Thermal study of Agar solution in a capillary Installation

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Abstract

The behavioral study of non-Newtonian fluids with heat transfer is a very active field of research. Researchers are more interested in the heat developed in cylindrical pipes, in forced convection. we were interested in this thermal transfer work during a flow of a non-Newtonian fluid which is an aqueous Agar Agar solution, through a cylindrical heating pipe and horizontal heat flux imposed in a capillary installation.

Keywords: Heat transfer, non-Newtonian fluid, Terminal rheological

1. Introduction

Rheology is the science that studies the deformations and the flow of matter. Its purpose is to analyze the mechanical behavior of substances and to establish their laws of behavior. [1] The field of application of rheology covers a wide range from a complex fluid to industrial shifts such as the agri-food, cosmetic, pharmaceutical, etc. In the very frequent case where one does not know the behavior of the fluid, it is preferable to use the experimental results and to treat them with the help of the Mooney relation [2] developed hereafter in order to determine the true law rheological fluid on the field actually experienced.

We have previously established the general relation of Rabinowitsch (1), which can be differentiated from τp to give.

$$\frac{Q}{\pi R^3} = \frac{1}{\tau_p^3}\int_0^{\tau_p} \tau^2 f(\tau) dr \tag{1}$$

Finally, from the experimental measurements $\frac{\Delta p}{L} = f(Q)$, we can determine the rheological law of the fluid $\tau p = f(\dot{\gamma} p)$ from the following three relationships:

$$\tau_p = \frac{\Delta p}{L}\frac{R}{2}$$
$$\dot{\gamma}_p = \frac{4Q}{\pi R^3}\left[\frac{3m+1}{4m}\right] \quad (2)$$
$$m = \frac{dlog(\frac{\Delta p}{L})}{dlogQ} = \frac{dlog\tau_p}{dlog\dot{\gamma}_{app}}$$

It must be remembered that Mooney Rabinowitsch's relation holds for all time-independent fluids, in laminar flow and assuming no wall effect; that is, the adhesion condition is always verified. So, in reality, the flow of fluids is often accompanied by sliding or wall effects.

It is possible to derive a simple criterion for comparing the effects of forced convection and natural convection when these two phenomena are in competition, that is to say when the movement can be the result of both a mechanical cause external and density gradient in the fluid. From the sizing of the set of Boussineq equations, it appears a dimensionless number Ri says Richardson. This number delimits the domains of forced convection with Ri << 1, natural convection Ri >> 1 and mixed convection (neighbor of the unit). This analysis is valid whatever the reference langer x.

2. MATERIALS AND METHODS

Agar-agar is a natural polysaccharide obtained from the cell wall of Rhodophyta (red algae). Agar-agar is considered biocompatible, non-toxic and cost-effective inert biopolymer [4].

2.1 Protocol for the preparation of agar-agar solutions

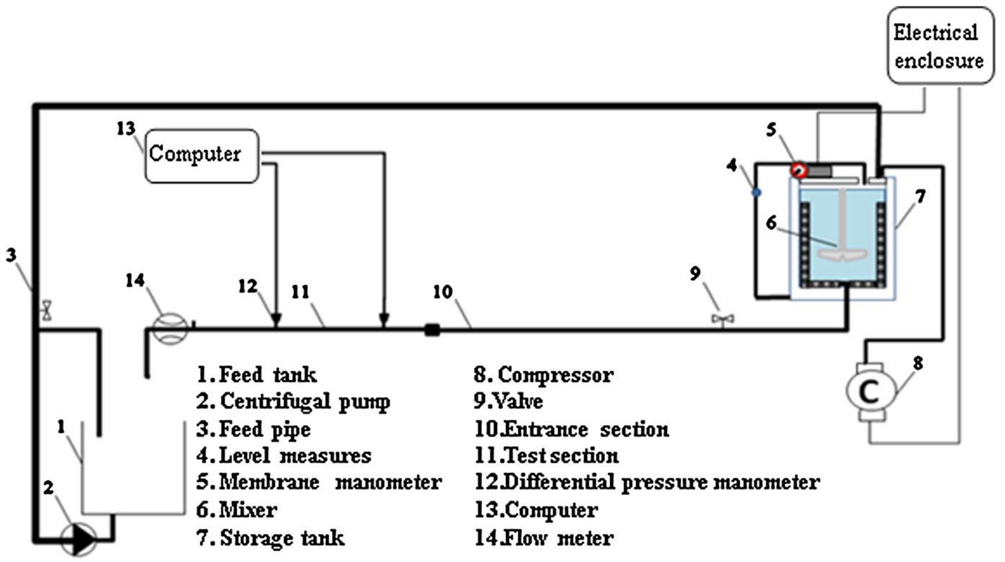
For this study, we have prepared two solutions of different concentration (0.1-0.15%). The experimental protocol adopted for the preparation of 50l agar-agar solution is detailed below. The one at a concentration of 0.1% (the same protocol is followed for the other concentrations):

- Prepare 50 liters of distilled water in a tank.
- Weigh 50g of agar-agar powder.
- Heat the distilled water to 90 ° C.
- Add the powder into distilled water while stirring (using a helical stirrer) until the material dissolves completely.
- Allow the mixture to sit in a tank at room temperature for a minimum of 6 hours to remove any air bubbles in the solution.

2.2. Rheological caracterisation

To characterize the rheological properties of non-Newtonian fluids (agar-agar solution, we adopted a method based on the measurement of pressure drop and flow rate. The experimental set-up conceived in our laboratory, which served as support for the present study, is illustrated in Figure 1.

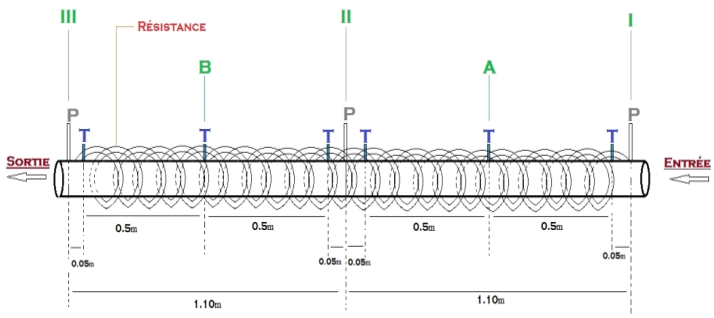
Figure 1. Schematic diagram of the experimental setup[3].



It consists essentially of: The storage bins up-and downstream, the fluid is thus aspirated from the upstream tank by a downstream pump unit equipped with a speed regulator toward the upstream tank with overpressure with respect to atmospheric pressure, a compressor, with circular horizontal pipes of 10 mm diameters placed at the end of a 3-m-long cylindrical pipe, used to establish the flow regime. The test lines are equipped with pressure sensors for measuring pressure. Flow measurement is carried out by means of an electromagnetic flowmeter.

the heating pipe measures two meters long, has been carried out and laid off within our laboratory, this pipe has diameters of 10 mm, in order to study the effect of temperature on the rheological behavior of the fluid not Newtonian, this pipe for heating the fluid. The heating is carried out by a heating coaxial wire (Thermocoax) wound on the measuring lines. It includes a Nickel-Chrome wire, placed in a stainless steel sheath. The wire is isolated from Teflon as an adhesive tape (75% virgin PTFE, 25% Fiberglass). The pipe assembly is effectively insulated by a glass wool casing. The heated measuring vein is embedded in an aluminum case

Figure 2 : General diagram of the heating pipe.



3. Results and discussion

3.1. Thermorheological study of the flow of Agar solution

The thermo-rheological study of agar solutions consists of studying the effect of temperature on the rheological behavior of agar solutions. For this purpose, we present in Fig III.3 and III.4 the evolution of the parietal shear stress as a function of the parietal shear rate for a concentration of 0.1% and 0.15% respectively, flowing in a pipe 8 mm in diameter and at different temperatures.

Figure 3**:** Effect of temperature on the rheological behavior of the agar agar solution. C = 0.1%, d = 8 mm

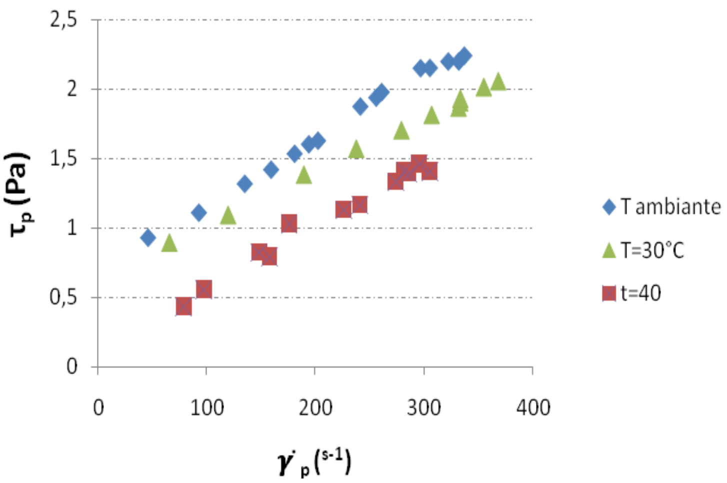
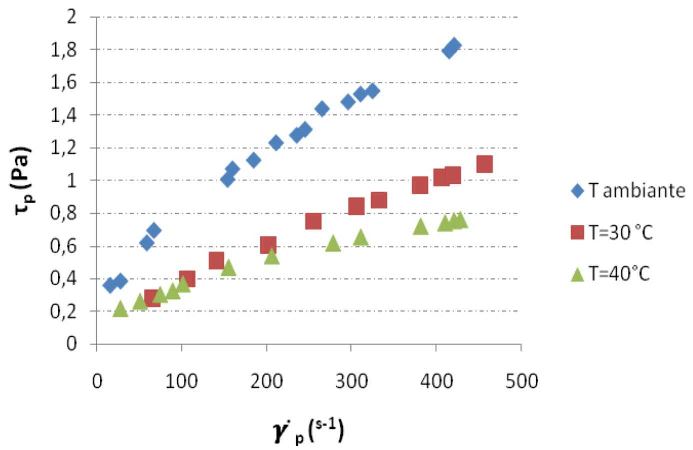


Figure 4: Effect of temperature on the rheological behavior of the agar agar solution. C = 0.15%, d = 8 mm



The previous Figure 3 and Figure 4 show that for a given shear rate, the shear stress decreases with increasing fluid temperature.

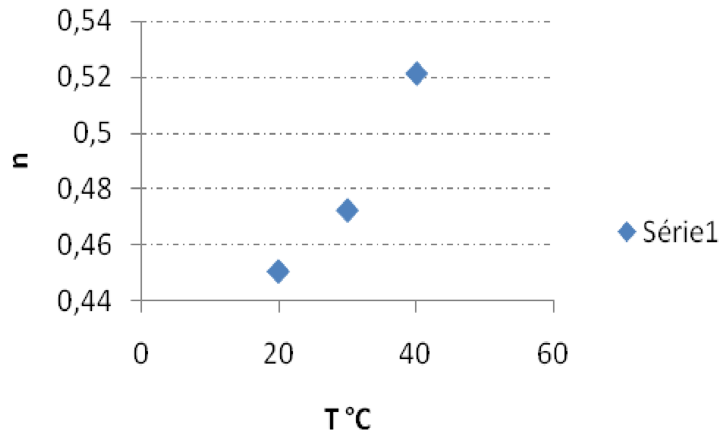
The decrease of the stress with the temperature is very widespread. This phenomenon can be explained by an increase in the thermal activity of the polymer molecules causing an increase in the free volume of the molecules and a simultaneous decrease in intermolecular and intramolecular interactions.

The values of the parameters of the rheological model adopted (Herschel-Bulkley), the flow index "n" and the consistency index "k" determined from the previous figures are grouped together in Tables 1 and 2.

Table 1: Rheological parameter of the Herschel-Bulkley model for a solution of agar agar at 0.1% d = 8 mm

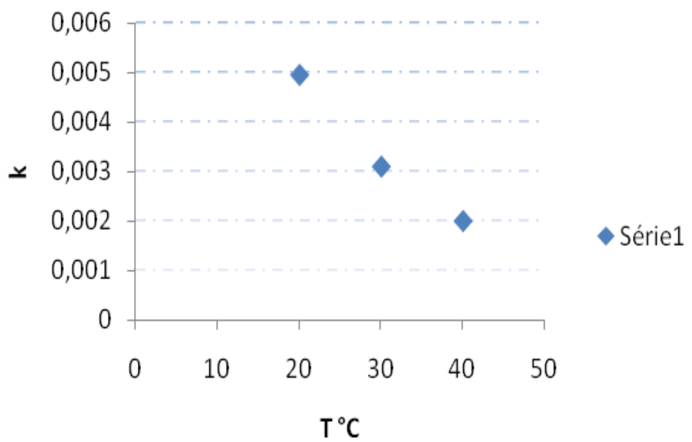
d (mm)	T (°C)	n	K
8	20	0.45061	0.00495
	30	0.4752	0.00312
	40	0.52148	0.00215

Figure 5: Evolution of the flow index as a function of temperature for a concentration of 0.1% to 8 mm in diameter.



The previous figure shows that the parameters of the Herschel-Bulkley model behave differently with the fluid temperature. We note on the one hand that the flow index is less than 1, thus indicating the pseudo-plastic character of the agar agar solution and, on the other hand, the flow index increases with the increase of temperature.

Figure 6: *Evolution of the consistency index as a function of temperature at a concentration of 0.1%, diameter 8 mm.*

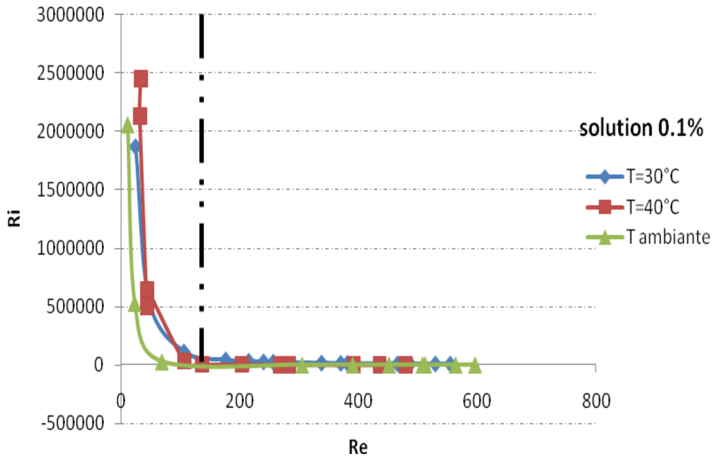


Regarding the dependence of the consistency index with temperature, we observe a decrease of "k" with the increase in temperature. This result is completely predictable, because the increase in temperature favors the deselining of the polymer chains. We found the same results for a concentration of 0.15%.

3.2. Competition between natural convection and forced convection

Figure 7 shows the evolution of the Richardson number as a function of the Reynolds number, for agar agar solutions of 0.1% heated at different temperatures flowing in an 8 mm diameter pipe.

Figure 7: *Evolution of the Richardson number as a function of the Reynolds number at different temperatures, for a concentration of 0.1% and a diameter of 8mm*.



From the previous figure, there are two zones:
The first, for values of the Reynolds number up to 100, we note that the Richardson number decreases with increasing Reynolds number. It can also be seen that for a constant Reynolds number, the higher the temperature, the larger the Richardson number. This is perhaps explained by the fact that the temperature increases the gravitational effects (Gr increases), the more the temperature is increased, the more we favor the natural convection regime.
The second zone, for Re> 100, the Richardson number reaches an almost zero asymptotic value, we notice that the temperature can be considered as a passive scalar and the Richardson number remains almost constant with the increase of Reynolds number. The increase in the Reynolds number reflects the predominance of the forces of inertia in front of the gravitational forces (Re >> Gr), hence the linear return limiting the null value. This means that temperature plays a key role in the characterization of the thermal flow regime.

We found the same results for a concentration of 0.15%.

3.3. Profile of Nusselt number according to Richardson number

We have been able to draw the graph below which represents the evolution of the local Nusselt number (z = 1 m, φ = 92W) as a function of the Richardson number for different fluid temperatures and for an 8 mm diameter pipe.

Figure 8: *Evolution of the local Nusselt number as a function of the Richardson number for different temperatures, C = 0.1%, d = 8 mm.*

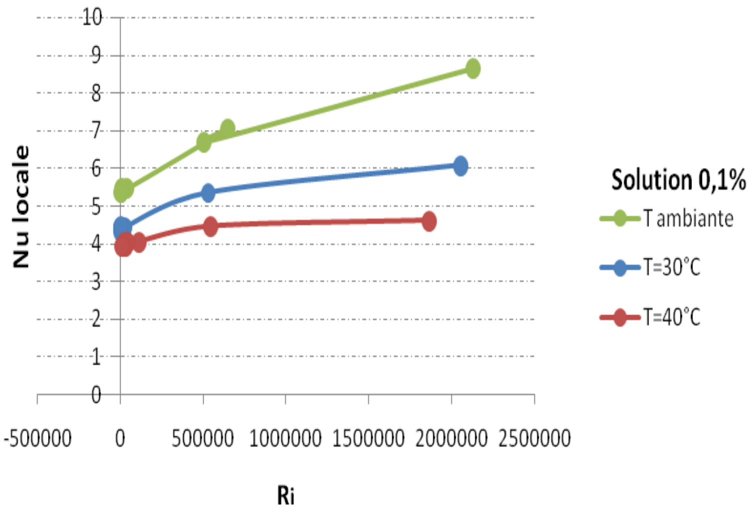
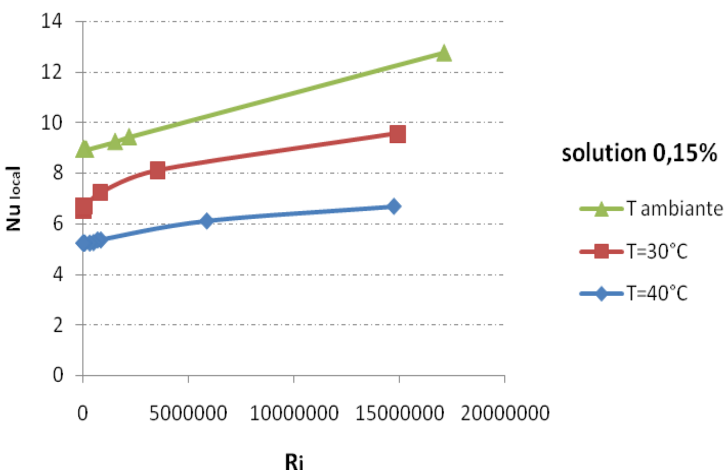


Figure 9: *Evolution of the local Nusselt number as a function of the Richardson number for different temperatures, C = 0.15%, d = 8 mm.*



From both, we find that the number of Nusselt increases with the number of Richardson regardless of the study temperature. In addition, an increase in temperature (n increases) disadvantages the heat transfer rate due to the lowering of the apparent viscosity of the fluid near the wall of the cylindrical pipe, which increases the local Reynolds number, the latter thins the thermal limit layer.
Therefore, it can be concluded that the general use of a low power index fluid can be economical to improve the efficiency of the thermal process.

4. Conclusion

we carried out a thermo-rheological study, where it was found that the fluid does not change its behavior with the increase of the temperature, it remains always of the type of Herschel-Bulkley, and by increasing the temperature, the stress of shear decreases, hence the viscosity of the fluid also decreases.

We also highlighted the thermo-dependence of our solution by plotting the variation of the flow indices "n" and consistency "K" as a function of temperature. The curves confirmed that our solution is thermo-dependent.

Finally, we studied the heat transfer in a cylindrical pipe with a constant parietal flow, where we put into play the competition between forced convection and natural convection at first. In a second step, we evaluated the Nusselt number according to Richardson. We have found that flow and temperature play a key role in the characterization of the thermal flow regime.

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