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# Numerical simulation of an oil droplet passing through an EHL contact

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ABSTRACT

In oil-air lubrication lubricants are supplied by droplets to tribo-pairs. Numerical work has been carried out to investigate transient EHL film when an oil droplet is entrained. Results show that entrainment speed, oil viscosity and wettability of the oil/solid interface significantly affect the lubricant side flow across the entrainment direction (termed as squeeze spread) at the inlet, and consequently different EHL behaviors are presented. For fast speeds, high oil viscosity and low wettability, when a small droplet passes through the central contact a dimple-shaped film is generated and bounding surfaces cannot be fully separated. Numerical results showed close correlation to the experiments. This study is beneficial to basic understanding of lubrication by limited lubricant supply.

## 1. Introduction

Machines are often supplied with larger amounts of lubricant than necessary because shortage of lubricant may result in catastrophic failure. However, the actual volume of lubricant required to separate the two bounding surfaces in a tribo-pair is very small. Oversupply of lubricant leads to wastage and an increase in friction and heat generation. In industrial practice, it is recognized that lubricant supply by means of small amounts over frequent intervals is the most effective way for eliminating negative effect from oversupply or undersupply of lubricant. Oil-air lubrication has been presented as an attractive approach to offer an accurate oil quantity, high cooling efficiency, dirt ingress preventing as well as environment-friendly. Subsequently this precision and effective lubrication method has been an optimal choice for many industrial applications such as high-speed ball-bearings, gears, wheel flanges and chains [1–9].

In recent years, lots of studies about oil-air lubrication have been carried out. Jeng and Cao [2] studied the influences of the preload, oil supply quantity and speeds on the bearing temperature rise. Wu and Kung [6] investigated the performance of a high-speed spindle and found that the oil volume-per-cycle, lubrication cycle and air pressure are the main factors to affect the temperature. Hohn et al. [7] examined the influence of lubricant quantities in an oil-air system on power loss, heat generation and load carrying capacity of gear transmission. The results showed that there exists a natural limitation for lowering the oil quantity for gear transmissions. Jiang and Mao [8] developed an experimental setup to demonstrate the influences of operation parameters on the temperature rise of both the hybrid ceramic ball bearing and steel ball bearing. Using an air-oil lubrication evaluation system, Moon et al. [9] explored the oil supply rate, which was gauged by the oil band width on an oil absorbent paper, under different oil discharge quantities, oil discharge intervals and oil viscosity.

Most of the above investigations are mostly concentrated on finding the proper working parameters for an industrial oil-air lubrication unit [2, 3, 5, 6, and 8]. However, there is little knowledge about how oil droplets work in building lubricating films inside the tribo-pairs. In fact, in oil-air lubrication, before lubricant entering the contact zone, it could be in the form of micro oil droplets. Those oil droplets gradually enter the contact zone and lubricate the bounding surfaces. This lubricant supply is different from that in the classical elastohydrodynamic lubrication (EHL) theory in which lubricants are provided with uniform lubricant layers [10,11]. Therefore their film-forming behaviors may be different. Recently, Zhang et al. [12] presented numerical work of EHL films generated by one oil droplet, and under the prescribed working parameters it was shown that when the oil droplet got into the central contact it could be squeezed (be flattened) largely and a thin film was then generated to separate the bounding surfaces totally. However, optical EHL experiments have been carried out in the authors' lab to measure film building process and the results, as shown in Fig. 1, are completely different from those in Ref [12]. It is interesting to find that a 5P4E oil droplet (with high viscosity) cannot be fully squeezed to a uniform thin layer within the central contact and the bounding surfaces are not separated thoroughly, and a dimple-shaped central film is generated. In fact, EHL with oil droplet supply can be modeled by starved EHL, where the oil distribution at the inlet plays an important role or the film formation is under inlet control. It is easy to find that the

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**Nomenclature**

| | |
|---|---|
| $a$ | radius of Hertz contact, m |
| $p$ | lubricant film pressure, Pa |
| $h$ | gap between bounding surfaces, m |
| $h_f$ | oil film thickness, m |
| $h_0$ | rigid gap between two bounding bodies at the contact center, m |
| $h_{cen}$ | central film thickness, m |
| $h_{in}$ | initial oil layer at the solid surface, m |
| $E'$ | reduced elastic modulus, Pa |
| $\theta$ | fractional film content |
| $R$ | base radius of a droplet, m |
| $R_c$ | height of a droplet, m |
| $x_0(t)$ | center coordinate of a droplet, m |
| $R_x$ | radius of a ball, m |
| $\rho_0$ | density, kg/m$^3$ |
| $\eta_0$ | viscosity, Pa·s |
| $\alpha$ | pressure-viscosity coefficient, Pa$^{-1}$ |
| $w$ | applied load, N |
| $u_e$ | entrainment speed, m/s |
| $t$ | time, s |
| $L$ | coverage length of the oil droplet, m |
| $T$ | dimensionless time, $T = u_e t/a$ |
| $x, y, z$ | coordinates, m |
| $X, Y, Z$ | dimensionless coordinates, $X = x/a$, $Y = y/a$, $Z = z/a$ |
| $x_{in}, x_{out}, y_{in}, y_{out}$ | boundary coordinates of the computing domain, m |

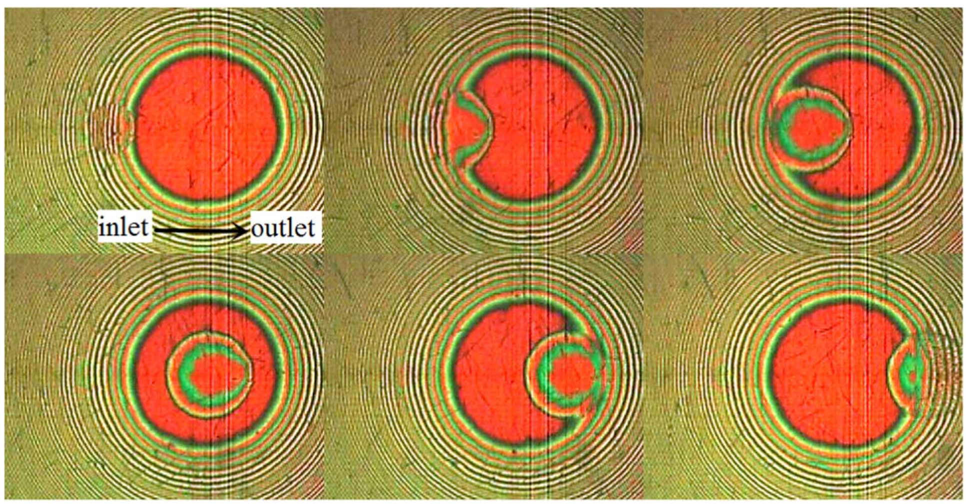


**Fig. 1.** Film building when an oil droplet passing through a ball-on-disc EHL contact zone, lubricant: 5P4E, $w$ =30 N, $u_e$=10 mm/s, radius of the steel ball =12.7 mm.

oil distributions at the inlet are different for Ref [12]. and the authors' experiments. The inlet control could also be found in the study of Dumont et al. [13]. In their work some oil is accommodated in a pit which contributed to some of the dimple film formation. To address the phenomena of dimple-shaped central film in Fig. 1, a numerical analysis is presented in this paper to examine EHL under conditions of oil droplet supply. By the transient lubrication model considering starvation condition, the influences on film building of different factors (entrainment speed, oil viscosity and initial base radius of micro oil droplet) are numerically studied. The results are beneficial to understand lubrication behavior when oil droplets are supplied to an EHL contact.

## 2. Theory model

Fig. 2(a) shows the distribution of oil droplets which are derived from the jet of the end nozzle in an oil-air lubrication system. It can be observed that most of the droplets are in spherical shape with different sizes. The diameter of most droplets is no more than 100 µm. Based on this observation, micro oil droplets in the present study are modeled as a spherical segment as shown in Fig. 2(b). The height of the oil droplet is $R_c$, and its base radius is $R$. The micro oil droplet is located along the center line of contact zone, and the oil supply equation is as follows:

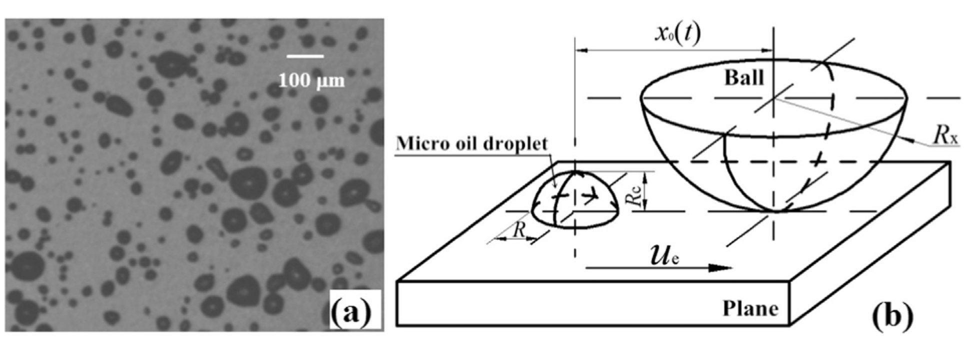


**Fig. 2.** Distribution of micro oil droplets in an oil-air lubrication system (a) and model of EHL with micro oil droplet supply (b).