Energy and the environment in beet sugar production

by Arne Sloth Jensen and Bernard Morin
Abstract

The beet sugar industry has improved its energy efficiency over the last 50 years, from using 250–300 kWh fuel per tonne of beet to 170 kWh for a good factory excluding pulp drying. This has been achieved through integration of the processes and good energy management, though without involving the pulp drying. Drum drying of the pulp requires 98 kWh/t beet. Therefore, the resulting total is 268 kWh/t.

In order to reduce the energy use it is useful to divide the different processes in the factory into energy “users” and energy “transformers”. The juice evaporator train is a “transformer”. When designed correctly all ingoing energy will leave the evaporator to be used elsewhere. Drum drying of pulp and the sugar house are “users”, as most energy supplied cannot be recovered. To save energy requires attention to the “users”, and the “transformers” shall be adapted to fit into the system, so they are only transformers. Examples of this are given. In doing so, it is possible to come down to approximately 140–150 kWh supplied energy as fuel. This includes making sugar into white sugar, molasses with a purity of around 60%, and drying all the beet pulp.

Energy saving offers reduced CO2 emission. Half of all the VOC (volatile organic compounds) leaving a sugar factory comes from the drum drying of pulp. Steam drying, however, produces no VOC and no dust emission to the atmosphere at all.
1 Energy “users” and “transformers”

Sugar production can be divided into individual stages, where those processes can be classified as an energy “user” or an energy “transformer”. For energy saving the “users” consumption shall be reduced to the extent possible or the process shall be changed to a “transformer”. The “transformers” shall be optimized, so that they really are “transformers” with a minimum of energy loss. This shall be the basis for energy saving and the set-up of computer model to get the best result.

Examples of “users” and “transformers” are shown in Table 1.

Some comments regarding what can be done to improve the various steps are also provided.

Sugar beet extraction requires heat energy, which is normally supplied by the evaporation plant. To minimise this energy requirement the temperature of the juice leaving the extraction plant needs to be as low as possible, since an increase in juice temperature is equal to a higher energy consumption in extraction. The available extraction technologies differ in efficiency in this respect. Careful operation is of importance. The DDS slope extractor is, in regard to energy consumption, one of the best extraction plants.

Juice heating up to about 92 °C is a “user”. The heating shall be done to the largest extent possible without use of bleed vapors of the evaporation station. Each tonne of steam taken from the evaporation means that about one tonne additional steam has to be produced by the boilers. The hot condensate from the evaporation plant and low pressure steam should be used for the juice heating. However, some bled vapor is needed for juice heating. Above 92 °C the heating is performed stepwise with bleed vapors from the evaporators, but this use is generally balanced by the flash steam from juice and condensate. A figure of this process is shown in Figure 1.

Evaporating crystallization is the largest energy “user”. Ways to reduce the energy consumption here are:

– High dry substance content (e.g. 78%) of the standard liquor for crystallization of white sugar. This is particularly common in France, where even 80% DS content is used in some cases.
– Use of 70% DS content syrup and little or no water for washing in the centrifuges. As less sugar is dissolved the load on the next evaporating crystallization stage is reduced. Furthermore, the sugar will leave the centrifuges drier, so there is an energy saving in the sugar drying.

### Table 1: Process steps divided in

<table>
<thead>
<tr>
<th>Energy “users”</th>
<th>Energy “transformers”:</th>
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<tbody>
<tr>
<td>– Extraction</td>
<td>– Boilers</td>
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<tr>
<td>– Juice heating</td>
<td>– Steam turbines</td>
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<tr>
<td>– Evaporating crystallization</td>
<td>– Juice evaporation</td>
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<tr>
<td>– Sugar drying</td>
<td>– Steam drying of pulp</td>
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<tr>
<td>– Power users</td>
<td></td>
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<tr>
<td>– Drum drying of pulp</td>
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![Fig. 1: Juice heating](image-url)
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- Two effect evaporating crystallization using crystallization vapors to heat an evaporating crystallizer.
- Continuous evaporating crystallization.

In order to avoid fine crystals in the high DS standard juice the C sugar and the part of B sugar are dissolved in juice of the 4th effect, as shown on Figure 2. Furthermore it is important that the buffer tank for standard liquor is designed with no dead corners and systematic plug flow.

Evaporation shall be an energy “transformer”. A possible loss to the condenser could be called “potential for saving”. The last step is for reasons of process control, but the transfer of energy in this shall be minimised, so it is almost only a flash tank.

To reduce the condenser loss of the evaporation plant, there are the well-known ways such as:

1. to bleed vapor for the users as far down in the line of evaporators as possible. To accomplish this an artificial pressure drop between the last 2 effects can be performed.
2. Increase the number of effects.
3. Recompression over one or two effects by thermo-compressors. This has a negative effect on the power production, and requires nearly the same heating area as proposal 2.

Electrical power. Reduction of its use will become more important in the future. If it cannot be supplied from outside, a high power demand can be a hindrance to fuel savings. How much power can be produced in case of a normal set up and in case of steam drying will be shown later.

Power consumption of factories varies considerably:
17 kWh\(_e\)/t beet Stege Sugar factory, Denmark 1989, including steam drying.
20 kWh\(_e\)/t beet Lesaffre Frères SA, Nangis, France, including steam drying.
25 kWh\(_e\)/t beet Common in Germany.
30 kWh\(_e\)/t beet High.

Drum drying of the beet pulp is a large “user” of energy consuming typically 98 kWh/t beet. The drum drier also pollutes the atmosphere with VOC. Its smell can be detected 20 km away and is usually half of the VOC emission from the factory. The dust emission is also large and almost impossible to bring down to under the limits for dust emission. This energy “user” should be changed into
a “transformer” in the form of a steam drier. That gives full energy recovery; even the electrical power consumed by the main motor will be recovered as heating steam for the evaporators. Therefore, it is theoretically possible to save more than 100% of the fuel used by drum drying. The only loss is the heat loss from the pressure vessel insulation, which is negligible.

The traditional set-up for a sugar factory with drum drying of the pulp is shown in Figure 3. In the chosen example, the fuel consumption of the sugar factory amounts to 204 kWh/t beet for sugar production and 98 kWh/t beet for pulp drying, which gives a total of 302 kWh/t beet. The factory produces 25 kWhel/t beet power needed for its own use. It could have produced more and supplied the surplus to the public grid, but in most countries this, taking the fuel costs and other costs into consideration, is not economically viable.

Steam drying of the pulp in the same factory will save all the fuel used by drum drying and the power used by the drier will be recovered as well, as shown in Figure 4. In one step the fuel consumption is reduced from 302 to 204 kWh/t beet. If the hot condensate from the evaporator, where the steam drier vapors are condensed, is cooled down to 0 °C, there could even be a...
reduction of fuel consumption by the steam boilers, but that is not possible. If cooled down to 70 °C it is possible to recover 95 of the 98 kWh/t beet used for high temperature pulp drying. In order to simplify the calculation, 98 kWh/t beet are assumed to be recovered [1].

In the example shown in Figure 4 it is just possible to produce the power needed for the sugar factory (25 kWh_el/t beet). This is based on an isentropic efficiency of the turbine $\eta_{isen} = 0.82$ and an efficiency of gear and generator $\eta_{mec-el} = 0.95$. If the heat energy consumption of this factory is reduced, it will not be possible to produce all the needed electrical power. In order to improve the situation EnerDry A/S has introduced an economizer into the steam drier (Figs. 5 and 6).

This economizer is an additional heat exchanger placed on the top of the main heat exchanger. In this the hot condensate from the main heat exchanger is used to preheat the circulating steam in the drier. Thereby the need for supply steam is reduced, and the amount of flash steam going back to the evaporation is reduced as well. This increases the amount of steam going through the steam turbine, whereby the power production is increased. This opens the possibility for further fuel savings in the factory and production of the total power requirements at the same time. In case of a 60 bar boiler, it is possible to reduce the fuel consumption to 176 kWh/t beet and still make enough power for the factory’s usage.

Heat energy savings in the factory e.g. by use of the proposals given above and/or introducing steam drying, may result in difficulties in producing enough electrical power. Perhaps there has been an investment in reduction of steam usage in the factory without an acknowledgement that one day this will result in the need for buying power, which might either be very expensive or not possible. 1 t less steam to the evaporator reduces electrical power production by 150 kW_el when the steam is expanded from 60 bar to 3.5 bar. Saving the same amount of heat energy in case of a factory with a steam drier expanding steam from 20 bar to 3 bar will roughly result in a reduction of electrical power production of 85 kW_el.

Some factories have invested in energy savings and got into a situation, where the introduction of steam drying will cause problems to produce enough electrical power. This poses a question: Is the need to buy power from outside due to savings in the factory or due to steam drying of the pulp?
Figure 7 shows that for a factory with a 40 bar boiler and a fuel consumption of 204 kWh/t beet a power production of roughly 25 kWh_{el}/t beet is possible. If the factory has a 60 bar boiler, the factory has the possibility to reduce fuel consumption to 176 kWh/t beet and still generate the same 25 kWh_{el}/t of beet.

For production of Figure 7, the following boundary conditions have been used:

- Boiler efficiency: 88%
- Steam chest pressure of 1st effect evaporator: 3.5 bar
- Isentropic efficiency of turbine: 82%
- Losses in gear and generator: 5%
- DS content of pressed pulp: 28%
- Pellet production (without molasses): 5.3% on beet

There is no correction for losses except those given by the efficiencies, and no steam
The factory produces white sugar EU No. 1 as bulk sugar. The power production is in balance with the factory’s needs. 80% of the pulp is steam dried. The gas consumption on a weekly average has been 157 kWh/t beet or 1100 kWh/t white sugar at a sugar content of beet of only 16.2%. With a higher sugar content the consumption per tonne of white sugar could have been lower. This is probably a world record. It is, however, still possible to improve a little, perhaps to 140 kWh/t beet.

The 140 kWh/t goal may seem ambitious, but with respect to experience and historical development in fuel reduction, it is found to be realistic.

A combination of low temperature drying and steam drying can be a possibility, which would make it easier to produce enough power, as more steam can go through the turbine (Fig. 9).

The low temperature drier can be used as a pre-drier. That increases the evaporation capacity of the drier. The combination of the two driers will cost more to install, operate, and maintain than one steam drier for the full drying. The advantage by the combination is the power situation. It shall be examined if it would be better to buy the missing power, if that is possible, and only install a steam drier.
How much of the pulp can be dried in a low temperature drier depends on what the energy efficiency of the factory is. A fully-effective sugar factory does not have any “free” energy above 60 °C. All condensate heat is used for juice heating. There is no low pressure steam from the evaporator since all of this is used for juice heating in a well-balanced factory.

The vapors of evaporation crystallization end up in the condenser water at about 60 °C. This energy is available for low temperature drying. If a factory is really fine adjusted to low energy consumption there will not be much “free” energy left.

Assuming the factory’s standard liquor has 78% DS by dissolving the B and C sugar as shown in Figure 2, the sugar house receives only about 5% water on beet. In addition wash water is added in the centrifugals. This amount is relatively small, and can be reduced by washing with syrup. Some of the water entering the sugar house will leave it with the molasses (about 0.7% on beet). The remainder will leave it as low pressure steam of which a part is used for juice heating. In the end there will be less than 4% low pressure steam on beet left.

1 kg low pressure steam at 60 °C can contains 23,577 kJ/kg condensation energy. A low temperature drier needs about 47,000 kJ to evaporate 1 kg water from the pulp. Therefore, 4% low pressure steam on beet can evaporate about 2% water on beet. Between 10 and 12% water on beet have to be evaporated during pulp drying. Therefore a highly efficient sugar factory can only dry less than 20% of the pulp in a low temperature drier.

The low temperature drier can be boosted by energy from hot condensate or steam from the evaporators. The heat from hot condensate over 60 °C should be used for juice heating. If that heat is used elsewhere, it must be replaced by vapors from the evaporators. Therefore, heat taken from hot condensate or from any effect of the evaporator will result in the same thing: This heat must be supplied to the first evaporator stage as steam. 1 kg steam taken from the evaporator – never mind from which effect – will require a additional 1 kg of boiler steam.
1 kg water evaporation in a low temperature drier requires \( \frac{47,000}{23,577} = 1.99 \) kg = 2 kg of low pressure steam from the last evaporator effect. This will, however, require 2 kg more steam from the boilers, and due to losses in the boiler it will demand roughly 53,000 kJ as fuel to the boilers. This is nearly the double of the amount of fuel needed for drum drying. It will load the whole line starting with the boiler, which must have more capacity with the higher flow through.

If a factory has installed a low temperature drier, based on free available waste energy at a time when the factory was less energy-efficient, this drier can be a hindrance for future energy savings.

2 Conclusions

The following conclusions can be drawn:
– For energy saving it is useful to divide the process steps into “users” and “transformers”. The “users” shall save energy as far as possible, and the “transformers” shall be pure “transformers”.
– Drum drying of beet pulp is the most severe “user”. This should be changed into a “transformer” in the form of a steam drier.
– If the pulp is drum-dried it is not possible to lower the fuel consumption of the factory below 240 kWh fuel per t beet.
– One factory in France requires only 157 kWh fuel per t beet, including its own power production and pulp drying.
– Any saving of heat energy – in the factory or by steam drying – reduces the possibility for the production of power. The saving of energy in the factory reduces the power production considerably more than energy saving by introducing steam drying related to the amount of fuel saving.
– In order to improve the power production EnerDry has introduced an “economizer” built into the steam drier.
– If a sugar factory is extremely low in energy consumption (i.e. <170 kWh/t beet), it is difficult to make enough power and dry all pulp. It can be necessary to buy power or to install a gas turbine.
– The power situation can be improved by a combination of steam drying and low temperature drying.
– A fully optimised sugar factory has only “free” heat available for drying a small part of the pulp (20%) in a low temperature drier.
– The only way to bring the total consumption of fuel to a factory with pulp drying into the range 140–200 kWh/t beet is by introducing steam drying.

References