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ANALYSIS OF PARAFFIN WAX ACTUATOR FOR FUTURE INCORPORATION IN A BRAILLE ACTIVE DOT

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Abstract This paper proposes to analyze paraffin wax actuator for future utilization as an actuation element for refreshable Braille dots. The paraffin is used as phase change material (PCM) for thermal energy transformation in linear work. The efficiency of a PCM is dependent on the encapsulated quantity and energy storage capacity per mass unit during its melting and solidification process. The investigation on the performance of PCM's for future incorporation into a Braille device actuator is performed in this paper.

Key words: phase change material, paraffin wax, solid-liquid state, Braille dot, analysis, thermal actuator

1. INTRODUCTION

Linear actuators based on conversion of thermal energy play an important role in an effective use of this energy, with multiple applications in mini and micro technology. However, one of the advantages associated with paraffin wax and other organic phase change materials (PCM) are their low thermal conductivity, which severely limited the rate of absorbing and releasing heat from and to the environment.

Among the solid–liquid PCMs, paraffin's offer some significant advantages over other PCMs. They have mass based latent heats and varied phase change temperatures giving flexibility to choose proper PCMs for different applications. When paraffin is microencapsulated, the convection heat transfer caused by melted paraffin is negligible. They are produced in substantial quantities by the chemical process industry and thus they are readily available and inexpensive. In particular; paraffin wax has attracted numerous attentions for its low cost, moderate energy densities, low vapor pressure, chemical inertness, and negligible super cooling [1,2].

Thermal actuators are usually simpler and easier to construct than their other counterparts such as electrostatic, piezoelectric, magnetostrictive or other actuators. The main disadvantage of thermal actuators is their slow speed. Therefore, these type of actuators stand to gain substantially from miniaturization and they have received renewed interest in the micro device community. The resistive heating is by far the most popular method that is used in micro actuators [3-5].

2. MATHERIAL ANALYSIS ISSUES

The various PCMs are generally divided into two main groups: organic and inorganic compounds. Organic compounds present several advantages like ability of congruently melting, self-nucleating properties, non-corrosive behavior and compatibility with conventional materials of construction. Sub-groups of organic compounds include paraffin and non-paraffin organics [6].

The paraffin used in this study consists mainly of $C_{25}H_{52}$ (solid state temperature $T_{solid\ state} < T_m$ [^oC], melting point $T_m = 64$ [^oC] and $T_{liquid\ state} > T_m$).

The reason for the huge volume expansion of paraffin when melted is that paraffin exists as crystal in its solid form, i.e. the molecules are packed close together. The more crystal in solid phase the larger volume expansion is to be expected at transition (Fig.1).

Phase change systems use the dimensional changes (expansion and contraction) that occur in materials as they undergo changes between phases (solid and liquid). Actuators which can be built harness the forces exerted by the phase changes, and they generally demonstrate full reversibility. Depending on the material, a phase change may be induced electrically, thermally, or ultrasonically, and may happen over a wide range of speeds and pressures [7].

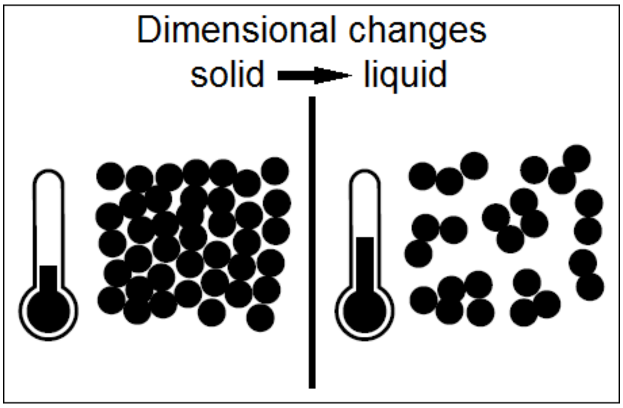

Fig. 1. Phase change process

The essential difficulty in dealing with phase change problems rests in the requirement to account for nonlinear phenomena that change in time and space according to [8].

3. MATHEMATICAL MODEL OF THE ACTUATOR

3.1. Thermal analysis

For the analysis of the PCM performance in order to incorporate in a linear actuator, we need to create a mathematical thermal model of the actuator. A model of the actuator is shown in figure 2. The temperature distribution is complex. However, we simply considered four thermal elements receiving the heat and their temperature changes. The components of the thermal actuator are: the heater 1, the operating material near the heater 2 (surface having melting temperature > 64[°C]), the main operating PCM 3, the flexible membrane 4 and the air from the environment noted 5. The heat capacity, the temperature and the heat transfer area of the elements are C_n [J/K], T_n[°C], and S_n [m^2] respectively. The heat flow rate and the heat transfer coefficient from an element to the next item are q_n [W], and h_n [W/m^2K], respectively. The coefficients t[s] and q_H represents the operating time and the heat flow rate to the heater heaving the value of 40 [W].

When power is supplied to the heater, the operating material near the heater quickly melts. For the period from the start till melting occurs, the heat equilibrium of all the thermal elements of the model are represented by the next differential equations corresponding to each element [8, 9].

$$\begin{cases} C_1 \dfrac{dT_1}{dt} = q_H - q_1 \\ q_H - q_1 = q_H - S_1 h_1 (T_1 - T_2) \end{cases} \tag{1}$$

$$\begin{cases} C_2 \dfrac{dT_2}{dt} = q_1 - q_2 \\ q_1 - q_2 = S_1 h_1 (T_1 - T_2) - S_2 h_2 (T_2 - T_3) \end{cases} \tag{2}$$

$$\begin{cases} C_3 \dfrac{dT_3}{dt} = q_2 - q_3 \\ q_2 - q_3 = S_2 h_2 (T_2 - T_3) - S_3 h_3 (T_3 - T_4) \end{cases} \tag{3}$$

$$\begin{cases} C_4 \dfrac{dT_4}{dt} = q_3 - q_4 \\ q_3 - q_4 = S_3 h_3 (T_3 - T_4) - S_4 h_4 (T_4 - T_a) \end{cases} \tag{4}$$

When the temperature of the PCM near the heater reaches the melting temperature (T_m = 64 [°C]), melting of the entire material is assumed to start from the sidewall of the heater. Then, the relating heat transfer coefficients h_l and h_2 are assumed to be changed to h_{1l} and h_{2l}. Consequently, for the second state of the active material (melting), the equations below (1-4) become following equations (5-8):

$$C_1 \frac{dT_1}{dt} = q_H - q_1 = q_H - S_1 h_{1l} (T_1 - T_2) \tag{5}$$

$$C_2 \frac{dT_2}{dt} = 0 \tag{6}$$

$$\begin{cases} C_3 \dfrac{dT_3}{dt} = q_2 - q_3 \\ q_2 - q_3 = S_2 h_{2l} (T_2 - T_3) - S_3 h_3 (T_3 - T_4) \end{cases} \tag{7}$$

$$\begin{cases} C_4 \dfrac{dT_4}{dt} = q_3 - q_4 \\ q_3 - q_4 = S_3 h_3 (T_3 - T_4) - S_4 h_4 (T_4 - T_a) \end{cases} \quad (8)$$

The equation (6) who has the zero value show that temperature T_2 maintains the melting temperature, T_a=20 [°C] (the temperature from the environment). The temperature of the medium remains more or less constant during the phase transition. For application of a material as a phase change material, information about its latent heat of phase transition as well as densities and specific heats are necessary.

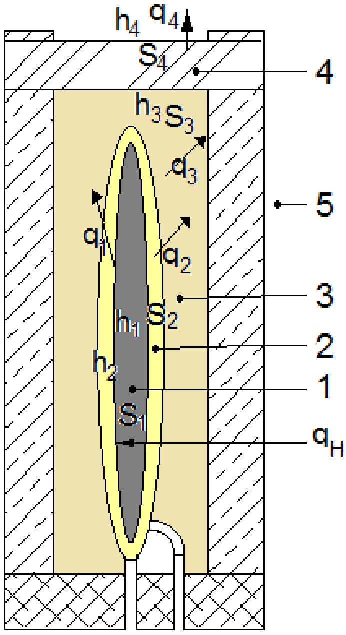

Fig. 2. Thermal model of the encapsulated type solid-liquid actuator

3.2 Expansion behavior analysis

This paraffin-based thermal actuator uses paraffin's relatively large volume change for actuation, as induced by paraffin's solid–liquid phase change.

When the paraffin temperature is passing to the melting point of 64 [°C], the volume is growing with ~15%. In our case, the extention is realized in form of a half-sphere, and its volume represents the additional volume, being the growing volume difference of *phase change material* compared to the initial. Knowing that, the numerical value of each Braille dot is possible to obtain.

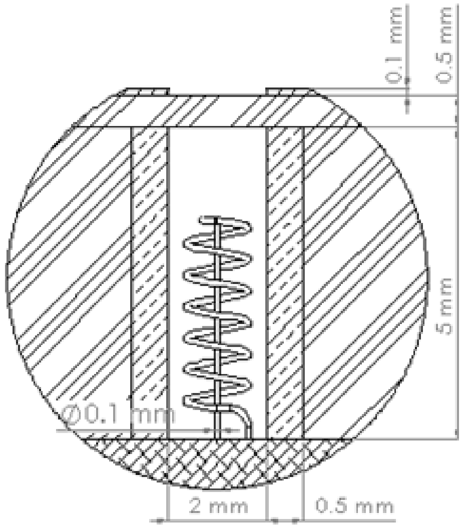

Fig. 3. Section through the paraffin wax actuator

In accordance with the sphere volume, its calculated radius will be equal with the Braille dot height. The notation for the paraffin cylinder and sphere are the following:

R_C - Cylinder radius [mm];

R_S - Sphere radius [mm];

h_C - Cylinder height [mm];

V_C - Cylinder volume [mm^3];

V_S - Sphere volume [mm^3].

The known values are:

R_C=1 [mm]

h_C =5 [mm]

$$V_C = \pi \cdot R_C^2 \cdot h_C = 15.7[mm^3] \quad (1)$$

$$V_S = 2(V_C \cdot \approx 15\%) \cong 4.71[mm^3] \quad (2)$$

$$R_S = \sqrt[3]{\frac{3 \cdot 4.71}{4 \cdot 3.1415}} = 1.04[mm] \quad (3)$$

Consistent with the result, an approximation of Braille pine displacement is ~1.04 [mm]. In figure 4 the two positions (initial and final) of the Braille membrane are presented.

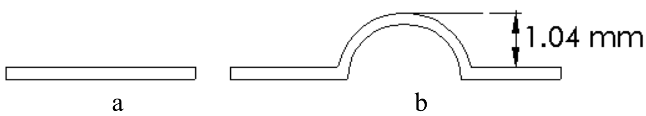

Fig. 4. The two position of the Braille dot: a) inactive dot; b) raised dot

4. CONCLUSION

A numerical investigation of transient heat transfer phenomenon during paraffin melting and solidification in an encapsulated recipient with resistive heated from a mini heater has been carried out. The reduction of the melting time of the composite PCM is in accordance with the increase in the thermal conductivity.

The obtained numerical results give a good estimation of the phase change material melting and solidification processes. It can be concluded that the presented work could provide guidelines for thermal performance and design optimizations of future actuator prototypes which will be incorporated in active Braille dots.

The total power consumption level of portable medical devices largely depends on its functionality and complexity. So, new approaches are conducted to simplify the solutions but respecting the same good functionality.

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Analiza performantelor unui actuator cu parafina pentru actionarea unui pin Braille

Aceasta lucrare isi propune sa analizeze performantele unui tip de parafină avand în vedere viitoare utilizare a acesteia in cadrul unui actuator termic incorporat in cadrul unei celule Braille. Parafina este utilizată ca material pe baza de schimbare de faza, transformand energia termica in lucru mecanic. Eficienta materialelor cu shimbare de faza este dependentă de cantitatea incapsulată si de capacitatea de stocare a energiei pe unitatea de masa in timpul procesului de topire si solidificare. In cadrul lucrarii s-a investigat performanta acestui tip de material pentru utilizarea sa ulterioara intr-un prototip de actuator in vederea actionarii unui dispozitiv Braille.

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