An efficient cooling technique for discontinuous Micro-Engines using Microencapsulated phase change materials

A. F. Khadrawi[1], A. Balabel[2], Ali Alzaed[3]

[1,2](CFD-Lab, Mechanical Engineering Dept., Taif University, Al-Haweiah, P.O. 888, Z.C. 21974, Taif, Saudi Arabia, khadrawi99@yahoo.com)

[3](Architecture Engineering Dept., Taif University, Al-Haweiah, P.O. 888, Z.C. 21974, Taif, Saudi Arabia, Email:dralzaed@gmail.com)

Abstract—*Phase change materials (PCMs) have the capability of storing heat (latent heat storage units) and phase transition point to the environment of the operating temperature. The purpose for which they are designed is to prevent heat loss by absorption or release thereof. In the present work an efficient cooling technique for micro-engines that operate intermittently, or discontinuously, has been presented and investigated analytically. It is found that the new phase-change cooling technique is more appropriate for cooling the micro engines that work for small discontinuous periods of time. Operational time that is defined as the time required by the phase-change solid material to be completely melted and converted to liquid is investigated in this study. This means that the engine is able to operate during this operational time by relying on the phase-change new cooling approach. It is found that the cooling operational time increases as both the melting temperature and the enthalpy of melting increase.*

Keywords—cooling; discontinuous operation; micro-engine; phase change material.

1. INTRODUCTION

Cooling of any hot system is restricted by mass flow rate, cooling capacity, and temperature of the used working fluid. It is very difficult to use air (low total heat capacity) to cool a very hot system. In addition, if air has low speed, then there will be a small mass of air available to carry away the released heat. To improve the system cooling using air as a working fluid, one must blow more air over the system. Furthermore, blowing more air will create more noise and consumes more power by the driving fans. Liquid-cooling is thus a good solution to a difficult problem, but sometimes it is even difficult to circulate enough cooling liquid through the system to keep it cool. A new cooling technique using phase change materials is proposed to enhance the cooling process.

Phase change materials (PCMs) have the capability of storing heat and phase transition point to the environment of the operating temperature. The purpose for which they are designed is to prevent heat loss by absorption or release therefrom. A new cooling technique using Phase Change Material in a car ceiling and wall buildings is investigated by Khadrawi at al. [1]. Fallahi and Fang [2-4] prepared microPCMs based upon different types of paraffins and analyze their thermal behavior. Alkan [5] studied the preparation, characterization and thermal properties of a microencapsulated PCM for thermal energy storage. Alvarado and Bukovec [6-7] come equally to performance microPCMs analysis with DSC and TGA techniques. The aim of the present work is to find an efficient cooling technique for discontinuous micro-engines using microencapsulated phase change materials which works for small period of time “on and off”. Also, this method will be much better for restarting since phase change material release heat upon restarting the machine and helps in warming up the engine. Hadam [8] discusses the transfer of heat during the melting of a phase-change material, determining the spread and inclination of the solid-liquid interface at the time.

Microencapsulation may be defined as the process of wrapping or surrounding one substance to another substance at very limited scale, producing capsules ranging from less than one micron to several hundred microns in size. The material used for encapsulating the nucleus is known as a membrane, coating, and shell or wall material. The microcapsules may have wall arranged in several layers with different thicknesses of the base. The applications of microencapsulated materials are almost limitless. Microencapsulated materials are used in pharmaceuticals, food, agriculture, cosmetics and textiles, fragrances, paints, paper, coatings, and printing applications, and many other industries. Historically, first commercial product used microcapsules was the carbonless copy paper. A microencapsulated colorless ink layer applied to the top sheet of paper, and a developer material is applied to the following sheet. When pressure is applied to the writing, the capsules broke and the ink reacts with the developer to produce the dark color of the copy. Nowadays microencapsulated materials used in the textile industry to improve the properties of the finished products.

Recently, improving the surface properties of fabrics based on microPCMs incorporating wool, observing a higher thermal activity, increased durability and improved fiber performance is discussed by Grahremanzadeh [9]. PCMs heat storage in thermoregulation nonwoven fibers are investigated by Zhang [10-11]. Choi [12] investigated the temperature changes of the tissues treated with PCMs in cold and temperate. The feasibility of a new cooling technique that uses PCMs for an engine is studied by Kim [13]. This new cooling system participates to intrinsic reduction in cooling system in terms of performance and volume. Using PCMs in flash memory cooling, following the recent replacement of hard drives for these devices is proposed by Wutting [14]. Cooling of mobile phones that use a PCMs, performing mobile experimental prototypes made of aluminum is examined by Setoh [15]. The study indicates that the use of heat sinks with PCMs was very active for cooling of mobile phones in the discontinuous moderate usage.

2. Analysis

Consider cylindrical micro engine as shown in Fig. 1. The gas temperature inside the engine is assumed to be $100\,^{o}C$ and it has high heat transfer coefficient, $h_g = 800 W/m^2\ K$, which means that the inner surface has the same temperature. The air temperature ($T_\infty = 25\,^{o}C$), the wall thicknesses ($\delta_1 = \delta_2 = 0.5\,cm$), the inner and outer radiuses ($r_{1i} = 3\,cm$, $r_{1o} = 3.5\,cm$, $r_{2i} = 4.5\,cm$, $r_{2o} = 5\,cm$), the thermal conductivity of the engine and the thermal conductivity of the jacket ($k_1 = k_2 35 W/mK$), respectively, and the density of the phase change material is ($\rho_m = 920\,kg/m^3$). The heat transfer coefficient of the phase change material is ($h_{sf} = 1000 W/m\ \ K$), which is inserted between the engine and the jacket, are assumed to be very high (low thermal resistance), so the outer surface temperature of the engine and the inner surface of the jacket are assumed equal the melting temperature of the phase change material.

From the energy balance

$$\frac{T_g - T_m}{R_3 + R_4 + R_5} = \dot{m} h_{sf} + \frac{T_m - T_\infty}{R_6 + R_7 + R_8} \quad (1)$$

where is the rate of change of melting material from solid to liquid and is given by:

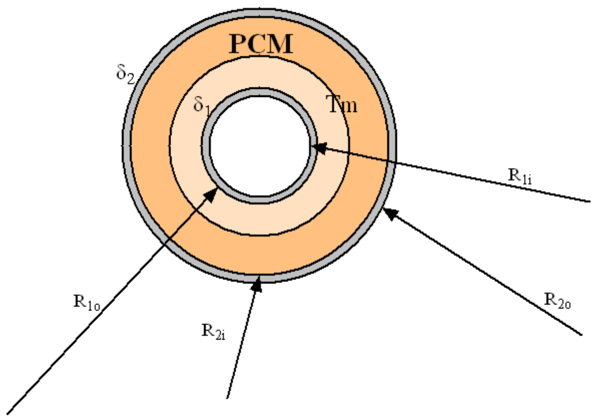

Fig. 1: Schematic representation of the domain under consideration.

$$\dot{m} = \left[\frac{T_g - T_m}{R_3 + R_4 + R_5} - \frac{T_m - T_\infty}{R_6 + R_7 + R_8}\right] \Big/ h_{sf} \quad (2)$$

Also, $\dot{m}_m\,\tau = V_m \rho_m$, where τ is the operational time of the system and is given by:

$$\tau = \frac{V_m \rho_m}{\dot{m}_m} \quad (3)$$

Where: $V_m = V_2 - V_1$, $R_3 = \dfrac{1}{h_g\, 2\pi r_{1i} L_1}$, $R_4 = \dfrac{\ln(r_{1o}/r_{1i})}{2\pi k_1 L_1}$, $R_5 = \dfrac{1}{h_m\, 2\pi r_{1o} L_1}$, $R_6 = \dfrac{1}{h_m\, 2\pi r_{2i} L_2}$, $R_7 = \dfrac{\ln(r_{2o}/r_{2i})}{2\pi k_2 L_2}$, $R_8 = \dfrac{1}{h_\infty\, 2\pi r_{2o} L_2}$, $R_9 = \dfrac{1}{h_\infty\, 2\pi r_{1o} L_1}$

The study introduces the engine operational time τ that is defined as the time required by the phase-change solid material to be completely melted. This means that the engine is able to operate during this operational time by relying on the phase-change new cooling approach.

3. Results and Discussion

Figure 2 shows the effect of melting temperature on the operating time at different values of latent heat of diffusion. It is obvious from this figure that as the melting temperature decreases the operational time of the system decreases. This means that as the melting temperature decreases the melting rate increases then the operational time of the system decreases. The latent heat of diffusion has small effect on the operational time of the system for $h_{sf} < 500\,kJ/kg$. Also, as the latent heat of diffusion decreases the operational time of the system decreases, especially for small values of T_m. Also, Figure 2 shows that a typical micro engineunder typical operating conditions and having typical dimensions may run for about 90 minutes. Figure 3 shows the effect of melting temperature on the melting rate at different values of latent heat of diffusion. It is clear that as the melting temperature decreases the melting rate increases.

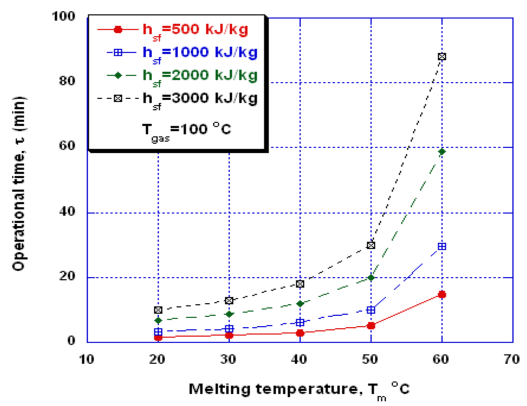

Fig. 2: Effect of melting temperature on surface temperature at different h_{sf}

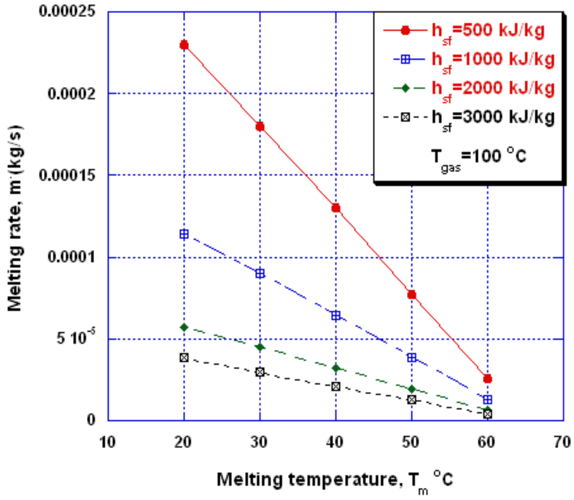

Fig. 3: Effect of melting temperature on melting rate at different h_{sf}

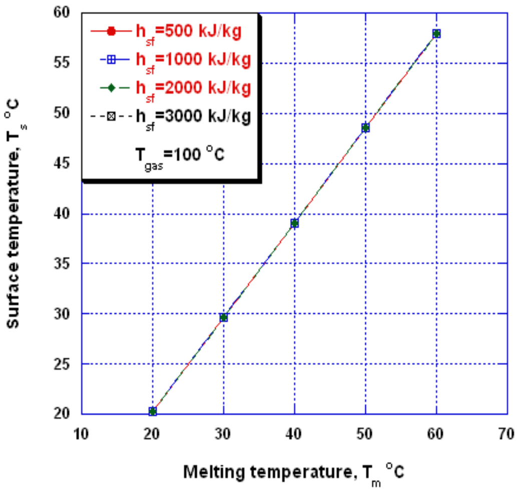

Fig. 4: Effect of melting temperature on surface temperature at different h_{sf}

Also, the enthalpy of melting or the latent heat of diffusion has insignificant effect on the melting rate for large values especially for large values of melting temperature $T_m > 60\ ^oC$. Fig. 4 shows the effect of melting temperature on the outer surface temperature of the jacket. It is clear that as the melting temperature increases the outer surface temperature increases, while the effect of the enthalpy of melting is insignificant.

4. CONCLUSION

A novel cooling technique is proposed to cool the micro engines that operate on intermittent or discontinues (on and off) basis. The new cooling technique uses a phase change material that melts when it is in contact with temperatures equal to or higher than the melting temperature and solidifies when it is in contact with temperatures equal to or less than the solidification temperature. It is found that the cooling operational time increases as both the melting temperature and the enthalpy of melting increase. The effect of the enthalpy of melting on the cooling operational time is found to be more pronounced at large values of melting temperatures. The study shows that a typical micro engine operates under typical operating conditions and having typical dimensions may run for about 70 minutes while relying on the proposed phase-change cooling technique.

REFERENCES

[1] A. F.Khadrawi, A.Balabel and Ali S.Alosaimy, “A new Cooling Technique Using Phase Change Material in A car Ceiling and Wall Buildings” International Journal of Heat and Technology, vol. 32, no. 2, pp. 185-190, 2014.

[2] Y. T. Fang, S. Y.Kuang,X. N. Gao and Z. G.Zhang, "Preparation of nanoencapsulated phase change material as latent functionally thermal fluid", Journal of Physics D-Applied Physics, vol. 42, no. 3, 2009.

[3] G. Y. Fang, H.Li, X. Liuand S. M.Wu "Experimental Investigation of Performances of Microcapsule Phase Change Material for Thermal Energy Storage", Chemical Engineering & Technology, vol. 33, no. 2, pp. 227-230, 2010.

[4] E. Fallahi, M. Barmar and M. H.Kish, "Preparation of Phase-change Material Microcapsules with Paraffin or Camel Fat Cores: Application to Fabrics", Iranian Polymer Journal, vol. 19, no. 4, pp. 277-286, 2010.

[5] C. Alkan, A. Sari, A. Karaipekli and O. Uzun, "Preparation, characterization, and thermal properties of microencapsulated phase change material for thermal energy storage", Solar Energy Materials and Solar Cells, vol. 93, no. 1, pp. 143-147, 2009.

[6] N. Bukovec, P. Bukovec, and V. Arbanas, “Tg and dsc investigation of CACL2.6H2O, A phase-change material for energy-storage”, Thermochimica Acta, vol. 148, pp. 281-288 ,1989.

[7] J. L. Alvarado, C. Marsh, C. Sohn, M. Vilceus, V. Hock, G. Phetteplace, and T. Newell, “Characterization of supercooling suppression of microencapsulated phase change material by using DSC", Journal of Thermal Analysis and Calorimetry, vol. 86, no.2, pp. 505-509, 2006.

[8] M. A. Hamdanand I. Al-Hinti, "Analysis of heat transfer during the melting of a phase-change material", Applied Thermal Engineering, vol. 24, no. 13, pp. 1935-1944, 2004.

[9] F. Ghahremanzadeh, A. Khoddami and C. M. Carr, "Improvement in Fastness Properties of Phase-Change Material Applied on Surface Modified Wool Fabrics", Fibers and Polymers, vol. 11, no. 8, pp. 1170-1180, 2010.

[10] Y. W. Zhang and A. Faghri, “ Analysis of forced convection heat transfer in microencapsulated phase change material suspensions", Journal of Thermophysics and Heat Transfer, vol. 9, no. 4, pp. 727-732, 1995.

[11] X. X.Zhang, X. C. Wang, H. Zhang, J. J. Niu and R. B. Yin, "Effect of phase change material content on properties of heat-storage and thermo-regulated fibres nonwoven", Indian Journal of Fibre &Textile Research, vol. 28, no. 3, pp. 265-269, 2003.

[12] K.Choi, H. J., Chung, B. Lee, K. H. Chung, G. S.Cho, M. Park, Y. Kim and S.Watanuki, "Clothing temperature changes of phase change material-treated warm-up in cold and warm environments", Fibers and Polymers, vol. 6, no. 4, pp. 343-347, 2005.

[13] K. B. Kim, K. W.Choi, Y. J Kim., K. H.Lee. and K. S.Lee, "Feasibility study on a novel cooling technique using a phase change material in an automotive engine", Energy, vol. 35, no. 1, pp. 478-484, 2010.

[14] M.Wuttig and C.Steimer, "Phase change materials: From material science to novel storagedevices", Applied Physics a-Materials Science & Processing, vol. 87, no. 3, pp. 411-417, 2007.