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Determination of the Required Power of Tube Electric Heater for Distillation Desalination Plant

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Abstract. This article deals with the determination of tube electric heater for a distillation desalination plant. Tube electric heater is required for the distillation process because it prepares input water for the working process on the start regime of the desalination plant. Depending on its power, a time consumed for start regime will vary. Meanwhile, technical requirements for distillation desalination plants with mechanical vapor compression demands that plant must reach design operational regime within a certain time limit. Correspondingly, selection of the power for tube electric heater became an important task during distillation desalination plant designing. Amount of energy, which is necessary to add during heating, depends on the amount of water inside, mass-dimensional characteristics of the desalination plant and heat transfer with the environment. Algorithm for power selection is developed. This model allows determining the time required for the plant to reach a design operation regime. This time varies dependently on the power of the heater. Both analytical and numerical models of this dependencies were developed. A numerical model was used utilized to estimate the influence of the heat exchange with the environment on starting operation time. For the described plant, required power of TEH is equal to 24 kW.

1. Introduction

Lack of the fresh water became a problem in recent years. According to researches, in 2025 about half of the states will suffer fresh water deficit [1]. Thus, generation of the fresh water is one of the main tasks which must be solved to ensure ecological safety of the Earth population. There are several ways of fresh water generation. One of the most promising is seawater desalination or waste water treatment. There are several ways to desalinate seawater. They include reverse osmosis (RO) [2], electrodialysis (ED) [3], freezing [4] and distillation [5-7]. RO plants have a higher efficiency, however, they require often change of the membranes. ED plants are applicable on the water with relatively small salinity. Freezing plants are currently under development but in future they will allow using cold energy of liquid natural gas for desalination purposes. MVC plants have satisfactory energy consumption but they require careful design of the steam compressor which operation is crucial for plant.

Distillation or thermal desalination is most distributed way to obtain freshwater from seawater. As it is known, seawater is a solution which consists of water which is volatile solvent and salts – non-volatile solid material which is solved in water. Distillation is seawater evaporation with its vapour further condensation.

Distillation plants in turn can be divided on Multi-effect distillation plants (MED) [8], multi-stage flash distillation plants (MSF) [9], multi-effect distillation plants with thermal vapour compression



(MED-TVC) [10] and plants with mechanical vapour compression (MVC) [11]. Every type of desalination plant has its own advantages and disadvantages. For example, MED plants can utilize waste heat of thermal power station, however, their efficiency is lower in comparison with RO plants.

This article deals with tube electric heater of MED-MVC desalination plant, which principal scheme is presented on figure 1.

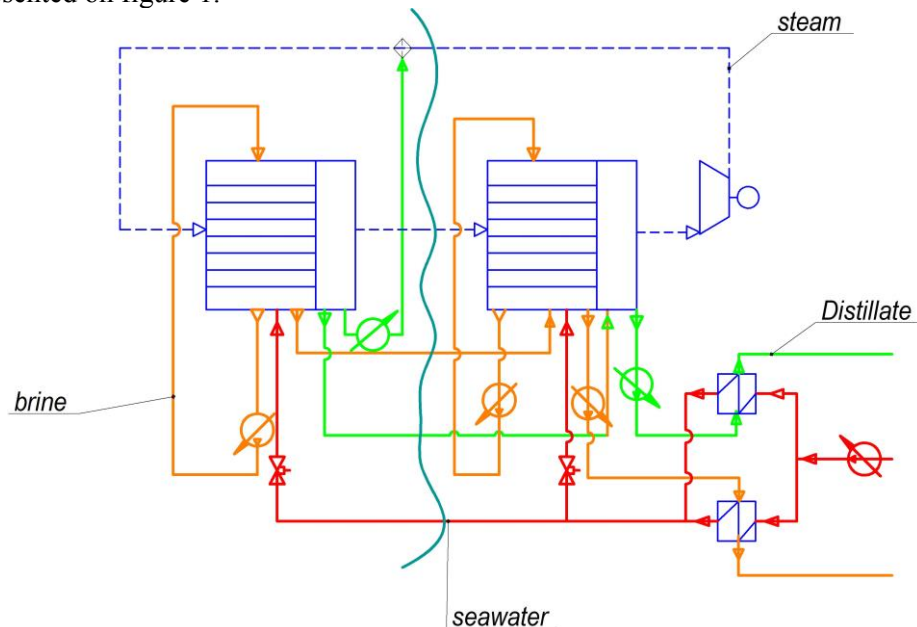


Figure 1. – Principal scheme of MED-MVC desalination plant

Main task of the tube electric heater (TEH) (figure 2) is initial water heating up to temperature of evaporation on the start operational regime of the desalination plant. Power of the TEH will influence heating rate and correspondingly, time when plant start to work on design regime.



Figure 2. – Tube electric heater

2. Mathematical model

In simplest case time for which plant will come at design operation regime can be determined as (neglecting heat capacity dependence on temperature):

$$\tau = \frac{c_w m_w (t_{wev} - t_{win})}{Q_{TEH}}, \quad (1)$$

where c_w – water heat capacity, m_w – water mass which is required to heat, t_{wev} and t_{win} – final (required) and initial temperatures of the water, Q_{TEH} – TEH power value.

However determination of the required power according to this formula will be connected with significant discrepancies (more than 50%) because heat transfer from water to walls and tubes of the evaporator is ignored in this calculation. Evaporator itself has significant heat capacity (comparable to heat capacity of water inside), thus heat transfer must be considered during determination of the required TEH power value.

In this case, heat transfer mechanism will contain three main equations:

$$\begin{cases} dt_w = \frac{Q_{TEH} - Q_{wall}}{m_w c_w} d\tau; \\ Q_{wall} = \alpha F (t_w - t_{wall}); \\ dt_{wall} = \frac{Q_{wall}}{m_{wall} c_{wall}} d\tau, \end{cases} \quad (2)$$

where t_w – water temperature in current moment of time, Q_{wall} – heat flux from the water to wall, α – heat transfer ratio from water to wall, t_{wall} – current wall temperature, m_{wall} – total mass of evaporator, c_{wall} – average heat capacity of the evaporator.

By derivation of the second equation of the system and substitution of the corresponding values of temperature derivative we receive linear homogenous differential equation of first order:

$$\frac{dQ_{wall}}{d\tau} = \alpha F \frac{Q_{TEH}}{m_w c_w} - Q_{wall} \alpha F \left(\frac{1}{m_w c_w} + \frac{1}{m_{wall} c_{wall}} \right). \quad (3)$$

Solution of such equation is an equation

$$Q_{wall} = -\frac{Z}{Y} e^{-Y\tau} + \frac{Z}{Y}, \quad (4)$$

where

$$\begin{aligned} Y &= \alpha F \left(\frac{1}{m_w c_w} + \frac{1}{m_{wall} c_{wall}} \right); \\ Z &= \frac{\alpha F Q_{TEH}}{m_w c_w}. \end{aligned} \quad (5)$$

Substitution of the expression (4) into temperature equations (2) and their integration gives water temperature and temperature of evaporator dependencies on time.

Initial data for calculation is presented in table 1.

Table 1. Initial data for calculation

Water heat capacity, J/kg °C	4174	Initial water temperature, °C	293
Water mass, kg	740	Required water temperature, °C	343
Walls heat capacity, J/kg °C	430	Heat transfer area, m ²	27.6
Evaporator mass, kg	10000	TEH power value, kW	24

Water and evaporator temperatures dependency is presented on figure 3. Temperature difference between evaporator walls and water as well as temperature increment of both water and walls are presented on figure 4.

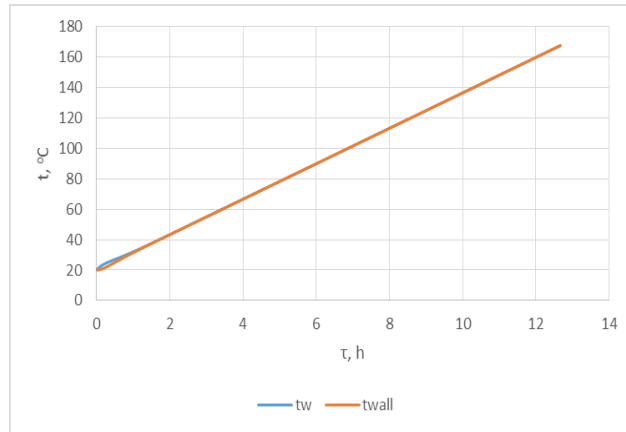


Figure 3. Water and walls temperature dependencies on time

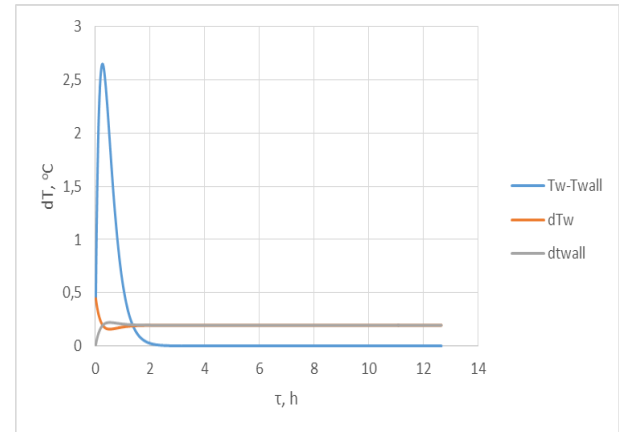


Figure 4. Temperature difference and water and walls temperature increment dependencies on time

As it can be seen from the plots, temperatures of the water and walls became almost the same after approximately 1.5 hours of heating. After that, heat flow is uniformly distributed between water and evaporator itself. Maximal temperature difference between the water and evaporator is equal to 2.65 °C and this value is reached after 0.5 hour of operation. For TEH with power value of 24 kW required regime is achieved after 4.5 hours

3. Updated mathematical model

Mathematical model, suggested above, has several disadvantages. Heat properties of the working fluid and material in real case significantly depend on temperature. Although, heat fluxes from the walls to environment are not considered and heat transfer ration from the water to walls is considered constant. Specification of the mathematical model causes significant complicity (and increase of the number) of differential equations (2) and impossibility to find their analytical solution.

Instead of this, it is suggested to solve equations (20) in numerical form by splitting the calculation on two stages. On the first stage it is suggested that all heat received from the TEH is consumed by water. Calculation of the water temperature for this case is performed. On the second stage, calculation of the heat transfer between water and walls takes place.

Algorithm for every time step is presented on figure 5.

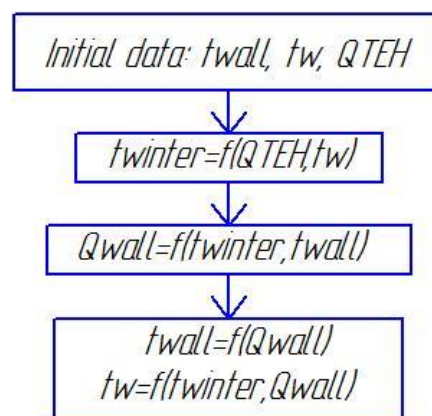


Figure 5. Algorithm for numerical solution

This model allows to take into account the change of the heat properties of the working fluid on every time step.

TEH operation efficiency can be estimated by time, which is required by the plant to achieve water temperature necessary for design operation regime. Comparison of the calculation by numerical and analytical solutions shows the deviation equal to 0.5% which is accurate enough.

Numerical solutions was utilized to obtain characteristics which shows time required for the plant to reach design operation regime depending on TEH power value.

Three variants of the model was analyzed:

- 1) with adiabatic walls;
- 2) with heat exchange between evaporator and environment;
- 3) with heat exchange between evaporator and environment and thermal insulation of the walls of the evaporator.

Heat exchange accounting was performed by calculation of the heat flow between the walls of the evaporator and environment depending on presence of the thermal insulation:

$$Q_{env} = \alpha_{air} F_{ext} (t_{wall} - t_{air});$$

$$Q_{envins} = \frac{1}{\frac{1}{\alpha_{air}} + \frac{\delta_{ins}}{\lambda_{ins}}} F_{ext} (t_{wall} - t_{air}), \quad (6)$$

where α_{air} – heat transfer ration from the walls to air, λ_{ins} and δ_{ins} – heat conductivity and thickness of the insulation.

The result of the analysis is presented on figure 6.

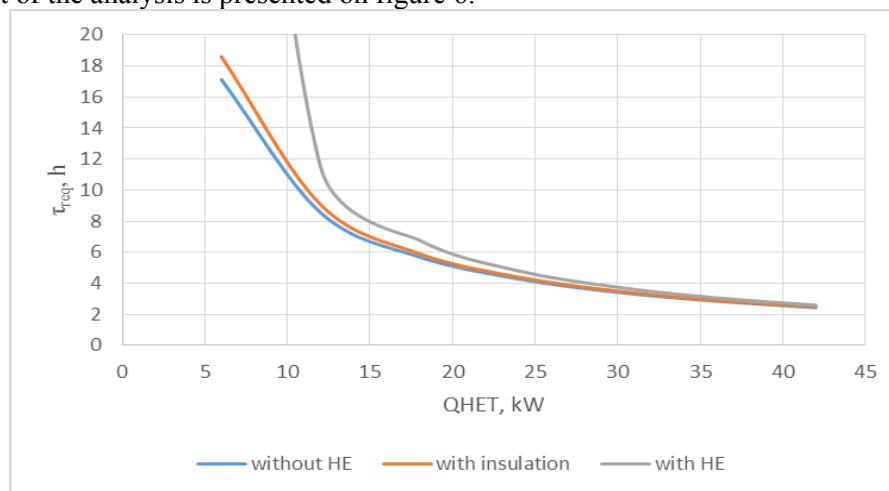


Figure 6. Required time dependency on Q_{TEH} power value

As it can be seen from the figure, presence of the heat exchange between walls and environment significantly slower plant operation start. This decrement is bigger in case of low value of Q_{TEH} . However, results of the case with thermal insulation has almost the same values as result without heat exchange with environment. This means that in case of presence of the thermal insulation heat exchange with environment can be neglected in term of determination of the heating rate. According to technical requirements applied for suggested plant, time of reaching operational regime must not exceed 5 hours. According to dependency, presented on figure 6, required total power of TEH must be more than 24 kW.

4. Conclusions

Mathematical model for process of heating of the distillation desalination plant is developed. This model allows to determine time required for the plant to reach design operation regime. This time varies dependently on the power of the heater. Both analytical and numerical models of this dependencies was developed. Numerical model was used utilized to estimate the influence of the heat

exchange with environment on starting operation time. For the described plant, required power of TEH is equal to 24 kW.

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