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PERFORMANCE ANALYSIS OF ADVANCED SPACECRAFT TPS

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INTRODUCTION

The National Space Plane, NASP, and other future space vehicles will have large liquid hydrogen, LH₂, fuel tanks. These will require efficient insulation systems to minimize LH₂ boiloff during a flight, including the critical launch phase. Many systems have been proposed that use combinations of: various insulation materials external to the tanks, Multi-Layer Insulation within the external insulation, and a foam liner inside the tank. A new concept, suggested by Howard Goldstein of NASA Ames, is to use a metal hydride in the manner of a phase change material, PCM, as part of the tank structure. This could be very desirable because the cooling mechanism would be operating directly on the fuel tank. This paper will give the results of a quick look at the feasibility of using the decomposition of metal hydrides as a combined PCM and structure within the insulation system of a liquid hydrogen fuel tank.

For this application, hydrogen, stored within the hydride would be released endothermically as the hydride reaches its critical temperature range, thus maintaining the tank temperature until all of the hydride has decomposed. Although the concept of using metal hydrides in fuel tank insulation systems is apparently new, metal hydrides have been suggested for storage of hydrogen for land based fuel cells. The basic concept of storing hydrogen in a hydride is discussed in Reference 1 and shown in Fig. 1. There the dissociation pressure is shown as a function of the hydrogen composition within a typical hydride. The temperature remains relatively constant as the hydride dissociates from maximum hydrogen concentration to nearly zero concentration. The temperature depends on the dissociation pressure. This reaction is reversible and generally without hysteresis. The numerous hydrides that exist provide a wide range of numbers that go with

this typical curve form as well as a wide range of heats of formation.

The procedure followed in this analysis was to make parametric calculations to establish the range of numbers for Fig. 1 that are required for a PCM to be effective. Then a search is made for a metal hydride that satisfies the requirements. Practical problems such as the strength requirements for the hydride are not within the scope of this preliminary analysis. It was assumed that the weight of the fuel tank was the same whether or not it was partially composed of a hydride.

ANALYSIS MODEL

This analysis was made using a simple one-dimensional model, Fig. 2. The insulation material used outside the metal hydride PCM is LI-900. A liquid hydrogen compatible foam is used inside the PCM. The foam is lined on the inside with a thin aluminum shell. The total insulation thickness (LI-900 plus foam) is varied in the analysis as well as their relative thicknesses. The PCM transition temperature and the dissociation heat capacity of the PCM are also varied.

A special one-dimensional, transient heat-flow computer code was written for this analysis. The temperature dependant thermal conductivity of LI-900 was accounted for. For simplicity of the comparative analysis, the physical and thermal properties of the foam were assumed to be the same as those of the LI-900. The basis of comparison for the various combinations of these parameters was the integrated heat flow through the aluminum liner.

A typical heat flux profile for a NASP flying a cruise trajectory was imposed on the top surface of the model.

RESULTS

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The dependence of liquid hydrogen boiloff weight on total insulation thickness is shown in Fig. 4. The lower pair of curves are for LI-900 insulation with and without PCM included. For both cases, the optimum insulation thickness is between 0.7 and 0.8 inch. The use of the PCM reduces the minimum weight of insulation plus boiloff LH2 by about 20% for this case. Most of this weight reduction is in the amount of LH2 boiled off, and because the weight of the two components are comparable, this means that the boiloff weight is reduced by almost 40%. The upper pair of curves show the corresponding result for LI-2200 insulation. The total weight saving is again about 20%, but because of the higher density of LI-2200 (22 lb/ft³ instead of 9 lb/ft³) the optimum insulation thickness is smaller and the amount of LH2 boiled off is larger.

The results shown in Fig. 4 were for cases with the PCM at a depth of 1/4 of the total thickness of the insulation and foam, with the transition temperature at 125 F, and with the heat absorbing capacity of the decomposing hydride equivalent to a 0.4 inch sheet of ice. The performance of the PCM depends on all of these quantities. Some insight on how is shown in Fig. 5. The curves show the heat fluxes to the aluminum liner of the tank as a function of time. The solid curve is for the case of no PCM. When the PCM is at a depth of 0.5 of the thickness, it is not very effective. For one thing, it takes longer for the temperature to reach the transitional level. The major effect, though, is that the transition temperature is fixed at a level closer to the liner than it is for the 0.25 inch depth case. Thus the thermal gradient at the liner is larger. For the 0.5 level not all of the 0.4 inch equivalent ice heat absorbing capacity is utilized. At the 0.25 level, it is used up near the end of ascent. For half this capacity, the

hydride is fully decomposed early in the ascent. When it is, the heat flux rises rapidly to the no PCM levels. The effect of transition temperature would appear the same on this figure as does the effect of PCM depth.

The effect of PCM depth is shown in more detail in Fig. 6. The minimum weights were determined from curves similar to those of Fig. 4. As indicated by Fig. 5 the optimum depth is dependent on the available heat absorbing capacity. It is apparent that for all cases, the PCM should be placed relatively near the surface for maximum benefit. The higher the available heat capacity, the closer the PCM should be placed to the surface. This trend is almost linear as shown by Fig. 7.

A typical trend of minimum weight with the transition temperature is shown in Fig. 8. It is apparent that a low transition temperature is desirable. However, this trend is limited by the fact that the PCM would decompose in the prelaunch environment if the transition temperature was too low. At the high end of the scale the PCM is ineffective because the transition temperature is not reached until well into the ascent unless the PCM is placed close to the surface. The PCM is placed close to the surface. Then, unless the absorption capacity is very large, the hydride temperature limit will be exceeded when the decomposition is completed.

The foregoing results were selected from a set of calculations in which the pertinent parameters were systematically varied. The maximum weight reduction due to the use of PCM was found to be about 25%. For this case the PCM was 0.14 deep within the insulation, the transition temperature was 125 F, and the heat absorption capacity was equivalent to 0.8 inch of ice. This is not a desirable design because the heat absorption requirement is so large and the tank structure is dangerously close to the surface, but it does indicate the maximum benefit attainable for this type of heat

protection system.

The final step of this study was to search the literature for the best metal hydride to match the indicated requirements. These requirements are: a large heat absorption capacity, a low transition temperature, a high rate of dissociation, stability in the prelaunch environments, and suitable structural characteristics. Unfortunately, most of the work on the use of metal hydrides for hydrogen storage has been directed toward fuel cell applications where a low heat absorption capacity and a high transition temperature is desired (Refs. 1 and 2). There are many binary and ternary hydrides with a wide range of characteristics. These characteristics can be varied substantially by the the addition of impurities.

The two most likely candidates found were MgNi-H and FeTiH. They both have low transition temperatures and high rates of decomposition. Both have a high storage capacity for hydrogen on a volume basis, but because of the high densities of the metal component, their capacity on a weight basis is reduced to near that of water. The capacity of MgNi-H is about 10% higher than water and that of FeTi-H is about 40% lower. There is also a question of the stability of these hydrides in the vacuum of space.

CONCLUSION

The analysis on the feasibility for using metal hydrides in the thermal protection system of cryogenic tanks in space was based on the heat capacity of ice as the PCM. It was found that with ice the thermal protection system weight could be reduced by, at most, about 20 per cent over an all LI-900 insulation. For this concept to be viable, a metal hydride with considerably more capacity than water would be required. None were found. Special metal hydrides were developed for hydrogen fuel storage applications and it may be possible to do so for the current application. Until this appears promising

further effort on this feasibility study does not seem warranted.

REFERENCE

1. Hydrogen: Its Technology and Implications, Volume II, Transition and Storage, Chemical Rubber Company Press, 1977.

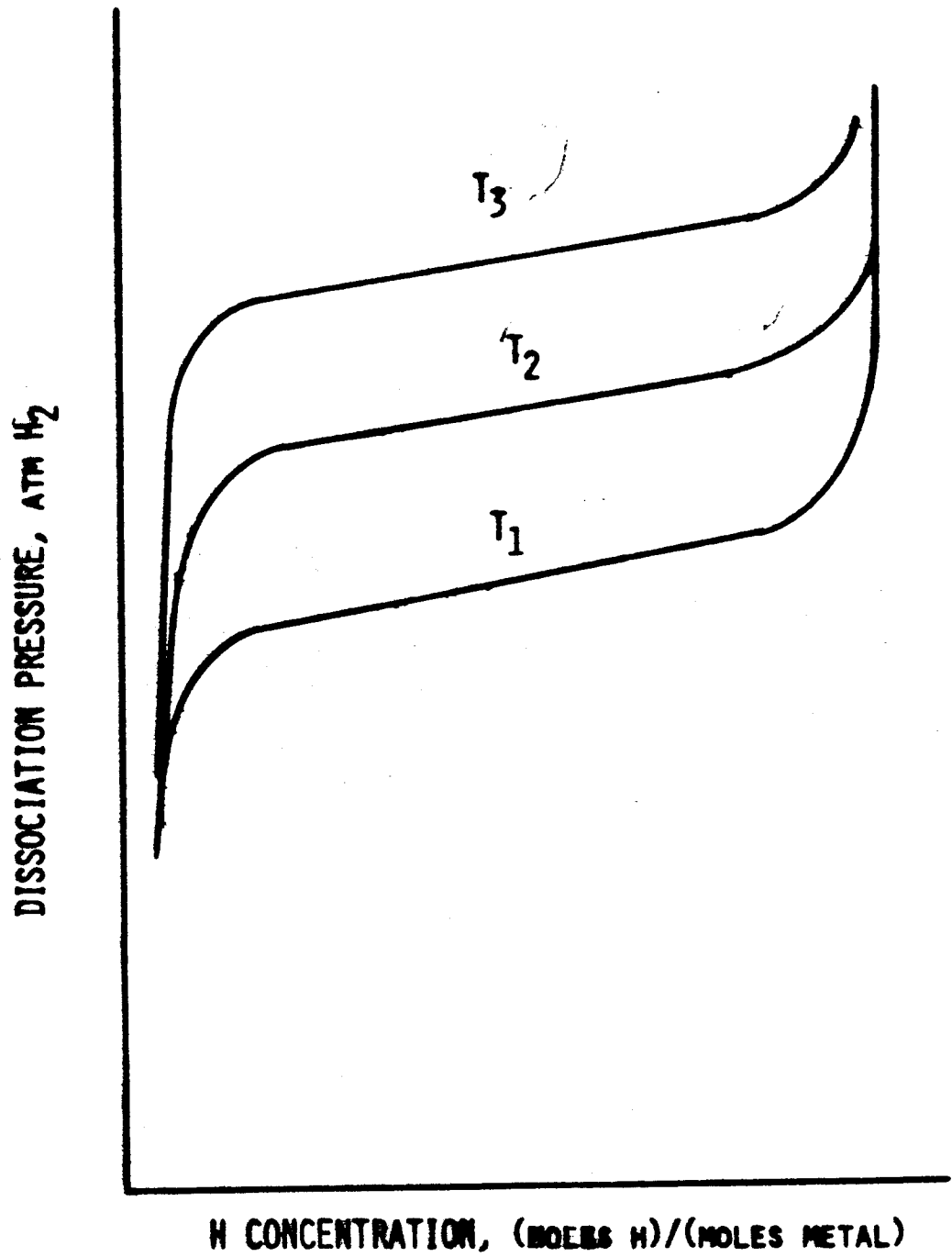


Figure 1. Phase change diagram for metal hydrides.

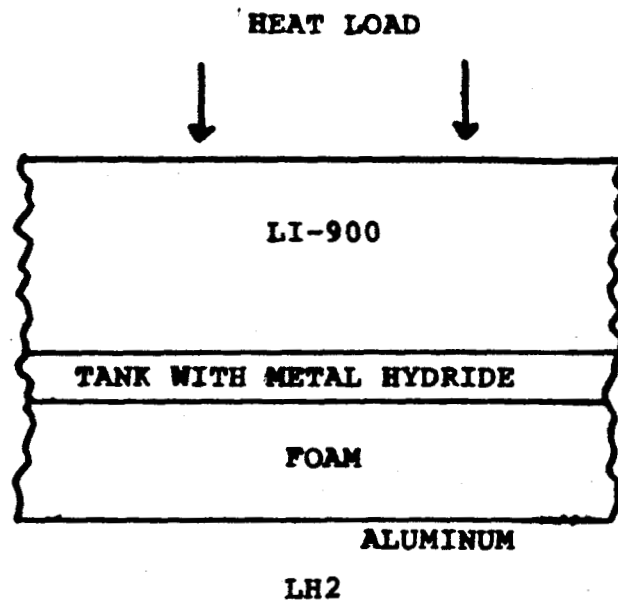


Figure 2. One dimensional model used for analysis.

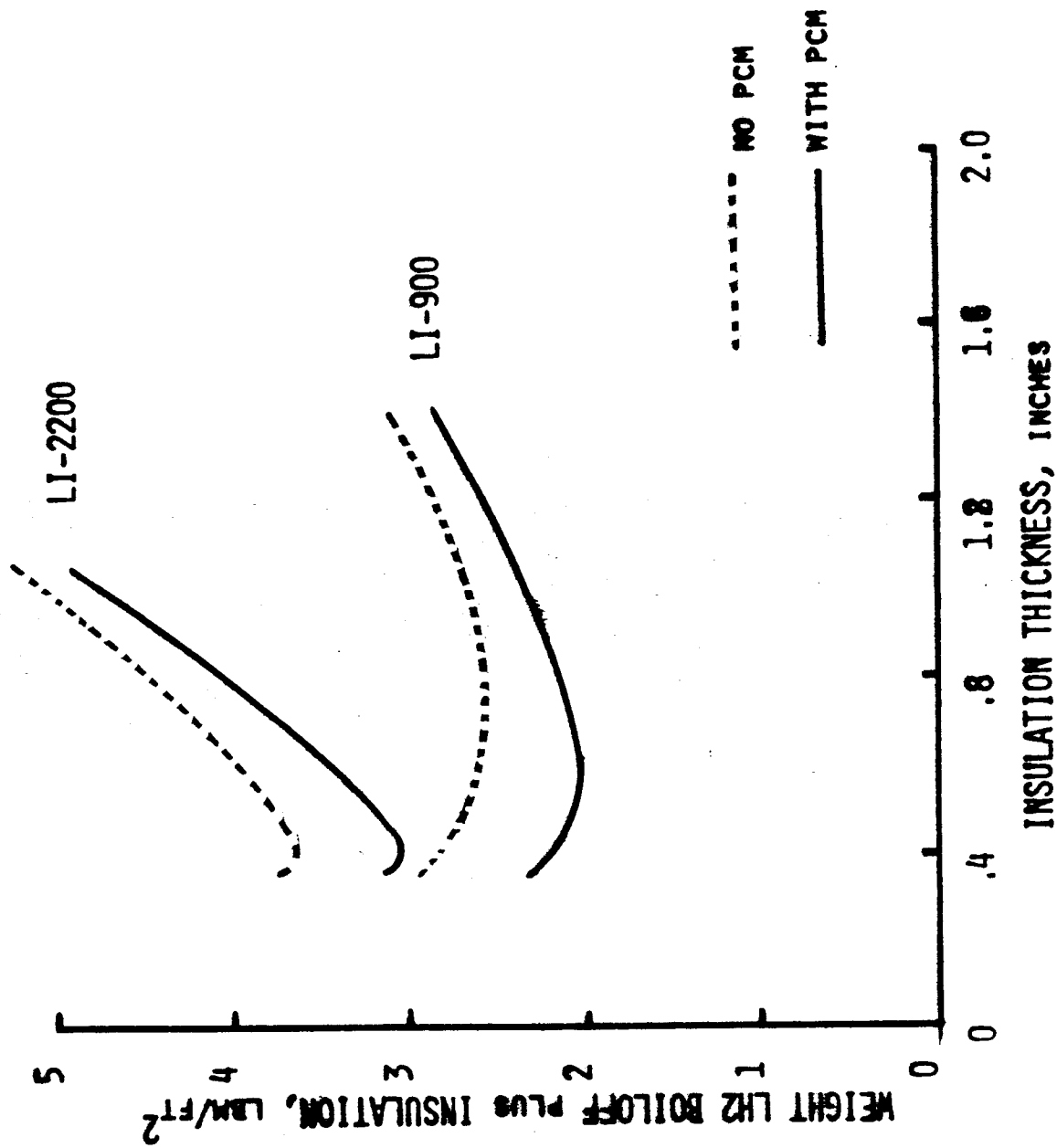


Figure 4. Effectiveness of metal hydride PCM as a thermal protection system component.

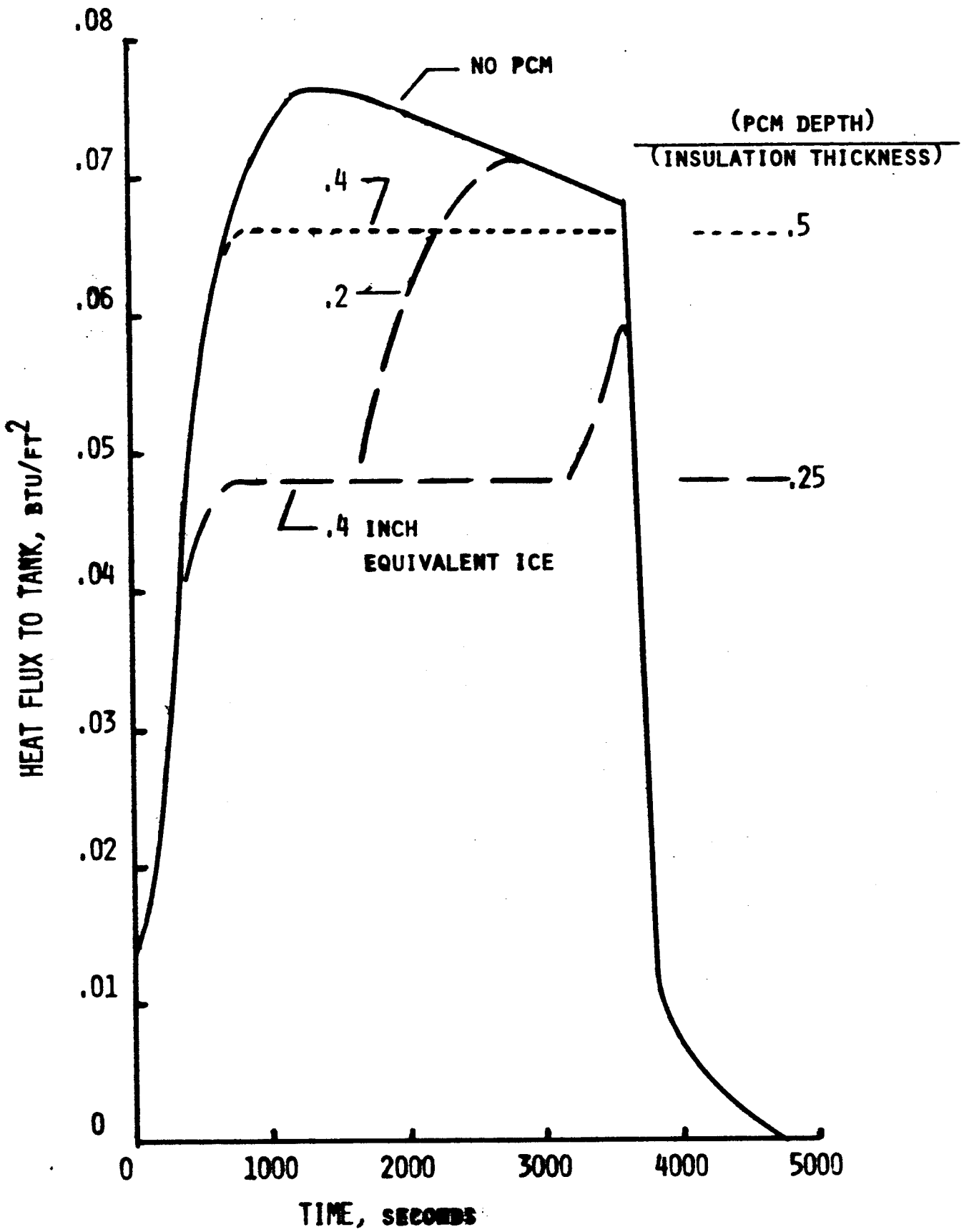


Figure 5. Dependence of heat flux to tank on model parameters.

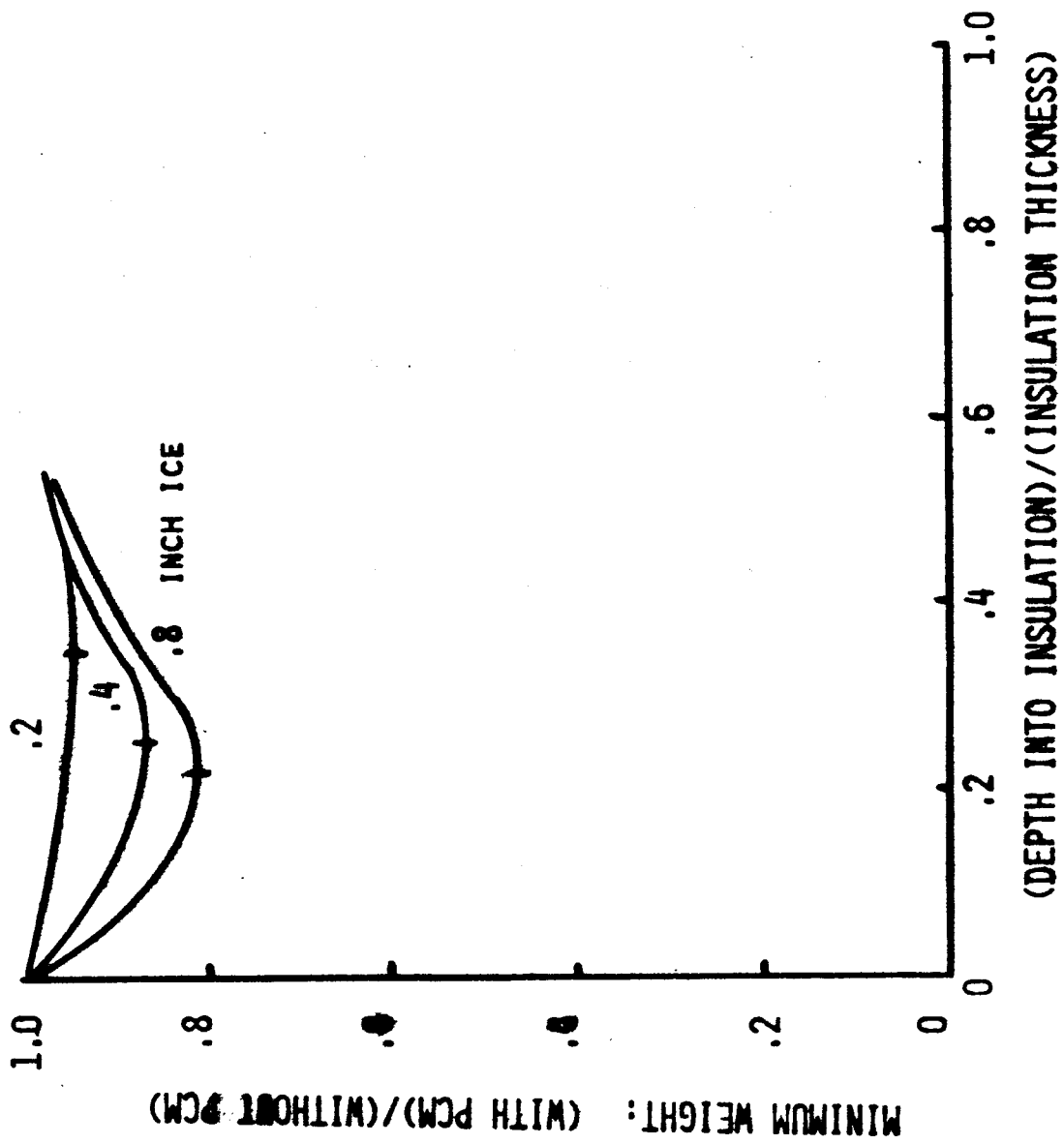


Figure 6. Dependence of minimum weight on depth of PCM within insulation.

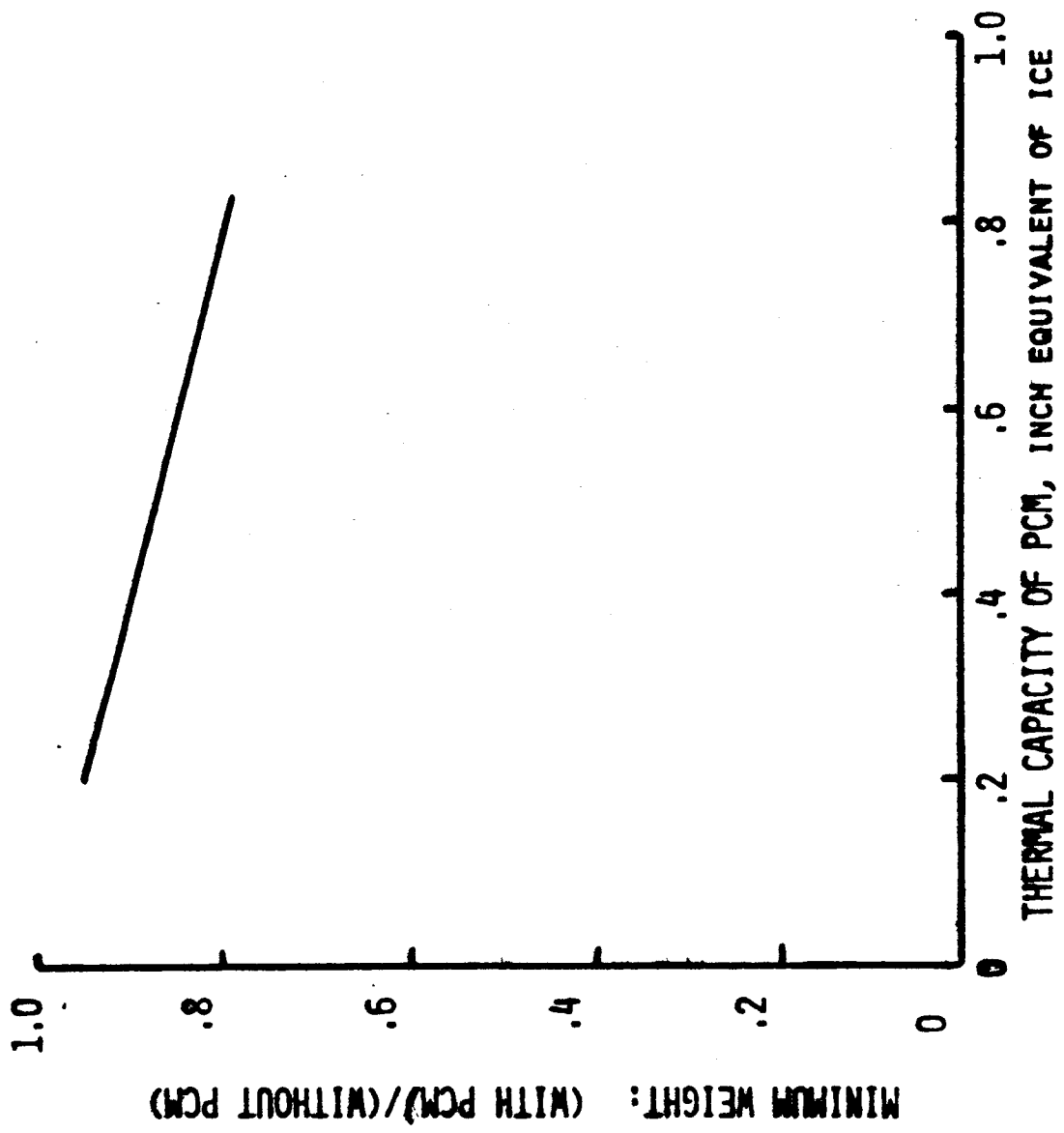


Figure 7. Dependence of minimum weight on thermal capacity of PCM.

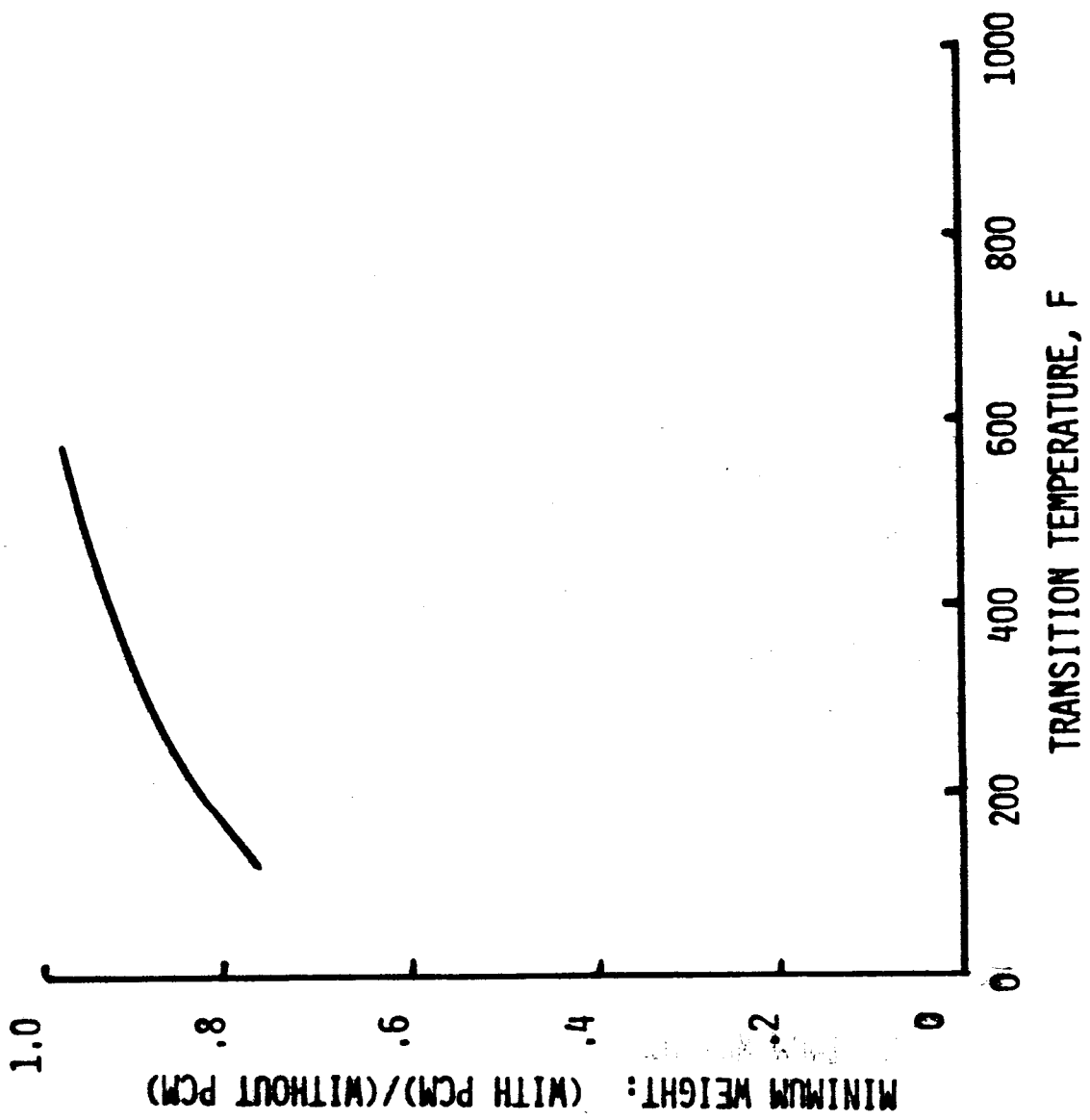


Figure 8. Dependence of minimum weight on transition temperature of PCM.