# Online Preparatory Training Course For BEE Energy Managers /Energy Auditors

## Certification Exam 2020

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**EnSave Consultancy and Training Pvt. Ltd.**

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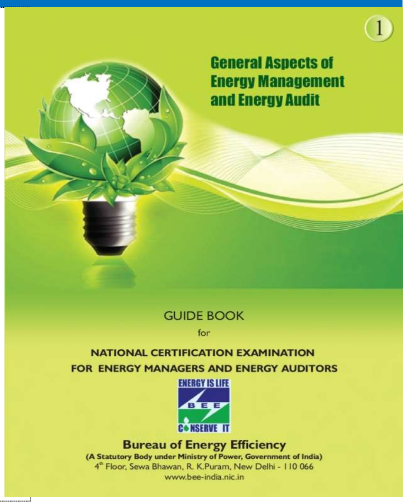
## BOOK 1 – GENERAL ASPECTS OF ENERGY MANAGEMENT AND ENERGY AUDIT

### Brief Contents





## Chapter-5 Materials and Energy Balance

Contents



## Chapter-5 Materials and Energy Balance

### Learning Objectives

**In this chapter you will learn about**

- ✓Need for material and energy balance
- ✓Understanding Sankey diagram and its uses
- ✓How to construct a process flow diagram?
- ✓Energy system analysis
- ✓How to carryout material and energy balance?

# 5.1 INTRODUCTION

- The law of conservation of mass and energy leads to what is called a mass (material) and energy balance.

- Material quantities, as they pass through processing operations, can be described by material balances. (First law)
- Energy quantities can be described by energy balances .
- If there is no accumulation, what goes into a process must come out. *Batch/continuous*

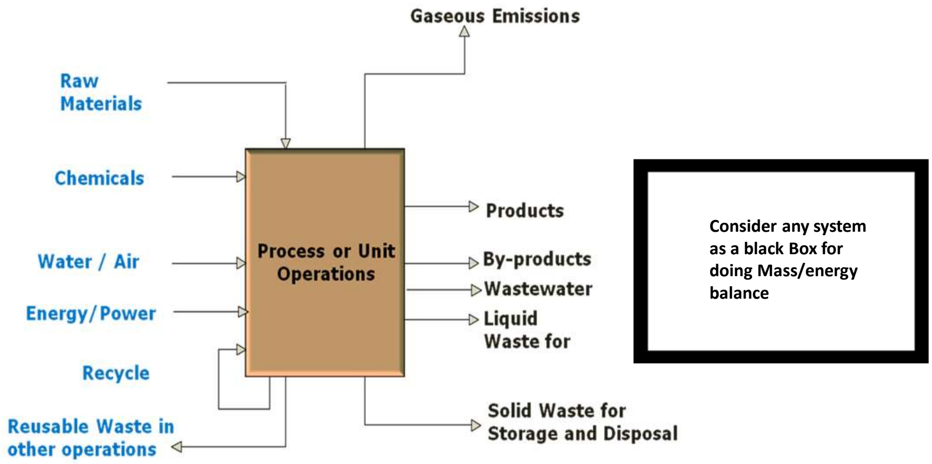
- **Energy balances are** used in the examination of the various stages of a process, over the whole production plant from the raw material to the finished product.
- **Material balances are** fundamental to the control of processing, control of yields of the products.
- Material balance can be determined from conceptual stage to final production stage

**Purpose of Material and Energy Balance**

- **To assess** the input, conversion efficiency, output and losses
- To quantify all material, energy and waste streams in a process or a system
- **Powerful tool** for establishing basis for improvement and potential savings



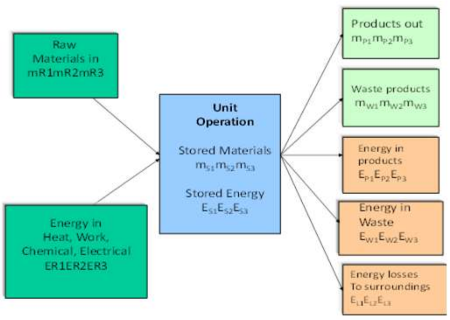
## 5.2 Components of Material and Energy Balance




Tyipcal Components of Material and Energy Balance of a Process or Unit Operation

## 5.3 BASIC PRINCIPLE

- If the unit operation, whatever its nature is seen as a whole it may be **represented diagrammatically as a box.**
- The mass and energy going into the box must balance with the mass and energy coming out.




Mass and Energy Balance

### Mass balance

- The law of conservation of mass leads to what is called a mass or a material balance.
- **Mass In = Mass Out + Mass Stored**
- Raw Materials = Products + Wastes + Stored Materials.

$$\Sigma m_R = \Sigma m_P + \Sigma m_W + \Sigma m_S$$

(where Σ (sigma) denotes the sum of all terms).

- If there are no chemical changes occurring in the plant, the law of conservation of mass will apply also to each component, so that for component A:
- $m_A$ in entering materials = $m_A$ in the exit materials + $m_A$ stored in plant.



- **For example**, in sugar plant , if the total quantity of sugar going into the plant is not equalled by the total of the purified sugar and the sugar in the waste liquors, then there is something wrong.
- Sugar is either being burned (chemically changed) or accumulating in the plant or else it is going unnoticed down the drain somewhere. In this case:
- $\mathbf{M_A = (m_{AP} + m_{AW} + m_{AU})}$

where $m_{AU}$ is the unknown loss and needs to be identified. So the material balance is now:

- **Raw Materials = Products + Waste Products + Stored Products + Losses**

where Losses are the unidentified materials.

The energy coming into a unit operation can be balanced with the energy coming out and the energy stored.

## Energy In = Energy Out + Energy Stored

$$\Sigma E_R = \Sigma E_P + \Sigma E_W + \Sigma E_L + \Sigma E_S$$

where

$\Sigma E_R = E_{R1} + E_{R2} + E_{R3} + \ldots$ = Total **Energy Entering**

$\Sigma E_p = E_{P1} + E_{P2} + E_{P3} + \ldots$ = Total **Energy Leaving with Products**

$\Sigma E_W = E_{W1} + E_{W2} + E_{W3} + \ldots$ =Total **Energy Leaving with Waste Materials**

$\Sigma E_L = E_{L1} + E_{L2} + E_{L3} + \ldots\ldots$= Total **Energy Lost to Surroundings**

$\Sigma E_S = E_{S1} + E_{S2} + E_{S3} + \ldots\ldots$ = Total **Energy stored**

Energy balances are often complicated because forms of energy can be interconverted, for example mechanical energy to heat energy, but overall the quantities must balance.



## 5.4 Classification of Processes

### A) Based on how the process varies with time

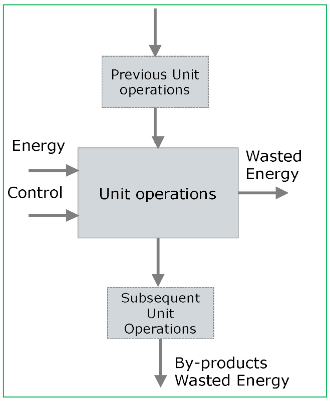
Steady-state process is one where none of the process variables change with time

Unsteady –state process is one where the process variables change with time

### B) Based on how the process was built to operate

**A continuous process** is one that has the feed streams and product streams moving into and out of the process all the time. Examples are oil refinery, distillation process etc.

**A batch process** is one where the feed streams are fed to the process to get it started. The feed material is then processed through various process steps and finished products are taken out at specific times.




**Representation of Process**

# 5.5 Material Balance

## Levels of Material Balance

The material balances can be developed at various levels:

- **Overall Material balance:** This involves input and output steams for complete plant
- **Section wise Material balances**: This involves M&E balances to be made for each section/department/cost centre. This would help to prioritise focus areas for efficiency improvement ***Example:*** *Paper Plant*
- **Equipment-wise** Material balances: Material balances for key equipment would help assess performance of equipment, which would in turn help identify energy and material losses. ***Example:*** *Evaporator, Heat exchanger*



E1

# Material Balance Procedure

**a) Define basis & units:** Choose a basis of calculations on quantity (mass **for batch process**) or flow rate (mass per hour **for continuous process**) of one of the process streams.

Concentrations can be expressed in many ways:

- weight/ weight **(w/w),**
- weight/volume **(w/v),**
- molar concentration (M),
- mole fraction.

- weight/weight concentration is the **weight of the solute divided by the total weight of the solution** and this is the fractional form of the percentage composition by weight.
- weight /volume concentration is the **weight of solute in the total volume of the solution.**
- The molar concentration is the number of molecular weights of the solute expressed in kg in 1 $m^3$ of the solution.
- The mole fraction is the ratio of the number of moles of the solute to the total number of moles of all species present in the solution.

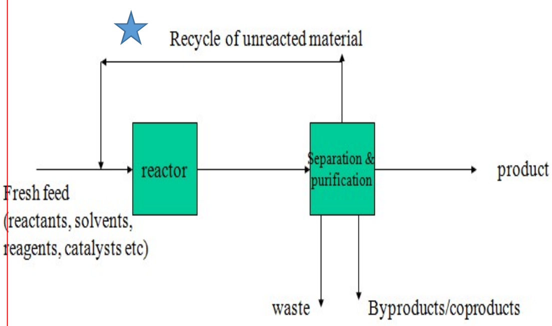
**Slide 12**

**E1** ENSAVE, 30-06-2020

## Typical Arrangement of a Process Flowchart

***b) Draw a flowchart***

- **Inputs of** the process could include raw materials, water, steam, energy (electricity, etc);
- **Process Steps** should be sequentially drawn from raw material to finished product &Intermediates. The operating process temperature, pressure, % concentration, etc. should be represented . The flow rate of various streams units like **$m^3$/h or kg/h**. In case of batch process t**he total cycle time**
- **Wastes / by products** could include solids, water, chemicals, energy. For each unit operation as well as for an entire plant, energy and mass balance diagram should be drawn.
- **Output of** the process is the final product produced




***c)Write Material Balance Equations:*** The following examples are illustration for writing the material balance equations



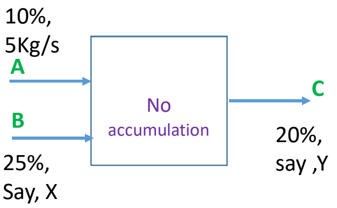
## Example5.1

A solution which contains 10% solids is mixed with 25% solid solution. A single output which is 20% solid is removed. If the 10% solution enters at 5.0 kg/s, what are the other rates? (Assume no accumulation)

**Solution:** Basis:

Solution A (INPUT) = 5 kg/s
Solution B (INPUT) = x kg/s
Solution C (OUTPUT) = y kg/s
Therefore A + B = C

**5 + X = Y.................. EQ -1**




Since solution A contains 10% solids, solution B contains 25% solids and solution C contains 20% solids the equation can be written as

**Solids 0.1 *5 +0.25 * X = 0.2 * Y......... EQ -2**
**Liquids 0.9 *5 +0.75*X = 0.8 * Y........... EQ -3**

**Substituting value** of Y from EQ -1 in EQ-2
0.5 + 0.25 X = 0.2 * (5 + X)
0.05 X = 0.5
**X = 10 kg/s**,
Substituting X in EQ-1, **Y= 15 kg/s**

## Example 5.2

A solution which is 80% oil, 15% usable by-products and 5% impurities, enters a refinery. One output is 92% oil and 6% usable by-products. The other output is 60% oil and flows at the rate of 1000 lit/hr (assume no accumulation, percent's by volume)

1. What is the flow rate of input?
2. What is the percent composition of the 1000 lit/hr output?
3. What percent of the original impurities are in the 1000 lit/hr output?

**Solution** Basis:
Input Stream A = X lit/hr
Output Stream B = Y lit/hr
Output Stream C = 1000 lit/hr

<u>Material balance equations</u>

1) Total: X = Y + 1000……………………..………..EQ-1
2) Oil: 0.8 * X = 0.92 * Y + 0.6 * 1000……………..EQ-2
3) UBP: 0.15 * X = 0.06 * Y + v * 1000…………..EQ-3
4) IMP: 0.05 * X = 0.02 * Y + w *1000……………EQ-4
5) OUTPUT impurities & UBP: <u>**v + w = 0.4**</u> ……..EQ-5

<u>Solving Equations</u> 1 and 2; substituting value of X in EQ-2

0.8 (Y + 1000) = 0.92 * Y + 600
0.8 Y + 800 = 0.92 Y + 600, ….. Y = 1666 lit/hr

Substituting Y in EQ-1

X = 1666 + 1000 = 2666 lit/hr = Flow rate of input stream
Substituting value of X and Y in EQ-3, <u>v= 30%</u>
Substituting value of v in EQ-5, <u>w = 10%</u>

Thus composition of 1000 lit/hr output stream is 60% oil, 30% usable by products and 10% impurities

Impurities in input stream = 0.05 * 26666 = 133.3 lit/hr

Impurities in 1000 lit/hr stream(10%) =100 lit/hr

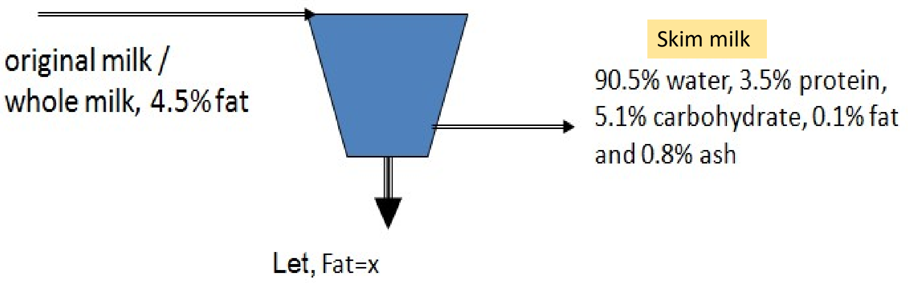
Therefore impurities in 1000 lit/hr stream as % input stream
= 100/1333.3 = 75%



## Example 5.3 : Constituent balance

**Skim milk** is prepared by the removal of some of the fat from **whole milk**. This skim milk is found to contain 90.5% water, 3.5% protein, 5.1% carbohydrate, 0.1% fat and 0.8% ash.

If the original milk contained 4.5% **fat,** calculate its composition assuming that fat only was removed to make the skim milk and that there are no losses in processing.



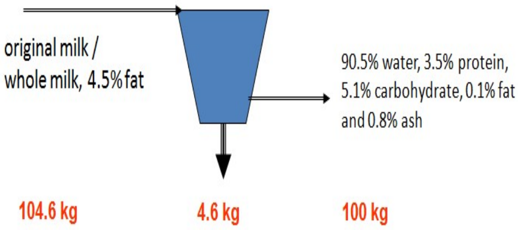
**Solution:**
Basis: 100 kg of skim milk.
This contains, 0.1 kg of fat. Let the fat which was removed from it to make skim milk be x kg.
Total original fat = (x + 0.1)kg
Total original mass = (100 + x) kg
it is known that the original fat content was 4.5% so

$$\frac{(x + 0.1)}{(100 + x)} = 0.045$$

$$x + 0.1 = 0.045(100 + x)$$

$$x = 4.6 \text{ kg}$$

So the composition of the whole milk is then
fat = 4.5%,
water = 90.5/104.6 = 86.5 %,
protein = 3.5/104.6 = 3.3 %,
Carbohydrate = 5.1/104.6 = 4.9%
and ash = 0.8%






## TYPES OF PROCESS SITUATIONS

**Continuous Processes** : In continuous processes, ***time also enters into consideration*** and the balances are related to unit time.

- Considering a continuous centrifuge separating **whole milk** into **skim milk** and **cream**, if the material holdup in the centrifuge is constant both in mass and in composition, then the quantities of the components entering and leaving in the different streams in unit time are constant and a mass balance can be written on this basis.
- Such an analysis assumes that the process is in a steady state, that is flows and quantities held up in vessels do not change with time.

**Example5.4 : Continuous Process balance**

In a continuous centrifuging of milk, if 35,000 kg of whole milk containing 4% fat is to be separated in a 6 hour period into skim milk with 0.45% fat and cream with 45 % fat, what is the flow rate of the two output streams from the continuous centrifuge which accomplishes the separation?

**Solution** Basis:

Total mass input per hour = 35000/6 =5833 kg
Total mass output for skim milk = Y
Total mass output for cream = z

***Material Balance Equations:***

1) Mass In = Mass Out: 5833 = Y + Z (i.e. Z = 5833-Y)
2) Fat In = Fat Out: 0.04 * 5833 = 0.0045 * Y + 0.45 * Z … EQ-2

**Substituting** Z from EQ-1 to EQ-2

0.04 * 5833 = 0.0045 Y + 0.45 * (5833 –Y)
Y = 5369 kg/hr
Substituting Y in EQ -1
Z = 464 kg/hr



## Example5.5 : Concentrations

A solution of common salt in water is prepared by adding 20 kg of salt to 100 kg of water, to make a liquid of density 1323 kg/m$^3$. Calculate the concentration of salt in this solution as a (a) weight fraction, (b) weight/volume fraction, (c) mole fraction, (d) molal concentration.

**Solution**

(a) Weight fraction $\frac{20}{(100 + 20)} = 0.167$

% weight / weight = 16.7%

(b) Weight/volume:

A density of 1323kg/m$^3$ means that lm$^3$ of solution weighs 1323kg,

but 1323kg of salt solution contains $= \frac{(20 \times 1323 \text{ kg of salt})}{(100 + 20)}$

= 220.5 kg salt / m3

1 m3 solution contains 220.5 kg salt.

Weight/volume fraction = 220.5 / 1000 = 0.2205

And so weight / volume = 22.1%

c) Moles of water = 100 / 18 = 5.56

Moles of salt = 20 / 58.5 = 0.34

Mole fraction of salt = 0.34 / (5.56 + 0.34) = 0.058

d) The molar concentration (M) is 220.5/58.5 = 3.77 moles in m$^3$

**Example 5.9 : Dust balance**

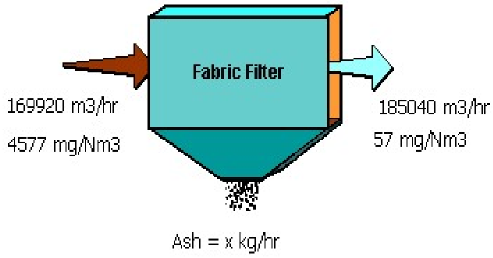
Dust balance, Mass $_{(in)}$ = Mass $_{(out)}$
Inlet gas dust = outlet gas dust + Hopper Ash

A bag filter is used to remove the dust from the inlet gas stream to meet the emission standards in cement, fertilizer and other chemical industries.

Inlet gas to a bag filter is 1,69,920 $m^3$/hr and the dust loading is 4577 mg/$m^3$.

Outlet gas from the bag filter is 1,85,040 $m^3$/hr and the dust loading is 57 mg/$m^3$.

What is the maximum quantity of ash that will have to be removed per hour from the bag filter hopper based on test results?




**Solution**

1. Calculation in/ out dust qty

Inlet dust qty =169920 ($m^3$/hr) x 4577 (mg/$m^3$) x 1/1000000 (kg/mg)= 777.7 kg/hr

Outlet dust qty = 185040 ($m^3$/hr) x 57 (mg/$m^3$) x 1/1000000 (kg/mg) = 10.6 kg/hr

2. Calculate ash qty (to be removed from the hopper)

Hopper ash = Inlet dust qty–Outlet dust qty = 777.7 kg/hr–10.6 kg/hr = 767.1 kg/hr

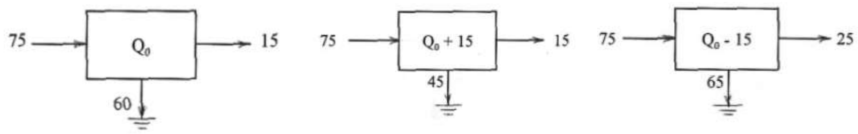


## 5.6 Energy Balance

❖The law of conservation of energy states that energy can neither be created nor destroyed.
❖The sinks are depositories of leakage or rejected energy.

**Conservation of Energy**

In a system, if the storage does not change, the ingoing and outgoing energy must be equal




**No Storage** **Storage Increased** **Storage Decreased**

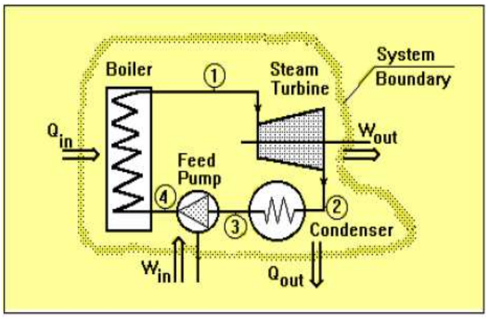
### Energy Balance in Power Plant Cycle

Applying the law of conservation of energy, if a system undergoes a process by heat and work transfer, then the net heat supplied, Q plus the net work input, W. is equal to the change of intrinsic (internal) energy, $\Delta U$ of the working fluid, i.e.

$\Sigma Q + \Sigma W = \Delta U$

Applying this general principle to a thermodynamic cycle, when the system undergoes a complete cycle. i.e. change in internal energy, $\Delta U = 0$.

$\Sigma Q + \Sigma W = 0$`




Where:

$\Sigma Q$ = The algebraic sum of the heat supplied to (+) or rejected from (-) the system.

$\Sigma W$ = The algebraic sum of the work done by surroundings on the system (+) or by the system on surroundings (-).

Applying the rule to the power plant gives:

$\Sigma Q = Q_{in} - Q_{out}$

$\Sigma W = W_{in} - W_{out}$

$Q_{in} + W_{in} - Q_{Out} - W_{out}$

$Q_{in}$ = Heat supplied to the system through boiler

$W_{in}$ = Feed-pump work

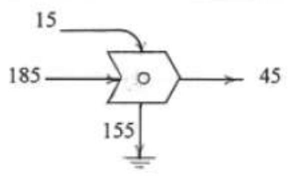
$Q_{Out}$ = Heat rejected from the system by condenser

$W_{out}$ = Turbine work



# Efficiency

The (thermodynamic) efficiency of a process is the ratio of useful output to input and is always less than 100%.




Input = 15 + 185

Output + Sink = 45 + 155

Eff = Output / Input

= 45/(15+185) = 45/200 = .225

No energy is lost in the end, only the forms have changed.

This loss of usable energy is due to many causes

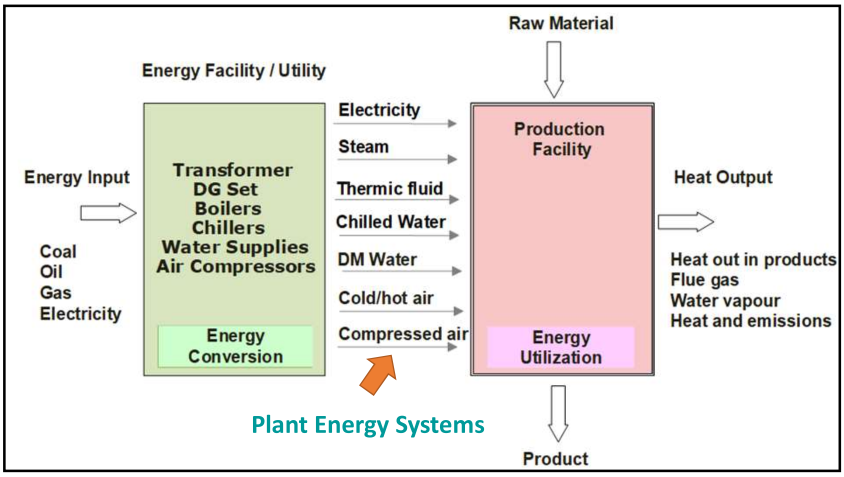
- In mechanical systems it is friction
- In electrical systems it is resistance
- In fluid systems it is turbulence, viscosity or mixing

# HEAT BALANCES

- The most common important energy form is heat energy and the conservation of this can be illustrated by considering operations such as heating and drying.
- In these, enthalpy (total heat) is conserved and as with the mass balances so enthalpy balances can be written round the various items of equipment. or process stages, or round the whole plant, and it is assumed that no appreciable heat is converted to other forms of energy such as work.



## 5.7 Facility as an Energy System




All energy/utility system can be classified into three areas like

- generation,
- distribution
- and utilisation

for the system approach and energy analysis.

**Example 5.10 : Furnace**

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 28°C. The maximum allowed increase in water temperature is 5°C.

**Calculate the quantity of water** required to cool the furnace. Neglect heat loss.

**Solution**

***Energy Stream #1***

Mass of furnace shell (m) = 2000 kg

Specific heat (Cp ) = 0.2 kCal/kg °C

Initial furnace temperature ($T_1$) = 90°C

Desired furnace shell temperature ($T_2$) = 55°C

Total heat that has to be removed from the furnace

**= m x Cp x ($T_1$ — $T_2$)**

= 2000 x 0.2 x (90- 55) = **14000 kCal**

***Energy Stream #2***

Quantity of water required =**X** kg

Specific heat of water = 1 kCal/kg °C

Inlet cooling water temperature ($T_3$) = 28°C

Maximum cooling water outlet temperature ($T_4$) = 33°C

Heat removed by water =X x 1 x (33 — 28) = 5**X** Kcal

For energy balance:

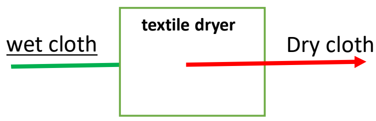
**Energy Stream #1 = Energy Stream #2**

quantity of water required (**X**) = 14000/5 = **2800 kg**



# Example 5.11: Dryer heat balance

A textile dryer is found to consume 4 m$^3$/hr of natural gas with a calorific value of 800 kJ /mole. If the throughput of the dryer is 60 kg of wet cloth per hour, drying it from 55% moisture to 10% moisture, estimate the overall thermal efficiency of the dryer taking into account the latent heat of evaporation only.




**Solution**

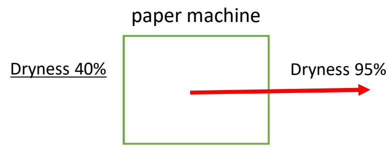
1) Initial moisture in wet cloth =60 x 0.55 = 33 kg moisture
2) Bone dry cloth = 60 x (1-0.55) =27 kg bone dry cloth
3) Final product moisture content 10% = 27/9 = 3 kg
4) So moisture removed /hr = 33 - 3 = 30 kg/hr
5) Latent heat of evaporation = 2257 kJ/k
6) Heat used for drying cloth = 30 x 2257 = 6.8 x 10$^4$ kJ/hr
7) Assuming the natural gas to be at standard temperature and pressure at which 1 mole occupies 22.4 liters
8) Rate of flow of natural gas = 4 m$^3$/hr = (4 x 1000)/22.4 = 179 moles/hr
9) Heat available from combustion 179 x 800 =14.3 x 10$^4$ kJ/hr
10) Approximate thermal efficiency of dryer = heat needed / heat used

6.8 x 10$^4$ /14.3 x 10$^4$ **= 48%**

**Example - Evaporation Rate**

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 35 kg/cm2. Latent heat of steam at 35 kg/cm2 is 5l3 kCal/kg. Assume 24 hours/day operation a) Estimate the quantity of moisture to be evaporated b) Input steam quantity required for evaporation (per hour). Consider enthalpy of evaporated moisture as 632 kCa1/kg.

**Solution**

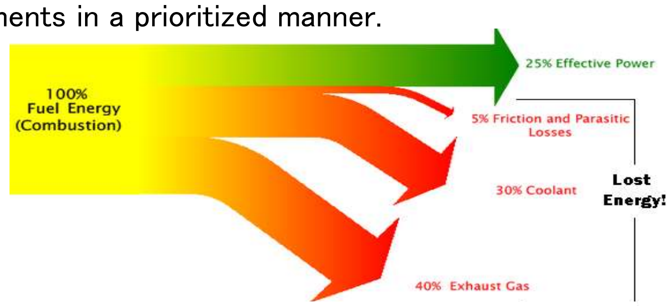



Production rate from a paper machine: =340 TPD or 14.16 TPH (tonnes/hour)
Inlet dryness to paper machine = 40%
Outlet dryness from paper machine- = 95%
Estimation of moisture to be evaporated
Paper weight in final product: =14.16 x **0.95** = 13.45 TPH
Weight of moisture before dryer: = [(100-40)/ 40] x 13.45 = 20.175 TPH
Weight of moisture after dryer: =14.16 x 0.05 = 0.707 TPH
***Evaporated moisture quantity:*** =20.175 - 0.707 =***19.468 TPH***
**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/cm$^2$ = 513 kCal/kg
Quantity of steam required: =12303776/513= 23984 kg or **23.98 MT/hour**



## 5.8 Energy Analysis and the Sankey Diagram

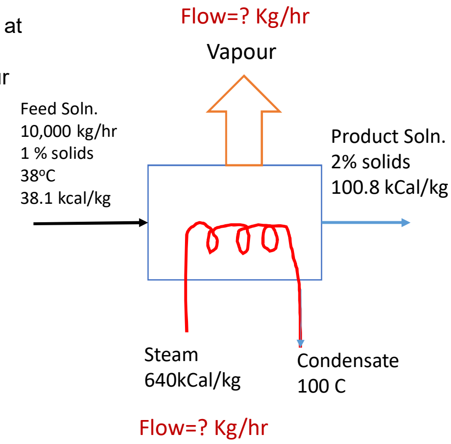
- The Sankey diagram is very useful tool to represent an entire input and output energy flow in any energy equipment or system such as boiler generation, fired heaters, furnaces after carrying out energy balance calculation. This diagram represents visually various outputs and losses so that energy managers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




**Sankey Diagram for an Internal Combustion Engine**

## Solved Example:

An evaporator is to be fed with 10,000 kg/hr of a solution having 1 % solids. The feed is at 38°C. It is to be concentrated to 2% solids. Steam is entering at a total enthalpy of 640 kCal/kg and the condensate leaves at 100°C. Enthalpies of feed are 38.1 kcal/kg, product solution is 100.8 kCal/kg and that of the vapour is 640 kCal/kg. Find the mass of vapour formed per hour and the mass of steam used per hour.




**Ans:**

**Mass of vapour**

Feed Flow rate = 10,000 kg/hr @ 1 % solids

Solids in = 10,000 x 1/100 = 100 kg/hr

Mass $flow_{out}$ x 2/100 = 100

Mass $flow_{out}$ = 10,000/2 = 5000 kg/hr

Vapour formed = 10,000 – 5000 = **5000 kg/hr**

Thick liquor = 5000 kg/hr

**Steam consumption:**

Enthalpy of feed = 10,000 x 38.1 = 38.1 x $10^4$ kCal

Enthalpy of the thick liquor = 100.8 x 5000 = 5,04,000 kCal

Enthalpy of the vapour = 640 x 5000 = 32,00,000 kCal

**Heat Balance**:

Heat input by steam + Heat in feed = Heat out in vapour + Heat out in thick liquor

[M x (640-100) + 38.1 x 10,000] = (32,00,000 + 5,04,000)

M x 540 = 33,23,000

Mass of steam required ,M = 33,23,000/540 = **6153.7 kg/hr**



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| 1. | The objective of material and energy balance is to assess the<br>**a) input-output** **b) conversion efficiency**<br>**c) losses** **d) all the above** ★ |
| 2. | In the material balance of a process or unit operation process, which component will not be considered on the input side?<br>**a) chemicals** **b) water/air** **c) recycle** ★ **d) by product** |
| 3. | In material balance of a process, recycle product is always considered as<br>**a) input to process** **b) output to process**<br>**c) both (a) and (b)** **d) none of them** ★ |
| 4. | In a chemical process two reactants A (200 kg) and B (200kg) are used as reactants. If conversion is 50%, A and B react in equal proportion then calculate the weight of the product formed is.<br>**a) 150 kg** **b) 200 kg** ★ **c) 250 kg** **d) 400 kg** |
| 5. | 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?<br>**a) 150 kcal** **b) 250 kcal** **c) 350 kcal** **d) 100 kcal** ★ |

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| 6. | In a utility steam boiler, heat loss due to radiation normally is in the range of<br><br>a) 10% b) 14% c) 1% d) 8% |
| 7. | Energy supplied by electricity, Q in kcal is equal to _____.<br><br>a) kWh x 8.6 b) kWh x 86 c) kWh x 860 d) none |
| 8. | Sankey diagram is a useful tool to represent ____.<br><br>a) financial strength of the company b) management philosophy<br>c) input and output energy flow d) human resource strength of the company |
| 9. | Which of the following formula is useful to determine the heat duty in conducting heat balance?<br><br>a) Q = M Cp Δ T b) Q = AV c) PV = n RT d) none of the above |
| 10. | A 230V , 100 W rated incandescent bulb is operated at a constant voltage of 250V. The approximate power consumption of bulb is<br><br>a) 100 W b) 118 W c) 85 W d) none of the above |



## Short Type Questions

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| **S-1** | During an air pollution monitoring study, the inlet gas stream to a bag filter was 200,000 m3 per hour. The outlet gas stream from the bag filter was a little bit higher at 210,000 m3 per hour. Dust load at the inlet was 6 gram/ m3and at the outlet 0.1 gram/ m3 .<br>How much dust in kg/hour was collected in the bag filter bin?<br>**inlet gas -outlet gas stream = Dust collected** |
| **S-5** | A shell and tube heat exchanger is cooled with stream of demineralized water. Evaluate the total heat rejected to cooling water (kcal/hr), if the water flow rate is 200 m3/hr and the temperature rise is 7°C.<br>**M Cp delta T** |
| L-2 | An autoclave contains 1000 cans of pea soup. It is heated to an overall temperature of 100 oC. If the cans are to be cooled to 40 oC before leaving the autoclave, how much cooling water is required if it enters at 15 oC and leaves at 35 oC?<br>The specific heats of the pea soup and the can metal are respectively 4.1 kJ/ kg oC and 0.50 kJ/ kg oC. The weight of each can is 60g and it contains 0.45 kg of pea soup. Assume that the heat content of the autoclave walls above 40 oC is 1.6 x 104 kJ and that there is no heat loss through the walls.<br>**For Cans: M Cp delta T + For Soup M Cp delta T = Cooling water= M Cp delta T** |

# Thank You

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