Methodical Approach of Hydrodynamics of Fleshy Film Lubrication in Strip Drawing Progression

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Abstract – The present paper work is an exploratory attempt to evaluate the effect of different parameters such as yield strength of work piece material, viscosity of lubricant, pressure coefficient of viscosity on lubricant film thickness, shear stress, pressure developed in lubricant film and temperature of the strip, lubricant film and die surface in strip drawing process. For this author has taken different work materials and different values of lubricant viscosity and pressure coefficient of viscosity and has analyzed the effect by changing one parameter on other parameters involved in strip drawing process. As a thick lubricant film would prevent contact between die and work piece and provide much friction between die and strip work piece on other hand if lubricant film is very thin then this would lead to die wear and cause inaccuracy/loss of surface finish in work piece as well as reduction in production. However these two requirements i.e. thick lubricant films and low friction do not generally occur together. A thick hydrodynamic film can be generated by using a highly viscous lubricant but comparatively lower viscous oil may be selected to generate a sufficiently thick hydrodynamic film to protect the surface. The present work would help in selecting suitable lubricant for a particular work material. For this analysis author has taken rigid-plastic model. The generation of heat in work zone we considered both due to viscous shear and strip deformation in thermal analysis. Results of analysis are presented in the form of graph, pressure, shear stress, temperature distributions and film profiles. In the present analysis, elastic-Plastic model has result in the following,

ELASTIC-PLASTIC ANALYSIS:

Film thickness at entry to plastic zone h^* = 0.0022428 mm

Location of entry to plastic zone x_i = 0.0035560 mm

In Previous theoretical studies a rigid–plastic model has been adopted for the work material (Carbon Steel), but in this analysis the influence the elastic deformation in the entry zone and elastic recovery at outlet is examined.

RIGID-PLASTIC ANALYSIS:

- **The result of previous analysis (Rigid-Plastic analysis) is given the following:**
- **Film thickness at entry to plastic zone h^* = 0.0021742 mm**
- **Location of entry to plastic zone x_i = 5.0800 mm**

INTRODUCTION-

Control of friction, lubrication and wear is a subject of interest in our modern society as it has been for thousands of years. Dragging animal carcasses in different weather conditions were, probably, the first tribological experiments. The early civilizations used animal fat, olive oil or tree trunks underneath sleds to reduce friction.

As the need of motion developed into transportation needs, even more control over friction was needed, brakes were required, and first attempts of using bearings and gears were materialized. With introduction of steam engines and further industrial developments, the role of friction, lubrication and wear became increasingly important.

Our modern society would collapse without strong knowledge of tribology. Just imagine that there are no lubricants, engines, bearings or gear boxes! In addition to automotive and industrial applications, tribology knowledge is used for many other purposes, including bio-medical applications (e.g. artificial joints), personal hygiene, conditioners, contraceptives, etc. The science of lubrication, friction and wear is highly interdisciplinary and involves physics, fluid dynamics, chemistry, mechanics, mathematics, etc. Input from these fields is continuously needed when new questions and challenges are addressed. In the early years of the last century scientists with a wide view of the principle of physics, chemistry and mathematics introduced the first tribological models and concepts that are still used today. One of the turning points in the development of mankind was the discovery of metal and its uses. Man has been using some plastic deformation process or other for many centuries now to shape the metal to suit his needs. But metal craft remained an artisan's forte and the final result depends on his judgment and expertise. Only in the last One Hundred Twenty years or so systematic study of metal deformation process has begin and a vast amount of literature is now available on this subject. Various theoretical and experimental studies has been conducted to understand the mechanics of deformation process. These theories have been helpful in extending process capabilities and selecting equipment and process is so complicated and is governed by so many factors that theories cannot predict the process parameters accurately and a little judgment is still needed to produce a highly successful product. Nowadays, owing to these bright minds, engineers have strong knowledge of tribology, helping them to develop efficient, safe and reliable products. Part of the research in tribology concerns the lubrication of the heavily loaded contacts referred to as Elasto-Hydrodynamic Lubrication or in short EHL. This is also the topic of the present thesis. Figure 1.1 shows a few typical examples of EHL contacts encountered in everyday life. The results presented in this thesis are focused on bearing applications, but they can be easily adapted to gears and automotive industry, bio-mechanical applications, etc.

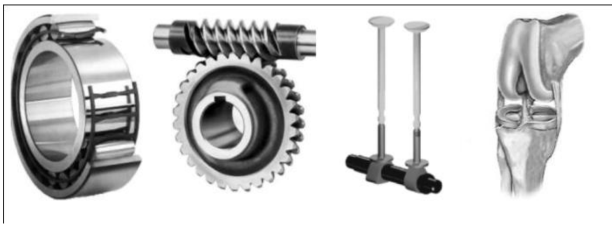

Figure-1.1

BOUNDARY CONDITIONS AND PROCESS ANALYSIS: The process consists of strip passing through die of conical shape. The lubricant film introduced during the process completely separates the die from work piece material. The film can be divided into three regions.

1. The inlet zone
2. The working zone
3. The outlet zone

In the inlet zone the lubricant is drawn into the space between strip and die by hydrodynamic wedge action. The lubricant pressure rises rapidly until the work piece yields at the inlet of working zone. In deformation zone the strip material yields plastically. In the outlet zone the strip again become rigid it provides stability in work piece and pressure almost remains constant in this zone. Process is shown in Fig. 1.2. Hydrodynamic Analysis of Inlet Zone Strip is drawn through a conical die and we assumed that strip remains rigid throughout the inlet region and the end of inlet region deformation of strip starts. This process is shown in Fig. (1.2). A wedge shape lubricant film is formed between die and strip.

The following assumptions are made:

1. The lubricant flow is a two-dimensional steady laminar flow.
2. Lubricant is an incompressible Newtonian liquid having a viscosity η that depends upon local pressure P which is given by:

$$\eta = \eta_i e^{\alpha P}$$

η_i is the Viscosity at $P = 0$

α is the Pressure coefficient of viscosity

3. Die remains rigid
4. No slipping of lubricant takes place on the die and work piece surfaces.
5. Strip remains rigid until it becomes plastic.
6. Thermal effects are neglected.
7. The change of P and η across the film thickness are disregarded and average values are used.
8. At boundary of inlet and work zone

At $h = h_m$,

$$\frac{dP}{dx} = 0$$

and $P = \sigma_y$, Where 'σ_y' stands for yielding stress of work material. The inlet zone is shown in Fig. 1.2. The viscosity pressure relationship will be written in exponential form

$$\eta = \eta_i e^{\alpha P}$$

The integral form of Reynolds equation is $\frac{dP}{dx} = -6\eta U_i \left[\frac{h-h_m}{h^3}\right]$

$$\frac{dp}{dx} = e^{-\alpha p}\frac{dp}{dx} = -6\eta_i U_i \left[\frac{h - h_m}{h^3}\right]$$

Where 'q' is known as the reduced pressure and the relationship between q and p is

$$q = \frac{1}{\alpha}[1 - e^{-\alpha p}]$$

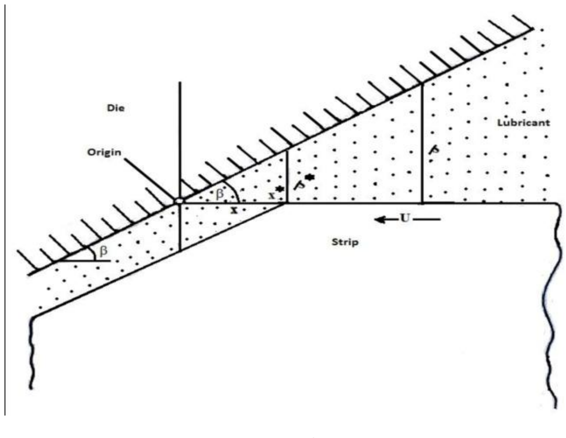

Figure: 1.2: Inlet film geometry

It is convenient to place the origin of co-ordinates at the point of intersection between the plane of the surface of the unreformed strip and the die as shown Fig. 1.2. The film thickness at any point in the inlet region is given by

$$H = \tan\beta$$

Substitution of this expression into equation and integration yields Boundary conditions

Let $p = q = 0$ when $x = x_i$ the subscript I referring to conditions at the point where the pressure starts to rise then

$$A = -\frac{1}{x_i} - \left(\frac{h_{m1}}{2\tan\beta}\right)\frac{1}{{x_i}^2}$$

and

$$q_1 = \frac{-6\eta_i U_i}{\tan^2\beta}\left[\frac{1}{x_i} - \frac{1}{x} + \frac{h_{m1}}{2\tan\beta}\left(\frac{1}{x^2} - \frac{1}{{x_i}^2}\right)\right] \text{........(i)}$$

If it assumed that yielding takes place at a point where $x = x^*$ and $h = h^*$, and that the yield pressure is high such that

$$q = \frac{1}{\alpha}[1 - e^{-\alpha p}]\,1 \approx \frac{1}{\alpha}$$

Then

$$h_{m1} = \frac{2\tan\beta.x.^* x_i}{(x^* + x_i)} - \frac{\tan^3\beta.{x_i}^2.x^{*2}}{3\eta_i\alpha U_i({x_i}^2 - x^{*2})} \qquad (3.9)$$

Or

$$h_{m1} = \frac{2h^* h_i}{(h^* + h_i)} - \frac{\tan\beta.{h_i}^2.h^{*2}}{3\eta_i\alpha U_i({h_i}^2 - h^{*2})} \qquad (3.10)\text{.........(ii)}$$

Substitution of equation (ii) into equation (i) shows that the reduced pressure in the inlet zone is given by

$$q_1 = \frac{6\eta_i U_i}{\tan\beta}\left[\frac{(h_i - h)(h - h^*)}{h^2(h^* + h_i)} + \right.$$

tan β h∗2hi2−h26ηiαUih2hi2−h∗2 (3.11) ...... (iii)

The pressure will rise rapidly to the yield pressure at the end of the inlet zone and then relatively slowly in the plastic region to satisfy the yield condition stated as

$$\sigma_x + P = \sigma_y\,'$$

In a region in which the normal stress will increase gradually. At the high pressures encountered in the plastic region the viscosity of the lubricant will be very high and probably several orders of magnitude greater than the inlet viscosity. Under these conditions the Poiseuille flow will be negligible compared with the Couette flow and the volume rate of flow per unit width in the plastic region will be given to a good approximation by

$$Q_2 = \approx \frac{-U_2 h_2}{2} \qquad (3.12)\text{......... (iv)}$$

The volume rate of flow per unit width in the inlet region is

$$Q_1 = \frac{U_1 h_1}{2} - \frac{{h_i}^3 dp}{12\eta\, dx} = -\frac{U_1 h_{m1}}{2} \qquad (3.13)\text{...........(v)}$$

Now $U_1 = U_2$ at the entry to region 2 and since continuity of flow demands that $Q_1 = Q_2$

Equation (iv) & (v) show that at entry to region 2

$$h_2 = h_{m1} = h^*$$

It is clear that $h_1 \rightarrow h_{m1}$ as the lubricant pressure and hence viscosity reach very high values and a good approximation to the film thickness at entry to the plastic region can be obtained by equating h_{m1} to h^* in equation (ii). The resulting expression can be rearranged as a quadratic in h^* to give

$$h^{*2} - h^*\left[\frac{{h_i}^2\tan\beta}{3\eta_i\alpha U_i} + 2h_i\right] + {h_i}^2 = 0 \qquad (3.16)\text{..............(vi)}$$

The solution of this quadratic is

$$h^* = h_i\left[1 + C\left\{1 - \sqrt{1 + \frac{2}{C}}\right\}\right] \qquad \text{...........(vii)}$$

Where,

$$C = \frac{h_i\tan\beta}{6\eta_i\alpha U_i}$$

Hence

$$h^* = \frac{h_i}{2C}\left[1 - \frac{1}{C} + \frac{5}{4C^2}\dots\right] \qquad (3.18)\text{ ....(viii)}$$

Now C is large, typically of order 10^2 and hence equation (viii) can be reduced with very little loss of accuracy to read

$$h^* = \frac{h_i}{2C}$$

$$h^* \approx \frac{3\eta_i\alpha U_i}{\tan\beta} \qquad (3.19)\text{...................................(ix)}$$

It will be noted that h^* independent of the length of the inlet film x.

RESULTS, DISCUSSION & CONCLUSION:

Results obtained for strip drawing of steel (yield stress $\sigma_y = 5.516 \times 10^8$ N/m^2, density $\rho = 7861.12$ Kg/m^3 and specific heat C = 272.389 Jule/Kg °C) Results obtained are shown graphically. Fig.1.3 and Fig.1.4 shows the variation of pressure and shear stress respectively. Initially it increases slowly but at the end of inlet region, increases rapidly and finally pressure reaches to the yield stress of work material. Film thickness predictions are important since the possibility of effective hydrodynamic action depends upon the relative magnitude of the predicted film thickness and surface quality of bounding solids. Film thickness variation shown in Fig. 1.5. It is noticeable that film thickness does not vary much for different work material. Fig. 1.6 shows film pressure decays relatively slowly (linearly) in work zone and remains constant in outlet zone, the similar variation of shear stress shown in Fig. 1.7. For different work material variation of temperature for die, lubricant film and strip are shown is Fig. 1.8 to Fig. 1.11 lubricant film and die temperature decreases linearly in work zone and remains constant in outlet zone. In work zone decrease in temperature indicates that viscous heating within the lubricant film is dominant than the heating due to strip deformation. For different value of coefficient of viscosity the variation of film thickness is shown in Fig. 1.12 from graph, it shows that for higher value of coefficient of viscosity, film thickness becomes more. Pressure variation with different coefficient of viscosity is shown in Fig. 1.13. Temperature variation with different coefficient of viscosity is shown in Fig. 1.14, from graph, it shows that temperature of die and lubricant film for low coefficient of viscosity is minimum.

Different value of pressure coefficient of viscosity, film thickness variation shown in Fig. 1.15 for higher value pressure coefficient of viscosity (α) film thickness higher. Pressure variation with different value of α is shown in Fig. 1.16. It shows that pressure does not depend on value of α. For work zone and outlet zone pressure variation is shown in Fig. 1.16.

Temperature variation with different value of α is shown in Fig. 1.17. This shows that strip temperature does not depend on α. It depends only on work material due to same work material for different value of α graph coincides.

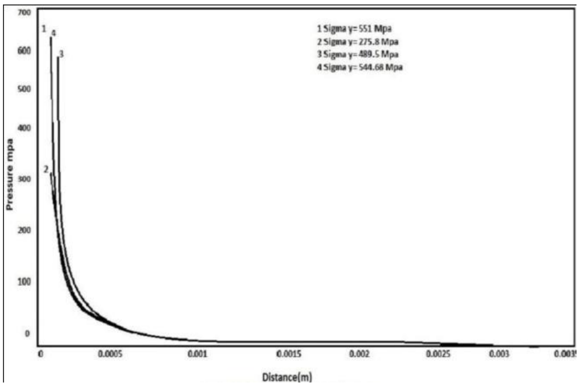

Figure: 1.3: variation of Pressure in inlet zone

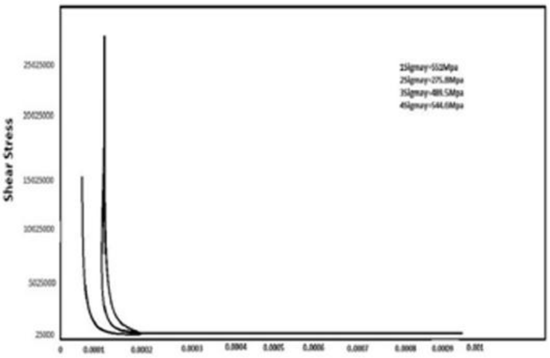

Figure: 1.4 variation of shear stress in inlet zone

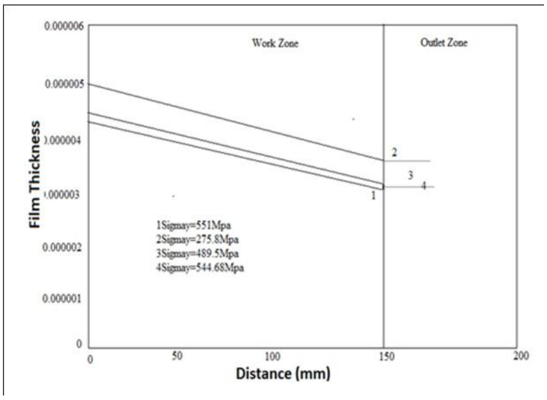

Figure: 1.5 variation of film thickness Vs distance

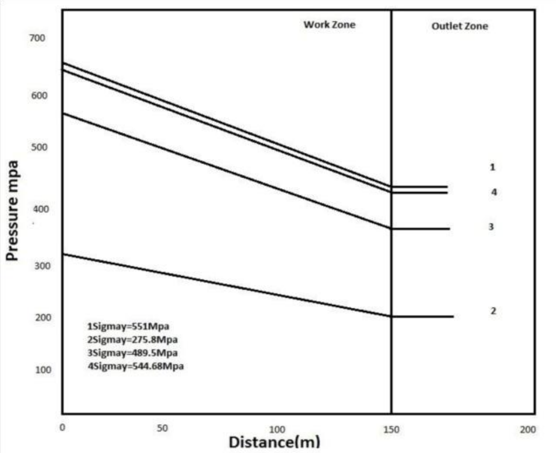

Figure: 1.6 variation of pressure

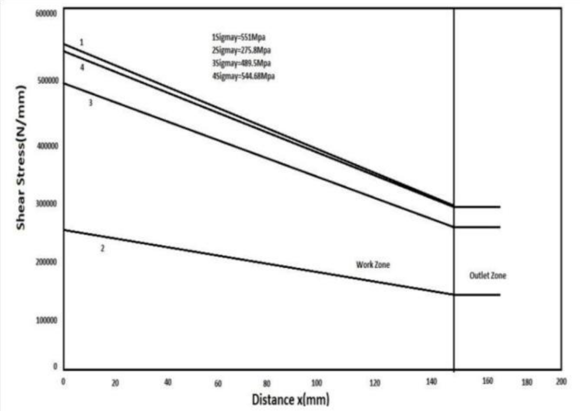

Figure: 1.7 variation of shear stress Vs distance

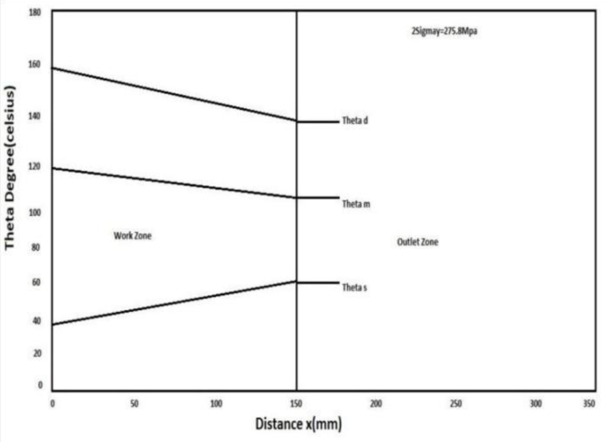

Figure: 1.8 variation of theta Vs distance

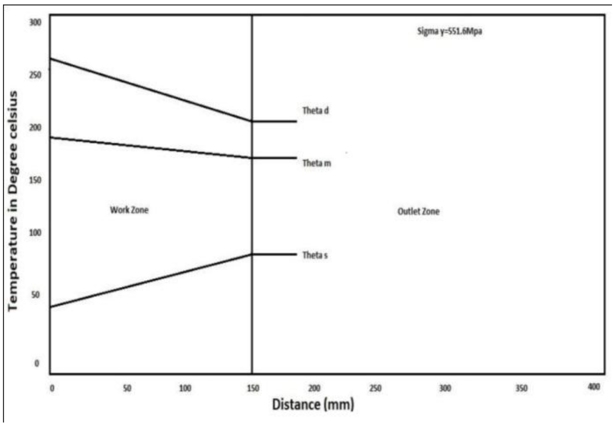

Figure: 1.9 variation of temperature Vs distance

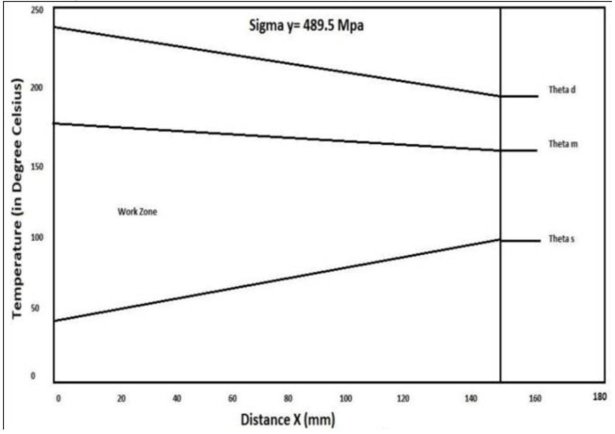

Figure: 1.10 variation of temperature Vs distance

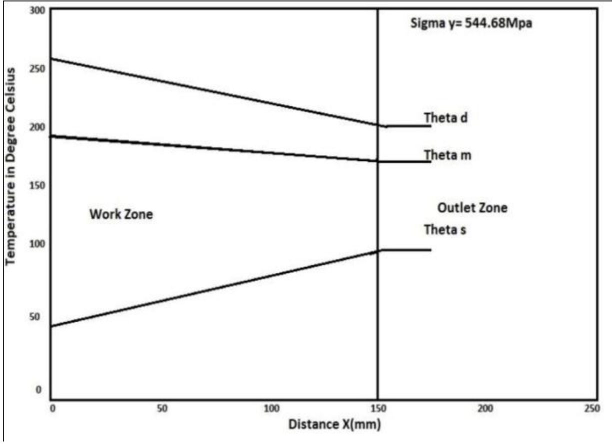

Figure: 1.11 variation of temperature Vs distance

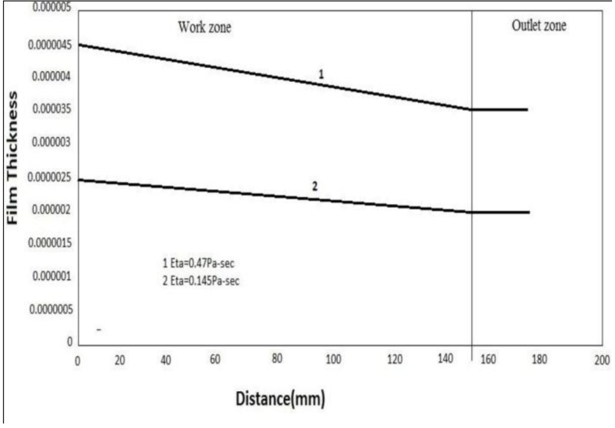

Figure: 1.12 variation of film thickness Vs distance

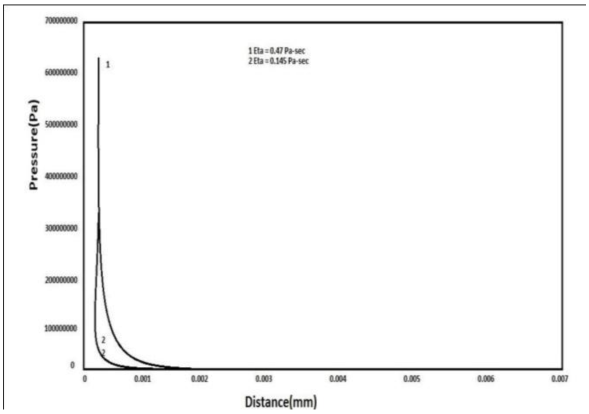

Figure: 1.13 variation of pressure Vs distance

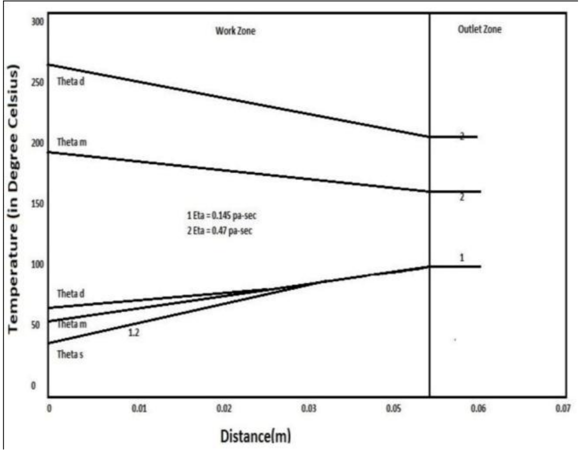

Figure: 1.14 variation of temperature Vs distance

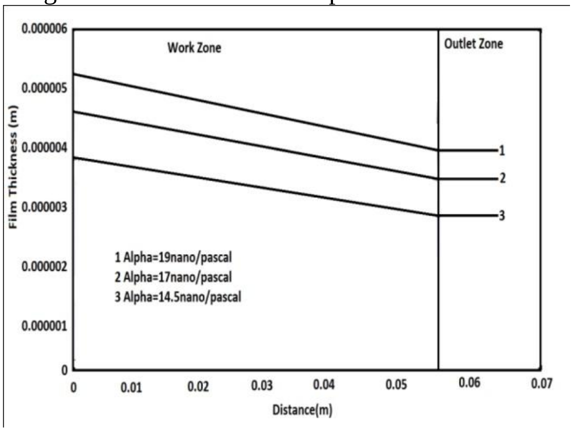

Figure: 1.15 variation of film thickness Vs distance

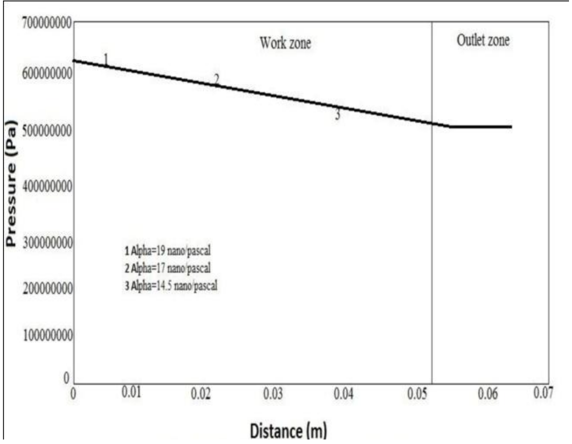

Figure: 1.16 variation of film pressure Vs distance

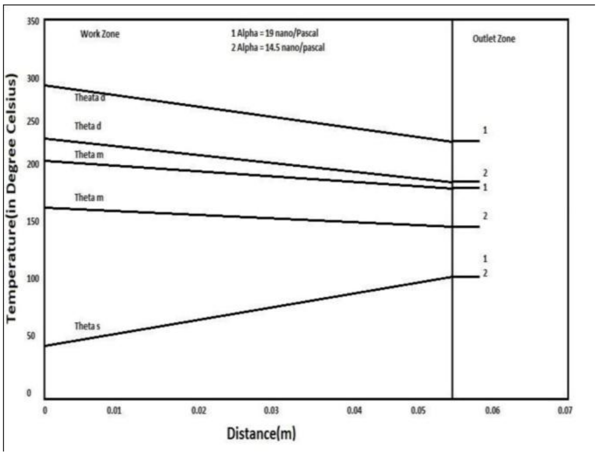

Figure: 1.17 variation of temperature Vs distance

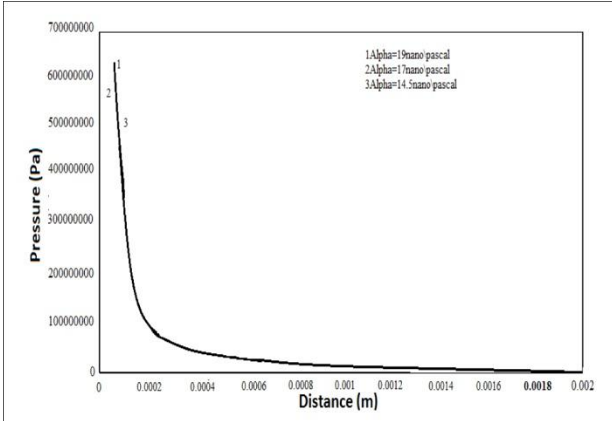

Figure: 1.18 variation of pressure Vs distance for inlet zone

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