UNIT III -THERMAL SYSTEMS

3.1 Stoichiometry

Stoichiometry is the study of the relationship between relative amounts of substances. The formula of a compound provides information about the relative amount of eachelement

present in either one molecule of the compound or one mole of the compound. For example,onemolecule of$CaCl_2$contains1molCa^{2+}ionsand 2molCl^-ions.

Stoichiometry can be used to determine the chemical formula of a compound bystudying the relative amounts of elements present or can be used to study the relativeamountsofcompoundsthatareconsumed and produced during achemicalreaction

3.2 EfficiencycomputationofBoilers

Efficiency testing helps us to find out how far the boiler efficiency drifts awayfromthebestefficiency.Anyobservedabnormaldeviationscouldthereforebeinvestigated to pinpoint the problem area for necessary corrective action. Hence it isnecessarytofindoutthecurrentlevelofefficiencyforperformanceevaluation,whichisaprerequisiteforenergy conservationactioninindustry.

Most standards for computation of boiler efficiency, including IS 8753and BS845 are designed for spot measurement of boiler efficiency. Basically Boilerefficiencycanbetestedbythefollowingmethods:

1) **The Direct Method:** Where the energy gain of the working fluid (water andsteam)iscomparedwiththeenergycontentoftheboilerfuel.
2) **The Indirect Method:** Where the efficiency is the difference between the lossesandtheenergyinput.

3.2.1 TheDirectMethodTesting

Thisisalsoknownas'input-outputmethod'duetothefactthatitneedsonlythe Useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. Thisefficiencycanbeevaluatedusingtheformula:

$$Boiler\ Efficiency = \frac{Heat\ Output}{Heat\ Input} \quad \text{x}100$$

$$Boiler\ Efficiency = \frac{\text{Steam flow rate x (steam enthalpy} - \text{ feed water enthalpy)}}{\text{Fuel firing rate x Gross calorific value}}\ x\,100$$

Example3.1

Water consumption and coal consumption weremeasured in a coal-fired boiler athourly intervals. Weighed quantities of coal were fed to the boiler during the trialperiod. Simultaneously water level difference was noted to calculate steam generationduring the trial period. Blow down was avoided during the test. The measured data isgivenbelow.

Type of boiler: Coal fired Boiler

Heat output data

Quantity of steam generated (output) : 8 TPH
Steam pressure / temperature : 10 kg/cm^2(g)/ 180°C
Enthalpy of steam(dry & Saturated)
at 10 kg/cm^2(g) pressure : 665 kCal/kg
Feed water temperature : 85°C
Enthalpy of feed water : 85 kCal/kg

Heat input data

Quantity of coal consumed (Input) : 1.6 TPH
GCV of coal : 4000 kCal/kg

Calculation

Boiler efficiency (η): $= \dfrac{Q \times (H - h) \times 100}{(q \times GCV)}$

Where **Q** = Quantity of steam generated per hour (kg/hr)
q = Quantity of fuel used per hour (kg/hr)
GCV = Gross calorific value of the fuel (kCal/kg)
H = Enthalpy of steam (kCal/kg)
h = Enthalpy of feed water (kCal/kg)

Boiler efficiency (η) $= \dfrac{8\ \text{TPH} \times 1000\text{kg/T} \times (665 - 85) \times 100}{1.6\ \text{TPH} \times 1000\text{kg/T} \times 4000\ \text{kCal/kg}}$

$= \mathbf{72.5\%}$

3.2.1.1 MeritsandDemeritsof Direct Method

Merits

- Plantpeoplecanevaluate quicklytheefficiencyofboilers
- Requiresfewparametersforcomputation
- Needsfewinstrumentsformonitoring

Demerits

- Doesnotgivecluestotheoperatorastowhyefficiencyofsystemislower
- Doesnot calculatevariouslossesaccountable forvariousefficiencylevels
- Evaporationratioandefficiencymaymislead,ifthesteamishighlywetduetowatercarryover

3.3 EnergyConservationOpportunitiesinBoilers

1. StackTemperature

Thestacktemperature(Temperatureusedtoremovewatervaporintheexhaustcondenses on the stack walls) should be as low as possible. An estimated 1% efficiency loss occurswithevery22°Cincreaseinstacktemperature.

2. FeedWaterPreheatingusingEconomizer

FeedWaterPreheatingusingeconomizerwouldreducetheexittemperatureto65°C, thereby increasing thermal efficiency by 5%.

3. Combustion Air Preheat

Combustion air preheating is an alternative to feed water pre-heating. In order to improve thermal efficiency by 1%, the combustion air temperature must be raised by 20 °C using pre-heater.

4. Incomplete Combustion

Incomplete combustion can arise from a shortage of air or surplus of fuel or poor distribution of fuel. It is usually obvious from the colour or smoke, and must be corrected immediately.

5. Excess Air Control

Controlling excess air to an optimum level always results in reduction in flue gas losses; for every 1% reduction in excess air there is approximately 0.6% rise in efficiency.

6. Radiation and Convection Heat Loss

Repairing or augmenting insulation can reduce heat loss through boiler walls and piping.

7. Automatic Blowdown Control

Uncontrolled continuous blow down is very wasteful. Automatic blow down controls can be installed that sense and respond to boiler water conductivity and pH. A 10% blowdown in a 15 kg/cm^2 boiler results in 3% efficiency loss.

8. Reduction of Scaling and Soot Losses

In oil and coal-fired boilers, soot buildup on tubes acts as an insulator against heat transfer. Any such deposits should be removed on a regular basis. It is estimated that 3 mm of soot can cause an increase in fuel consumption by 2.5% due to increased flue gas temperatures. Periodic off-line cleaning of radiant furnace surfaces, boiler tube banks, economizers and air heaters may be necessary to remove stubborn deposits.

9. Variable Speed Control for Fans, Blowers and Pumps

The possibility of replacing the dampers by a VSD should be improve the system efficiency.

10. EffectofBoilerLoadingonEfficiency

Themaximumefficiencyoftheboilerdoesnotoccuratfullload,butataboouttwo-thirdsofthefullload.

12. ProperBoilerScheduling

Operateafewernumberof boilersathigherloads,thantooperatealargenumberatlow loads.

13. BoilerReplacement

Thepotentialsavingsfromreplacingaboilerdependontheanticipatedchangeinoverallefficiency.Achangeinaboiler canbefinanciallyattractiveiftheexistingboileris:

- oldandinefficient
- notcapableoffiringcheaper substitutionfuel
- overorunder-sizedforpresentrequirements
- notdesignedforidealloadingconditions

3.4 EfficiencycomputationofFurnaces

Afurnaceisanequipmenttomeltmetalsforcastingorheatmaterialsforchangeofshape(rolling,forgingetc)orchange ofproperties(heattreatment).

Theefficiencyoffurnacecanbejudgedbymeasuringtheamountoffuelneededperunitweightof material.

$$\text{Thermal efficiency of the furnace} = \frac{\text{Heat in the stock}}{\text{Heat in the fuel consumed for heating the stock}}$$

Thequantityofheat tobeimparted(Q)tothestock canbefoundfrom

$$Q=m\times Cp(t_1-t_2)$$

Where

Q = Quantityof heatofstockinkCal

m= Weightofthe stockinkg

Cp = Mean specific heat of stock in

kCal/kg°Ct_1=Finaltemperatureofstockdesired,°

C

t_2=Initialtemperatureofthestockbeforeitentersthefurnace,°C

Example3.2

Anoil-firedreheatingfurnacehasanoperatingtemperatureofaround1340°C.Average fuel consumption is 400 litres/hour. The flue gas exit temperature is 750 °C after airpre-heater. Air is preheated from ambient temperature of 40 °C to 190 °C through an air pre-heater. The furnace has 460 mm thick wall (x) on the billet extraction outlet side, which is 1 mhigh (D) and 1 m wide. The other data are as given below. Find out the efficiency of thefurnace bydirectmethod.

Exitfluegastemperature =

750°CAmbient temperature =

40°CPreheatedair temperature =

190°CSpecificgravityofoil =0.92

Averagefueloilconsumption= 400 Litres/hr

=400 ×0.92 =368kg/hr

Calorificvalueofoil = 10000

kCal/kgAverage O2 percentage influe gas=

12%Weightofstock =

6000kg/hrSpecificheatofBillet =0.12kCal/kg/°C

Averagesurfacetemperatureofheating +soaking zone=122 °C

Average surface temperature of area other than heating and soaking zone = 80

°CArea ofheating+soakingzone =70.18m2

Areaotherthanheatingand soaking zone=12.6m2

Solution:

Heatinput =400 litres/hr

=

368kg/hrHeat output

$=m \times Cp \times \Delta T$

$= 6000kg \times 0.12 \times (1340 - 40)$

=936000kCal

Efficiency = 936000× 100/(368× 10000)
=25.43%
=25%(app)
Losses =75%(app)

3.5 EnergyConservationmeasuresinFurnaces

1) Completecombustionwithminimumexcessair
2) Correctheatdistribution
3) Operatefurnaceatthedesiredtemperature
4) Reduceheatlossesfromfurnaceopenings
5) Maintaincorrect amountoffurnacedraught
6) Optimum capacity utilizationof furnace will givemaximum thermalefficiency
7) Wasteheatrecoveryfromthefluegasesimprovessystemefficiency
8) Minimumrefractorylosses

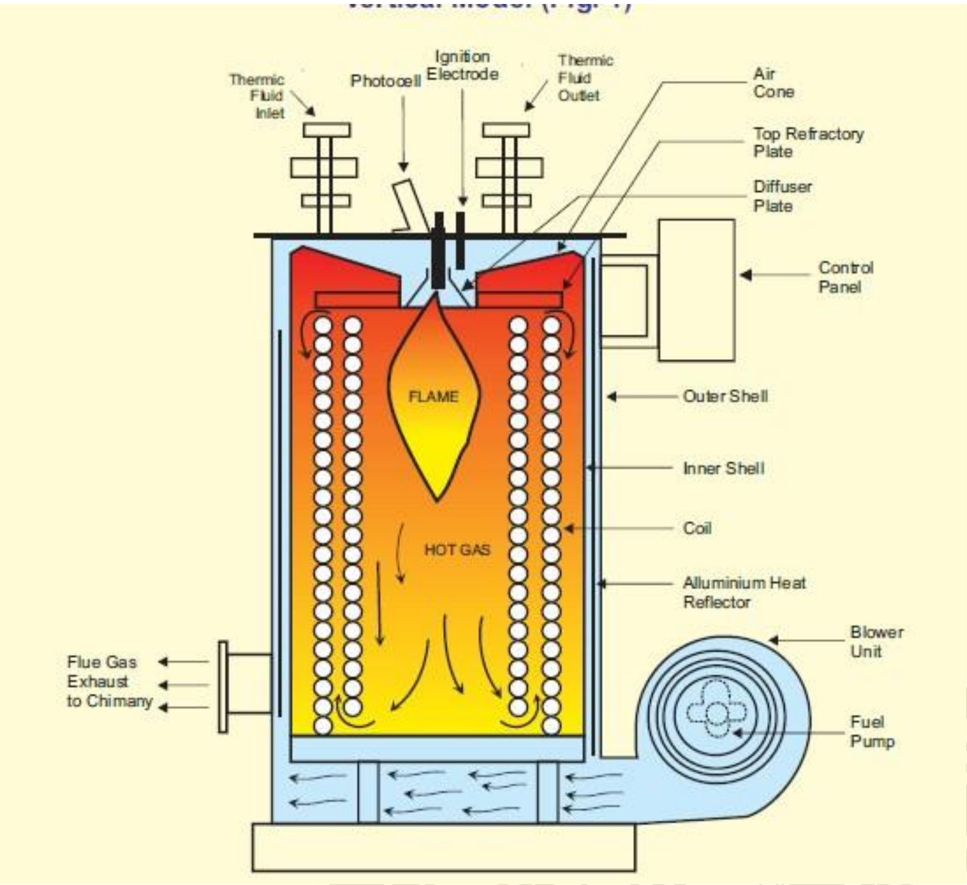
Theappropriatechoiceofrefractoryandinsulationmaterialsgoesalongway inachievingfairly high fuelsavingsin industrial furnaces

9) UseofCeramicCoatingsinfurnacechamberpromotesrapidandefficienttransferofheat,therebyextendedlifeofrefractories.

3.6 ThermicFluidHeaters

Thermic Fluid is used as a heat transfer mechanism in some industrial process andheating applications. Thermic Fluid may be a vegetableor mineral based oil and the oil maybe raised to a high temperature without the need for any pressurization. The relatively highflow and return temperatures may limit the potential for flue gas heat recovery unless someother system can absorb this heat usefully. Careful design and selection is required to achievebestenergyefficiency.

Thermic fluid heaters are used just to heat the water, not necessarily producing steam.Water is heated by passing hot thermic fluid in tubes submerged in water. This arrangement issimilartothefire-tubeboiler.



The combustion air enters through the fan inlet, travels upwards through the spacebetween the inner shell & the outer shell, gets pre-heated & enters the top mounted burner Hotflue gases travel down the full length of the vessel creating the first (radiant) pass The fluegases then travel upwards through the spacebetween theinner coil & the outer coil creatingthe second (convection) pass The third (convection) pass is downwards through the spacebetweentheoutercoil&theinnershelltothefluegas outlet.

3.7 Steam:Concept,Properties&Usage

Steam has been a popular mode of conveying energy since the industrial revolution.Steam is used for generating power and also used in process industries such as sugar,paper,fertilizer,refineries,petrochemicals,chemical,food,syntheticfiberandtextiles.

Thefollowingcharacteristicsofsteammakeitsopopularandusefultotheindustry:

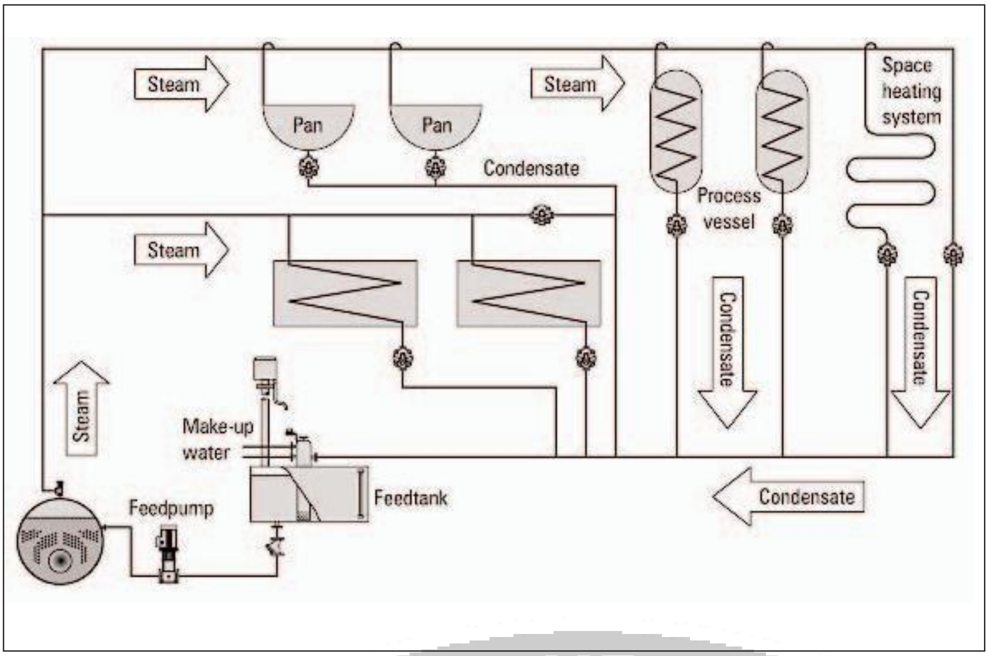
- Highestspecificheat andlatentheat
- Highestheattransfercoefficient
- Easytocontrolanddistribute
- Cheapandinert

Water can exist in the form of solid (ice), liquid (water) and gas (steam) respectively.If heat energy is added to water, its temperature rises until a value is reached at which thewater can no longer exist as a liquid. We call this the "saturation" point and with anyfurther of energy, some of the water will boil off as steam. This evaporationrequires relatively large amounts of energy, and while it is being added, the water and thesteam released are both at the same temperature. Equally, if steam is made to release theenergy that was added to evaporate it, then the steam will condense and water at sametemperature willbeformed.

3.8 SteamDistribution

The steam distribution system is the essential link between the steam generator andthe steam user. Whatever the source, an efficient steam distribution system is essential ifsteam of the right quality and pressure is to be supplied, in the right quantity, to the steamusing equipment. Installation and maintenance of the steam system are important issues,andmustbe consideredatthe designstage.

Figure 3.2SteamDistributionSystem



As steam condenses in a process, flow is induced in the supply pipe. Condensate has averysmall volume compared to the steam, and this causes a pressure drop, which causesthe steam to flow through the pipes. The steam generated in the boiler must be conveyedthrough pipe work to the point where its heat energy is required. Initially there will be oneor more main pipes, or 'steam mains', which carry steam from the boiler in the generaldirection of the steam using plant. Smaller branch pipes can then carry the steam to theindividual pieces of equip- ment. A typical steam distribution system is shown in Figure3.2.

3.9 SteamTraps

The purpose of installing the steam traps is to obtain fast heating of the product andequipmentby keeping the steam linesand equipmentfree of condensate,airand non-condensable gases.A steam trap is a valve device thatdischarges condensate andairfromthe line orpiece ofequipmentwithoutdischargingthe steam.

Thethreeimportantfunctionsofsteamtrapsare:

- Todischargecondensateassoonasitisformed.
- Nottoallowsteamtoescape.

- Tobecapableofdischargingairandotherincondensiblegases.

3.9.1 TypesofStemTraps

Therearethreebasictypesofsteamtrapintowhichallvariationsfall,allthreeareclassifiedbyInternationalStandardISO6704:1982.

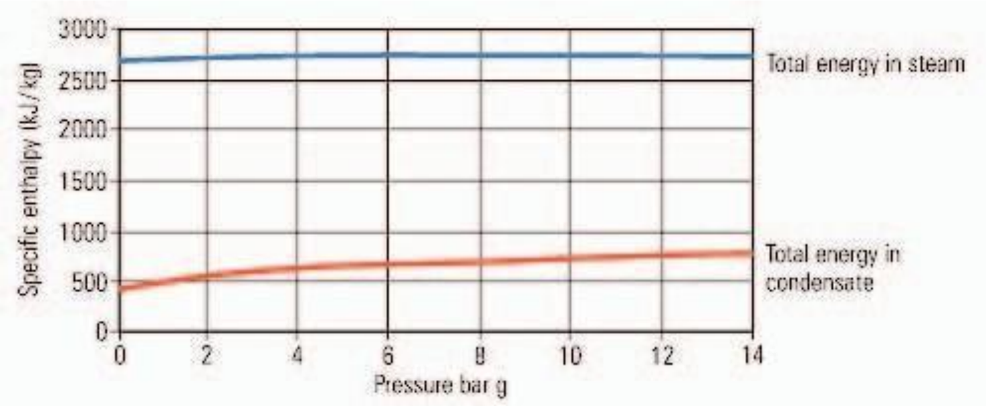
Thermostatic (operated by changes in fluid temperature) - The temperature of saturatedsteam is determined by its pressure. In the steam space, steam gives up its enthalpy ofevaporation (heat), producing condensate at steam temperature. As a result of any furtherheatloss,thetemperatureofthecondensatewillfall.Athermostatictrapwillpasscondensate whenthislowertemperatureissensed.Assteamreachesthetrap,thetemperature increases andthetrapcloses.

Mechanical (operated by changes in fluid density) - This range of steam traps operates bysensing the difference in density between steam and condensate. These steam traps include'ball floattraps' and'inverted bucket traps'. In the 'ball floattrap', the ball rises in thepresence of condensate, opening a valve which passes the denser condensate. With the'inverted bucket trap', the inverted bucket floats when steam reaches the trap and rises to shutthe valve.Bothare essentially'mechanical'intheirmethodofoperation.

Thermodynamic (operated by changes in fluid dynamics) - Thermodynamic steam trapsrelypartlyontheformationofflashsteamfromcondensate.Thisgroupincludes'thermodynamic','disc','impulse'and'labyrinth'steamtraps.

3.10 CondensateRecovery

Figure3.3HeatContentofSteamandCondensateat theSamePressure



The steam condenses after giving off its latent heat in the heating coil or the jacket ofthe process equipment. A sizable portion (about 25%) of the total heat in the steam leavesthe process equipmentas hotwater. Figure 3.3 compares the amountof energy in akilogram of steam and condensate at the same pressure. The percentage of energy incondensate to that in steam can vary from 18% at 1 bar g to 30% at 14 bar g; clearly theliquid condensate is worth reclaiming. If this water is returned to the boiler house, it willreducethefuelrequirementsoftheboiler.Forevery60°Criseinthefeedwatertemperature,there willbe approximately1%savingoffuelintheboiler.

3.10.1 BenefitsofCondensateRecovery

- Waterchargesarereduced.
- Effluentchargesandpossiblecoolingcostsarereduced.
- Fuelcosts arereduced.
- Moresteamcanbeproducedfromtheboiler.
- Boilerblowdownisreduced-lessenergyis lostfromtheboiler.
- Chemicaltreatment ofrawmake-up waterisreduced.

3.11 FlashSteamRecovery

Flash steam is produced when condensate at a high pressure is released to a lower pressureandcanbe usedforlowpressure heating.

The higher the steam pressure andlower the flash steam pressure the greater thequantity of flash steam thatcan begenerated. Inmany cases,flash steam from highpressure equipments is made use of directly on the low pressure equipments to reduce useofsteamthroughpressurereducingvalves.

Theflashsteamquantitycanbecalculated bythefollowingformulawiththehelp ofasteamtable:

$$\text{Flashsteamavailable }\% = (S1 - S2)/L2$$

Where: S_1 isthesensibleheatofhigherpressurecondensate.

S_2 is the sensible heat of the steam at lower pressure (at which it has beenflashed). L_2 isthelatentheat offlashsteam(atlowerpressure).

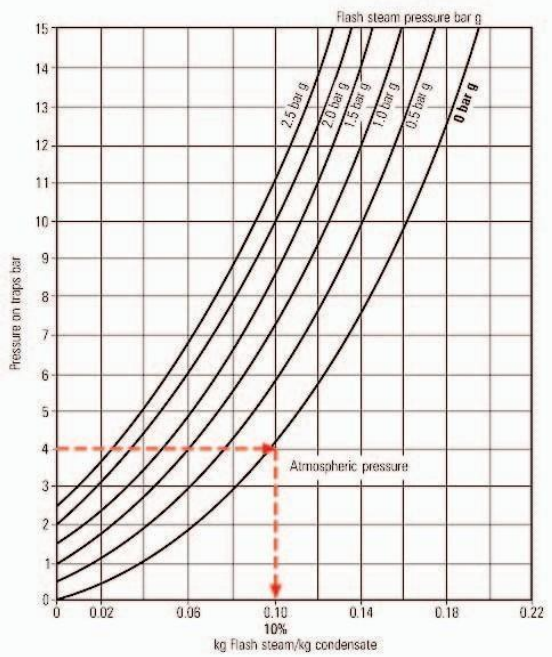


Figure3.4QuantityofFlash SteamGraph

Flash steam can be used on low pressure applications like direct injection and canreplace an equal quantity of live steam that would be otherwise required. The demand forflash steam should exceed its supply, so that there is no build up of pressure in the flashvessel and the consequent loss of steam through the safety valve. Generally, the simplestmethod of using flash steam is to flash from a machine/equipment at a higher pressure to amachine/equipmentata lowerpressure, thereby augmenting steam supply tothe lowpressure equipment.

In general, a flash system should run at the lowest possible pressure so that themaximumamountofflashisavailableandthebackpressureonthehighpressuresystemsiskept aslowaspossible.

Flash steam from the condensate can be separated in an equipment called the 'flashvessel'. This is a vertical vessel as shown in the Figure 3.5. The diameter of the vessel issuch that a considerable drop in velocity allows the condensate to fall to the bottom of thevessel from where itis drained out by a steam trap preferably afloat trap. Flash steamitself rises to leave the vessel at the top. The height of the vessel should be sufficientenoughtoavoidwaterbeingcarriedoverintheflashsteam.

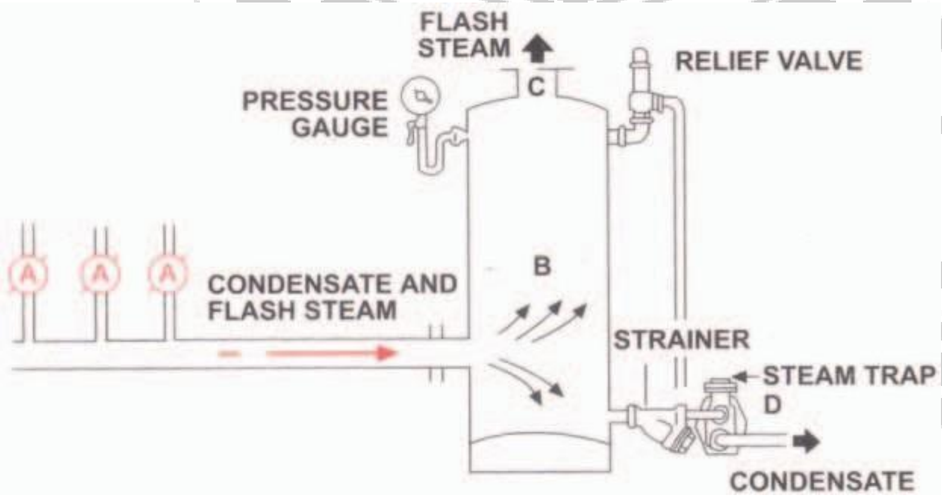


Figure3.5FlashSteamRecovery

The condensate from the traps (A) along with some flash steam generated passes through vessel (B). The flash steam is let out through (C) and the residual condensate from (B) goes out through the steam trap (D). The flash vessel is usually fitted with a 'pressure gauge' to know the quality of flash steam leaving the vessel. A 'safety valve' is also provided to vent out the steam in case of high pressure build up in the vessel.