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Industrial Pasteurisation Process Improvement Possibilities

Dejan Macut[a], Veljko Filipan*[b]

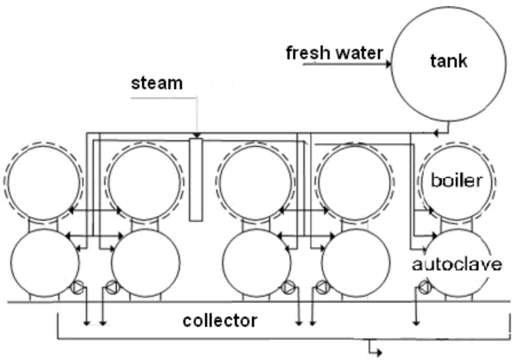
[a]University of Zagreb, Faculty of Chemical Engineering & Technology, Marulićev trg 19, HR-10000 Zagreb, Croatia
[b]University of Zagreb, Faculty of Chemical Engineering & Technology, Department of Thermodynamics, Mechanical Engineering and Energy, Savska 16, HR-10000 Zagreb, Croatia
vfilipan@fkit.hr

In this paper the possibilities of improvements of an industrial process of subsequent pasteurisation were considered in a case study of a pasteurisation plant. The current process has extremely high operating costs, and the aim is therefore to consider the improvement possibilities and savings. Firstly the process was analyzed, and then possible measurements and calculations were provided. Simple mathematical model of the process was derived and verified. Several savings potentials and some real modification of the process are discussed and the results are summarized in the paper. Technically and economically optimal modification is proposed for the realization. The economic viability calculation of proposed system was carried out. Running costs are estimated and annual fresh water savings consumption is calculated. Taking into account the investment cost of equipment the payback period of the system is estimated.

1. Introduction

The paper deals with an industrial technological process of subsequent pasteurisation. Studied plant, shown in Figure 1, consists of five autoclaves. Every autoclave is equipped with its own boiler, feeding and recirculation pumps and automatic control devices (Jedinstvo, 1994). Low pressure saturated steam is used for heating and fresh water for cooling purposes. Fresh drinking water from water supply network is accumulated in a storage tank on a higher point of the building as shown in Figure 1b.


a)



b)

Figure 1: The analyzed plant for subsequent pasteurisation in present state.

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The process starts by heating the water in the boiler to a given temperature, while at the same time autoclave is being filled with products in baskets. Doors of autoclave are closed and then the process continues automatically: hot water is released from boiler to the autoclave where it is additionally heated by the steam and mixed intensively by the recirculation pump. After expiring of the preset time, the heating program stops and cooling water is pumped into the autoclave. Along with cooling, water from autoclave is being raised into the boiler again, where it will be heated for another process. After the boiler is completely filled, outlet valve of the autoclave opens and warm water starts to flow out simultaneously and at the same flow rate as the inlet cooling water. Therefore, slow and uniformly cooling is achieved, but the consumption of fresh water is extremely high. Three different programs of pasteurisation are implemented in the plant. Programs differ in maximum temperatures and the duration of heating and cooling phases: pasteurisation temperatures range from 74 °C to 90 °C, heating phases duration is from 17 min to 30 min, and cooling phases duration varies from 37 min to 58 min.

2.Process data and modelling

Temperatures during various programs of pasteurisation were measured by multichannel temperature measuring device with two resistor probes. First probe was placed in autoclave water and a second one at autoclave outlet. Temperature of cooling water was measured by simple immersion of thermometer into the cooling water storage tank. Cooling water flow rate was estimated by measuring water level in the storage tank with previously closed fresh water supply and with only one autoclave in operation. In standard procedure only products are weighted before pasteurisation process, but in studied cases steel baskets holding the products were weighted too. Warm water quantity in autoclaves during phases of constant temperature maintenance is calculated from data of water levels in corresponding boilers.
Temperature regime during one of the studied cases of pasteurisation is shown in Figure 2. It can be seen that the period of temperature stabilisation in autoclave in the beginning phase is followed by the period of constant temperature maintenance and then by the period of cooling. Output temperature before the point of joining curves is just a result of autoclave venting. After that point, output water temperature is slightly higher than the autoclave temperature.

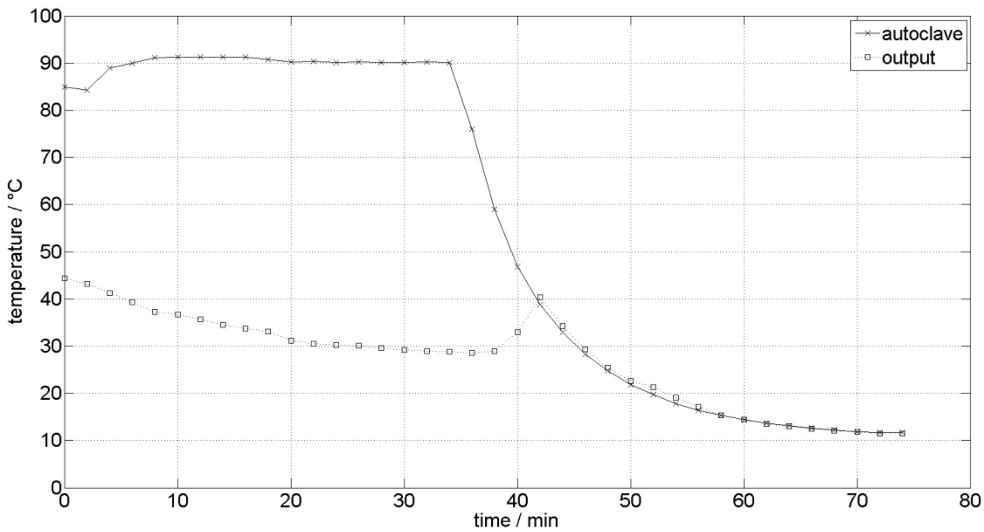

Figure 2: Temperatures vs. time diagram for water in autoclave and at its outlet.

Fresh water temperature in storage tank was measured between 10 °C and 12 °C, depending on water temperature in the supply network. Cooling water flow rate was calculated from the measured water

level variations and storage tank geometry, and it was estimated as 0,38 m^3/min. The product quantity in autoclaves varied from 500 kg to 1000 kg, and steel baskets weighted about 100 kg per basket.
Using abovementioned process data and measured values, the mathematical model of the process is developed in Matlab (Ban et al. 2010). Iterative calculation procedure is based on assumptions that temperatures of product, steel baskets, autoclave tank and water are the same in whole volume in every calculated moment and that their temperature and temperature of cooling water completely equalizes between two calculated moments. It was also assumed that in every iteration step cooling water enters into autoclave simultaneously as the water of higher temperature flows out. Using the mass and energy balance equations and necessary data from literature (Beer, 1994; Budin et al., 2002; Engineering Toolbox, 2011; Kraut, 2009; Lovrić, 2003) the equilibrium temperature achieved in autoclave is derived as:

$$T_{\text{equilibrium}} = \text{X}\, T_{\text{autoclave}} + \text{Y}\, T_{\text{cooling water}} \quad (1)$$

where $T_{\text{autoclave}}$ is autoclave temperature before entering of the cooling water and $T_{\text{cooling water}}$ is inlet cooling water temperature.
The parameters X and Y are estimated as 0,77 and 0.23 respectively.
Validity of the model was tested and comparison of measured and calculated data is shown in Figure 3. It can be seen that the modelled and experimental results are very close and therefore this model can be used for process simulation purposes.

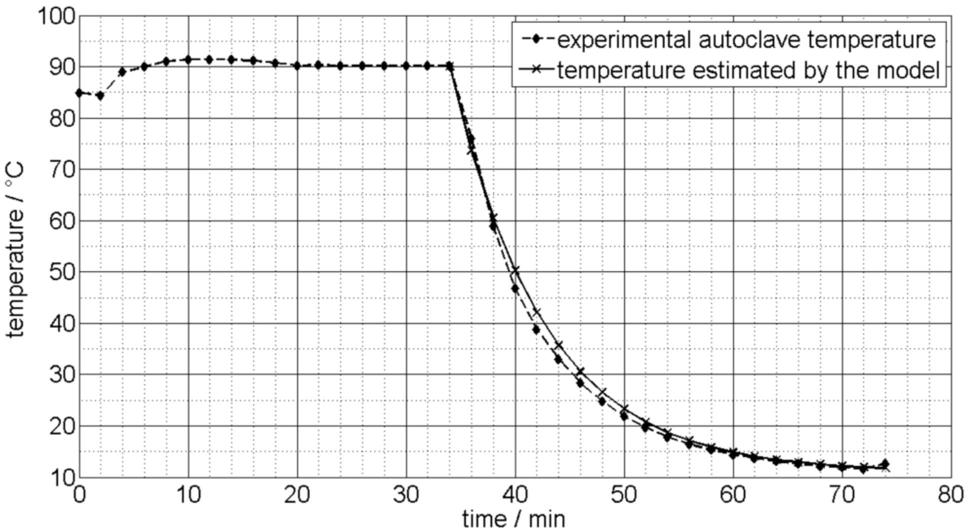

Figure 3: Comparison of measured and calculated temperatures of water in autoclave.

3.Process improvement possibilities

Current process is analyzed from the technological, economical and environmental aspects and simulations of the process are done using the developed and verified model. According to that analysis and simulation results, some modification of the process are proposed. These possible modifications are given here in short and explained where necessary.
First and the most important process modification could be to stop the cooling phase after reaching the desired product centre temperature, and not after the predetermined time interval. This is important because cooling water temperatures differ greatly by seasons and large quantity of fresh water can be saved, especially in colder seasons (Dobraš, 2011).

Another improvement possibility would be to collect the cooling water and reusing it in other processes such as washing. With that, all water quantity and waste heat could be reutilized and consequently large savings could be achieved.
Next improvement possibility could be to use the same cooling water for successive cooling of several autoclaves. This can be done by connecting the outlet of the first autoclave with the inlet of feeding pump of the second autoclave and so on. In that case the first autoclave cooling regime would be the same as it is used now, but in the second and the third autoclave cooling would be a little bit slower. However, simulation shows that appropriate cooling rate can still be achieved. Simulation results for outlet water temperatures of successive cooling of three autoclaves are shown in Figure 4. This modification results with high savings in cooling water consumption (it can be lowered up to 50 %) and also with additional heat savings (some amount of heat for the next heating process in boilers is saved). Although that improvement is connected only with relatively small investment the concept is not accepted because the remaining water consumption is still relatively high and because such mode of operation would interfere with the working dynamics.

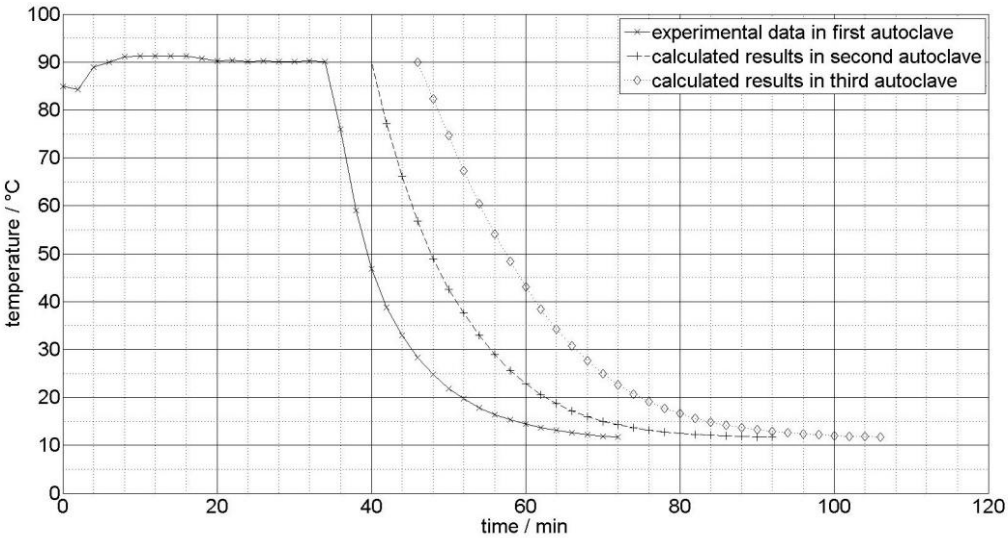

Figure 4: The simulation results for successive cooling of two and three autoclaves.

Next improvement possibility proposed for the realisation is introducing of the cooling water recirculation system. Heat from the cooling water warmed in previous process is rejected to the surrounding air by an open cooling tower with induced draft (Figure 5). In that case the temperature of cooling water in accumulation tank can be maintained at constant level in all seasons. Therefore, a heat exchanger is installed, for the purpose of additional water cooling during the periods of high surrounding air wet-bulb temperatures.
In order to estimate the quantity of heat that has to be taken by existing cooling system, and to design the proper cooling tower some assumptions have to be made. They include: inlet cooling water temperature is constant at 10 °C; there is the same quantity, volume and specific heat capacity of pasteurisation products in each program; cooling tower temperature drop is proportional to the temperature difference of inlet warm water and ambient air wet-bulb temperature; the coefficient of proportionality for chosen cooling tower is 0.67.
Temperatures of cooling water at autoclave outlet are calculated by equation (1). Cooling water output temperature from autoclaves varies significantly, as well as cooling water flow rate, which depends on number of autoclaves in cooling phases at the same moment. For that reason, cooling tower would be working in different conditions and is dimensioned by the maximum possible flow rate (the effect of smaller flow rates was neglected). Calculation is made in the spreadsheet for every month of the year according to the average monthly wet-bulb temperatures (DHMZ, 2011). After estimation of

temperature of the cooling water that leaves the cooling tower, the average temperature was calculated. This can be done because the water flows into the storage tank where its temperatures spontaneously equalize. Calculation shows that in warmer periods of the year average temperature of cooling water that leaves the cooling tower exceeds 10 °C and therefore additional cooling is needed.

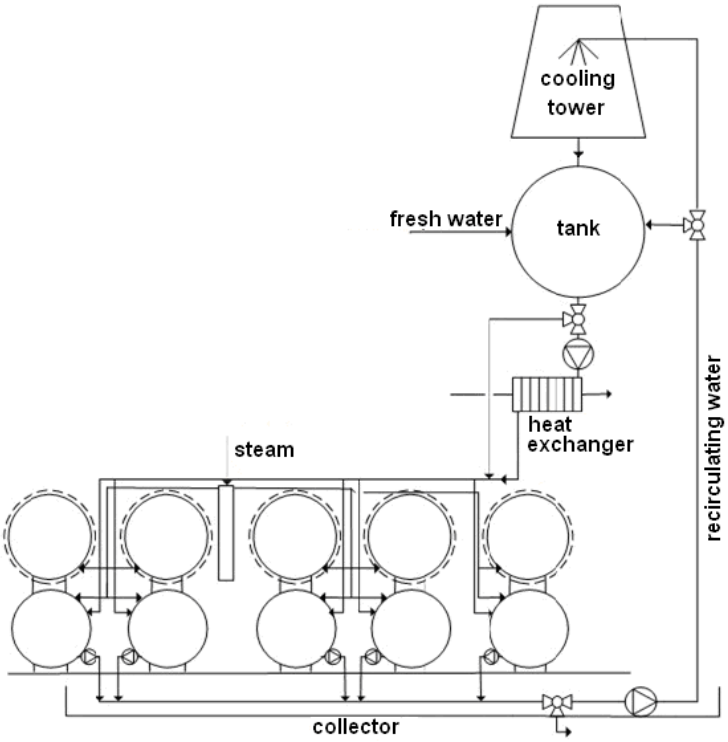

Figure 5: Scheme of the process modification proposed for the realisation.

In the economic viability calculation of the proposed system several costs have to be included. There are electrical energy costs for the existing cooling system, for the electromotor of the cooling tower fan, for the cooling tower heaters in winter conditions, and for the electromotors of the recirculation pumps. Moreover, there are costs of make-up water for recirculation system and costs of chemicals for water treatment (Dobraš, 2011; Klasiček, 2011). The estimated values of those particular operating costs are given in Table 1, and total operating costs of the recirculation system are 6,700 €/y.

Table 1: Annual operating costs of the recirculation system

Annual operating cost of proposed recirculation system	
Cost of water cooling by existing refrigeration system	4.000 €/y
Costs water of losses	530 €/y
Electrical energy costs for fan electromotor	310 €/y
Electrical energy costs for heater in winter periods	560 €/y
Electrical energy costs for pumps electromotors	500 €/y
Water treatment costs	800 €/y
Total operating cost:	6.700 €/y

Fresh water savings in comparison with current process using single-pass cooling is about 22,650 m^3/y or 40,800 €/y. With cooling tower price of 20,000 €, heat exchanger price of 5,000 € and price of pumps and pipelines with installation of 10,000 €, payback period would be around one year, which is especially cost effective.

4.Conclusion

The current process has extremely high operating costs, particularly its consumption of fresh water for cooling purposes is very high. The aim is therefore to consider the improvement possibilities of the process from the energy, economical and ecological aspects. At first, the process was analyzed and then possible measurements and calculations were provided. Simple mathematical model of the process was derived. Several savings potentials and some real modifications of the process are discussed and the results are summarized in the paper.

First and the most important improvement possibility could be to stop the cooling phase after reaching the desired product centre temperature, and not after predetermined time interval. This is important because cooling water temperatures differ greatly by seasons. The other proposed process modifications would be to collect the cooling water and reuse it in other processes such as washing. With that, all water quantity and waste heat would be reutilized and consequently highest savings would be achieved. Next improvement possibility would be using the same cooling water for successive cooling of several autoclaves. With that, small amounts of heat, but lots of cooling water would be saved with relatively small investment. Calculation results imply that successive cooling modification could lower the cooling water consumption for about 50 %. Concept is rejected because water consumption would still be relatively high and because such operation mode would interfere with working dynamics. Technical and economical optimal modification of the process, shown in Figure 5, is chosen for the realization and supported by values of potential savings and payback period. This modification is based on cooling water recirculation system where heat of warmed water would be rejected by an open cooling tower with induced draft, after which the water would flow through a heat exchanger, in order to maintain constant cooling water temperatures during periods of high wet bulb temperatures of the surrounding air. The economic viability calculation of the proposed system was carried out. Running costs, primarily the costs of electrical energy used by the system, the costs of make-up water and the costs of chemicals for water treatment are estimated, and annual savings on fresh water consumption in comparison to the current process using single-pass cooling is calculated. Taking into account the investment costs for equipment (cooling tower, heat exchanger, pumps with pipelines) the payback period of the proposed system is estimated at about one year.

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