al_2O_3, 2.50% CaO, 1.21% MgO, 24.70% Fe_2O_3, 1.11% Na_2O and 3.24% K_2O. Determine the ash behavior at 1400 °C.