Chapter 1.4 Material and Energy Balance

Part – I: Objective type questions and answers

1.	The objective of material and energy balance is to assess the: a) input-output b) conversion efficiency c) losses d) all the above e) none of the above
2.	In the material balance of a process or unit operation process, which component will not be considered on the input side? a) Chemicals b) Water/air c) Recycle d) By product
3.	In material balance of a process, recycle product is always considered as a) input to process b) output to process c) both (a) and (b) d) none of them
4.	Losses in material and energy balance is considered as a) inputs b) outputs c) both (a) and (b) d) none of the above
5.	Sankey diagram shows in graphics ___. a) energy input b) energy output c) energy balance d) all the above
6.	In a chemical process of two reactants A (200 kg) and B (200kg) is used as reactants. If conversion is 50% and A and B reacts in equal proportion then calculate the weight of the product formed. a) 150 kg b) 200 kg c) 250 kg d) 400 kg
7.	In a furnace, the lower the exhaust temperature ____ is the furnace efficiency. a) lower b) moderate c) higher d) none of above
8.	Which of the following is the predominant loss in a furnace oil fired boiler? a) dry flue gas losses b) heat loss due to moisture in air c) heat loss due to radiation and convection d) heat loss due to moisture in fuel
9.	In a heat treatment furnace the material is heated up to 800 °C from ambient temperature of 30 ° C considering the specific heat of material as 0.13 kCal / kg °C. What is the energy content in one kg of material after heating? a) 150 kCal b) 250 kCal c) 350 kCal 4) 100 kCal
10.	If feed of 100 tonnes per hour at 5% concentration is fed to a crystallizer, the product obtained at 25% concentration is equal to ____ tonnes per hour. a) 20 b) 25 c) 35 d) 40
11.	In an utility steam boiler, heat loss due to radiation normally is in the range of a) 10% b) 14% c) 1% d) 8%

12.	Energy supplied by combustion of fuel is equal to a) mass of fuel consumed x its calorific value b) mass of fuel consumed x its density c) mass of fuel consumed x its specific heat d) mass of fuel consumed x its heat capacity
13.	In a coal fired boiler, hourly consumption of coal is 1000 kg. The ash content in the coal is 3%. Calculate the quantity of ash formed per day. Boiler operates 24 hrs/day. a) 50 kg b) 300 kg c) 33 kg d) 720 kg
14.	Sankey diagram represents an entire input and output energy flow. State True or False?
15.	Material and energy balance will identify areas to concentrate for energy conservation. True or False
16.	In a drying process moisture is reduced from 60% to 30%. Initial weight of the material is 200 kg. Calculate the final weight of the product. a) 100 b) 120 c) 130 d) 114.3
17.	Energy supplied by electricity, Q in kCal is equal to _____ . a) kWh x 8.6 b) kWh x 86 c) kWh x 860 d) none
18.	Which one is a secondary form of energy? a) Furnace oil b) natural gas c) electricity d) coal
19.	In material and energy balance, cycle time play an important role. True or False
20.	Sankey diagram is an useful tool to represent ____. a) financial strength of the company b) management philosophy c) input and output energy flow d) human resource strength of the company

Part – II: Short type Questions and answers:

1. The plant has four heat exchangers and cooling water is circulated through these exchangers. The details are given below.

Heat exchanger	Water flow, m^3/h	Temperature raise, °C
1	200	7
2	300	8
3	400	3
4	500	2

Evaluate heat rejection (kCal/h) of each heat exchanger and total heat rejected to cooling water.

Heat exchanger	Water flow, m^3/h	Temperature raise, °C	Heat rejection, kCal/h
1	200	7	14,00,000
2	300	8	24,00,000
3	400	3	12,00,000
4	500	2	10,00,000
			60,00,000

2. Define specific power consumption with an example.

The specific energy consumption is defined as the energy required to produce a unit of output.

e.g. : Compressors:

A compressor generates 100 cfm of air at 7 kg/cm^2 pressure. The power drawn by the motor is 18 kW.

i.e. Specific energy consumption is = 18/100

= 0.18 kW/cfm @ 7kg/cm^2

3. Why Sankey diagram is useful in energy balance calculations?

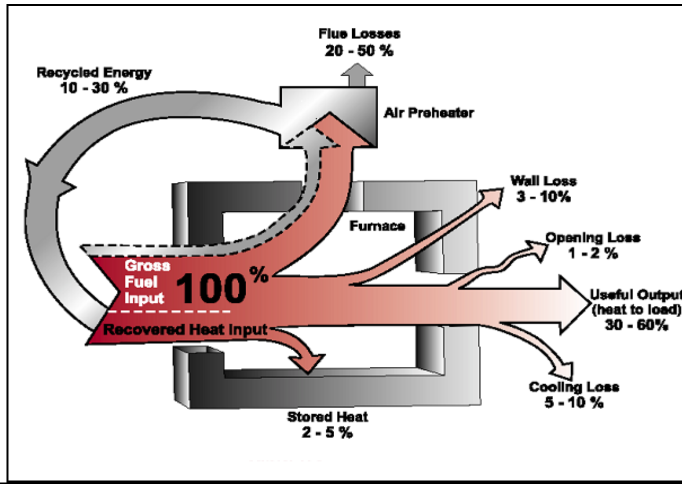
The Sankey diagram is very useful tool to represent an entire input and output energy flow in any energy equipment or system such as boiler generation, fired heaters, furnaces after carrying out energy balance calculation. This diagram represents visually various outputs and losses so that energy managers can focus on finding improvements in a prioritized manner.

4. List any three guidelines for mass and energy balance.

- For a complex production stream, it is better to first draft the overall material and energy balance.
- While splitting up the total system, choose, simple discrete sub-systems. The process flow diagram could be useful here.
- Choose the material and energy balance envelope such that, the number of streams entering and leaving, is the smallest possible.
- Always choose recycle streams (material and energy) within the envelope.

5. Draw a typical Sankey diagram of reheating furnace

Ans.



6. How material and energy balance helps in energy conservation?

In material and energy balance study by assessing the input, conversion efficiency, output and losses helps in establishing the basis for improvements and potential savings. It helps in finding improvements in a prioritised manner.

7. What way material and energy balance study is useful for a Top management?

a. Material and energy balances are important, since they make it possible to identify and quantify previously unknown losses and emissions.

b. These balances are useful for monitoring the improvements made in an ongoing project, and while evaluating cost benefits by the Top management.

c. Inefficient use of raw materials and energy in production processes are reflected as wastes. This makes the top management to take quick remedial actions.

8. What is the purpose of material and energy balance?

The basic purpose of material and energy balance is

- to quantify all the material, energy and waste streams in a process or a system.
- to find out the difference between calculated/designed values and measured/actual values thereby making it possible to identify previously unknown losses and emissions.

9. Differentiate exothermic and endothermic reactions.

Exothermic reaction: A chemical reaction in which Heat is released.

Endothermic reaction: A chemical reaction in which heat is absorbed.

10. List any three energy loss components in chemical plant.

Energy loss components in chemical plants are:

1. Flue / exhaust gas losses (from boilers, reactors etc.)
2. Evaporation loss (from cooling tower, condenser)
3. Surface heat losses (boilers, process equipment etc.)

11.	For complete combustion of 1 kg of a typical coal 12 kg of air is required. Calorific value of coal is 4200 kCal/kg with ash content of 22%. What is the quantity (in kg) flue gas generated by burning 5 kg coal? Flue gas generated by burning the coal in the presence of air is: Flue gas quantity (per kg of coal) : combustion air + quantity of fuel- ash : 12 + 1 - 0.22 : 12.78 kg Quantity of flue gas by burning 5 kg of coal : 5 x 12.78 = 63.9 kg.
12.	List any three energy loss components of induction furnace Induction furnace energy loss components 1. Cooling coil loss 2. Auxiliary system losses 3. Radiation heat loss
13.	In reheating furnace, which loss component will be recovered (or) recycled energy. In reheating furnace, a part of the waste heat in the flue gas losses is recoverable.
14.	List the items to be represented for a preparation of a process flow chart. Items to be represented in flow charts are: 1. Input to the process 2. Process steps 3. Wastes / by products 4. Output from the process (or) final products
15.	What are the various levels of mass and energy balances? The material and energy (M&E) balances required to be developed at the various levels are: 1. Overall M&E balance: This involves the input and output streams for complete plant. 2. Section wise M&E balances: In the sequence of process flow, material and energy balances are required to be made for each section/department/cost centres. This would help to prioritize focus areas for efficiency improvement. 3. Equipment-wise M&E balances: M&E balances, for key equipment would help assess performance of equipment, which would in turn help identify and quantify energy and material avoidable losses.

16.	In a textile mill, an evaporator concentrates a liquor containing solids of 6% by w/w (weight by weight) to produce an output containing 30% solids w/w. Calculate the evaporation of water per 100 kg of feed to the evaporator. Inlet solid contents : 6% Out let solids contents : 30% Feed : 100 kg Solids content in kg. in feed : 100 x 0.06 = 6 kg Out let solid content in kg. : 6 kg i.e. Quantity of water evaporated : $\left(100 - \frac{100}{30} x\, 6\right) = 80 kg$
17.	List out any three boiler sub systems. Plants boiler sub systems: 1. Fuel supply system 2. Combustion air system 3. Boiler feed water system
18.	Why evaluation of energy and mass balance is important?. Material and energy balances are important, since they make it possible to identify and quantify previously unknown losses and emissions. These balances are also useful for monitoring the advances made in an ongoing project and while evaluating cost benefits.
19.	A sample of coal from the mine is found to contain 67.2% carbon and 22.3% ash. The refuse obtained at the end of combustion is analysed to contain 7.1% carbon and the rest is ash. Compute the % of the original carbon unburnt in the refuse. Data: Coal – 67.2% carbon Ash- 22.3% Refuse – 7.1% carbon Ash – 92.9% Basis: 100 kg of coal Ash remains the same in refuse and coal Mass of carbon in coal : 67.2 kg Mass of ash in coal : 22.3 kg Mass of ash in refuse : 22.3 kg Mass of refuse : 100/92.9 x 22.3 = 24 kg Quantity of carbon in refuse : 7.1/100 x 24 = 1.704 kg % of original carbon remaining unburnt in the refuse: 1.704/67.2 x 100 : 2.53%

20.	A furnace shell has to be cooled from 90 °C to 55 °C. The mass of the furnace shell is 2 tonnes, the specific heat of furnace shell is 0.2 kCal/kg °C. Water is available at 29 °C. The maximum allowed increase in water temperature is 5 °C. Calculate the quantity of water required to cool the furnace. Neglect heat loss. Total heat that has to be removed from the furnace = 2000 x 0.2 x (90- 55) = 14000 kCal Quantity of water required = 14000/5 = 2800 kg

Part – III Long type Questions and answers:

1.	Discuss the procedure followed during energy and mass balance calculation. The energy and mass balance is a calculation procedure that basically checks if directly or indirectly measured energy and mass flows are in agreement with the energy and mass conservation principles This balance is of the utmost importance and is an indispensable tool for a clear understanding of the energy and mass situation achieved practice. In order to use it correctly, the following procedure should be used: • Clearly identify the problem to be studied. • Define a boundary that encloses the entire system or sub-system to be analysed. Entering and leaving mass and energy flows must be measured at the boundary. • The boundary must be chosen in such a way that: a) All relevant flows must cross it, all non-relevant flows being within the boundary. b) Measurements at the boundary must be possible in an easy and accurate manner. • Select an appropriate test period depending on the type of process and product. • Carry out the measurements. • Calculate the energy and mass flow. • Verify an energy and mass balance. If the balances are outside acceptable limits, then repeat the measurements. • The energy release or use in endothermic and exothermic processes should be taken into consideration in the energy balance.
2.	A boiler is fed with soft water containing 120 mg/l dissolved solids. As per IS standards the maximum dissolved solids in the boiler should not exceed 3500 mg/l for boilers, operating up to 2 MPa. In order to maintain the specified level, a continuous blow down system is adopted. Find the percentage of feed water which will be blown down. Basis 1 kg of feed water Let blow down quantity : x kg

	Dissolved solids in blow down	: 3500 mg/l
		: X x 3500 = 120 x 1 i.e. X – 0.0343 kg
	% blow down	: 0.0343/1 x 100 = 3.43%
3.	Production rate from a paper machine is 340 tonnes per day (TPD). Inlet and outlet dryness to paper machine is 40% and 95% respectively. Evaporated moisture temperature is 80 °C. To evaporate moisture, the steam is supplied at 3.5 kg/cm² (a). Latent heat of steam at 3.5 kg/cm²(a) is 513 kCal/kg. Assume 24 hours/day operation. i) Estimate the quantity of moisture to be evaporated ii) Input steam quantity required for evaporation (per hour) Note: Consider enthalpy of evaporated moisture as 632 kcal/kg	
	Production rate from a paper machine	: 340 TPD : 14.16 TPH (tonnes per hour)
	Inlet dryness to paper machine	: 40%
	Outlet dryness from paper machine	: 95%
	i) Estimation of moisture to be evaporated:	
	Paper weight in final product	: 14.16 x 0.95 = 13.45 TPH
	Weight of moisture before dryer	: $\left(\frac{100-40}{40}\right)x13.45$ = 20.175 TPH
	Weight of moisture after dryer	: $\left(\frac{100-95}{95}\right)x13.45$ = 0.707 TPH
	Evaporated moisture quantity	: 20.175 - 0.707 = 19.468 TPH
	ii) Input steam quantity required for evaporation	
	Evaporated moisture temperature	: 80 °C
	Enthalpy of evaporated moisture	: 632 kCal/kg
	Heat available in moisture (sensible & latent)	: 632 x 19468 : 12303776 kCal/h
	For evaporation minimum equivalent heat available should be supplied from steam	
	Latent Heat available in supply steam (at 3.5 kg/cm² (a))	: 513 kCal/kg
	Quantity of steam required	: 23984 kg :23.98 MT/hour

4. Steam balance of a brewery is given below

Steam generation		Tonnes per day
a)	Make-up water quantity	52.00
b)	Condensate return	
	Brew house	42.48
	Bottling	2.47
c)	Total steam generation	96.95
Steam utilisation		
	Brew house	
a.	Mash Tank	10.89
b.	Work kettle	27.45
c.	Raw water heating	3.90
d.	Process water heating	3.62
	Bottling section	
e.	Pasteurisation machines	28.99
f.	Washing machines	18.68
G	Miscellaneous (blow down, yeast drying, keg filling)	3.42
		96.95

i) What will be the condensate return as % of steam generation?

ii) Which equipment consumes more steam?

iii) What will be the percentage of bottling section steam load?

i) Condensate returns as % of steam generation

Condensate returns quantity:

- Brew house + bottling section: 42.48 + 2.47 = 44.95 kL
- Total steam generation quantity: 96.95 Tonnes

% of condensate return : (44.95 /96.95) x 100 : 46.3 %

ii) Pasteurization machines consumes higher steam quantity (28.99 Tonnes)

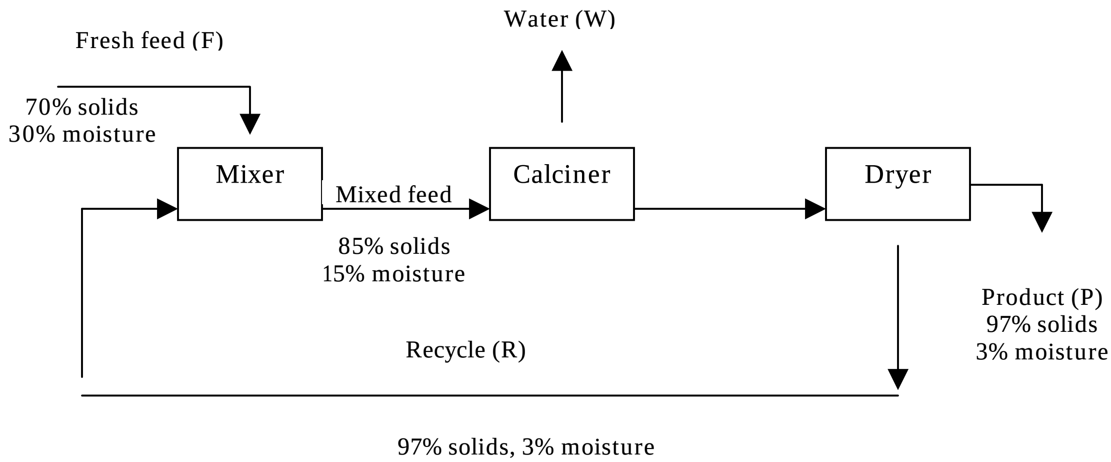
iii) Bottling section steam load as % of steam generation

Bottling section quantity:

- Pasteurisation + washing machines: 28.99 + 18.68 = 47.67 Tonnes
- Total steam generation quantity: 96.95 Tonnes

% of bottling section steam load: (47.67 /96.95) x 100 : 49.1 %

5. In a particular drying operation, it is necessary to hold the moisture content of feed to a calciner to 15% (W/W) to prevent lumping and sticking. This is accomplishing by mixing the feed having 30% moisture (w/w) with recycle steam of dried material having 3% moisture (w/w). The dryer operation is shown in fig below. What fraction of the dried product must be recycled.



Let F indicates quantity of feed

R indicates quantity of recycle

P indicates quantity of product

$0.7F + 0.97R$	$= 0.85\,(F + R)$	
	$= 0.12\,R = 0.15\,F$	
R	$= 15/12\,F$	
$0.85\,(F + R)$	$= 0.97\,(P + R)$	
$0.85\,(F + 1.25F)$	$= 0.97\,P + 0.97 \times 1.25\,F$	
$1.91\,F$	$= 0.97\,P + 1.21F$	
$0.7\,F$	$= 0.97\,P$	
F	$= 1.386\,P$	
R	$= 1.386\,P x\,1.25$	
R	$= 1.7325\,P$	
$P + R$	$= 1 + 1.7325$	$= 2.7325$
R	$= \frac{1.7325}{2.7325} x100$	$= 63.4\%$