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Effect surface tension on squeeze film characteristics with different viscosity

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Effect surface tension on squeeze film characteristics with different viscosity

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Abstract. The aim of this paper is study the phenomenon of surface tension in viscous liquids and determine the influencing elements represented temperature , Reynold number and couple stress., also shed light on the strength of cohesion between particles and its relationship to the bonding force. The phenomenon was studied depending on continuity equation and Navier-Stokes equations and theoretical analysis was found porosity and film thickness.

1.Introduction

The surface tension is explained as changes in the internal forces of the particles, which leads to a change in the external signal of each molecule, and the attraction forces arise between the molecules in the same liquid, so that one molecule is linked to several particles from all directions, and all the forces are equal, so that the resultant force in the negative x-axis is equal to the of the forces in the positive x-axis, and the resultant of the forces in the negative y-axis is equal to the resultant of the forces in the positive y-axis, and thus the resultant of all forces is equal to zero. In addition, at the same time the molecule on the. surface is subjected to attractive forces from the inner layers, but since the molecule is bound with neighboring molecules, its energy is higher than the energy of the molecule in the inner layer, and it remains at the surface, and this situation does not continue. Because the particles on the surface are in a state of high energy, the fluid reduces energy by reducing the number of molecules on the surface. [1] [2] Factors that are affecting surface tension are the temperature, variable viscosity, and couple stress, and. These influences differ from one liquid to another. [3], On the basis of these variables, two types of forces are classified in the surface tension, the adhesion strength between water and air, and the cohesion force between the liquid molecules, and in each type of force, cohesive films are formed. **[5].** The surface tension measurement following the maximum pressure bubble method (MPBM) is based on the determination of the pressure difference between inside and outside of an air bubble at the moment. The bubble is detached from the immersed end of a capillary; this method has been known for more than 160 years [6]**.** The studying of the effect of surface tension on film pressure and average velocity is done through a continuity equation and Navier-Stokes equations [7]. so analyzed the results and determined the influencing parameters through a number of graphs and tables

2.General analysis:

The basics equations governing with fluid flow in the horizontal membrane and in a two-dimensional system, in the absence of body force and body couple stress derived from continuity equation and Stokes and Navier-Stokes equations [1]

$$\nabla V = 0 \tag{1}$$

$$\rho \frac{DU}{Dt} = -\nabla p + \mu \nabla^2 U + \sigma \nabla^2 h \tag{2}$$

Where (V ,U) are the fluid velocity , ρ is the density , p is the film pressure fluid , μ is the dynamic viscosity , σ is tension surface and $h = h(x)$ is a function describing the separation between two plates..

Figure.1 shows the physical configuration the media of porosity. Sliding motion. The lubricant in internal flow is_ a couple stress fluid

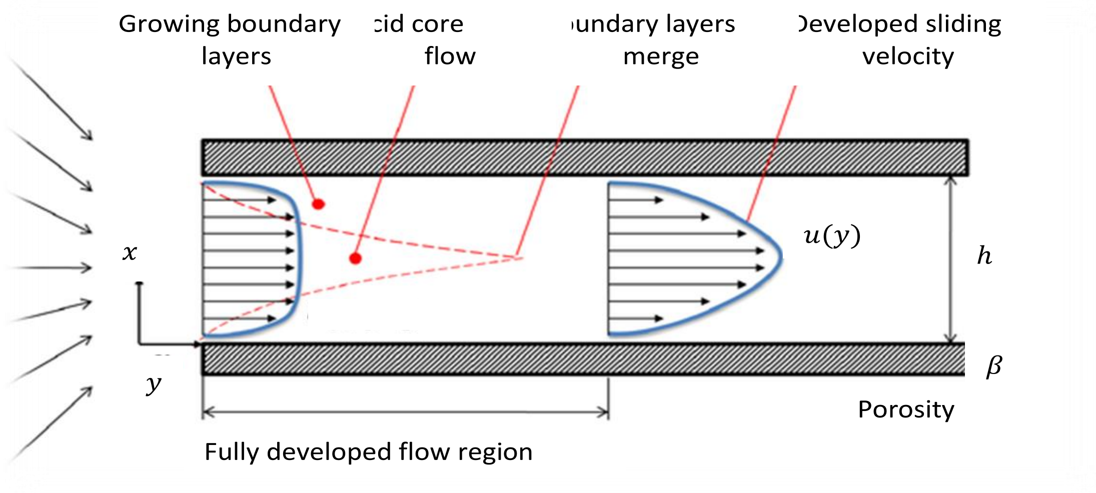

Figure.1 Geometry and coordinates of the media of porosity

Under the usual assumptions of film lubrication [7] applicable to a thin film , the equations of motion (1) and (2) takes the form

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{3}$$

$$\frac{\partial^2 u}{\partial y^2} = \frac{1}{\mu}\frac{\partial p}{\partial x} - \frac{\sigma}{\mu}\frac{\partial^2 h}{\partial x^2} \tag{4}$$

Boundary condition for the media of porosity are

1. Stress condition on the free surface of the membrane when $y = h$ then

$$\tau = \mu \frac{\partial u}{\partial y} \tag{5}$$

2. Normal stress condition when $y = h$ then

$$p = -\beta \frac{\partial h}{\partial x} \tag{6}$$

Where β be porosity of thin layer

3. The boundary conditions for the velocity component $u(x, y)$ at the surfaces of the plate are

i. $u(x,0)=\frac{\partial^2 u(x,0)}{\partial y^2}=0 \quad , \mathrm{v}(\mathrm{x},0)=0$ (7)

ii. $u(x,h)=\frac{\partial^2 u(x,h)}{\partial z^2}=0 \quad , \mathrm{v}(\mathrm{x},\mathrm{h})=W$ (8)

By derivation normal stress condition with respect to x , w get the following:

$$\frac{\partial p}{\partial x}=-\beta\frac{\partial^2 h}{\partial x^2} \tag{9}$$

By comparing equation (9) with equation (4), we get the following: -

$$\frac{\partial^2 u}{\partial y^2}=\frac{1}{\mu}\frac{\partial p}{\partial x}+\frac{\sigma}{\beta\mu}\frac{\partial p}{\partial x} \tag{10}$$

Integrating equation (10) with the boundary conditions yields the expression of $u(x,y)$

$$u(x,y)=\frac{1}{2\mu}\frac{\partial p}{\partial x}\left(1+\frac{\sigma}{\beta}\right)(y^2-yh) \tag{11}$$

Integrating equation (3) with respect to y with the boundary conditions of $v(x,y)$,we can obtain the porosity non Newtonian.

$$v(x,h)=\frac{1}{24\mu}\frac{\partial^2 p}{\partial x^2}\left(1+\frac{\sigma}{\beta}\right)h^3 \tag{12}$$

Then the modified Reynolds equation governing the film pressure can be written as:

$$24\mu W=\frac{\partial^2 p}{\partial x^2}\left(1+\frac{\sigma}{\beta}\right)h^3 \tag{13}$$

3. Film Pressure:

Introducing the non-dimensional parameters in the governing equations for the pressure is of importance for both theoretical and computational purposes. It is also off importance to present the various parameters in the lubrication system, in non-dimensional form.

$$p^*=-\frac{ph_\circ^2}{W} \qquad \sigma=\frac{\bar{\sigma}h}{\mathrm{W}} \qquad h^*=\frac{\mathrm{h}}{h_\circ} \qquad \mu=\frac{\bar{\mu}}{pt}$$

$$x^*=\frac{x}{h_\circ} \qquad \beta=\frac{R}{h} \qquad L=\frac{R}{a} \tag{14}$$

Apply equation (14) into equation (13) it was obtained the final form of dimensionless modified Reynolds equation as:-

$$\frac{\partial^2 p^*}{\partial x^{*2}}=\frac{12\,\mu h_0}{\left(1+\frac{\sigma}{\beta}\right)h^{*3}} \tag{15}$$

Boundary condition for the film pressure a of the media of porosity as follows:

$$p^*=0 \;\; at \quad x^*=5 \tag{16}$$

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$$\frac{dp^*}{dr^*} = 0 \; at \quad x^* = 0 \tag{17}$$

Integrating the nondimensional modified Reynolds equation with respect to x^* by applying the above boundary condition the film pressure is obtained as:

$$p^* = \frac{150\,\mu\,h_0 + 6\,\mu\,h_0\,x^{*2}}{\left(1+\frac{\sigma}{\beta}\right)h^{*3}} \tag{18}$$

4. **Cohesion forces**

The molecules of a homogeneous substance are linked by forces called molecular attraction forces (cohesion forces) that hold the molecules of this substance together see figure 2. The Cohesion forces of molecular lubricant fluid can be determined:

$$\alpha = 2T \int px\, dx \tag{19}$$

$$T = \varepsilon\sqrt{2\mu} \tag{20}$$

Where ε is permeability of cohesive membranes. Introduce the dimensionless cohesion forces in the media of porosity.

$$\alpha^* = -\frac{\alpha}{W} \tag{21}$$

Substituted quantity (21) into equation (19). We get the following formula

$$\alpha^* = 2T \int_0^L p^* x^*\, dx^* \tag{22}$$

Where dimensionless length

We integrate dimensionless pressure with respect to the length of cohesive membranes and thus we obtain the general form:

$$\alpha^* = \frac{150\,\mu T h_0}{(1+\frac{\sigma}{\beta})} L^2 - \frac{3\,\mu T h_0}{(1+\frac{\sigma}{\beta})} L^4 \tag{23}$$

5. Average velocity

The flow (laminar- turbulent) of viscosity fluid results in film pressure between Cohesive membranes due to the interaction between the liquid molecules and is expressed in the following equation:

$$-\frac{\partial p}{\partial x} t + 2R_e\omega + \frac{\partial \tau}{\partial y} = 0 \tag{24}$$

Where R_e is the Reynold number and ω is the couple stress fluid . Integrating equation (24) with respect to y with Stress condition on the free surface of the membrane when $y = h$ then is obtained as:

$$\left(\frac{\partial p}{\partial x} t - 2R_e\omega\right) y + A = \mu \frac{\partial u}{\partial y} \tag{25}$$

Where A constant integration , integrating equation (25) with respect to y with boundary conditions .for $y = 0, u = 0$ and $y = h, u = 0$ .The velocity distribution equation over y-axis may be found as :

$$u = \left(\frac{1}{2\mu}\frac{\partial p}{\partial x} t - \frac{1}{\mu} R_e\omega\right)(y^2 - yh) \tag{26}$$

Since $dq = -\frac{1}{t}udy$ discharge q of the the media of porosity ,may be bounded by the integration of dq thus:

$$q = \int_0^a -\left(\frac{1}{2\mu}\frac{\partial p}{\partial x}t - \frac{1}{\mu}R_e\omega\right)(y^2 - yh)dy \qquad (27)$$

non-dimensional discharge become as:

$$q^* = \int_0^a -\left(\frac{1}{2}\frac{\partial p^*}{\partial x^*} - \frac{1}{\mu}R_e\omega\right)(y^{*2} - y^*h^*)dy^* \qquad (28)$$

To obtain $\frac{\partial p^*}{\partial x^*}$ derive the dimensionless film pressure equation

$$\frac{\partial p^*}{\partial x^*} = \frac{12\,\mu\,h_0\,x^*}{\left(1+\frac{\sigma}{\beta}\right)h^{*3}} \qquad (29)$$

Substitute equation (29) in equation (28), we will get the following:

$$q^* = \left(\frac{1}{\mu}R_e\omega - \frac{6\,\mu\,h_0\,x^*}{\left(1+\frac{\sigma}{\beta}\right)h^{*3}}\right)\left(\frac{a^3}{3} - \frac{a^2}{2}h^*\right) \qquad (30)$$

The dimensionless average velocity of the flow the liquid lubricant flow V is

$$V = \left(\frac{1}{\mu}R_e\omega - \frac{6\,\mu\,h_0\,x^*}{\left(1+\frac{\sigma}{\beta}\right)h^{*3}}\right)\left(\frac{a^2}{3} - \frac{a}{2}h^*\right) \qquad (31)$$

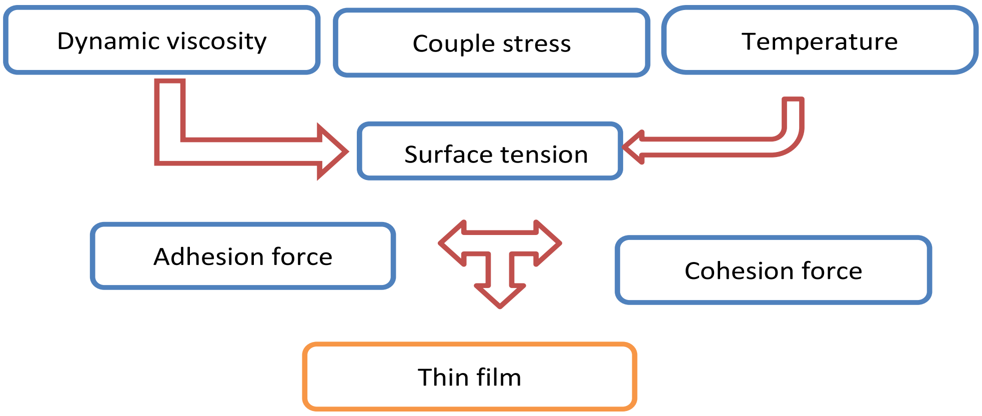

Figure 2: shows the Influencing parameters on surface tensor

6. Result and Discussion:

In this section, graphical results are inserted in order to see that the action of different film thickness h, وparameters such porosity β Dynamic viscosity μ, surface tension u temperature T, length of the cohesive films L, Reynold number R_e and the couple stress fluid ω is. All graphs have been plotted by means of MATHEMATICA 12 software

6.1 Film pressure P^*

The aim of this subsection is to analyze the effect of different emerging parameters on the film pressure $\boldsymbol{P}^*$. The graphs of the film pressure $\boldsymbol{P}^*$ .The graphs of the film pressure P^*have been plotted versus distance radial x^* in Figures 3-6. The influence of the porosity β on the film pressure is illustrated in Figure 3. It is observed that the film pressure $\boldsymbol{P}^*$.increases with an increase in porosity β. Figure 4 explains that the rise in viscosity parameter μ that leads to rise the film pressure see table 1 . The explanation for this is that the higher the viscosity increases the cohesion of the films which causes an increases in couple stress which leads to raise the film pressure that raises the pressure, Figure 5 shows that relationship between pressure and surface tension, it noticed that the increase in surface tension is offset by a decrease in the pressures, see table 2. Figure 6 shown that the film pressure increases with decrease in film thickness. In fact decrease in h means increased expansion of the coherent membranes and results in an increase in pressure .

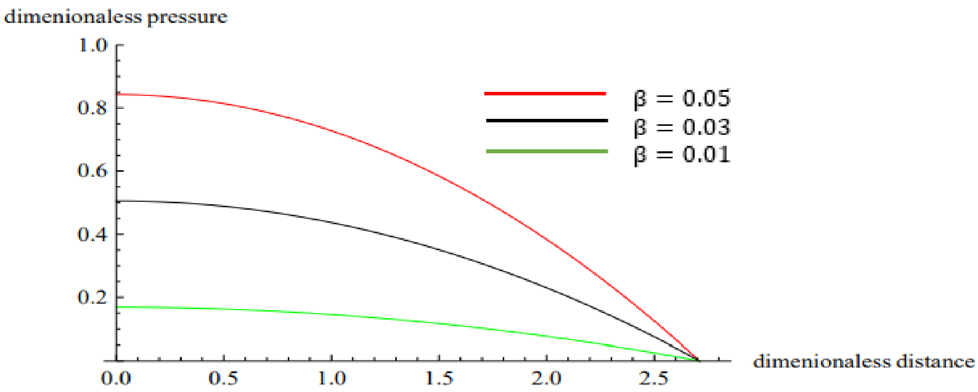

Figure 3: shows the variation of dimensionless pressure (p^*) with dimensionless distance for different porosity parameter (β)

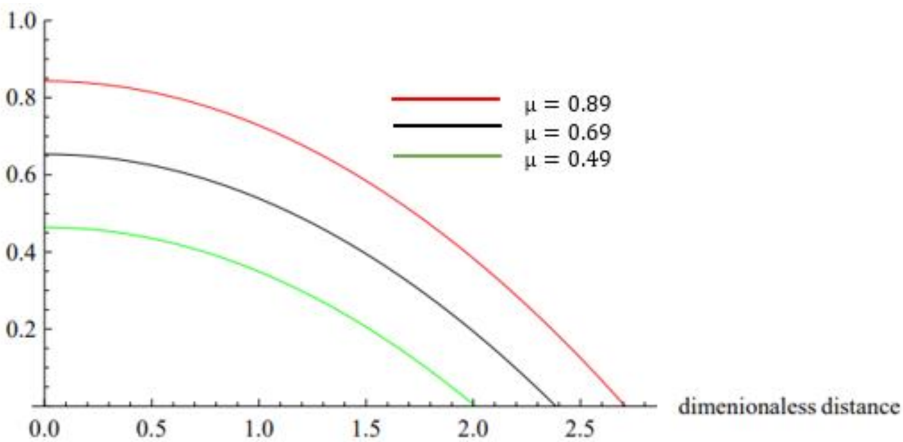

Figure 4: shows the variation of dimensionless pressure (p^*) with dimensionless distance for different viscosity parameter (μ)

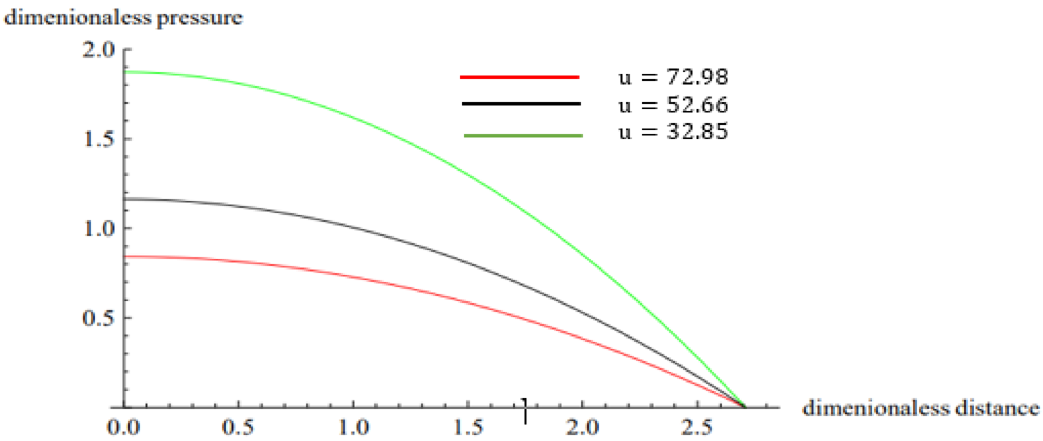

Figure 5: shows the variation of dimensionless pressure (p^{*}) with dimensionless distance for different surface tenser parameter (u)

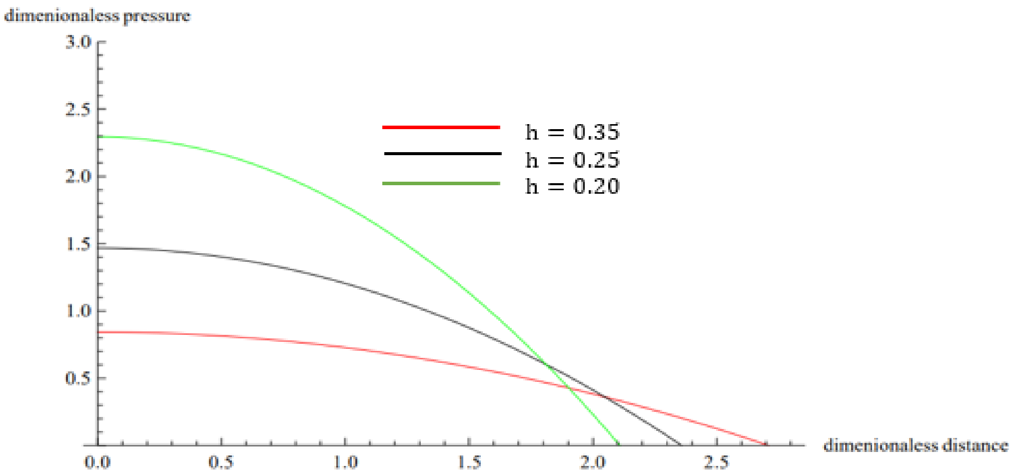

Figure 6: shows the variation of dimensionless pressure (p^{*}) with dimensionless distance for different film thickness parameter (h)

Table 1. Relationship between pressure and dynamic viscosity

$\beta = 0.05$, $\mu = 0.89$							
High Cohesion forces							
σ	72	71	70	69	68	67	66
p^*	0.383	0.398	0.394	0.401	0.405	0.411	0.418
Low Cohesion forces							
σ	52	51	50	49	48	47	48
p^*	0.52	0.53	0.55	0.60	0.63	0.68	0.70

Table 2. Relationship between pressure and surface tenser

$\beta = 0.05$, $\mu = 0.89$							
High Cohesion forces							
σ	72	71	70	69	68	67	66
p^*	0.383	0.398	0.394	0.401	0.405	0.411	0.418
Low Cohesion forces							
σ	52	51	50	49	48	47	48
p^*	0.52	0.53	0.55	0.60	0.63	0.68	0.70

6.2 Cohesion forces σ^*

The graphs of the cohesion force between particle have been plotted versus temperature in Figures 7-9The influence of a variation in cohesion force between particles as a result of the temperature variation. Figure 7 discuss the effect of dynamic viscosity on cohesion force $\boldsymbol{\sigma}^*$. It is shown that the cohesion force $\boldsymbol{\sigma}^*$ increases with an increase in dynamic viscosity μ. Figure 8 shows that with increase in surface tension lead to decrease in cohesion force. When the surface tension is high, it means that the particles that penetrate through the porous medium have more potential energy than the molecules in the medium and therefore the bonding force is less. The effect of Cohesion forces and film thickness$h$ are discussed through Figure 9. When a lubricating liquid flows, it causes film thinning and an increase in cohesive strength.

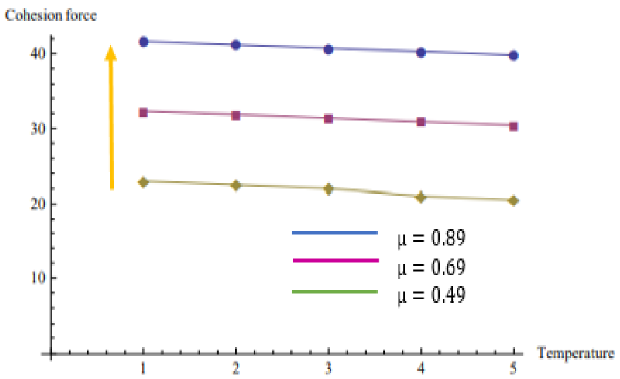

Figure7. shows the variation of cohesion (α^*) with temperature for different dynamic viscosity parameter (μ)

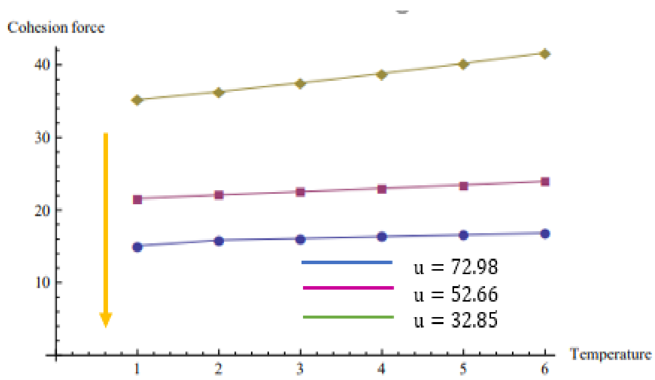

Figure8. shows the variation of cohesion(α^*)with temperature for different tension parameter (u)

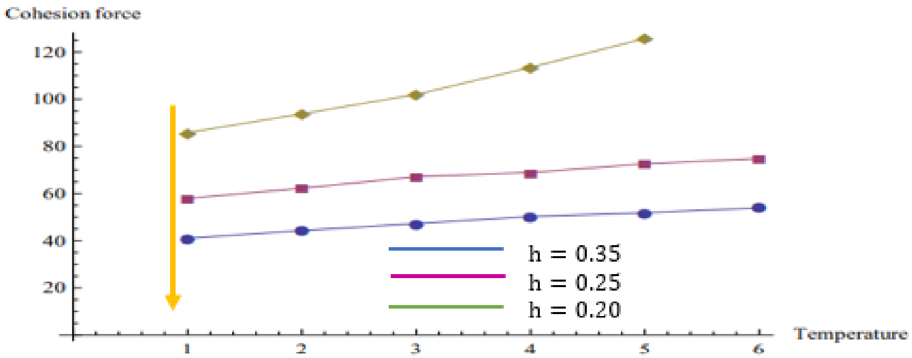

Figure 9. shows the variation of cohesion (α^*) with temperature for different film thickness parameter (h)

6.3 Average velocity (V)

The graphs of the average dimensionless velocity have been plotted versus dimensionless distance in Figures 10-13 and study the influence of the parameters $R_a, \omega, u,$ *and* β on the average velocity. The variation in average velocity (V) with the Reynold number is discussed in Figure 10. It is observed that V decreases in laminar and increases in turbulent, see table 3 .Relationship average velocity with tension show in Figure (11). It is observed that V decreases with increases in tension The variation in average velocity (V) with porosity is discussed in Figure 12. It is observed that V increases with increases in porosity .Relationship average velocity with couple stress show in Figure (13). It is observed that V increases with increases in couple stress

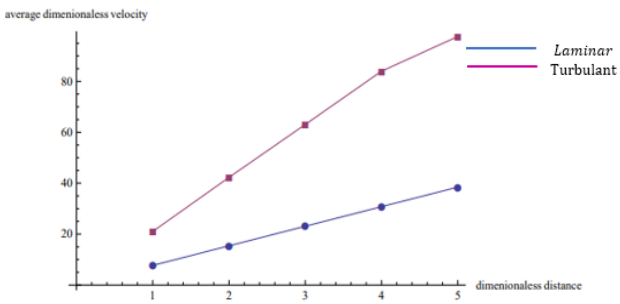

Figure 10.shows the variation average velocity (V) with dimensionless distance for different (R_a)

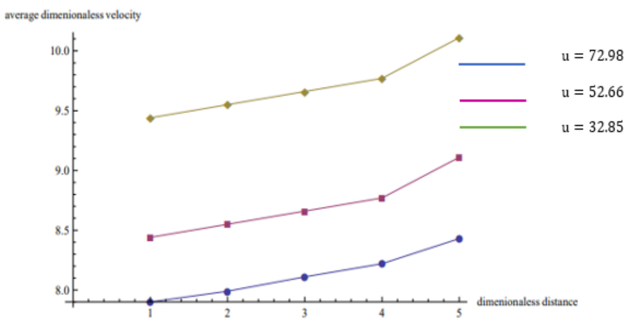

Figure11shows the variation average velocity (V) with dimensionless distance for different tension parameter (u)

Table 3. Relationship between average velocity and couple stress

		$\beta = 0.05$, $\mu = 0.89$			
		Laminar			
ω	0.05	0.04	0.03	0.02	0.01
V	38.47	30.78	23.09	15.40	7.71
		Turbulant			
ω	48	47	0.05	0.04	0.03
V	0.70	0.68	105.13	84.11	63.08

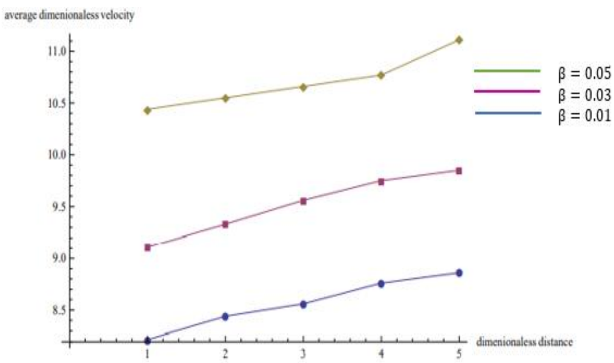

Figure12: shows the variation average velocity (V) with dimensionless distance for different porosity (β)

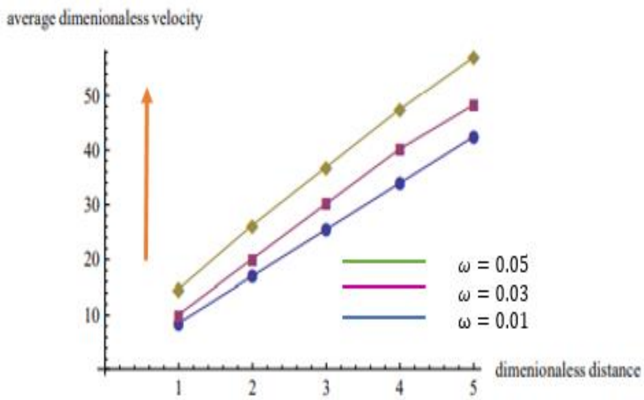

Figure13. shows the variation average velocity (V) with dimensionless distance for different couple stress(ω)

7. Conclusions

On the basic of continuity equation and Navier-Stokes equations, this paper investigates the effects of surface tension with different viscosity and couple stress The film pressure solved, to investigate the cohesion force and average viscosity, and study effective of parameters on tension through figures. We can conclude the following observations .

1. Film pressure is an increasing with increasing porosity and dynamic viscosity.
2. Film pressure is a decreasing with increasing tension and film thickness.
3. Cohesion force between molecular is increases with an increase of the dynamic viscosity.
4. Cohesion force between molecular is a decreasing with an increase tension and film thickness.

Average velocity is an increasing with increasing couple stress and porosity and decreasing with an increase tension.

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