EXPERIMENTAL DETERMINATION OF SOME THERMAL PROPERTIES OF RAPHIA VINIFERA GUM

by

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Abstract

The thermal properties - thermal conductivity, specific heat capacity and viscosity of raphia gum are studied experimentally. The results show that thermal conductivity varies from 0.0164 to 0.0403 (W/m^{o}k) for moisture content and temperature ranging from 59.77 to 93.13% (W.b) and 40 to 80 (^{o}C) respectively. The specific heat capacity is from 1.178 to 1.315 (KJ/kg^{o}C) for moisture content and temperature of 59.77 to 70.06% (W.B) and 50 to 70 (^{o}C) respectively. The gum is a non-Newtonian pseudoplastic fluid and hence its viscosity is determined from the shear rate against shear stress plot.

Nomentclature

A	(m^2)	Area			
B		Slope of plot	t	(s)	Time
L	(m)	Thickness of speciment	s		Instrument reasing
M	(g)	Mass	μ	(Ns/m^2)	Viscosity of the standard liquid used in the calibration of the cncentric cylinder.
F	(MPa)	Shear force			
D		Share rate	**Subscripts**		
T(^{o}C)		Temperature	h		hot plate
C_P	(KJ/Kg ^{o}C)	Specific heat capacity	s		saple
k	(W/m ^{o}C)	Thermal conductivity	g		guin
m		Heat loss factor	w		water
η	(Ns/m^2)	Voscosity	c		caloritmeter

Introduction

A knowledge of thermal properties of materials is one which is frequently desired in many areas of engineering applications. A few of such areas include thermal storage for low temperature application, equipment design, insulation for refrigeration and air-conditioning technology. The raphia palm known as Raphia Vinifera is an evergreen tree commonly found in swampy and rainforest regions of the tropics. The cut trunk produces a gummy exudate which may be seen as a whitish or pale yellow jelly depending on age. This exudate (the gum of interest) has a relatively high water content which makes it remain as "wet jelly". Amongst the work done in the area, we mention: Chiori [1] who studied the rheological and emulsifying properties of this gum. Krumel [2] who worked on the now properties of gums used in food industries.

Instrumentation and Experimental procedure

(i) Thermal Conductivity A primary run-off tests with two standard equipments for thermal conductivity measurement modified Fitch Apparatus and Probe equipment, were conducted and the former was found more applicable than the later.

The Modified Fitch Apparatus by Odigboh [3] is a modification of Fitch [4] original apparatus which permits the transient flow of heat from the source through the test specimen to a heat sink of known mass and specific heat.

Making a thermal energy balance, the heat gained by the heat sink is equal the beat supplied to it from the beat source, for the case of no beat losses.

Consequently,

$$MC_P \frac{dT}{dt} = \frac{kA}{L} = (T_h - T_s) \qquad (1)$$

$$\therefore \frac{dT}{T_h - T_s} \; \frac{kA}{MCpL} dt \qquad (2)$$

Integrate the above equation to get:

$$ln\,(T_h - T_s) = \frac{kA}{MCpL} + \; Constant$$

Hence $\frac{kA}{MCpL}$ is the slope represented by B of the graph of $In\,(T_h - T_s)$ against t form where

$$k = \frac{BMC_pL}{A} \qquad (3)$$

The transient response of each specimen to a step input in heat source temperature is experimentally recorded and the thermal conductivity determined as in equation (3).

(ii) Viscosity. Viscosity measurements are made using the Haake rotoviscometer. The viscosity is estimated from the shear-rate versus shear stress curve by making use of the relationship

$$\eta = \mu(s/3) \times 2.575 \qquad (4)$$

and $F = \eta D$ (5)

where 2.575 is the calibration constant of the particular concentric cylinder used.

An alternative analytical method for the determination of viscosity for non-Newtonian fluid by making use of angle of deviation from Newtonian

fluid has been proposed by Ayenor [5].

(iii) Specific Heat Capacity The heat chamber apparatus is used and a total of twenty-eight tests are carried out.

Tile specific heat capacity is determined by substituting experimental recorded values into the following equation

$$C_{pg} \frac{(M_W C_{pw} + M_c C_{pc})(T_2 - T_1 + m)}{M_g(T_g - T_2)} \qquad (6)$$

Where m is determined from the heat loss correction graph, T_1 is the initial temperature of water and calorimeter and T_2 is the higher temperature of the mixture.

Test Specimens

Four different samples 1,2,3 and 4 of Gistare contents 59.71%.64.14%, 93.15% and 70.06% (W.b) respectively of the natural gum were used for the experiments.

For the thermal conductivity and specific heat capacity, Experiments were performed under varying temperatures 80°C, 30°C and 26.5°C.

For the viscosity experiment, each specimen is placed in the sensor of the rotoviscometer which is immersed in a constant temperature bath of 25°C with thermometers for taking temperatures at which the viscosity measurements are made.

Results and Discussion

The results of the thermal properties – thermal conductivity, specific heat and viscosity arc shown in Tables 1, 2 and respectively. Figure 1 and 2 show the variation of thermal conductivity with mean temperature and moisture content for different samples respectively. From Figures 1 and 2; the thermal conductivity as expected increases with temperature, bulk density and moisture content.

From Table 1, the thermal conductivity of the material varies from 0.0164 to 0.0403(W/M°K) for moisture content and temperature ranging from 59.77 to 93.13% (W.b) and 40 to 80 °C) respectively. From Table 2, the specific heat capacity of the material increases with temperature and decreases with moisture content. It ranges from 1.178 to 1315 (KJ/Kg°C) for moisture content and temperature of 59.77 to 70.06% (W.b) and 50 to 70°C) respectively.

The viscosity of the material is determined from the shear rate against shear stress plot as it is a non-Newtonian pseudoplastic fluid . Figure 3 is the variation of shear rate with shear stress for two different samples. The viscosity decreases with temperature and moisture content.

Conclusions

As a material for low temperature thermal storage the thermal conductivity and specific heat capacity compare favourably to that of calcium chloride hexahydrate ($CaCl_2$. $6H_20$) as given by Carlson [6]. The raphia gum could find application because of its low thermal conductivity as a material for fare-control.

The high viscosity of the gum could open a wide field of application in printing paints and adhesives industries.

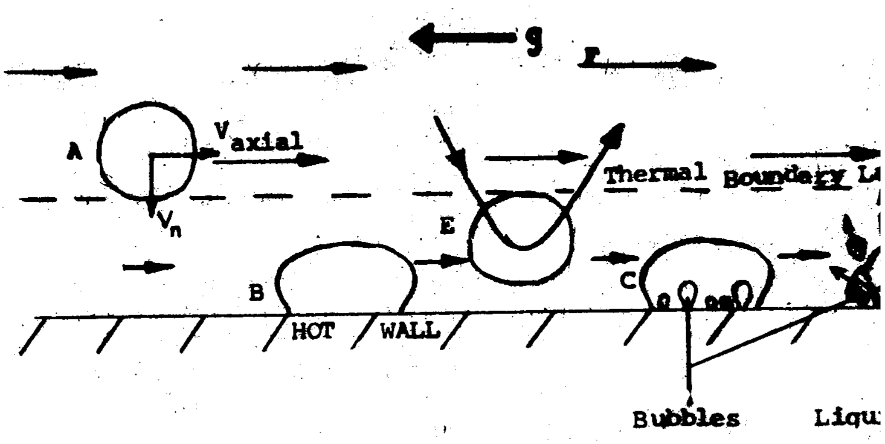

Figure 4a: Dispersed flow heat transfer process

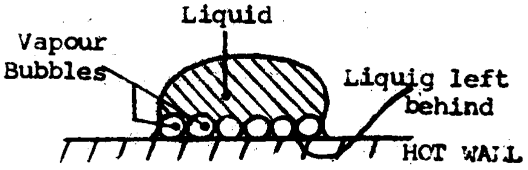

Figure 4b: Idealised bubble geometry at end of bubble growth (Square array)

A. Liquid drop entering thermal boundary layer with velocity V_n normal to wall
B. Liquid drop of higher kinetic energy based on V_n, arriving on wall and beginning to absorb heat from wall via conduction.
C. Nucleation and bubble growth period; part of liquid drop is ejected into the mainstream by escaping vapour bubbles; part is left on wall to evaporate
E. Liquid drop of lower kinetic energy in thermal boundary layer and being reversed into the main flow without touching the wall.
F. Bulk vapour flow

Figure 4: Dispersed flow heat transfer model

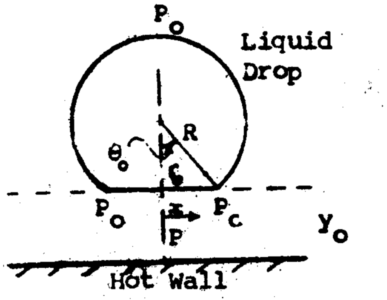

Figure 5: Effective Drop Shape: Truncated Sphere

F as a function of Y. The pressure distribution between a drop and the wall, and hence F, depends very much on the shape of die drop. A compromise truncated shape, as shown in figure 5, was used as the "effective" drop shape

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Pressure Distribution Between Drop and Hot Wall

The following assumptions have been made:

a) Imposed axial velocity is small compared to the velocity of vapour generated from the drop, within the thermal boundary layer.

b) Inertia terms in the equation of motion of the vapour between the drop and the wall are negligible compared to viscous terms.
c) Pressure at ends of truncation diameter is equal to system pressure.
d) Radiation from wall to drop is negligible.
e) Vapour velocities-are symmetric about a normal to wall, through the centre of the drop. Velocities perpendicular to this normal are predominant
f) Wall facing the drop is at uniform temperature. Liquid facing the wall is at the saturation temperature corresponding to average pressure between drop and wall.
g) Vapour properties are calculated at film temperature $T_f = 1/2\ (T_w + T_s)$

The velocity distribution becomes

$$u = \frac{1}{\mu_{vf}}\frac{dp}{dx}\ (Y - Y_o)Y \qquad (18)$$

From contiuity,

$$\int_{0}^{Y_o} \rho_{vf} 2\pi\ xudy = \int_{0}^{x} \frac{(q/A)\delta}{h_{fg}}\ 2\pi\ xudx \quad (19)$$

$(q/A)\delta = \frac{k_{vf}\Delta T}{Y_o}$ (simple conduction through vapour) (20)

at x = r_o, P = P_o. Thus

$$P - P_o = \frac{6\mu_{vf}k_{vf}(T_w - T_s)}{\rho_{vf}h_{fg}Y_o}\ r_o{}^2 - X^2 \qquad (21)$$

$$F = \int_{0}^{r_o} 2\pi\ \times (P - P_o)dx \qquad (22)$$

$$F = \frac{3\pi\mu_{vf}k_{vf}(T_w - T_s)}{\rho_{vf}h_{fg}Y_o r_o} \qquad (23)$$

For the detailed derivation of equations (18), to (25), see [10]. Introducting equation (23) into equation (9) yields,

$$3\pi(RSin\theta_o)^4 \int_{Y_{min}}^{Y_{b1}} \frac{\mu_{vf}k_{vf}(T_w - T_s)}{\rho_{vf}h_{fg}} \left(\frac{1}{Y_o}\right) dY_o = E_{b1} \qquad (24)$$

T_s and hence $\mu_{vf} k_{vf \rho_{vf}}$ and h_{fg} vary with Y_o. If the local average pressure rise between drop and wall is small so that change in T_s is small compared to T, or to (T_w - T_s), then T, may be assumed constant. Such conditions are more likely at the lower mass flux ranges. In the event that this approximation is not possible, a finite difference solution of equation (9), in which the local T_s is adjusted at each time step to correspond to the new average local pressure, will be necessary. With the above simplification, and since the force is negligible for Yo > Y $_{bl}$,
i.e

$$\int_{Y_{min}}^{Y_{b1}} Fdy = \int_{Y_{min}}^{\infty} Fdy \qquad (25)$$

integration of equation (24) yeild

$$\Delta T(Sin\theta_o)^4 = y^3{}_{min}\left(\frac{\rho_{vf}h_{fg}}{\pi\mu_{vf}k_{vfR^4}}\right)E_{b1} \quad (26)$$

Contact with the wall is defined as the event that a drop reaches the wall roughness, i.e. that $Y_{min} = \varepsilon$, where ε is the roughness height. If we now recall
the definition of E_w as the 'Kinetic energy' a drop needs to have at entry to the thermal boundary layer in order to just reach the wall at the system wall superheat ΔT_w, and of E_m as the statistical mean of the distributed Kinetic energies of the drops based on velocity normal to wall at entry to thermal boundary layer; - we then define ΔT_m as the wall superheat which would permit a drop with energy E_m to just reach the wall. Applying equation (26) to both E_w and E_m, and using the contact criterion,

$$\Delta T_w(Sin\theta_o)^4 = \varepsilon^3\left(\frac{\rho_{vf}h_{fg}}{\pi\mu_{vf}k_{vfR^4}}\right)E_m \qquad (27)$$

$$\Delta T_w(Sin\theta_o)^4 = \varepsilon^3\left(\frac{\rho_{vf}h_{fg}}{\pi\mu_{vf}k_{vfm^4}}\right)E_w \qquad (28)$$

At low flow rates, most of the drops lie within a narrow size band, as shown by Rosen [8]. We can assume R = R_m. Dividing equation (27) by equation (28) yield

$$\frac{E_w}{E_m}\ \frac{\Delta T_w}{\Delta T_m} \qquad (29)$$

Substituting equation (29) into equation (17),

$$\gamma = exp\left(-\frac{\Delta T_w}{\Delta T_m}\right) \qquad (30)$$

Table 2: Measured values of specific heat capacity

Samples	Moisture content % (w.b)	Initial Temperature of water T (°C)	Specific heat capacity (KJ/Kg°C)		
			Final Temperature of Gum		
			50	56	67
1	59.79	29.5 30.00	1.296 1.298	1.303 1.303	1.314
2	64.14	29.5 30.0	1.257 1.260	1.263 1.264	1.316 1.270
3	7.06	29.5 30.00	1.164 1.1678	1.166 1.1678	1.179 1.179

Table 3: Typical Reading of the viscometer and determined values

Temperature = 25± 0.1 °C M. C. = 92% (w.b)

Speed (r.p.m.)	Viscometer Head	Speed factor (U)	Instrument Reading(s)			(S/3)	Ux(S/3)	D	N	nD
3.6	50	162	31.5	23.0	-	27.3	4422.60	3.27	11388.20	37239.40
7.2	50	81	32.0	28.5	25.5	28.67	2322.00	6.53	5979.15	39043.85
10.8	50	54	32.5	32.0	26.5	30.33	1638.00	9.80	4217.85	04133.93
21.6	50	27	40.0	37.5	31.0	36.17	976.50	19.59	2514.49	49258.81
32.4	50	18	43.0	41.5	35.0	39.83	717.00	29.39	1846.27	54262.02
64.8	50	9	51.0	48.0	39.0	46.00	414.00	58.78	1066.05	62662.42
97.2	50	6	58.5	54.0	44.0	52.17	313.00	88.17	805.97	71062.81
194.4	50	3	73.0	65.5	54.0	64.17	192.50	176.33	495.69	87404.57
291.6	50	2	81.5	74.5	61.0	72.33	144.67	264.50	372.52	98530.65
583.2	500	1	9.5		7.0	82.50	82.50	529.00	212.44	112379.48

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