Influence of reduced temperatures in evaporation and crystallisation on the sugar quality and energy consumption in sugar production

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1. Introduction

Increasing energy costs in almost all economics influence worldwide in last decades all separation processes. Thus, also the sugar industry was developed with new machines as well as with improved computer technology. One of challenges in sugar fabrication is without doubt the reduction of energy consumption [Smejkal et al., 2005].

Roughly 100 years ago was a steam consumption in common German sugar factories equal to 120 kg/100 kg beets. In sixties, with first oil crisis were the factories pushed up to implement newest evaporators and a design of crystallisation became more important. However, the steam consumption overlap 50 kg/100kg beets significantly. First in last eighteens the steam usage attacked 25-30 kg [Fleischer et al., 2005].

Recently, up to date sugar factories in Germany consume not more than 20 kg steam per 100 kg beets. The most important parameters by reducing energy costs are not only spare apparatuses, among all VKT´s and plate evaporators, but also a progressive design on evaporation and crystallisation units. Under “design” could be here understood a layout of steam consumers starting at first evaporation effect and, moreover, adjustment of temperature profiles from the extraction and juice purification to the crystallisation of C-sugar.

While a reconstruction of crystallisation or evaporation unit and investment to newest machinery remains extreme high costs, an engineering design could effort almost every sugar factory. The implementation of correct and for all of tailored balance of steam consumers leads itself mostly to surprising results.

2. Aim of the presentation

The aim of this contribution is to present latest news in design of evaporation and crystallisation units. In particular, a beet sugar factory with common lime juice purification, 5-effects evaporation unit equipped with falling film evaporators and 3 stage crystallisation will be presented. Based on our know-how, the improvements on steam consumer strategy and new layout of heat exchangers will be demonstrated, leading to significant decrease of steam consumption of discussed case study. A modified sugar factory layout will be introduced, presenting the benefits of chosen process design.

3. Process description of basic beet sugar factory

For the purpose of this contribution, a common beet sugar factory (basic process variant) operating in middle Europe with beet slicing capacity of 500 t/h was assumed. The industrial process data are of course confidential and thus, an anonymous average performance of up-to-date sugar factories was chosen for particular balancing. The classical juice purification with prelimer and hot liming is performed and the evaporation occurs in 5 effects, lined in a series. A 3-product crystallisation scheme was proposed. An overview of process parameters used in a balance is given in Table I.

Table I: Process simulation assumptions – basic process variant

Parameter	Basic sugar factory
Slicing capacity (t/h)	500
Draft (kg/dt Beets)	110,76
Losses in extraction (kg/dt B)	0,26
Juice purification	classical
Evaporation	5-effects
Evaporation apparatus	falling film
Crystallisation	3-product scheme
Crystallisation apparatus	Horizontal, stirred
Purity of molasses (%)	60
Sucrose content in beets (%)	17,65

Classical juice purification is assumed and the process data are summarised in Table II.

Table II: Process simulation assumptions – juice purification

Parameter	Value
Preliming temperature (°C)	55
Main liming (°C)	83
1. Carbonation temperature (°C)	83
1. Carbonation temperature (°C)	93
Thin juice dry substance (%)	16,92
Thin juice sugar content (%)	15,77

Detailed scheme of the process flow diagram is given in Figure 1 a, b and c.

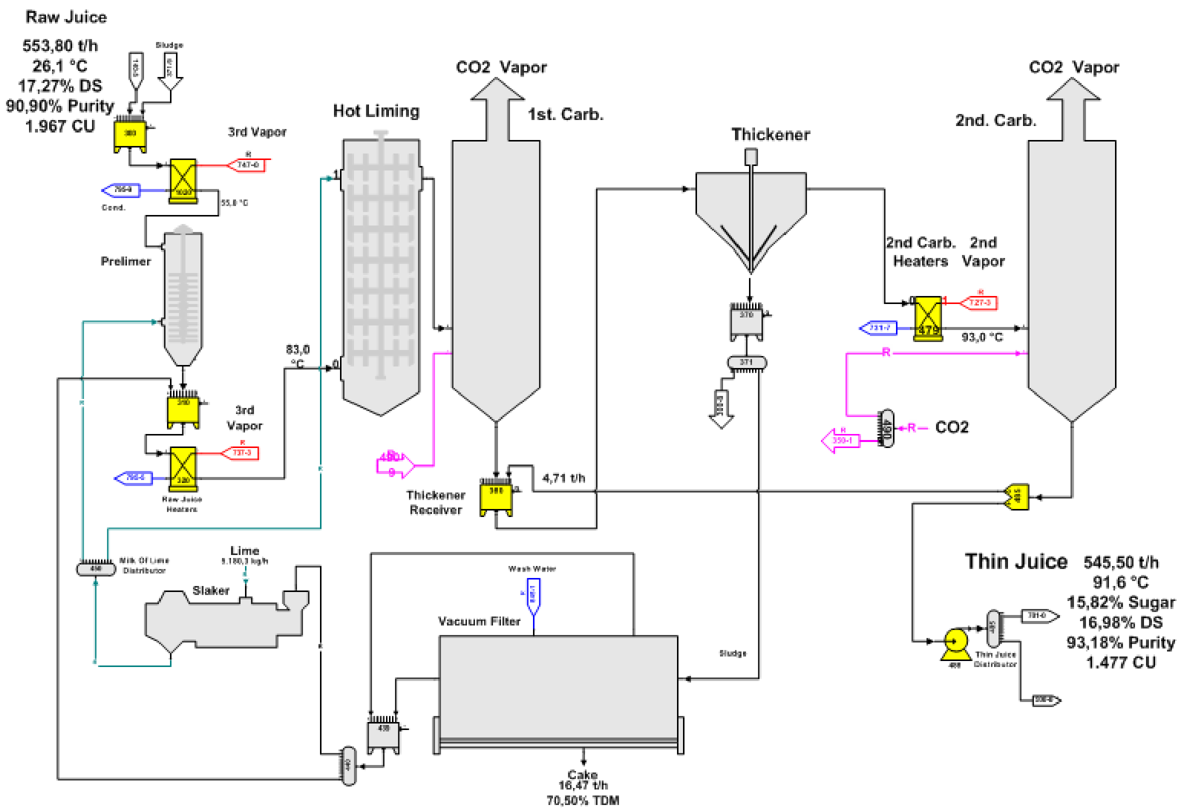

Figure 1a: Flow diagram of juice purification in basic process variant

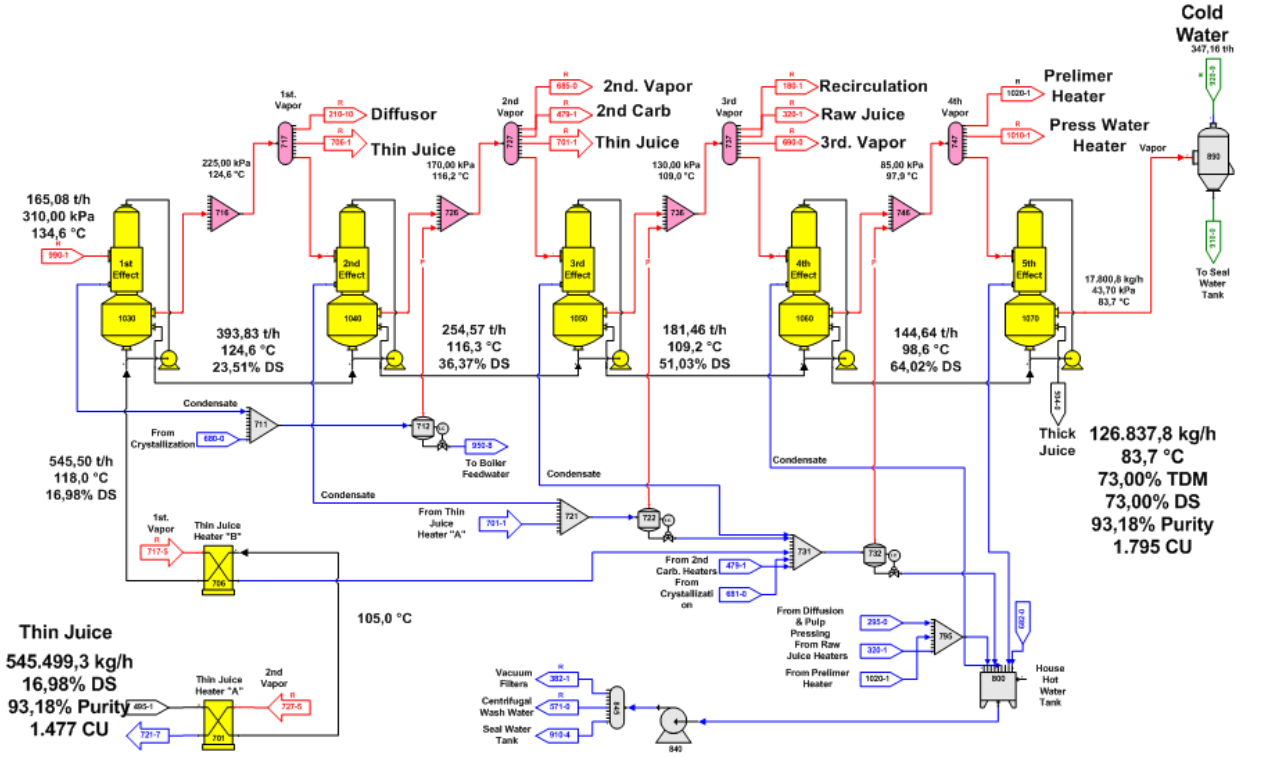

Figure 1b: Flow diagram of evaporation unit in basic process variant

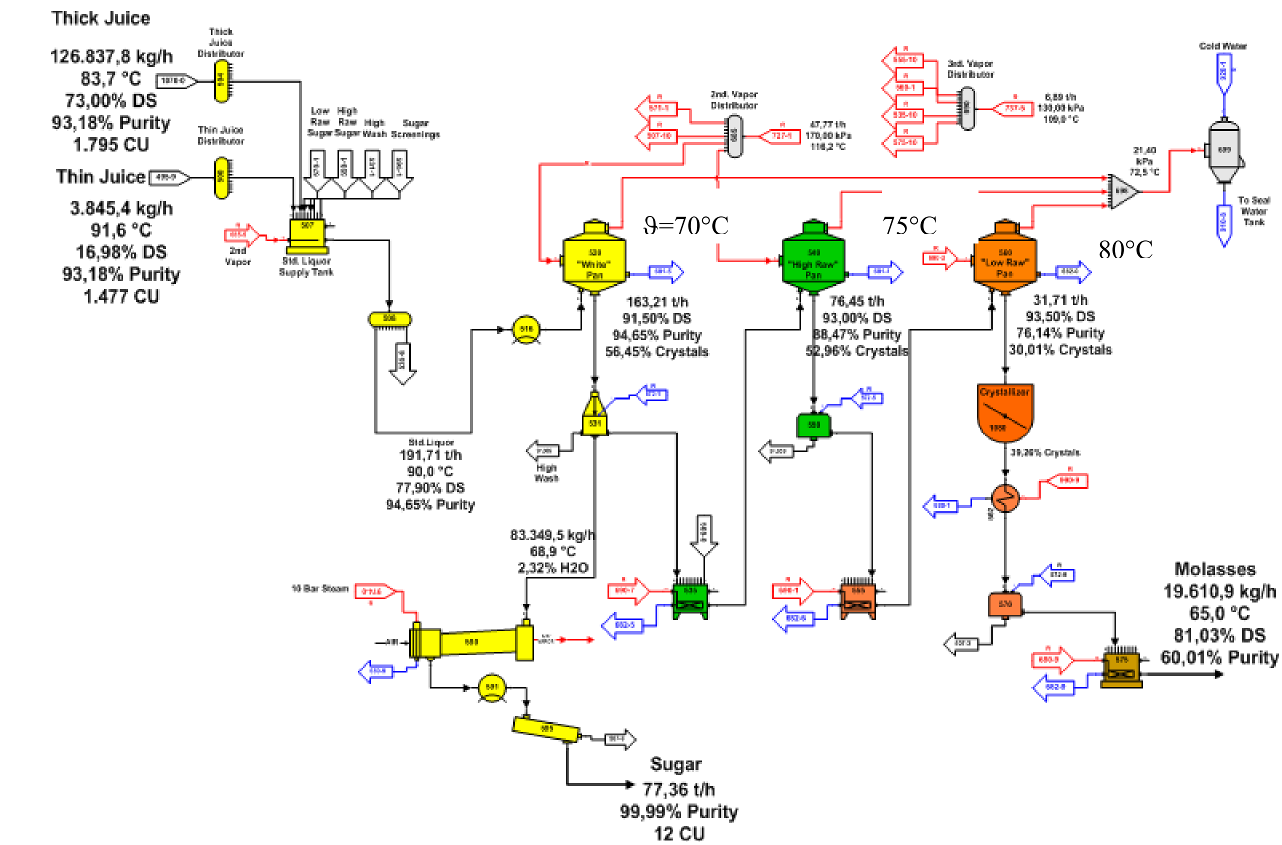

Figure 1c: Flow diagram of crystallisation in basic process variant

Falling film evaporators and horizontal, stirred crystallisers are assumed. Using special design tools, the performance of this sugar factory will be studied. Achieved results are the subject of first part of following overview.

4. Results and discussion

Already presented basic process variant of a common beet sugar factory will be balanced and the results will be discussed. Later on, the consumptions of steam as well as other aspects of sugar production will be withdrawn and presented.

In the second part of the paper, the design measures for the improvement of the function of some parts of standard (basic) sugar factory will be applied. Achieved results will be discussed with respect to stream consumption and heat-exchange efficiency of modified process variant, i.e. of modified sugar factory.

4.1 Process results of basic process variant

Beet sugar factory presented in Chapter 3 with slicing capacity of 500 t/h beet consumes for the white sugar production 33 kg/h steam/100 kg beet. This value is given by simple heat recovery of vapour from 1st evaporation effect. The vapours from 2nd – 4th vapour were used for juice pre-heating and first of all for crystallisation. The vapour from the last evaporation effect was fed into the condensation system.

The detailed balance of the evaporation unit in the basic process variant is given in detail in Table III.

Table III: Evaporation unit of basic process variant

Evaporator	1. effect	2. effect	3. effect	4. effect	5. effect
Steam temp. (°C)	134,6	124,6	116,2	109	97,9
Steam pressure (bar)	3,1	2,25	1,70	1,3	0,85
Vapour temp. (°C)	124,6	116,2	109	97,9	83,7
Steam pressure (bar)	2,25	1,70	1,30	0,85	0,44
Juice temp. in (°C)	118,0	124,6	116,3	109,2	98,6
Juice temp. out (°C)	124,6	116,3	109,2	98,6	83,7
Dry substance of juice-out (%)	23,51	36,37	51,03	64,02	73
Overall temperature difference (K)	10,0	8,4	7,2	11,1	14,2
k-value ($W/m^2 \cdot K$)	2411	2075	1568	1015	707
Heat exchange area (m^2)	4000	5000	5000	3000	2000
Sum of heat exchange area(m^2)			**19000**		

For pre-heating and evaporation of the juice, a heat exchange surface area of 1200 m^2 is required.

The results from Table III are extended by Figures 1a-c and give an overall balance of studied basic process variant. An overview of the project economy is summarised in Table IV.

Table IV: Production parameters of basic process variant

Parameter	Basic sugar factory
Steam consumption (kg/dt beets)	33,0
Heat exchange area for juice preheating and purification (m^2)	1200
Evaporation heat exchange area (m^2)	19 000
A-sugar production (t/h)	77,4

4.1 Design tools applied for the reduction of energy consumption

The changes in the layout of basic sugar factory were made mostly in utilisation of vapour streams in juice pre-heating and purification. The setup of evaporation unit was slightly modified, too. The most important difference in layout of evaporation consists of connection setup with pre-evaporator and 4 evaporation effects.

The details about the process assumptions in the modified process variants and their comparison to the basic process variant is listed in Table V.

Table V: Process simulation assumptions – basic and modified process variant

Parameter	Basic sugar factory	Modified sugar factory
Slicing capacity (t/h)	500	500
Sucrose content in beets (%)	17,65	17,65
Draft (kg/dt Beets)	110,76	110,76
Losses in extraction (kg/dt B)	0,26	0,26
Juice purification	classical	classical
Evaporation	5-effects	5-effects
Evaporation apparatus	falling film	falling film
Setup of evaporators	Straight, 5 effects connected in line	Setup with pre-evaporator and 4 effects
Crystallisation	3-product scheme	3-product scheme
Crystallisation apparatus	Horizontal, stirred	Horizontal, stirred
Purity of molasses (%)	60	60

To improve the function of evaporators and to reduce the stream demand, the minimisation of temperature difference *(ΔT)* was applied. Moreover, the usage of hot water for selective pre-heating of cold raw juice was proposed.

In the modified process variant, slicing capacity, sugar production and water evaporation haven't been changed and all other process parameters remain the same for both process variants. Thus, they can be compared directly.

4.1 Modified process variant

The changes of basic process variant can be withdrawn from next Figures 2 a, b and c. In the modified process variant the same hardware for sugar production was utilised.

In **juice purification**, the heating strategy was changed. For raw juice preheating, a falling water and end condensate were used, i.e. hot water was utilised to enhance the heat balance of the system. Moreover, selective layout of vapour connections from last evaporation effects enables an improved heat-exchange in pre-limer and 2nd carbonatation.

In **evaporation**, a pre-evaporator was considered, playing an important role in efficient utilisation of the steam. The benefits of pre-evaporator setup compared to linear sentence of evaporators (in-line setup) could be summarised as follow:

- Due to lower viscosity, the evaporation in pre-evaporator is much more efficient
- Lower inlet temperature of thin juice from purification enables to use lower vapour temperature stream, from i.e. 4th effect
- According to enthalpy balance, the enthalpy stream from the pre-evaporator is higher

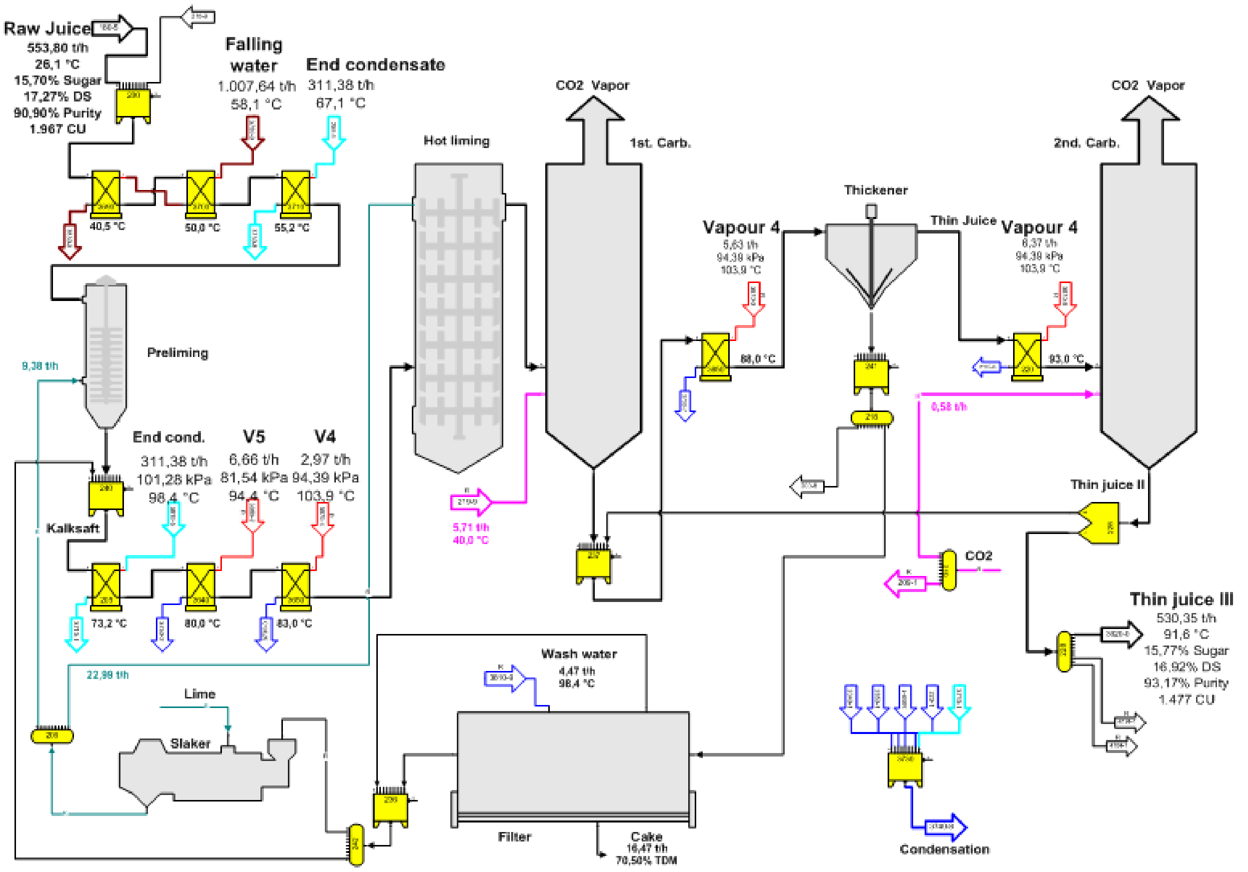

Figure 2a: Flow diagram of juice purification in modified process variant (V4,5 = vapour 4,5)

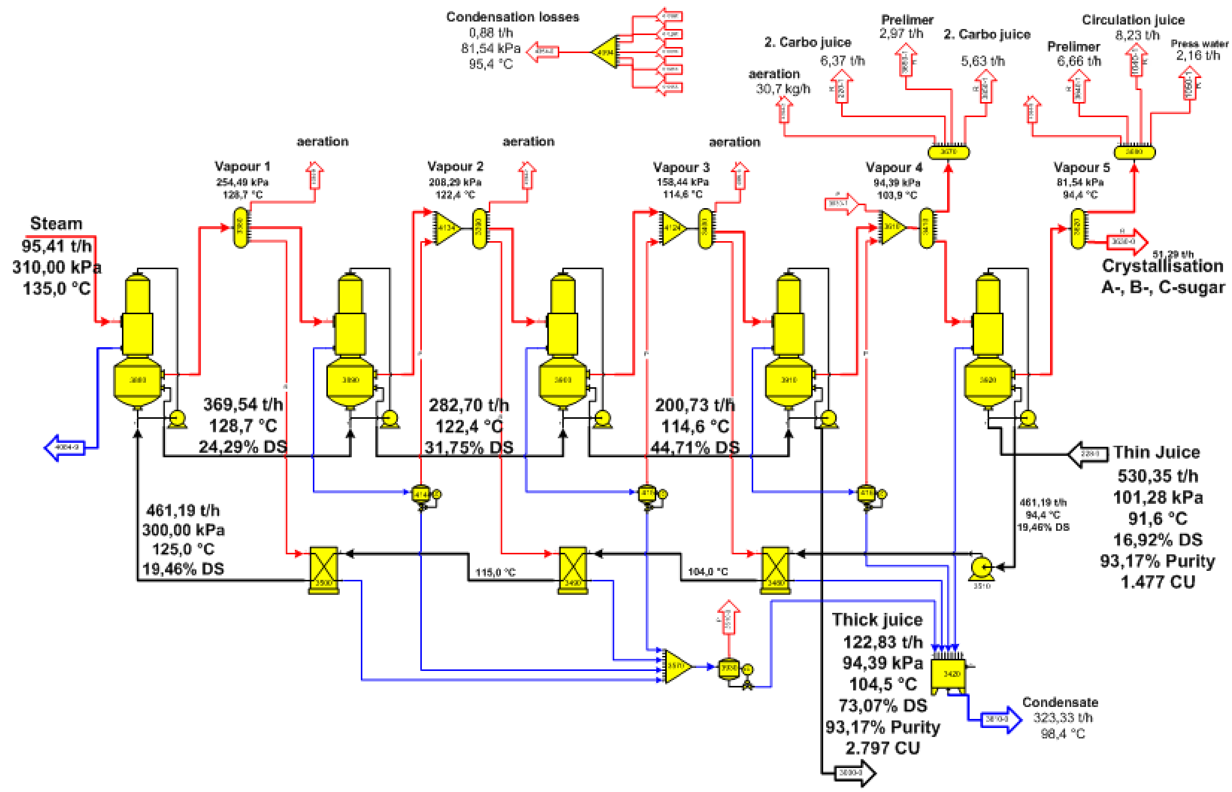

Figure 2b: Flow diagram of evaporation in modified process variant

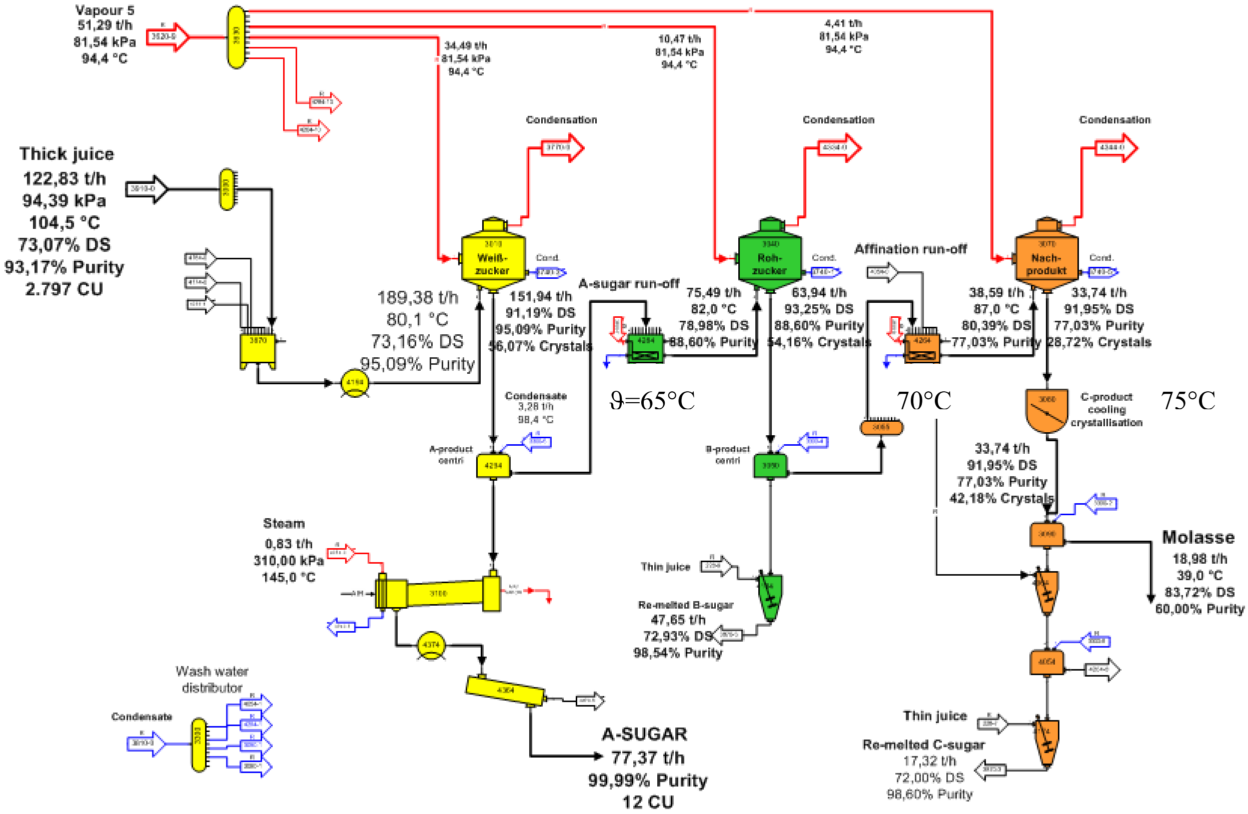

Figure 2c: Flow diagram of crystallisation in modified process variant

In addition, the vapour from first three effects are applied <u>only</u> for preheating of thin juice (after pre-evaporator) and for corresponding heating of next evaporation stage, see Figure 2b.

The vapour from 4th effect is used for juice purification and pre-heating, the vapour from pre-evaporator supplies the crystallisation.

In **crystallisation**, no changes are foreseen, only due to advanced crystallisation strategy, oriented to improved quality of sugar solutions [Smejkal et al., 2007], the crystallisation temperatures were slightly reduced and amount 65, 70 and 75 °C for A-, B- and C-crystallisation, resp., see Figure 2c. The heat exchange area for crystallisation remains the same compared to the basic process variant.

4.1 Achieved results of modified process variant

Presented <u>novel design and already described process modifications result in significantly lower stream consumption</u>. Instead of 33 kg steam, only 19,0 kg steam/100 kg beets is needed for sugar production in modified process variant. <u>That means,</u>

applying proposed process changes without any expensive hardware investments, a profit of almost 14 kg steam/100 kg beets could be achieved. That results in a spares (process benefits) of 1 700 t steam daily.

Slightly modified temperature profile in evaporation and crystallisation affects the heat exchange surface area in juice purification. Lower ΔT in juice preheating leads on one hand side to reduced steam consumption, on another should be paid by slightly extended heat exchange area. An additional separation effort of roughly 800 m^2 is required. However, this investment, if any, will be paid off very fast due to serious spares on stream consumption.

In evaporation, a novel separation strategy was foreseen, resulting in different distribution of vapour mass fluxes and moreover in modified temperature profile. The overall results of the evaporation unit in the modified process variant are presented in Table VI.

Table VI: Evaporation unit of modified process variant

Evaporator	1. effect	2. effect	3. effect	4. effect	5. effect
Steam temp. (°C)	135,0	128,7	122,4	114,6	103,9
Steam pressure (bar)	3,1	2,54	2,08	1,58	0,94
Vapour temp. (°C)	128,7	122,4	114,6	103,9	94,4
Steam pressure (bar)	2,54	2,08	1,58	0,94	0,81
Juice temp. in (°C)	125,0	128,7	122,4	114,6	91,6
Juice temp. out (°C)	128,7	122,4	114,6	104,5	94,4
Dry substance of juice-out (%)	24,29	31,75	44,71	73,07	16,92
Overall temperature difference (K)	6,3	6,3	7,8	10,7	9,5
k-value($W/m^2 \cdot K$)	2419	2220	1857	949	2389
Heat exchange area (m^2)	4000	4000	4000	6000	4000
Sum of heat exchange area (m^2)			**22000**		

Another setup of the evaporation unit enables serious reduction of the steam consumption. Due to lowering of temperature gradients and consequently by applying totally different strategy of evaporation, the heat exchange area in the modified process variant is about 3000 m^2 higher (or 13,6 %) compared to the basic process assumption.

But, taking in account the slicing capacity of 500 t/h beets and the reduction of 14 kg steam/100 kg beets in the modified process variant is the extension of required heat exchange area very simple to invest and all costs will be paid off in very short time.

The final comparison of both process variants is given in Table VII.

Table VII: Production results of basic and modified process variant

Parameter	Basic	Modified
Steam consumption (kg/dt beets)	33,0	19,0
Heat-exchanger surface area -purification (m^2)	1200	2000
Heat-exchanger surface area -evaporation (m^2)	19 000	22 000
A-sugar production (t/h)	77,4	77,4

5. Conclusions

Presented results form a peculiar base for further engineering discussion of possible energy spares (and thus, on process benefit) in a way of process design. Instead of expensive and time-intensive hardware changes and investments, an effective and robust process design tools were presented, which are applicable to almost all types of sugar fabrication.

The main idea of this contribution was to show the measures and trends in process design and intensification, improving the steam consumption of sugar production. Detailed design changes presented here can be concluded as follow:

- In juice purification and preheating, a selective utilisation of vapour from last evaporation effects was used and moreover, hot water was applied for cold raw juice preheating
- A pre-evaporator was assumed instead of in-line evaporators setup
- The steam from first 3 evaporation effects were used only for evaporation and thin juice preheating

These design measures lead to significantly reduction of steam consumption with an business benefit for 500 t/h slicing capacity of roughly 1700 t/day steam. Slightly increased heat exchange area is required in juice purification and evaporation.

Already presented design approach can be used after modification for almost every beet sugar factory, working i.e. with Robert´s evaporators.

6. Acknowledgement

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7. References

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