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CONVENTIONAL WALLBOARD WITH LATENT HEAT STORAGE FOR PASSIVE SOLAR APPLICATIONS

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ABSTRACT

Conventional wallboard impregnated with octadecane paraffin (Melting Point - 73.5°F) is being developed as a building material with latent heat storage for passive solar applications. Impregnation was accomplished simply by soaking the wallboard in molten paraffin. Concentrations of paraffin in the combined product as high as 35% by weight were achieved. In support of this concept, a computer model was developed to describe thermal transport and storage by a phase change material (PCM) dispersed in a porous media. The computer model was confirmed by comparison with known analytical solutions where the PCM melts at a specific melting point. However, agreement between the model and an experimentally produced thermal transient involving impregnated wallboard was only good after the model was modified to allow the paraffin to melt over a temperature range. This was accomplished by replacing the heat of fusion with a triangular heat capacity relationship that mimics the triangular melt curve found through differential scanning calorimetry. When this change was made, agreement between the model and the experimental transient was very good.

1. INTRODUCTION

Conventional gypsum wallboard impregnated with octadecane paraffin has been identified by Dr. Ival Salyer, of the University of Dayton Research Institute (UDRI), as an attractive latent heat thermal energy storage component for the passive solar application. The melting point of technical grade octadecane is about 75°F, and its heat of fusion is about 80 Btu/lb. There are several ways to impregnate wallboard with paraffin. The easiest is to simply immerse the wallboard into a vat of molten paraffin; the wallboard absorbs the paraffin like a sponge. Concentrations up to 35 wt% of the combined product can be obtained. This method was selected for development work because it does not involve the wallboard manufacturer. Full-sized sheets (4 × 8 ft) of wallboard have been impregnated by this method, and the paraffin distribution has been shown to be completely uniform throughout the board. UDRI has exposed impregnated boards to elevated temperatures (100°F) for extended periods and has thermally cycled them across the melting point many times with no deleterious effects [1]. UDRI is currently investigating the effect of fire retardants on the flammability of this material. In support of this concept, Oak Ridge National Laboratory (ORNL) has developed a computer model, WALL88, to describe thermal transport and storage by a confined latent heat storage material in the wallboard configuration [2]. ORNL has also measured the thermal conductivity of impregnated wallboard [3], and developed experimental thermal transient data with which to confirm the analytical model. Comparison of the computer model to the experimental transient is the subject of this report [4].

2. THERMAL ANALYSIS

WALL88 is a numerical code developed to study transient thermal transport and storage of both sensible and latent heat in multi-component building materials. Specifically, WALL88 was prepared for the two-dimensional rectangular case of wallboard. The code can treat the phase change material (PCM) as if it were uniformly mixed with the matrix material or as if the PCM were present in the form of discrete two-dimensional pellets distributed randomly throughout the solid support matrix. The randomness of the method is based on the use of a random number generator. The surface boundary condition considers both convective heat transfer with the room air and direct gain of solar energy. A constant surface temperature can also be imposed by setting the heat transfer coefficient equal to infinity. WALL88 is available on diskettes in both source and executable forms and in both FORTRAN and Microsoft BASIC language versions.

The original version of WALL88 treated the PCM as an ideal storage material; i.e., one that melted and froze at a specific temperature. The sensible and latent energy storage components of this version were confirmed by comparing it to known analytical solutions. Nevertheless, it was felt that the best confirmation of WALL88 would result from its comparison to an experimentally produced thermal transient with wallboard.

The experimental thermal transient was developed with equipment used to measure the thermal conductivity of building materials. Figure 1 shows a sideview schematic of the device. It consists of a very thin screen wire resistance heater with 4 sheets of wallboard on both sides (2-directional heat flow), and enclosed by thick copper plates containing cooling coils. The screen wire heater is 3 × 5 ft. The samples to be tested are 2 × 3 ft and are surrounded by a picture frame of low conductivity material. The heating transient is produced as follows: first, the stack of eight sample sheets of wallboard (4 above and 4 below the heater) was allowed to become isothermal at a temperature below the melting point of the paraffin. During this period the heater was turned off and the temperature of the wallboard stack was controlled by the cooling coils. Thermocouples were placed on the heater, between each sheet of wallboard, and between the wallboard and copper cooling plate. Five thermocouples were located at each position. Typically, several days were required for the stack to become isothermal. Then, at time equal to zero, the heater was turned on to a predetermined power level, and the thermal transient was initiated. The heater power level and the copper plate temperature were held constant, and all temperatures were recorded continuously during the transient. Typically a transient lasted several days. At the end of the transient, the temperature gradient through the stack of wallboard was a straight line. From the heater power and the temperature difference across the stack we could compute the thermal conductivity for later use in the computer model confirmation studies. Note that the copper cold plates were maintained below the melting point during the entire transient, but the wallboards near the heater were taken above the melting point. Thus, at the end of the transient, the liquid-solid phase front was located somewhere inside the stack.

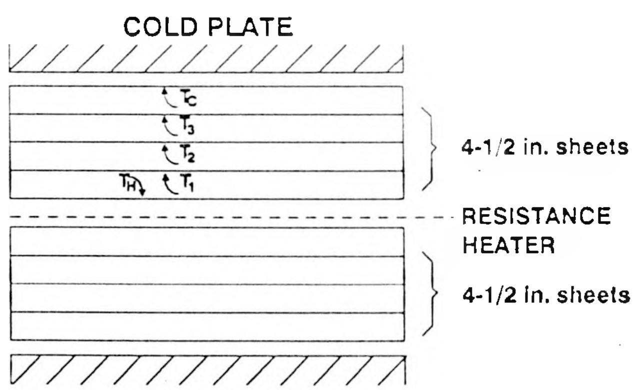

Figure 1 - Thermal transient experiment

Figure 2 compares the results of the experimental thermal transient using wallboard that contained 30% paraffin with a simulation of the transient by WALL88. The temperatures are defined in Figure 1. For this calculation the melting point of the paraffin was taken to be 74.0°F. The heat of fusion of octadecane is 84 Btu/lb-paraffin which is equivalent to 25.2 Btu/lb-wallboard. The thermal conductivity was the measured value of 0.134 Btu/hr-ft-°F, and the heat capacity was also a measured value of 0.35 Btu/lb°F. Agreement between the measured and computed curves is poor. An important observation is that the computed values tend to level off at the melting point, as one would expect. However, the measured values show no tendency to level off.

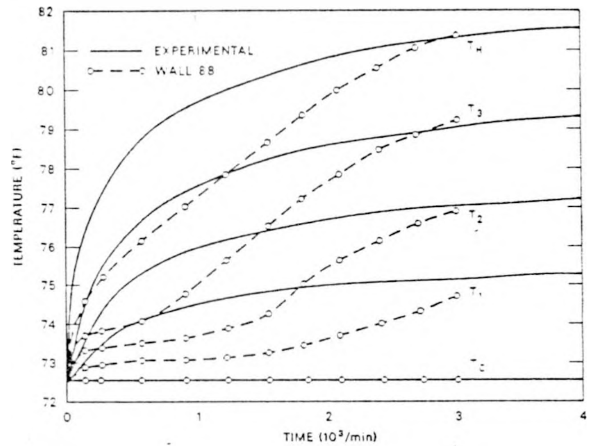

Figure 2 - Comparison of WALL88 to measured data. Assumed melting point = 74°F

It became apparent that treating melting as occurring at a specific temperature was inadequate for the situation. A DSC plot for the octadecane used in these tests is shown in Figure 3.

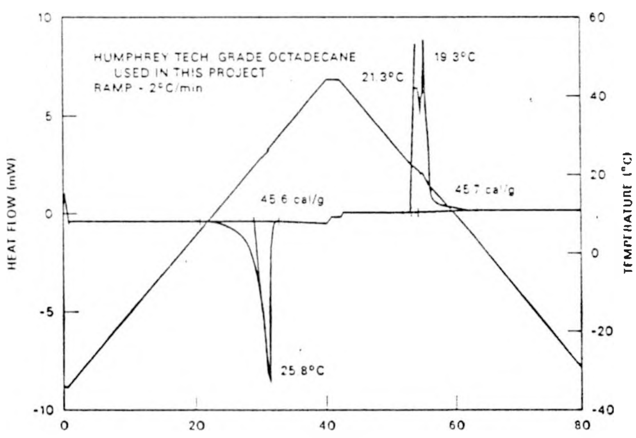

Figure 3 - DSC plot of octadecane paraffin

The triangular section of the melt curve covers a range of about 10°F. The experimental transient also covers a range of about 10°F, and since they coincide, this effect must be accounted for. This was accomplished by replacing the specific melting point in the code with the triangular heat capacity relationship shown in Figure 4. This relationship is similar to the triangular portion of the melt curve on the DSC plot. TA and TB represent the intersection of the triangular legs with the horizontal line on the DSC curve. TM represents the melting point and would be the peak temperature on the DSC melt curve. Cp-Max is a computed value such that the shaded area under the triangle is equal to the heat of fusion of the PCM.

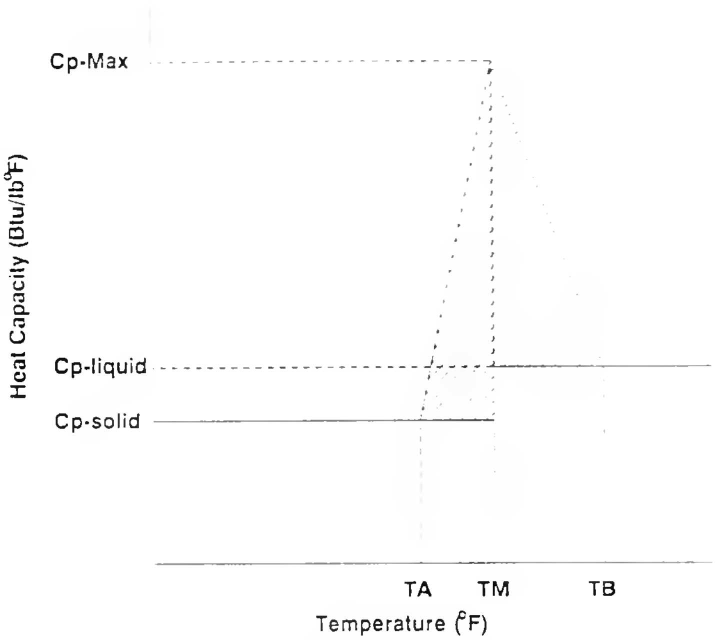

Figure 4 - Heat capacity relationship to simulate a melting range.

The comparisons shown in Figure 2 were repeated with the triangular heat capacity relationship. TM was taken to be 74.0°F; TA and TB were 67.1°F and 77.9°F respectively. Cp-Max was computed to be 5.01 Btu/lb°F based on a heat of fusion of 25.2 Btu/lb-wallboard. The results of this calculation are shown in Figure 5. Agreement between measured and computed temperatures are still not good. However, the situation has improved because the leveling off of the computed values near the paraffin melting point is no longer present.

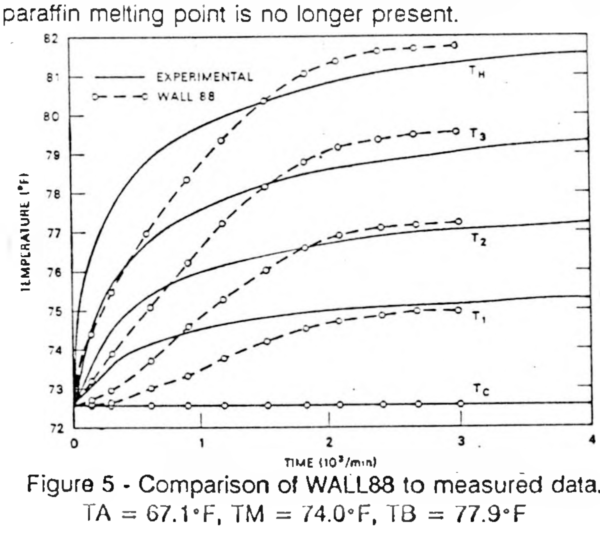

Figure 5 - Comparison of WALL88 to measured data. TA = 67.1°F, TM = 74.0°F, TB = 77.9°F

Input data for the next computer run was taken entirely from the melt curve of the DSC plot (Figure 3). The value of TM was taken to be 78.5°F. TA and TB were taken to be the temperatures where the base of the triangular portion of the melt phase intersects the horizontal line, 71.6°F and 82.4°F respectively. The heat of fusion measured by the DSC includes the tail of the melt curve; i.e., the curved portion of the melt phase between 20 min and 28 min. This portion accounts for about 30% of the heat of fusion. It is not included in the triangular heat capacity relationship since it is outside the range of the transient experiment. Thus the heat of fusion was reduced to 70% of the original value to eliminate this effect. This resulted in a new Cp-Max of 3.62 Btu/lb°F. Results of this computer run are shown in Figure 6. Agreement between experimental and computed values is quite good.

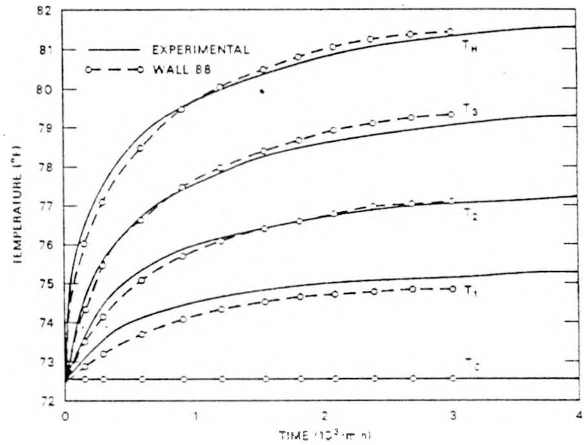

Figure 6 - Comparison of WALL88 to measured data. TA = 71.6°F, TM = 78.5°, TB = 82.4°F

When the heating transient experiments had reached steady state, the electric heater was turned off. The cold plates were left on and maintained the same temperature as during the heating transient. Thus, as the stack of wallboard equilibrated to the cold plate temperature, data for a cooling transient was generated. The data for this cooling transient are shown in Figure 7. Note that temperature T_H wanders during the transient and finally ends almost 1/2°F below the equilibrium temperature. The problem with T_H is unknown; however, little weight was given to this temperature in the data analysis.

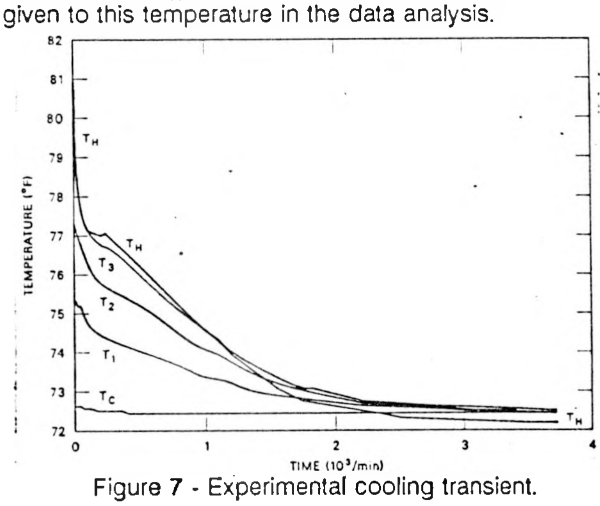

Figure 7 - Experimental cooling transient.

A series of simulation runs were made with WALL88 to match the cooling transient. The series generally followed the same sequence as for the heating transient. Only the final simulation will be reported here. For this WALL88 run, TM was taken to be 75.0°F (slightly above the melting point). TA and TB were 67.6°F and 78.5°F respectively. All other thermal parameters (C_p, k, H_{fusion}) were the same as for the heating transient runs. The results of this calculation are shown in Figure 8. Agreement between measured and computed values is fairly good but not as good as for the heating transients. Probably the reason is that the freezing curve from the DSC plot contains two peaks, and the triangular heat capacity relationship was developed for a single peak as displayed by the DSC melting curve.

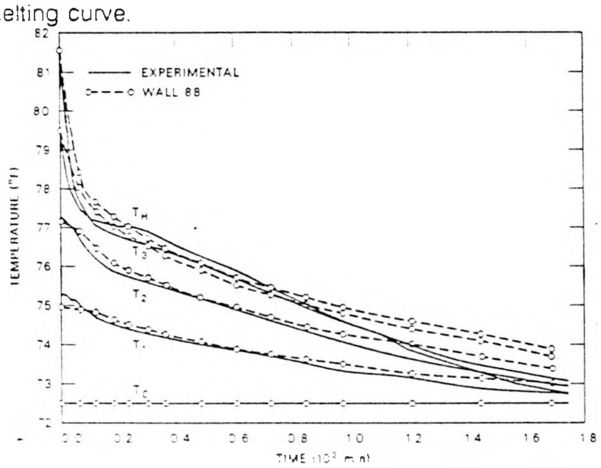

Figure 8 - Comparison of WALL88 to measured data.
TA = 67.6°F, TM = 75.0°F, TB = 78.5°F

3. CONCLUSIONS

A computer model, WALL88, was developed to describe thermal energy transport and storage by a thermal energy storage system based on the latent heat of fusion. The model was validated by comparing it to known analytical solutions. In addition, results of the model were compared with experimentally produced thermal transients in wallboard impregnated with paraffin. In order to get good agreement between the model and experimental data, it was necessary to modify the model in such a way that the paraffin melted over a range of temperature. To accomplish this, the latent heat of fusion was replaced with a triangular shaped heat capacity relationship that looked very similar to the triangular shaped melting phase of a DSC curve. With this change, computed and experimental temperatures during transients were found to agree. Thus the triangular heat capacity relationship is effective in characterizing a material that melts over a temperature range.

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