Economic analysis – somewhat wangled

VLP – Processing lines of food industry - Example

The example is an economic analysis of running costs of juice pasteurisation. Recommended variation is a pressure pasteurisation in packing, compared variant is a thermal pasteurisation. A pressure equipment producer performed the analysis. Calculations are reached to 1 kg of juice. A production line capacity is 10000 kg/h, working time 20 h/d. It is 200000 kg/d.

1. variant = Thermal juice pasteurisation

Heating juice to a past. temperature and re-cooling to an inlet temp.

Specific heat of a juice c_J = 3,9 kJ/kgK, juice inlet temperature t_0 = 20 °C, juice pasteurisation temperature t_P = 80 °C, juice outlet temp. t_C = 20 °C (after cooling).

Heat energy (heat) needed for heating of 1 kg of juice from 20 to 80 °C

$$Q_P = m * c_J * (t_P - t_0) = 1*3,9*(80 - 20) = 234,0 \text{ kJ/kg}$$

For re-cooling of juice from past. temperature back to 20 °C it is necessary to take off amount of heat

$$Q_C = m * c_J * (t_P - t_C) = 1*3,9*(80 - 20) = 234,0 \text{ kJ/kg}$$

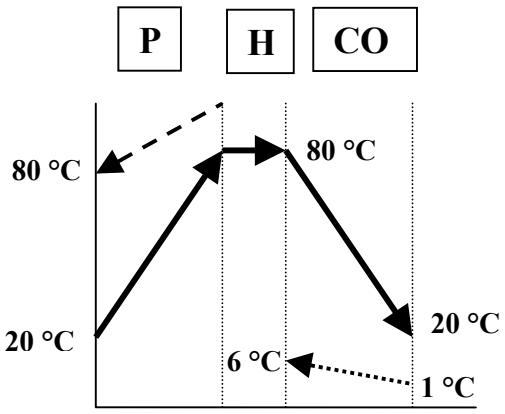
For the cooling is necessary a chilled water (c_W = 4,186 kJ/kgK), that is heated from 1 °C to 6 °C. Its amount is

$$m_{CW} = Q_C / (c_W * (t_{W1} - t_{W0})) = 234,0 / (4,186 * (6 - 1)) = 11,2 \text{ kg/kg}$$

For re-cooling of the chilled water (back from 6 to 1 °C) we need a cooling system. Its energy consumption is estimated to 10 % of total taken off heat. That is

$$Q_{CS} = 0,1 * 234,0 = 23,4 \text{ kJ/kg}$$

A course of temperatures during the pasteurisation process is in the next fig.



P – pasteurisation e.g. past. of juice with hot water

H – holding time at 80 °C

CO – cooling of juice with chilled water

juice

hot water

chilled water

Course of temperature during heating and cooling

Equipment sanitation and cleaning

The equipment is necessary to clean every day, it is 1 times per 20 h of work. Inside volume of the system is c. 1200 l, for cleaning and sanitation is necessary c. 10 times more amount of cleansers etc. (for every cleaning or sanitation operation). Cleaning and sanitation consists of following operations: Pre-rinse with a cold water, pre-rinse with a hot water (e.g. condensate 80 °C), rinse with a soda lye solution (80 °C - caustic soda – NaOH c.2 %), rinse with a hot water (80 °C) and a final rinse with a cold drinking water. Rinsing hot and drinking water are re-used for the first and second pre-rinses. Than is the total water consumption for cleaning and sanitation per 1 day:

$3*1200*10/1000 = 36\ m^3/d.$

For price of water 29,- Kč/m^3 it is $36*29 = 1044$,- Kč/d and for 1 kg of juice is the price of water for cleaning (sanitation)

$C_{WS} = 1044 / 200000 = 0{,}005$ Kč/kg

For a calculation of an energy consumption for cleansers heating it is supposed that we have to heat the 1st rinse (hot water), 2nd rinse (lye solution) and 3rd rinse (hot water). Amount of one rinsing medium related to the 1 kg of juice is

m = 12000 / 200000 = 0,06 kg/kg, or for 3 media (rinses) 3*0,06 = 0,18 kg/kg

Energy consumption for heating of 1 medium (hot water, lye, hot water) 20 °C to 80 °C is

$$Q_{W1} \approx Q_{LS} \approx Q_{W2} = m * c_W * (t_1 - t_0) = 0,06*4,186*(80 - 20) = 15,07 \text{ kJ/kg}$$

Note: We suppose that $m_{W1} = m_{LS} = m_{W2} = m$ and $c_{W1} = c_{LS} = c_{W2}$.

Energy consumption for sanitation of 1 kg of juice is

$$Q_S = Q_{W1} + Q_{LS} + Q_{W2} = 3*15,07 = 45,21 \text{ kJ/kg}$$

Filling into packing

Juice is filled into a multi-layer pasteboard box (e.g. Tetrapak - PVC, paper, AL foil, paper). A price of it is c. C_{PAC} = 4,- Kč/kg of juice.

Fixed assets depreciation – depreciation rate 10 %

A line price is c. 75 000 000,- Kč, depreciation time is 10 years and annual running time is 300 days for 20 h. Depreciation sum per 1 kg of juice is

$$C_{DEP} = 75000000/(10*300*20*10000) = 0,125 \text{ Kč/kg}$$

Costs of energy

It is supposed the price of an energy (in heat or electric energy) c_{EN} = 4,- Kč/kWh (1 kWh = 3600 kJ). Than is the cost for thermal processing of 1 kg of juice

$$C_{EN} = c_{EN} * (Q_P + Q_{CS} + Q_S) = 4,0*(243 + 23,4 + 45,21) / 3600 = 0,346 \text{ Kč/kg}$$

Total costs for thermal pasteurisation incl. packing

The total cost is a sum of prices of energy, water, depreciation and packing:

$$\mathbf{C} = C_{EN} + C_{WS} + C_{DEP} + C_{PAC} = 0{,}346 + 0{,}005 + 0{,}125 + 4{,}00 = \underline{\mathbf{4{,}476\ Kč/kg}}$$

2. variant = Pressure pasteurisation in packing

The juice is filled into PET bottles. A filling machine price is 500 000,- Kč, 1,4 l bottle price is c. 4,- Kč. A pressure chamber has volume of 150 l, diameter 400 mm and height 1200 mm. The chamber will hold 75 bottles at 1,4 l. Total juice amount in 1 batch is c. 105 kg.

Costs of energy

An energy needed for compression of 1 kg of water is determined as a performance of a piston in a cylinder, compressing a liquid with a modulus of elasticity E and density ρ (for water are $E = 2*10^9$ Pa; $\rho \approx 1000$ kg/m^3). For inactivation of funguses and yeasts is a needed pressure p = 400 MPa with holding time 10 min.):

$$E_{CE} = p^2 / (2*\rho*E) = (400*10^6)^2 / (2*1000*2*10^9) = 40000 \text{ J/kg} = 40 \text{ kJ/kg}$$

In the pressure chamber with volume 150 l is 105 kg of juice (rest is working water). Than is the energy consumption related for 1 kg of product

$$E_{CEP} = E_{CE} * V_{CHAM} / V_{PROD} \approx 40*150/105 = 57{,}1 \text{ kJ/kg}$$

For the price of electricity c_{EE} = 4,- Kč/kWh is the price of energy

$C_{EE} = c_{EE} * E_{CEP} = 4{,}00*57{,}1 / 3600 = 0{,}06$ Kč/kg

Depreciation

An isostatic press price is 20 000 000,- Kč and a filling machine price is 500 000,- Kč (it has not to be an aseptic one). Working time is 20 h/d for 300 days in year. Press lifetime is 6 years. 3 cycles are carried out in 1 hour (2 min. loading, 1 min. closing, 2 min. pressuring, 10 min. holding time, 1 min. decompression, 1 min. opening, 2 min. unloading a 1 min. reserve).

In 1 h is pasteurised 105*3 = 315 kg of juice. In 1 day is produced 315*20 = **6300 kg of juice** (**see x 200 000 kg/d for the thermal pasteurisation**). Depreciation related to 1 kg of product is

$C_{DEP} = (20\,000\,000+500\,000)/(6*300*6300) = 1{,}81$ Kč/kg

Total costs for pressure pasteurisation incl. packing

$C = C_{EE} + C_{PAC} + C_{DEP} = 0{,}06 + 4{,}00/1{,}4 + 1{,}81 =$ **4,727 Kč/kg**

Note: Service and staff costs are not taken into account, as they are practically the same for both variants.

Regarding the substantially lower production in the pressure pasteurisation the depreciation related to 1 kg of juice is substantially higher.

Realistic economic analysis of the same case

1. variant = Thermal juice treatment (pasteurisation)

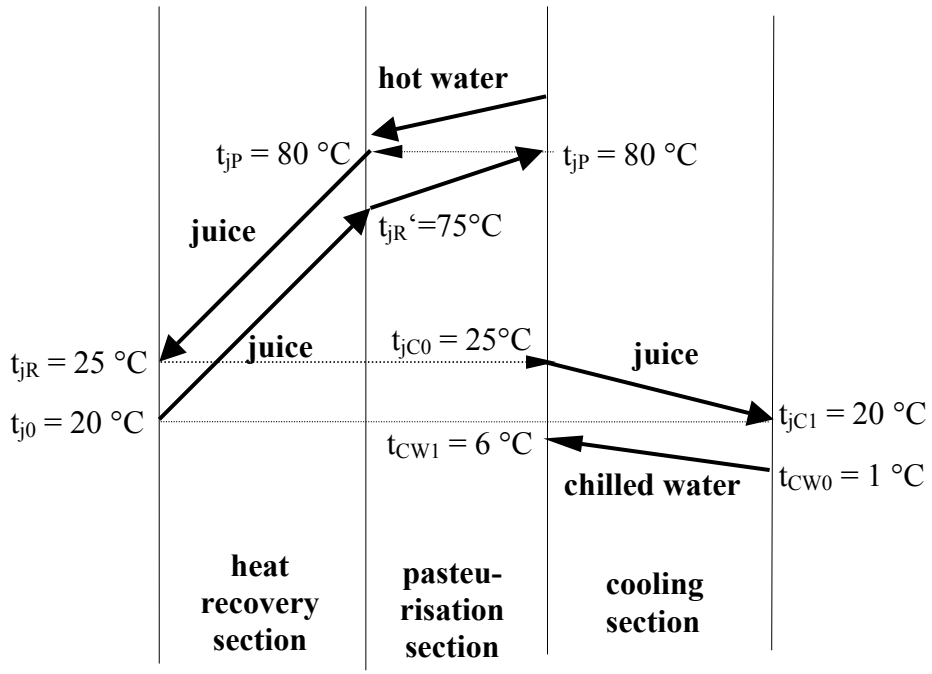
Correction of incorrect presumptions:

1) Better heat utilisation

A heat recovery is usually used for juice pasteurisation. This means that the entering cold juice is preheated by the hot pasteurised juice (that is cooled). Plate heat exchangers for juices are able to work with temperature difference c. 2 to 5 °C (between hot and cold liquids). We suppose the worse value - 5 °C. Than it is possible to cool the pasteurised juice till c. 25 °C. Entering cold juice is in the case heated to c. 75 °C. Corresponding heat recovery degree in the heater is than

$$SR = \frac{Qutilised}{Qrequired} = \frac{(80-25)}{(80-20)} * 100 = 91{,}6\%$$

A course of temperatures during the pasteurisation process for the case is in the next fig.



2) Heating with a cheap steam and not with an expensive electric energy

There is, in the first analysis, supposed the energy cost C_{EN} = 4,- Kč/kWh. But the cost corresponds to a cost of electricity. For such devices is using of an electric heating uneconomic**. So we will consider the heating of circulating hot water with a steam**. The cost of steam is

c_{S1} = 333,- Kč/GJ = 1,20 Kč/kWh.

Note:
The cost of steam produced from brown coal was in 1994 (t“ = 130 °C, p“ = 270 kPa) c. 120 – 150 Kč/t = 44 – 55 Kč/GJ (owing to coal calorific value and a boiler thermal efficiency), from natural gas c. 290 Kč/t = 110 Kč/GJ and from fuel oil c. 185 Kč/t = 70 Kč/GJ. A cost of heat from heating plants was in 1995 on an average c. 250 Kč/GJ and a cost for households regulated by government was in 1997 268 Kč/GJ. The steam cost used in the calculation is a bit exaggerated. Therefore there is a reserve in our calculation. It means, that costs for energy will be lower in reality.

Heat energy (heat) needed for heating of 1 kg of juice from 75 to 80 °C (= past. t.)

$$Q_P = 1*3,9*(80 – 75) = 19,5 \text{ kJ/kg}$$

For re-cooling of juice from temperature of 25 °C back to 20 °C it is necessary to take off amount of heat

$$Q_C = 1*3,9*(25 – 20) = 19,5 \text{ kJ/kg}$$

Amount of chilled water needed for juice cooling (1°C → 6 °C):

$$m_{CW} = 19,5 / (4,18*(6 – 1)) = 0,93 \text{ kg/kg}$$

Energy consumption for the cooling system (10 % of taken off heat like before)

$$Q_{CS} = 0,1*19,5 = 1,95 \text{ kJ/kg}$$

3) Lye solution is not poured out after every cleaning but is used about 1 week

Lye solution is used c. 1 week. in the case we can neglect a water consumption for its preparation. Therefore is the water consumption for sanitation lower by c. 0,06 kg/kg and it is

$m_{WS} = 2*0,06 = 0,12$ kg/kg or 24 m^3/d.

The cost of water is than (for pre-rinsing and rinsing with hot water):

$C_{WS} = 24*29/ 200000 = 0,0035$ Kč/kg

Energy consumption is the same as the same numbers and amounts of solutions are heated.

Corrected total costs for thermal pasteurisation

The cost of packing (box) is assumed the same like for the previous case. Depreciation is higher as there is necessary to increase heat transfer area (installation of the heat recovery section). The cost is higher by c. 30000,- Kč. The biggest share in the line cost has the aceptic filling machine. The heater / cooler incl. a stand costs for the output c. 80000.-, Kč. It means that its cost is increased c. 38 %. A depreciation increase is than (lifetime is c. 10 years):

$\Delta C_{ODP} = 30000/(10*300*20*10000) = 0,00005$ Kč/kg

This is a neglecting sum. The depreciation is practically the same for both variants.

Costs for heat energy for pasteurisation

$C_P = C_{P1} * Q_P = 333*19,5*10^3/10^9 = 0,0065$ Kč/kg

Costs for electricity for cooling system

$$C_{ECS} = C_{EE} * Q_{CS} = 4{,}00*1{,}95 / 3600 = 0{,}0022 \text{ Kč/kg}$$

Costs for heating of cleansers (using steam)

$$C_{ES} = C_{P1} * Q_S = 333*45{,}21*10^3/10^9 = 0{,}0151 \text{ Kč/kg}$$

Total costs of energy

$$C_E = C_P + C_{ECS} + C_{ES} = 0{,}0065 + 0{,}0022 + 0{,}0151 = 0{,}024 \text{ Kč/kg}$$

Total costs for the variant are

$$C = C_E + C_{PAC} + C_{DEP} + C_{WS} = 0{,}024 + 4{,}000 + 0{,}125 + 0{,}0035 = \mathbf{4{,}153 \text{ Kč/kg}}$$

From above mentioned calculations follows that for the realistic analysis is possible to reduce costs for energy and water from 0,35 Kč/kg to c. 0,03 Kč/kg. It is till only c. 9 %. Nevertheless the costs are (together with depreciation) in comparison with costs of packing and juice negligible.

Note:
In 1999 was a cost of sugar in bought sugar beet 5875 Kč/t and a factory price was 10860 Kč/t. In means that the price of raw material was c. 54 % of the factory price (a rest 46 % = other raw materials (limestone, coke, chemicals etc.), energy, wages, depreciation, profit etc.).

4) Labour costs

The costs were supposed the same for both variants. But, if we supposed only 1 worker per work-shift, the cost will not be the same owing to different line's outputs. The thermal pasteurisation line has output 200 000 kg/d, the pressure past. line has output 6300 kg/d. We suppose labour cost c. 20000.- Kč/m (incl. insurance etc.) and 3 shift in a day. Than is the labour cost per day

300 days/year / 12 month = 25 d/m 3*20000/25 = 2400,- Kč/d

Labour costs per 1 kg of product are

Thermal pasteurisation $C_L = 2400 / 200000 = 0{,}012$ Kč/kg

Pressure pasteurisation $C_L = 2400 / 6300 = 0{,}38$ Kč/kg

Different time consuming work

Thermal pasteurisation:
The line is PC controlled, the staff work is only supervision.

Pressure pasteurisation:
Manual operations with bottles (inserting into the pressure chamber or a handling basket and taking out bottles). Every 20 minutes handle with 75 bottles. It is

$20*60 / 75 * 2 = 8$ sec per bottle

From this follows that 1 worker per shift for manual handling and line control is probably insufficient. A result of it is in additional labour costs increasing.

Total costs for both variants including labour costs are for:

Thermal pasteurisation:

$C_{TT} = C + C_L = 4{,}153 + 0{,}012 =$ **4,165 Kč/kg**

Pressure pasteurisation:

$C_{TP} = C + C_L = 4{,}727 + 0{,}381 =$ **5,108 Kč/kg**

Difference between both variants for the realistic analysis:

$\Delta C_T = C_{TP} - C_{TT} = 5{,}108 - 4{,}165 =$ **0,943 Kč/kg**

Difference between both variants for the wangled analysis:

$\Delta C_T = C_{TP} - C_{TT} = 4{,}727 - 4{,}476 =$ **0,251 Kč/kg**