Food Science and Quality Management
ISSN 2224-6088 (Paper) ISSN 2225-0557 (Online)
Vol.22, 2013
www.iiste.org

# Rheological Quality and Influence Factor of Moroccan Prickly Pear Juice (*Opuntia ficus indica* L.)

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## Abstract

Rheological properties of prickly pear juice fruit of cactus (*Opuntia ficus indica*) and impacts of temperature, shearing rate and pH value on its viscosity were studied using a rotational concentric cylinders viscometer. The results show that the viscosity of prickly pear juice decreases with the increase of its temperature and shearing rate. The solution presents pseudo-plasticity fluid, which shows the characters of shear thinning as follows: first, its viscosity decreases gradually as the temperature increases. The viscosity decreases sharply at both acid and alkaline conditions, indicating that it is influenced apparently by pH value.

**Keywords**: Prickly Pear, Juice, temperature, shearing rate, pH, Viscosity

## 1. Introduction

Prickly pear (*Opuntia ficus indica)* (figure 1) is one of the important commercial fruits in many countries and very well adapted to the arid and semiarid climate (Inglese et al.2002; Piga et *al.* 2004). It is cultivated in Morocco and grows in many other countries such as Mexico, United States, South Africa, Australia, and Mediterranean basin countries.

One of the most frequently utilized fruit and vegetable technologies is juice production. This juice, which is a complex mixture of vitamins, polyphenols, sugar, minerals include calcium, potassium, and magnesium, ascorbic acid, fibers and free amino acids (Sepúlveda & Sáenz 1990, Hasib et *al.* 2006, Dehbi *et al.* 2013), is an excellent source of pigments such as the red-violet betacyanins and the yellow-orange betaxanthins. Cactus fruits, in contrast to red beetroot, may be used in food without negative flavour impacts as those derived from beetroot extracts.

Knowledge of the viscosity is of primary importance to the fruit juice industry, it is important in quality control, storage and processing of foods, stability measurements, and in predicting texture (Abu-Jdayil et al. 2004, El batal et *al.* 2012). The accurate viscosity data over wide temperature, pressure, pH, physical state of dispersion and concentration regions are needed for a various research and engineering applications in any branch of food industry.

Physicochemical and rheological properties of mucilage extracted from *Opuntia spp.* have been studied by several research groups (Trachtenberg & Mayer 1982; Cardenas et *al.* 1997; Medina-Torres et al. 2000; Majdoub et *al.* 2001).

Mucilages and gums are heteropolysaccharides with rheological properties that are of great interest for a number of applications. Biological sources of mucilage that have been studied include flaxseed gum, Alyssum homolocarpum seed, nopal cactus (Opuntia ficus indica) (Medina-Torres et al.2000; Koocheki et al. 2009; Wang et al. 2010; Leon-Martinez et *al.* 2011). The demand for hydrocolloids with a specific functionality has increased recently in the foodstuffs industry (Koocheki et *al.* 2009). To satisfy this demand, research on new sources of polysaccharides, such as Hylocereus undatus, is needed. The rheological properties of dragon fruit (Hylocereus spp.) purees have been studied (Liaotrakoon et *al.* 2011); however, the properties of mucilage isolated from the stalks of the plant have not been investigated.

Rheological properties of fruit juices also appear to be very much dependent in their varieties, state of ripening, concentration of juice/pulp and temperature variation. Therefore the present investigation was undertaken to study the rheological properties of prickly pear juice as a function of temperature, shear rates and pH.

## 2. Materials and methods

### *2.1. Experimental device*

The rheological characterization of Opuntia cactus fruit juice solution has been performed using a rotational rheometer, shear rate imposed (RM180, Figure. 2). This unit basically consists of two concentric cylinders making, between them, a small annular space (gap) that contains the test fluid whose viscosity is to be determined. The inner cylinder (bob) is driven at constant rotation speed by direct-current motor, while the outer one (tube) is rigidly coupled to a measuring head which maintains it at rest.

A built-in microprocessor calculates the values for the viscosity η, with the aid of the measured torque, M, on the bob, the set rotation speed, Ω, and the measurement system used, according to the formula (1):

$$\eta = \frac{\tau}{\dot{D}} \qquad (1)$$

Where $\dot{D}$ is the shear rate and τ is the shear stress, which are given, respectively, by:

$$\dot{D} = k_{\dot{D}}\Omega \quad \text{and} \quad \tau = k_{\tau}M \qquad (2)$$

$k_{\dot{D}}$ and $k_{\tau}$ being conversion factors related to the geometry of the system.

To perform measurements at different temperatures, the measuring system (bob and tube) is soaked (dipped) in a thermostat tank thermally controlled and the sample temperature is measured by a Pt100 probe immersed in the substance.

More details related to the design, functioning and use of RM180 are given in (www.mapleinstruments.com).

### *2.2 . Production of juice and measurement of viscosity*

Opuntia ficus indica fruits samples were collected during the period in August 2010 in the region of Marrakesh (Morocco), where they grow naturally. Three different lots of fruits were harvested, carefully washed with water to remove the glochids and the obtained juice was centrifuged (4000 x g , 30min at 4°C) and the supernatant juice was stored at -20°C before being used (figure 3).

Conventional rheometrical tests, at different temperature, were carried out for cactus juice using the RM180 above described. Before each measurement, a pre-shear at 50 s-1 was applied to each sample. Then the apparent shear rate was increased step by step from 10 s-1 to1000 s-1.

## 3. Result and discussion

### *3.1. Variation of the viscosity of O.F.I juice with the shear rate*

The viscosity as a function of shear rate at different temperatures is shown in Figure. 3. At low shear rate, the viscosity was varied significantly in the temperature range of 20–60 °C. At high shear rate, the viscosity decreased with shear rate and its measurement became more difficult as the material was spun out of the plates at high speed.

According to the figure above represented, and generally, for a given temperature, η evolves as a hyperbolic function of $\dot{D}$.

The experimental data showed a non-Newtonian behaviour for the Opuntia juice (Figure. 4), that retainedits pseudoplastic characteristic, indicated by the value of the flow behaviour index (n), being less than 1 (Table 1).

This fact indicates that the pseudo-plastic behavior exhibited by aqueous solution of O.F.I derivative can be well quantified by the following power-law model, due originally to Ostwald-de Waele:

$$\eta = K\,\dot{D}^{\,n-1}$$

Where n and K are the flow behavior and consistency indexes, respectively. Then, the degree of shear-thinning for O.F.I juice solution could be measured by the value of n, which almost constant when the pseudo-plasticity increases. From the results listed in Table 1, n has the values ranging from 0,27 to 0,32 are observed for three derivative solutions, showing their shear-thinning property.

Table 1: Flow behavior index (n), consistency index (K) and corresponding linear regression coefficient (LRC) for different temperatures (T).

| **T(°C)** | **n** | **K (Pa .S)** | **LRC** |
|---|---|---|---|
| **20** | 0.27 | 11.44 | 0.988 |
| **30** | 0.29 | 6.818 | 0.995 |
| **40** | 0.29 | 5.177 | 0.984 |
| **50** | 0.30 | 3.609 | 0.979 |
| **60** | 0.32 | 2.642 | 0.975 |

### *3.2. Effect of temperature on viscosity of O.F.I juice*

Temperature has significant effect on rheological characteristics of concentrated food products. As can be seen from Figure 5, It indicates that an increase in temperature, over a range of 20–60 °C, reduce the viscosity of O.F.I juice solution, which indicates the thermo-dependent behavior of such a solution, at a constant shear rate.. This result corroborates the microscopic model of liquids viscosity according to which this quantity is a decreasing function of the temperature (Guyon et al.1991).

This expresses the dependence of the temperature effect on the shear rate and can be explained by the fact that at weak strain rates the molecular structural disintegration is not complete, which opens the way to the temperature to manifest its effect, while at strong rates of strain the intermolecular liaisons are completely broken and the temperature cannot bring more effect.

However, the effect of temperature on consistency coefficients obtained at of opuntia juice is illustrated in Figure 6. Temperature dependency of consistency coefficient from shear at different shear rate is generally expressed by Arrhenius relationship Eqs. (3):

$$K = Aʈ \exp(Eʈ/RT) \qquad (3)$$

Where K is the consistency coefficient at shear rate, and Aʈ, are the pre exponential constants; Eʈ and is the corresponding activation energy values; R is the universal gas constant and T is absolute temperature (Ahmed 2004).

In this study K undergoes a decrease with this quantity, like the viscosity. Such trends can be approached, with a linear regression coefficient (LRC) of about 0,983, by:

$$K = 22.15´ \exp(-0.03´T) \qquad (4)$$

In terms of rheological parameters n, the temperature effect is illustrated in Figure 7. It is to observe that n almost remains constant with the augmentation of T, which means that the temperature acts such that the pseudo-plastic behavior tends to be Newtonian

$$n = 0.001´T + 0.25 \qquad (5)$$

The last empirical relation is as an approximation of the Arrhenius model provided the temperature variation is relatively small, which is the case in this study.

### *3.3. Influence of pH on O.F.I juice solution viscosity*

The viscosity variations with pH are displayed in Figure 8 for T=18 °C and three various values of the shear rate. First, lower shear rate induces highest viscosity whatever the pH value imposed by the experience, as mentioned before. On the other hand, the viscosity evolution presents a maximum at pH=5 for the 10s value of the shear rate. And after this value of pH, the viscosity decreased gradually.

The reduction of the viscosity at acidic conditions may be explained by the ionization carboxyl groups above the pH 8. A comparable argument was given by Trachtenberg & Mayer (1982) who explained the increase in the intrinsic viscosity, but in this case the study is carried out on mucilage with the pH. Medina-Torres (2000) also studied the pH effect on apparent viscosity of Opuntia ficus indica and concluded that such increase was related to conformational changes in the molecule of the mucilage. Huei Chen & Yuu Chen (2001) as well reported that increase in pH, increased the apparent viscosity of the green laver mucilage.

However for the two other shear rates it observed that the viscosity was not varied significantly in the pH range of 3-9. The maximum viscosity results in alkalescency of the solution.

## 4. ¶Conclusions

In this study the influence of shear rate, temperature and pH on viscosity of juice of Opuntia Ficus Indica (O.F.I ) has been investigated by experimental way. The corresponding main conclusions are summarized in the following:

- The O.F.I juice exhibits a pseudo-plastic behavior, since its effective viscosity is a decreasing function of the shear rate, and therefore can be classified as a non- Newtonian fluid.

- The O.F.I solution is a thermo-dependent fluid in as much as its effective viscosity decreases with the temperature, depending on whether the shear rate is lower or higher.

- The effect of the pH is such that the viscosity of O.F.I juice reaches a maximum at a pH value of pH=5 for the 10s value of the shear rate

In short, O.F.I juice can be made to reach the best useful effect according to its rheological property through suitable processing technology in concrete productive practice.

## Acknowledgements

We thank Professor M. Naïmi for the helpful discussions and the generous access to the rheometer.

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***Figure 1:*** *Prickly pear (Opuntia ficus indica* L.)

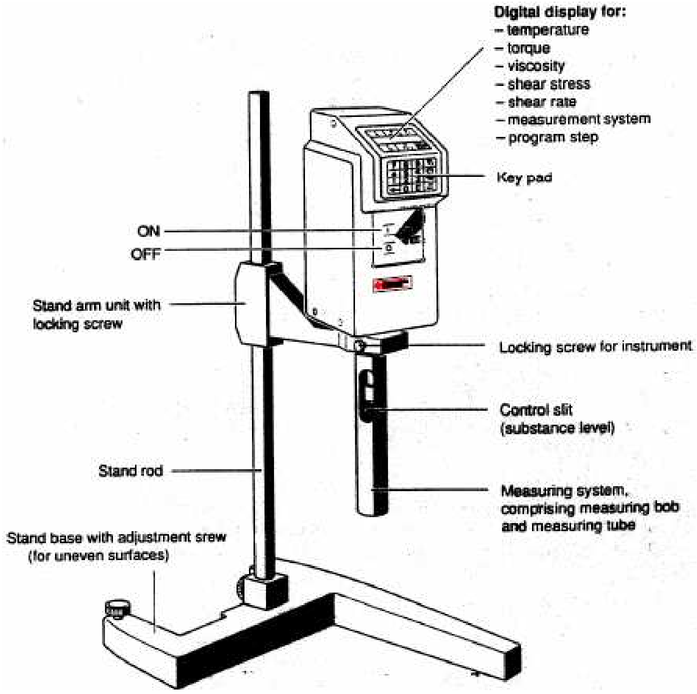

***Figure 2***. *Torsion Couette viscometer used*

***Figure 3:*** *Centrifuged prickly pear juice*

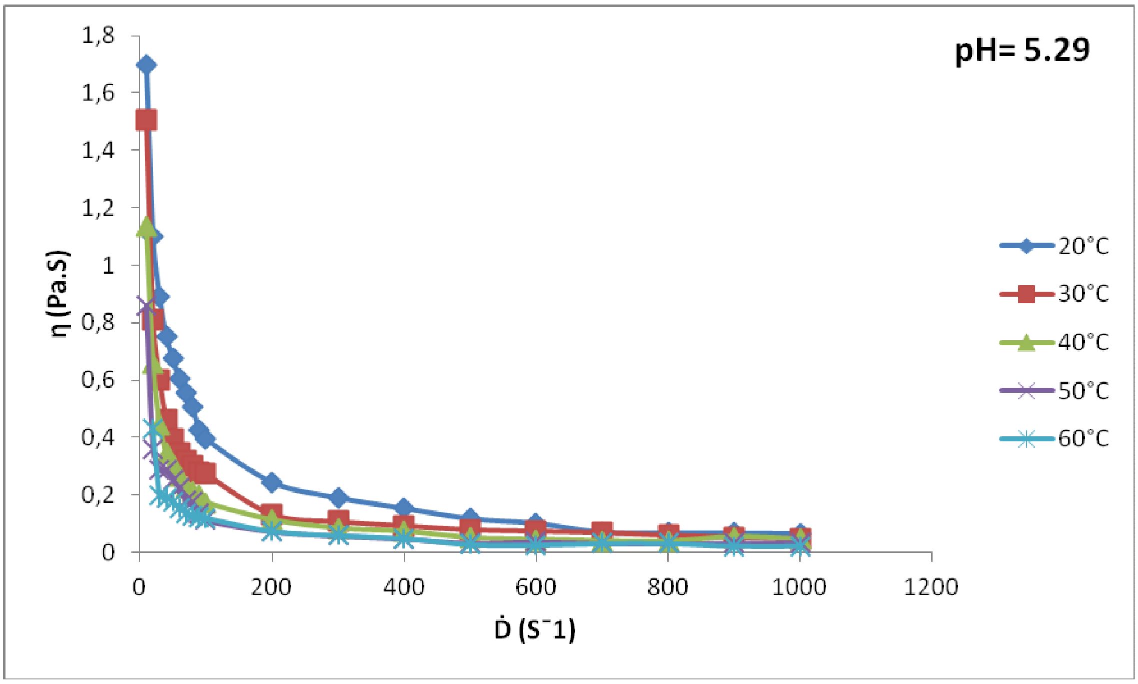

***Figure4**: Effect of shear rate ($\dot{D}$) on the apparent viscosity ($\eta$) of O.F.I solution for different temperatures*

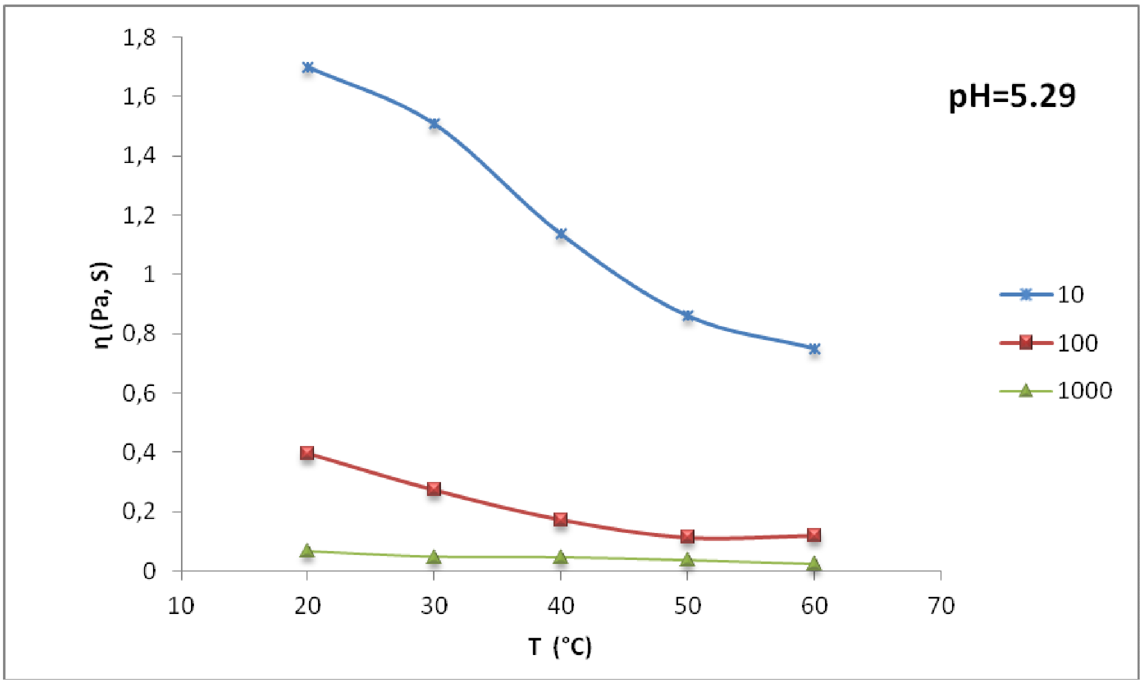

***Figure. 5:** Evolution of the effective viscosity ($\eta$) with the temperature for different values of the shear rate*

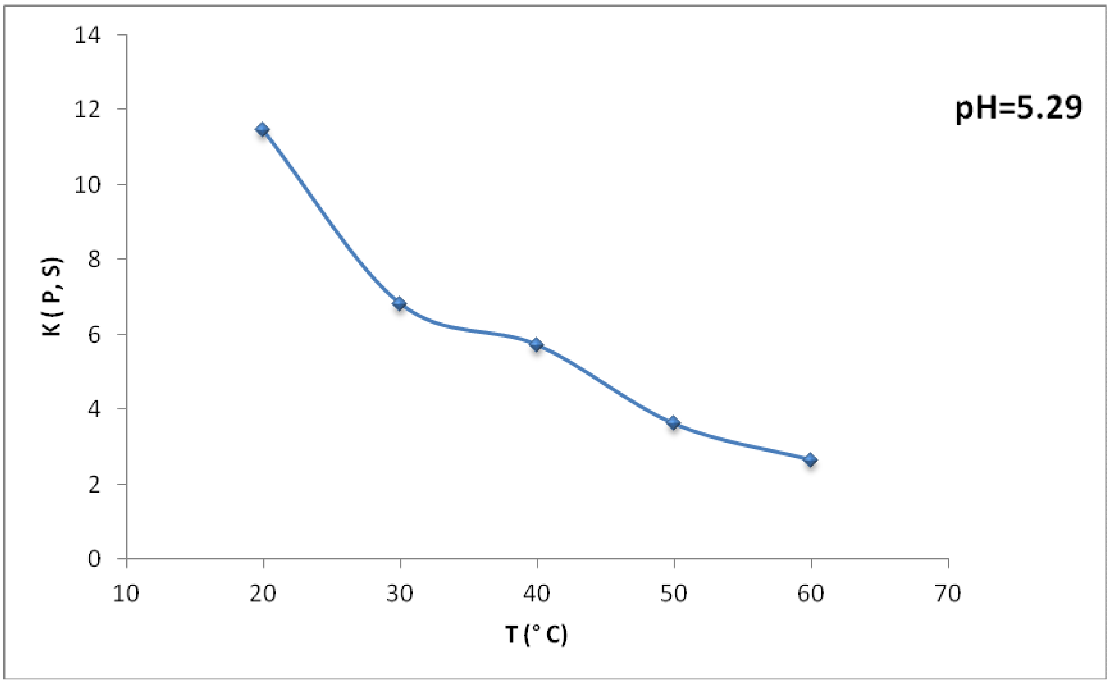

***Figure. 6:*** *Variation of the consistency index (K) with the temperature (T).*

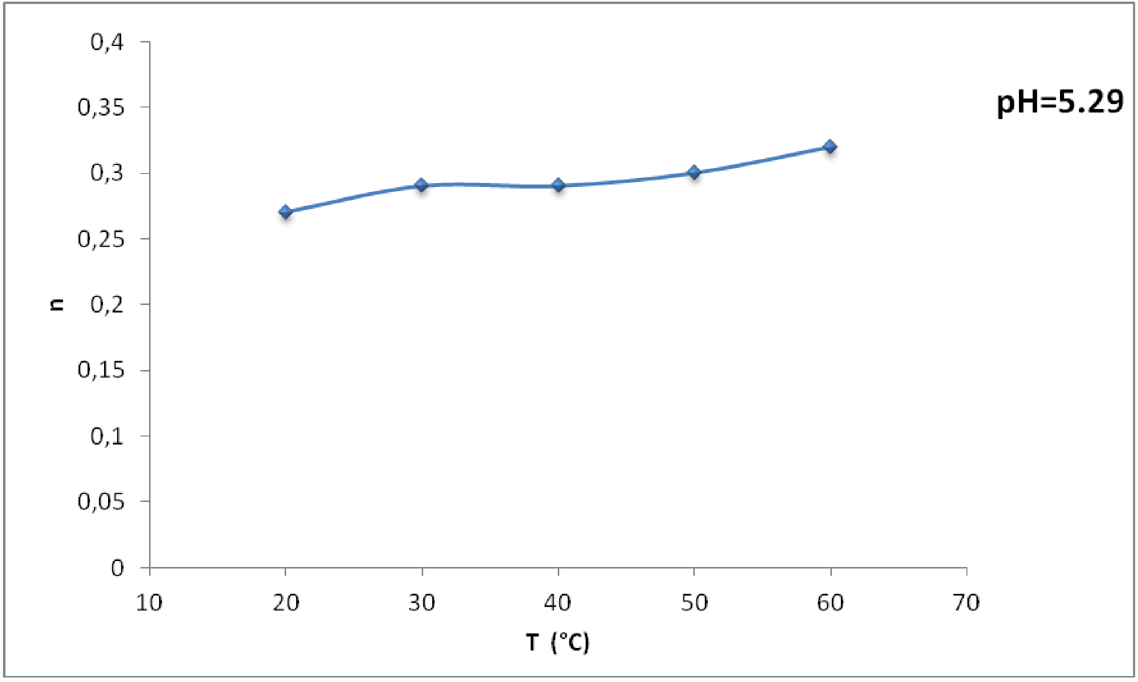

***Figure. 7:*** *Variation of the behavior index (η) with the temperature (T).*

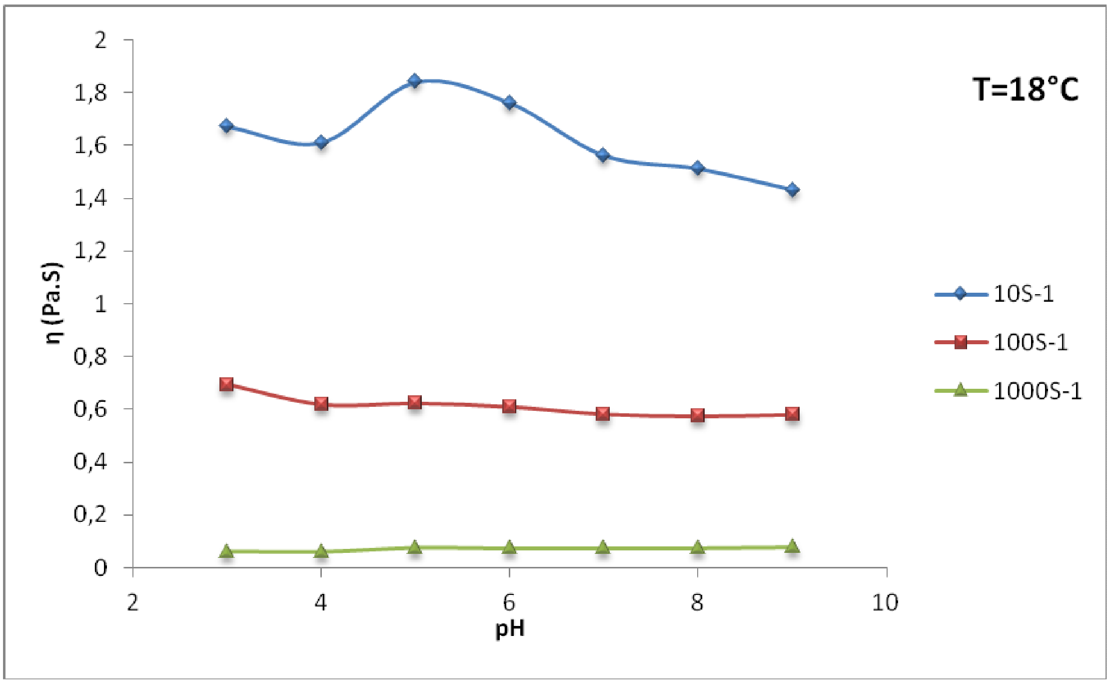

*Figure .8:* *pH effect on O.F.I juice viscosity for different shear rates*

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