PART - I

Production & Saving of Steam in Sugar Factories
Chapter I
INTRODUCTION:

Steam an energy source:

Steam the main energy source, used in the process of cane sugar production, is generated by burning Bagasse, which is a byproduct obtained through cane crushing operations. Normally, cane contains enough fibre, which can produce sufficient steam for the manufacture of sugar from cane. The advantage of using steam, as energy for such operation is that it can be easily distributed & controlled. Moreover it can serve dual purpose that of generating necessary motive power for running the plant & equipment, as well as supplying heat for the process operations such as, evaporation, boiling etc. Besides water and steam possess following unusual qualities.

- Water is plentifully available on earth and therefore cheap.
- Water boils into steam at temperature, much below metallurgical range of boiler materials.
- Evaporation of water into steam involves high heat absorption and hence, they both act as “heat sponges”.

And another special feature of steam production in sugar factories is the availability of renewable biomass fuel, a byproduct of cane after juice extraction.

Boiler as integral part:

Boiler plant therefore becomes an integral part of cane sugar factory and the nature of load, which a sugar factory imposes on the steam generation plant, has a great bearing on the design and operation of boilers.

The nature of this load is continuously fluctuating one and the end use of this load as also levels of pressure normally encountered in modern sugar factories can be seen from the following table.
<table>
<thead>
<tr>
<th>Sr.no</th>
<th>Steam conditions</th>
<th>Equipment</th>
<th>Purpose</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20-21 Kg/sq.cm at about 340° C</td>
<td>Back pressure or pass out condensing Steam turbines</td>
<td>For generating electric power</td>
<td>Fairly steady as long as crushing operations uninterrupted</td>
</tr>
<tr>
<td>2</td>
<td>20-21 kg/sq.cm at about 340° C</td>
<td>Back pressure steam turbines</td>
<td>For driving cane mills</td>
<td>Load fluctuates moderately as long as crushing rate is fairly constant. Load widely fluctuates with interruptions in plant operation.</td>
</tr>
<tr>
<td>3</td>
<td>7 Kg/sq.cm</td>
<td>Reducing valve (RV)</td>
<td>For drying of sugar, melting of sulphur, washing of pipe lines, heating of molasses etc.</td>
<td>Load fairly steady quantum is small and limited.</td>
</tr>
<tr>
<td>4</td>
<td>1 to 1.5 Kg/sq.cm</td>
<td>Reducing valve (RV)</td>
<td>To augment exhaust steam used for process</td>
<td></td>
</tr>
</tbody>
</table>

The task before sugar factory boiler operator, is to meet the challenge of generating steam under most adverse conditions and at the same time make efforts to achieve energy conservation goals without compromising efficiencies.

Some fundamentals:

In the following paragraphs, some basic elements of steam generation such as properties of steam, principles of combustion and heat transfer etc are briefly discussed.

Properties of steam:

Imagine a kg of water is heated in a cylinder fitted with a piston on which various pressures could be applied. From the following series of graphs it can be seen that the
same general sequence of events occurs at each pressure level. First water temperature rises and its volume increases slightly. The boiling begins; volume increases greatly while temperature stays constant. When all water has changed to steam the volume continues to increase on further heating and the temperature rises. This is called super heating.

The above charts demonstrate graphically that as pressure increases, heat required bringing water to the boiling point i.e. "Sensible heat" goes up, where as amount of heat necessary to vaporize it i.e. "Latent heat" tends to get less. Eventually at a pressure of 225.42 kg/sq.cm, a point is reached where the water turns into steam without boiling. At this point all the heat that is given to the water has gone into making steam, and the point is called as "Critical pressure". The final graph summarises the conditions shown in the preceding ones, plus two other pressure levels.

If we heat water and its Vapour, in a sealed quartz tube one would see at any condition below the critical point, a clearly defined level separating water and steam. Near the critical pressure the water level becomes indistinct, then vanishes.
After studying the graphs depicted above, it would now be possible to understand clearly the following definitions:

1) **Enthalpy of liquid**: This is the amount of heat added to bring the water from zero degrees C up to the boiling point, which varies according to the pressure applied.

2) **Enthalpy of evaporation**: This is the heat added to the boiling water until it is converted to vapours. During this process, temperature remains constant.

3) **Enthalpy of saturated steam (or vapour)**: This is the total of (1) + (2) above.

4) **Saturation temperature**: As long as steam remains contact with water, both are at the same temperature, which is called “Saturation temperature”.

5) **Super heat**: Steam can then be separated and further heated which is called “Super heating of steam”.

6) **Total enthalpy**: This additional heat (5) combined with (1), (2) and (3) above becomes “Total enthalpy” of super heated steam.

**Principles of Combustion**:

Combustion may be defined as the “rapid chemical combustion of oxygen with combustible elements of a fuel”. There are just three combustible chemical elements of significance – Carbon, hydrogen, and Sulphur. Though sulphur is of minor significance as far as source of heat concerned.

Carbon and hydrogen when burned to completion with oxygen unite according to the following equations:

\[
C + O_2 = CO_2
\]
\[
2H_2 + O_2 = 2H_2O
\]

These combustion reactions are exothermic and heat is released, when these reactions occur. The objective of good combustion is to release all of the heat, while minimising losses due to imperfect combustion and superfluous air.

There is always a reference to three Ts of combustion they are:

- **Temperature**: enough high temperature is needed to ignite the constituents of fuel.
- **Turbulence**: is needed for proper mixing of oxygen with constituents.
- **Time**: enough time should be given to complete combustion.
a) Fundamental laws:

All combustions are based on the following fundamental physics laws:

i) Conservation of matter:

"Matter is neither destroyed nor created". There is always a weight balance between the sum of weights of components, entering into process of combustion and sum of combustion products leaving the process.

ii) Conservation of energy:

"Energy is neither created nor destroyed". The sum of energies entering the process must equal the sum of energies leaving, although the proportion or form may change. In combustion chemical energy is exchanged for heat energy.

iii) The ideal gas law:

"Volume of an ideal gas is directly proportional to its absolute temperature and inversely proportional to its absolute temperature". The proportional constant is found to be the same for one molecule of any ideal gas. For eg.

\[ V_m = \frac{RT}{P} \]

where,

\[ V_m = \text{Volume cu mtr/kg mole of gas} \]
\[ T = \text{absolute temperature deg k} \]
\[ P = \text{Absolute pressure kg/sq.cm} \]
\[ R = \text{Universal gas constant} = 8.314 \text{ kj/kg mol/k} \]

In short this law states that 1 kg mol of any gas at standard atmospheric pressure and deg C occupies 22.414 cu.mtr.\(^{(1)}\)

iv) Law of combining weights:

"All substances combine in accordance with simple definite weight relationships". These relationships are exactly proportional to the molecular weights of constituents. For eg "Carbon" (molecular weight = 12) combines with "Oxygen" (molecular weight = 32) to form "Carbon dioxide" (molecular weight = 44).

v) Avagadro's Law:

"Equal volumes of different gases at the same pressure and temperature, contain same number of molecules".
vi) Dalton's Law:

"The total pressure of a mixture of gases is the sum of partial pressures, which would be exerted by each of the constituent gas, if it were to occupy alone the same volume as that of the mixture, at the same temperature"

vii) Amagat's Law:

"The total volume, occupied by a mixture of gases, is equal to the sum of volumes which would be occupied by each of the constituent gas if it were at the same pressure and temperature as that of the mixture"

b) Chemical reactions of combustion:

The most common reactions of combustions between fuels (both fossil & gaseous) and oxygen, which are usually encountered in all combustion calculations are given in the following table. These equations are based on the seven fundamental laws and summarise the molecular and weight relationship along with heat release of combustion.

<table>
<thead>
<tr>
<th>Combustible Elements</th>
<th>Chemical reactions</th>
<th>Molecular relation</th>
<th>Weight (Kg) relation</th>
<th>Heat release kcal/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon to CO</td>
<td>2C+O₂ = 2CO</td>
<td>2 + 1 = 2</td>
<td>24+32 = 56</td>
<td>2195</td>
</tr>
<tr>
<td>Carbon to CO₂</td>
<td>C+O₂ = CO₂</td>
<td>1 + 1 = 1</td>
<td>12+32 = 44</td>
<td>7817</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>2CO+O₂ = 2CO₂</td>
<td>2 + 1 = 2</td>
<td>56+32 = 88</td>
<td>2409</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>2H₂+O₂ = 2H₂O</td>
<td>2 + 1 = 2</td>
<td>4+32 = 36</td>
<td>33874</td>
</tr>
<tr>
<td>Sulphur to SO₂</td>
<td>S+O₂ = SO₂</td>
<td>1 + 1 = 1</td>
<td>32+32 = 64</td>
<td>2206</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄+2CO₂ = CO₂+2H₂O</td>
<td>1+2 = 1+2</td>
<td>16+64 = 80</td>
<td>13236</td>
</tr>
<tr>
<td>Acetylene</td>
<td>2C₂H₂+5O₂ = 4CO₂+2H₂O</td>
<td>2+5 = 4+2</td>
<td>52+160 = 212</td>
<td>11920</td>
</tr>
<tr>
<td>Ethylene</td>
<td>C₂H₄+3O₂ = 2CO₂+2H₂O</td>
<td>1+3 = 2+2</td>
<td>28+96 = 124</td>
<td>11994</td>
</tr>
<tr>
<td>Ethane</td>
<td>2C₂H₆+3O₂ = 4CO₂+6H₂O</td>
<td>2+7 = 4+6</td>
<td>60+224 = 284</td>
<td>12377</td>
</tr>
</tbody>
</table>
c) Heat of combustion and its measurement:

The chemical reactions of fuels and their derivatives mentioned in the above paragraph are called “Exothermic reactions” since; the heat is released while they take place such as in a boiler furnace.

[Note : As against this there are “endothermic reactions” where heat is absorbed so as to induce the reaction eg. In a “Producer gas plant” where combustible matter in solid fuel is converted into combustible gases. Here in the primary zone CO₂ is formed which is then passed over a layer of hot coal or coke in the secondary zone, so as to form CO by inducing the following reaction.

\[ C + CO₂ = 2 CO \]

And since the heat is utilised in this process this equation is written as

\[ C + CO₂ = 2CO - 38558 \text{ k cal/kg} \]

The amount of heat generated by complete combustion is constant for any given combustion of combustible constituents of fuel and is not affected by the manner in which the combustion takes place, provided it id complete.

The heat thus released by the fuel is also termed as “Colorific value” (CV) of the fuel and is expressed as “Kilo Calories” (K cal) or “British Thermal Units (BTU) per unit weight of the fuel (1 kg or 1 lb resp) burned completely under the prescribed conditions.

d) High and low heat values:

Theoretically, whole of the calorific value of a fuel can be profitably used such as for raising steam but in practice some of it is always lost by radiation or as heat carried away by the chimney gases etc. In addition, when the fuel contains some water as free moisture and also any hydrogen as its constituent then as a result of combustion steam is formed and is present in the products of combustion. This steam does not condense in an industrial plant like boiler and thus its heat content equivalent to the latent heat of the steam, is carried away along the exit flue gases. Consequently, it can be argued that this lost heat is not useful for heating purpose and therefore should not be included in the CV of the fuel. However, since this heat is originally present in the fuel and is produced by its complete combustion has to be accounted for and therefore there has been a practice to quote two CV’s for a fuel.
i) "Higher or gross CV" (GCV) which includes the heat in the water vapours generated during complete combustion &
ii) "Lower or net CV" (NCV) which is obtained by deducing from the "Gross CV" the latent heat given up by the condensation and cooling of the water vapour.

"Gross calorific value (GCV)" of a solid and liquid fuel can be determined accurately in a laboratory, with the help of a special apparatus, called “Calorific Bomb” under standard procedure. It is a skilled operation in which, an accurate weight of fuel usually one gram is burned in an atmosphere of compressed oxygen in the "bomb". The bomb is immersed in water and the temperature rise of water is measured with extreme accuracy. The GCV includes the latent heat of evaporation of the water vapours produced in the combustion when the products of combustion are cooled to 25°C.

However, approximate heat values for the most of the fuels can be calculated, with the help of 'DULONGs' formula given below, if the "Ultimate chemical analysis" of the fuel is known.

\[ k \text{ cal/kg} = 8072 \text{ C} + 34425 (\text{H}_2 - \frac{\text{O}_2}{8}) + 2248 \text{ S} \]

where C, H\text{2}, O\text{2} and S are proportionate weights of resp. Carbon, hydrogen, Oxygen and Sulphur present in the fuel as given by "Ultimate analysis".

The values arrived at by the above formula are reasonably accurate, within 2 to 3 percent and are used as routine check for the values determined by the calorimeter.

Direct Determination of "Net or Lower calorific value (NCV)" is difficult, because it cannot be done, while allowing all the products of combustion, remaining in gaseous state. NCV is therefore, calculated indirectly by the following formula.

\[ \text{NCV (K cal/Kg)} = \text{GCV (K cal/Kg)} - 577 \text{ W} \]

Where:

- \( w \) = weight of water formed (in Kg) per Kg of fuel.
- 577 = latent heat of vaporization at 25°C (in case of solid & liquid fuels only)

Calorific values of solid and liquid fuels, determined with the help of “Bomb Calorimeter” are depicted on constant volume basis, whereas the combustion of fuel in a boiler furnace takes place at atmospheric pressure, which is more or less constant. However it has been proved by tests that, the difference between two and the correction factor to be applied, are very small and therefore could be neglected.

As regards gaseous fuels the calorific values are normally first determined on the "Gross content-pressure" basis, using continuous flow calorimeter. The reference temperature is 15°C.
The NCV is then calculated, by subtracting the value arrived by the following formula,

\[
4.36 \left( \frac{H_2 + C(X)H(y) \times H(y)}{2} \right) \text{ k cal/m}^3
\]

Where-

- \(H_2\) = percentage of Hydrogen in the fuel
- \(C(X)H(y) = \) percentage of unburnt Hydrocarbon gas fuel
- \(H(y)\) = percentage of hydrogen atoms in the molecule of the unburnt Hydrocarbon gas.

Heat transfer:

Heat transfer deals with the transmission of thermal energy from one point to another, the source of which may be a burning fuel such as in a boiler furnace.

While the fundamentals of heat transfer are simple viz the three recognized modes of “Conduction”, “Convection” and “Radiation” their practical application may be extremely complex because of irregular configuration of equipment simultaneous operation of different modes of heat transfer and continuous fluctuations in working condition such as those encountered in a boiler operation. Therefore, in practical application of heat transfer principles it is necessary to combine scientific fundamentals with information acquired through experience.

In the following paragraphs it has been endeavored to describe briefly these fundamentals without going into the details of theory.

a) Conduction:

Conduction transfer is a movement of energy through a material from one point to another or to a contiguous material. Crudely speaking, heat is visualized as molecular activity i.e. vibrations of molecules of a material increasing on receiving heat and then transmitting these vibrations to adjacent molecules thus, establishing heat flow from hot part to cooler part as shown in fig.
Substances differ greatly in ability to conduct heat. Gases and vapours are poorest conductor. Liquids are better but metals are the best. Heat conduction is expressed as “Thermal conductivity” (k) in K cal per hr sq.mtr. Per degree C per unit thickness. The following table indicates thermal conductivity of different metals and other materials, which are generally used for boiler marking (except silver & copper which are included for comparative purpose).

Thermal conductivity (k) of selected materials
(k cal per hr sq.mtr. Per °C per unit thickness)

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>k</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>357</td>
<td>These are approximate</td>
</tr>
<tr>
<td>Copper</td>
<td>327</td>
<td>values at room temp.</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>43.4</td>
<td></td>
</tr>
<tr>
<td>Alloy steel (Cr 18% Ni 8%)</td>
<td>13.4</td>
<td></td>
</tr>
<tr>
<td>First quality Fire brick</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td>Insulating fire brick</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>85% magnesia</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>
The following tables show thermal conductivity (k) of different gases and products of combustion of important fuels normally encountered in boiler operation.

**Gases at atmospheric pressure**

<table>
<thead>
<tr>
<th>Temp C</th>
<th>Air</th>
<th>CO₂</th>
<th>O₂</th>
<th>N₂</th>
<th>H₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>-17.38</td>
<td>0.020</td>
<td>0.012</td>
<td>0.019</td>
<td>0.020</td>
<td>0.133</td>
</tr>
<tr>
<td>250</td>
<td>0.037</td>
<td>0.031</td>
<td>0.038</td>
<td>0.032</td>
<td>0.248</td>
</tr>
<tr>
<td>500</td>
<td>0.050</td>
<td>0.047</td>
<td>0.055</td>
<td>0.041</td>
<td>0.337</td>
</tr>
<tr>
<td>800</td>
<td>0.059</td>
<td>0.063</td>
<td>0.069</td>
<td>0.050</td>
<td>0.416</td>
</tr>
<tr>
<td>1100</td>
<td>0.070</td>
<td>0.077</td>
<td>0.083</td>
<td>0.058</td>
<td>0.486</td>
</tr>
<tr>
<td>1375</td>
<td>0.078</td>
<td>0.090</td>
<td>0.098</td>
<td>0.065</td>
<td>0.553</td>
</tr>
<tr>
<td>1650</td>
<td>0.086</td>
<td>0.099</td>
<td>0.113</td>
<td>0.078</td>
<td>0.620</td>
</tr>
</tbody>
</table>

**Gases from various fuels at atmospheric pressure**

<table>
<thead>
<tr>
<th>Temp C</th>
<th>Natural gas</th>
<th>Fuel oil</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>-17.38</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>250</td>
<td>0.032</td>
<td>0.032</td>
<td>0.032</td>
</tr>
<tr>
<td>500</td>
<td>0.044</td>
<td>0.043</td>
<td>0.043</td>
</tr>
<tr>
<td>800</td>
<td>0.055</td>
<td>0.053</td>
<td>0.053</td>
</tr>
<tr>
<td>1100</td>
<td>0.065</td>
<td>0.064</td>
<td>0.064</td>
</tr>
<tr>
<td>1375</td>
<td>0.075</td>
<td>0.073</td>
<td>0.074</td>
</tr>
</tbody>
</table>

It will be seen that the temperature of the material affects thermal conductivity but these variations, which are measurable, are not greatly and stay within limit. For most heat transfer calculations it will be sufficiently accurate to assume a constant conductivity corresponding to average temperature.

**b) Convection:**

In contrast to conduction heat transfer, convection transfer takes place by the movement of the heated material itself. When any fluid is heated its density (weight per unit volume) decreases. When part of a mass of fluid is heated (just as in the case of boiler, water adjacent to the heated tube surface gets heated) the cooler and heavier portion will tend to displace the heated portion. Result is continuous flow of cooler fluid to the heated area and of heated fluid, away from it setting up convection current as shown in fig.
Here, the moving hot fluid becomes the heat transfer medium. When density difference alone creates flow it is called "natural convection", when a fan or pump aids the flow it is "forced convection".

It may be noted that, even though the fluid after getting heated is moving in currents and transferring heat, a thin film of liquid adheres to the hot surface over which it is moving. Heat transfer through this film of liquid is by conductance and such should be taken into consideration, while calculating overall convection heat transfer.

c) Radiation:

All the bodies radiate energy. "Radiation" does not need a transmitting medium it travels through vacuum as well as through gas. Like light waves, a body exposed to radiation is heated only on the side which is exposed.

Amount of energy radiated by a body, depends upon to some extent on its size, shape and substance, but mainly on the fourth power of all the body's absolute temperature. Thus, if absolute temperature is doubled, radiation will become sixteen times. It may also be observed that, two bodies in sight of each other, exchange radiation energy between them. According to their absolute temperatures and the net amount of energy transferred is the difference of the fourth power of two radiations as shown in fig.
d) Heat transfer in practical case:

In the following figure actual conditions obtained in a typical boiler furnace are shown which give an idea of all modes of heat transfer taking place simultaneously and the complex interaction thereby.
The gas flow is convection current, carrying heat from the furnace to the tubes. These tubes also receive heat by radiation from the flames. The heat received by tubes is transferred to water and inside the tubes by conduction. The tube wall has form outside a thin film of gas and from outside a thin film of water or vapour and the heat conduction takes place through this composite wall according to the thermal conductivity of these materials.

a) Green field project:

Co generation introduction:

In case of new integrated project consisting of a cane sugar factory and a cogeneration plant the problem is somewhat simpler. Highest possible pressure and temperature for the steam may be adopted with the aim of exporting maximum power the only constraint being the financial and economical consideration. In such a case the sugar factory will be completely electrically driven and all the equipments and systems designs could be highly energy sufficient. Such an approach will be appreciably enhancing the viability of the project. The power generation mode could also be through an “automatic, single or double extraction, condensing” turbine and thus it could be a highly efficient system. The factors that contribute to achieve this aim are:

i) Milling system could be designed to obtain desired level of extraction efficiency and final bagasse moisture without any constraint or compromise.

ii) Energy efficient mill drives could be incorporated which result in saving of in house power consumption.

iii) A well planned bagasse handling and feeding system can be designed which helps to reduce the moisture and enhance combustion efficiency of boilers.

iv) Various process systems and equipments installed would incorporate latest designs, contributing to energy conservation goals.

Existing sugar plants:

Power generation potential and the export of surplus power may get constrained due to conditions prevailing in the sugar plant such as:

i) The existing steam conditions:

The steam driven prime movers of the sugar factory especially the mill drive turbines will have to be supplied with steam of same condition, extracted from the cogeneration cycle. To that extent, the power generation will suffer unless, extensive modifications are proposed to be undertaken so as to replace mill drives by either electrical or hydraulic motors.
ii) The existing level of energy consumption:

This energy in terms of steam and electrical power, required for sugar manufacture, will have to be supplied from the cogeneration system and to that extent, will reduce the export quantum of surplus power. This energy depends on the various systems and designs of plant and machinery employed in the sugar factory.

The above two factors have significant influence on the quantum of surplus power for export. Hence this makes it imperative to execute a time bond programme for optimizing energy conservation in the sugar plant.

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The following three figures depict in general terms, the steam cycles indicated at a, b (i) and b (ii) shows the possible power generation in each case with assumptions as specified.

Fig 1

Fig 1 shows a steam cycle for a 'green field' combined sugar factory – bagasse cogeneration project, which envisages plant and machineries with modern system designs incorporating highly efficient energy conservation methods to give predicted performances as per assumptions.
Fig 2 envisages imposing a topping cycle in the existing sugar plant where the old boilers are replaced with new steam generator of high pressure and high temperature. All the steam generated by the boiler is supplied to a "topping" turbo generator of extraction condensing type, the extracted steam being driven prime movers including factory turbo generator set remain undisturbed. The power generated by the topping turboset is exported.

The cycle is especially more beneficial for the factories where the present steam pressure is rather low, say around 15 kg/sq.cm. However, it can also be used for an existing pressure of 21 kg/sq.cm².
Fig 3 also depicts a topping cycle but here the existing factory turbo set is eliminated and all the electric power is generated by the topping turbo set. Since production of electricity from high pressure steam is more efficient, more power is available for export.

Following table gives some indication of total power that can be generated and the exportable quantum under different options. Certain assumptions are made as below:

**Assumptions:**

1) Sugar factory parameters: (existing sugar factories)

- Cane crushing rate – 100tch
- Bagasse moisture – 50%
- Steam pressure – 22 kg/cm² (A)
- Steam temperature – 340 C
- Steam consumption – 50% on cane (average)
- Power consumption – 18 – 20 kw
- Mill drive – By backpressure turbine (single wheel)
- Power generation – Through backpressure turboset (Multi stage)
2) Cogeneration steam cycle:

- Steam pressure – 65 kg/cm²
- Steam temperature – 480°C
- Boiler efficiency – 68%
- Power generation – During season only
- Power generation mode – Automatic single / double extraction condensing type.
- Overall efficiency of turboset – 85% (assumed on lower side)

3) Steam and power cycle for “Green field project”

- Cane crushing rate – 100 tch
- Bagasse percent cane - 30
- Mill drive – either DC or Hydraulic motors
- Total power consumption of factory – 28 kw/tch
- Factory steam consumption – 47% on cane (average)
- Cogeneration steam cycle – As in (2) above .
<table>
<thead>
<tr>
<th>Option</th>
<th>Total steam Generation</th>
<th>Steam cycle and extraction pressure</th>
<th>Specific steam Consumption</th>
<th>Power Generated</th>
<th>In house Consumption</th>
<th>Export Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Field Project</td>
<td>66 tph @ 65 kg/sq.cm and temp 500°C basis of Bagasse</td>
<td>Automatic double extrn condensing a) 1st extrn 3 tph @ 10 kg/sq.cm</td>
<td>6.61</td>
<td>0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) 2nd extrn 44 tph @ 2 kg/sq.cm</td>
<td>5.96</td>
<td>7.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) To condensing 19 tph @ 0.175 kg/sq.cm</td>
<td>5.21</td>
<td>3.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>11.47</td>
<td>2.8</td>
<td>8.67</td>
<td></td>
</tr>
<tr>
<td>Topping Cycle</td>
<td>64 tph at Automatic single extrn condensing a) 1st extrn 50 tph @ 22 kg/sq.cm &amp; prime movers moisture</td>
<td>15.0</td>
<td>3.33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) To condensing 14 tph @ 0.175 kg/sq.cm</td>
<td>5.21</td>
<td>2.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>generated by factory</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>6.01</td>
<td>6.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topping Cycle</td>
<td>64 tph at Automatic double extrn condensing a) 1st extrn 23 tph @ 22 kg/sq.cm &amp; 350 C</td>
<td>15.0</td>
<td>1.53</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) 2nd extrn 27 tph @ 2 kg/sq.cm</td>
<td>5.96</td>
<td>4.53</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>c) To condensing 14 tph @ 0.175 kg/sq.cm</td>
<td>5.21</td>
<td>2.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>8.74</td>
<td>2.0</td>
<td>6.74</td>
<td></td>
</tr>
</tbody>
</table>
Note:
It must be noted that these are broad theoretical calculations. When finer details are considered some variations may be expected.

Bagasse gasification:

Cogeneration of surplus power can also be undertaken via bagasse gasification. Coal and biomass gasification has been under investigation for several decades but it was only after oil embargo, that interest really grew for the adoption of this technology as an alternative for power generation. The biomass is seen as an interesting and promising alternative fuel for gasification due to its availability as agricultural and industrial residues and the fact that is renewable.

To assure a high, overall thermal efficiency for the gasification/power generation process the use of gas turbines in a combined cycle seems to be one of the best choices. It is estimated that overall thermal efficiency of biomass integrated gasifier/gas turbine with combine cycle will be between 20 and 50%.

However, there are two factors, which impose limitations on the use biogas in a gas turbine. These are one- the level of contaminants present in gas and second- its low calorific value. Several R&D programme are undertaken to overcome these problems.

In a case of “aeroderivative” natural gas turbines, “steam injection” for power and efficiency augmentation, had already been established and existed since 1980. The same system is being developed for biomass gas fired turbines. E.D.LARSON made a detailed investigation on this subject and presented an economic case study based on the Jamaican Monymusk factory, which indicated attractive returns as compared to conventional steam turbine generation.

Following figure shows proposed schematic representation of a biomass gasifier steam injected gas turbine cogeneration cycle.
The author of this study expect that commercialization of this proposed technology could take place within 5 years since the problems related to gasification of biomass fuels are less complicated than coal.

BIOTEN Inc of AMERICA a wholly owned subsidiary of “Eastern Utilities Associates” of Boston has already developed and commercialized biomass fueled combustion turbine system for power generation which is of course without steam injection steam. They have already setup and are operating a full scale 5.8 MW commercial demonstration plant at their test facility at “Red Boiling Springs” in Tennessee, which is fueled by locally available fresh cut, saw dust. But they are currently testing other fuels such as wood ships, rice husk, sugar cane leaves and bagasse and claim that they can certify suitability of their combustion turbine system for these fuels.

However a recent study on bagasse and biomass gasification presented in the last ISSCT conference highlighted that the bagasse gasification technologies for large-scale power generation are not yet sufficiently mature. Some of the key hurdles pinpointed are:

i) Specific gasification capacity (expressed as tons of biomass per unit volume of gasifier) of a unit, which is feasible for a comparatively smaller size of power generation plant (less than 10MW) could be prohibitively expensive to construct and operate a scaled up larger size unit (less than 50MW).
ii) Bagasse does not feed well into a pressurized gasifier unit, using conventional feeding equipment such as one developed for feeding wood chips.

iii) Bagasse has low alkali metal content which is not of significant concern for gas turbine operation as well as for gas cleaning equipment.

iv) Moisture content of raw bagasse may present a problem that could have impact on overall cycle design.

v) Rate of gasification retards due to charring of bagasse that takes place after initial devolutilisation. This indicates that separate arrangement may be necessary for handling of char.

All this discussion implies that, a very careful techno economic study would be necessary before conceiving any such application.

**Administrative control:**

Economic viability of a cogeneration project is the most important considerations that takes precedence over all the aspects, while conceiving such a scheme it is therefore essential that an effective administrative control is created separate from the sugar factory management to look after and oversee all aspects of cogeneration plant including those pertaining to finance and technical. Following are some of the points that can have significant effects on successful functioning of the project.

**Power purchase agreement:**

It is obvious that generally a public utility or the state grid will purchase the generated power unless they can agree for ‘banking and wheeling’ of power to a distant consumer arranged independently by the cogenerator.

Depending o the terms and conditions of the agreement, feasibility of generating and supplying power all the year round should be examined. In such a case the cogeneration plant will have to be worked off season on an alternative fuel which again necessitates careful techno economic assessment especially taking into considerations the availability and reliability of such fuel i.e. coal, lignite, oil etc. In case this alternative is not very attractive then procurement of excess bagasse from other factories or other biomass fuel like cane trash could also be considered. In any case necessary study in operational practices to be applied to should be made.

Another aspect to be considered to is the mode of power supply to utility. There are three basic ways by which power can be supplied.

a) Power to be supplied as and when available and in whatever quantity possible.
b) Firm commitment to supply minimum quantum of power throughout the day.

c) To supply committed power during the day as follows:

- Maximum during the peak demand hours
- Minimum during off peak hours
- Average during rest of the hours.

The quantum of power in each phase of supply has to be decided, depending on the capacity of the cogeneration plant and the requirements of the sugar factory.

It is very easy to follow the system mentioned at (a) because this does not impose any restrictions on the sugar factory working. However, in this case the utility may not be very happy to accept such uncontrolled irregularity in the supply and can choose to offer lower tariff for the purchase power.

Case (b) is better than (a) and more preferable but here the responsibility is to maintain the export power component irrespective of any disturbance in the sugar cane processing. This has to be achieved by striving to:

- Run the plant with minimum stoppages,
- Work the boilers on stored bagasse by arranging efficient bagasse retrieving system and
- The mode of power generation should be either through combination of backpressure and condensing turbosets or an extraction condensing turboset.

Case © is obviously ideal and could be advantageous to both the cogenerator as well as the utility, who would be willing to offer higher tariff for the power purchased during peak hours. In this case however, superior efforts are needed on the part of the cogenerator for maintaining variable power demand throughout the day without causing any disturbances in the sugar factory operations whatsoever. Here the mode of power generation should be necessarily through “automatic extraction (either single or double), condensing turbo generator” with complex instrumentation, protective devices and computerized programming for load dispatch.

System of billing:

Well-defined system for recording meter readings, method of billing and payment terms of bill amounts should form the part of agreement. Also action plan for the resolving any disputes that may arise in this respect may also be inbuilt into the agreement.

In view of a heavy capital investments needed and the high-tech nature of a cogeneration project there are complexity of problems both administrative and technical in setting up such project. To handle these a separate and highprofile organization is required to be created. Unfortunately, most of the sugar factories in India who have otherwise good
potential to undertake such exercise are not able to do so due to financial constraints and lack of infrastructure. It is then that some alternatives are to be considered.

a) Independent power generating company:

A third party could be involved, who may offer to build the project on the basis of "Build, own, operate and transfer" (BOOT). However, such a scheme involves lot of legalities and needs complete willingness and cooperation from the sugar factory, which will have to provide guarantees for the supply of entire bagasse to the generating company. Another problem that may crop up is that the cogenerator would, naturally like to impose some restrictions on the consumption of steam and power by the factory whereas, the factory on their part may not sincerely desire to do so. It may therefore seem that there would have to be some inbuilt incentives for the factory to practice energy conservation methods, which again may rise to some additional controversies.

If therefore, such an endeavor has to be a success then it is absolutely necessary that there is complete willingness and a sense of involvement from both sides in each other's efficient performance. A well designed 'interface system' will have to be developed with clear demaration of responsibilities in respect of –

a) Receiving measured quantities of steam and power into the factory at one point
b) Export of all bagasse and condensate to the cogeneration plant, at a mutually agreed point.

As a matter of fact, BOOT system is a softer option for a sugar factory but it is obvious that the factory will have limited advantages and limited revenue earnings.

b) Sugar factory's participation:

The best alternative of course is to involve the factory to the extent possible, to actively participate in the project along with the cogenerator. In such a case the factory could have a suitable share in the revenue of the cogeneration plant and thus, will be continuously interested in exercising energy conservation practices an essential step, for the success of cogeneration scheme. However, this demands a change in attitude of the factory technologists. Their interest is no more just restricted to manufacture of sugar alone but they to tune themselves to the uninterrupted working of a public utility power project.