NOTES 1

THE FUNDAMENTAL ASSUMPTIONS OF HYDRODYNAMIC LUBRICATION

Fluid film lubrication is a hydrodynamic phenomenon characterized by a lubricant flowing in the narrow gap between two closely spaced surfaces. Notes 1 develops, from the fundamental equations of fluid mechanics – mass and momentum transport of a Newtonian fluid, the classical equations for motion of a lubricant in a thin film. An order of magnitude analysis reveals that the pressure does not vary across the film, and hence, one momentum transport equation is not needed. In addition, the analysis reveals that fluid inertia effects are seldom important in most thin film lubricant configurations, i.e. those in which the film thickness is orders of magnitude smaller than the wetted surfaces dimensions. Reynolds numbers for shear type flow and squeeze film type flow are defined. Applications where thin film fluid inertia effects are important are noted. Incidentally, abrupt changes in film geometry, like at the inlet and outlet sections of a film region are a common source for fluid inertia induced pressure drops (or rises).

Nomenclature

C	Characteristic film clearance. $= R_B - R_J$, journal bearing radial clearance
h	Film thickness
L_*	Characteristic length
P	Hydrodynamic pressure
p	$\dfrac{P\,C^2}{\mu U_*\,L_*}$. Dimensionless pressure
R_B , R_J	Bearing and Journal Radii
Re	$\dfrac{\rho U_* C}{\mu}$. Shear flow Reynolds number
Re_*	$\dfrac{\rho U_* C}{\mu}\left(\dfrac{C}{L_*}\right)$. Modified shear flow Reynolds number
Re_s	$\dfrac{\rho\,\omega_* C^2}{\mu}$, Squeeze film Reynolds number
V_x, V_y, V_z	Fluid velocities along x, y, z directions
v_x, v_y, v_z	$V_x/U_*, V_y/V_*, V_z/U_*$ Dimensionless fluid velocities
U_* , V_*	Characteristic fluid speeds – along & across film thickness $V_* = U_* C/L_*$
t	Time
x, y, z	Coordinate system on plane of bearing
$\overline{x}, \overline{y}, \overline{z}$	$x/L_*, y/C, z/L_*$. Dimensionless coordinates
ρ	Fluid density
μ	Fluid absolute viscosity
ω_*	Characteristic frequency for unsteady or transient motions
Ω	Journal angular speed (rad/s)

Fluid flow in a general physical domain is governed by the principles of:

a) conservation of mass (1 equation),

b) conservation of linear momentum (3 equations), and

c) conservation (transport) of energy (1 equation),

In an Eulerian frame of reference, the fluid flow is fully defined by the velocity components $\boldsymbol{V}=(V_x,V_y,V_z)$,the pressure *(P)*, and the temperature *(T)* fields. The material properties of the fluid, density and viscosity, are in general, functions of its thermophysical state, i.e., *f(P,T).*

Figure 1 depicts an idealized geometry of a fluid film bearing. The major characteristic of a lubricant film, and which allows a major simplification of its analysis, is that **the thickness of the film *(h)* is very small when compared to its length *(L)* or to its radius of curvature *(R)*, i.e.**

$$(h/L) \text{ or } (h/R) \quad <<< 1.$$

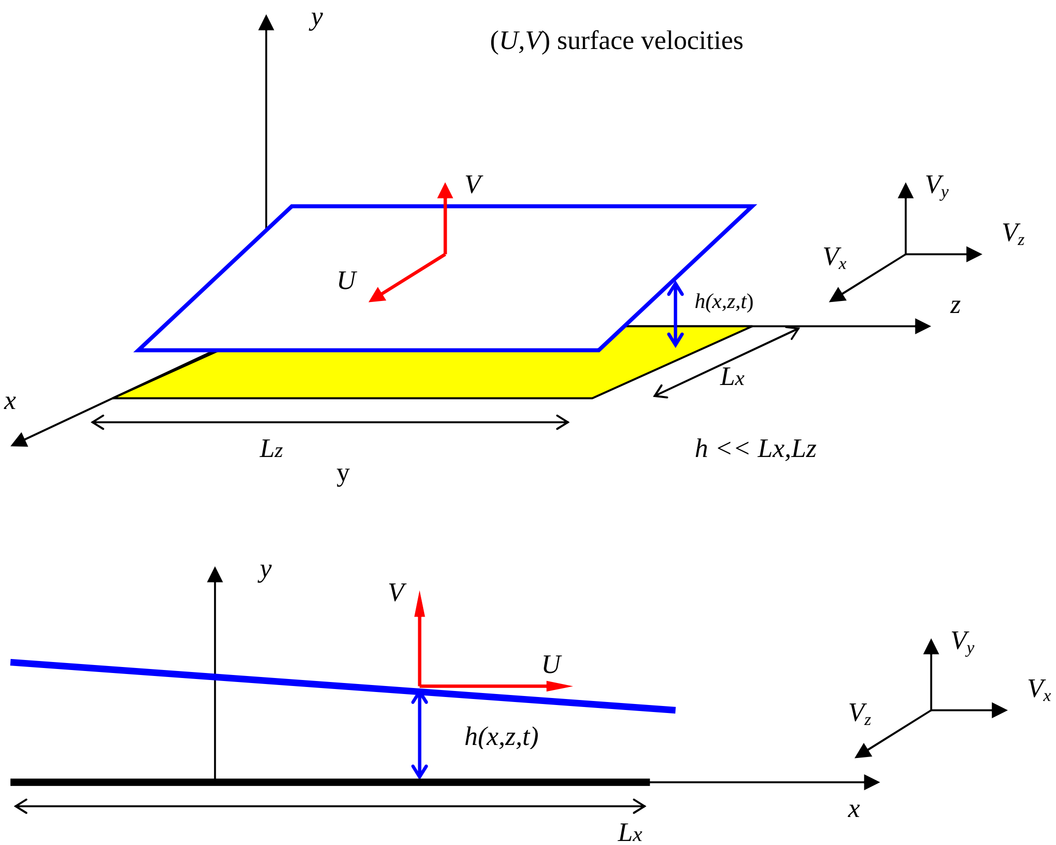
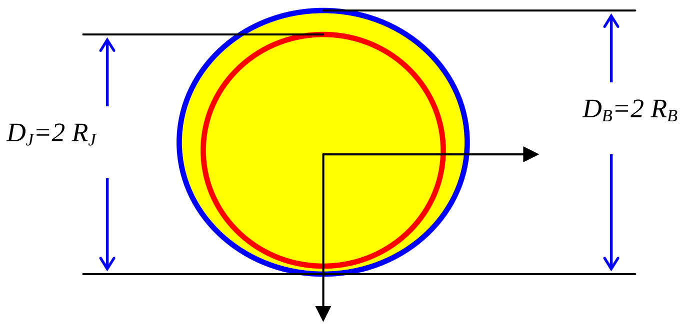


Figure 1. Geometry of flow region in a fluid film bearing *($h << L_x , L_z$)*

For example, in journal bearings, the film thickness is approximately equal to the film radial clearance, $h=C= (R_B - R_J)$; where R_B and R_J are the radii of the bearing and the journal, respectively. The characteristic geometrical dimension is either the bearing radius R_B or its axial length L.



Schematic view of a cylindrical bearing

In most thin fluid film applications with incompressible liquids, C/R_B =0.001 = 10^{-3}; while in gas film bearings, C/R_B=0.0001=10^{-4} typically.

As a consequence of the smallness in film thickness, **the effects of the film curvature are negligible on the operation of the thin film bearing.**

This assumption allows the prescription of an orthogonal Cartesian coordinate system (x, y, z) on the plane of the lubricant film, see Figure 1. The ***x***-axis lies in the direction of the relative motion of the bearing surfaces, and the ***y***-axis is along the direction of the minimum film dimension, i.e. across the film thickness.

For an incompressible, isoviscous Newtonian fluid, the equations of laminar flow continuity and momentum transport within the film region are:

continuity equation:

$$\frac{\partial V_x}{\partial x}+\frac{\partial V_y}{\partial y}+\frac{\partial V_z}{\partial z}=0 \tag{1.1}$$

momentum transport equations:

$$\rho\left\{\frac{\partial V_x}{\partial t}+V_x\frac{\partial V_x}{\partial x}+V_y\frac{\partial V_x}{\partial y}+V_z\frac{\partial V_x}{\partial z}\right\}=-\frac{\partial P}{\partial x}+\mu\;\Delta(V_x) \tag{1.2}$$

$$\rho\left\{\frac{\partial V_y}{\partial t}+V_x\frac{\partial V_y}{\partial x}+V_y\frac{\partial V_y}{\partial y}+V_z\frac{\partial V_y}{\partial z}\right\}=-\frac{\partial P}{\partial y}+\mu\;\Delta(V_y) \tag{1.3}$$

$$\rho\left\{\frac{\partial V_z}{\partial t}+V_x\frac{\partial V_z}{\partial x}+V_y\frac{\partial V_z}{\partial y}+V_z\frac{\partial V_z}{\partial z}\right\}=-\frac{\partial P}{\partial z}+\mu\;\Delta(V_z) \tag{1.4}$$

with the Laplacian operator
$$\Delta=\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2} \tag{1.5}$$

and where *(V_x, V_y, V_z)* are the fluid velocity components, *P* is the hydrodynamic pressure, and (ρ, μ*)* correspond to the material fluid density and absolute viscosity, respectively.

Dimensionless equations of motion

An analysis of the relative magnitude of each term in the equations of motion determines their relative importance on the flow mechanics. The order of magnitude analysis enables further simplifications adequate to model fluid flows in thin film geometries.

Define dimensionless spatial coordinates and time as

$$\bar{x} = x/L_*, \quad \bar{y} = y/C, \quad \bar{z} = z/L_* \qquad \tau = t\,\omega_* \tag{1.6}$$

where L_* is a characteristic length and *C* is a characteristic film thickness, ω_* is a characteristic frequency for unsteady or transient motions of the bearing surfaces. Note that the dimensionless variables above are of order (1), i.e. unit value. Dimensionless fluid film velocities follow as

$$v_x = \frac{V_x}{U_*}; v_z = \frac{V_z}{U_*}; \; v_y = \frac{V_y}{V_*}; \tag{1.7}$$

where U_* is a characteristic fluid speed, typically the sliding velocity of the runner surface. For example, in journal bearings $U_*=\Omega R_J$ where Ω is the journal angular speed in rad/s.

Substitution of the dimensionless variables into the continuity equation (1) renders the following expression

$$\frac{U_*}{L_*}\frac{\partial v_x}{\partial \bar{x}} + \frac{V_*}{C}\frac{\partial v_y}{\partial \bar{y}} + \frac{U_*}{L_*}\frac{\partial v_z}{\partial \bar{z}} = 0 \tag{1.8}$$

Multiplying this expression by *(L_*/U_*)* gives

$$\frac{\partial v_x}{\partial \bar{x}} + \left(\frac{V_*}{U_*}\frac{L_*}{C}\right)\frac{\partial v_y}{\partial \bar{y}} + \frac{\partial v_z}{\partial \bar{z}} = 0 \tag{1.9}$$

Thus, the characteristic cross-film velocity (V_*) must be defined as

$$\frac{V_*}{U_*}\frac{L_*}{C} = 1; \; i.e. \;\; V_* = U_*\frac{C}{L_*} \tag{1.10}$$

for all terms in the dimensionless continuity equation to be of the same order, i.e.

$$\frac{\partial v_x}{\partial \bar{x}}+\frac{\partial v_y}{\partial \bar{y}}+\frac{\partial v_z}{\partial \bar{z}}=0 \tag{1.11}$$

Thus, the cross film velocity $V_y <<< (V_x, V_z)$ is much smaller than the other two flow velocities in the plane of the fluid flow. This also means that small changes in the cross-film velocity V_y causes large variations in the fluid velocities along the *(x, y)* directions.

For hydrodynamic thin films, the dimensionless pressure (*p*) is defined according to

$$p=\frac{P\,C^2}{\mu U_*\, L_*} \tag{1.12}$$

Note that the product $(\mu U_* L_*/C^2)$ is a characteristic pressure proportional to the fluid viscosity, the surface sliding speed, and inversely proportional to the film thickness squared.

Substitution of the dimensionless coordinates and variables into the momentum equations (1.2) thru (1.4) renders the **momentum equations in the plane of motion, (*x, z*) directions,** as**:**

$$\rho\omega_*\frac{C^2}{\mu}\frac{\partial v_x}{\partial \tau}+\rho\frac{U_*}{\mu}\frac{C^2}{L_*}\left\{v_x\frac{\partial v_x}{\partial \bar{x}}+v_y\frac{\partial v_x}{\partial \bar{y}}+v_z\frac{\partial v_x}{\partial \bar{z}}\right\}=-\frac{\partial p}{\partial \bar{x}}+\frac{\partial v_x^2}{\partial \bar{y}^2}+\frac{C^2}{L_*^2}\left\{\frac{\partial^2 v_x}{\partial \bar{x}^2}+\frac{\partial^2 v_x}{\partial \bar{z}^2}\right\} \tag{1.13}$$

$$\rho\omega_*\frac{C^2}{\mu}\frac{\partial v_z}{\partial \tau}+\rho\frac{U_*}{\mu}\frac{C^2}{L_*}\left\{v_x\frac{\partial v_z}{\partial \bar{x}}+v_y\frac{\partial v_z}{\partial \bar{y}}+v_z\frac{\partial v_z}{\partial \bar{z}}\right\}=-\frac{\partial p}{\partial \bar{z}}+\frac{\partial v_z^2}{\partial \bar{y}^2}+\frac{C^2}{L_*^2}\left\{\frac{\partial^2 v_z}{\partial \bar{x}^2}+\frac{\partial^2 v_z}{\partial \bar{z}^2}\right\} \tag{1.14}$$

and the **momentum equation across the film, (*y*) direction,** as**:**

$$\rho\omega_*\frac{C^2}{\mu}\frac{C^2}{L_*^2}\frac{\partial v_y}{\partial \tau}+\rho\frac{U_*}{\mu}\frac{C^2}{L_*}\frac{C^2}{L_*^2}\left\{v_x\frac{\partial v_y}{\partial \bar{x}}+v_y\frac{\partial v_y}{\partial \bar{y}}+v_z\frac{\partial v_y}{\partial \bar{z}}\right\}=-\frac{\partial p}{\partial \bar{y}}+\frac{C^2}{L_*^2}\frac{\partial v_y^2}{\partial \bar{y}^2}+\frac{C^4}{L_*^4}\left\{\frac{\partial^2 v_y}{\partial \bar{x}^2}+\frac{\partial^2 v_y}{\partial \bar{z}^2}\right\}$$

(1.15)

The smallness of $(C/L_*)<<1$ (gap to length ratio) permits to disregard the flow terms of order $(C/L_*)^2$ and higher in the equations above. Thus, the **momentum transport equations in the plane of motion, (*x, z*) directions,** reduce to**:**

$$\mathrm{Re}_s\frac{\partial v_x}{\partial \tau}+\mathrm{Re}_*\left\{v_x\frac{\partial v_x}{\partial \bar{x}}+v_y\frac{\partial v_x}{\partial \bar{y}}+v_z\frac{\partial v_x}{\partial \bar{z}}\right\}=-\frac{\partial p}{\partial \bar{x}}+\frac{\partial v_x^2}{\partial \bar{y}^2} \tag{1.14}$$

$$\mathrm{Re}_s\frac{\partial v_z}{\partial \tau}+\mathrm{Re}_*\left\{v_x\frac{\partial v_z}{\partial \bar{x}}+v_y\frac{\partial v_z}{\partial \bar{y}}+v_z\frac{\partial v_z}{\partial \bar{z}}\right\}=-\frac{\partial p}{\partial \bar{z}}+\frac{\partial v_z^2}{\partial \bar{y}^2} \tag{1.15}$$

and the **momentum** equation for fluid motions **across the film, *y* direction,** reduces to:

$$0 = \frac{\partial p}{\partial \bar{y}} \tag{1.16}$$

This equation shows that the fluid pressure is uniform or constant across the film thickness, i.e. $p = f(x, z, t)$ only, regardless of the fluid inertia (or turbulent) character of the flow.

The following flow parameters appear in equations (1.14-15),

$$\mathrm{Re}_* = \mathrm{Re}\,(C/L_*), \qquad \mathbf{Re} = \frac{\rho U_* C}{\mu} \tag{17}$$

Re is the flow **Reynolds number** based on the characteristic speed (U_*). This number denotes the ratio between fluid inertia (advection) forces and viscous-shear forces, i.e. $\left(\frac{\rho U_*^2}{\mu U_* / C} \right)$**.** And,

$$\mathbf{Re}_s = \frac{\rho\, \omega_* C^2}{\mu} \tag{18}$$

is the **squeeze film Reynolds** number denoting the ratio between temporal fluid inertia forces due to transient motions and viscous-shear forces, i.e. $\left(\frac{\rho\, \omega_* U_* C}{\mu U_* / C} \right)$

Fluid inertia effects in thin film flows are of importance only in those applications where both Reynolds numbers are larger than ONE[1], i.e. Re_*, $\mathrm{Re}_s >> 1$.

As noted earlier, the film thickness to length ratio (C/L_*) in thin film flows is typically very small. Thus, fluid inertia terms are to be retained for flows with Reynolds numbers of the order:

$$\mathrm{Re} \;>\; (L_*/C) \times 1 \;>\; 1,000 \;\text{ for }\; (C/L_*) = 0.001 = 10^{-3} \tag{1.19}$$

Note that in hydrodynamic journal bearings, $\omega_* = \Omega$ and $U_* = \Omega R_J$, then $\mathrm{Re}_s = \mathrm{Re}_*$

Classical lubrication is based on the assumption that fluid inertia effects are negligible. In most practical applications handling mineral oils, $(\mathrm{Re}_s, \mathrm{Re}_*) \to 0$. Hence, one can assume effectively the fluid is inertialess or purely viscous.

[1] In actuality, Re > 12 for steady flow film bearing as will be demonstrated in later developments in these notes.

Thus, the thin film laminar flow of an incompressible, inertialess, and isoviscous fluid is governed by the following equations, in dimensional form given as:

continuity (mass conservation):

$$\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} + \frac{\partial V_z}{\partial z} = 0 \tag{1.20}$$

(*x*, *z*) –momentum transport:

$$0 = -\frac{\partial P}{\partial x} + \mu \frac{\partial^2 V_x}{\partial y^2} \tag{1.21}$$

$$0 = -\frac{\partial P}{\partial z} + \mu \frac{\partial^2 V_z}{\partial y^2} \tag{1.22}$$

with $P = f(x, z, t)$. Equations (1.21) and (1.22) establish a quasi-static balance of pressure forces equaling viscous shear forces. Note also that the time coordinate disappears from the governing equations. This means that **time is just a parameter** in **inertialess thin film flows.**

Table 1 shows the Reynolds numbers (Re) for a typical journal bearing application operating with different fluids. The example bearing is a 3 inch diameter ($2R_J$) journal and the clearance to radius ratio (C/R_J) is 0.001, a typical value for journal bearings. Two rotational speeds of 1,000 and 10,000 rpm (Ω=104.7 and 1,047 rad/s) are noted in the table. Recall that the shear flow Reynolds number is

$\mathrm{Re} = \rho U_* C/\mu = \rho\, \Omega R_J C/\mu = \Omega R_J C/\nu$, where $\nu = \mu/\rho$ is the fluid kinematic viscosity.

The Re magnitudes reported reveal that bearing applications with mineral oils and air do not need to include fluid inertia effects, i.e. Re < 1,000. However, process fluid applications using water, R134a refrigerant and cryogenic fluids show large Reynolds numbers at a speed of 10,000 rpm.

Note that current bearing applications using process liquids to replace mineral oils may operate at speeds well above 10,000 rpm. Incidentally, the operating speed of cryogenic turbopumps ranges from 25 krpm – 110 krpm, and future applications (currently in the works) will operate at speeds close to 200 krpm!
Incidentally, process gas and liquid **annular seals,** isolating regions of high and low pressures in a typical compressor or pump, have larger radial clearances than load supporting fluid film bearings. For example, in water neck-ring and interstage seals in pumps, *R/C* ~ 250, and thus fluid inertia effects are of importance even at relatively low rotational speeds (~1,000 rpm and higher).

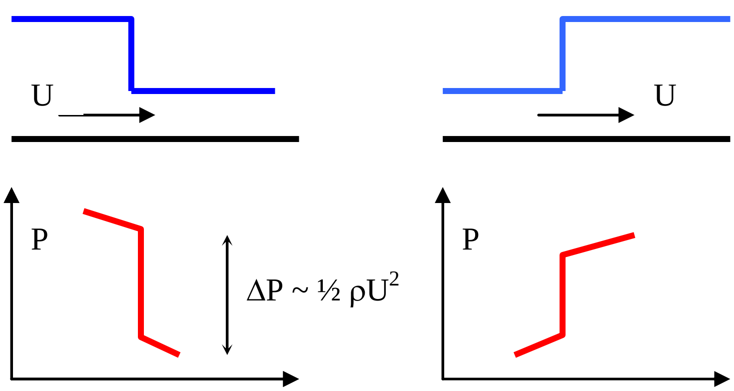
Table 1. Importance of fluid inertia effects on several fluid film bearing applications. *(c/R)*=0.001, R_J =38.1 mm (1.5 inch)

fluid	Absolute viscosity (μ) lbm-ft.s x 10^{-5}	Kinematic viscosity (ν) ft^2/s x 10^{-6}	Kinematic viscosity (ν) centistokes	Re at 1,000 rpm	Re at 10,000 rpm
Air	1.23	165.5	15.4	9.88	98.8
Thick oil ISO VG 32	1,682	323	30.0	5.07	50.7
Light oil ISO VG 3	120	23	2.14	71.1	711.3
Water	64	10.3	1.00	158.8	1,588
Liquid hydrogen	1.075	2.32	0.216	705.2	7,052
Liquid oxygen	10.47	2.06	0.191	794.2	7,942
Liquid nitrogen	13.93	1.93	0.179	847.7	8,477
R134 refrigerant	13.30	1.76	0.163	929.6	9,296

Other fluid inertia effects

The analysis above addressed to the importance of fluid inertia effects within the thin film flow domain. However, fluid inertia effects may also be of great importance at the inlet to the film and discharge from the film sections in a typical pad bearing or seal application. Depending on the flow conditions upstream of a sudden contraction or a sudden enlargement, a fraction of the dynamic pressure head, typically given as ($\frac{1}{2}\rho U^2$), is lost or recovered.

Sudden pressure losses are typical at the recess edges of a recess of pocket in a hydrostatic bearing and at the inlet section of an annular pressure seal. The same phenomenon also occurs at the leading edge of a bearing pad in high speed tilting pad bearings. A sudden pressure recovery is also quite typical at the discharge plane of a pressurized annular or labyrinth seal. Note that the importance of fluid inertia effects may be restricted only to the inlet and discharge sections, and may not be relevant within the thin film flow domain.



Pressure drop/rise at sudden changes in film thickness

PROPERTIES OF VARIOUS SUBSTANCES

	AIR	CO_2 Sat. Liquid	WATER	OIL	UNITS
TEMPERATURE	70*	68‡	70*	70*	°F
DENSITY	0.074	48.4	62.3	53	lbm/ft^3
	0.0099	6.47	8.32	7.1	lbm/gal
VISCOSITY, DYNAMIC KINEMATIC	1.23 165.5	4.82 1.00	64.3 10.3	120 23	$x10^5$lbm/ft sec $x10^6ft^2/sec$
INTERNAL ENERGY, u	90.34	236.5	38.1	112	Btu/lbm
ENTHALPY, h	126.66	236.5	38.1	112	Btu/lbm
ENTROPY, s	0.5962	0.783	0.0745	0.3	Btu/lbm°R
SPECIFIC HEAT CAPACITY, Cp Cv	0.2398 0.1712	1.008 1.008	0.999 0.999	0.5 0.5	Btu/lbm°R Btu/lbm°R
THERMAL CONDUCTIVITY	0.015	0.0468	0.0350	0.075	Btu/hr ft°R
BULK MODULUS	.094 20.28	Not Available	1354 292251.24	1620 349665.	$x10^6$lbm/ft sec^2
CRITICAL POINT • PRESSURE • TEMPERATURE	------ ------	1070.6 87.9	3208.2 705.47	------ ------	psi °F
TRIPLE POINT • PRESSURE • TEMPERATURE	----- -----	75.13 69.9	3207.4 32.02	----- -----	psi °F

*at 147 psi
‡ at 830 psi

TYPICAL CRYOGENIC PROPELLANT PROPERTIES

	O_2	H_2	CH_4	N_2	UNITS
LIQUID TEMPERATURE*	-300	-424	-290	-320	°F
DENSITY	72.04	4.64	28.01	50.80	lbm/ft^3
	9.63	0.62	3.74	6.79	lbm/gal
VISCOSITY, DYNAMIC **KINEMATIC**	13.93 1.93	1.075 2.32	12.77 4.56	10.47 2.06	$x10^5$lbm/ft sec $x10^6ft^2/sec$
INTERNAL ENERGY, u	-58.76	-116.6	-149.8	-52.7	Btu/lbm
ENTHALPY, h	-57.74	-100.6	-147.2	-51.2	Btu/lbm
ENTROPY, s	0.694	1.783	1.038	0.676	Btu/lbm°R
SPECIFIC HEAT CAPACITY, Cp **Cv**	0.401 0.223	2.029 1.340	0.795 0.504	0.244 0.485	Btu/lbm°R Btu/lbm°R
THERMAL CONDUCTIVITY	0.0895	0.0530	0.1273	0.0785	Btu/hr ft°R
BULK MODULUS	668.4 144270.	75.8 16360.	699.4 150960.	488.5 105439.24	$x10^6$lbm/ft sec^2 psi
CRITICAL POINT • **PRESSURE** • **TEMPERATURE**	731.4 -181.8	187.51 -400.6	654.57 -117.0	492.5 -232.4	psi °F
TRIPLE POINT • **PRESSURE** • **TEMPERATURE**	0.022 -362.2	1.021 -435.2	1.70 -296.8	5.54 -346	psi °F

*AT 400 psi

Mobil Velocite Oil Numbered Series

EXAMPLE

Spindle and Hydraulic Oils

Product Description

The Mobil Velocite Oil Numbered Series oils are premium performance products primarily designed for the lubrication of high-speed spindles in machine tools. They are also used in some critical hydraulic, circulation systems and air line oilers where the appropriate viscosity grade is selected. They are formulated from select high-quality, low viscosity base oils and additives that impart good resistance to oxidation and protection from rust and corrosion. They possess very good resistance to foaming and separate readily from water.

Features & Benefits

The Mobil Velocite Oil Numbered Series provide exceptional lubrication of close-tolerance bearings which helps keep the bearings running cool and helps maintain the precision required by many of today's critical machine tools. Although the Mobil Velocite Oil Numbered Series oils were designed for spindle bearings, they exhibit the required properties to function as low pressure hydraulic and circulating oils as long as the proper viscosity is selected. This feature can help minimise inventory costs and reduce the potential for product misapplication.

Features	Advantages and Potential Benefits
Good Oxidation Resistance	Helps reduce critical deposit formation Improves oil life
Very Good Rust and Corrosion Protection	Improves equipment life Provides increased precision long-term
Effective Water Separation	Resists emulsion formation Keeps moisture out of critical lubrication areas Allows easy removal of moisture from system reservoirs

Applications

- High speed spindle bearings in machine tools and equipment where high speeds and fine clearances are involved
- Precision grinders, lathes, jig borers and tracer mechanisms
- For sleeve type spindle bearings having greater clearances, the choice of viscosity depends on the relation between clearance and spindle speed
- Low pressure hydraulic systems where appropriate viscosity is selected
- Air line oilers (Mobil Velocite Oil No. 10)
- For some sensitive instruments such as telescopes, laboratory equipment, etc.

Due to continual product research and development, the information contained herein is subject to change without notification.
Typical properties may vary slightly. Additional health and safety information on this product can be found on the Material Safety Data Sheet, which is available on line at www.imperialoil.ca, or by contacting Lubricants and Petroleum Specialties, Technical Help Desk, 1-800-268-3183.
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Specifications & Approvals

Mobil Velocite Oil Numbered Series meets or exceeds the following industry specifications:	No 6	No 10
Cincinnati Machine P-62	X	-
Cincinnati Machine P-45	-	X

Typical Properties

Mobil Velocite Oil Numbered Series	No 6	No 10
ISO VG	10	22
Viscosity, ASTM D 445		
cSt @ 40ºC	10.0	22.0
cSt @ 100ºC	2.62	4.0
Total Acid Number, ASTM D 974, mgKOH/g	0.06	0.1
Copper Strip Corrosion, 3 hrs @ 100ºC, ASTM D 130	1A	1A
Rust Characteristics, Proc A, ASTM D 665	Pass	Pass
Pour Point, ºC, ASTM D 97	-15	-30
Flash Point, ºC, ASTM D 92	180	212
Density @ 15ºC, ASTM D 4052, kg/L	0.844	0.862

Precautions

MOBIL VELOCITE is manufactured from high quality petroleum base stocks, carefully blended with selected additives. As with all petroleum products, good personal hygiene and careful handling should always be practiced. Avoid prolonged contact to skin, splashing into the eyes, ingestion or vapour inhalation. Please refer to our Imperial Oil Material Safety Data Sheet for further information.

Note: This product is not controlled under Canadian WHMIS legislation.

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Mobil DTE 790 Series

Premium Performance Turbine Oils

EXAMPLE

Product Description

Mobil DTE 790 Series lubricants are premium performance turbine oils that are engineered to meet the requirements of the most severe steam turbine designs and operation, with maximum oil charge life. Mobil DTE 790 Series oils are based on proprietary, very high quality, hydrotreated base stocks and selected additives which provide outstanding resistance to oxidation and chemical degradation over time, which is exemplified by exceptional color stability, a key factor in assessing oil stability in some regions of the world. Mobil DTE 790 lubricants also exhibit excellent water separability, resistance to emulsion formation and anti-foaming characteristics which provides efficient operation, and good air release properties which is critical for hydraulic control mechanisms.

The exceptional oxidation stability performance of Mobil DTE 790 oils has resulted in outstanding performance in even the most severe, and largest capacity steam turbine applications. These products have an outstanding reputation for equipment reliability and avoiding unscheduled downtime. This reputation is exemplified by the very high percent of nuclear turbine operators who choose Mobil DTE 790 lubricants. Their performance in service is also recognized to provide very long charge life, in excess of conventional turbine oils, and high resistance to deposit formation and filter plugging. While primarily engineered for steam turbine service, Mobil DTE 790 Series oils also find application in non-geared gas turbine service.

The performance features of Mobil DTE 790 Series oils translate into excellent equipment protection, reliable operation, with reduced downtime and extended oil charge life. Mobil DTE 790 Series oils, in the appropriate grade, meet or exceed the requirements of major steam and gas turbine builders.

Features & Benefits

The Mobil DTE family of products is well known and highly regarded worldwide based on their outstanding performance and the R&D expertise and the global technical support which stand behind the brand. The exceptional performance of one series of oils which make up this family, Mobil DTE 790 Series, has made it the choice of steam turbine operators around the world for many decades.

Close contacts with steam turbine designers worldwide is the key factor in our understanding of the challenges for the lubricant in the most advanced designs. Our research scientists use this information, along with proprietary tests, to simulate the severity of the latest generation turbine designs in advancing Mobil DTE 790 formulation technology.

For Mobil DTE 790 Series oils this work has resulted in a formulation based on a special hydrotreated basestock, along with specially chosen additives to provide exceptional oxidation stability and deposit control which results in superb equipment protection, highly reliable operation and long oil charge life. A review of the features, advantages and potential benefits of the product are shown below:

ExxonMobil Lubricants & Specialties
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Features	Advantages and Potential Benefits
Superb oxidation, chemical and color stability	Extended oil charge life and reduced oil changeout costs
	Reduced filter plugging and equipment fouling for reduced downtime and maintenance costs
	High level of turbine system reliability and reduced unanticipated downtime
Excellent water seperability and foam control	Improved operating efficiency and reduced operating expenses
Very good air release properties	Avoids erratic operation and pump cavitation, reducing pump replacement

Applications

Mobil DTE 790 Series lubricants are premium performance turbine oils engineered to meet the requirements of: circulation systems of direct-connected steam turbine and gas turbines; ring-oiled bearings of geared and direct-connected turbines; hydraulic control systems of turbines. Specific applications include:

- Electric power generation by utilities, including nuclear plants.
- Electric power generation by industrial users, such as paper mills

Specifications & Approvals

Mobil DTE 790 Series meets or exceeds the following industry specifications	797	798
Alstom Power Sweden MAT 812101	X	
Alstom Power Sweden MAT 812102		X
GEC Alstom NBA P 50001	X	X
GE GEK 28143-A	X	X
GE GEK 46506-D	X	
GE GEK 27070	X	
DIN 51515-1	L-TD 32	L-TD 46

Mobil DTE 790 Series has the following builder approvals	797	798
Alstom Power HTGD 90 117, non-geared	X	X
Siemens TLV 9013 04, non-geared	X	X

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Typical Properties

Mobil DTE 790 Series	797	798
ISO Viscosity Grade	32	46
Viscosity, ASTM D 445		
cSt @ 40º C	30.1	44.3
cSt @ 100º C	5.4	6.8
Viscosity Index, ASTM D 2270	110	106
Pour Point, ºC, ASTM D 97	-30	-30
Flash Point, ºC, ASTM D 92	221	232
Density @15º C, ASTM D 1298, kg/l	0.85	0.86
TOST, ASTM D 943, Hours to 2 NN	6500	5500
Rust Prevention, ASTM D 665,		
Distilled Water	Pass	Pass
Sea Water	Pass	Pass
Water Seperability, ASTM D 1401, Min. to 3 ml emulsion @ 54º C	15	20
Copper Strip Corrosion, ASTM D 130, 3 hrs @ 100º C	1A	1A
Foam Test, ASTM D 892, Seq I Tendency / Stability, ml/ml	20/0	20/0
Air Release, ASTM D 3427, 50º C, min.	2	3

Health & Safety

Based on available information, this product is not expected to produce adverse effects on health when used for the intended application and the recommendations provided in the Material Safety Data Sheet (MSDS) are followed. MSDS's are available upon request through your sales contract office, or via the Internet. This product should not be used for purposes other than its intended use. If disposing of used product, take care to protect the environment.

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