SQUEEZE FILMS WITH POWER-LAW LUBRICANT CONSIDERING THERMAL EFFECTS AND CONSISTENCY

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ABSTRACT

In this paper we consider the consistency variation across as well as along the film thickness by adopting the model we proposed for such a variation. In particular, we study squeeze films on rigid solids for various geometries such as parallel plates. In this a Generalized Reynolds equation for power-law lubricants taking the consistency variation k across as well as along the film is derived and various special cases have been obtained. It is applied to study the squeeze film between parallel plates by taking consistency variation. A parameter q is introduced to see the effects of thermal variation. It is proved that due to thermal effect the load capacity and time of squeezing decreases for all values of flow behavior of index n.

Key Words: Peripheral layer thickness, Consistency ratio, Thermal factor, Eccentricity, Flow behavior index

1.1 INTRODUCTION

The squeeze film lubrication phenomenon applies to the two lubricated surfaces approaching each other with normal velocity. It has been one of the subject of interest in lubrication applications and rheological studies [1-15]. Through such a study is not of great practical value, but it is representative of time dependent lubrication. Theoretical work on squeeze films using a Newtonian fluid on various geometric configurations was reported by Archibald. Several investigators have analyzed squeeze film lubrication using non-Newtonian. These studies, in general, do not take into consideration of the variation of viscosity/ of the lubricant. Such a consideration is warranted by an increase in the effective viscosity, particularly in the lubricant layer very near the bearing surfaces. Needs observed a predominant enhancement of viscosity during squeezing. To detect the influence of bounding surfaces on viscosity of the squeezed films, he conducted a series of experiments using two optically plane parallel plates approaching each other with a normal velocity, and measured film thickness down to 0.635E-03mm. He noticed an increasing discrepancy between the measured and theoretical (as measured from classical Newtonian theory) intervals of time (response time) for film thicknesses of less than 0.127E-02mm. The increase in the effective viscosity in such a thin film was attributed to the influence of metal surfaces on the fluid layer in their convicinity, causing the fluid to behave in a more rigid fashion. Derjaguin [4] observed an increase in viscosity in the liquids where polar surface active substances were present at a distance up to 0.1μm from the solid boundary. He pointed out that in liquid polymers and in polymer solutions, there is generally an increase in viscosity at a distance up to 7 or 8μm from solid boundary. Hayward and Isdale [3] attributed the abnormality in theology to dirt and remarked that in pure liquids this would not happen. In the experimental findings of Askwith et. al [12]. it has been pointed out that the organic liquid in contact with the bearing surfaces formed a high viscous layer adjacent to it. Yousif et.al [1] observed that the molecules of the liquid in intimate contact with the adsorbed layer of the bounding surface must behave differently from the adjacent molecules in the bulk lubricant. However, the entire nature of the surface of the influence and the distance to which it penetrates has not been fully understood.

It is evident, that there exists a strong case for the consideration of consistency variation in squeeze films [2,13]. The effects of consistency variation have been considered in Newtonian fluids. Scant attention has been given to such a variation. using non-Newtonian fluids with particular reference to squeeze films, Shukla et.al[9] analyzed the non- behavior of lubricants through power law model by considering consistency variation across the film thickness. In this chapter, we consider the consistency variation across as well as along the film thickness by adopting the model we proposed for such a variation. In particular, we study squeeze films on rigid solids for various geometries such as parallel plates, journal bearing etc. and the effects of consistency variation on load and response time are analyzed in each case.

1.2. PARALLEL PLATES

In this section, we consider the flow between two parallel plates of length 2d, approaching each other normally with a velocity V due to a symmetrically placed load (Fig 1.1). The plates are separated by a film thickness of 2h.

with the usual assumptions of lubrication theory, the governing equations. of motion for a power law fluid in the case of squeezing is obtained with reference to Fig 1.1 and putting U=0 in generalized Reynolds equations.

$$\frac{d}{dx}\left[\frac{n}{2n+1}\, {h_1}^{q/n}(f_0)h^{(2n+1-q)/n}\left(-\frac{1}{m_1}\frac{dp}{dx}\right)^{1/n}\right] = V \tag{1.1}$$

Where

$$(f_0) = 1 - (1-k^{-1/n})\{1-(1-a/h)^{(2n+1)/n}\} \tag{1.2}$$

and h_1 is the initial film thickness measured at x = - d just before squeezing commences. Pressure attains its maximum at x = 0, i.e., $\frac{dp}{dx} = 0$ at x = 0. Using this condition in the integration of eqn.(4.1) we get,

$$\frac{dp}{dx} = -m_1\left(\frac{2n+1}{n}\frac{V_x}{(f_0)}\right)^n\left(\frac{1}{h_1}\right)^q\left(\frac{1}{h}\right)^{2n+1-q} \tag{1.3}$$

Integrating again eqn. (1.3) using condition p = 0, at x = d, we obtain the expression for pressure p. Denoting it by $p_{k,q}$ we have

$$P_{k,q} = \frac{m_1}{n+1}\left(\frac{2n+1}{n}\frac{V_x}{(f_0)}\right)^n\left(\frac{1}{h_1}\right)^q\left(\frac{1}{h}\right)^{2n+1-q}(d^{n+1} - x^{n+1}) \tag{1.4}$$

The load capacity $w_{k,q}$ per unit width is given by

$$W_{k,q} = 2 \int_0^d P_{k,q}\ (x)\ dx \quad (1.5)$$

Which on using eqn. (1.4) becomes

$$W_{k,q} = \frac{2m_1}{n+2} \left(\frac{2n+1}{n} \frac{V_x}{(f_0)}\right)^n d^{n+2} \left(\frac{1}{h_1}\right)^q \left(\frac{1}{h}\right)^{2n+1-q} \quad (1.6)$$

The squeezing time $t_{k,q}$ from an initial film thickness $2h_1$ to a subsequent film thickness $2h_{2,}$ say, is obtained by putting $-V= \frac{dh}{dx}$ in eqn. (4.6) and integrating, we have

$$t_{k,q} = \frac{2n+1}{n}$$

$$*d^{(n+2)/n} \left(\frac{2m_1}{(n+2)w_{k,q}}\right)^{1/n} \left(\frac{1}{h_1}\right)^{q/n} \int_{h_2}^{h_1} \frac{dh}{(1-(1-\mathrm{k}-1/\mathrm{n})\{1-(1-\mathrm{a}/\mathrm{h})(2\mathrm{n}+1)/\mathrm{n}\})\, h^{(2n+1-q)/n}}$$

(1.7)

When consistency variation along the film thickness only is considered (which can be obtained by taking k) , eqn. (1.6) and (1.7) become

$$W_{k,q} = \frac{2m_1}{n+2} \left(\frac{2n+1}{n(1-(1-\mathrm{k}-1/\mathrm{n})\{1-(1-\mathrm{a}/\mathrm{h})(2\mathrm{n}+1)/\mathrm{n}\})} V\right)^n d^{n+2} \left(\frac{1}{h_1}\right)^q \left(\frac{1}{h}\right)^{2n+1-q}$$

(1.8)

and

$t_{k,q}$ =

$$\frac{2n+1}{n+1-q} d^{(n+2)/n} \left(\frac{2m_1}{(n+2)w_{1,q}}\right)^{1/n} \frac{1}{(1-(1-\mathrm{k}-1/\mathrm{n})\{1-(1-\mathrm{a}/\mathrm{h})(2\mathrm{n}+1)/\mathrm{n}\})} \left(\frac{1}{h_1}\right)^{q/n} \left[\left(\frac{1}{h_2}\right)^{(n+1-q)/n} - \right.$$

$$1h1(n+1-q)/n \quad (1.9)$$

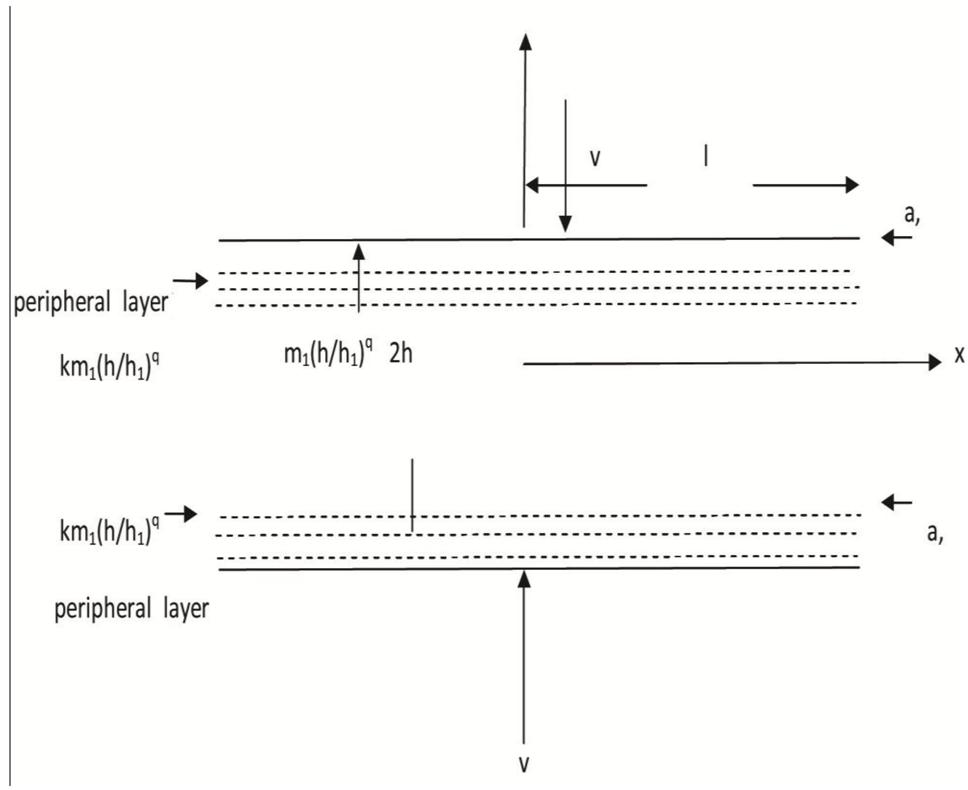

Fig1.1: Squeeze film between parallel plate

To determine the effect of thermal factor q on load and response time, we define the following quantities:

$$\overline{W}_{p,q} = \frac{W_{k,q}}{W_{k,0}} = H^q \qquad (1.10)$$

$$\overline{t}_{p,q} = \frac{t_{k,q}}{t_{k,0}} = \frac{I_{k,q}}{I_{k,0}} \qquad (1.11)$$

Where

$$I_{k,q} = \int_{H_2}^{1} 1/F_0\left[H^{(2n+1-q)/n}\right] dH \quad (1.12)$$

$$H = h/h_1 ,\ \bar{a} = a/h_1 ,\ H_2 = h_2/h_1 \quad (1.13)$$

1.3 RESULTS AND DISCUSSION

Equation (1.10) and (1.11) are evaluated numerically and graphs have been plotted.

Fig (1.2) shows that dimension less load capacity Vs dimensionless peripheral layer thickness $\bar{a}$ for different k. We can see that load capacity decreases with the increase of peripheral layer thickness $\bar{a}$. It decreases with k when consistency ratio k < 1 and there is no change when k = 1, and it increases when k > 1.

Fig (1.3) shows that dimensionless load capacity Vs dimensionless peripheral layer thickness for different q. We can see that load capacity decreases with the increase of peripheral layer thickness $\bar{a}$ and it decreases with the increase of q. Fig (1.4) shows that dimension less load capacity Vs dimensionless peripheral layer thickness for different q. We can see that load capacity decreases with the increase of peripheral layer thickness $\bar{a}$ and it decreases with the increase of q.

Fig (1.5) shows that dimension less load capacity Vs dimensionless peripheral layer thickness for different flow behavior index n. We can see that load capacity increases with the increase of peripheral layer thickness $\bar{a}$ and it decreases with the increase of flow behavior index n. Fig (1.6) shows that dimension less load capacity Vs dimensionless peripheral layer thickness for different flow behavior index n. We can see that load capacity increases with the increase of peripheral layer thickness $\bar{a}$ and it increases with the increase of flow behavior index n.

Fig (1.7) shows that squeezing time Vs dimensionless peripheral layer thickness for different consistency k. We can see that squeezing time decreases with the increase of peripheral layer thickness $\bar{a}$ and it decreases with $\bar{a}$ when consistency ratio k < 1 and there is no change when k = 1, it increases when k > 1.

Fig (1.8) shows that squeezing time Vs dimensionless peripheral layer thickness for different flow behavior n. We can see that squeezing time increases with the increase of peripheral layer thickness $\bar{a}$ and it increases with the increase of flow behavior index n.

Fig (1.9) shows that squeezing time Vs dimensionless peripheral layer thickness for different thermal factor q. We can see that squeezing time increases with the increase of peripheral layer thickness $\bar{a}$ and it increases with the increase of thermal factor q. Fig (1.10) shows that squeezing time Vs dimensionless peripheral layer thickness for different thermal factor q. We can see that squeezing time increases with the increase of peripheral layer thickness $\bar{a}$ and it decreases with the increase of thermal factor q.

Fig (1.11) shows that squeezing time Vs dimensionless peripheral layer thickness for different of flow behavior index n. We can see that squeezing time decreases with the increase of peripheral layer thickness $\bar{a}$ and it increases with the increase of flow behavior index n.

1.4 GRAPHS

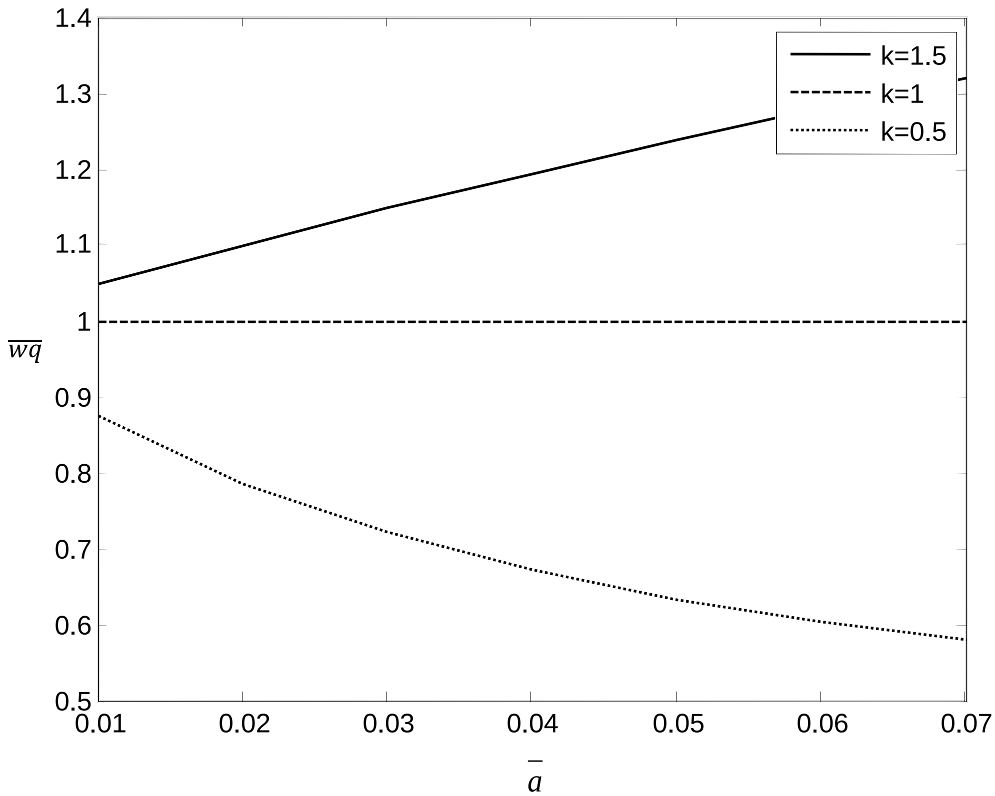

Fig 1.2: Dimensionless load Vs $\bar{a}$ for different consistency k

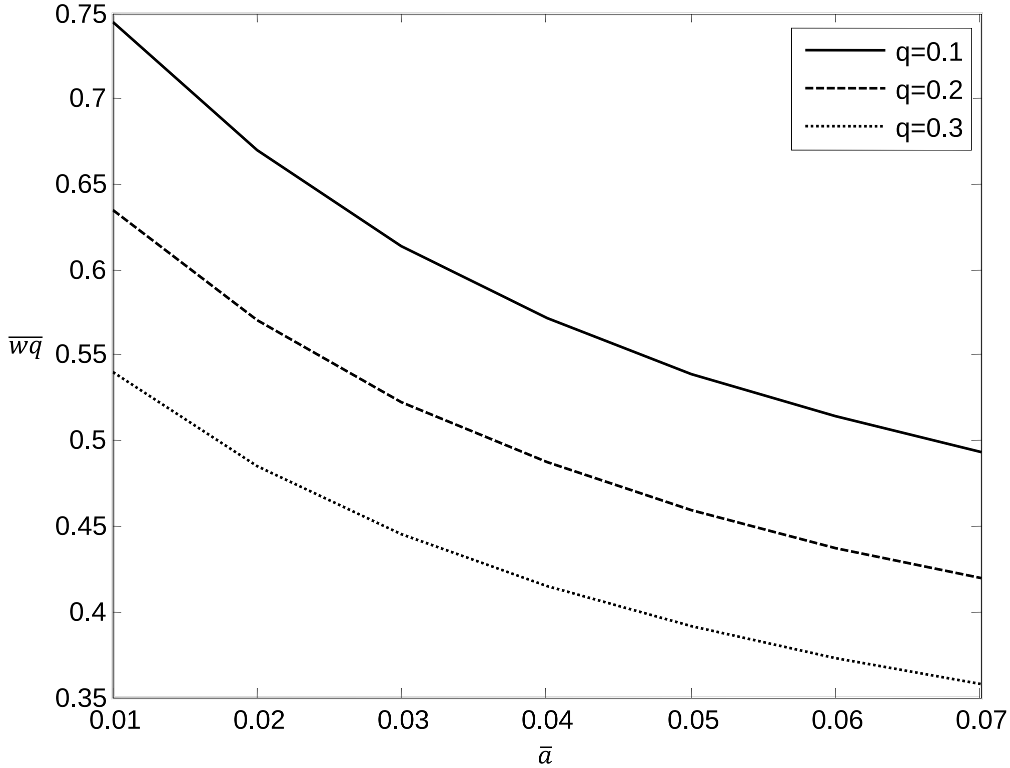

Fig 1.3: Dimensionless load Vs peripheral $\bar{a}$ for different Thermal factor q

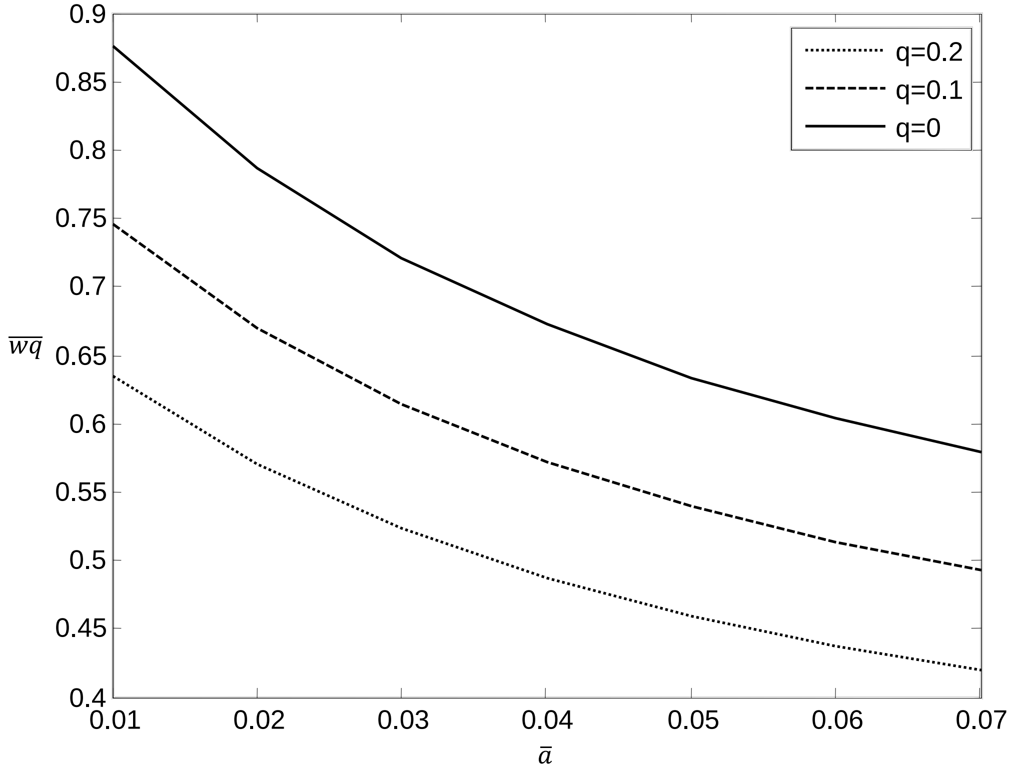

Fig1.4: Dimensionless load Vs $\overline{a}$ for different Thermal factor q

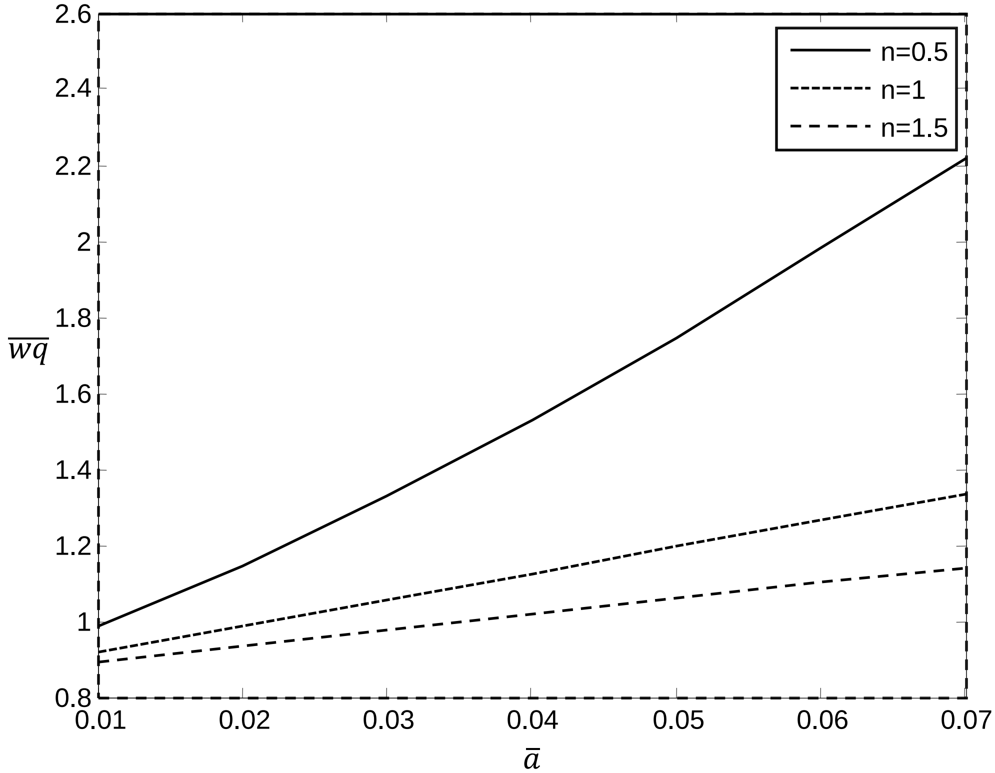

Fig1.5: Dimensionless load Vs $\bar{a}$ for different flow behavior n at k=2

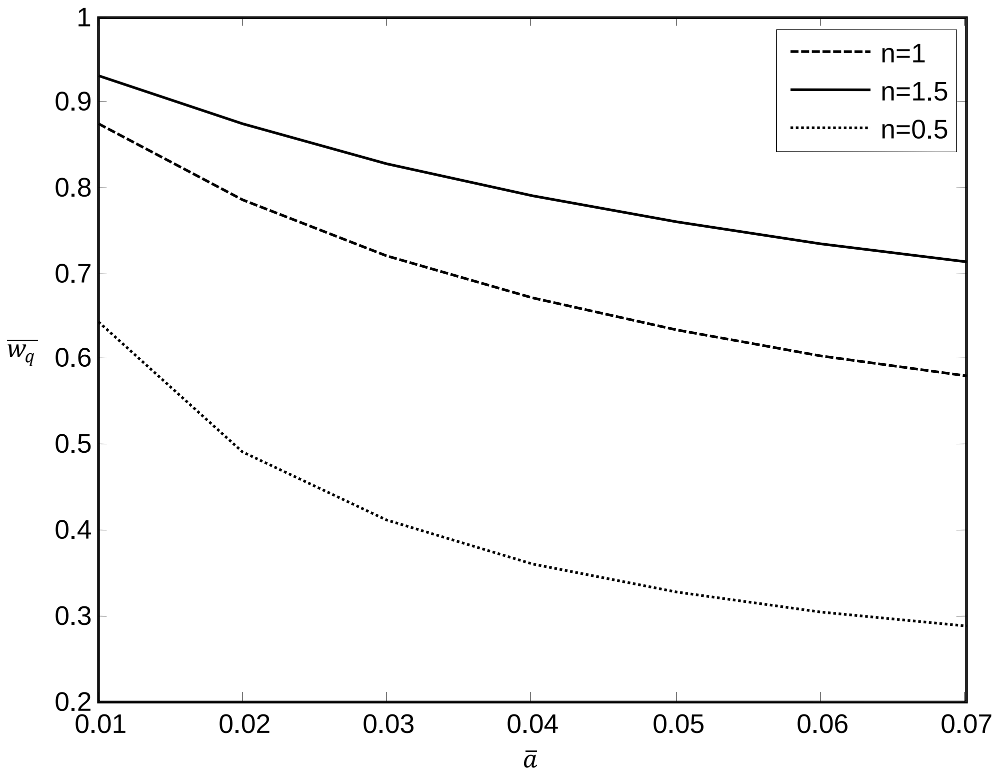

Fig1.6: Dimensionless load Vs $\bar{a}$ Different flow behavior n at k=0.5

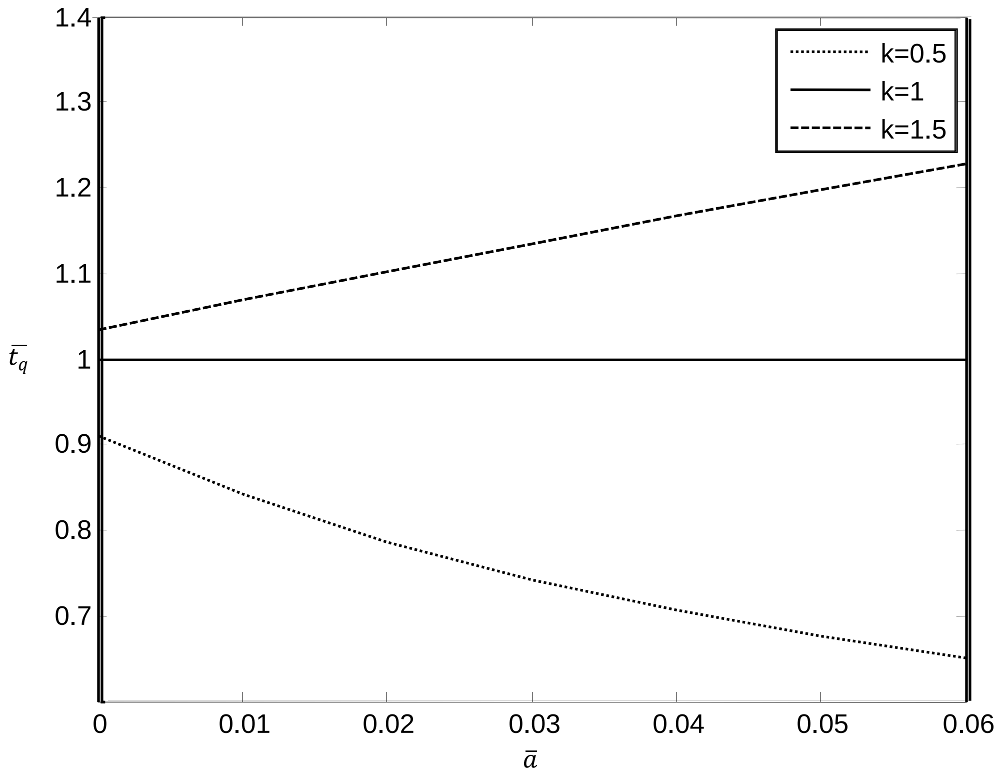

Fig 1.7: Squeezing time Vs $\bar{a}$ for various consistency k

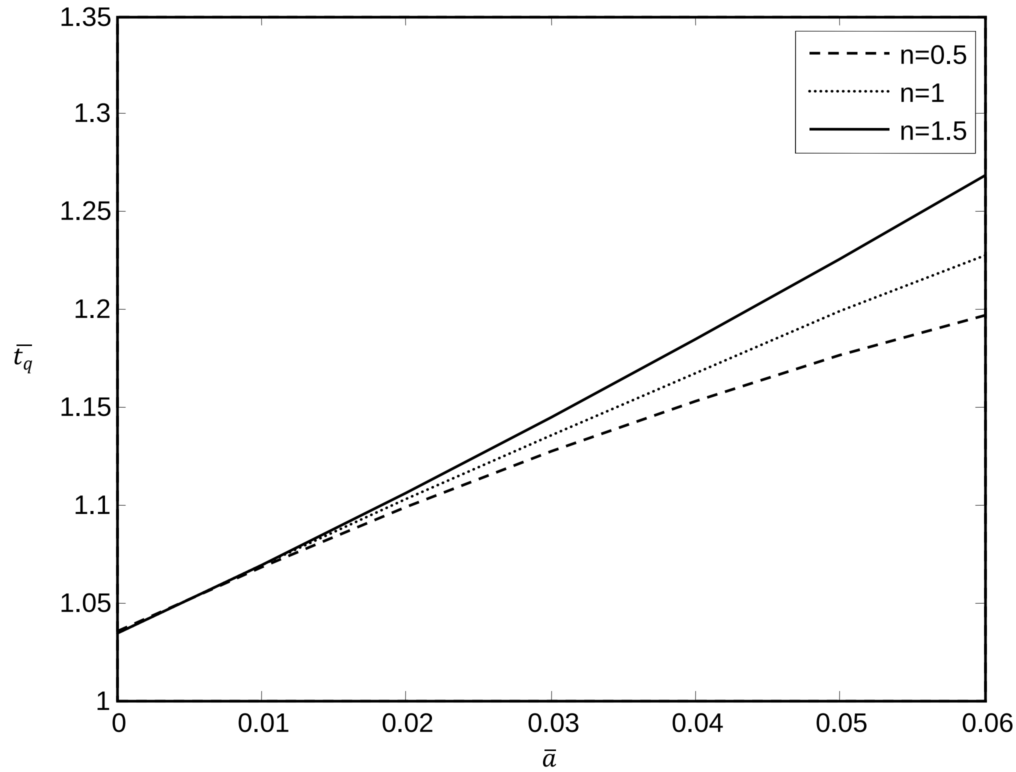

Fig 1.8: Squeezing time Vs $\bar{a}$ for various n

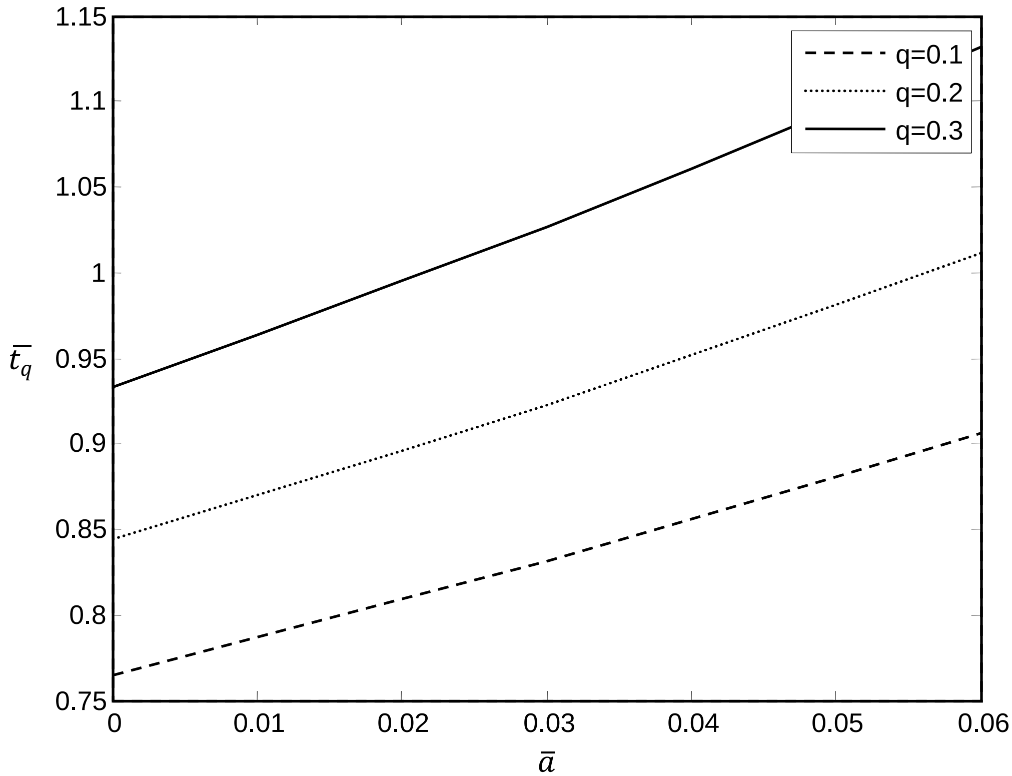
q=0.1
q=0.2
q=0.3
$\overline{t_q}$
$\bar{a}$
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0
0.01
0.02
0.03
0.04
0.05
0.06

Fig 1.9: Squeezing time Vs $\overline{a}$ for various Thermal factor q

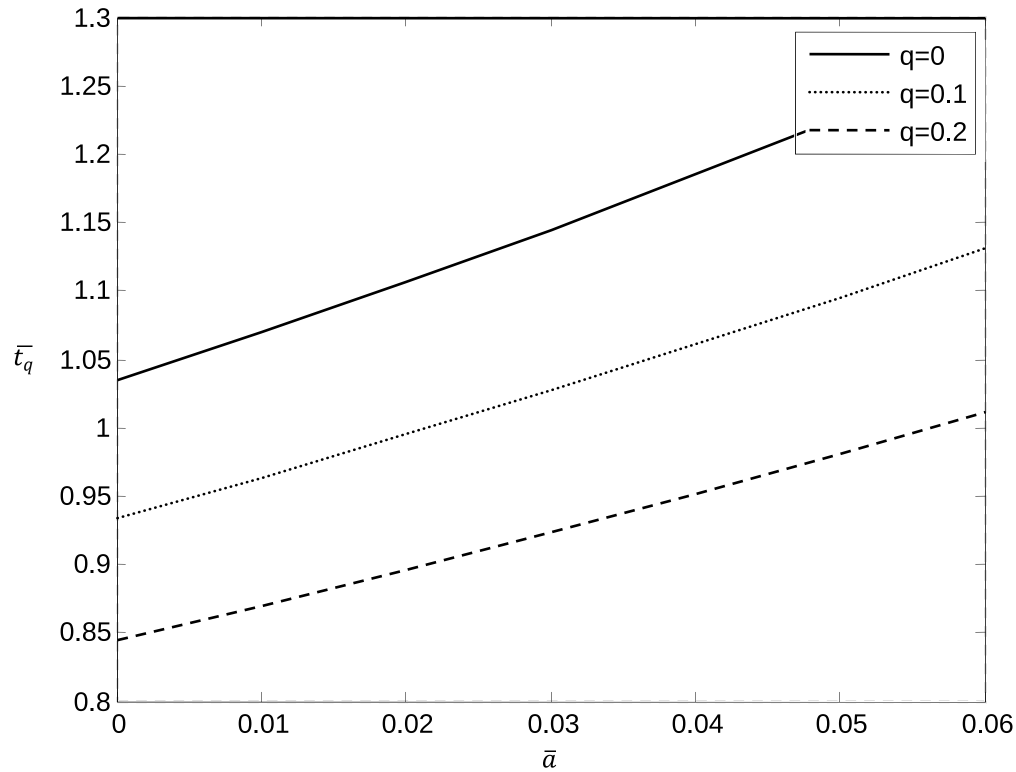

Fig 1.10: Squeezing time Vs $\bar{a}$ for various q

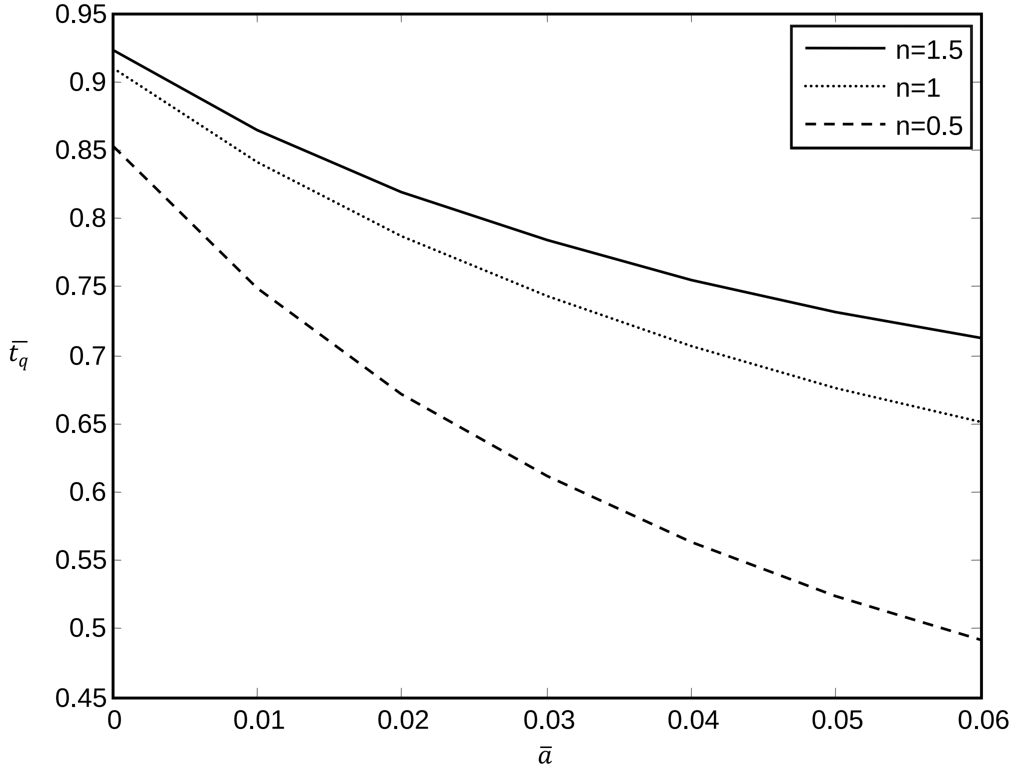

Fig 1.11: Squeezing time Vs $\bar{a}$ for various n

1.5 SUMMARY

In this chapter Generalized Reynolds equation for power-law lubricants taking the consistency variation k across as well as along the film is derived and various special cases have been obtained s . It is applied to study the squeeze film between parallel plates by taking consistency variation. A parameter q is introduced to see the effects of thermal variation. It is proved that due to thermal effect the load capacity and time of squeezing decreases for all values of flow behavior of index n.

NOMENCLATURE

a	Peripheral layer thickness
$\bar{a}$	Non-dimensional quantities corresponding to a
c	Radial clearance
d	Length of parallel plates
2h	Orch film thickness
$2h_1$,$2h_2$	Initial and subsequent film thicknesses
K	Consistency ratio
m1	Consistency index
n	Flow behavior index
p	Hydrodynamic pressure
q	Thermal factor
r	Polar coordinate
R	Radius of the circular plate, sphere,
t	Time
$t_{k,q}$	Response time
V	Normal velocities
$W_{K,q}$	Load capacity

$\bar{W}_s, \bar{W}q$ Load ratios

ε Eccentricity

ε_1 Final eccentricity position

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