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Optimal energy management in brewing

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The energy performance is one very important parameter in evaluating the resilience of industrial processes. The optimal usage of the energy is a key task today, because it determines the state of the environment and the final product's price. In this paper is described a method for minimizing energy consumption by heat integration in conventional brewing. A scheme for heat integration with usage of separated heat tanks is proposed, their aim is to save heat energy. A mathematical model that describes the heat transfer processes is developed. Based on this model is proposed a strategy for optimal management of energy resources with separate heat tanks. The optimization task is formulated in accordance with the mathematical nonlinear programming MNLP and is solved with the program package GAMS. The proposed method was tested with data from a real working production.

Keywords: heat integration, batch reactors, heat tanks, brewing

INTRODUCTION

Energy saving is cited as one of the global problems to be solved in the contemporary world. Sources of energy constantly decrease which has a negative effect on the environment. This fact provokes work in two main directions - searching for alternative energy sources and developing approaches for optimal utilization of energy resources.

In industrial production systems, the optimal use of energy sources is one of the main problems [1]. The use of energy and raw materials in different industrial productions requires improving of the efficiency in process management and waste minimization to meet the environmental specifications [2, 3]. The contemporary tendencies indicate that the industry is working towards waste reduction and improving the sustainability of the processes. This is because the effective usage of the sources is admitted as a key element of sustainable development and a successful strategy for reducing negative environmental impacts and production costs. One of the approaches used in solving the problems related to the optimal use of energy, is the integration approach. It can be described as a systematically oriented method that is used during the design and reconstruction of industrial production systems for optimal use of resources (energy or raw materials) and/or reduction of the emissions of harmful gases. The method of heat integration of the processes is focused on optimizing the consumption of heat, power and fuel [4, 5].

In most batch productions, there is a large number of processes requiring heating and cooling from external sources. Utilization of heat energy in batch processes is limited in terms of temperature levels and time intervals [6, 7]. Such is the production of dairy products, beer, biochemical substances. They require large amounts of water and energy [8]. In particular, upto 8% of the total production costs of beer are estimated as energy costs [9]. There are various scientific studies, which present approaches for improving energy efficiency of the breweries. In [10-11] it is presents guide layout of monitoring and measuring energy, the consumption of utilities and target setting for brewing in Canada and in London. It is provided information on the relationship between the use of energy and the generation of greenhouse gases in the brewing industry. The guide attention is directed to potential opportunities to improve energy efficiency in brewery processes. The research [12] provides information on potential energy efficiency opportunities for breweries. In [13], it is suggested includes cogeneration systems with different prime movers (steam turbine and gas turbine), and a generation system with a back-pressure steam turbine. The paper [14] gives an overview over the state of the art in the brewing industry commonly realized in large breweries and presents important barriers to efficiency in smaller companies. It is proposed [15] a brewery modeling tool, who can predict industrial thermal energy demand variables to satisfactory extent.

Due to growing concerns about the increased emissions of CO_2 and the need to implement more sustainable solutions are offered measures, such as those presented by [16] and [17].

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Numerous studies in this area indicate the ongoing interest of the authors, caused by the untapped potential of batch production of the food industry, eg. beer production. Most of the proposed solutions are based only on theoretical assumptions and do not take into account data from existing industries. Because of this, the question for optimal management aiming to reduce energy dependence on real production processes, still remains.

The aim of this work is to propose a practical method for energy saving through process heat integration in a batch system by conventional brewing.

PROCESS DESCRIBTION

It is studying a beer production process, which corresponds to the conventional brewing and includes the following main stages (Figure 1):

Stage 1: Milling - Before the mashing process, the malt/barley must be milled in a wet or dry process. It is done for easier malt degradation to sugars, amino acids and other substances;

Stage 2: Mashing - Mashing is carried out after mixing of the malt with water $45^{\circ}C$. This process forms a so-called malt mash. A special feature here is that the temperature during the mashing is raised in steps and then kept constant for a while at different mashing rests;

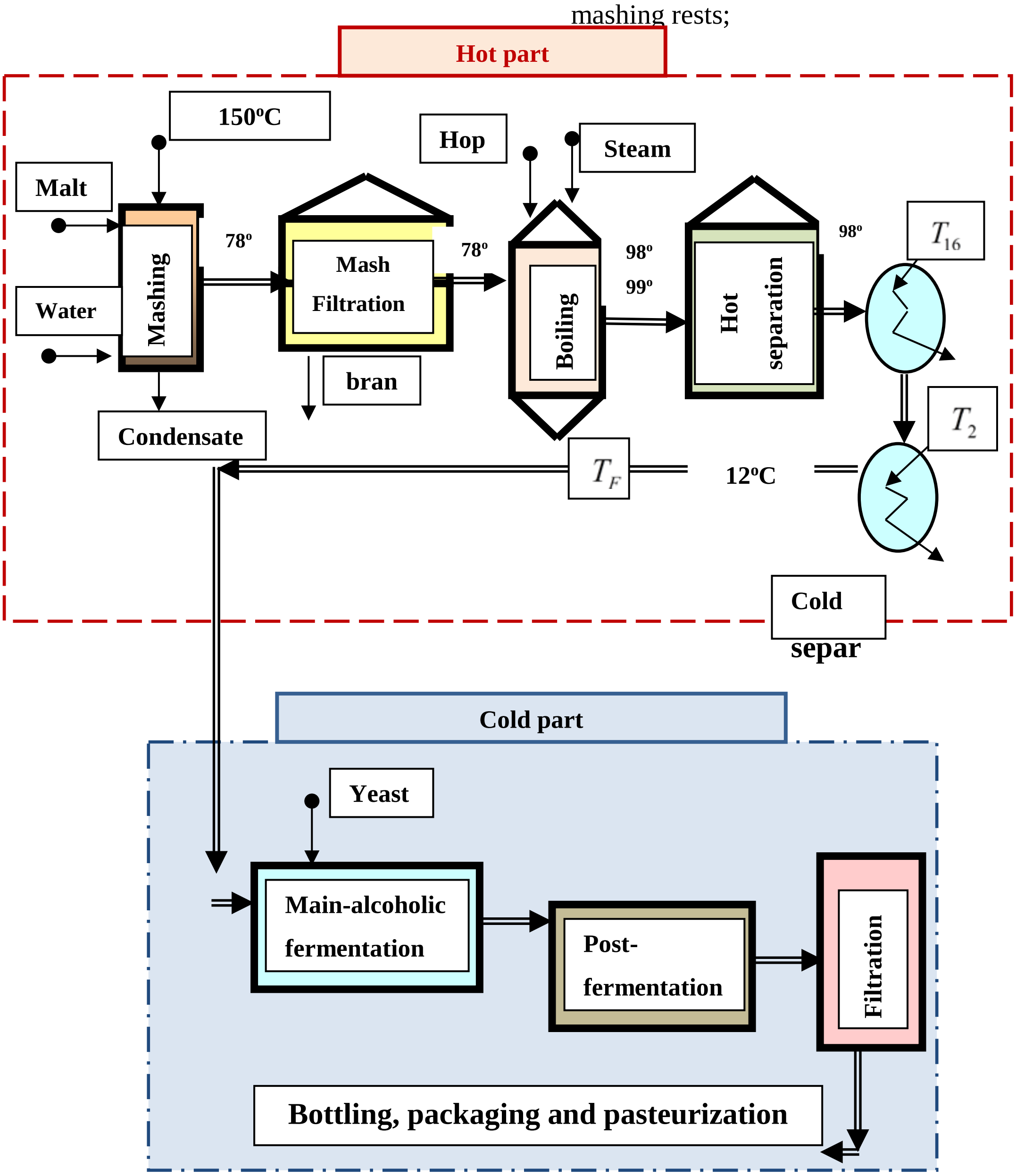

Fig.1. Scheme of conventional beer production without heat integration

Stage 3: Mash Filtration - During mash filtration, the wort is separated from the spent grains with filter bags. The wort is with temperature of $78^{\circ}C$. From wort subsequently is obtained beer.;

Stage 4: Boiling - After mash filtration, the wort is boiled together with hops to add bitterness to the taste of the beer. The boiling takes roughly an hour and the boiler is heated with steam. After the brewing the wort's temperature is $98^{\circ}C$;

Stage 5: Hot separation of hops and malt residues - During this stage, is formed a sludge as a boiling result. The process is carried out by temperature $98-99^{\circ}C$;

Stage 6: Cold separation - Cold sludge is formed after cooling the hopped wort. Cooling is carried out in two sections. In the first section, wort is cooled with water with a temperature of $16^{\circ}C$. The second section cools with water with a temperature of $2^{\circ}C$. At the end of the process, the wort is with temperature $12^{\circ}C$.

Stage 7: Adding of yeast

Main-alcoholic fermentation performed by yeast;

Post-fermentation and maturation - two interrelated processes that naturally follow the main alcoholic fermentation;

Stage 8: Filtration of beer;

Stage 9: Bottling, packaging and pasteurization

The so called "Calming" of beer is mandatory operation that occurs immediately after its filtration. Then beer is fed for bottling.

The production process of beer is presented as composed of two parts - hot (production of wort Stage 2 - Stage 6) and cold (fermentation, maturing and beer processing Stage 6 - Stage 9). Figure 1 presents the scheme of conventional beer production without heat integration.

PROBLEM DESCRIPTION

The focus in this work is the conventional brewing process, presented in two parts - hot (wort production) and cold (fermentation, maturation and beer treatment). For the purposes of heat integration, we are interested in the hot part of brewing. This is so because there could be seen the basic processes of "Heating" and "Cooling." Generally, after wort boiling with hops and the following separation of hops and malt waste, the mixture with temperature $98^{\circ}C$ is cooled to $12^{\circ}C$. For the cooling purposes is used water with temperature $16^{\circ}C$ and water with temperature $2^{\circ}C$. The idea for the reduction of energy consumption is to integrate processes "Heating" and "Cooling" by using thermal tanks. These reservoirs act as separate heat reservoirs. The purpose of this operation is that the heated water, stored in the heat storage tanks is used for carrying out the processes of mash production and mash filtration and for vessels washing.

In this case, it is not necessary to stick to a work schedule of the devices in industrial unit. This leads to reducing the amount of wastewater and steam.

This idea can be realized through the creation of an appropriate scheme, along which we need to define the set of independent variables to ensure minimum means spent for carrying out of processes. Figure 2 presents the proposed scheme for process management.

Heat integration using heat tanks

From the presented technology can be seen that there are processes "Heating" and "Cooling", which demand usage of energy from outside. The reduction of energy used from outside can be achieved by certain scheme of heat integration. Due to process constraints it is not possible to use the scheme for direct heat integration. For this it is proposed the usage of segregated heat tanks serving for storing thermal energy for its use in another time interval (Fig. 2).

The characteristic feature of the proposed scheme shown in Figure 2 is the block for cooling and heat integration. Wort with temperature T_0^P and debit m_n^P enters for cooling in heat exchangers A_1, A_2, A_3, A_4. The waste water after the heat exchangers is stored in four tanks V_{80}^*, V_{45}^*, $V_{Washing}^*$, V_{Waste}^*.

The task of process management is limited to the determination of multitude independent variables which to minimize the money spent to conduct processes. The task restrictions are related to the technological requirements for carrying out the processes, and also with the demands to the technical equipment for performing cooling.

Mathematical model of the motivation example

The proposed method for heat integration can be applied to traditional brewing. The technological process includes 9 main stages. The data about the parameters of the "heating-cooling" process are presented in Table 1.

It is assumed that the process of cooling and heat integration is carried out in N successive time intervals. For each time interval the cooling is carried out with a constant debit of streams.

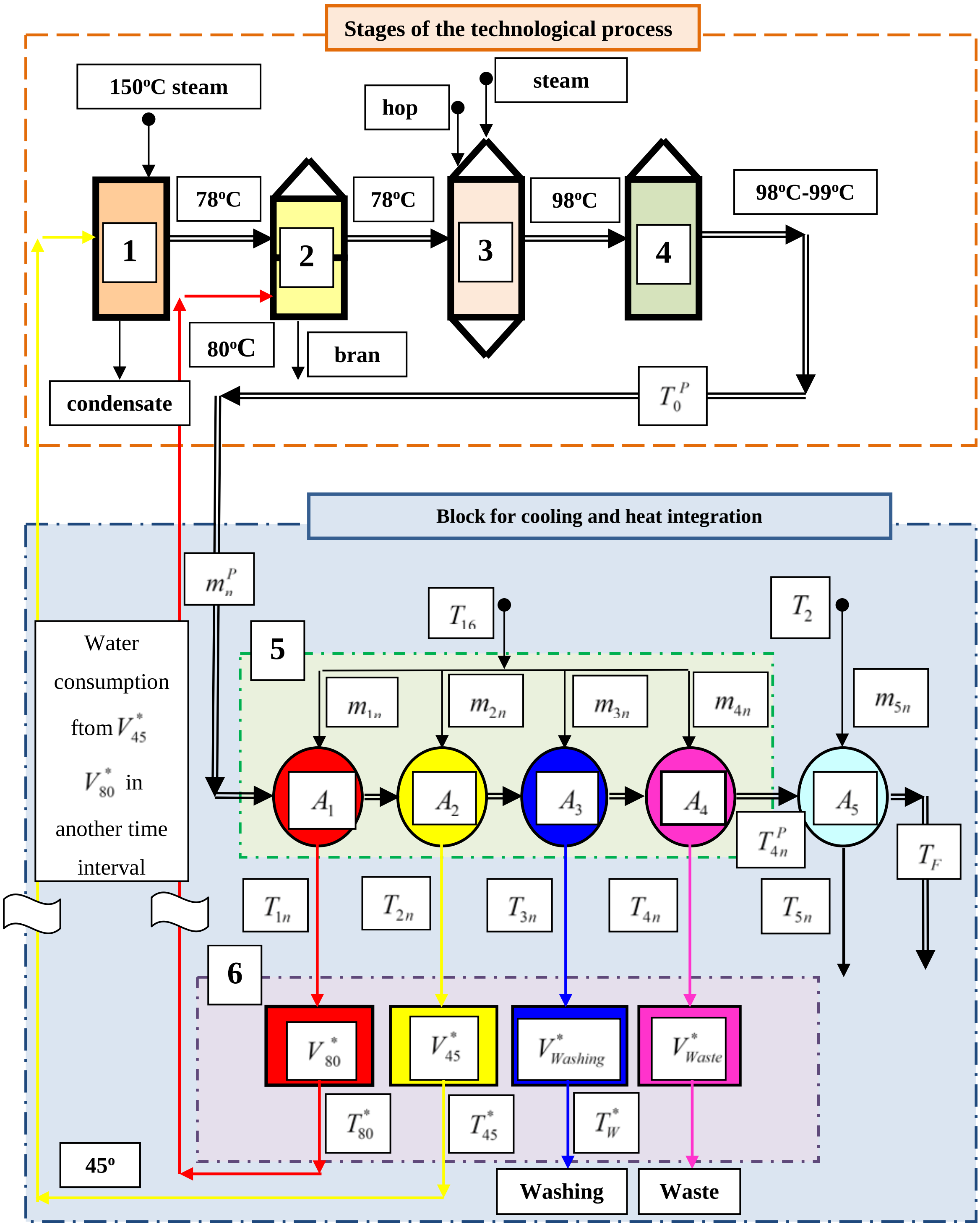

Fig.2. Scheme of the system for heat integration with separated heat tanks

The mathematical model describing the temperature levels (for the n-th time interval) that are achieved in each of the heat exchangers is given by the following relationships:

For heat exchanger A_1 that performs wort cooling from starting temperature T_0^P to temperature T_{1n}^P, the water temperature after the heat exchanger A_1 will be T_{1n}:

$$T_{1n}^P = T_0^P - \left(T_0^P - T_{16}\right)\Phi e_{1n}$$
$$T_{1n} = T_{16} + \left(T_0^P - T_{16}\right)k_{1n}\Phi e_{1n} \qquad (1)$$

where

$$k_{1n}=\left|\frac{T_{16}-T_{1n}}{T_{1n}^{P}-T_{0}^{P}}\right|=\frac{m_n^P Cp_P}{m_{1n}Cp_{16}},$$

$$w_{1n}=\frac{1}{m_n^P Cp_P}-\frac{1}{m_{1n}Cp_{16}},$$

$$\Phi e_{1n}=\frac{T_{1n}^P-T_0^P}{T_{1n}^P-T_{16}}=\frac{1-\exp\left(-w_{1n}U_1A_1\right)}{1-k_{1n}\exp\left(-w_{1n}U_1A_1\right)}$$

Table 1. Parameters of the processes in a brewery

Parameters	Value	Dimension
Cp_P	3970	$[kJm^{-3}K^{-1}]$
Cp_{H_2O}	4190	$[kJkm^{-3}K^{-1}]$
m_n^P	0.0139	$[m^3/\sec]$
m_{1n}	0.025	$[m^3/\sec]$
T_0^P	98	$[^\circ C]$
T_{16}	16	$[^\circ C]$
T_2	2	$[^\circ C]$
V_{80}	≤ 35	$[m^3]$
V_{45}	≤ 34	$[m^3]$
$V_{Washing}$	≤ 35	$[m^3]$
V_{Waste}	≤ 35	$[m^3]$
$Cost_{16}$	2,184	$[lw/m^3]$
C_{Steam}	0.075510^{-3}	$[lw/kJ]$
C_{W2}	0.16210^{-3}	$[lw/kJ]$

For heat exchanger A_2 that performs wort cooling from starting temperature T_{1n}^P to temperature T_{2n}^P, the water temperature after the heat exchanger A_2 will be T_{2n}:

$$\begin{aligned}T_{2n}^P&=T_{1n}^P-\left(T_{1n}^P-T_{16}\right)\Phi e_{2n}\\T_{2n}&=T_{16}+\left(T_{1n}^P-T_{16}\right)k_{2n}\Phi e_{2n}\end{aligned}\tag{2}$$

where

$$k_{2n}=\left|\frac{T_{16}-T_{2n}}{T_{2n}^{P}-T_{1n}^{P}}\right|=\frac{m_n^P Cp_P}{m_{2n}Cp_{16}},$$

$$w_{2n}=\frac{1}{m_n^P Cp_P}-\frac{1}{m_{2n}Cp_{16}},$$

$$\Phi e_{2n}=\frac{T_{2n}^P-T_{1n}^P}{T_{2n}^P-T_{16}}=\frac{1-\exp\left(-w_{2n}U_2A_2\right)}{1-k_{2n}\exp\left(-w_{2n}U_2A_2\right)}$$

For heat exchanger A_3 that performs wort cooling from starting temperature T_{2n}^P to temperature T_{3n}^P, the water temperature after the heat exchanger A_3 will be T_{3n}:

$$\begin{aligned}T_{3n}^P&=T_{2n}^P-\left(T_{2n}^P-T_{16}\right)\Phi e_{3n}\\T_{3n}&=T_{16}+\left(T_{2n}^P-T_{16}\right)k_{3n}\Phi e_{3n}\end{aligned}\tag{3}$$

where

$$k_{3n}=\left|\frac{T_{16}-T_{3n}}{T_{3n}^{P}-T_{2n}^{P}}\right|=\frac{m_n^P Cp_P}{m_{3n}Cp_{16}},$$

$$w_{3n}=\frac{1}{m_n^P Cp_P}-\frac{1}{m_{3n}Cp_{16}},$$

$$\Phi e_{3n}=\frac{T_{3n}^P-T_{2n}^P}{T_{3n}^P-T_{16}}=\frac{1-\exp\left(-w_{3n}U_3A_3\right)}{1-k_{3n}\exp\left(-w_{3n}U_3A_3\right)}$$

For heat exchanger A_4 that performs wort cooling from starting temperature T_{3n}^P to temperature T_{4n}^P, the water temperature after the heat exchanger A_4 will be T_{4n}:

$$\begin{aligned}T_{4n}^P&=T_{3n}^P-\left(T_{3n}^P-T_{16}\right)\Phi e_{4n}\\T_{4n}&=T_{16}+\left(T_{3n}^P-T_{16}\right)k_{4n}\Phi e_{4n}\end{aligned}\tag{4}$$

where

$$k_{4n}=\left|\frac{T_{16}-T_{4n}}{T_{4n}^{P}-T_{3n}^{P}}\right|=\frac{m_n^P Cp_P}{m_{4n}Cp_{16}},$$

$$w_{4n}=\frac{1}{m_n^P Cp_P}-\frac{1}{m_{4n}Cp_{16}},$$

$$\Phi e_{4n}=\frac{T_{4n}^P-T_{3n}^P}{T_{4n}^P-T_{16}}=\frac{1-\exp\left(-w_{4n}U_4A_4\right)}{1-k_{4n}\exp\left(-w_{4n}U_4A_4\right)}$$

For heat exchanger A_5 that performs wort cooling from starting temperature T_{4n}^P to temperature T_{5n}^P, the water temperature after the heat exchanger A_5 will be T_{5n}:

$$\left.\begin{aligned}T_{5n}^P&=T_{4n}^P-\left(T_{4n}^P-T_{2}\right)\Phi e_{5n}\\T_{5n}&=T_{2}+\left(T_{4n}^P-T_{2}\right)k_{5n}\Phi e_{5n}\end{aligned}\right\}\tag{5}$$

where

$$k_{5n} = \left| \frac{T_2 - T_{5n}}{T_{5n}^P - T_{4n}^P} \right| = \frac{m_n^P Cp_P}{m_{5n} Cp_2},$$

$$w_{5n} = \frac{1}{m_n^P Cp_P} - \frac{1}{m_{5n} Cp_2}$$

$$T_{5n}^P = T_F^*,$$

$$\Phi e_{5n} = \frac{T_{5n}^P - T_{4n}^P}{T_{5n}^P - T_2} = \frac{1 - \exp(-w_{5n} U_5 A_5)}{1 - k_{5n} \exp(-w_{5n} U_5 A_5)}$$

The mathematical model describing the working temperature and volume, which are reached as a result of the heat exchange for each heat tank is given in the following way:

For heat tank V_{80} the volume V_{80}^* and the temperature T_{80}^* arereached as a result of heat exchange:

$$V_{80}^* = \sum_{n=1}^{5} (m_{1n} t_n) \tag{6}$$

$$T_{80}^* = \frac{\sum_{n=1}^{5} (T_{1n} m_{1n} t_n)}{\sum_{n=1}^{5} (m_{1n} t_n)} \tag{7}$$

For heat tank V_{45} the volume V_{45}^* and the temperature T_{45}^* is reached as a result of heat exchange:

$$V_{45}^* = \sum_{n=1}^{5} (m_{2n} t_n) \tag{8}$$

$$T_{45}^* = \frac{\sum_{n=1}^{5} (T_{2n} m_{2n} t_n)}{\sum_{n=1}^{5} (m_{2n} t_n)} \tag{9}$$

For heat tank $V_{Washing}$ the volume $V^*_{Washing}$ and the temperature $T^*_{Washing}$ is reached as result of heat exchange:

$$V_{Washing}^* = \sum_{n=1}^{5} (m_{3n} t_n) \tag{10}$$

$$T_{Washing}^* = \frac{\sum_{n=1}^{5} (T_{3n} m_{3n} t_n)}{\sum_{n=1}^{5} (m_{3n} t_n)} \tag{11}$$

For heat tank V_{Waste} the volume V^*_{Waste} and the temperature T^*_{Waste} is reached as a result of heat exchange:

$$V_{Waste}^* = \sum_{n=1}^{5} (m_{4n} t_n) \tag{12}$$

$$T_{Waste}^* = \frac{\sum_{n=1}^{5} (T_{4n} m_{4n} t_n)}{\sum_{n=1}^{5} (m_{4n} t_n)} \tag{13}$$

The energy that is necessary to carry out the processes can be presented by the following mathematical relationships:

$$E_{45} = (T_{45} - T_{45}^*) V_{45}^* Cp_{16} + (T_{45} - T_{16})(V_{45} - V_{45}^*) Cp_{16} \tag{14}$$

$$E_{80} = (T_{80} - T_{80}^*) V_{80}^* Cp_{16} + (T_{80} - T_{16})(V_{80} - V_{80}^*) Cp_{16} \tag{15}$$

$$E_{Washing} = (T_{Washing} - T_{Washing}^*) V_{Washing}^* Cp_{16} + (T_{Washing} - T_{16})(V_{Washing} - V_{Washing}^*) Cp_{16} \tag{16}$$

$$E_2 = \sum_{n=1}^{n=5} \left(Cp_2 m_{5n} t_n (T_{5n} - T_2) \right) \tag{17}$$

The cost of the energy that is necessary to ensure the technological processes is calculated according to the relation:

$$Cost = (E_{45} + E_{80} + E_{Washing}) Cost_{16} + E_2 Cost_2 \tag{18}$$

Variables

The essence of the management process is to determine the set of independent variables to ensure the fulfillment of the objective function or in other words to minimize the money spent on conducting the processes.

These independent variables are:

$$X = \{m_{in}, A_n, m_n^P, t_n\}, \ \forall i, n$$

where

$$\left.\begin{array}{l} m_{in}, \quad \forall n \in (1, N), \forall i \in (1, 5) \\ A_n, m_n^P, t_n, \quad \forall n \in (1, N) \end{array}\right\} \tag{19}$$

Restrictions

Task restrictions are related to the technological requirements for carrying out the processes, and also with requirements to the technical equipment carrying out the cooling. In this case, the plurality of task restrictions are:

$$\left.\begin{aligned} T_{45}^{*} &\le T_{45} \\ V_{45}^{*} &= V_{45} \end{aligned}\right\} \quad (20)$$

$$\left.\begin{aligned} T_{80}^{*} &\le T_{80} \\ V_{80}^{*} &= V_{80} \end{aligned}\right\} \quad (21)$$

$$\left.\begin{aligned} T_{Washing}^{*} &\le T_{Washing} \\ V_{Washing}^{*} &\le V_{Washing} \end{aligned}\right\} \quad (22)$$

$$V_{Beer} = \sum_{n=1}^{n=5} \left(t_n m_n^P \right) \quad (23)$$

$$A_i \le A_i^{MAX}, \quad \forall \mathrm{i} \in (1,5) \quad (24)$$

$$\sum_{n=1}^{n=5} t_n \le t_{cold} \quad (25)$$

$$T_{5n}^{P} \le T_F \quad (26)$$

Aim of heat integration

The aim of heat integration is to minimize the amount of used energy resources for carrying out the processes. This can be achieved by providing a possibility of maximum utilization of the heat from the cooling of the wort.

The objective function of the heat integration is:

$$MINIMIZE \{Cost(X)\} \quad (27)$$

The presented task is formulated in terms of the mathematical nonlinear programming MNLP and it is solved with programming package GAMS.

RESULTS

As a result of applying the method of heat integration using heat tanks in the process of brewing were achieved results presented in the following tables:

In Table 2 the optimal temperature levels of the wort are shown that are reached at the output of the heat exchangers.

Table 2 shows that by the proposed scheme with heat integration (Fig.2) the temperature of the wort gradually decreases after leaving each of the heat exchangers, which results in reducing the energy usage required for the cooling process.

Table 2. Optimal temperature of the wort at the output of the heat exchangers

Heat exchangers	Temperature by scheme without heat integration [ºC]	Temperature by scheme with one heat tank [ºC]	Temperature by scheme with separate heat tanks [ºC]
A_1	22	22	55.016
A_2	12	12	36.095
A_3	-	-	23.308
A_4	-	-	18.560
A_5	-	-	12.000

Table 3 presents the optimal parameters (temperature and volume) in the used additional heat tanks.

Table 3. Optimal temperature and volume in the heat tanks

Hot tank	Scheme without heat integration		Scheme with one heat tank		Scheme with separate heat tanks	
	V [m^3]	T [ºC]	V [m^3]	T [ºC]	V [m^3]	T [ºC]
V_{80}	-	-	-	-	35	80
V_{45}	-	-	140	45.57	34	45
V_{Wash}	-	-	-	-	35	35.039
V_{waste}	-	-	-	-	36	22.872

The energy required to carry out the processes in the execution of various schemes is presented in Table 4. It follows from Table 4 that by the implementation of the heat integration scheme with usage of separate heat tanks (Fig.2) the energy needed to obtain water with a temperature of 45ºC and water with a temperature of 80ºC is minimized. The total amount of energy required to carry out the processes by using separate heat tanks (Fig.2) is by about 45% lower than that according to the scheme realized in the practice (scheme with one heat tank).

Table 4. Energy needed for carrying out the processes

Resource	Energy needed to carry out processes without heat integration *[kJ]*	Energy needed to carry out processes with one heat tank *[kJ]*	Energy needed to carry out processes withseparate heat tanks *[kJ]*
E_2	1432469.724	1432469.724	1432469.724
E_{45}	4131340.000	81171.729	1.944
E_{80}	9385600.000	5049190.867	2.145
E_{Wash}	5719350.000	1382940.867	2927238.395
Total	**20668759.72**	**7945773.187**	**4359712.208**

From Table 5 is clear that the optimal process control leads to significant cost reductions for obtaining water with temperature of 45ºC and 80ºC.

Table 5. Cost of energy sources without heat integration and with heat integration processes

Resource	Cost of energy by scheme without heat integration [$lv.$]	Cost of energy by scheme with one heat tank [$lv.$]	Cost of energy by scheme with separate heat tanks [$lv.$]
$Cost_2$	232.060	232.060	232.060
$Cost_{45}$	311.916	-6.128	1.467841E-4
$Cost_{80}$	708.613	381.214	1.619686E-4
$Cost_{Wash}$	431.811	104.412	221.006
Total	**1684.400**	**711.558**	**453.067**

The installation of one heat tank, as is often the case in practice, leads to a reduction in energy consumption by about 57% compared to the case without heat integration. When specialized segregated tanks are used, as shown in Fig.2, the cost of energy is by 36% lower compared to the case realized in practice.

It can be noted that by optimal process management no special devices that provide optimal change of the coolant flow are necessary.

CONCLUSIONS

In this study, it was described a conventional brewing. The production process was presented as composed of two parts - hot and cold. In presented paper, it was proposed strategy for optimal management of processes "Heating" and "Cooling". It was designed a new structure for heat integration with separated heat tanks and the suitable mathematical model describing the process of wort production.

Optimization task was formulated in accordance with the mathematical nonlinear programming MNLP, aiming to minimize the cost of reusing energy resources, and was solved with the software package GAMS. The proposed method was tested with data from a real working production. The results were indicated in a few summary tables. As a strategy result (when specialized segregated tanks are used), it is possible the energy cost to be a 36% lower compared to the case realized in practice.

NOTATIONS

Cp Heat capacity, $\left[kJm^{-3}K^{-1}\right]$

ρ Density, $\left[kg/m^3\right]$

T Flow temperature, [$^\circ C$]

V Volume of apparatus, $\left[m^3\right]$

t Time intervals, $[s]$

C_{Steam} Cost of steam, $[lw/kJ]$

C_{W5} Cost of water with temperature $5^o C$,$[lw/kJ]$

F^{MAX} Maximum flow rate, $\left[m^3/s\right]$

A Heat exchange surface, $\left[m^2\right]$

U Coefficient of heat transfer, $\left[kJ \sec^{-1} m^{-2} K^{-1}\right]$

m Flow rate, $\left[m^3/\sec\right]$

E Energy needed to carry out the processes, $[kJ]$

V^* Volume, which is reached as a result of heat exchange, $\left[m^3\right]$

V_{Beer} Volume of cooling wort, $\left[m^3\right]$

A_i^{MAX} Maximum heat exchange surface, $\left[m^2\right]$

T_F Temperature of the cooled wort, [$^\circ C$]

V_{45} Volume of water with temperature $45^\circ C$, $\left[m^3\right]$

V_{80} Volume of water with temperature $80^\circ C$, $\left[m^3\right]$

$V_{Washing}$ Volume of water for washing, $\left[m^3\right]$

T_{45} Water temperature $45^\circ C$

T_{80} Water temperature $80^\circ C$

T_{16} Water temperature $16^\circ C$

$T_{Washing}$ Temperature of washing water, [$^\circ C$]

T_2 Water temperature

$Cost_{16}$ Cost per unit of energy consumed to heat water $16^\circ C$ for technological needs, $[lv]$

$Cost_2$ Cost per unit of energy by cooling the beer with water $2^\circ C$,$[lv.]$

lv. Bulgarian levs

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ОПТИМАЛНО УПРАВЛЕНИЕ НА ЕНЕРГИЯТА В ПИВОВАРСТВОТО

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(Резюме)

Енергийната ефективност е един много важен показател при оценка устойчивостта на промишлените процеси. Оптималното използване на енергията е основна задача и днес, тъй като определя състоянието на околната среда и крайната цена на продукта. Настоящата разработка описва метод за минимизиране консумацията на енергия чрез топлинна интеграция на процесите при конвенционално пивопроизводство. Предложена е схема за топлинна интеграция с използване на разделни топлинни резервоари, служещи за съхранение на топлинна енергия. Разработен е математичен модел, който описва топлопреносните процеси. На база на модела е предложена стратегия за оптимално управление на енергоресурсите с използване на разделни топлинни резервоари. Оптимизационната задача е формулирана в термините на математичното нелинейно програмиране MNLP и е решена с програмния пакет GAMS. Предложеният метод е тестван с използване на данни от реално работещо производство.