Comparison of syrup heating with perforated tubes or plate heat exchangers

VLP – Processing lines of food industry - Example
5/2000

1. Data for calculation

Amount of syrup	M_{S1} = 100 t
Saccharisation of syrup	S_S = 65 % (≈ sucrose content, dry matter)
Syrup heating up	from t_{S1} = 70 °C to t_{S2} = 90 °C
Specific heat of syrup	c_S = 2,95 MJ/t°C

Back-pressure steam (p_{BPS} = 350 kPa; t''_{BPS} = 139 °C) and vapours from an evaporation station (from the 3rd and 4th effects t''_{V3} = 103 °C; t''_{V4} = 90 °C) are available for the syrup heating.

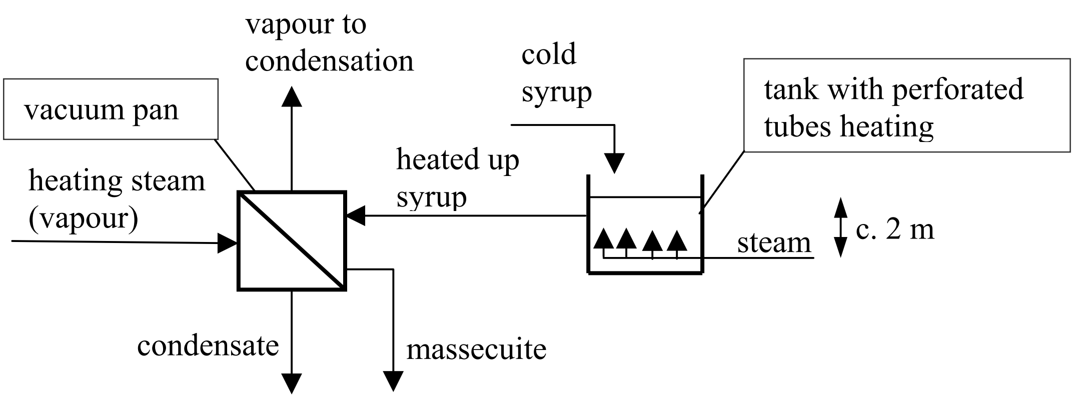
2. Heat necessary for syrup heating

By reason of our work simplification we do not take into account any heat losses.

$$Q_S = M_S * c_S * (t_{S2} - t_{S1}) = 100 * 2{,}95 * (90 - 70) = 5900 \text{ MJ}$$

3. Steam quantity necessary for syrup heating

3.1. Perforated tubes – steam flows directly into syrup



Syrup heating with perforated tubes

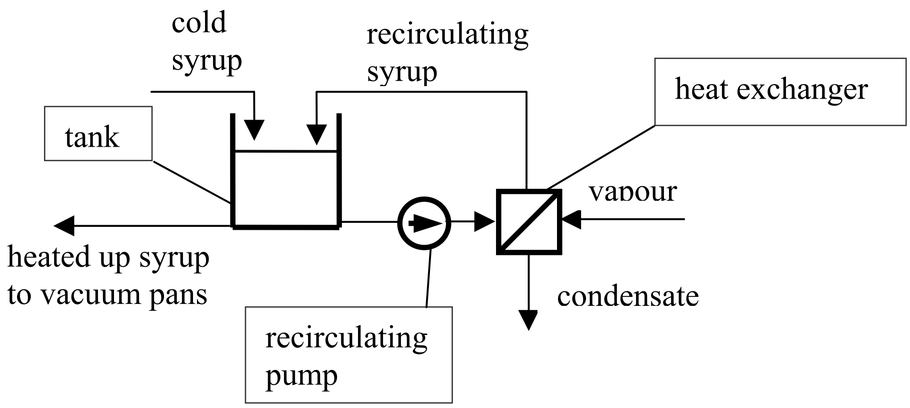
There is a direct injection of steam into the syrup (liquid level over the perforated tubes is c. 2 m) in the case. Therefore we have to use the back-pressure steam (exhaust steam from a back-pressure turbine) with pressure 350 kPa. Its latent (evaporation) heat is r_{BPS} = 2147 MJ/t. Amount of steam going to perforated tubes (steam injector) is

$$M_{SPTH} = Q_S / r_{BPS} = 5900 / 2147 = 2,75 \text{ t}$$

The steam condenses in the syrup. From it follows, that the syrup is diluted with a rising condensate. As the result of it is, that the condensate has to be evaporated in vacuum pans again. For evaporating of the condensate is, in theory, need the same amount of heating steam (vapour). It is c. 2,75 t (in reality it will be higher – different evaporating heats, heat losses). Than is a total steam and vapour consumption in the part of boiling house (we take into account only syrup heating and evaporating of excessive condensate) c.:

$$\mathbf{M_{STPTH}} = 2,75 + 2,75 = \mathbf{5,50 \text{ t/100 t of syrup}}$$

3.2. Plate heat exchanger



Heated syrup circulates through plate heat exchanger

As the plate HE is able to work (economically) with a low temperature difference (higher like 3 – 5 °C), it is not necessary to use the back-pressure steam. For such viscous solutions it is necessary to use the higher temp. difference. We assume heating with the 3rd vapour (from the 3rd evaporator effect - temperature t''_{V3} = 103 °C). Evaporation heat is r_{V3} = 2249 MJ/t (the 4th vapour temperature - c. 90 °C - is not sufficient – ev. for the syrup preheating). Amount of vapour needed for the syrup heating is than

$$M_{VPHE} = Q_S / r_{V3} = 5900 / 2249 = 2,62 \text{ t}$$

As the syrup is not diluted is the total vapour consumption in the part of the boiling house unchanged (no condensate from syrup is evaporated and a vapour (steam) consumption in the boiling house is calculated only from a balance of dry matters of thick juice, syrups, massecuite etc.). Vapour consumption in the part of the boiling house is than

M_{VTPHE} = 2,62 t/100 t of syrup

The solution benefits us a vapour (steam) saving c. 5,50 – 2,62 = 2,88 t / 100 t of syrup.

The higher 3rd vapour utilisation results in lower vapour lose in condensation, consequently in steam savings in an evaporator. An increasing of an 3rd vapour withdrawal is ΔO_3 = 2,62 t and the vapour loss in condensation is lower by $\Delta X = 3/4 * \Delta O_3$ (supposing 4th effects evaporator – see example " Simplified calculation of sugar juice evaporator and examples of its optimisation").

The result of this is, that a steam consumption of evaporator, including the new 3rd vapour withdrawal, increases only by

$\Delta M_{SEVAP} = \Delta O_3 - \Delta X = 1/4 * \Delta O_3$ = 0,66 t/100 t of syrup

4. Comparison of steam consumption in the sugar factory

The substitution of perforated tube heating by the plate HE saves following amount of steam

$\Delta M_{SSUG1} = M_{STPTH} - \Delta M_{SEVAP}$ = 5,50 – 0,66 = **4,84 t of steam / 100 t of syrup**

5. Economic analysis

Let us assume a sugar factory processing following amounts of syrups (that have to be heated up):

Syrup A	M_{SA} = 1055 t/d
Syrup B	M_{SB} = 499 t/d

(the sugar factory capacity is of 4000 t beet/d)

The substitution of perforated tube syrup heating by the plate HE brings in steam savings

$\Delta M_{SSUG} = \Delta M_{SSUG1} * (M_{SA} + M_{SB}) / 100$
ΔM_{SSUG} = 4,84 * (1055 + 499) / 100 = 75,2 t/d = **3,1 t/h of steam**

For 80 days of campaign it is

$\Delta \mathbf{M}_{SSUGC}$ = 80 * 75,2 = **6017 t of steam**

For a steam cost c. 250,- Kč/t is an annual savings (80 days of campaign)

ΔC = 6017 * 250 = 1 504 000,- Kč

Note:
We suppose only costs for fuel, without depreciation, wages, maintenance etc. It is possible to accept the method for a comparison of economy of various variants, as the costs (depreciation, wages etc.) are practically the same in one factory for the variants.

A cost of the plate HE, pumps, piping, control system etc. is c. from 500000 to 800000,- Kč. From it follows **rate of (investment) return**

RR = (500000 to 800000) Kč / (72,5 t/d * 250 Kč/t) = **28 to 44 days**

Evaporator balance when an exhaust steam is replaced with the 3rd vapour

	Plate HE	Perforated tube heating
4°	$W_4' = X' + O_4$	$W_4 = X + O_4$
3°	$W_3' = X' + O_4 + O_3 + \Delta O_3$	$W_3 = X + O_4 + O_3$
2°	$W_2' = X' + O_4 + O_3 + \Delta O_3 + O_2$	$W_2 = X + O_4 + O_3 + O_2$
1°	$W_1' = X' + O_4 + O_3 + \Delta O_3 + O_2 + O_1 \approx M_{EVAP}'$	$W_1 = X + O_4 + O_3 + O_2 + O_1 \approx M_{EVAP}$
	$M_{SSUG}' = M_{EVAP}'$	$M_{SSUG} = M_{EVAP} + M_{STPTH}$

Wi .... evaporated water in effect i
Oi .... vapour withdrawal from effect i
X ..... vapour loss to condensation
M .... amount of steam

Total amount of evaporated water for both variants is

$$W = \Sigma W_i = 4*X + 4*O_4 + 3*O_3 + 2*O_2 + O_1$$

$$W' = \Sigma W_i' = 4*X' + 4*O_4 + 3*O_3 + 3*\Delta O_3 + 2*O_2 + O_1$$

Condensation lost – vapour going from the 4th effect to condenser

$$X = (W - O_1 - 2*O_2 - 3*O_3 - 4*O_4) / 4$$

$$X' = (W - O_1 - 2*O_2 - 3*O_3 - 3*\Delta O_3 - 4*O_4) / 4 = X - 3/4 * \Delta O_3$$

Evaporator steam consumption

$$M_{EVAP}' = X' + O_4 + O_3 + \Delta O_3 + O_2 + O_1 = (X - 3/4 * \Delta O_3) + O_4 + O_3 + \Delta O_3 + O_2 + O_1$$

$$M_{EVAP}' = M_{EVAP} + 1/4 * \Delta O_3$$

Comparison of total steam consumption for both variants ($M_{BPS} \approx \Delta O_3$)

Perforated tube heating	Plate HE
$M_{Stotal} = M_{EVAP} + M_{BPS} \approx M_{EVAP} + \Delta O_3$	$M_{Stotal}' = M_{EVAP}' + 0 = M_{EVAP} + 1/4 * \Delta O_3$

Compared to back pressure steam utilisation we save ¾ O_3 (it is ¾ Q_S + effect of dilluting)

Note: For shifting of a back pressure withdrawal to a 1st vapour is

$X' = X - 1/4 * \Delta O_1$; $M_{EVAP}' = M_{EVAP} + 3/4 * \Delta O_1$; saving = $1/4 * \Delta O_1$

For shifting of a back-pressure withdrawal to a 2nd vapour is

$X' = X - 2/4 * \Delta O_2$; $M_{EVAP}' = M_{EVAP} + 2/4 * \Delta O_2$; saving = $2/4 * \Delta O_2$

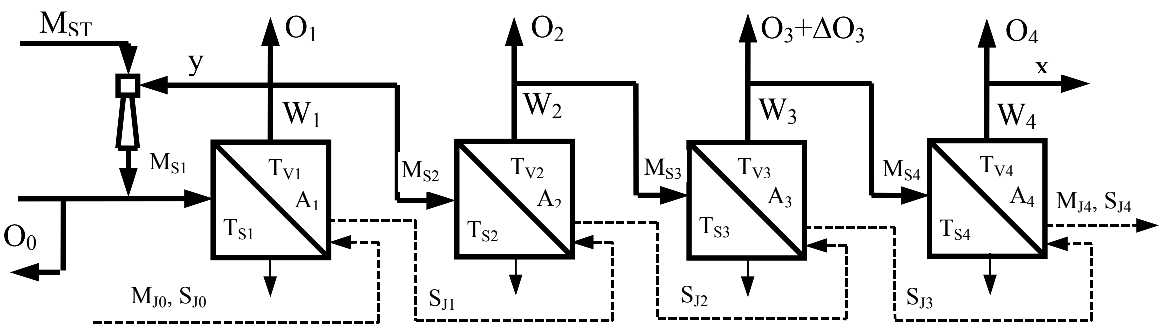
For shifting of a back-pressure withdrawal to a 3rd vapour is

$X' = X - 3/4 * \Delta O_3$; $M_{EVAP}' = M_{EVAP} + 1/4 * \Delta O_3$; saving = $3/4 * \Delta O_3$

For shifting of a back pressure withdrawal to a 4th vapour is

$X' = X - 4/4 * \Delta O_4$; $M_{EVAP}' = M_{EVAP} + 0/4 * \Delta O_4$; saving = $4/4 * \Delta O_4$

These relations are valid for a case, when a withdrawal shift results in a lower vapour loss into condensation.



Flow sheet of a 4th effect evaporator with or without a thermocompressor

steam, vapour ------------ juice ———— condensate