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# THERMO-TECHNICAL EVALUATIONS OF THE SUGAR PRODUCTION PROCESS 1/

by

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## SUMMARY

A unique feature of the sugar industry is the substantial inter-relationship of heat requirements for power generation and process heating.

Sugar beet factories and separate refineries require an outside source of fuel whereas a cane factory should be self-sufficient in fuel for both heating and power requirements.

Electric power is extensively used in all three applications but cane factories still prefer steam turbines to drive the mills.

Attention is drawn to the importance of power factor control in electric power reticulation of a sugar factory.

The heat and energy balance is not particularly critical in the case of sugar beet factories and separate refineries but is so for a cane factory.

Important factor in thermal balances for a sugar refinery, beet factory and cane factory are separately identified.

The sugar cane factory has additional items for concern in the fuel value of the residual bagasse, the efficiency of the steam generators and the fibre content of the cane. Imbibition quantities and process steam economy control are required in the factory. The steam required for power units should be slightly less than that required to provide all process heating requirements. Distribution of heat requirement figures are suggested.

## A. Introduction

The energy balance of a sugar factory is of vital importance for its economic survival. It is one of the best industrial examples of the combined use of steam for power generation and process heating. Success is largely dependent upon the correctness of distribution between these two uses which the designer is able to achieve.

The general comments are applicable to sugar beet factories and refineries as well as to cane factories, but the cane factories consume a substantially higher proportion of power and hence the balance is significantly different.

There are occasions with sugar refineries and possibly also with sugar beet factories when local authority regulations do not permit the generation of electric power unless the factory is prepared to be completely independent of any supply of power from the local authority such as when the factory operations are shut down or if a surplus is required over and above the factory supply. The reason usually given for this is that a local authority must carry the insurance against power failure in their own area and the sugar factory should not just use the authority supply as an insurance which is the most expensive portion of electric power generation.

Some more liberal authorities might reach an agreement with the facotry in the nature of reciprocal power failure insurance.

Sugar cane factories on the other hand are normally capable of producing not only their own electric power requirements but also a surplus for which other uses may or may not be sought.

## B. The Power Cycle

In the case of sugar beet factories and refineries modern practice requires all the power needs to be generated inthe form of electric power. The types of operations conducted in these factories do not include major prime movers as the mills are in a sugar cane factory. The generation of electric power may be centralised in the factory and operated as a service to provide the needs of the factory itself.

Sugar cane mills have conventionally been driven by steam operated prime movers, but there are a few examples of electrically driven mills. Their economic justification leaves room for differences of opinion but they do present a very tidy arrangement.

The complete interdependence of all services in a sugar factory cannot be too strongly emphasised. The variables are of such a nature however that there is a substantial margin for flexibility in the selection of the controlling parameters.

## C. Electric Power Generation and Reticulation

This is the most highly specialised area of the general thermo cycle in a sugar factory. The specialised knowledge lies not so much in the generation of electricity itself as in its reticulation and use.

The world is divided into two main frequency usages - 50 Hz and 60 Hz. Each has both advantages and disadvantages and it seems unlikely that there will be any reconciliation. Occasionally frequency changes may be installed to provide possibly a range of frequency values for the purpose of speed control.

There is general agreement in the generation of alternating current as such (i.e. no zero Hz frequency generation) although there are uses for direct current in speed control of motors but this is usually provided through locally installed rectifier systems.

Voltages are provided over a wide range according to individual specifications.

One of the most important criteria of operation in the use of electricity is the power factor. This is the ratio between power needed and powed actually used. Low power factor values result very largely from underloaded and unsuitable types of motors. As well as correcting motor loading and motor types as far as possible the power factor may be further corrected by use of condensers or of suitable types of synchronous motors of which the compensated asynchronous motors appear to offer the most economical solution.

## D. Thermal Balance in a Sugar Refinery

This will be considered first as the most simple of the three groups of case studies in sugar factories.

The power load in a refinery is relatively small compared with the heat load, being essentially that required for pumps, fans and centrifugals. Steam supplied at say 25 bars and 350°C can be used to provide approximately 25% of its heat for power generation and the balance for process heating.

This means that all the power required by a refinery can be generated well within the process heat load requirements. Such is desirable as it avoids the necessity of condensing any steam other than in carrying out evaporation.

The balance of the process steam is supplied directly from the high pressure main through a reducing valve.

The amount of power which is generated from the steam is directly related to the temperature drop of the steam as it passes through the prime mover. Therefore a refinery can tolerate a lower temperature drop than can a cane mill. The result is that exhaust steam is usually at a much higher pressure and a correspondingly high temperature with substantial advantage to the design of sugar boiling pans. With the higher difference between steam heating temperature and massecuite boiling temperature it is possible to make worthwhile economies in the amount of heating surface to be provided.

The kind of differences in exhaust steam pressure between those employed in a refinery and those employed in a cane mill are of the order of 4 bars, with 4.5 to 5 bar being used in a refinery and 0.5 to 1 bar in a cane mill.

Steam which is exhausted from a prime mover, especially a turbine, or simply results from passing through a pressure reducing valve is invariably superheated. When it comes to using this steam for process heating very poor heat transfer characteristics are achieved until the superheat is removed. The reason for this is that superheated steam transfers its heat as though it were a hot gas and the transferred heat must penetrate a highly insulating gas film adjacent to the heating surface. On the other hand saturated steam transfers its heat very much faster (of the order of 1000 times) by virtue of the condensation of the liquid film on the surface of the heating surface which is much more effective in transferring heat.

A small amount of superheat can generally be tolerated as the turbulence on the condensing side of a heating surface will usually throw condensate around to a degree that will result in the incoming steam being saturated before it reaches the heating surface. If, however, this is inadequate as is the case with large amounts of superheat, then provision should be made for desuperheating in the low pressure steam main well before the steam reaches the sugar boiling pans. Complete desuperheating is often considered undesirable because wet steam is not clean to handle and is to this extent wasteful.

Because independent refineries generate the whole of their steam requirements from purchased fuel any economies which can be effected in steam consumption provide a worthwhile benefit in the over-all cost of refining. The cost of steam may be approximately one third of the total cost of the whole refining process.

In order to be abls to identify possible areas where savings might be mads, it is necessary to find out just how the steam is being used in different stages of the refining process and as far as possible to account for the full amount being produced.

In order to be able to identify possible areas where savings might be made it is necessary to find out just how the steam is being used in different stages of the refining process and as far as possible to account for the full amount being produced.

Items of importance when it comes to studying economies include the usage of water for dilution of syrups and during the boiling operations. Insulation of hot surfaces may be inadequate. Also there may be an uneconomical amount of remelting especially when screening of product sugars is practiced and reject size fractions are remelted.

Instrumentation can go a long way towards improving thermal efficiencies but the instruments need to be maintained in good working order and to be used to their full advantage to justify their cost of installation.

Multiple effect evaporation may or may not be justified in a refinery. When employed it is for concentrating the washings from filter presses and bone char or ion exchange resin decolourisers. Alternatively a somewhat similar economy may be effected by returning the washings to the melter to displace water which otherwise would be needed. The relative economics of the two alternative procedures needs to be mathematically evaluated.

## E. Sugar Beet Factories

The sugar beet factories resemble refineries in the respect of having to purchase all fuel requirements from outside sources and also in having a more modest requirement for power than cane mills. On the other hand they resemble cane mills in that juice concentration is necessary before sugar boiling is carried out.

It is common practice for a beet factory to produce refined quality sugar whereas a big proportion of cane factories produce only raw sugar. The proportion of cane factories producing sugar for direct consumption is increasing and it is likely that this trend will continue with the quality of the product also increasing. The necessity to purchase fuel makes it possible to put a value on steam and hence cost its use. The justification for capital expenditure may thereby be evaluated.

This most importantly applies to the arrangement for multiple effect evaporation. As with a refinery, the low proportion of power required for prime movers allows a relatively high pressure to operate in the exhaust steam main for process boiling. As well as enabling full advantage of the beneficial heat transfer characteristics to be employed for economising in heating surface at the pan stage it does provide substantial flexibility in the arrangement of the multiple effect evaporators.

It is possible, for example, to operate the evaporators at triple effect with vapour heating for the sugar boiling pans. There are other difficulties in achieving successful operation of this type of arrangement. For example the evaporators are continuously operating vessels whereas the sugar boiling pans operate in batches. There is substantial steam economy in operating the two together but substantial operating difficulties.

Endeavours are being made to develop a satisfactory continuously boiling pan but up to date success in this direction has been only of a limited character.

Another direction in which maximum steam economy has been sought in a beet factory has been to operate evaporators with five or even six effects. This retains the advantage of dissociating the continuous operation from the succeeding batch operations but does not have quite as good steam economy as if the pans could be operated on a continuous basis with vapour from the evaporators.

Steam bleeding from the evaporators for juice heating is also an important measure for improving steam economy. In the beet industry it is usually worth while taking this in at least two and possibly even three stages.

For three stage operation primary heating would be with vapour from the third effect, secondary heating with vapour from the second effect and final heating with vapour from the first effect. With high steam temperatures the vapour from the first effect is usually hot enough to complete juice heating without having to use a steam heated final juice heater.

Another type of arrangement which some design engineers prefer is to employ a pre-evaporator which provides vapour for juice heating.

The relative economics of the various systems need to be carefully evaluated in terms of both capital and operating cost and are both an interesting and rewarding exercise requiring a high degree of mathematical skill and understanding of the principles involved in the calculations.

## F. Sugar Cane Factories

The new features in these factories as compared with the two types just discussed are the availability of fuel in the form of fibre from the cane as bagasse, and the high mechanical power requirement for the preparation and milling of the cane.

It is not possible to put a price on steam which makes rigorous optimising calculations difficult to effect. Quite often the situation arises in which fuel is used over and above that which is available in bagasse and this costs money but the steam so generated is only marginal. The value of this fuel, however, is important in costing capital and operating requirments to enable such extraneous fuel to be minimised or eliminated.

A multiple balance is required for optimising calculations. The fuel potential of the bagasse needs to be balanced against the heat requirements of the process. In between the steam required for power generation needs to be slightly less than that required for the process.

Over the past thirty years practice has been slowly changing from reciprocating engine drives to steam turbine drives and occasional electric motor drives for the cane mills themselves and for the knives and shredder used as preparatory devices.

Turbines do not necessarily use less steam than the reciprocating engines they replaced. As turbines go they are relatively small units and difficult to make and operate at high efficiencies. One requirement of a mill engine is that it must be able to operate over a wide range of speed and also generate substantial power over this speed range. To generate power at low speeds a turbine operates at very low efficiency.

The turbine in the power house used to generate electricity is large enough to be made reasonably efficient and operates at a satisfactory constant load factor.

This has resulted in arguments favouring full electrification of mill drives and centralising of steam usage in only large turbine in the power house.

There have been a few very tidy arrangements along these lines but the proposals have not gained widespread popularily.

Turbines driving sugar mills can be arranged for centralised operation reducing the manpower requirements where multiple prime movers are employed along a milling train.

Drives for cane knives and shredders have been slow in developing for turbine operation with high speed reciprocating steam engines appearing as an intermediate stage. As power requirements for these operations increases with demands for a higher degree of effectiveness and substantial increase in rates of throughput it has become easier to justify the employment of turbine drives in these places.

The fuel potential of the bagasse itself is a function of three variables - the fibre content of the cane itself, the moisture content of the bagasse and to a lesser extent the sucrose left in the bagasse. As sucrose has a higher proportion of oxygen than does the fibrous portion of the bagasse it has a correspondingly lower calorific value. But sugar is a very expensive fuel under any circumstances and every endeavour should be made to achieve maximum extraction at the milling train.

Bagasse moisture is to a certain extend under the control of the engineer and its optimisation becomes a subject for very careful study.

Related to the fuel value of bagasse and the steam requirements of the process is the efficiency of the steam generator unit itself.

Assuming efficient operation on the process side a high steam comsumption generally results from a high usage of imbibition at the milling train (or diffuser system) or a low steam economy at the evaporators. If these are justified then a high efficiency is needed at the steam generator unless the fibre is high.

The extreme in this direction within the experience of the author was to obtain a fuel balance with minimal use of extraneous fuel at start-up or finishing periods when fibre in cane was at 10.5% and imbibition 200% on fibre. This required the use of quintuple effect evaporation of juice with vapour bleeding from the second and third effects for primary and secondary juice heating. Exhanst steam pressures were minimal at about 0.5 bar which necessitated final juice heating with exhaust steam as first effect vapour was just not hot enough.

Maximum economy was effected in sugar boiling by effective instrumentation and controlled dilution of recycle syrups.

To complete the picture it was necessary also to achieve maximum effeciency at the steam generators with values as high as 68% ($B_h$).

At the other extreme operation has been observed with fibre values as high as 15%, imbibition only 15% and boiler efficiency as low as 45% ($B_l$).

In between these two conditions lie most of the regular operating conditions.

The fuel value of bagasse and the ultimate analysis of the fibre were determined for Queensland conditions in 1937 and have been used as the basis for most relevant calculations since that time. Recent checks of these figures have indicated no significant change in the ultimate analysis but some possible doubt concerning the calorific value relationship. The recent data tend to give lower values for similar quality bagasse to the extent of about 5 to 7%.

The magnitude of present day values for fibre in cane tend to reduce the emphasis on boiler efficiency. Also air heaters and/or economisers have become more common with out always achieving the corresponding increase in efficiency which might have been expected.

Calorific values for fuels are commonly recorded in terms of gross ($B_h$) or nett ($B_1$) values depending on whether the latent heat of condensation of water vapour in the flue gases is taken into account or not. The gross value is the one most readily determined analytically in the standard type of bomb calorimeter.

In practice it is not possible to recover the latent heat of condensation of the water vapour in the flue gases and the nett calorific value gives a more realistic indication of the real value of the fuel.

When using hydrocarbon oils or coal as fuel the difference between the two calorific values is not of particularly high significance, but in the case of bagasse which is practically a carbohydrate and also carries a very high proportion of moisture there is a quite significant difference between the two values.

It has become common practice to refer most steam generator effeciencies totthe gross calorific value of bagasse on the grounds that the moisture content of the bagasse is partly under the control of the engineer, and a low moisture content of the bagasse assists steam generator operation and will show more improvement in efficiency on gross calorific value.

The author as a matter of personal opinion contests the validity of these arguments in the light of present day best practice and prefers the use of the nett calorific value. Efficiencies based on these values are more meaningful when being compared with efficiencies of steam generators operating on hydrocarbon oils or coal, or even wood.

A knowledge of the ultimate analysis of the fibre of bagasse is needed in order to calculate the composition of the flue gases which is needed to get an understanding of the real behaviour of the fuel in the furnace itself.

The steam requirements of a cane factory are usually evaluated as a percentage of the cane processed, although a figure in terms of megajoules per tonne of cane might be more meaningful.

A figure of 55% for the steam/cane relationship is not unusual with a subdivision of the following order of magnitude

| | |
|---|---|
| Power: | 3.6% on cane |
| Heaters: | 4.2% |
| Evaporators: | 25.2% |
| Pans: | 14.3% |
| Miscellaneous: | 7.7% |
| | 55.0% |

The total has been known to vary over the range of 50 to 65% with corresponding variations in ditribution. Nevertheless the figure of 55% is considered to be reasonably representative of conditions with quadruple effect evaporation, bleeding from the first effect for juice heating and an imbibition of about 250% on fibre.

Each individual factory needs to make its own calculations and assess the costs of the thermodynamic cycle.

The amount of imbibition should be related to the effectiveness of extraction at the milling train but it is seldom possible to obtain an exact mathematical evaluation of the relationship.

It can be seen that the proportion of heat required for power generation is very small indeed and only about 6.5% of the total steam used. From this one might conclude that its assessment is a matter of relatively minor importance. This may be so in itself, but the assessment of the proportion of steam required by the prime movers is of major significance.

It must be arranged that the exhaust from the prime movers is on the average substantially less that the total required for process. Make-up steam is then supplied through a reducing valve or automatic pressure control which expands steam isothermally from the high pressure main to the lc pressure main. If at any time the exhaust from the prime movera is above process requirements, the exhaust pressure will build up; steam consumption of the engines then increases as a result, giving a further increase in exhaust pressure and so auto-amplification develops. Steam must be blown to atmosphere to save steam under such circumstances.

Steam accumulators are sometimes used to try to even out the fluctuations between supply and demand which are usually caused by the batch conditions of the pan boiling operations. This can provide some ameloration with benefit to the steam generators.

It should never be necessary to purchase electric power for a cane sugar factory from an outside supplier. On the other hand useful amounts of electricity can quite often be generated by a sugar cane factory over and above its own requirements. Sometimes this may be used for driving irrigation pumps to supply the needs of the cane growing district. Under well organised circumstances it may be possible to feed the surplus into the national grid or assist the local electrical generating authority.

The best conditions for such an arrangement would be associated with a factory operating at high daily crushing capacity, with cane having a high fibre and having a good general steam economy within the processing area. It would be necessary to employ pass-out type turbines to drive the electric generators with steam not required for process being handled by a surface condenser of the conventional electric power house type.

Questions:

1. What constitutes efficient usage of steam in a sugar factory?
2. How may this be assessed?
3. In what way can the maximum fuel value of sugar cane bagasse be employed?

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