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Performance Enhancement Of Sugar Mill By Alternate Cooling System For Condenser

Paras Chouhan, Avin Chandrakar

Research Scholar Oriental University, Indore (M.P) A.P (M.E.D) Oriental University, Indore (M.P)
vinchandrakar@oriental.ac.in, chouhanparas15@Gmail.com.

Abstract: Agro industry plays a crucial role in the industrialization process of developing countries. Sugar industry is second largest agro industry in the world. In sugar manufacturing plants there are various processes for production of sugar i.e. extraction of juice, clarification, evaporation, concentration of juice, forming and separating crystals etc. These processes consumed energies in the form of mechanical energy, electrical energy and heat energy. So there are various sources of waste heat in sugar factory i.e. waste heat from hot flue gasses, hot water from evaporative body and boiler blow down. The large amount of waste heat passes from various devices of sugar factory causes decrease in the efficiency of sugar plants, and also increase the "Global Warming" which is very dangerous for our environment. The present cooling system for condenser is inappropriate & hence decrease vacuum in evaporators and pans. This will increase the boiling point temperature of juice. The proposed cooling system gives solution of both problems. The most important source of waste heat i.e. hot flue gases are use to run absorption chiller. The absorption chiller gives better cooling system for condenser. There will be improvement in condensation of vapour in condenser which will cause increase vacuum in evaporators and pans thereby reducing boiling point temperature of juice. This reduced boiling point temperature of juice requires less amount of steam for boiling, ultimately saving of bagasse and fuel economy can be attained. Thus this arrangement can be treated as the efficient method of utilization of waste heat for cooling condenser water in sugar factory thus saving further depletion of natural resources like coal, petroleum or else increasing its availability to other important processes and one can hope that the "waste heat recovery" may play an even greater role in the industrial development in this new millennium.

Key word: Boiling of juice, bagasse yields, crushing, scrubbing system, vacuum measurement, gur.

Introduction: The sugar industry processes sugar cane and sugar beet to manufacture edible sugar. More than 60% of the world's sugar production is from sugar cane, the balance is from sugar beet. Sugar manufacturing is a highly seasonal industry, with season lengths of about 6 to 18 weeks for beets and 20 to 32 weeks for cane. Approximately 10% of the sugar cane can be processed to commercial sugar, using approximately 20 cubic meters of water per metric ton (m3/t) of cane processed. Sugar cane contains 70% water; 14% fiber; 13.3% saccharose (about 10 to 15% sucrose), and 2.7% soluble impurities. Sugar canes are generally washed, after which juice is extracted from them. The juice is clarified to remove mud, evaporated to prepare syrup, crystallized to separate out the liquor, and centrifuged to separate molasses from the crystals. Sugar crystals are then dried and may be further refined before bagging for shipment. In some places juice is extracted by a diffusion process that can give higher rates of extraction with lower energy consumption and reduced operating and maintenance costs. For processing sugar beet (water, 75%; sugar, 17%), only the washing, preparation, and extraction processes are different. After washing, the beet is sliced, and the slices are drawn into a slowly rotating diffuser where a countercurrent flow of water is used to remove sugar from the beet slices. Approximately 15 cubic meters (m^3) of water and 28 kilowatt-hours (kWh) of energy are consumed per metric ton of beet processed. Sugar refining involves removal of impurities and decolonization. The steps generally followed include, affixation, melting, clarification, decolonization, evaporation, crystallization, and finishing. Decolonization methods use granular activated carbon, powdered activated carbon, ion exchange resins, and other materials.

1 Methodology

1.1 Raw Sugar Milling with Present Cooling System:

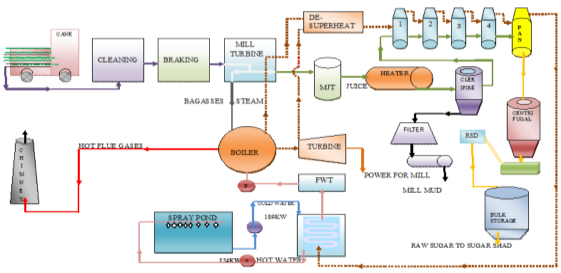

Fig.1.1 Raw Sugar Milling with Present Cooling System

Cane Unloading: Mature canes are gathered by a combination of manual and mechanical methods. Cane is then placed into large piles and picked up, tied, and transported to a sugar factory by means of tractor, truck, or bull car etc.

Cleaning: Canes are cut at ground level, its leaves are removed and the top is trimmed off by cutting off the last mature joint. This process is known as "primary cleaning".

Cane Braking: Stalks are thoroughly washed and cut when reaching the sugar mill. After the cleaning process, a machine led by a series of rotating knives, shreds the cane into pieces. This is known as "grinding."

Mill Turbine: After grinding, hot water is sprayed on to the sugarcane then crushed in mill turbine for extract the juice. The crushing process must break up the hard nodes of the cane and flatten the stems. The juice is collected, filtered and sometimes treated and then boiled to drive off the excess water. The dried cane residue (bagasse) is often used as fuel for this process.

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Clarifiers: Juice should be filtered through a cloth before boiling in order to remove any solids such as dirt or particles of cane. Large-scale sugar processors add lime to the juice in order to coagulate impurities which then settle out. The juice is then neutralized with sulphur dioxide. Small-scale producers add a variety of clarificants to the juice including wood ash. All of these have the effect of settling out impurities.

Evaporation (Juice Boiling): The clear juice which results from the clarifying process is put under a vacuum, where the juice boils at a low temperature and begins to evaporate. It is heated until it forms into thick, brown syrup. This is done in large pans over open fires or simple furnaces. The essential requirement is for clean pans and tools. Sediment settles to the bottom of the pan during boiling and is dredged out. Scum rises to the top and is skimmed off both of these wastes can be fed to cattle. A large pan such as that pictured in figure 3.1 would hold about 100 kg of juice reducing to around 20kg of gur. The pans are usually made from galvanized mild steel sheets. The boiling point temperature of juice about 105°C.The end point of the boiling process is judged from experience; from the sight and sound of the boiling juice. After boiling of juice vapour passes from vacuum pans and then passing through condenser for phase change process and feed hot water to boiler.

Centrifugal: By evaporating what little water is left in the sugar syrup, crystallization takes place. Inside a sterilized vacuum pan, pulverized sugar is fed into the pan as the liquid evaporates, causing the formation of crystals. The remaining mixture is a thick mass of large crystals, which is sent to a centrifuge to spin and dry the crystals. The dried product is raw sugar, still inedible.

Bulk Storage:
After screening, the finished, refined granulated sugar is sent to conditioning bins, and then to storage bins prior to packaging or bulk load out. Almost all packaged sugar uses multiwall paper containers, cardboard cartons, or polyethylene bags; bulk load out is the load out of the sugar to specially designed bulk hopper cars or tank trucks.

1.2 Steam Condenser:
A steam condenser is a device or an application in which steam condenser and heat released by steam is absorbed by water. The hot water feed into boiler by means of feed pump. It serves the following purposes:

- It maintains a very back pressure on pans and evaporators side in sugar manufacturing plant. The thermal efficiency of a condensing unit therefore is higher than that of non condensing unit for the same available steam.

1.2.1Condenser Efficiency: It is defined as the ratio of the difference between the outlet and inlet temperatures of cooling water to the difference between the temperature corresponding to the vacuum in the condenser and inlet temperature of cooling water.

$$\text{Condensre efficiency} = \frac{\text{Rise in tempratuer of cooling water}}{\text{Temp. corresponding to vacuum in condenser - Inlet temp. of cooling water}}$$

$$= \frac{(tw_2 - tw_1)}{(ts - tw_1)}$$

Where: - tw_1 = temp. of incoming water to cond.
tw_2 = temp. of outgoing water from cond.
ts = saturation temp. of steam

- Its main function in sugar manufacturing plant is to condense the exhausts steam from the vacuum pans and thus recover the high quality feed water for reuse in the plant.
- A more useful function is to create a vacuum pressure (in case of using enclosed box for heat exchange) and thus maintain back pressure for evaporators and pans.

1.2.2Vacuum Measurement: The term vacuum in case of a condenser pressure below atmospheric pressure. It is generally expressed in mm of mercury. The vacuum is measured by means of a vacuum gauge. Usually for calculation purpose the vacuum gauge reading is corrected to standard barometric reading 760 mm as follows. Corrected vacuum in mm of Hg = (760 - absolute pressure in mm of Hg) = 760 – (actual barometric height – actual vacuum).

- By increasing the back pressure:
  - Reduces the boiling temperature of juice.
  - Increases the plant efficiency.
  - Reduces the steam flow rate.

1.3 Determining the Waste Heat Quantity:
In any heat recovery situation it is essential to know the amount of heat recoverable and also its usage. The total heat that could be recovered can be calculated using this formula.

$$Q = V \times \rho \times C_p \times \Delta T$$

Where, Q = the heat content in kcal.
V = the flow rate of the substance in m^3/hr.
P = the density of the flue gas in kg/m
C_p = the sp. heat of substance in kCal/kg°C.
ΔT = temperature difference in °C [3].

1.4 Identifying Waste Heat Sources in Sugar Factory:

1.4.1 Boiler Flue Gases:
- Boiler flue gases are major sources of waste heat in sugar factory.
- The essential quality of heat is not the amount but rather its “value”. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved.
- Large quantity of hot flue gases is generated from boilers, kilns, ovens and furnaces. If some of this wastes heat could be recovered. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized by adopting following measures as outlined in this chapter.

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1.5 Limitations of Present System:

- The power consumption for pumps -313 kW. For pumping hot water from condenser to spray pound – 2pumps of 124kW.For pumping cold water from spray pound to condenser – 3pumps of 189kW.
- Steam to Bagasse ratio – Approximately 1.8 to 2, that is1.8-2 kg of steam required 1 kg of bagasse.
- Increase in temperature of incoming water affects condensation of vapours in condenser and in turn affects vacuum in evaporator body.
- Increase in boiling point of juice in the evaporative body increases the steam and bagasse consumption.
- Large quantity of cooling water is needed for cooling the condenser.

Proposed cooling system for condenser which shown in fig.3.4 is efficient cooling system for condenser. The basic aim of this system is reduction in the inlet temp of cooling water by incorporating a vapour absorption unit `which runs on waste heat in boiler flue gases.

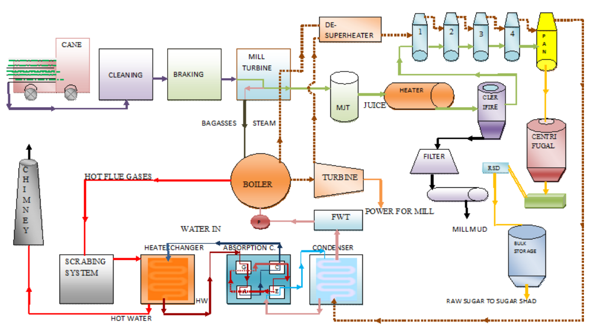

Fig.1.2 Raw Sugar Milling with Proposed Cooling System

Components-

- ➢ Scrubbing system to remove suspended matter from hot flue gases.
- ➢ A heat exchanger between flue gas and water.

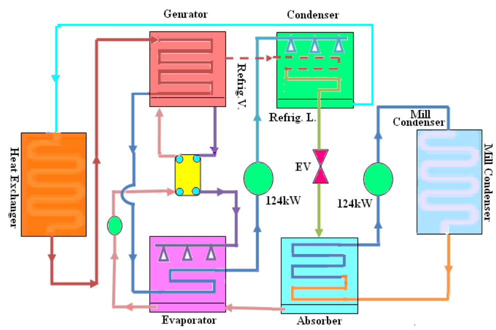

Fig. 1.3 Absorption Chillier with Proposed Cooling System

1.6 Benefits from Proposed System:

- Flue gases from boiler will be passed through a scrubbing system where the suspended matter and unborn particles will be removed.
- Then this gas will be passed through a heat exchanger where the water will be heated by flue gases.
- This hot water will be then used as heat source for the absorption refrigeration system. The hot water from the condenser will be passed through the absorption refrigeration machine where its temperature will be decreased.
- This cold water will be then passed to the condenser for cooling purpose. Proposed system will be able to cool the condenser cooling water to lower temperature.
- The power required for spraying the water will be saved. The power will be required for pumping the condenser water through the absorption chillier and heat exchanger. It is proposed to estimate the saving in power by this arrangement.
- It also expected because of low temperature of cooling water rate of condensation of cooling water will be more and it will create more vacuum in the evaporator and pans. This will lower down the boiling point in the evaporator and it will reduce steam consumption and ultimately result in bagasse saving.
- As the particulate matter in gases is reduced due to scrubbing system, it will reduce the pollution at the factory site.
- As the temperature of cooling water is less the quantity of water required for condensing vapours will also is less. This will result in saving of water when there is scarcity of water. Low boiling temperature will improve the quality of sugar.

2. Result & Discussion:

2.1Calculation of Waste Heat Sources in Sugar Mill:

There are number of waste heat sources in sugar factory i.e. boiler flue gases, boiler blow down water, and hot water over flow. The amount of waste heat can be calculated below.

2.1.1 Boiler Flue Gases:

The major source of waste heat is boiler flue gases and the value of waste heat can calculated below. Waste heat content of flue gases [10];

Q = 4.187K ((1-W) (1.4M-0.13) +0. 5) * t

Where:-

Q Amount of waste heat in flue gases kJ/kg.
K = $K_1 * K_2$
K_1 = % of bagasse in cane (28 % factory data)
K_2 = Quantity of cane required to get unit quantity of sugar.=11(data of factory).
W = Moisture content in bagasse average
= 50 % (from data of factory).
M = Ratio of actual air to theoretical air. = 1.4
t = Temp of fine gases going to chimney.
= 180°C (from data of factory).

Thus waste heat content in flue gases can be calculated as

Q = (4.187) (0.28) (11) (1-0.5) (1.4*1.4-0.13) +0.5)*180

Q = 3285 kJ/kg of sugar.

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2.1.2 Boiler Blow down Water:

The second largest waste heat source in sugar factory is boiler blow down water. The amount of heat content of blow down can be calculated as.Blow down to control the amount of Total Dissolved Solid (TDS) in the boiler water for smooth operation.Blow down amount varies from 2 to 3 % of evaporative capacity or steam generation rate.

$$\mathbf{Q = M_b.\ C_b.\ T_b}$$

Where: Q = Heat carried in KJ/kg of sugar M_b = Average quantity of blow down in kg/kg of sugar = 2.5 % of evaporative capacity of boiler (from data of factory) = 0.025 * (50% of cane crushed) = 0.025 * (0.5 * 11) per kg of sugar C_b = Sp. Heat of water = 4.187 kJ/kg K T_b = temp of blow down = 340 °C (from data of factory)

$$\mathbf{Q = 0.\ 025\ (0.5 * 11) * 4.187 * 340}$$
$$\mathbf{Q = 195.7\ kJ/kg\ of\ sugar}$$

2.1.3 Hot Water Overflow:

Other source of waste heat is hot water overflow in sugar factory. Condensate from 1 and 2 evaporators body is used as feed hot water for 3 and 4 evaporators body and pans for the process. Normally the condensate produced is more than that required for the process. By measuring the excess quantity of hot water, heat carried by excess water can be calculated.

$$\mathbf{Q = M_c.C_c.T_c}$$

Where: - M_c = quantity of surplus condensate = 7.5% of cane crushed (data factory) = 0.075 * 11 C_c= 4.187 kJ/ kg K T_c = temp of hot water = 65°C

$$\mathbf{Q = (0.075)\ (11)\ (4.187)\ (65)}$$
$$\mathbf{Q = 224.5\ kJ/kg\ of\ sugar}$$

2.2 Results of Present Cooling System:

- Vapours from evaporators and vacuum pans enter in condensers at about 60-65°C. The heat from vapour is absorbed by cold water introduced in the condenser. The temperature of this cold water is around 30-35°C. The heat exchange between vapours and water is affected by
  - Contact time of vapours with cold water.
  - Contact surface offered by cold water to vapours.
- The temperature of outgoing water (45-50°C) from condenser, after cooling the incoming vapour from evaporators and pans. The temperature of incoming and outgoing water changes according to ambient conditions.tw2=44°C (from company data)
- Warm water leaving the condenser flows in spray pond by gravity channel, and cooling with the help of spray nozzles. The cooling water temperature around 35-40°C returns through gravity channel and it is pumped to the condenser. Thus it is a closed system.

tw_1 = 37°C (from company data) This temperature of cooling water at inlet to condenser (tw_1 = 37°C). So the present cooling system for condenser is inappropriate and hence decrease vacuum in evaporators and pans. This decreased vacuum in evaporators causes increases the boiling point temperature of juice from 102°C to 106°C.

2.2.1 Vacuum Measurement:

Corrected vacuum in mm of Hg = (760 - absolute pressure in mm of Hg) =760–(actual barometric height – actual vacuum) Absolute pre. = 680 mm of Hg company data) = 760 – 680 in mm of Hg = 84× 0.001333bar = 0.11196bar Saturation temperature of steam corresponding to the condenser vacuum ts = 48°C (steam table).

2.2.2 Condenser Efficiency:

$$\text{Condenser efficiency} = \frac{(tw_2 - tw_1)}{(ts - tw_1)}$$
$$= \frac{(44° - 37°)}{(48° - 37°)} = 61.54\%$$

2.2.3 Power Consumption:

In present cooling system there are five pumps use for cooling the condenser water. The total power consumption for pumps 313kWh. (From data of factory)

- For pumping hot water from condenser to spray pound – 2pumps of 124kWh.
- For pumping cold water from spray pound to condenser – 3pumps of 189kWh.

2.2.4 Bagasse Consumption:

Bagasse calculation are: bagasse in cane 28%, bagasse generated 32.2 tones/h, bagacilo 0.47tones/h, bagasse losses 0.1tones/h, so net bagasse 31.63 tones/h, 1 tones produce 2.2 tons steam at 87 atm, fuel required 31.3 tonnes/h, surplus bagasse 0.33 tones/h. Increase in boiling point of juice increases the steam and bagasse consumption.

2.2.5 Quality of Sugar:

This temperature of cooling water at inlet to condenser (tw_1 = 37°C) is inappropriate and hence decrease vacuum in evaporators and pans. This decreased vacuum in evaporator causes increases the boiling temperature of juice from 102°C to 106°C and decrease the quality of sugar.

2.3 Results of Proposed Cooling System:

- The temperature of outgoing water (45-50°C) from condenser, after cooling the incoming vapour from evaporators and pans. The temperature of incoming and outgoing water changes according to ambient conditions. tw_2 = 44°C (from company data)
- Warm water leaving the condenser flows to the absorption chillier and it is cooled at 30°C. The cooled water around 30°C pumped to the condenser. Thus it is a closed system.

Temperature of incoming water to condenser = tw_1 = 30°C .This temperature of cooling water at inlet to condenser (tw_1 = 30°C) provide appropriate cooling for condenser and hence increases vacuum in evaporator and pans, ultimately results in bagasse saving.

2.3.1 Vacuum Measurement:
Vacuum in mm of Hg = (760 - absolute pressure in mm of Hg) (Absolute pressure = 667 mm of Hg) = 760 – 667 in mm of Hg = 93× 0.001333bar = 0.123969bar Saturation temperature of steam corresponding to the condenser vacuum ts = 50.5°C (steam table).

2.3.2 Condenser Efficiency:

$$\text{Condenser efficiency} = \frac{(tw_2 - tw_1)}{(ts - tw_1)}$$

$$\text{Condenser efficiency} = \frac{(44° - 30°)}{(50.5° - 30°)}$$

=68.23%

So by the use of proposed cooling increases the efficiency of condenser.

2.3.3 Bagasse Saving Calculation [from company data]:

- Factory Capacity=2500 TCD
- Temperature of the water=85-90°C
- Qty. of the raw juice=150 m^3 /h
- Temperature of the juice=30° C
- Calorific value of bagasse with 50% moisture 2200 Kcal/Kg
- Working of sugar mill=24 hours 200 Days
- Boiler efficiency=70%

2.3.4 The Possible Heat Recovery and the Saving of Bagasse:
Heat Recovery = Mass x Sp.heat x Temp.diff.
= 20000 x 1 x 30°C
= 6, 00,000 kcal /hr

Saving of Bagasse = 6, 00,000 ÷ 2200 kg/hr
= 272.7273 kg /hr

Saving w.r.t efficiency of boiler = 272.7273 ÷ 0.70 = 389.61 kg /hr

Yearly saving = 389.61 x 24 x 200(company data) = 1870128 kg = 1870 tons/year The proposed cooling system increase the efficiency of condenser (approximate 07%) and increase vacuum in evaporators and pans. These vacuums decrease the boiling point of juice. (Approximate 6°C). So by the use of proposed system, fuel (bagasse) saving 1870 tons per year.

2.3.5 The Cost Saving on the basis of the Indian Conditions:
The cost of saving by sale of bagasse Total bagasse saved per year =1870 tons /yr Cost of the bagasse per ton =2300Rs/tones So total saving by sale of bagasse =1870*2300Rs/year. Additional revenue generated=4301000 Rs/year.

2.3.6 Power Saving:
Present cooling system for condenser required 313kWh power for pumping water from condenser to spray pound and spray pound to condenser. While proposed cooling system required 265kWh power for pumping water for cooling the condenser. So by the use proposed cooling system, power saving around 48kWh

1kWh = 1unit in one hour.
48kWh = 48units/h

There for power saving per day (24 hour) in sugar mill are as:

48*24=1152 units per day

So total power saving per day in Rs, if the cost of one unit ≈8 Rs

1152*8 = 9216 Rs /day.

Total power saving by proposed cooling system in one year, if 200 days of working in sugar industry: 9216*200 = 18,43,200Rs/year Total additional revenue generated by sugar mill by use of proposed cooling system.

Saving from bagasse = 43,01,000 Rs/year
Power saving = 18,43,200 Rs/year

Total add. Revenue = 61,44,200 Rs/year

3 Conclusion

- Energy audit is an important tool to identify the areas of energy conservation in sugar factory.
- Waste heat sources in sugar factory are:-
  - Boiler flue gases
  - Boiler blow down
  - Hot condensate
- Most important waste heat source - Boiler flue gas Boiler flue gas heat can be utilized to run

absorption chiller.

- The chiller will cool condenser water.
- The proposed alternate cooling system with absorption chiller reduces the power required in spray pond, improvement in condensation of vapours in condenser thereby increasing of condenser efficiency, low boiling point of juice in evaporator thereby saving of steam and bagasse.

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