Heat – Technological Scheme for Cooling of Mineral Water

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Abstract - **Republic Bulgaria is rich of mineral waters, which are used for drinking and curative purposes. The mineral water for drinking purposes is bottling in plastic bottles and the technology for bottling of the water requires to cool it to definite temperature before bottling.**

The aim of this paper is to be studied different heat-technological schemes for bottling of mineral water and be pointed out their advantages and disadvantages. In result of that the most effective scheme can be chosen at given conditions of bottling.

Keywords - **mineral water, bottling, heat schemes for cooling, heat exchangers**

I. Introduction

Republic Bulgaria is rich of mineral springs which waters possess curative qualities and they are used as drinking water in the our country and abroad. For meeting of market needs these waters are bottled in plastic bottles for single use. However in the most cases the temperature of the mineral waters is higher than the ambient temperature. This fact creates problems with the water bottling because deforming of the bottles after cooling of the water filled in them. That's why the mineral waters have to be cooled to temperature of 25 ^{0}C before their bottling.

Two heat - technological schemes of installations for cooling of mineral waters before their bottling are offered in this paper. The mineral water cooling is realized indirectly in a plate heat exchanger. Circulating water is used as cooling fluid. In the first heat - technological scheme this circulation water is cooled on the other hand in a coil heat exchanger, sunk in a natural or artificial water basin. A freezing plant is used for cooling of the circulation water in the second scheme.

The aim of the paper is to be studied different heat-technological schemes for cooling of mineral water before its bottling and to be pointed out their advantages and disadvantages.

II. Materials and Methods

In the studied case the mineral water which is subject to bottling has temperature of 47 ^{0}C and has to be cooled to temperature of 25 ^{0}C. The first variant of scheme for cooling of mineral water with sunk heat - exchanger is presented on fig. 1. The cooling of the mineral water occurs indirectly in a plate heat - exchanger 1 as for cooling fluid is used circulating in closed loop water. This water takes away the heat from the mineral water and on the other hand it is cooled in a heat - exchanger 2 sunk in a natural or artificial water basin.

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The last heat - exchanger represents pipe coil from two, three or four parallel pipes with diameter Φ60x3,5 and length in dependence of the mass flow rate of the cooled mineral water.

Two variants of the sunk heat - exchanger at volumetric flow rate of mineral water $\dot{V}_1$ = 20 m^3/h are presented on fig 2. In the first variant (fig. 2a) the coil is manufactured from two parallel pipes and in the second variant (fig. 2b) the coil is manufactured from three parallel pipes.

Other two variants of the sunk heat - exchanger at volumetric flow rate of mineral water $\dot{V}_2$ = 30 m^3/h are presented on fig 3. In the first variant (fig. 3a) the coil is manufactured from three parallel pipes and in the second variant (fig. 3b) the coil is manufactured from four parallel pipes.

In the second principle heat - technological scheme of installation for cooling of mineral water freezing plant is used instead of the sunk heat - exchanger.

III. Experimental Results and Data Analysis

A. Heat - technological scheme of installation with sunk heat - exchanger

Heat and constructional calculations of the plate and the sunk heat - exchangers are carried out and their parameters are determined as follow:

1.Determining of plate heat - exchanger parameters

It is accepted that the fluids in the heat - exchanger flow in countercurrent as the mineral water is cooled from temperature of 47 ^{0}C to temperature of 25 ^{0}C and the circulating water is cooled from temperature of 20 ^{0}C to temperature of 30 ^{0}C.

The mean temperature difference between the temperatures of the two fluids is determined from the equation of mean logarithmic temperature difference

$$\Delta t_{CP} = \frac{\Delta t_A - \Delta t_B}{\ln \frac{\Delta t_A}{\Delta t_B}}, \quad K \qquad (1)$$

where Δt_A and Δt_B are larger and smaller temperature differences in the two ends of the heat-exchange surface, K

The mass flow rate of the cooled mineral water is calculated from the equation

$$\dot{m}_{M.W} = \frac{\dot{V}_i . \rho}{3600}, \quad kg/s \qquad (2)$$

where $\dot{V}_i$ is volumetric flow rate of the mineral water, m^3/h;

ρ - density of the mineral water, kg/m^3, and the heat flow rate which has to be taken away from the mineral water in the plate heat - exchanger is determined from the equation of the energy balance of the heat - exchanger

$$\dot{Q}_P = \dot{m}_{M.W}.c_P.(t'-t''),\ \text{kW} \quad (3)$$

where c_P is a specific heat capacity of the mineral water, J/(kg.K);

t' and t'' - temperatures of the mineral water at the inlet and the outlet of the heat - exchanger respectively, K.

The necessary heat-exchange surface of the plate heat-exchanger is determined from the basic equation of heat transfer

$$F_P = \frac{\dot{Q}_P}{k_P.\Delta t_{CP}},\ \text{m}^2 \quad (4)$$

where k_P is heat transfer coefficient, W/(m^2.K).

Its value is accepted according to [5].

The necessary mass flow rate of the circulating water is determined from the equation of the energy balance of the heat - exchanger

$$\dot{m}_{C.W} = \frac{\dot{Q}_P}{c_P.\left(t_W^{'} - t_W^{''}\right)},\ \text{kg/s} \quad (5)$$

where c_P is a specific heat capacity of the circulating water, J/(kg.K);

$t_W^{'}$ and $t_W^{''}$ - temperatures of the circulating water at the inlet and the outlet of the heat - exchanger respectively, K.

The results from the heat calculations of the plate heat exchanger for two different volumetric flow rates of the cooled mineral water ($\dot{V}_1$ = 20 m^3/h and $\dot{V}_2$ = 30 m^3/h) are presented in table I.

Table I

Results from the Heat Calculation of the Plate Heat Exchanger

N	Parameters	Sym-bol	Unit	Value at $\dot{V}_1$=20 m^3/h	Value at $\dot{V}_2$=30 m^3/h
1	Mean temperature difference	Δt_{CP}	K	9,83	9,83
2	Mass flow rate of mineral water	$\dot{m}_{M.W}$	kg/s	5,55	8,33
3	Heat flow rate	$\dot{Q}_P$	kW	512	768
4	Heat transfer surface	F_P	m^2	26	39
5	Mass flow rate of circulating water	$\dot{m}_{C.W}$	kg/s	12	18,3

2.Determining of the parameters of the sunk heat - exchanger (coil)

It is accepted that the temperature of the water in the water basin is 14 ^{0}C and it is constant. The circulating water is cooled from temperature of 30 ^{0}C to temperature of 20 ^{0}C. Thus the mean temperature difference between the temperatures of the two fluid in the heat - exchanger is determined from the equation (1).

The heat flow rate which has to be taken away from the circulating water is determined from the equation of energy balance of the sunk heat - exchanger

$$\dot{Q}_C = \dot{m}_{C.W}.c_P.\left(t_W^{'} - t_W^{''}\right),\ \text{kW} \quad (6)$$

where c_P is a specific heat capacity of the circulating water, J/(kg.K).

The necessary heat-exchange surface of the coil heat-exchanger is determined from the basic equation of heat transfer

$$F_C = \frac{\dot{Q}_C}{k_C.\Delta t_{CP}},\ \text{m}^2 \quad (7)$$

where k_C is heat transfer coefficient of the coil heat-exchanger, W/(m^2.K).

Its value is accepted according to [6].

The total length of the coil is determined from the equation

$$L = \frac{F_C}{\pi.d_{BH}},\ \text{m} \quad (7)$$

where d_{BH} is outside pipe diameter, m.

Determining of the speed of the water in the coil pipe

The water speed is determined from the equation of continuity

$$w = \frac{\dot{m}_{C.W}.v}{f.n'},\ \text{m/s} \quad (8)$$

where v is water specific volume, m^3/kg;

f - clear opening of one pipe, m^2;

n' - number of parallel pipe of the coil heat - exchanger.

*Determining of the coil heat - exchanger pipe number with unit length **l** = 6 m* (fig. 2a)

The pipe number of the coil heat - exchanger is determined as the total length is divided of the unit pipe length

$$n = \frac{L}{l}, \quad (9)$$

and overall length of the coil heat - exchanger a (fig. 3a) depends on the interval between the two next pipes a' (fig. 3b) and pipe number n and it is calculated from the equation

$$a = a'.\ n,\ \text{m.} \quad (10)$$

Determining of the total mass of the coil heat - exchanger pipes

The mass of one linear meter pipe from carbon steel and with dimensions Φ60x3,5 is m' = 4,88 kg [1], and the total mass of the coil pipes is calculated from the equation

$$m = m' . L , \quad kg. \quad (11)$$

Costs for the coil heat - exchanger pipes

The price of the pipes is P_T = 2 BGL per kg and the total costs for the coil heat - exchanger pipes is calculated from the equation

$$C_T = P_T . m, \quad BGL. \quad (12)$$

The results from the heat and constructional calculations of the sunk heat exchanger for two different volumetric flow rates of the cooled mineral water ($\dot{V}_1$ = 20 m^3/h and $\dot{V}_2$ = 30 m^3/h) are presented in table II.

Table II

Results from the Heat and Constructional Calculation of the Coil Heat Exchanger

N	Parameters	Symbol	Unit	Value at $\dot{V}_1$=20 m^3/h	Value at $\dot{V}_2$=30 m^3/h
1	Mean temperature difference	Δt_{CP}	K	10,2	10,2
2	Heat flow rate	$\dot{Q}_C$	kW	503	767
3	Heat transfer surface	F_C	m^2	82	125
4	Total length of the coil pipes	L	m	435	663
5	Mass flow rate of water in 1 pipe	$\dot{m}_1$	kg/s	6 [a]	6,1 [c]
6	Mass flow rate of water in 1 pipe	$\dot{m}_1$	kg/s	4 [b]	4,575 [d]
7	Speed of the water in the pipes	w	m /s	2,72 [a]	2,76 [c]
8	Speed of the water in the pipes	w	m /s	1,8 [b]	2,07 [d]
9	Pipes number	n	-	73	111
10	Overall length of the coil heat - exchanger	a	m	9	13
11	Total mass of coil pipes	m	kg	2 123	3 235
12	Costs for coil pipes	C_T	BGL	4 246	6 470

*Note

a/the variant with two parallel pipes of the coil and volumetric flow rate $\dot{V}_1$ = 20 m^3/h (fig. 2a);

b/the variant with three parallel pipes of the coil volumetric flow rate $\dot{V}_1$ = 20 m^3/h (fig. 2b);

c/the variant with three parallel pipes of the coil volumetric flow rate $\dot{V}_2$ = 30 m^3/h (fig. 3a);

d/the variant with four parallel pipes of the coil volumetric flow rate $\dot{V}_2$ = 30 m^3/h (fig. 3b).

B. Heat - technological scheme with freezing plant

The electrical power consumed from the freezing plant is N_{EL} = 90 kW and it is determined in result of the heat calculations of the freezing plant [2,3,4] and the heat flow rate which has to be taken away from the circulating water. The operating costs of the freezing plant compressor are determined at electrical energy price of 0,15 BGL per kWh.

For 24 hours they are - 2 160 kWh and 324 BGL.

IV. Conclusions

1.Two heat - technological schemes of installations for cooling of mineral water before its bottling are offered in this paper. The cooling of the mineral water is performed indirectly in a plate heat - exchanger as the circulating heat transfer carrier is cooled on the other hand in a sunk heat - exchanger in the first heat - technological scheme and a freezing plant is used in the second heat - technological scheme.

2.The operating costs for the first scheme with sunk heat - exchanger are significantly lower in comparison with these for the second scheme with a freezing plant.

3.The first heat - technological scheme could be used successfully if there is a natural or artificial water basin near by bottling plants.

4.The result from this investigation could be useful for the companies bottling mineral water.

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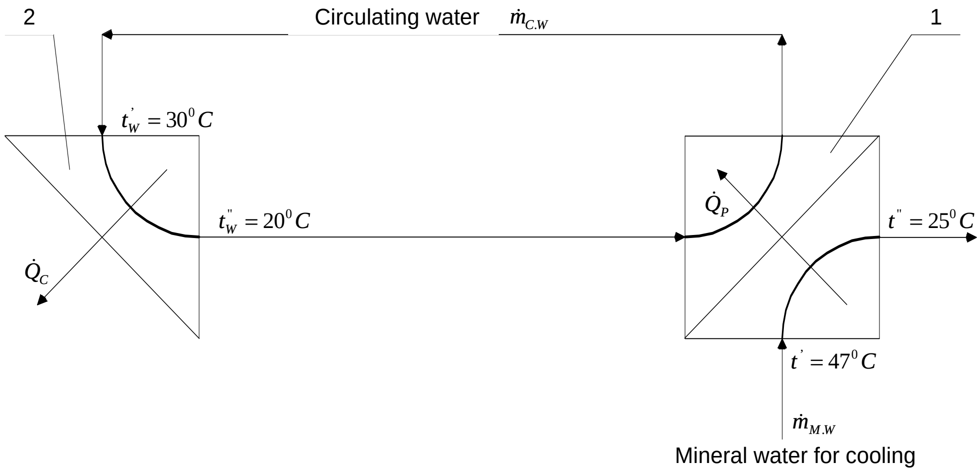

Fig. 1.Sceme of installation of mineral water cooling with sunk heat - exchanger
1 - Plate heat - exchanger; 2 - Sunk heat - exchanger (coil)

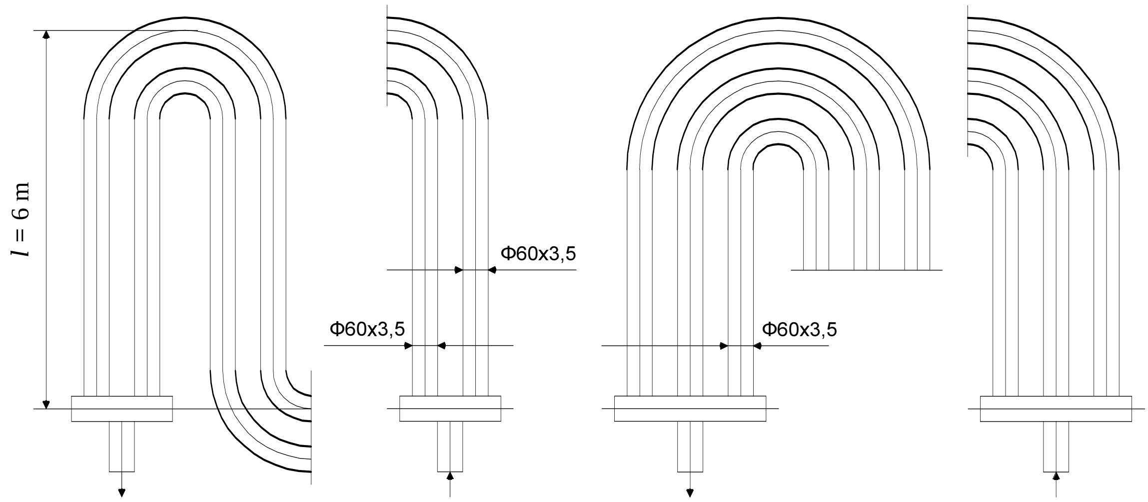

Fig. 2. Variant of the first scheme of installation with sunk heat exchanger at volumetric flow rate $\dot{V}_1$ = 20 m^3/h

Fig. 3. Variant of the first scheme of installation with sunk heat exchanger at volumetric flow rate and $\dot{V}_2$ = 30 m^3/h