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EXPERIMENTAL DETERMINATION OF SOME PHYSICAL AND THERMAL PROPERTIES OF LOCAL VEGETABLE OIL FOR USING AS COOLANT IN A SOLAR COOKER WITH PLANE SENSOR

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ABSTRACT

This paper deals with a solar cooker that functions with thermosiphon and uses vegetable oil as coolant. The use of this fluid requires the knowledge of its density, its dynamic viscosity (variable according to its temperature) and of its heat-storage capacity. Therefore, we conducted an experimental determination of these properties for the cotton seed oil, the groundnut oil, the oil of CANARIUM, the artisanal red oil, SODEPALM red oil, the industrial palm oil, the oil of Shea tree, the Coconut oil and the oil of "KIBI". The results are presented in graphs as regards the density and dynamic viscosity, and in a table with regard to the heat-storage capacity. The knowledge of these various sizes enables to make a good choice of the coolant that best adapts to this type of equipment.

1. INTRODUCTION

Solar energy is ultimately a nonpolluting energy, free, for which its rational use requires a know-how in terms of collection and storage for a rational use. These uses include in solar-fired heaters, solar cookers, electricity produced from solar (photovoltaic cells), etc., for domestic needs [1]. The usually elaborate solar cookers, include solar systems that use parabolic sensors to concentrate the solar rays on a hearth. The new trend is to move to the cooker that uses a plane sensor functioning with thermosiphon where the coolant (oil) circulates by natural convection [1], [2*]*. In Thermics, it is essential to make a good choice of the coolant which is appropriate for the solar equipment to build. The knowledge of certain physical and thermal properties of the fluid, like the variation of its density and its dynamic viscosity according to temperature ([7], [8]), together with the knowledge of its heating capacity, enable possible to control a simulation of the system operation by the cycle of thermosiphon and to roughly plan the cooking temperatures that can be reached. Then, we will present the material used for these measurements, as well as the methodology adopted. Results are presented in the form of graphs or tables followed by comments. We have proposed after this comment, oils that are best adapted for this type of system [6].

2. MATERIALS AND METHODS

2.1. Principle of the densities measurements:

Equipment to take measurements includes:

- NiCr/NiAl thermocouples of the type K and precision 0.3;
- An adjustable hotplate;
- A container filled with sand;
- A test-tube (which contains oil to be studied);
- A polystyrene container containing ice at 0 °C and tighly sealed;
- A Millivoltmeter BBC Goerz Metrewatt ;

- A graduated densimeter from 100 to 600 (from 10 to 10).

Considering T the temperature which one wants to know using the thermocouples: T-T0 = A v + B; where A and B are determined by calibration of the thermocouples (v in mV). The calibration on March 06 gave us: T = -1,9076 + 25,2296 v with R=1,00 and that on September 21 gave us: T=-2,7136 + 24,7223 v with R=1,00.

By definition $\rho(T) = \frac{M}{V(T)}$ (1) ; M is the oil mass (in kg), V is its volume (in m^3) which varies according to the temperature T (we used °C here) and ρ is its density (in kg/m^3) which also varies according to the temperature T [2] [3] [4].

2.2. Principle of dynamic viscosities measurements :

To determine the dynamic viscosity of these vegetable oils, we used a rheometer of the type STV, with a system of measurement A-E [2]. It is a rheometer with coaxial cylinders, provided with a synchronous motor which drives the body of measurement and which turns at constant speed (three speeds are considered; this enables to obtain three points to draw the rheogram.

We have: $\mu = \frac{\tau}{(du|dr)}$ (2); τ is the shear stress (in N/m^2), du/dr is it speed gradient (in s^{-1}) and μ is dynamic viscosity (in N s/m^2) [4].

2.3. Principle of heat-storage capacities measurements :

Equipment for for these measurements includes:

- A calorimeter
- The accessories of the calorimeter which are:
  - A thermometer;
  - An agitator;
  - A container (in which is put the fluid to assess its heat-storage capacity) to be placed within the calorimeter;
  - An electric stove which enables to heat water (until boiling);
  - A second container which contains a water mass to be heated;
  - A balance.

To make measurements, we used the method of the mixtures: a quantity of heat Q is provided to a mass M of oil contained in the calorimeter. Q = (M Cp + m1 C1 + m2 C2 +........... + mn Cn) (θf - θi) (3); m1, m2......, mn are the masses of the various accessories (calorimeter, agitator, thermometer, container); C1, C2…, Cn are the corresponding specific heats; θf is the final temperature (hot oil-water mixture); θi is the initial temperature of the oil mass M; µ = m1 C1+ m2 C2 +...... + mn Cn (4) is water equivalent of the calorimeter and its accessories (which is measurable). The quantity of heat Q provided to oil derives from boilingwater. Another of its expressions is: Q=me (θ0-θf) (5); θ0 = boiling water temperature. From the expressions (3), (4) and (5), it can be deduced: me (θ0-θf) = (M Cp + µ) (θf-θi) (6), i.e. $Cp = \frac{me}{M}\frac{\theta 0-\theta f}{\theta f-\theta i} - \frac{\mu}{M}$ (7). Cp is in kcal/kg °C or kj/kg °C, like C1, C2…, Cn; Q is in kcal or J and µ in kcal/°C or kj/°C [2] [3] [4].

3. RESULTS AND DISCUSSIONS

3.1. Densities

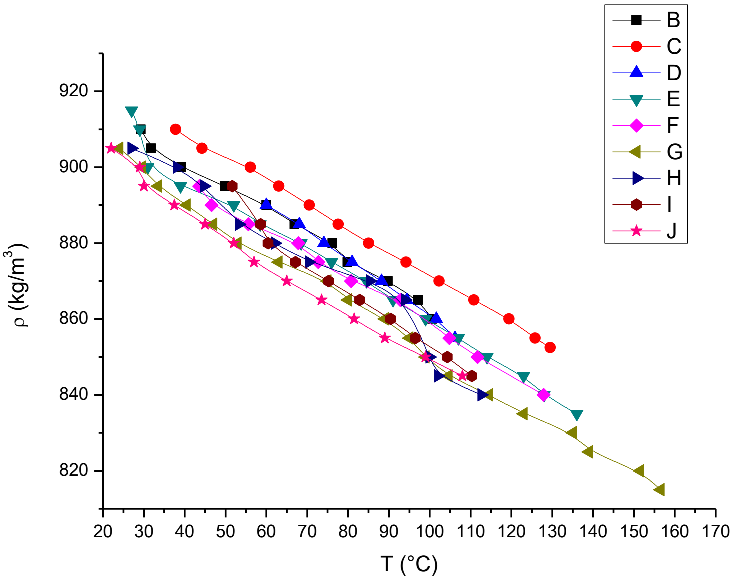

Figure 1: graph of the densities variation [6]

Caption : B : Coconut oil ; C : KIBI oil ; D : CANARIUM oil ; E : cotton seed oil ; F : Shea tree oil ; G : groundnut oil ; H : SODEPALM red oil ; I : artisanal red oil ; J : industrial palm oil.

By definition $\rho(T) = \frac{M}{V(T)}$, M being constant because evaporation is negligible. When the temperature increases, oil dilates, therefore increases its volume. Consequently, the density decreases when the oil volume increases. The curves represented here are very close decreasing lines of equation $\rho(T) = A - B * T$ with A, B ≥ 0. Heavy oils are those with representations above the others, including for example: industrial palm oil, Shea tree oil, cotton seed oil, etc. ([6***]**, [7***]**, [11]***)*.

3.2. Dynamic viscosities

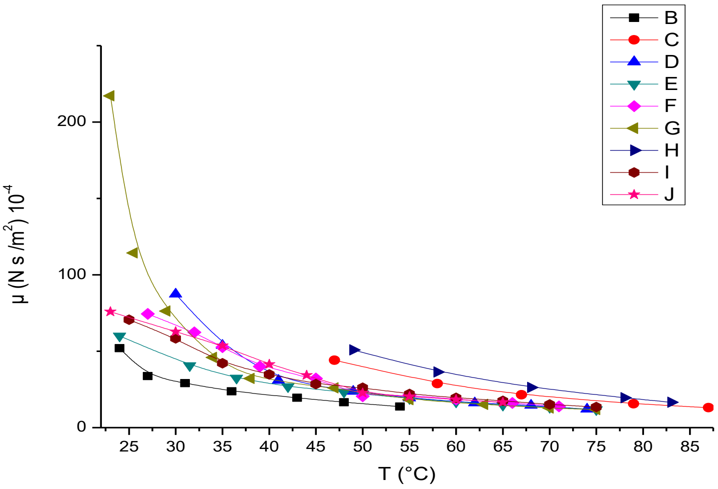

Figure 2: graph of oils dynamic viscosities [6]

In the legend, the various letters represent:
B: oil of Coconut; C: CANARIUM oil; D: SODEPALM red oil; E: cotton seed oil; F: KIBI oil ; G: artisanal palm oil; H:Shea tree oil ; I: groundnut oil; J: industrial palm oil.

Base on logarithm, all the curves of dynamic viscosity decrease with temperature. The same type of behavior is observed for all these vegetable oils studied. Figure 2 enables to compare various viscosities directly when temperature increases. From 75 °C, there is very little difference between viscosities of various oils, meaning that at this moment, they have almost similar behaviors. During measurements, we noticed that CANARIUM oil, Shea tree oil, and SODEPALM red oil become solid while they remain exposed to the ambient temperature during several days without getting heated.

Rheological study of oils ([10***]***):

Usually, the rheological behavior of oils occurs in 2 ways:

- either its rheological graph is presented as follow: Newtonian rheological behavior

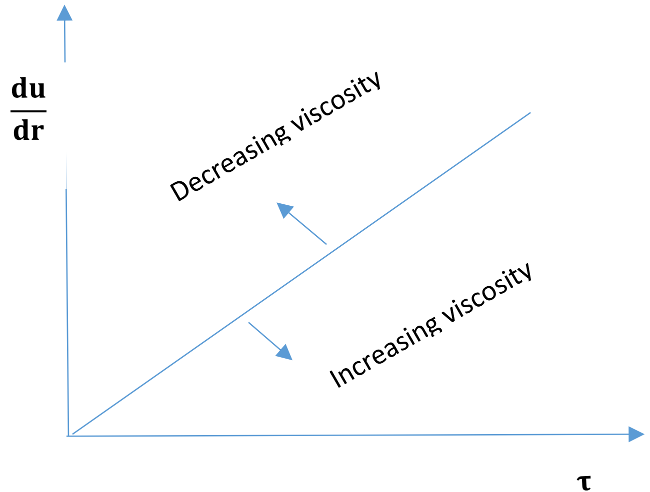

Figure 3: rheogram taking the gradient speed into account (Newtonian Behavior)

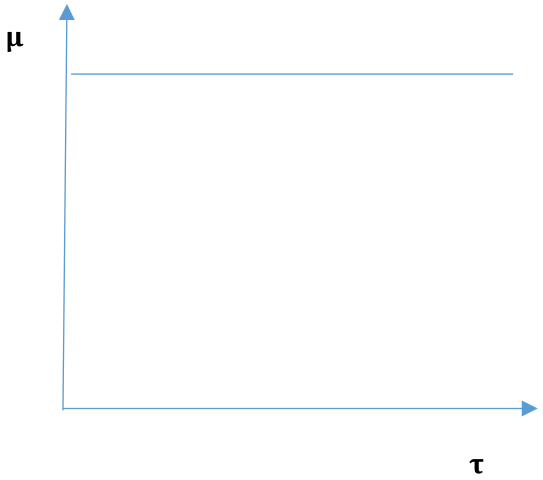

Figure 4: rheogram taking dynamic viscosity into account (Newtonnian behavior)

With: du/dr = gradient speed;
μ = dynamic viscosity;
τ = shear stress.

For all our studied oils, at low temperatures (ambient), the Newtonian behavior is checked except for CANARIUM oil, shea tree oil, SODEPALM red oil. At sight, these oils "sleep" at ambient temperature. But, above 30 °C, they become Newtonian. The rheogram is like the figure above.

- or its rheological graph is as follow: plastic rheological behavior

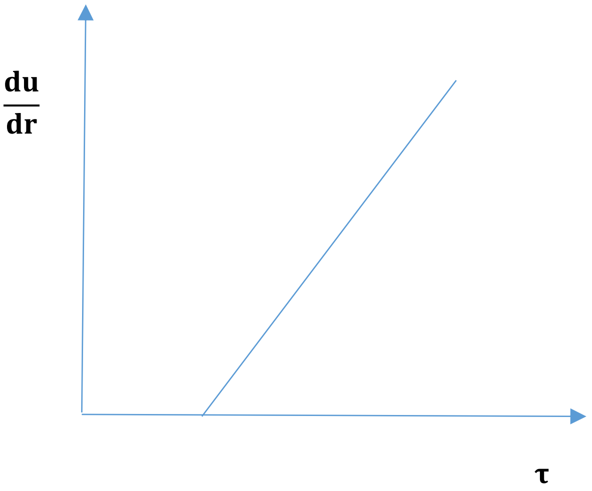

Figure 5: rheogram taking the gradient speed into account (plastic Behavior)

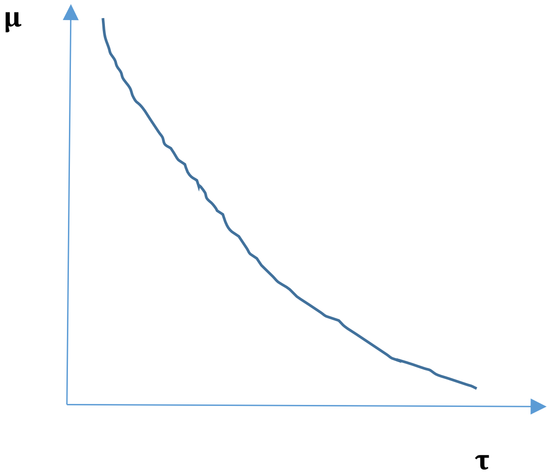

Figure 6: rheogram taking dynamic viscosity i ccoount (plastic behavior)

The plastic substances are characterized by a limit corresponding to a shear stress below which the substance stops flowing; it becomes a solid body. The rheogram is presented under one of the figures above (figure 5 or figure 6). Only three oils abovementioned confirmthis behavior at the ambient temperature. But above 30 °C, all oils studied adopt a Newtonian behavior.

3.3. Heat-storage capacities ([6], [12])

Experimental measurements of the heat-storage capacities of these oils are presented in a table. We used two identical assemblies with different calorimeters which give us values slightly different from the heat-storage capacity of each oil. In the last table, we made the average of the first two to show final values:

Table 1: Measurements with the first calorimeter

Calorimeter 1 µ1 = 245,32 cal/°C							
Oils	**M (g)**	**me (g)**	**Θi (°C)**	**Θ0 (°C)**	**Θf (°C)**	**Cp (kcal/kg°C)**	**Cp (kj/kg°C)**
Cotton	38.7	271.5	25.5	93	49	6.796	28.407
KIBI	58.4	427.5	25.5	93	51	7.856	32.838
Industrial Palm	71	474.4	24	93.5	51.5	6.749	28.211
Groundnut	34.5	122.5	25	93	38	7.911	33.066
CANARIUM	50.2	433.7	26.5	93	52	7.96	33.27
Red artisanal	17	260	25.5	93	52.5	8.51	35.572
Red SODEPALM	47.7	392	25	93.5	51.5	7.882	32.947
Coconut	32	249	27	93	49	7.896	33.005
Shea butter	27.7	85.3	43	93	51	7.311	30.560

Tableau 2: Measurements with the second calorimeter

Calorimeter 2 µ2 = 297,7 cal/°C							
Oils	**M (g)**	**me (g)**	**Θi (°C)**	**Θ0 (°C)**	**Θf (°C)**	**Cp (kcal/kg°C)**	**Cp (kj/kg°C)**
Cotton	17.7	225.4	24.5	93	48.5	6.793	28.395
KIBI	46.7	336	26	93	48.5	7.855	32.834
industrial Palm	39.1	306.3	24	92	48	6.75	28.215
Groundnut	35	296.5	27.5	92.5	51	7.951	33.235
CANARIUM	37.2	189.1	26	92	42	7.88	32.938
Red artisanal	31.8	336.5	28	92.5	52	8.495	35.509
Red SODEPALM	33.6	352.4	25.5	93	51.5	7.88	32.938
Coconut	28	295.4	25.5	93	50	7.884	32.955
Shea butter	24.7	268.9	31.5	93	53.6	7.306	30.539

Table 3: Average and classification by descending order [6]

Oils	**Cp (kcal/kg °C)**	**Cp (kj/kg °C)**
Red artisanal	8.502	35.54
CANARIUM	7.955	33.254
Groundnut	7.895	33
Coconut	7.89	32.98
Red SODEPALM	7.881	32.94
Kibi	7.8555	32.836
Shea tree	7.3085	30.55
Cotton	6.7945	28.4
Industrial Palm	6.7495	28.213

From results, we note that mainly, the heaviest oils (notably those which become solid or pasty at ambient temperature), shea butter excepted, have the best heat-storage capacities. On the other hand, light oils such as Coconut, groundnut, KIBI (which are not solidified or do not become pasty at ambient temperature) have also very good heat-storage capacities compared to the others. It is therefore interesting to take into account primarily vegetable oils which are not solidified (or do not become pasty) at ambient temperature for the type of system that we intend to conceive. Indeed, when the solar rays appear in the morning, the natural circulation of the fluid in the system must start as soon as possible. However, , "sleeping" oils at the ambient temperature are usable provided they are mixed with a chemical product ([8], [9]) which would turn them into liquids at low temperatures. But this treatment decreases their heat-storage capacity ([6]), ([10]) and this would be like using light oils withlower capacities than these heavy oils.

4. CONCLUSION

In this study, we could determine the density, dynamic viscosity and heat-storage capacity of some of the vegetable oils. We noticed that most of "heavy" oils such as the SODEPALM red oil, red artisanal, CANARIUM have good physical properties. But a major disadvantage can prevent their use as coolant in solar systems with natural circulation ([6]), namely their plastic behavior at ambient temperature (about 22 °C) when they "sleep". A solution would be to mix them with chemical products which would eliminate this property. However, this would disturb the physical properties studied. It would be interesting to conduct the experiment which will enable to assess the new physical properties of these oils. In addition, , we note that "light" oils such as Coconut oil, groundnut oil and KIBI also show good physical properties. Their use in these solar systems must be encouraged, at least, in tropical countries where there is no risk of plastic behavior during a large part of the year.

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