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(54) Title: TRANSIENT ANALYSIS OF PHASE CHANGE MATERIAL HEAT EXCHANGER

(57) Abstract: According to an embodiment of the invention, a method 100 for identifying transient thermal behaviour of a phase change material (PCM) heat exchanger by simulation is disclosed. The method 100 receives the inputs 102 for modelling the phase change material heat exchanger. A model is simulated 104 for analysing the transient behaviour of the heat exchanger such that the simulation model varies the simulation conditions depending on a temperature of the phase change material.

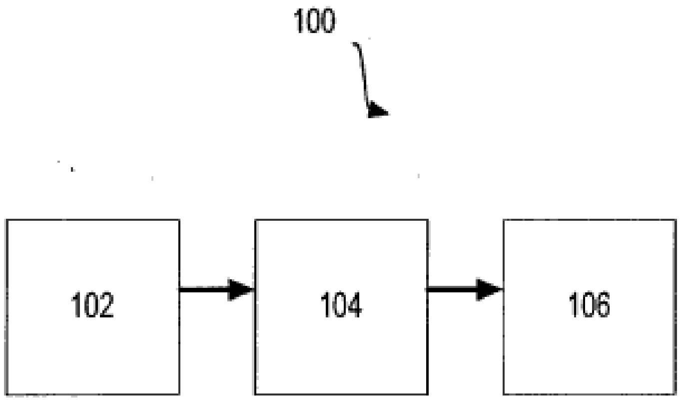

Figure 1

TRANSIENT ANALYSIS OF PHASE CHANGE MATERIAL HEAT EXCHANGER

ABSTRACT

According to an embodiment of the invention, a method 100 for identifying transient thermal behaviour of a phase change material (PCM) heat exchanger by simulation is disclosed. The method 100 receives the inputs 102 for modelling the phase change material heat exchanger. A model is simulated 104 for analysing the transient behaviour of the heat exchanger such that the simulation model varies the simulation conditions depending on a temperature of the phase change material.

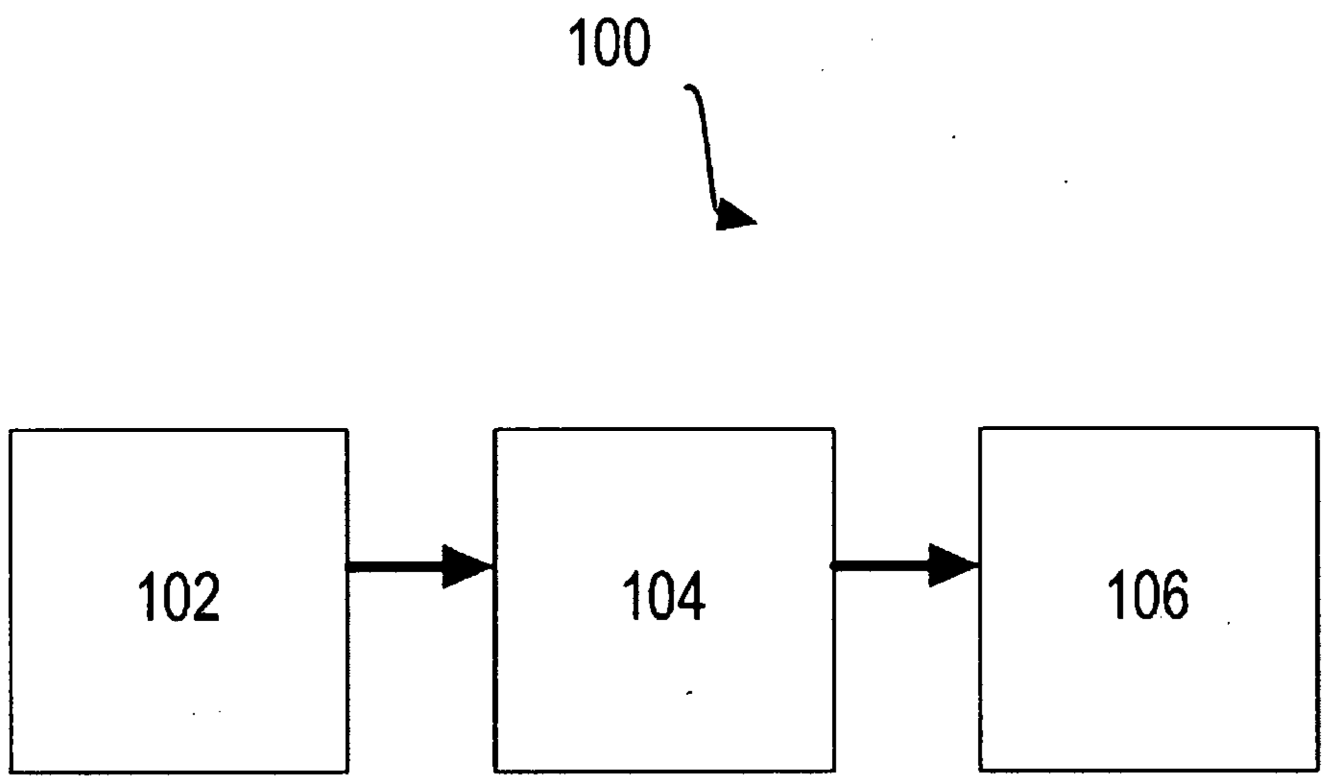

Figure 1

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Claims:

1. A method 100 for identifying transient thermal behaviour of a phase change material (PCM) heat exchanger by simulation, the method 100 comprising:

receiving inputs 102 for modelling the phase change material heat exchanger; and

simulating a model 104 using the received inputs for analysing the transient behaviour of the heat exchanger such that the simulation model varies the simulation conditions depending on a temperature of the phase change material.

2. The method of claim 1 wherein a heat transfer between the heat exchanger and the PCM is through natural convection.

3. The method of claim 1 wherein the inputs for modelling the heat exchanger are received using macro based template.

4. The method of claim 1 further comprising: the simulation model can be used for varied operating parameters of the heat exchanger.

Dated this 13th day of April 2015

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FIELD OF INVENTION

The present invention relates generally to a method for simulating a heat exchanger.

BACKGROUND

Simulation is the imitation of the operation of a real-world process or system over time. A computer simulation is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works. By changing variables in the simulation, predictions may be made about the behaviour of the system. It is a tool to virtually investigate the behaviour of the system under study. One of the widely used application of simulation lies in heat exchangers.

Heat exchanger are typically used for heat transfer applications. There are many types of heat exchanger, however heat exchanger utilizing a phase change material (PCM) has been widely used in latent heat thermal storage systems for heat pumps, solar engineering, and spacecraft thermal control applications. The uses of PCMs for heating and cooling applications for buildings have been investigated within the past decade. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications.

A reasonable analysis is done on modelling the PCM heat exchanger at two phases i.e. when PCM changes from solid to liquid state. However, little analysis is done on modelling the transient analysis of PCM heat exchanger at all the three phases, say solid, mushy and liquid state. Hence, there is a need for a simulation model for analysing the transient behaviour of a PCM heat exchanger at all the three states of the PCM.

SUMMARY OF THE INVENTION

According to an embodiment of the invention, a method for identifying transient thermal behaviour of a phase change material (PCM) heat exchanger by simulation is disclosed. The method receives the inputs for modelling the phase change material heat exchanger. A model is simulated for analysing the transient behaviour of the heat exchanger such that the simulation model varies the simulation conditions depending on a temperature of the phase change material.

BRIEF DESCRIPTION OF DRAWINGS

Other objects, features, and advantages of the invention will be apparent from the following description when read with reference to the accompanying drawings. In the drawings, wherein like reference numerals denote corresponding parts throughout the several views:

Figure 1 shows a block diagram of modelling PCM heat exchanger, according to one embodiment of the invention; and

Figure 2 shows a graph of enthalpy vs temperature of a PCM heat exchanger, according to an embodiment of the invention.

DETAILED DESCRIPTION OF DRAWINGS

The following description with reference to the accompanying drawings is provided to assist in a comprehensive understanding of exemplary embodiments of the invention as defined by the claims and their equivalents. It includes various specific details to assist in that understanding but these are to be regarded as merely exemplary. Accordingly, those of ordinary skill in the art will recognize that various changes and modifications of the embodiments described herein can be made without departing from the scope and spirit of the invention. In addition, descriptions of well-known functions and constructions are omitted for clarity and conciseness.

Figure 1 illustrates a block diagram of process 100 for simulating PCM heat exchanger, according to an embodiment of the invention. The process 100 illustrates an exemplary embodiment for modelling plate fin PCM heat exchanger using a simulation software. According to an embodiment, the simulation software may be selected from a group consisting of MATLAB, Simulink and VisSim software. According to an embodiment of the invention, PCM may include any known phase change material such as, but not limited to paraffin, ice, etc.

At step 102, inputs may be received for modelling the heat exchanger. According to an exemplary embodiment, the inputs for modelling the heat exchanger may be received through a macro based template. The inputs may include design parameters, material properties, fluid properties and initial conditions of the heat exchanger.

According to an embodiment of the invention, the design parameters may include parameters such as height, depth and width of the heat exchanger, diagonal pitch between tube centers, longitudinal tube spacing in the flow direction, transverse tube spacing to the flow direction, number of rows, number of columns, depth of the fins, height of the fins, thickness of the fins and spacing of the fins, number of plate fins, inside and outside tube diameter, tube length, U bend radius of curvature, no. of U bends, width, height, depth, thickness, fin width and fin depth of water jacket, plate height, plate depth and plate thickness of end fin and gravity.

According to another embodiment of the invention, the material properties may include properties such as tube metal initial temperature, water jacket initial temperature, tube metal thermal conductivity, tube metal density, tube metal heat capacity, fin thermal conductivity, fin density, water jacket thermal conductivity, water jacket heat capacity and water jacket density.

According to yet another embodiment of the invention, the fluid properties may include properties of tube side fluid, PCM and ambient air The fluid properties of tube side fluid may include prandtl number, thermal conductivity, dynamic viscosity, heat capacity and density of tube water. The fluid properties of ambient air may include prandtl number, thermal conductivity, dynamic viscosity, heat capacity and density. The fluid properties of PCM may include melting temperature, heat capacity of liquid, heat capacity of solid, thermal conductivity of solid, thermal conductivity of liquid, density of liquid, density of solid and latent heat capacity.

According to an exemplary embodiment of the invention, the initial conditions may include tube water velocity, tube water mass flow rate, tube water inlet temperature, tube water initial temperature, PCM initial temperature, air ambient temperature, air velocity, air mass flow rate and initial time delay in experiments.

The inputs received at step 102 may further include heat transfer area of the tube's inner, outer and fin area; mass and volume of tube water, tube metal and fin mass; and thermal resistance for tube water, tube metal, fin overall efficiency and outside heat transfer coefficient.

At step 104, the inputs received in step 102 may be processed to simulate a model for an exemplary heat exchanger with phase change material. According to an embodiment, the heat exchanger may be a plate fin heat exchanger. According to another embodiment of the invention, the simulation process may vary the simulation conditions depending on a temperature of the PCM. According to another embodiment of the invention, the simulation conditions may be used for varied operating parameters of the heat exchanger. The model may be generated by using one or more governing equations.

According to an exemplary embodiment of the invention, the heat exchanger system may include copper tubes defining an inside tube flow, and plain plate fins provided in an outer jacket containing PCM. According to an exemplary embodiment, heat exchanger may be used for thermal storage purposes and the inside tube may contain a coolant fluid. The coolant may absorb heat from the system and may transfer the absorbed heat to the copper tubes. The temperature rate of change of the system at each segment may be theoretically calculated by using one or more governing equations.

For the purpose of illustration, exemplary governing equations are illustrated in the description below. The exemplary governing equations are only for illustration purposes and not limiting thereto.

According to an exemplary embodiment, the heat transfer taking place between the heated water flowing in the tube and tube metal may be governed by the following equation:

$$m_w C_{pw} \frac{dT_{wout}}{dt} = \dot{m}_w C_{pw}(T_{win} - T_{wout}) - \frac{(T_{wout} - T_{surf})}{R_{water} + R_{surf}}$$

According to another exemplary embodiment, the heat transfer taking place from tube metal to PCM may be governed by the following equation:

$$m_{surf}C_{psurf}\frac{dT_{surf}}{dt} = \frac{(T_{wout} - T_{surf})}{R_{water} + R_{surf}} - \frac{(T_{surf} - T_{pcm})}{R_{pcm}}$$

According to yet another exemplary embodiment, the heat transfer taking place from PCM to ambient may be governed by the following equation:

$$m_{wj}C_{pwj}\frac{dT_{wj}}{dt} = \frac{(T_{pcm} - T_{wj})}{R_{wj}} - \frac{(T_{wj} - T_{amb})}{R_{air}}$$

wherein m corresponds to Mass in kg, T corresponds to Temperature in K, R corresponds to Thermal Resistance in k/w and C_p corresponds to Heat capacity in J/(kg K). The subscripts surf corresponds to Metal tube, pcm corresponds to Phase change material, wj corresponds to Water Jacket, w corresponds to Tube water, out corresponds to outlet, in corresponds to inlet and amb correspond to ambient.

The phase change of the PCM may further be modelled using another set of governing equations. The PCM may include solid, mushy and liquid state with change in time and temperature. According to an exemplary embodiment of the invention, separate equations may be used to identify PCM temperature at solid, mushy and liquid state. According to another embodiment, the equations may be calculated by considering heat conduction only.

Solid state:

The heat released by the tube metal may be equal to the energy transfer causing the temperature change in PCM in solid state.

$$T_{pcm} < T_s$$

$$\rho_s V C_s \frac{dT_{pcm}}{dt} = \frac{(T_{surf} - T_{pcm})}{R_{pcm}} - \frac{(T_{pcm} - T_{wj})}{R_{wj}}$$

Mushy state:

After the PCM temperature reaches the phase change level, the energy supplied to the PCM may be stored in the material in the form of latent heat.

$$T_s < \mathrm{T_{pcm}} < T_l$$

$$\rho_l V \mathrm{C_l} \frac{\mathrm{dT_{pcm}}}{\mathrm{dt}} = \frac{(\mathrm{T_{surf}} - \mathrm{T_{pcm}})}{\mathrm{R_{pcm}}} - \frac{(\mathrm{T_{pcm}} - \mathrm{T_{wj}})}{\mathrm{R_{wj}}}$$

Liquid state:

The liquid phase temperature may be calculated by considering conduction heat transfer and heat losses to outer jacket.

$$\mathrm{T_{pcm}} > T_l$$

$$\rho_{pcm} V \mathrm{C_{pcm}} \frac{\mathrm{dT_{pcm}}}{\mathrm{dt}} = \left[\frac{(\mathrm{T_{surf}} - \mathrm{T_{pcm}})}{\mathrm{R_{pcm}}} - \frac{(\mathrm{T_{pcm}} - \mathrm{T_{wj}})}{\mathrm{R_{wj}}}\right] * \left(\frac{1}{1 + \frac{Latent\ Heat}{\mathrm{C_{pcm}}\,(T_l - T_s)}}\right)$$

Where

$$\rho_{pcm} = \frac{\rho_s + \rho_l}{2}$$

$$\mathrm{C_{pcm}} = \frac{\mathrm{C_s} + \mathrm{C_l}}{2}$$

wherein ρ corresponds to Density (kg/m^3), C corresponds to Heat Capacity (J/kg K), V corresponds to Volume (m^3) and R corresponds to Heat Transfer Resistance (K/W). The subscripts *l* corresponds to liquid, s corresponds to solid, pcm corresponds to laminar flow, wj corresponds to water jacket and surf corresponds to metal surface.

At step 106, outputs of the simulation model may be in the form of temperature output results, enthalpy calculation results and heat transfer rate output results. The temperature output results may be Plate Fin (PF) heat exchanger-PCM temperatures at specified locations. The enthalpy calculation results may include heat content calculations. The heat transfer rate output results may include PF heat transfer rate from tube metal to PCM and PF heat transfer rate from water jacket to ambient. According to an embodiment of the invention, the output may be according to a pre-defined format. According to another embodiment of the invention, the output may be in a format specified by user.

Figure 2 illustrates an exemplary graph of enthalpy vs temperature of the illustrated PCM heat exchanger, according to an embodiment of the invention. When the PCM at a solid phase is warmed up, sensible temperature increases with time, until it reaches a melting temperature. The energy received by the PCM is used for breaking the intermolecular bonds and the PCM material changes from the solid state to the liquid state. The temperature, theoretically, does not rise until the whole material is in molten form. The amount of energy required to change the PCM from the solid state to the liquid state is called latent heat. The temperature rise in latent heat zone may be due to temperature difference between solidus and liquidus temperature. Once the PCM reaches the liquid state, the temperature starts increasing with time.

For the purpose of illustration, plate-fin heat exchanger has been used in various exemplary embodiments of the invention. The plate-fin heat exchanger is for illustration purpose only and not limiting thereto. Any other heat exchanger may be used without deviating from the scope of this invention.

In the drawings and specification there has been set forth preferred embodiments of the invention, and although specific terms are employed, these are used in a generic and descriptive sense only and not for purposes of limitation. Changes in the form and the proportion of parts, as well as in the substitution of equivalents, are contemplated as circumstances may suggest or render expedient without departing from the spirit or scope of the invention.

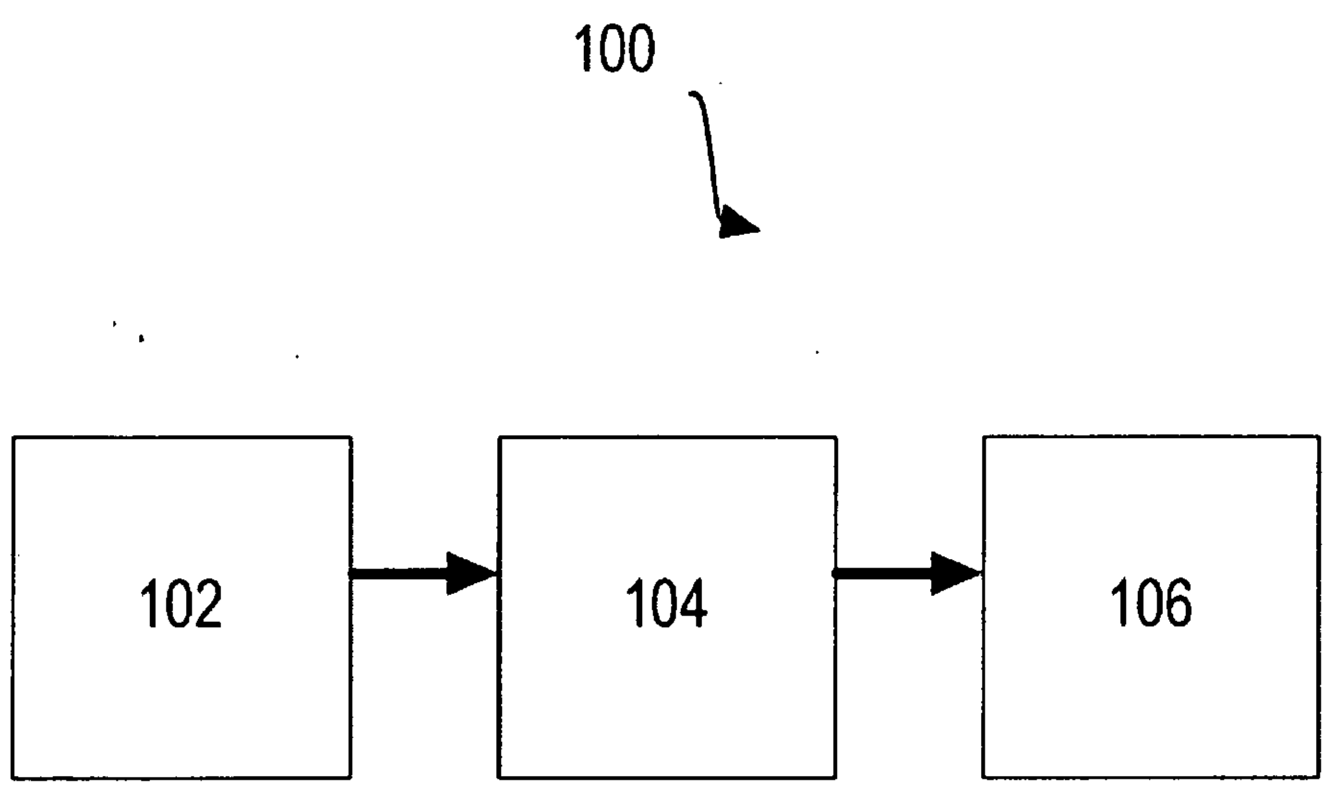

Figure 1

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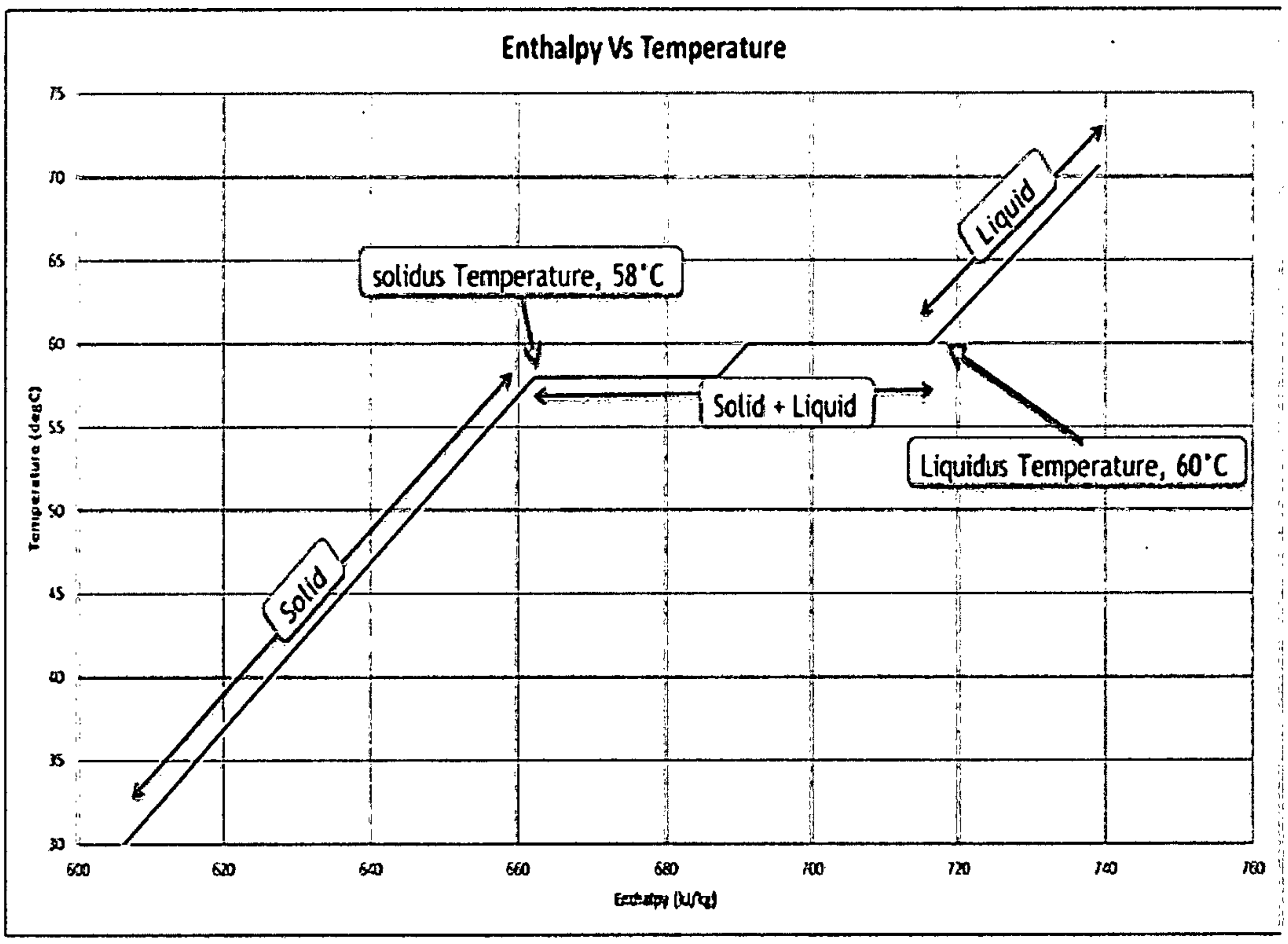

Figure 2

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