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WATER, STEAM, GAS AND ENERGY SUPPLY AND CONSUMPTION PROBLEMS EXPERIENCED IN THE SUGAR INDUSTRY 1/

by

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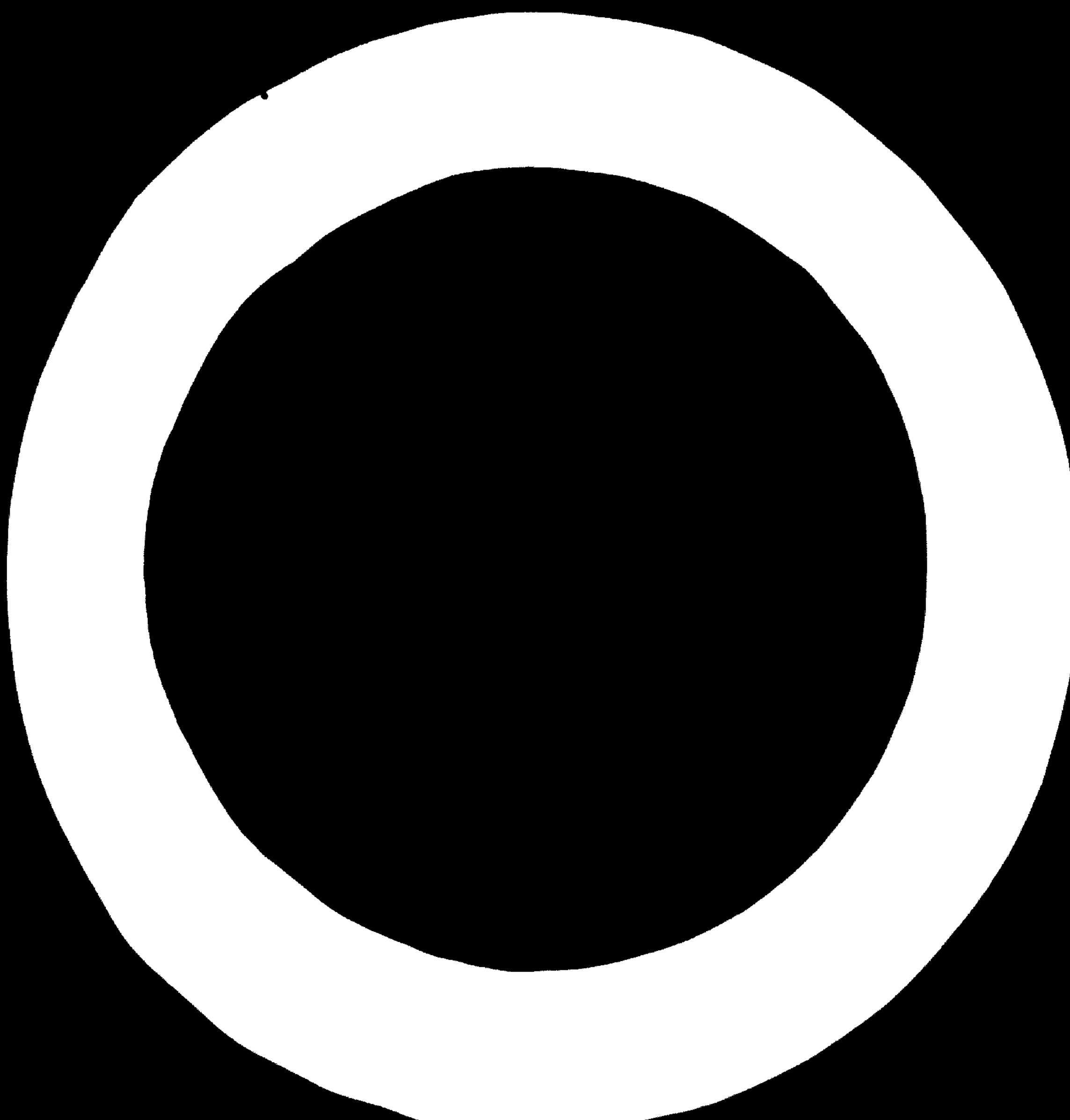


INTRODUCTION

The sugar industry is one of the oldest food industries ever practiced by mankind. It has made its way through quite a long and primitive path unknown to industries which were developed after the discovery and commercial use of steam and electric energy.

In the early days cane stalks used to be crushed by animal-driven stone mills, and the extracted juice was concentrated in open clay vats using heating stones. When, later on, man learnt how to make copper vessels, cane fibers were used as fuel to concentrate the juice over a naked fire to such a consistency that a solid brownish mass of raw sugar was obtained on cooling. Such sugar contains the whole solid matter of the juice. Even now small brownish loaves of such raw sugar are produced in one or two villages in upper Egypt, while considerable quantities of such quality are produced in India.

The basic foundations of the sugar technology of today were laid down after the introduction of the utilization of steam in the sugar factories for heating and driving engines. Since then the main features of sugar factories have remained more or less unchanged, with, however, the following differences:

a) The actual generation of machinery may have ten to twenty times the capacity of the first generation.

b) The replacement of batch operations by continuous ones.

c) Mechanization and process control automation.

The sugar industry is an agro-industry, where sugar is extracted either from cane stalks or beet roots which are perishable plant tissues. Apart from the quality of the crop, one of the most important factors influencing the performance of a sugar factory is the possibility to keep it running regularly at its maximum capacity. Next to a regular supply of sugar crop to the factory, a regular supply of water, steam and electric energy is a must.

It follows that the main water pumping station, the steam generating plant and the powerhouse should be designed and run with the utmost care and maximum safety precautions. A failure in the water pumps or a poor quality of steam fed to the powerhouse might result in a complete stoppage of the factory.

I. WATER

I.1 Two main factors are decisive when choosing the location of a sugar factory, namely:

a) The closest proximity to the cane or beet growing fields, to avoid excessive transportation costs of bulky material.

b) The availability of an ample water supply, since a sugar factory is a big water consumer.

Water used by a sugar factory could be classified under two main headings: cold water and hot water. The former represents the bulk of the total requirements.

I.2 Cold water

Under this heading the following consumers could be identified:

a) Beet fluming and washing (beet only);

b) Condenser cooling water;

c) Cooling water for steam turbines, compressors, ring sealed vacuum pumps, mill bearings, pump bearings, etc...

d) Imbibition water (cane only);

e) Gas washing;

f) Cooling crystallizers;

g) Start-up of steam boilers;

h) Potable water for factory and factory village.

The requirements under (a) and (b) are by far the largest. However, the actual consumption of one or the other is subject to many variables.

I.2.1 Beet fluming and washing

Water consumption per ton of beet for fluming and washing is influenced by two factors, namely:

a) The proportion of soil carried along with the roots from the fields to the factory. Depending upon whether the beets are manual . or mechanically harvested and on the soil moisture at harvesting time, the percentage of soil in relation to the beet may range from 4 to 40%.

Higher soil contents of the beet would be reflected as a higher demand for washing water, a higher volume of mud to be evacuated from the water clarifier and consequently a higher water consumption.

b) The type of equipment used for beet transportation to the washers. When beet pumps are used the vehiculating water volume would be about 20% higher than that required with other conveying systems.

It follows that the capacity of the clarifier, through which the fluming and washing water is recycled, would be influenced by the same factors governing transportation and washing water consumption.

In the case of an existing factory where harvesting has to be shifted from manual to full mechanization, it would be justified to check on the capacities of the clarifier and the pumps of the whole station. Chlorine consumption at the clarifier might also increase.

Although the water requirements for beet fluming, transportation and washing is quite considerable ($\pm$ 800% to 1,000% beet) the actual consumption is only equivalent to the water contents of the spent mud from the clarifier, and is mainly a function of the soil contents of the roots.

The consumption at this stage could be reduced, to some extent, by the reutilization of cooling water at certain other stages of the processing, such as the powerhouse and the ring sealed vacuum pumps.

I.2.2 <u>Condensing cooling water</u>

The main water consumer common to both cane and beet factories is the condensing plant. To establish the rate of consumption at the condensing plant a distinction has to be made between two different cases:

a) A factory located next to a big river, with no restrictions on the size of the main pumping station, or next to the sea. In such a case the cooling water is used only once.

b) If the water supply by the factory site is limited or if the factory has to pay a high price for its water consumption, however, the water from the condenser's leg has to be recirculated through a cooling tower or a spray pond for cooling and reutilization.

In the first case (a) the installed capacity of the main pumping station supplying the factory with process water would be about ten times that in case (b).

The initial investment cost in case (b) is likely to be higher, but there is often not much choice and a recirculation system has to be installed.

For a given crushing rate the condenser cooling water requirements are variable and are governed by two main factors:

a) The quantity of vapour to be condensed per ton of cane or beet;

b) The type of condenser.

A. <u>The quantity of water to be condensed</u>

This quantity is also variable and is a function of:

1. The number of effects of the evaporation. Most cane factories have quadruple effects and all beet factories have quintuple effects. Some cane factories have quintuple effects: however, the heating surface of the first, or pre-evaporator, should be so limited that the retention time of juice should not exceed two minutes in order to avoid inversion and caramelization.

2. The total quantity of vapour bled from the evaporation for use in the heaters and vacuum pans. In fact the use of a heater in the condenser line to raise the temperature of mixed juice in a cane sugar factory to $\pm$ 45°C would reduce the quantity of vapour to be condensed from the evaporation from $\pm$ 10 to 7% cane. The same arrangement could be foreseen in a beet factory for heating the first heater of the diffusion recirculation juice. The use of a heater in the condenser line would reduce the steam consumption and the water requirements of the condenser. However, it is essential to ensure that the heater's tubes are in good shape, since tube failure in such a case would cause considerable juice losses.

3. The total quantity of vapour to be condensed at the vacuum-pan station. This is mainly influenced by the quality of sugar to be produced and

the number of strikes. The number of strikes may vary from two in a beet factory producing raw sugar to five in a cane factory producing refined sugar.

In general, for a given boiling scheme steam saving and consequently condensing cooling water savings could be realised through:

- Avoiding recirculation of malasses by increasing the efficiency of exhaustion at the pans and cooling crystallizers.

- Avoiding excessive dilution of malasses and washings and controlling the Brix of remelts.

Using optimum quantity of washing water at the centrifugals.

However, the total quantity of vapour to be condensed from the pans of a given factory is not uniform since massecuite boiling is still a batch process, in almost all sugar factories, where evaporation rates vary widely during the course of one strike. This explains the wide difference between the rates of condensing water applied in practice by the industry and the theoretical demand.

B. The type of condenser

Two main systems are well known to the sugar industry:

1. The counter-current barometric condenser, where a vacuum pump is used to extract the air and non-condensable gases from the top of the condenser.

2. The jet condenser which is a co-current type condenser. This system eliminates the vacuum pump as well as the air piping between the condenser and the pans, which is often subject to corrosion especially where juice sulphitation is adopted at the clarification plant.

In practice, the condensing water demand of the first type is about 30kg. per kg. of vapour, while it is about 60kg. water per kg. vapour for the second type.

In cases where the water supply to the factory is subject to certain limitations and condenser cooling water has to be recycled, the counter-current condenser would be the only solution.

The second type could only be used where an ample water supply is available. Nevertheless, it is likely that when comparing the savings due to the elimination of the vacuum pump and the air pipings against the extra investment incurred for a larger water pumping station from source to factory, a larger main cold water duct, higher pumping capacitv for condenser water injection and a larger duct for the hot well effluent, the results would be in favour of a counter-current condenser and air pump.

Generally, juice vapours from both the last effect of the evaporation and the vacuum pans are corrosive since they contain a certain proportion of organic volatile matter, and they could be quite aggressive where juice and/or melt sulphitation is practiced. If the condenser and the air pipings, especially at the bends, were not protected with an anti-corrosive paint, failure of such pipings and the eventual collapse of the condenser would not be uncommon.

I.2.3 Cooling water for steam turbines, etc...; Gas washing and Cooling crystallizers

Subject to the suspended matter contents of the raw water supplied to the factory, a simple filtration through a sand filter or sedimentation followed by filtration might be necessary, since it is recommendable that the requirements of the above-mentioned consumers should be free of suspended matter.

Generally, the hardness of river water is no impediment to its use as cooling water for steam turbines, unless otherwise stipulated by the machine manufacturer. Furthermore, the hardness of cooling water for ring-sealed vacuum pumps, and gas washing or quenching has no serious implications on the performance of such stations.

If, however, hard water is used for cooling crystallizers, scales would be deposited, in the long run, on the interior surface of the cooling elements. The extent of scaling could be judged by the falling off in performance of the crystallizers. Since mechanical scale removal in such cases is practically impossible and since chemical methods would be quite tedious, it might be advisable to conceive a closed cooling water system where a make-up of soft water would be introduced whenever necessary. Such a closed cooling system, combined with an alcalinization of the water, is quite advantageous, since it also solves the problem of corrosion of the cooling surface, which is quite frequent.

If necessary a certain reduction of cold water consumption could be obtained by the reutilization of cooling water from steam turbines and ring-sealed vacuum pumps for beet washing or eventually as imbibition water in cane factories.

I.2.4 Imbibition water

Whether sugar extraction from sugar cane is carried out by a train of mills or by a diffusion plant, imbibition water demand range between 200 and 250% fibers. It is added before the last mill of a mill train, or at a certain distance from the tail of the diffuser. In both cases it is recommendable to use cold water, for the following reasons:

a) Hot water of $\pm$ 70°C could not be added before the last mill without causing slipping and overfeed at the last mill. The time of contact between the imbibition water and the fibers being quite limited, it is unlikely that the use of hot water would increase the extraction, since almost all the cells are supposed to have been already opened before the last mill. If such was the case, the main effect of imbibition water would be to dilute a readily available residual juice. On the other hand, the use of hot imbibition water would raise the temperature of juice and fibers all over the train of mill to about 35°C, a degree favourable to bacterial activity.

b) In the case of cane diffusion, the use of cold imbibition water is a great advantage since it decreases, to some extent, the bagasse temperature before the dewatering mill and consequently reduces slipping and overfeed of that mill.

I.2.5 Start-up of steam boilers

Condensates from the first and second effects of the evaporation station are generally sufficient in quantity and quality to cover the requirements of the steam generating plant. For starting up the factory, and in case of eventual contamination of condensates of the second effect with sugar, or the stoppage of mills for more than two to three hours, cold boiler feed water has to be used. The quality of such water has to be the same as a non-chlorinated potable water. Furthermore, it has to be either softened or deionized. The choice of either processes depends mainly on the steam pressure of the steam boilers. Such water treatment installation is normally used for a limited period during the season, and it does not seem justified to conceive it for automatic control of operation. With manually operated ion exchange beds, however, special care has to be devoted to the rincing operation in order to avoid the introduction of sodium chloride or acids into the boilers. To meet such temporary demand for cold filtered water it is common to slightly overdimension the potable water plant of the factory and to keep a buffer storage capacity of soft water equivalent to two hours requirements of the steam boilers.

I.2.6 Potable water

Since most sugar factories are located far from cities or big villages, they have to be self-sufficient with regard to certain facilities. Potable water requirements are in direct proportion to the number of inhabitants of the factory village.

It is not unusual for a sugar factory initially designed for a given capacity to be extended after some time and for the number of inhabitants of the village to increase with time. Hence it is often justified not to seek maximum economy while deciding the capacities of social facilities of the village in general and the potable water plant in particular.

I.3 Hot water

I.3.1 Supply

A sugar factory produces hot water in excess of its requirements because the condensates from the evaporation include, besides the condensed steam of the first effect, the condensed juice vapour of the next effects. Water to be taken off at evaporation in a beet factory amounts to about 95% beet, against about 80% cane. This difference is attributed to the two following reasons:

a) For almost the same brix, the weight of juice to be evaporated amounts to ± 120% beet against 95-100% cane.

b) Because beet factory evaporation is under pressure, with appreciable bleeding from the forth vessel, while cane factory evaporation is under vacuum. The quantity of vapour leaving the last vessel to the condenser is consequently much less in a beet factory.

It follows that the total quantity of condensates from evaporation, heaters and vacuum pans in a beet factory is higher than in a cane factory: ± 135% beet against ± 115% cane.

The total volume of condensates varies from one factory to another and is mainly influenced by the weight of the juice to be evaporated and the quantity of water to be evaporated at the vacuum pans.

I.3.2 <u>Main characteristics</u>

a) <u>Exhaust steam condensates</u>

This applies to condensates from the first effect of the evaporation as well as condensates from vacuum pans or heaters heated with exhaust steam. If exhaust steam originatea from steam turbines, the condensates could be considered as distilled water. Condensates of exhaust steam from steam engines are contaminated with oil in proportions ranging from 3 to 20 p.p.m., depending on the state of the engine and the efficiency of the mechanical oil separator. In practice it is hardly possible to free such condensates from their oil contents before using them as boiler feed water. Partial success could be achieved by filtering these condensates through columns packed with coke.

The contamination of exhaust steam with oil is quite undesirable, since oil gets deposited on the tubes of the heating chests, decreasing to a great extent their thermal conductivity. Furthermore, the presence of more than 1 p.p.m. of oil in the condensates, used as boiler feed water, could be the cause of foaming and tube bursting.

Since condensates from the first effect of evaporation are insufficient to cover the requirements of the steam boilers, condensates from the second effect are partially or totally used as make-up.

b) <u>Juice vapour condensates</u>

These are condensates from effects other than the first, as well as from heaters and vacuum pans heated by vapour bled from the evaporation. Such condensates are usually contaminated with volatile organic matter originating from the juice. Depending on the efficiency of the entrainment catchers, they could also be contaminated with sugar.

The presence of traces of sugar in the condensates would render them inappropriate as boiler feed water. Hence a strict control of the presence of traces of sugar in boiler feed water has to be maintained. If an automatic sugar detector based on conductivity is used, its zero setting should be checked periodically in order to avoid losing useful hot boiler feed water or sending sugar to the steam boilers.

The normal impurities in condensates are the following :

(i) Organic volatile matter, usually expressed as acetaldehyde;

(ii) Ammonia;

(iii) SO_2 in case of juice sulfitation.

Although these three impurities are supposed to be present only in condensates of juice vapour, since they are volatile they are also present in exhaust steam condensates due to the use of condensates of the second effect as boiler feed water.

A recent investigation carried out on the impurities in condensates at five Egyptian sugar factories gave the following results. All five factories crush the same varieties and follow the same sulfitation process.

Factory	N° 1	N° 2	N° 3	N° 4	N° 5
p.H. of clear juice	6.85	6.80	6.60	7.00	6.60
x Alcalinity p.p.m.					
pre-evaporator	12.5	21.0	11.0	9.5	13.0
1st effect	12.0	13.0	10.0	11.0	9.5
2nd effect	8.0	- 2.5	10.0	-1.0	- 4.5
Volatile matter (p.p.m.) expressed as acetaldehyde					
pre-evaporator	264	800	388	97	352
1st effect	362	839	477	121	561
2nd effect	466	746	477	128	375
Ammonia (p.p.m.)					
pre-evaporator	16.5	14.0	7.0	6.0	9.5
1st effect	17.5	14.5	9.0	8.0	16.0
2nd effect	19.0	14.5	9.0	14.0	12.5
SO_2 (p.p.m.)					
pre-evaporator	0.91	0.93	0.85	2.55	1.07
1st effect	1.03	0.98	1.29	2.52	1.62
2nd effect	1.08	2.10	1.29	3.82	2.40

x phenolphthaline as indicator

The above-mentioned results and other findings are summarized hereafter:

(i) Correlation between the p.H. of the juice to be evaporated and the SO_2 contents of the condensates is significant. To reduce the SO_2 contents in the condensates to a minimum value, the p.H. of the clear juice has to be maintained around 7.0.

(ii) The alcalinity of the condensates decreases gradually from the first to the last effect.

(iii) Thermal deairation of the condensates used as boiler feeder water decreases to some extent the ammonia and SO_2 contents, but it has almost no effect on the organic volatile matter.

(iv) Condensates to be used as boiler feed water could be freed from the volatile organic matter by adsorption on a column packed with either an ion-exchange resin (quaternary ammonium) or active charcoal at the rate of 85 to 100 Gr. of volatile organic matter per 1. of resin or charcoal.

I.3.3 <u>Main hot water consumers</u>

A. <u>Boiler feed water</u>

Usually condensates from the first and the second effects are amply sufficient to cover the requirements of the steam generating plant. The boiler feed water requirements are always higher than the respective quantities of steam produced. Assuming a normal rate of blow-down the difference between the two values is a function of the following factors:

(i) The quantity of steam used for heating malasses by steam injection and that used at the centrifugal station.

(ii) The quality of lagging all over the factory. With poor lagging the difference attains a maximum and the condensates from both the two first effects might no longer be sufficient to cover the requirements of the steam boilers. Such a situation might lead to the use of condensates of poorer quality or the use of cold water as make-up.

Where condensates from the vacuum pans are used as boiler feed water it would be advisable to discard the condensates just before cutting off the vacuum to drop the strike and when starting a new strike in order to avoid contamination of the condensates with sugar in case of tube failure.

B. Maceration water

The present paper has already stressed the advantages of using cold imbibition water in a cane sugar factory. On the contrary, in the beet sugar industry hot water is used at the diffusion plant at the rate of 40 to 50% beet. The hot water is usually acidified with sulphuric or sulphurous acid to increase the efficiency of the pulp dewatering presses. As a result of such acidification a certain wear on the screws of the presses is quite common.

C. Sweetening-off water

Hot water is used for sweetening-off rotary vacuum filters in both cane and beet factories as well as candle filters in the beet sugar industry. In cane sugar factories the use of hot water for sweetening-off vacuum filters is of a certain importance, since it keeps the muds at a temperature near to the fusion point of the cane wax of the muds, and consequently renders the sweetening-off more efficient.

Hot water is also used for sweetening-off and back-wash of juice softening ion exchange beds in the beet sugar industry. It might be of interest to point out that if such operations are not sufficiently controlled they can be an important source of undetermined losses. Furthermore, in order to avoid heavy dilution of the juice before evaporation, it would be advisable to use the effluent,from the sweetening-off of such beds, of a Brix less than 10.0 in the boiling house for melt preparation or molasses dilution. Effluent of a Brix higher than 10.0 could be sent to the evaporation.

D. Molasses dilution and sugar washing

Although these are minor consumers, optimum molasses dilution before feeding into the pans and the use of optimum quantities of water for sugar washing, at the centrifugals, contribute to a considerable extent to the exhaustion at the vacuum pans, the steam consumption of the factory and the quality of the final sugar.

II. STEAM

2.1 Almost all the unit operations involved in the sugar industry consume steam either to optimise certain chemical or physical changes during the juice clarification or to remove water from the thin juice at the evaporation plant. Further quantities of water are removed at the vacuum pans to allow the sucrose to crystallise. Other unit operations are minor consumers of process steam, but their impact on the final results of the factory could be significant.

Since considerable power loads are involved in the sugar industry, steam is used to generate electric energy and the exhaust steam from prime-movers is used as process steam.

It is quite justified to assume that for a new sugar factory an optimum balance of power and process steam requirements could be realised if all local conditions, especially those related to the sugar crop quality, were taken into consideration. Generally the problem arises when an old sugar factory is undergoing extension or renovation, which frequently involves a rearrangement of the evaporation, heaters and pans as well as the extension of their heating surfaces. While carrying out such modifications, the re-establishment of an optimum balance of power and process steam has to be borne in mind at the same level of importance as the volume of investment.

2.2 The importance of economic use of steam

The steam consumption of a sugar factory is quite considerable. It ranges from 300 - 350 Kg. per t. beet to 500 - 550 Kg. per t. cane.

A beet sugar factory has to pay for its fuel consumption which accounts for about 30% of the total cost of all consumables of the factory. Hence steam economy reflects directly on the sugar production cost.

On the contrary, a cane sugar factory has the privilege of getting its fuel requirements through the raw material itself. This does not mean that heat economy in a cane factory is not of great importance. It should be considered as equally important as if fuel had to be purchased, for the following reasons:

(a) Low fiber contents of the cane would result in less fuel being available for the steam generating plant and a make-up of fuel might be required. Firing a mixture of bagasse and oil in the same furnace is usually associated with poor steam boiler efficiency.

(b) A surplus of bagasse is a valuable raw material for pannel and paper manufacturing, especially in view of the fact that world demand for these commodities is regularly increasing. The importance of heat economy in the cane sugar industry would become more apparent if part or the whole production of useful fibers of a cane sugar factory were to be transformed into paper or pannel.

3.3 Main steam consumers

The bulk of the latent heat of the steam produced by a sugar factory is consumed at the evaporation and vacuum pans.

Generally, bleeding from the evaporation of a cane sugar factory is sufficient to cover the requirements of almost all the heaters and partially those of the vacuum pans. At beet sugar factories, where pressure quantiple evaporation sets are used, bleeding is sufficient to cover the requirements of almost all the heaters and vacuum pans.

Minor quantities of steam are consumed at the following stations:

- Mill cleaning.
- Molasses heating before feeding into the pans.
- Melt preparation.
- Centrifugals.
- Sugar drying.

3.4 [illegible]

3.4.1 [illegible]

An evaporation station is usually designed to evaporate a certain quantity of water per unit of time. The use of excessive quantities of water at the mills or at the diffusion would increase the load on the evaporation, the Brix of the thick juice would drop and extra quantities of water would have to be evaporated at the vacuum pans in single effect.

The use of excessive dilution water might increase sugar extraction, but it would certainly increase the extraction of non-sugars, which would mean that the extra sugar extracted would be of lower purity.

Attractive extraction figures could be quite misleading if undetermined losses at the extraction plant were not taken into account.

In all cases, it would be useful to determine the rate of dilution at the extraction plant on a cost-benefit basis and not on the basis of the extraction figure as the only criterion.

2.6.2 The evaporation station

For a given percentage of imbibition or maceration water used at the extraction plant, steam consumption would be influenced by factors inherent to the evaporation station, namely

(a) The number of effects and the bleeding scheme.

(b) Scale formation on the juice side and oil deposits on the steam side would reduce the thermal conductivity of the heating sheets, resulting in a thick juice of a low Brix and higher steam consumption at the vacuum pans. In certain cases, where scaling on the juice side is heavy, spare evaporation vessels are foreseen to keep the factory running non-stop during the crushing season.

The problem of scale formation in the beet sugar industry could be solved by the use of softening ion-exchange resins.

The commercial development of softening resins suitable to handle sugar cane juice would be greatly appreciated by the cane sugar industry.

2.6.3 [illegible]

Steam consumption is directly proportional to the total quantity of water to be evaporated at the different stations, which varies widely from one factory to another. The main factor influencing the steam consumption of the plant is the sugar quality, since extra quantities of water have to be evaporated in the case of factories producing white or refined sugar.

However, for a given boiling scheme, other factors could largely influence the steam consumption of the vacuum pans:

(a) The Brix of the thick juice, which has to be maintained between 60 and 65 if steam economy is sought.

(b) The quantity of water used to dilute molasses could be the cause of higher steam consumption if it were not controlled. A simple way to keep such control would be to establish for each run-off the degree Brix equivalent to the saturated solution of the run-off at the temperature of the vacuum pans, and to check the Bx of the diluted molasses from time to time.

(c) The efficiency of exhaustion at the vacuum pans and cooling crystallisers, as well as the efficiency of curing at the centrifugals, would influence to a great extent the total quantity of masse-cuite dropped per ton of cane or beet. For the same factory, the total amount of boiled M.C. would increase by about 25% if the above-mentioned factors were not observed. A useful practice to control such factors would be to determine periodically during the season the crystallised sugar % M.C. and the total dry matter in M.C. % cane or beet.

3.6.4 Crushing rates

Heat losses for a given factory being almost a constant, it is evident that the lowest steam consumption can be attained if the factory runs regularly at its maximum capacity. In old factories and, in certain cases, in newly built factories, the maximum capacity is equal to that of the bottle neck station. In certain circumstances, such as one that has suffered a killing frost, it might be justified to consent to higher losses in favour of higher crushing rates.

Another factor which influences steam consumption is the fluctuation of crushing rates. In practice the main cause of such fluctuations is poor maintenance. Other causes could be lack of co-ordination between the field and the factory or bad organisation at the factory.

3.6.5 Lagging

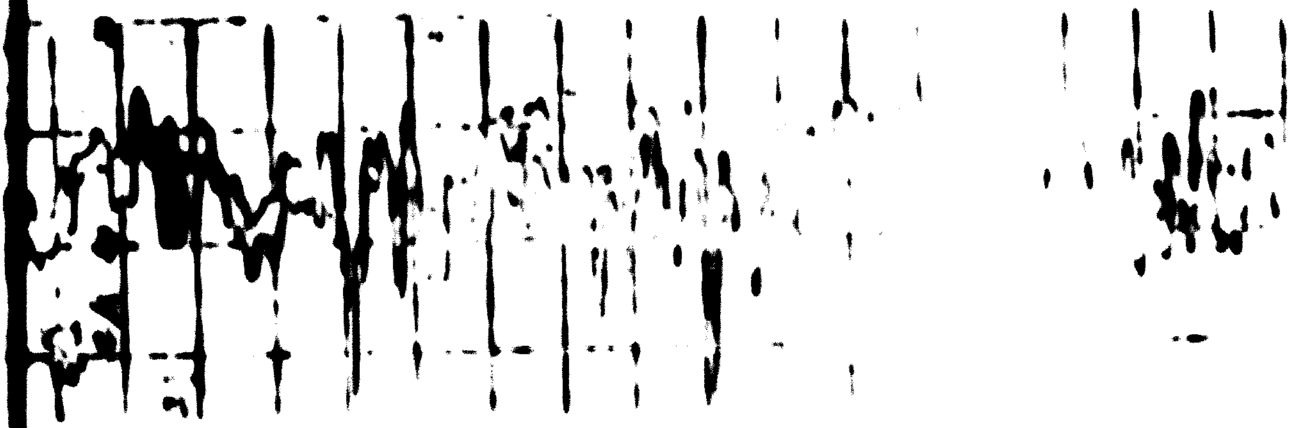
This factor is sometimes overlooked in old factories while carrying out modifications or extension works, either by using a poor insulating material or by applying the wrong thickness. For similar cases it has been found that steam savings of about 9% could be achieved by correcting the lagging specifications. For a cane sugar factory crushing 8,000 tons per day such savings would represent an economy of almost a steam boiler of 20 t/h.

2.5 Fluctuation of steam demand

The steam consumption of a sugar factory is subject to wide fluctuations due to the frequent variation of the situation at certain consumer stations. The most irregular consumer is the vacuum pan station, where the process is still a batch one and where the rate of evaporation (kg/m² h) is subject to wide variations in the course of one strike.

With sudden peak loads the steam pressure generally drops and could cause heavy carryover. If the steam boilers were not equipped with efficient steam separators, repeated carryover would result in scale deposit on the blades of the steam turbines and might even damage them.

Below is a steam flow chart of a cane sugar factory boiler showing the wide load fluctuations



In order to even out such fluctuations, regular crushing rates should be observed and the operations at the vacuum pans have to be organised in such a way that only one strike is started at a time. Investment in a steam accumulator might also be justified. In all cases steam boilers should be equipped with efficient steam separators to protect the steam turbines against the results of eventual carryover.

2.6 Boiler size and steam pressure

2.6.1 The choice of the appropriate sized boiler for a sugar factory depends mainly on the factory crushing rate. The investment cost per ton steam/h. is lower for higher unit output of the boiler. This fact, combined with the actual trend to build sugar factories of daily capacities up to 10,000 ton beet and up to 15,000 ton cane, favours the use of boilers of unit output up to 100 t./steam/h. for cane sugar factories and of higher output for beet sugar factories. However, certain limitations on the unit output of the steam boiler might arise, namely

a) Due to load fluctuations it is more advantageous to have more than one unit, per factory, running at 80 to 85% of their maximum continuous rated capacity to cover the requirements of the factory.

b) The majority of cane sugar factories, as well as a minor proportion of beet sugar factories in the world are situated in developing countries, usually quite far from the facilities available from steam boiler manufacturers. The use of boilers of large unit output might considerably reduce the crushing rate of the factory if a boiler was shut down for one reason or another.

An acceptable suggestion would be a minimum of two boilers for the smallest factory and a maximum of six boilers for the biggest one and for 80% of the rated capacity of the installed steam generating plant to be sufficient to satisfy the requirements of the factory.

In all cases it is of capital importance to feed the boilers with water of the correct quality and to maintain the boiler water to the specifications of the manufacturer since the main difficulties encountered at the steam generating plant and the power house arise from the boiler feed water quality.

2.6.2 The pressure of exhaust steam used at the evaporation station and the power to be generated by the prime movers are the two variables that decide the steam pressure at the boilers. To avoid blowing a surplus of exhaust steam over the roof of the factory, its quantity should not exceed 85% of the total process steam, the remaining 15% being obtained by throttling and desuperheating live steam.

The application of the lassivation process (commercialized as continuous diffusion) for the extraction of cane sugar would render such a target easily attainable due to the substantial reduction of exhaust steam produced at the mills without, however, increasing the loads at the power house.

Unless the sugar factory was to supply electric energy to an irrigation scheme or to sell electric energy to another consumer, steam generation at pressures higher than about 16 at. for cane sugar factories and about 35 at. for beet sugar factories would hardly be justified. It is likely that higher boiler efficiency due to steam generation at higher pressures would be offset by a higher investment cost as well as a demand for boiler feed water of a higher quality.

III. WATER AND STEAM IN SUGAR REFINERIES

The term refinery is here applied to factories handling raw and producing refined sugar. The process involves raw affination, melt clarification and decolourising and water removal to allow the sucrose to crystallize. To exhaust the decolourised liquor a six-strike system is usually adopted. The general conception of water and steam usages is fundamentally the same as that in the sugar factories with, however, certain particular differences in approach.

3.1 The main cold water consumers are the condensing plant and the steam boilers. The actual consumption of condenser cooling water is a function of the system adopted for their usage. When condenser cooling water is recycled through a cooling tower the consumption ranges between 1,3 and 1,5 m^3 per ton refined sugar. On the other hand, the requirements are influenced by the quantity of water to be evaporated at the vacuum pans, which is also variable and a function of the following conditions:

a) The Brix of the decolourised liquor;

b) The quantity of water used for run-off dilution;

c) The quantity of sugar-washing water used at the different centrifugals;

d) The efficiency of exhaustion of the massecuite at the vacuum pans, expressed as crystallised sugar % massecuite.

The condensates of a sugar refinery originate from the heaters and vacuum pans. Due to the probability of their being contaminated with sugar it would be recommendable to use the condensates as process water for sweetening-off and washing of bone char and filters as well as for melt preparation. The steam generating plant has to be fed, in such a case, with filtered and softened or de-ionized water. The requirements of boiler feed water range from 1,4 to 1,7 m^3 per ton of refined sugar; the variation being a function of the steam consumption and the blow-down at the boilers.

3.2. Fuel for steam generation and char regeneration is the main consumable in a sugar refinery. Hence the steam consumption rates and the steam boiler efficiency reflect to a substantial extent on the refining cost. The steam consumption is governed by the same conditions influencing the condenser cooling water mentioned under para. 3.1, as well as by the daily output of the refinery and the lagging quality.

Usually a contradiction arises between the demands of the melt clarification and decolourizing plants for a low Brix, especially if the starch contents of the raw are higher than 200 p.p.m., and the demands of optimum heat economy for a high Brix. The best compromise would be to keep the Brix of the melt at 60 and to concentrate the decolourized liquor, through a triple effect evaporator, to 68 - 70 before boiling at the vacuum pans.

Steam consumption ranges from 135% refined sugar, if all factors influencing steam economy are observed, to 170% or even more if no tight control on the whole process is otherwise kept.

IV. GAS

Two different gases are used in the sugar industry as clarification agents and/or as decolourising agents, namely carbon dioxide and sulphur dioxide.

4.1 Carbon dioxide

This gas is used in connection with the carbonation process, where a certain quantity of milk of lime is added to the sugar solution and neutralised with CO_2. Fine crystels of calcium carbonate, originally having produced the quicklime and the gas, are formed and act through adsorption as clarifying agents and filter aid.

4.1.1 Carbonation is the only process used in the beet sugar industry for juice clarification, as well as in the majority of sugar refineries for melt clarificetion and partiel decolourization. The application of the carbonation process in the cane sugar industry to produce white sugar is quite limited, for the following reasons:

a) A substantiel proportion of world cane sugar is produced as raw, where a simple defecation with milk of lime is quite sufficient for juice clarification.

b) Due to technological and cost considerations, it would be more advantageous to adopt e sulphitetion process and reboiling of B melt to produce white cane suger for local consumption.

In suger factories applying the carbonation process for juice clarification, the CO_2 is produced by the lime kiln as a result of the calcination of limestone end the combustion of the fuel used for the celcination. Hence the CO_2 available in the gas is usually in excess of the requirements of the carbonation plant. The gas from the kiln is scrubbed with cold weter to free it from unburnt fuel or duet. The choice between using liquid fuel or coke for the lime kiln has to be made in function of their respective locel prices. The CO_2 contents of the gas ranges between 30 - 36% end the ges absorption could be as high as 90% subject to the design of the carbonation tower.

4.1.2 In sugar refineries either the phosphoric acid - lime treatment or the carbonation process is used for melt clarification and partiel colour adsorption. The latter is by far the cheeper, since the only required re-agent is milk of lime. The quantity of CaO used for melt carbonation ranges from 0.6 to 1.2% on rew sugar and is mainly influenced by the filtrebility of the raw sugar melt and its sterch content.

Due to the limited requirements of CaO for the carbonation plant of a refinery, investment in a continuous lime kiln would not be justified. Purchased quicklime or eventually e small batch lime kiln would be an appropriate solution. Boiler flue gases are usually used et the carbonation station of a refinery.

The gas has to be freed from dust and fly ashes by cycloning separators and then scrubbed with cold water. Subject to the sulphur content of the fuel used at the steam generating plant, it might be necessary to scrub the gas in two successive scrubbers. In the first with cold water and in the second with a soda ash solution, continually recycled through the scrubber. A make-up of soda ash has to be added to keep a p.H of about 7.5 at the second scrubber and the ring-sealed compressor which delivers the clean gas to the saturation vessels.

Due to the low content of CO_2 in the gas ($\pm$ 9%) and the reduced alcalinity of the medium at the saturation vessels, the absorption efficiency does not exceed 45%. This explains the big volume of gas required for melt carbonation when using flue gases. The requirements amount to 160 - 180 m^3 of flue gases per ton refined sugar.

4.2 Sulphur dioxide

Sulphur dioxide is used for sugar cane juice clarification and colour reduction when producing white sulphitation sugar, while in beet sugar manufacturing it is only used in very small amounts as a colour inhibitor when applied to the clear juice before evaporation. Sulphur dioxide is not used in the process of sugar refining.

4.2.1 In white sulphitation cane sugar manufacturing several variations of SO_2 usage are in application, mainly:

a) Presulphitation of the cold mixed juice to p.H. 3.5 - 4.0, followed by simultaneous liming and sulphitation.

b) Simultaneous liming and sulphitation of the mixed juice at 72 - 75°C to p.h. $\pm$ 7.5.

c) Thick juice sulphitation to p.H. 5.8 - 5.9.

For continuous juice presulphitation and thick juice sulphitation, the juice and the gas are introduced, in counter-current, into an absorption tower where the retention time of the juice is adjustable. On the other hand, simultaneous liming and sulphitation are carried out in a tower equipped with a recycling pump to avoid local high alcalinity. The retention time of the juice is adjustable through a telescopic tube.

4.2.2 The SO_2 consumption is influenced to some extent by the conditions of temperature and final p.H., but to a greater extent by the quantity of lime to be neutralized and the efficiency of absorption which is subject to variation in function of the design of the sulphitation tower. If the SO_2 gas was generated at the factory, the consumption would also be influenced by the fluctuation of crushing rates, since the quantity of sulphur to be burnt per hour is preset for a certain crushing rate. At crushing rates below the preset value, a certain volume of gas has to be blown to the atmosphere.

Expressed as elemental sulphur, the consumption in sulphitation white sugar factories ranges between 550 and 700 Gr. per ton cane, whilst when used as a colour inhibitor in the beet sugar industry the consumption, expressed as sulphur, is limited to 15 - 20 Gr. per ton beet.

4.2.3 Sulphur dioxide used in sugar manufacturing could be either purchased by the factory as liquid SO_2 or generated at the sugar factory.

Due to the very limited requirements of a beet sugar factory applying thin juice sulphitation, the generation of the gas at the factory would not be justified even for the big units, and liquid SO_2 is usually used unless it has to be transported over a considerable distance.

When SO_2 is used in cane sugar manufacturing, however, the picture is quite different, and in most cases the gas has to be generated at the factory for the following reasons:

a) The consumption is considerable (1 to 1.4 Kg. SO_2/ton cane).

b) Heavy transport costs would be incurred if liquid SO_2 was used, since most cane factories are situated far from industrial centers where liquid SO_2 is eventually produced.

c) Many cane-growing countries do not produce liquid SO_2.

If liquid SO_2 was produced in the country, the choice between using liquid SO_2 or generating it at the factory has to be established on a cost basis, taking into account the following factors in favour of liquid SO_2 usage:

a) Better p.H. control;

b) Air polution is reduced to a minimum;

c) Saving of the investment and maintenance cost of the sulphur generating station.

4.2.4 The sulphur used for SO_2 generation should be arsenic-free and its ash and bituminous substances content should not exceed 0.1% for each. Usually the gas contains 10 - 15% SO_2.

Two different types of equipment used for SO_2 gas generation in the sugar industry could be identified:

a) The traditional suphur stove. The actual generation of this stove could operate continuously while fed with melted sulphur. With sulphur of high ash content the stove has to be shut down from time to time to remove the ashes. The air supplied to the furnace should be dry to avoid the formation of sulphuric acid. When quicklime is used as a drying agent, appropriate air filter should be used at the suction side of the compressor. The use of silicagel could be a more reliable solution. The cooled gas has to be freed from sublimed sulphur through a column packed with big size gravel. A stove of this type of 3 m^2 burning surface could produce sufficient SO_2 gas to cover the requirement of 100 ton cane/h. and a stand-by unit would usually be recommended if the factory was running a non-stop crushing season.

b) The continuous type sulphur furnace, where melted sulphur is injected by a pump through a burner into the combustion stationary chamber. A primary air compressor supplies air to atomize the melted sulphur and a secondary air comprssor supplies the furnace with its air requirements.

The gas leaving the furnace at $\pm$ 750°C is quenched and further scrubbed with cold water. The unit capacity ranges from 180 to 360 Kg. sulphur/h. The gas at the outlet of the scrubber being wet, the pipelines and valves between the cooler and the sulphitation tower should be made of corrosion-proof material.

If appropriate construction material is used all over the station, such a type could operate trouble-free and would be indicated for crushing rates of more than 300 ton cane/hour. However, the investment cost is fairly high.

4.2.5 Although cane juice sulphitation is the cheapest process to produce white cane sugar, certain problems are associated with its usage:

a) Heavier scale deposit on the heating surface of heaters and evaporators.

b) Corrosion of the condensers and the pipelines between the condenser and the evaporation and vacuum pans.

c) Condensates of the 2nd effect could be acidic if the p.H. of the clear thin juice drops below 6.5.

d) Inversion at the vacuum pans might occur if the p.H. of the sulphured thick juice drops below 5.8.

V. ELECTRIC ENERGY

Electric energy generated at a sugar factory could be considered as a by-product of the usage of large quantities of process steam of low pressure. The requirements of process steam could allow for the generation of a surplus of power. However, if the factory was not selling electric energy to an external consumer it would be recommendable for the exhaust steam from the prime movers not to exceed 85% of the requirements. Such a measure would avoid the loss of exhaust steam due to fluctuations of process demand which is quite common in the sugar industry.

5.1 Electric energy requirements of a sugar factory of a given capacity depend mainly on two factors:

a) The extent of mechanization of the process.

b) The power consumption of steam-driven units.

As far as (a) is concerned, the actual trend for extensive mechanization is justified even in developing countries. In fact full process mechanization secures more efficient process control and provides a solution for reduction to a minimum of the problem of seasonal labour in the sugar industry. Furthermore, the regular increase in the cost of living and the unavoidable increase in labour costs would in the long run also favourise mechanization.

As concerns (b), electrification of big power consuming units, such as the mills for example, is not justified from the viewpoint of heat economy, since it involves the double transformation of energy. This explains the general tendency to power the mills with steam engines in former days, and with individual steam turbines during the last 25 years. On the same principle it would also be more advantageous to power large consumers, such as shredders, big cane knives, big compressors and feed water pumps with steam turbine drives. However, in old factories the electrification of smaller steam drives and consumers, located far from the live steam and exhaust headers, such as dry-vacuum pumps and molasses heaters, would be advantageous from the viewpoint of avoiding lengthy pipings and heat losses due to leakage, condensation and bunging.

5.2 If exceptional cases of electrically-driven mills are excluded, the electric energy requirements of a highly mechanised sugar factory range between 13 and 15 KW per ton cane/hour, whilst they range between 26 and 30 KW per ton beet/hour.

Even if cheap electric power was available from an external source, it would be much more economical for a sugar factory to generate its own energy since, in all cases, a considerable quantity of process steam is required.

The question which might arise is the necessity of installing a stand-by turbo-alternator set. In this respect a distinction has to be made between two cases:

a) The availability of an external source of energy to which the power-house of the factory could be connected.

b) The absence of such a source.

In the former case, (a), a stand-by set would not be necessary. For factories of daily crushing rates higher than 4,000 tons it would be safer to have more than one set and to size the purchased power stand-by to meet 30 to 40% of the factory requirements.

In the latter case, (b), one of two solutions could be adopted: either to instal a stand-by set or to instal more than one set sized in such a way that if one was to be shut down, the other set or sets could take 60 to 70% of the load at the full crushing rate.

It is true that accidents resulting in the loss of the factory's generated energy are quite rare. However, the absence of stand-by in case of a serious accident might mean the loss of a whole crop.

Usually, where no external source of energy is available, the factory has to be equipped with a Diesel generating set to cover the energy requirements during the off-season. The main consumers during the off-season are the workshops and the factory village.

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