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Thermal Design and Analysis on Energy Storage Systems using Sodium Sulphate Decahydrate with a Heat Exchanger Model

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ABSTRACT: Energy storage system in the form of Latent heat is more versatile form of storing thermal energy. In the case of solar thermal power conversion systems, waste heat recovery process, sensible heat supply and chemical process heating. Phase change materials which can be employed in the heat exchangers to store temporary heat in the form of latent heat. This paper deals with sodium sulphate decahydrate in annuls of the regenerative heat exchanger. A computational fluid dynamic Analysis is conducted to analysis specific energy density of the material under the design conditions at high level applications. In process heating we need to provide sustainable amount of sensible heat to increase the efficiency of the overall plant in those conditions we need robust energy storage device to employ and to operate under the amide specifications. Due to the effective properties of the selected material it is allowed to improve velocity of the fluid circulating inside annuls will be an effective factor for handling higher mass flow rates. The analysis is more concentrated on the rate of heat exchange to improve effectiveness of the heat exchanger, so that handling of High heat capacity process also possible with this model of energy storage system. Sodium sulfate decahydrate is a substance with high heat of fusion which is capable of storing or releasing large amount of energy. The temperature of sodium sulfate decahydrate also remains constant during the phase change which is useful for keeping the subject at uniform temperature. In the present paper, we are considering a regenerative type heat exchanger in which the fluid is passing through the inner tube and the sodium sulfate decahydrate is inserted in the annulus in the exchanger. Then thermal analysis is done by studying the temperature profiles of the sodium sulfate decahydrate. When sodium sulfate decahydrate is having high thermal conductivity, the temperature gradient required for the storage material is small. We can observe uniform temperature distribution as the thermal conductivity for the sodium sulphate decahydrate is high. Due to this uniform temperature distribution, Forced convection takes place in the liquid domain of sodium sulfate decahydrate

KEYWORDS: Phase change materials, Regenerative heat exchanger, Energy storage systems, Sodium sulphate decahydrate etc.

I. INTRODUCTION

Energy Storage plays an important role in conservation of energy from various heat sinks. In the process plants we need short term storage of energy to supply as a sensible heat to the same process. Sensible heat storage is the most efficient way of storing energy due to higher storage density and with a smaller temperature difference between storing and releasing heat [1]. In the Phase change Materials we have various temperature ranges are available like par-fine wax which are having moderated thermal energy density but low thermal conductivity. These kinds of materials required to have more surface area to store and retrieve the heat under practical conditions. The efficiency of such devices will be determined by its acceptance of temperature range and the specific energy density in the storage. Heating materials which undergo phase change and stores energy in the form of latent heat. The ideal requirements of energy storage are rapid access and versatility of the energy form the store is delivered. Conversation of one form of stored energy into another form of stored energy may be advantageous in order to suit utilization. Energy storage at low temperatures is needed in renewable systems such as solar absorbers delivering space heating, hot water, and eventually heat for cooking up to 100°C [4]. The actual heat storage devices may be of modest size, aiming at delivering heat during the night after a sunny day, or they may be somewhat larger, capable of meeting the demand during a number of consecutive overcast days [3]. Finally, the storage system may provide seasonal storage of heat, as

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required at high latitudes where seasonal variations in solar radiation are large and, furthermore, heat loads are to some extent inversely correlated with the length of the day.

In the thermal energy storage methods we can also use materials for storing energy without phase change. Whereas in the form of phase change amount of energy that can be stored is double than the sensible heat storage method [2]. The storage operates isothermally at the melting point of the material, if isothermal operation at the phase change temperature is difficult and the system operates over a range of temperature between the upper limit and the lower limit that includes the melting point. The sensible heat contribution also considered and the amount of energy stored is calculated with equation 1.

$$E = m\left[\left\{\int_{T_1}^{T^*} C_{ps}dT\right\} + \lambda + \left\{\int_{T^*}^{T_2} C_{Pl}dT\right\}\right]$$

In the above equation T_1 and T_2 represents the operating temperature range and the C_{ps} and C_{pl} represents the specific heats of the solid and liquid phases and T^* is the melting point. There are large numbers of phase change materials that melt and solidify at a wide range of temperatures and making them attractive in large number of applications [9]. Paraffin waxes are cheap and have moderate thermal energy storage density, but low thermal conductivity hence it required large surface area. The better option is to select hydrate salts to have larger energy storage density and higher thermal conductivity.

II. REGENERATIVE HEAT EXCHANGER FOR ENERGY STORAGE

A regenerative type heat exchanger typically uses the fluid from heat source and transfer to Phase change material in the same system. In the regenerative heat exchangers both hot and cold fluids will pass through the same chamber and heat is transferred through a partition wall. The operation of regenerative heat exchanger involves the temporary storage of the heat transferred to annulus [10]. The phase change material which is inserted inside annuls will store heat in the form of latent heat. The analysis of the heat transfer problem is about phase change and solidification along with the solid- liquid boundary.

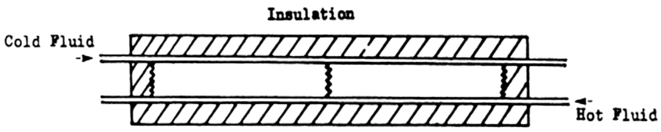

Fig. 1: Sodium Sulphate Decahydrate arrangements in Annulus

The analysis is based on the speed at which the latent heat is absorbed or lost at the boundary, so that the position of the boundary is not known prior and forms part of the solution [6]. When the substance that is pure, the solidification occurs at a single temperature, in this later case it was appropriate to consider energy equation in terms of enthalpy under advective movements in the inner of the liquid is discharged and it will be expressed mathematically as in the equation below.

$$\rho\frac{\partial h}{\partial t} = \vec{\nabla}(\lambda.\vec{\nabla}T)$$

The method evaluates the equation to find temperature at each point and the value of the thermo physical properties [5]. According to the temperature field it is possible to ascertain the position of the two boundaries. It will be a specific consideration in the computational fluid dynamic analysis to address enthalpy and flow interaction with the sodium decahydrate.

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III. PHASE CHANGE MATERIALS

Phase change materials are the latent heat materials which has low temperature range. When compared to sensible heat storage , Phase change materials have high energy density of melting and solidification. The main properties of Phase change materials are, it has a high latent heat of fusion and also, high specific heat which provides additional sensible heat storage effect. This property also avoids sub-cooling. These have high thermal conductivities, which are helpful for in decreasing the temperature gradient for charging the storage material. Also Phase change materials are non – poisonous, non-flammable and non-explosive.

Phase change materials generally have high heats of fusions. In this the reason that, they can easily absorb more energy before melting of solidifying. During the phase change, the temperature of the Phase change material remains constant. Therefore, a uniform temperature will be maintained during the phase change process.

IV. CFD ANALYSIS ON SODIUM SULPHATE DECAHYDRATE

Inorganic phase change materials are engineered hydrated salt solution made from natural salts with DE-mineralized water. The chemical composition of salts is varied in the mixture to achieve required phase change temperature [7].
Special nucleating agents are added to the mixture to minimize phase change salt separation and eliminating super cooling requirement that are otherwise characteristic of hydrated salt PCM .

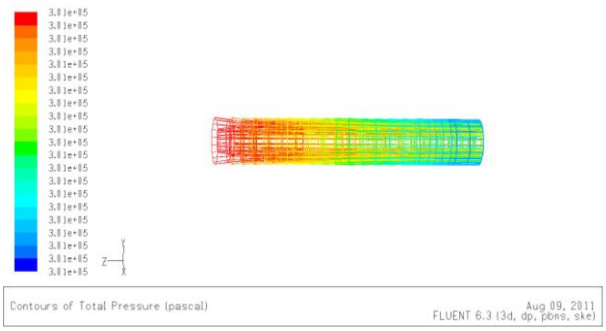

Fig. 2: Total Pressure Profile in the Annuls

Pressure inside the system also plays an important role in string the energy, from the total pressure contours shown in the figure 2 above. The out let pressure is high when sodium sulphate decahydrate attains the liquid state by gaining the energy from the hot fluid. In applications with low temperature difference very high storage densities can be achieved using sodium sulphate decahydrate [8]. Concentrating the storage density with increasing the temperature difference the advantage compared to water gets lower because of the increasing influence of the sensible heat.
From the above figure, we can say that, in the annulus, there is a change in the total pressure at each step. This change is because of the change of phase inside the heat exchanger due to the PCM.

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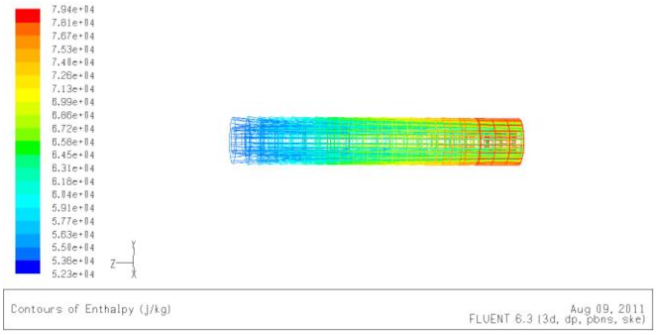

Fig. 3: Enthalpy in Sodium Sulphate Decahydrate Annuls

From the above enthalpy contour plot, we can say that, as per the given initial and boundary conditions, enthalpy contours shown a decent increase at every time step.

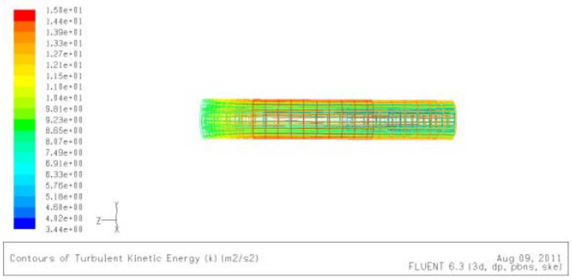

Fig. 4: Turbulent Kinetic Energy in Sodium Sulphate Decahydrate Annuls

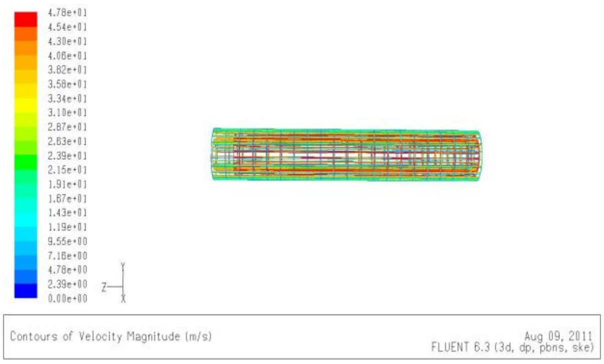

Fig. 5: Velocity Magnitude in Sodium Sulphate Decahydrate Annuls

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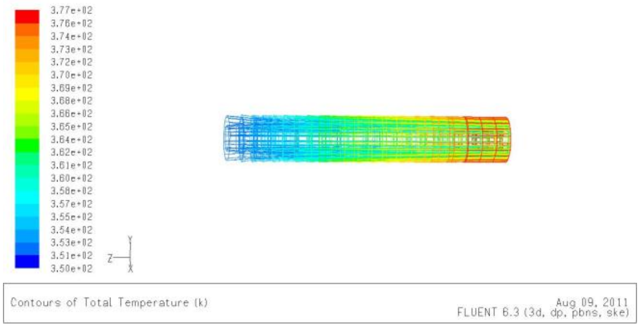

Fig. 6: Total Temperature Contours

In the total temperature contours of latent heat transfer between the hot fluid and sodium sulphate decahydrate is shown in the figure 2 below. The heat interaction at the inlet is high due to high enthalpy content

The enthalpy content in the annuals is represented by the contours of enthalpy in the figure 4, total kinetic energy and velocity magnitude of the flow is represented in the figures 5 and 6. The energy density is a direct representation from the 7.95 $e^{+}04$ is the maximum enthalpy in J/Kg at a speed of 47.8 m/s which indicates the effective design of the heat exchange and also the storage system silent futures.

V. CONCLUSIONS

In this paper we tried to understand the behavior of the sodium sulphate decahydrate under high temperature difference. The main objective is to demonstrate the heat transfer mechanism in a regenerative heat exchanger with hydrate salts as a phase change material. The total enthalpy content from the computational fluid dynamic analysis results indicate the effectiveness of the heat exchange process with the moderated phase change materials. Also in this analysis we can understand that at high temperature difference the problem of super cooling in the phase change materials is minimized. Interesting factor in the thermal energy storage is necessary discharge power from the above analysis we can understand that for short term storage the discharge power is high.

VI. FUTURE DEVELOPMENT OF THE WORK

In the present paper, as we tried to show the analysis of a Heat exchanger with PCM's through Computational Fluid Dynamics, we can increase the complexity of the heat exchanger. For example, predicting the effect of PCM in spiral heat exchanger makes this work much more interest in the field of Computational Fluid Dynamics.

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