Phase change materials (PCM) are substances with specific heat that varies in response to the temperature changes and increases rapidly in temperature of phase transition. It means that heat capacity of PCM tank compared to heat capacity of water tank at the same volume. Therefore, this energy gives the possibility for long-term heat and cold storage. Number of deep change and discharge cycles – number of phase changes from solid to liquid – is one of the limitation of phase change materials. Therefore, the best solution is to charge and consume energy stored in PCM tank as PCM in transition phase. This requires developing an adaptive control system enabling evaluation of charge and discharge rate of PCM storage tank. In order to achieve that, it is necessary to perform simulation tests using PCM mathematical model. There was a need to modify this model due to the fact that PCM characteristics in operating conditions are different from classical model.

INTRODUCTION

Phase change materials (PCM) are substances that are characterised by significant increase of specific heat in transition phase as they change their physical state, for instance from solid to liquid. Therefore, heat capacity of PCM tank compared to heat capacity of water tank at the same volume is much higher. This enables PCM, which is put in air tight container, to act as energy storage with the possibility for long-term heat and cold storage. Despite the fact that phase change materials have been used since the late 19th century, the technology of producing, storing and also controlling charge and discharge system of PCM tank is still being improved and developed. Phase change materials are used in different sectors of the economy due to their physico-chemical characteristics. There are research projects studying the potential of using PCM in hybrid supply system combining solar thermal installation and compressor; ground source heat pump that would cover demand of residential building for cold and heat. Thermal Energy Storage System for Energy Efficient Buildings. Application in domestic solar thermal systems and heat pumps (TESSEb) is one of these projects and is financially supported by the Horizon 2020 Research Innovation Action (RIA) of the European Commission. The main operational problems are the control of PCM tank system and real-time calculation of the energy stored in the tank. These problems are the result of differences between PCM characteristics in operating conditions and those specified in catalogues [1]. The solution is to develop an adaptive control system which requires simulation tests. In order to perform them, it is necessary to modify classical model of phase change material so that its adaptation to PCM characteristics in operating conditions would be possible.

CLASSICAL PCM MODEL

According to literature, the change in specific heat as a function of temperature is represented by the curve (Fig. 1) which is the basic model of phase change material. The figure shows that the value of PCM specific heat is constant in a limited solid phase in a temperature range between \( T_{\text{SN}} \) and \( T_{\text{L}} \) and liquid between \( T_{\text{L}} \) and \( T_{\text{M}} \). The value of specific heat is variable in transition phase in a temperature range between \( T_{\text{SN}} \) and \( T_{\text{L}} \). If the temperature increases above the value of \( T_{\text{L}} \), the value of PCM specific heat also increases. It reaches the maximum value, known as latent heat \( c_p_{\text{sol}} \). If the temperature of PCM continues to increase to the value of \( T_{\text{M}} \), the value of specific heat decreases. According to classical PCM model, the changes in specific heat with increasing temperature are symmetric with respect to the axis running through the point of \( c_p_{\text{sol}} \) [2]. There is a problem with mathematical formula describing the curve representing PCM specific heat variation as a function of temperature. Knowing this formula, it would be possible to define heat capacity of PCM storage tank at any volume and perform simulation tests for any changes in PCM temperature.

\[
\begin{align*}
\begin{array}{c|c|c|c}
\text{Phase} & \text{Solid} & \text{Liquid} & \text{Transition} \\
\hline
\text{x} & \text{y}1 & \text{y5} & \text{y}\text{x}
\end{array}
\end{align*}
\]

Fig. 2. PCM specific heat variation as a function of temperature – basic model.

MODIFIED CLASSICAL PCM MODEL

Classical model of phase change material that is presented in figure 1 was modified. The curve representing specific heat variation as a function of temperature was divided into six parts (Fig. 2) which were described using equations (1). The curve is plotted using three points. The first point has coordinates \((x_1, y_1)\) that refer to temperature and specific heat of PCM transition from solid to transition phase respectively. The second point has coordinates \((x_2, y_2)\) that refer to temperature and latent heat (maximum value) respectively. The third point has coordinates \((x_3, y_3)\) that refer to temperature and specific heat of PCM transition from transition phase to liquid phase. The value of variable \(P_{\text{max}}\) is crucial to modify classical PCM model. It defines the position of specific heat peak point with respect to starting and ending points of phase change. This variable is used for adding asymmetry to Gaussian curve, that shows the change in PCM specific heat as a function of temperature with respect to the point whose coordinates are \((x_2, y_2)\), and adapting it to actual characteristics.

\[
\begin{align*}
\begin{array}{c|c|c|c|c}
\text{x} & \text{y}1 & \text{y5} & \text{y}\text{x} \\
\hline
\text{x} & \text{y}1 & \text{y5} & \text{y}\text{x} \\
\end{array}
\end{align*}
\]

Fig. 2. The curve representing PCM specific heat variation as a function of temperature for \(P_{\text{max}} = 0.5\).

SUMMARY AND CONCLUSIONS

Phase change materials (PCM) can store heat and cold for a long period of time. The number of deep charge and discharge cycles is a crucial parameter that has an impact on aging process of phase change material. Therefore, the monitoring of charge (discharge) rate of PCM storage tank is a very important issue when the system is in operation. Moreover, there is a difficulty with differences between PCM characteristics in operating conditions and those specified in catalogues. The solution of this problem is to develop an adaptive control system of PCM storage tank, which requires simulation tests based on PCM model that would be able to copy PCM characteristics in operating conditions. Thus, classical PCM model was modified by dividing the curve representing the correlation between specific heat and temperature of PCM into six parts. The results of presented simulation tests show that the position of latent heat point with respect to PCM temperature has a major impact on the amount of energy which can be stored in the tank (the same PCM mass). This means that if the simulation tests were performed using classical model of PCM whose characteristics would be defined by catalogue data, and the point of latent heat would be moved to the left with respect to PCM temperature in operating conditions, less energy would be stored in the tank compared to the information shown in catalogues. As a consequence of using classical model of PCM, PCM storage tank would be often deeply discharged and overcharged, which would significantly shorten service life of phase change material. The process of charging and discharging PCM storage tank can be optimised by implementing method that was presented in this paper.

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