Contemporary Engineering Sciences, Vol. 13, 2020, no. 1, 59 - 68
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2020.91455

Optimizing the Performance of the Wort Preheater with the Aim of Improving Resource Efficiency in Beer Production

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Abstract

Resource efficiency in the brewing industry involves the use of energy and water with minimal wastage and negative environmental impact. As it is often impossible to maintain the recommended parameter values in the actual operation of the plant, due to a number of disturbance factors, it is necessary to find an easy and efficient way to maintain the parameter values in the relationships that result in the least possible losses. This paper presents the use of a software simulation model for the purpose of simulating the operation of a wort preheater, with the aim of managing its operation in a real environment with maximum resource efficiency.

Keywords: resource efficiency, brewing industry, wort preheater

1 Introduction

Resource efficiency in production has arisen as one of the main requirements to achieve in modern industrial sites [1]. It represents a way to make better use of the resources used in a particular technology /production process. With the above goal in mind, there exist a bunch of approaches to quantify the performance of a production process like, for instance, the very extended one called Key Performance Indicators (KPI) [2]. These indicators are usually computed for long-time periods like months or after the production campaign is finished. So, they are not suitable to support operational decisions. This need has led to the recently developed set of the so-called Resource Efficiency Indicators (REI) [3]. The aim of these indicators is computing resource-efficiency measurements in short periods of time (even online), so they can be used for decision support to improve process operation in real time. [4]. In this paper, we aim to address the problem of resource efficiency in beer production, particularly efficiency of wort preheater. By using an offline simulation model to predict performance of the preheater in various cases, it is possible to gather data which can later be use for calculation of Resource Efficiency Indicators.

Also, efficient use of resources means minimization of potential pollution "at source", it is possible to suppress excessive pollution of natural resources: water, land and air. Therefore, resource efficiency represents a preventive action which is aimed to maximize the use of limited resources and minimize losses (waste, waste streams). Industrial plants are significant pollutants, which is also the case with beer production considered in this paper. Beer production is a significant consumer of various types of resources, the most important being water, heat and electricity. High water consumption is characteristic of this type of industry due to the high requirements for compliance with hygiene standards. Water is used in beer production for technological, energy and sanitation purposes. It is primarily used as a raw material but also for other production and non-production processes in the brewing industry. Thermal energy is used in production departments with the highest consumption in the boiling plant, but it is also used in other parts of the technological process of production, as well as in non-production segments within the entire plant.

The ways of optimizing the use of water and boiler fuel in the production of industrial steam can be collectively referred to as resource efficiency. Appropriate measures, based on constant monitoring of energy and production flows, can achieve energy savings of 10-15%. The main resources in the production of industrial steam are water and energy, which should be used efficiently. In doing so, it is necessary to ensure sufficient quantities of quality water, which is possible by applying a developed technological process that involves the preparation, maintenance and control of water quality in all segments of the water-steam cycle [5]. Systems for steam distribution and condensate recovery, together with the boiler room and final consumers, represent a system for centralized energy supply as a heat carrier. The return of the condensate from the process to the boiler room and its reuse means energy Brewery water consumption ranges from 0.32-2.0 [m^3/hl of beer], thermal energy consumption ranges from 118.7-355 [MJ/hl of beer], while electricity consumption ranges from 7-12.5 [kWh/hl of beer] [6]. Consumption of certain types of energy and water in the production of beer depends on a number of factors, and therefore the above specific consumption intervals are quite wide. Accordingly, the assessment of the justification of current energy consumption should be made at each facility [6].

2 Beer production technology

The data presented in this paper are for the Tuzla Brewery, Bosnia and Herzegovina. The Tuzla Brewery has been operating continuously since 1884, producing beer, mineral water and juices. Cooling energy consumption occurs in all key beer production processes. Technologists are constantly monitoring energy consumption and trying to reduce it per unit of product. With the measures taken, electricity consumption for the operation of ammonia refrigeration compressors can be reduced by up to 13% [7]. Energy efficiency is an important component of the plant in its environmental strategy. Electricity and heat are used in the brewing process. Thermal energy is used to produce steam in boilers, which is mainly used for boiling wit and heating water [8]. The beer industry is usually a high pollution and energy consumption industry and the polluter has a huge environmental impact. Therefore, it is necessary to reduce energy consumption and emissions in the brewing industry [9,10]. Cleaner production means production processes, the conservation of raw materials and energy, maximizing waste reduction, recycling and reuse at the enterprise level, as well as reducing the amount and toxicity of all emissions and waste before they exit the production process [9].

Any improvement in the steam distribution and condensate recovery systems has a direct effect on the heat transfer to end users and on the efficiency of the boiler and associated equipment [11]. Resource efficiency in the production of industrial steam is affected by: quality of boiler feed water, type and cycle of boiling and desalination of boilers, condensate recovery from the process, oxygen content (O_2) in flue gases, flue gas temperature, fuel temperature at the inlet to the burner, pipe insulation, valves, flanges, chimneys and other boiler equipment, etc. [11,12,13,14]. Beer production is the central plant of the factory, and includes several stages, whereas regarding consumption of resources (water and heat), the boiling plant stands out, the scheme of which is given in Figure 1. Figure 1 shows the scheme of part of the production process in the boiling plant. Attention should be paid to the heat exchangers i.e wort preheater and wort cooler, since their operation directly affects the efficient consumption of resources (energy and water). The technological process of beer production should be performed according to the standardized values of pressure, temperature and flow at appropriate points in the production cycle, in which case the best use of resources is achieved. However, in actual work, it often happens that individual parameters deviate from the normalized values. The causes of deviations are different, leading to resource losses and the need to optimize parameters to improve resource efficiency. Care should be taken that optimization of the parameters should not impair the technological process of beer production. In accordance with the above, the values of the wort and water parameters at the inlet and outlet of the preheater and cooler standardized. However, if one of them deviates other parameters should be adjusted in order to maintain maximum energy and resource efficiency of the mentioned heat exchangers. Figure 2 shows a wort preheater, whose resource efficiency will be analyzed below.

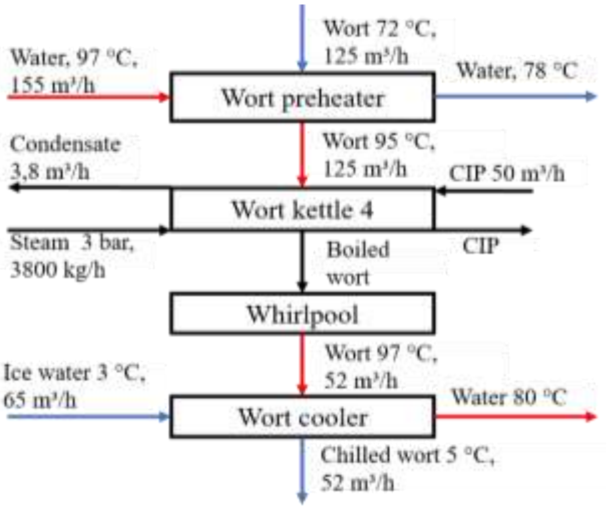

Figure 1 Scheme of the production process in the boiling plant

A simulation model was installed for the selected preheater in order to determine, to which extent and how, the deviations of the parameters of the heat transmitter and receiver (water and wort) affect the efficient use of energy and water in the production process. Based on the results of simulations of the preheater operation, the optimal values of water and wort parameters in the actual operation could be determined, in order for the exchanger to operate with maximum energy resource efficiency.

Figure 2 Wort preheater in Tuzla Brewery

There are normative setpoints for the parameters of the heat transmitter and receiver entering the preheater, as well as the deviation intervals that are "allowed" by these same standards. It has been demonstrated by experience that deviations from the norms within the recommended limits do not affect the technological process of production, but it is proved that any significant deviation of parameters from normative setpoints causes a decrease in the overall degree of efficiency of the plant. Due to all of the above, the simulation model for the selected exchanger was set up.

3 A simulation performance model of the wort preheater

GateCycle^{TM} software, is used to model the preheater performance. This software can be used for both design and performance evaluation of elements of thermal power plants. GateCycle^{TM} is a combination of a graphical user interface with detailed analytical models of thermodynamic processes in thermal power plants, as well as heat transfer and flow processes, which enables design and simulation analyzes of all levels of complexity, some of which are:

- Performance simulations of system elements for "off design" working conditions, when main design characteristics have already been set and cannot be changed (i.e. heat exchange surface of a preheater);
- Predicting the effects of proposed parameter changes on existing plant elements (i.e changing one or more operating parameters of a heat transmitter/receiver to achieve maximum resource efficiency of the heat exchanger, if for some reason one or more parameters deviate from their nominal values thereby exchanging the heat with reduced utilization);

The software model was created and verified using data from normative testing conducted for Tuzla Brewery. In case of preheater operation at the normative values of the above parameters, the heat received by the wort is calculated using the expression (1):

$$Q_s = 125 \cdot 1045 \cdot 3.98 \cdot (95 - 72) = 3321.5[kW] \tag{1}$$

while the amount of heat delivered by the water is (2):

$$Q_v = 155 \cdot 1000 \cdot 4.187 \cdot (97 - 78) = 3425.2[kW] \tag{2}$$

In the ideal case of heat transfer, the values defined by expressions (1) and (2) would be equal. In the case of realistic operating conditions, this difference is due to heat transfer losses. The degree of utilization of the exchanger is greatest when the parameters are equal to nominal, as shown by expressions (1) and (2). The quantities of heat delivered and received are determined by the expression (3):

$$Q = m \cdot \rho \cdot c_p \cdot (t_{ul} - t_{iz}) \tag{3}$$

where are: Q - amount of heat exchanged (transmitted from water to wort) [kW], c_p - specific heat capacity (water/wort) [kJ/kgK], ρ - density (water/wort) [kg/m^3], m - flow (water/wort) [m^3/h], t_{iz} - outlet temperature (water/wort) [°C], t_{ul} - inlet temperature (water/wort) [°C].

Figure 3 (L), shows a design model of a preheater and simulation model convergence, containing elements that define heat exchanger, as well as water and wort inlet/outlet parameters. Adjustment of the data in the project model was carried out until satisfactory agreement of data from the project model and normative tests was achieved. The stacking was related to the size of the heat exchange surface, the inlet/outlet water/wort temperatures, the water/wort flow as well as the convection heat transfer coefficient. Recommendations from the literature and practice state that the values of the convection heat transfer coefficients range from α = 2,000-4,000 [W/m^{2}K] [15], where the following operating conditions apply: for poor conditions α = 400 [W/m^{2}K], for normal conditions α = 1,600 [W/m^{2}K], for good conditions α = 7,000 [W/m^{2}K].

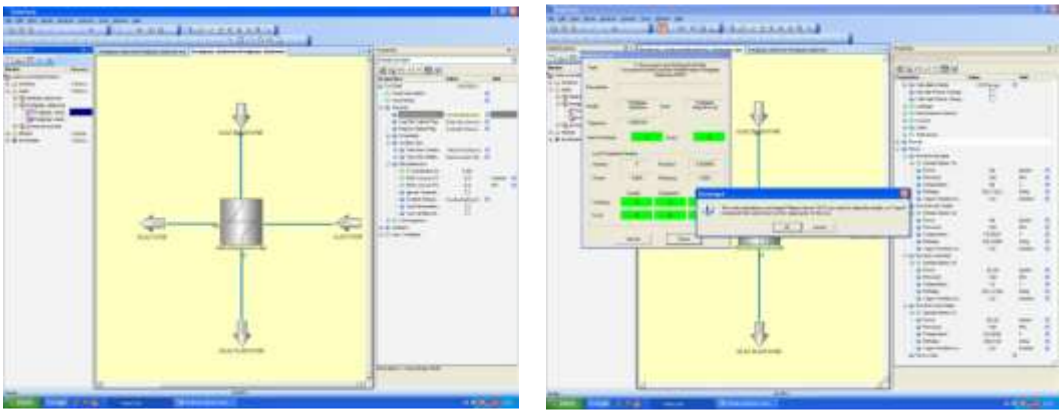

Figure 3 Design model (L) and simulation model convergence (R)

When fitting the model, the value of the convection heat transfer coefficient for normal to good conditions was adopted, taking into account the operating conditions of the heat exchanger, which include soiling, limescale etc. By comparing the values of the parameters obtained for the design model with the values of the same parameters from the normative tests, it was found that there is a mean relative deviation of up to 5%, which is satisfactory in this case. Verification and validation of the model was carried out, as well as its "locking" and switching to "off-design" mode, a simulation version in which it is not possible to change the value of the exchange surface or the convection heat transfer coefficient. However, in the simulation version of the model, it is possible to change the values of the input parameters such as temperature and water/wort flow, and monitor the resulting water/wort temperature output values accordingly.
Although the simulation model is validated with respect to the design parameters, in order to be considered useful, it is necessary to converge the simulation model after an iterative simulation process when changing any of the input parameters (temperature, water/wort flow at the inlet to the exchanger) in order for the output values of the parameters to be obtained. Figure 3 (R), shows a convergence of the simulation model.

4 Analysis of simulation results

During the actual operation of the plant, due to various disturbance factors, it is impossible to constantly maintain exactly the set values of the input parameters in the preheater, equal to the nominal values from the normative tests. Therefore, based on work experience, it is recommended that temperatures be maintained within the recommended limits. The water entering the preheater of the wort to heat it should have a temperature in the range t_{ulV} = 90-98 [°C]. According to the norm, the wort flow rate is 36.28 [kg/s] and has not been changed during the simulations. During the actual process, it is not recommended to change this parameter due to the technological process of beer production. The water at the outlet of the preheater is cooled and is recommended to be in the range of 75-85 [°C]. From the preheater, the water goes to an energy tank where it is reheated. The output temperature of the wort should be in the range t_{izlS} = 90-99 [°C], where it is recommended to keep this temperature closer to the upper limit due to the process subsequently taking place in the wort boiler. In compliance with the quality of the beer production process, the temperature of the wort at the inlet of the preheater should be in the range of 72-75 [°C]. Considering the recommended interval limits for water and wort temperatures, and changing the water flow but not the wort flow, eight series of simulations were performed for different combinations of the above parameters. From eight series of simulations i.e. dozens of individual simulations that satisfy from the point of view of the convergence of the simulation model, only those were originally singled out that were found to match the output results with the aforementioned parameter intervals. This satisfied the practice recommendation and rejected all other simulations as unsatisfactory. Following the recommended intervals for the output parameters, over 50 valid simulations were obtained. For these, the absolute and relative error deviations were calculated by comparing simulation obtained value of the exchanged amount of heat between water and the wort, and its nominal value which is 3321.5 [kW]. Relative errors were in the range of 0.5-25%, indicating that in the actual operation of the plant situations can occur when there is a significant deviation of the actual efficiency of the heat exchanger from its nominal value, resulting in the loss of resources. Then, from the set of valid simulations, those for which the value of the relative error in the heat exchange is greater than 5% were excluded, and the results of remaining simulations are shown in Table 1 (below). The reason for choosing only these simulations lies in the assumption that in the given situations, in case of change of one of the input parameters, it would be easier and faster to correct another parameter in order to "iron out" the difference in deviation of the actual from the nominal operating conditions. In accordance with the foregoing, Table 1 shows the results of simulations of the work of the wort preheater, in cases where the water and wort temperatures are at the recommended intervals, although still deviating from the recommended normative value. The resulting simulation values of the heat exchanged between heat transmitter (water) and the heat receiver (wort) are also shown.

Table 1 Results of series of simulations that comply with pre-conditions for water/wort temperatures and flow

No.	**t_{ulV} (°C) water inlet**	**t_{izlV} (°C) water outlet**	**m_V (kg/s) water flow**	**t_{izlS} (°C) wort outlet**	**Q_{slsim} (kW) simul. value**	**IΔQI (kW)= Q_{slsim}- Q_{slnorm}**	**ΣQ = IΔQI/ Q_{slnorm} (%)**
1.	97	77,86	43,05	94,51	3250,7	70,76	2,13
2.	98	78,09	43,05	95,41	3380,7	59,21	1,78
3.	97	77,30	41	94,06	3185,7	135,75	4,08
4.	97	77,57	42	94,28	3217,5	103,98	3,13
5.	97	77,85	43	94,5	3249,2	72,21	2,17
6.	97	78,12	44	94,69	3276,7	44,77	1,35
7.	97	78,39	45	94,88	3304,1	17,33	0,52
8.	98	76,68	38	94,13	3195,8	125,64	3,78
9.	97	77,86	43,05	94,51	3250,7	70,76	2,13
11.	97	77,86	43,05	94,51	3250,7	70,76	2,13
12.	97	77,86	43	94,51	3250,7	70,76	2,13
13.	96,5	77,99	44	94,24	3211,7	109,75	3,30
14.	96	78	44,5	93,87	3158,3	163,18	4,91
15.	97	77,85	43	94,5	3249,2	72,21	2,17
16.	96,5	77,99	44	94,24	3211,7	109,75	3,30
17.	96	78,13	45	93,96	3171,3	150,19	4,52

By comparing the simulation and the normative value of the exchanged amount of heat, the simulation values are lower in absolute terms. If only the absolute difference of the changed quantities of heat were observed, the conclusion would be that the heat exchange in the preheater is realized with less specific energy consumption. However, such savings are apparent because they are mainly due to the lower output temperature of the wort, and accordingly it will be necessary to bring more energy into the wort boiler. Table 1 also shows the relative deviations of the exchanged amount of heat according to the simulations and the norm i.e. with a relative error of less than 5%. The simulations shown can serve to control the production process in a facility. In case of deviation of the input parameters of water or wort in the preheater, it may be decided to adjust one or more parameters (i.e .flow or temperature of the inlet water) to bring the process as close as possible to the normative values and thus avoid unnecessary waste of resources. Of course, it is impossible to predict all possible combinations of parameters that can occur in a real process, but it is possible to find a more approximate combination of parameters that causes the least possible loss of resources. As mentioned above, if the simulation results are used to manage the current parameters as the process proceeds, it is recommended to select those simulations that have a smaller relative deviation of the exchanged amount of heat compared to the normative one. The amount of the maximum allowable relative deviation can be estimated on the basis of previous experience, where it should not exceed the 10% limit.

5 Conclusion

Resource efficiency in the production process is significant, both from the point of view of optimal use of resources and because of the need for minimal negative environmental impact. Given that operating parameters in the production process often deviate from their prescribed values and thus lead to inefficient use of resources, there is a need to resolve such situations on the spot and preferably in a simple and efficient manner. This paper shows how the use of a simulation computer model, which is based on a mathematical model of heat exchange in a wort preheater, can adjust the appropriate input parameters in response to the deviation of other input parameters as well. The ultimate goal is to achieve a minimum deviation of efficiency from its normative value, that is, maximum resource efficiency.

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Received: April 17, 2020; Published: April 30, 2020