ME 308
MACHINE ELEMENTS II

CHAPTER 4

JOURNAL BEARINGS
PART_3

(NO ROLLING ELEMENTS,

ONLY A SHAFT, A HOLE AND SOME LUBRICANT/OIL IN BETWEEN)

Design Suggestions

1. Start design (also analysis) by listing the given parameters

2. List the required parameters

3. Write down the relation between required parameters and the known parameters of ΔT= ? or S= ?

4. Use some recommended (suggested) values given in the tables and figures of P values, c values and PV_{max} values if not given in the problem or Assume them.

5. Start with an l/d= unity if geometry of bearing is not fixed then increase this ratio if thin film lubrication is likely to occur decrease this ratio if thick film lubrication or high temperatures are likely to occur.

6. A long bearing (large *l/d* ratio) reduces the coefficient of friction and side flow and therefore is desirable where thin-film lubrication is present.
   On the other hand, a short bearing results in a greater flow of oil out of the end and thus keeping the bearing cooler.
   Where force – feed or positive lubrication ($P_s>0$) is present. The *l/d* ratio should be relatively small.

7. If shaft deflection is likely to be severe, a short bearing should be used to prevent metal-to-metal contact at the ends of the bearing.

8. Always consider using of a partial bearing if high temperatures are a problem, become relieving the non-load bearing area of a bearing can very substantially reduce the heat generated.

9. Choose bearing material with satisfactory compressive and fatigue strength while having low melting point and low modulus of elasticity. (Table 12-3). It should have resistance to wear and corrosion. It should have low friction coefficient (can be reduced by some design means)

EXAMPLE 4.4:

A journal bearing has a diameter of 64 mm and length of 32 mm. The journal is to operate at a speed of 1800 rpm and carry a load of 3500 N. If SAE 20 oil at an inlet temperature of 44 ºC is to be used. What should be the radial clearance for:

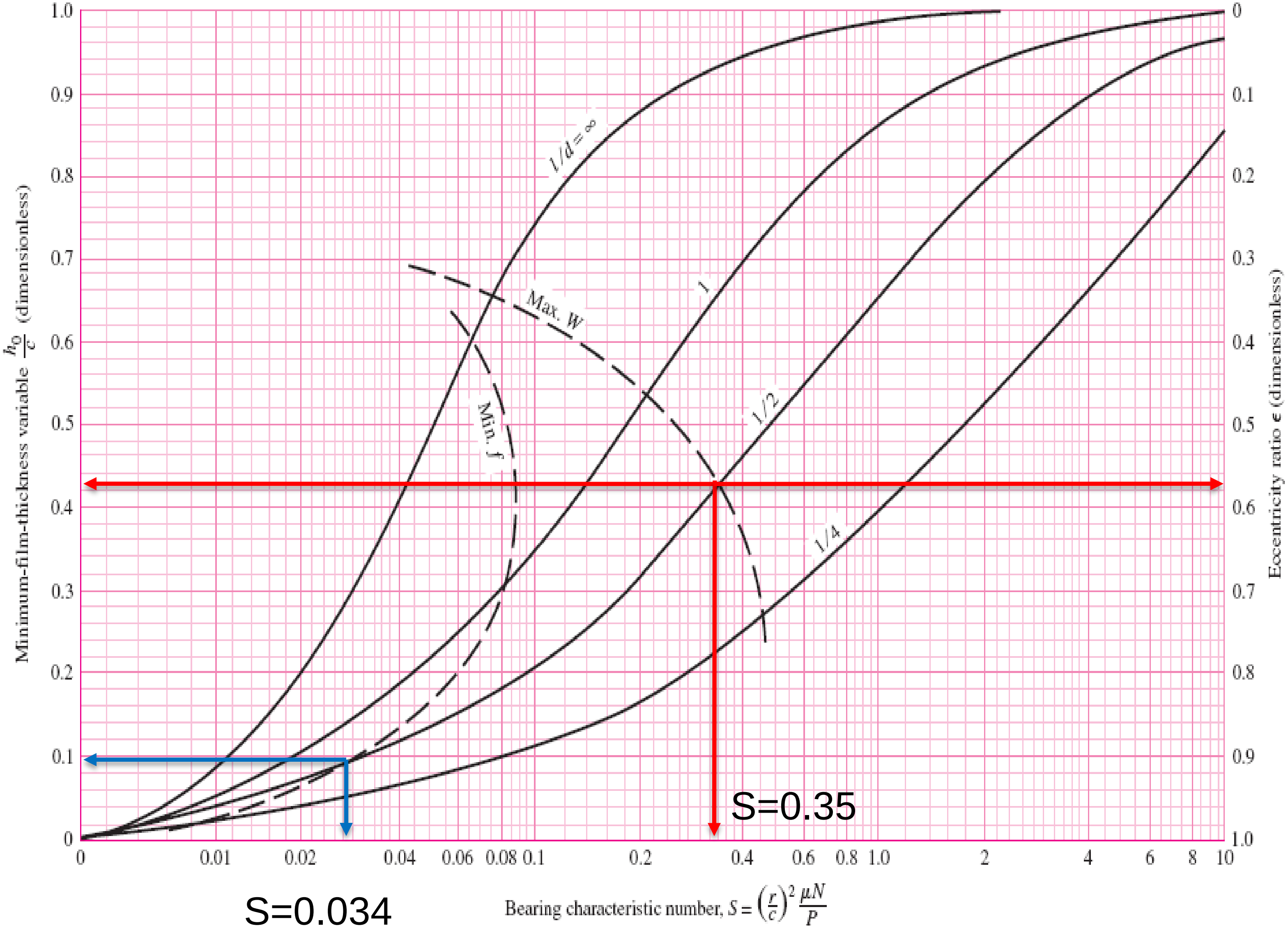
a) Optimum load carrying capacity
b) Minimum friction or power loss condition.

d= 64 mm → r= 32 mm
l= 32 mm → l/d= 32/64= 1/2
N= 1800 rpm = 30 rev/s
W= 3500 N
T_i = 44ºC
SAE 20 oil
c= ?

Table 12-3 RECOMMENDED UNIT LOADS FOR SLEEVE BEARINGS

Application	Unit load, kPa	Application	Unit load, kPa
Air compressors:		Diesel engines:	
Main bearings	1 000– 2 000	Main bearings	6 000–12 000
Crankpin	2 000– 4 000	Crankpin	8 000–15 000
Automotive engines:		Wristpin	14 000–15 000
Main bearings	4 000– 5 000	Electric motors	800– 1 500
Crankpin	10 000–15 000	Gear reducers	800– 1 500
Centrifugal pumps	600– 1 200	Steam turbines	800– 1 500

a) For optimum load carrying capacity with *l/d* = 1/2



$$For\ \ S = 0.35 \qquad P = \frac{W}{2rl} = \frac{3500}{2\times 32\times 32} = 1.709\ \ MPa$$

$$\frac{h_0}{c} = 0.425$$

$$\varepsilon = 0.575$$

$$\text{For}\ \ S = 0.35 \qquad \frac{l}{d} = \frac{1}{2}$$

$$\frac{r}{c}f = 8.0 \quad \& \quad T_{\text{var}} \cong 31\ {}^{o}C$$

$$\frac{Q}{rcNl} = 4.8 \quad \& \quad \frac{Q_s}{Q} = 0.72$$

$$\Delta T_{{}^{o}C} = \frac{8.30P}{\left[1 - \frac{1}{2}\times\frac{Q_s}{Q}\right]} \times \frac{\frac{r}{c}f}{\frac{Q}{rcNl}} = 36.93\ \ {}^{o}C \qquad \Delta T = T_{\text{var}}\frac{P}{\gamma C_H} = 31\times\frac{1.709\times 10^{6}}{861\times 1760} \cong 35\ {}^{o}C$$

$$T_{ave} = T_{in} + \frac{\Delta T}{2} = 44 + \frac{36}{2} = 62\ {}^{o}C \quad \rightarrow \mu = 16\times 10^{-3}\ Pa - \sec$$

$$S = \left(\frac{r}{c}\right)^{2}\frac{\mu N}{P} = 0.35 \qquad c_{load} = \left[\frac{r^{2}}{S}\frac{\mu N}{P}\right]^{1/2} = 0.0268\,mm \cong 27\ \mu m$$

$\left(\frac{r}{c}\right) f = 8.0 \quad (p540)(p444)$

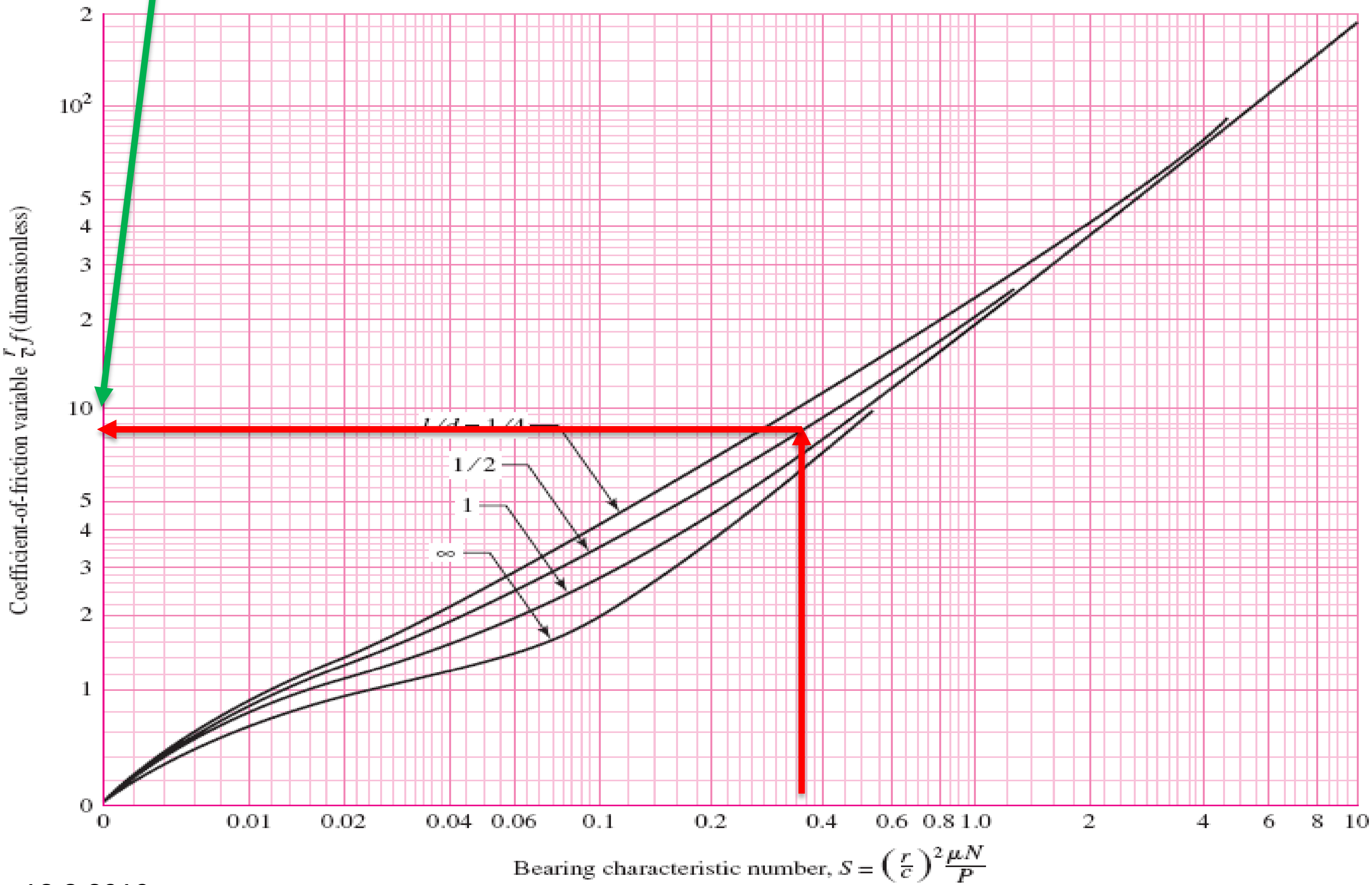
For $S = 0.35$

$\frac{l}{d} = \frac{1}{2}$

For $S = 0.034$

$\frac{l}{d} = \frac{1}{2}$

$\left(\frac{r}{c}\right) f = 1.7$



$$For\ \ S = 0.35$$

$$\frac{l}{d} = \frac{1}{2}$$

$$T_{\text{var}} = 31\ ^{o}C$$

$$T_{\text{var}} = 7\ \ ^{o}C$$

$$For\ \ S = 0.034$$

$$\frac{l}{d} = \frac{1}{2}$$

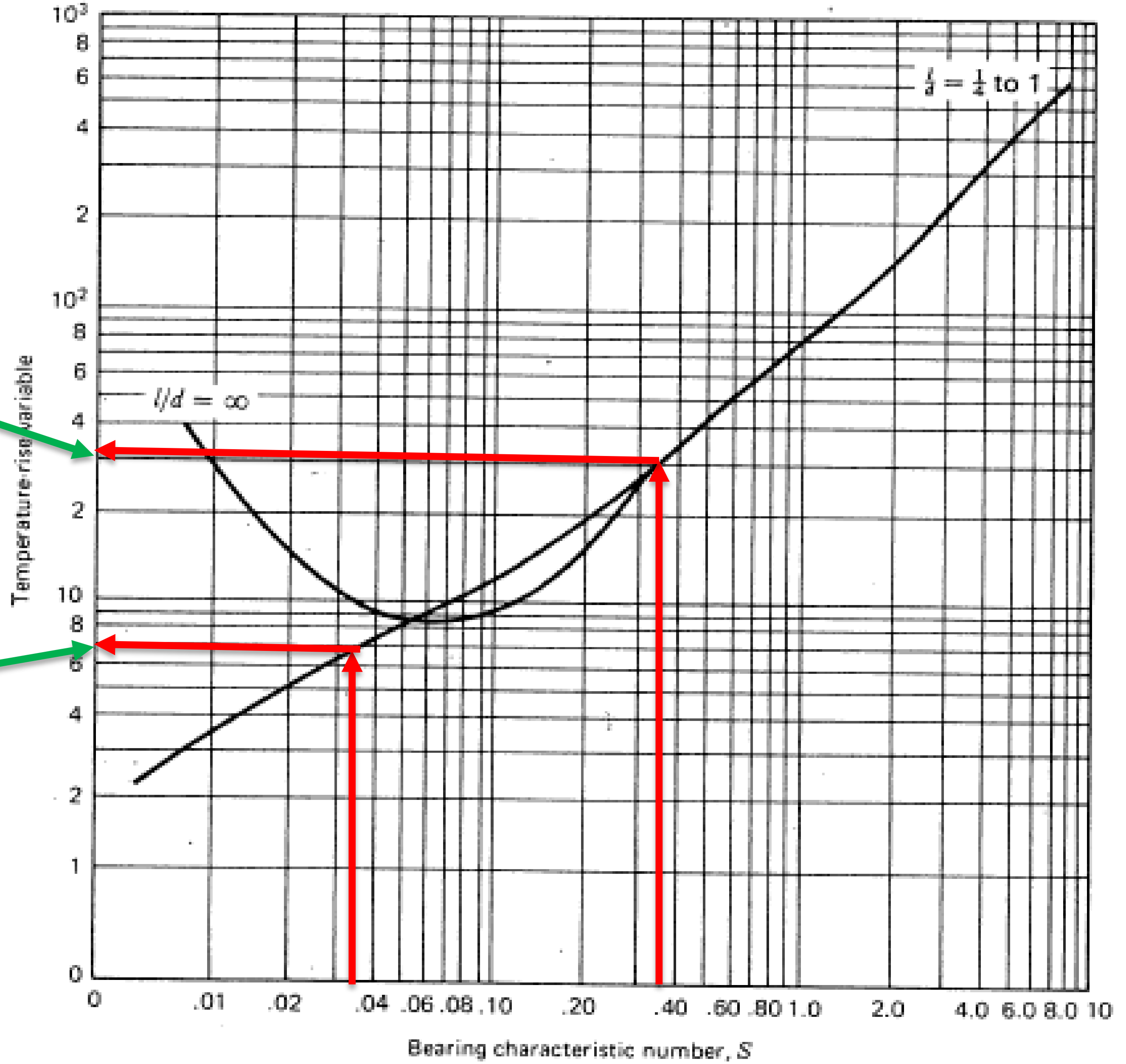


FIGURE 12-12 Chart for temperature-rise variable $T(\text{var}) = \gamma C_H\, \Delta T/P$. In plotting this chart it was found that the curves for $l/d = \frac{1}{4}, \frac{1}{2}$, and 1 were so close together that they could not be distinguished from a single curve.

$$\frac{Q}{rcNl} = 4.8 \quad (p541)(p445)$$

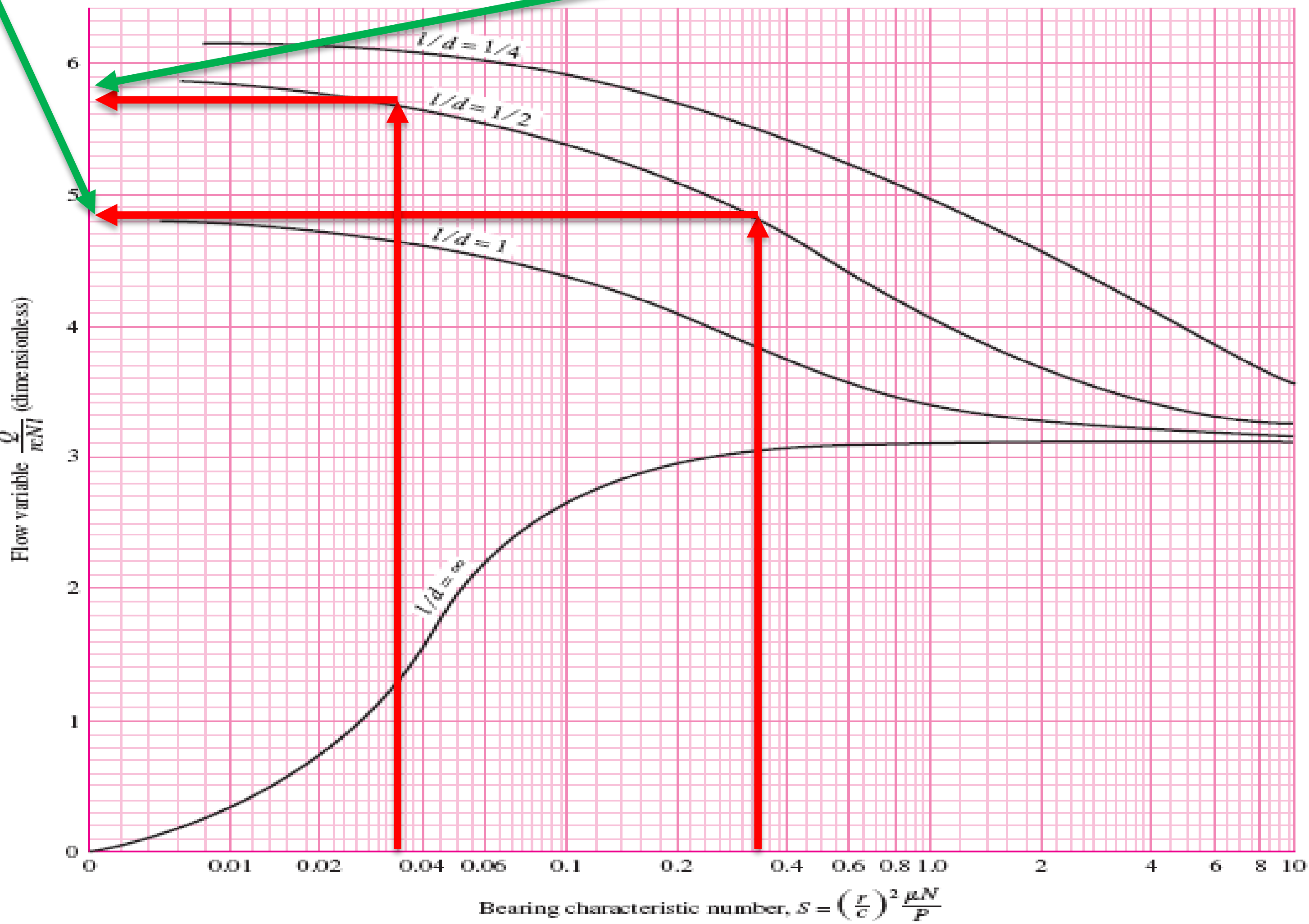
$$\frac{Q}{rcNl} = 5.65$$

$$For \;\; S = 0.034$$

$$\frac{l}{d} = \frac{1}{2}$$

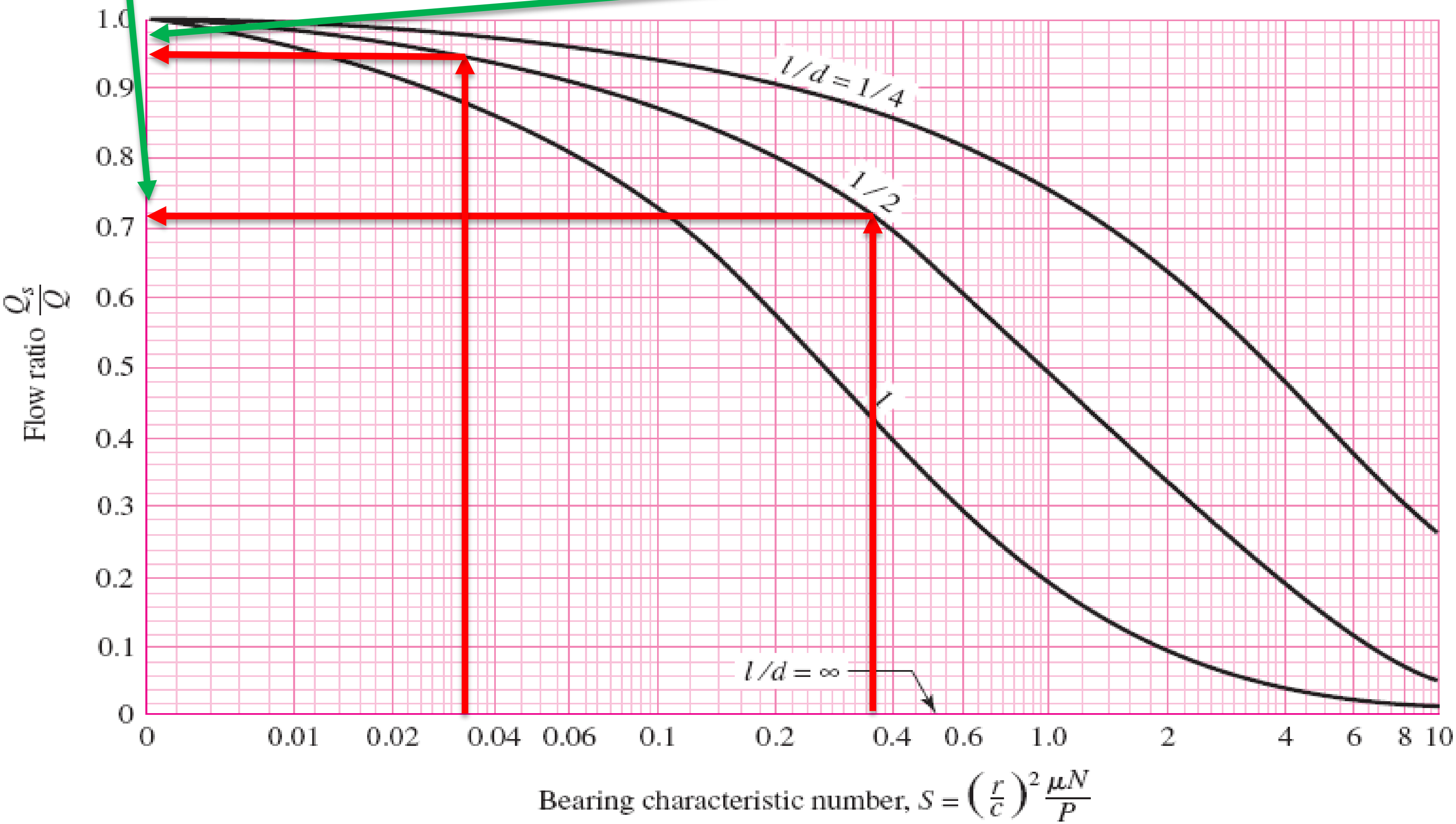
$$For \;\; S = 0.35$$

$$\frac{l}{d} = \frac{1}{2}$$



$\frac{Q_s}{Q} = 0.72$ (p542)(p446) For $S = 0.35$ $\frac{l}{d} = \frac{1}{2}$

For $S = 0.034$ $\frac{l}{d} = \frac{1}{2}$ $\frac{Q_s}{Q} = 0.94$



Now from chart Fig. 12.12 pp. 534 (Fig. 12.10 pp. 435)

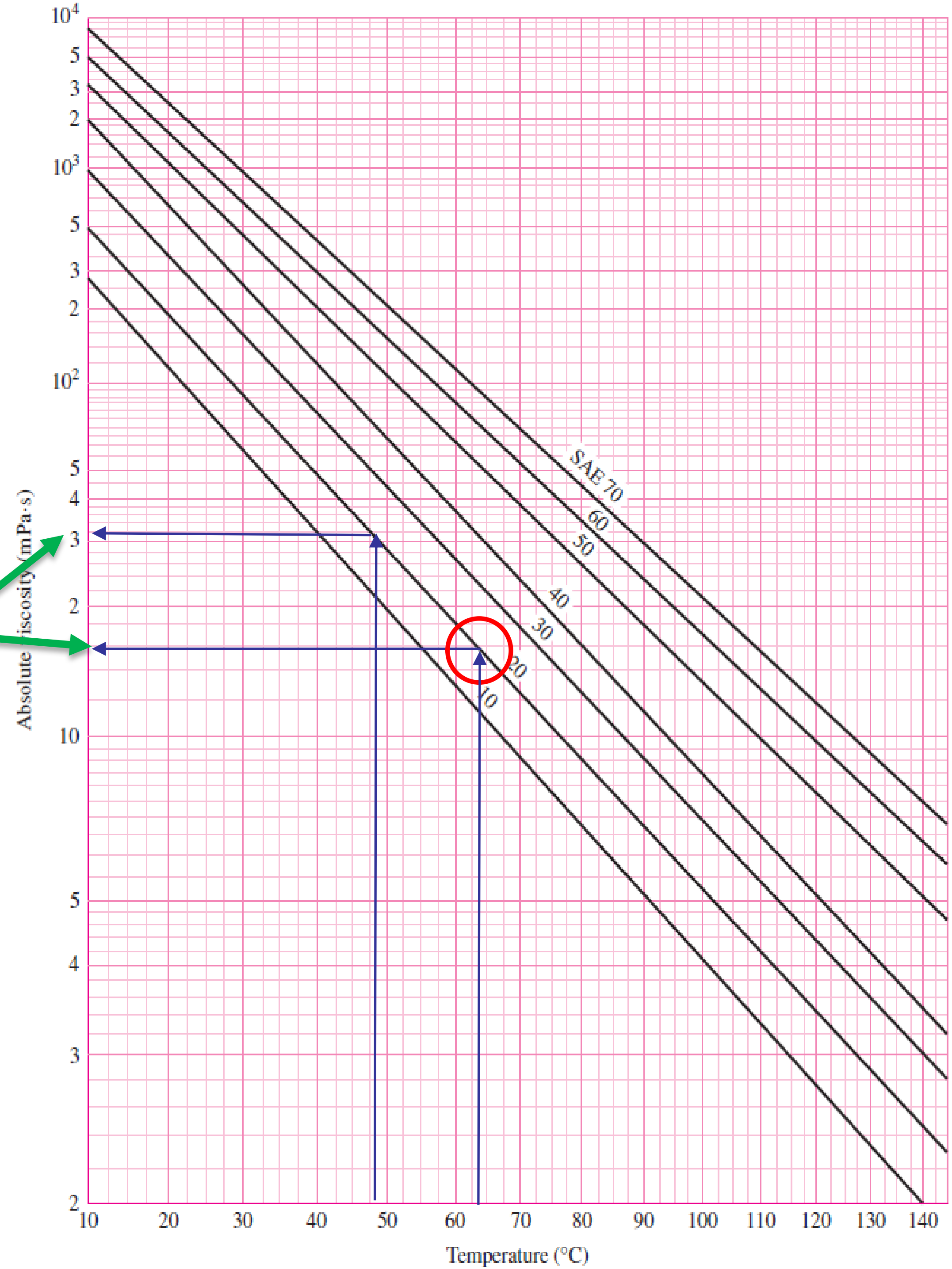
SAE 20

$$T_{ave} = 62\ ^oC$$

$$\rightarrow \mu = 16\times10^{-3}\, Pa - \sec$$

$$T_{ave} \cong 48\ ^oC$$

$$\rightarrow \mu = 32\times10^{-3}\ Pa - \sec$$



b) For minimum friction or power loss: $$\Delta T = T_{var}\frac{P}{\gamma C_H} = 7\times\frac{1.709\times10^6}{861\times1760} \cong 8\ ^oC$$

$$For\ \ S = 0.034 \quad \& \quad \frac{h_0}{c} = 0.11$$

$$For\ \ S = 0.034 \qquad \frac{r}{c}f = 1.7 \quad \& \quad T_{var} \cong 7\ ^oC$$

$$\Delta T_{^oC} = \frac{8.30P}{\left[1-\frac{1}{2}\times\frac{Q_s}{Q}\right]}\times\frac{\frac{r}{c}f}{\frac{Q}{rcNl}} = 8.05\ \ ^oC \qquad \frac{l}{d} = \frac{1}{2} \qquad \frac{Q}{rcNl} = 5.65 \quad \& \quad \frac{Q_s}{Q} = 0.94$$

$$\Delta T_{^oC} = 8.05\ ^oC \quad \left(< \Delta T \cong 36.0\ ^oC \quad \text{based on load}\right)$$

$$T_{ave} = T_{in} + \frac{\Delta T}{2} = 44 + \frac{8.05}{2} \cong 48\ ^oC \quad \to \mu = 32\times10^{-3}\ Pa-\sec$$

$$c_{fric} = \left[\frac{r^2}{S}\frac{\mu N}{P}\right]^{1/2} = \left[\frac{32^2}{0.034}\frac{32\times10^{-3}\times30}{1.709\times10^6}\right]^{1/2} = 0.13\,mm \cong 130\ \mu m$$

$$130\ \mu m > 27\ \mu m$$

$$c_{fr} > c_{load}$$

EXAMPLE 4.5:

A sleeve bearing is 100 mm diameter and has *l/d* ratio of 1/2. It has a frictional power loss of 100 watts when the load is 3000 N and the journal speed is 900 rpm for c/r=0.002.

a)Compute the minimum film thickness (h_0=?)

b)What is the viscosity of the oil and proper grade for an operating temperature of 71 ^oC (T_{ave}=?).

c)What is the temperature increase? Θ_{Pmax} =? P_{max} =?

Solution:

Given:

$$\frac{l}{d} = \frac{1}{2} \qquad d = 100\ mm \qquad W = 3000\ N \qquad P_{loss} = 100\ watts$$

$$N = 900\ rpm = 15\ rps \qquad \frac{c}{r} = 0.002 \qquad c = 0.002 \times 50 = 0.1\ mm$$

a) The frictional power loss is given by;

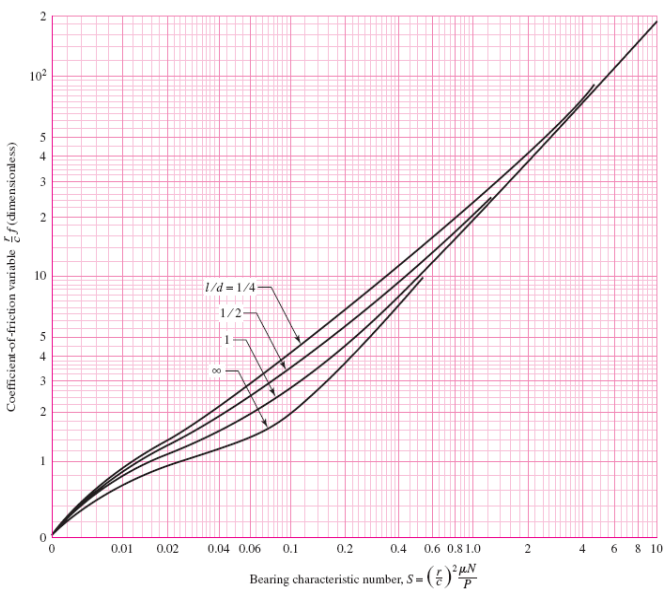
$$P_{loss} = T_{loss} \times w \frac{rad}{\sec} = (f \times W \times r) \times (2\pi N)$$

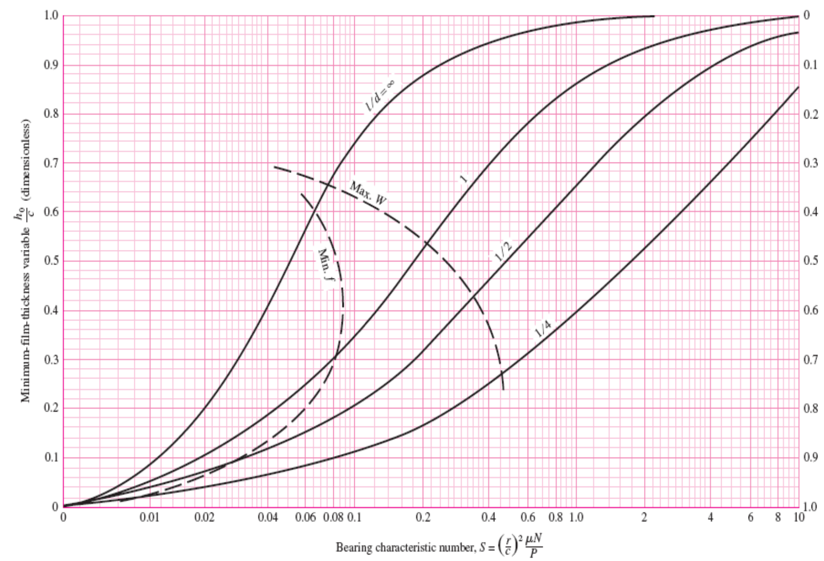
$$T_{loss} = F_{fric} \times r$$

$$F_{fric} = W \times f$$

where only f is unknown

$$f = \frac{P_{loss}}{W \times r \times 2\pi N} = \frac{100}{3000 \times 0.05 \times 2\pi \times 15} = 0.00707$$





from this figure S can be determined.

$$\frac{r}{c} = \frac{1}{0.002} = 500 \rightarrow \frac{r}{c} f = 3.535 \quad \& \quad \frac{l}{d} = \frac{1}{2}; \quad \underline{\underline{S = 0.1}}$$

$$\frac{h_0}{c} = 0.21 \rightarrow h_0 = 0.21 \times c = 0.021\ mm \qquad \underline{\underline{h_0 = 21\ \mu m}}$$

b)

$$S = \left(\frac{r}{c}\right)^2 \frac{\mu N}{P} \qquad P = \frac{W}{ld} = \frac{3000}{50 \times 100} = 0.6\ \ MPa$$

$$\mu = \frac{SP}{N\left(\frac{r}{c}\right)^2} = \frac{0.1 \times 0.6 \times 10^6}{15(500)^2} = 0.016\ Pa - \sec = \quad \underline{\underline{16\ mPa - \sec}}$$

For operating temperature of 71 ^{o}C (T_{ave}=71).
<u>SAE 30 is the suitable oil to be used</u>.

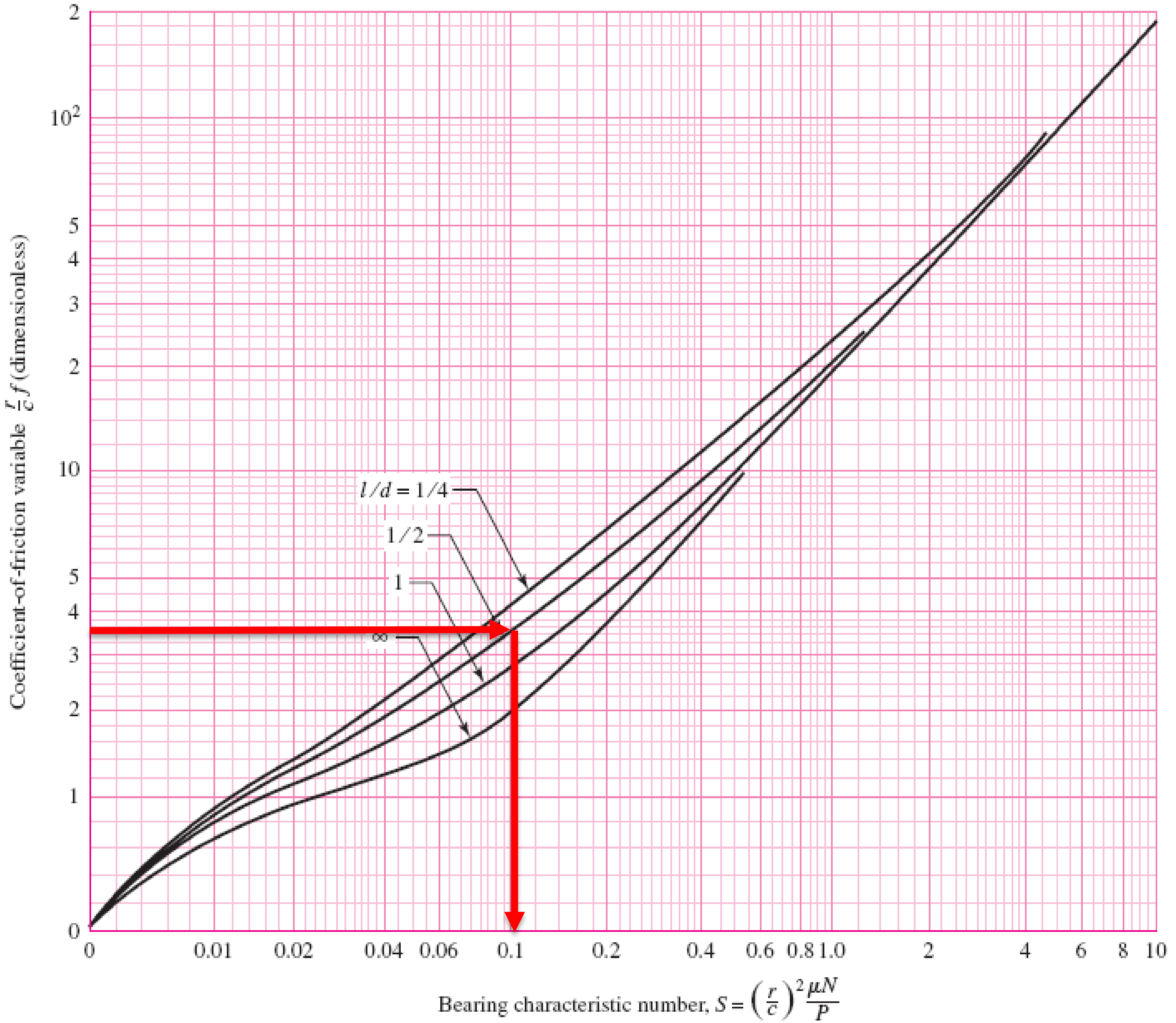
$$For$$

$$\frac{r}{c}f = 3.535$$

$$\&$$

$$\frac{l}{d} = \frac{1}{2};$$

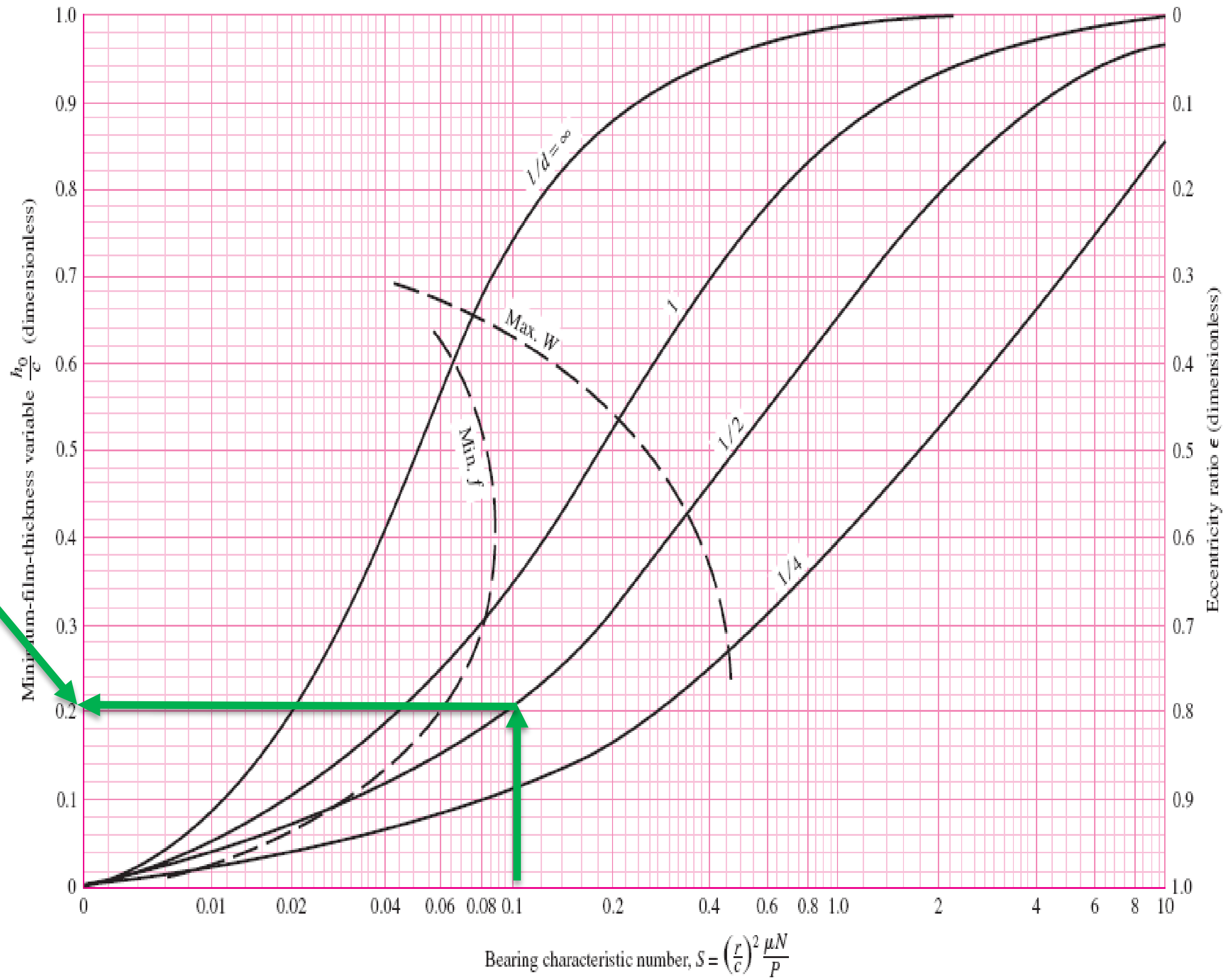
$$\underline{\underline{S = 0.1}}$$



$$For \quad S = 0.1$$

$$\frac{l}{d} = \frac{1}{2}$$

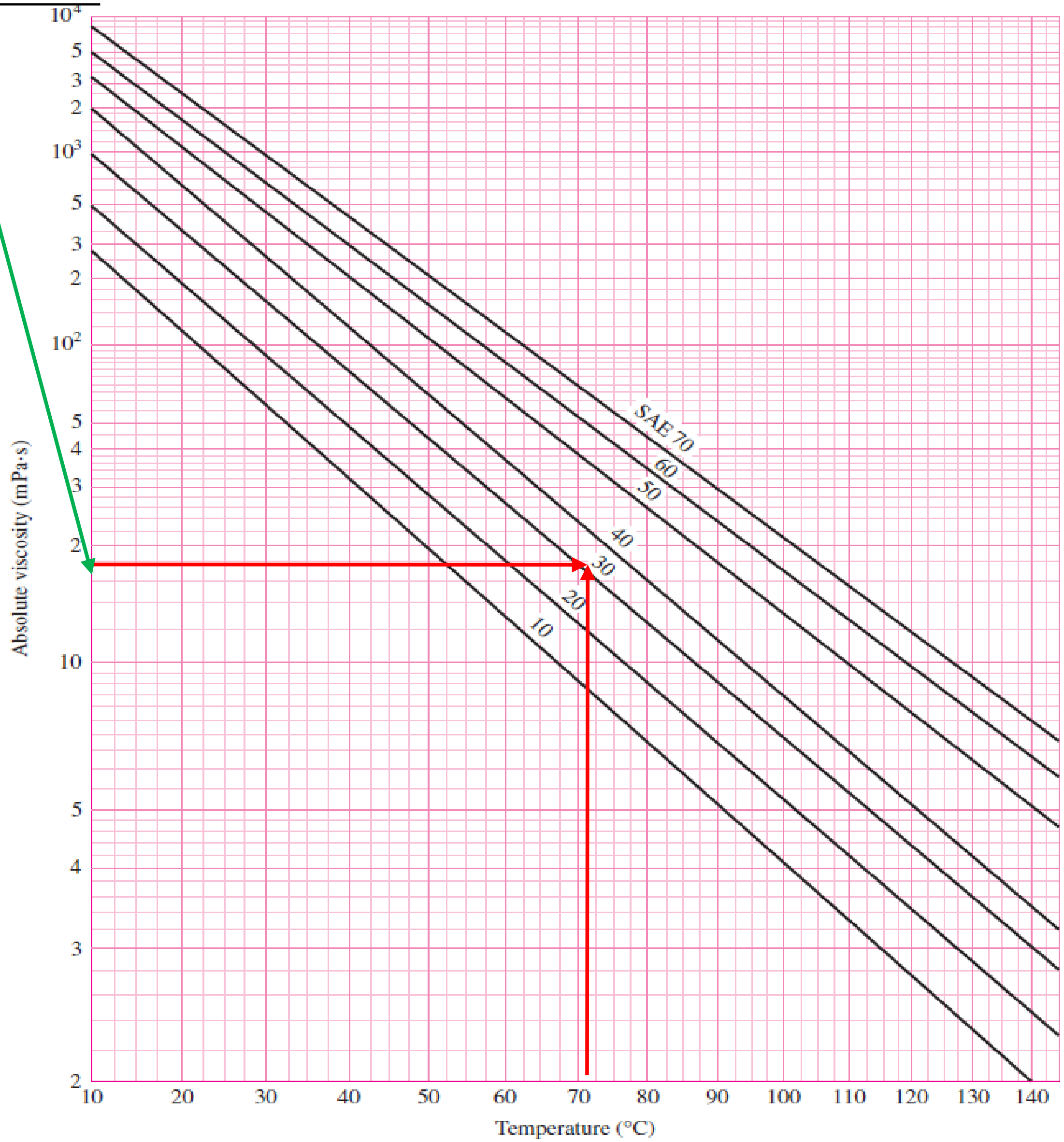
$$\frac{h_0}{c} = 0.21$$



$$\mu = 0.016\ Pa - \sec = \underline{\underline{16\ mPa - \sec}}$$

For operating temperature of 71 °C (T_{ave}=71).

<u>SAE 30 is the suitable oil to be used</u>.



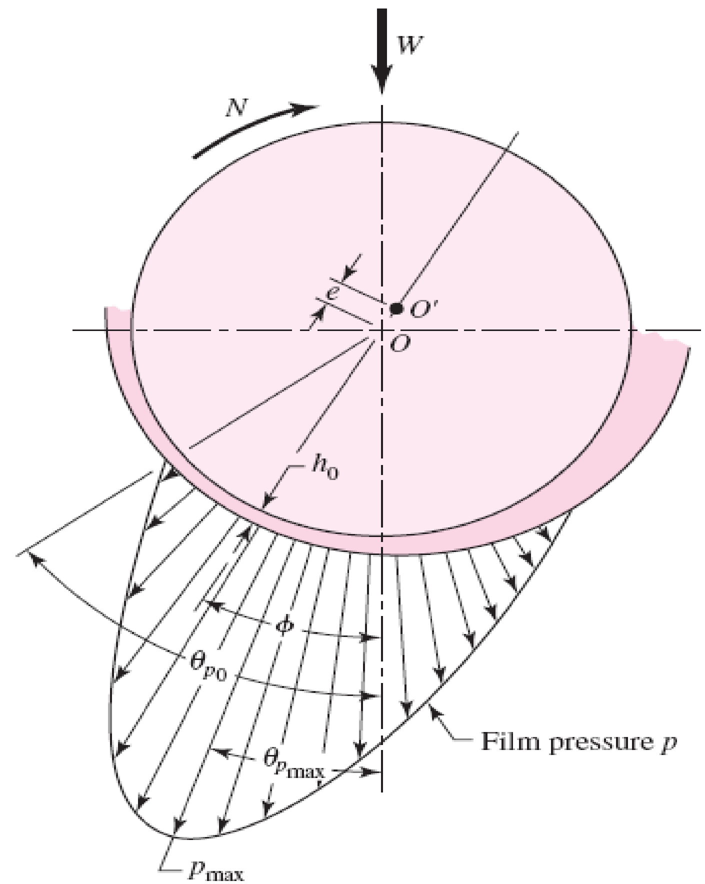
c)

$$\Delta T_{o_C} = \frac{8.30 \times P}{\left[1 - \frac{1}{2} \times \frac{Q_s}{Q}\right]} \times \frac{\frac{r}{c} f}{\frac{Q}{rcNl}} = \frac{8.30 \times 0.6}{1 - \frac{1}{2} \times 0.87} \times \frac{3.535}{5.4} = 5.77 \quad {}^oC$$

$$\theta_{P_{\max}} = 16.5^o \qquad \frac{P}{P_{\max}} = 0.27$$

$$P_{\max} = \frac{0.6}{0.27} = 2.22 \;\; MPa$$

$$\Delta T = T_{\text{var}} \frac{P}{\gamma C_H} = 14 \times \frac{0.6 \times 10^6}{861 \times 1760} \cong 5.5 \;\; {}^oC$$



$$\frac{Q}{rcNl} = 5.4 \quad (p541)(p445)$$

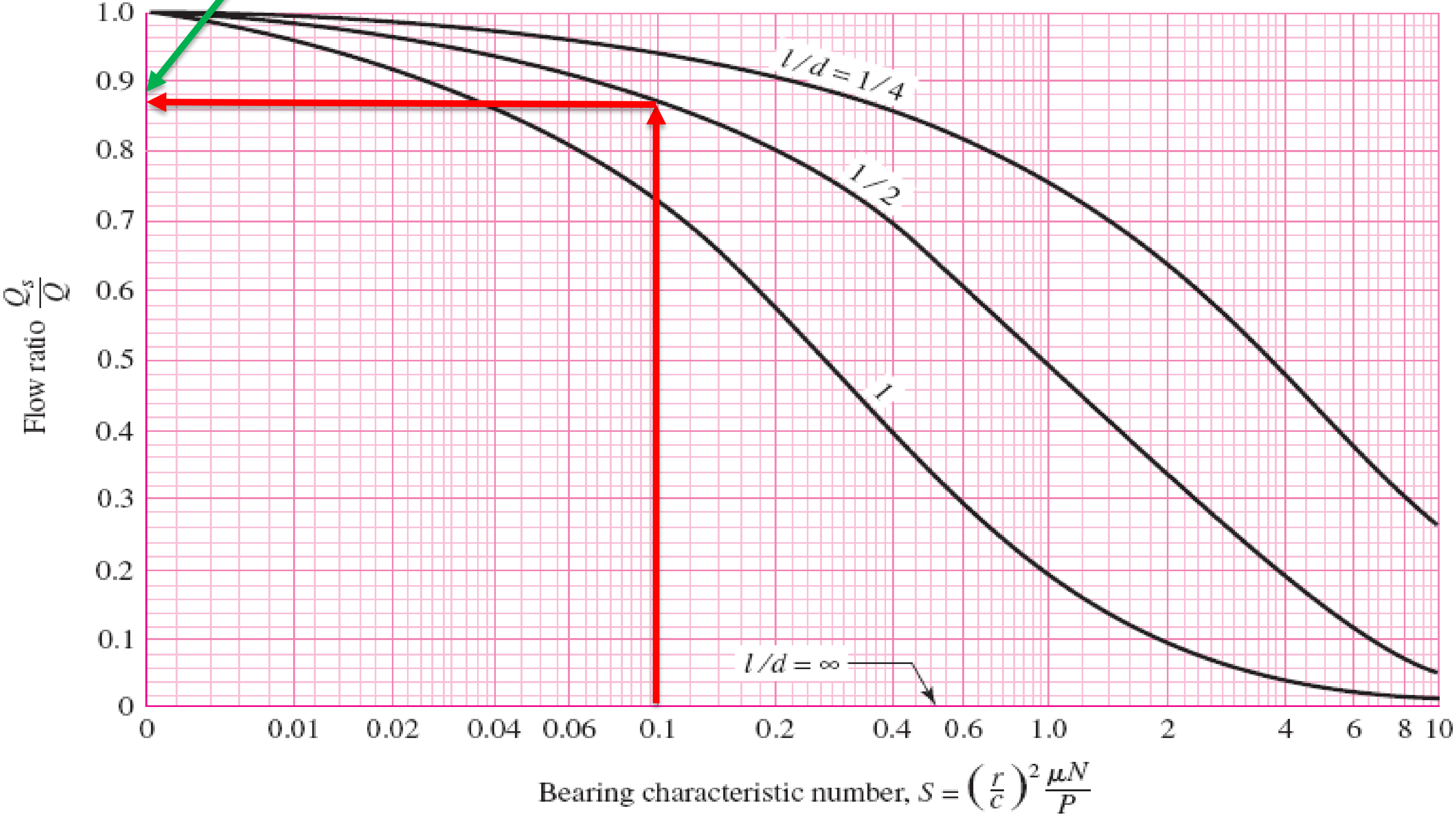
$$For \;\; S = 0.1$$

$$\frac{l}{d} = \frac{1}{2}$$

$$\frac{Q_s}{Q} = 0.87 \quad (p542)(p446)$$

$$For \;\; S = 0.1$$

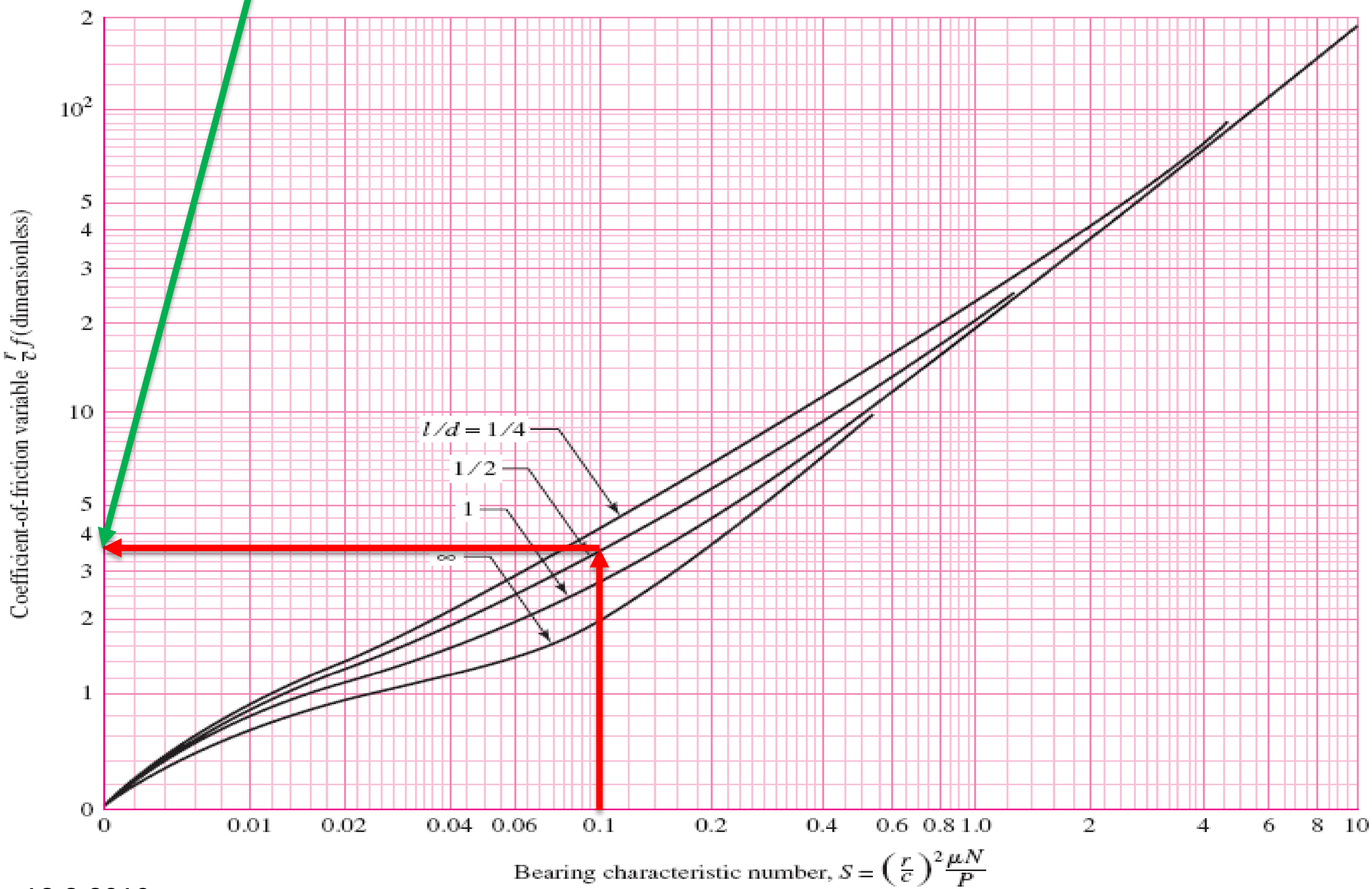
$$\frac{l}{d} = \frac{1}{2}$$



$$\left(\frac{r}{c}\right)f = 3.535 \quad (p540)(p444)$$

$$For \;\; S = 0.1$$

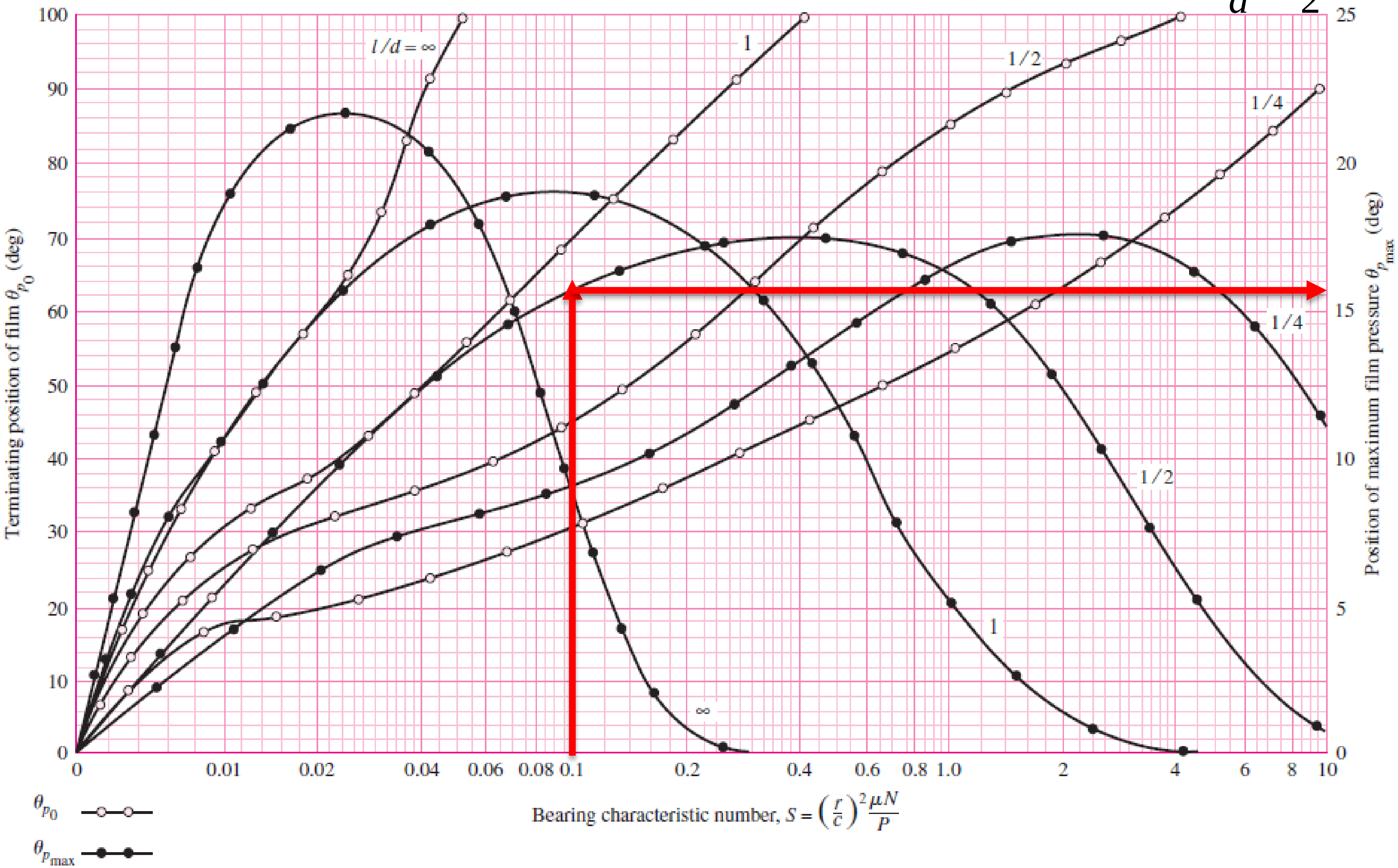
$$\frac{l}{d} = \frac{1}{2}$$



$$\theta_{P_{max}} = 16.5^o$$

$$For \ \ S = 0.1$$

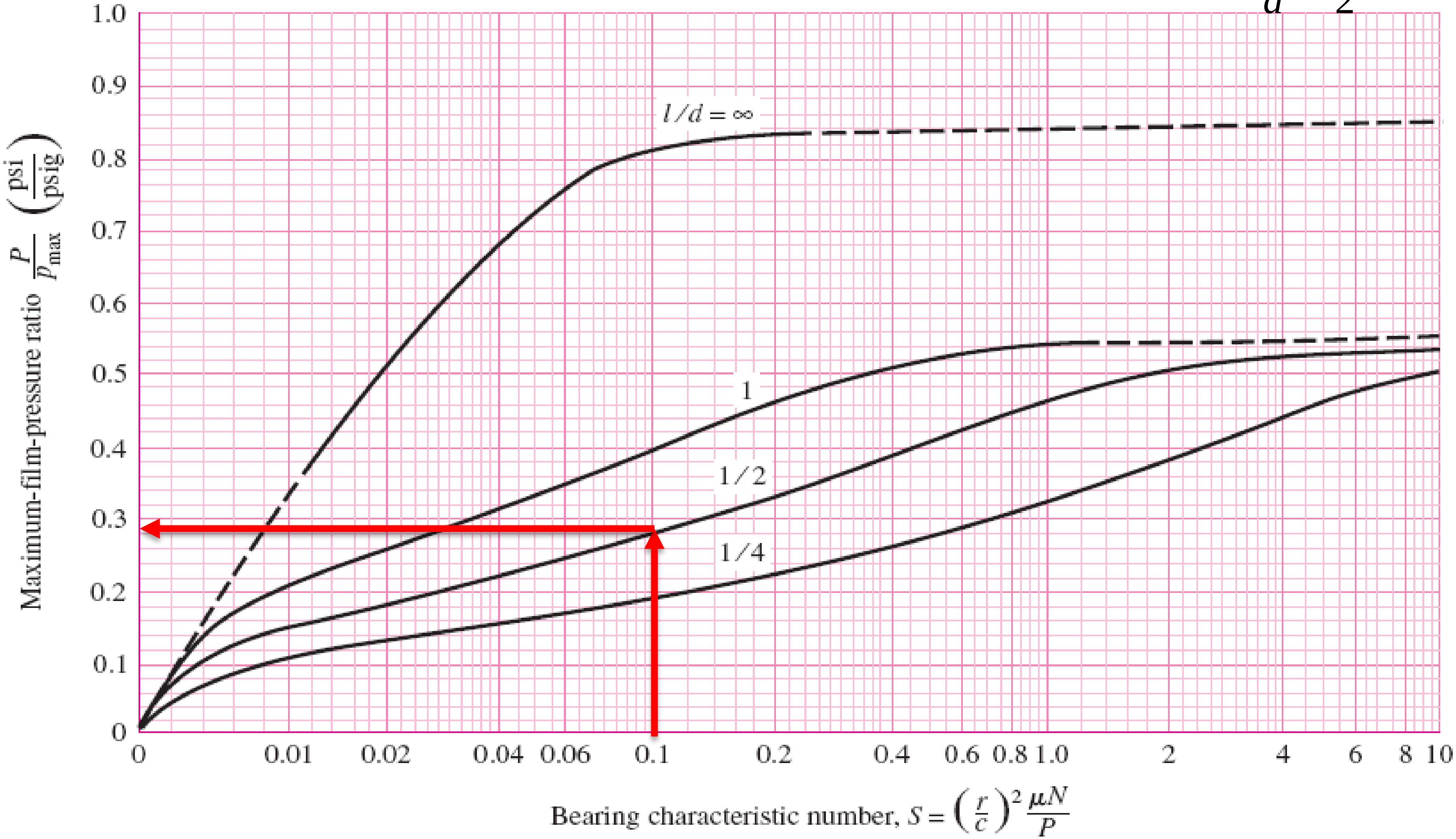
$$\frac{l}{d} = \frac{1}{2}$$



$$\frac{P}{P_{\max}} = 0.27$$

$$For \quad S = 0.1$$

$$\frac{l}{d} = \frac{1}{2}$$



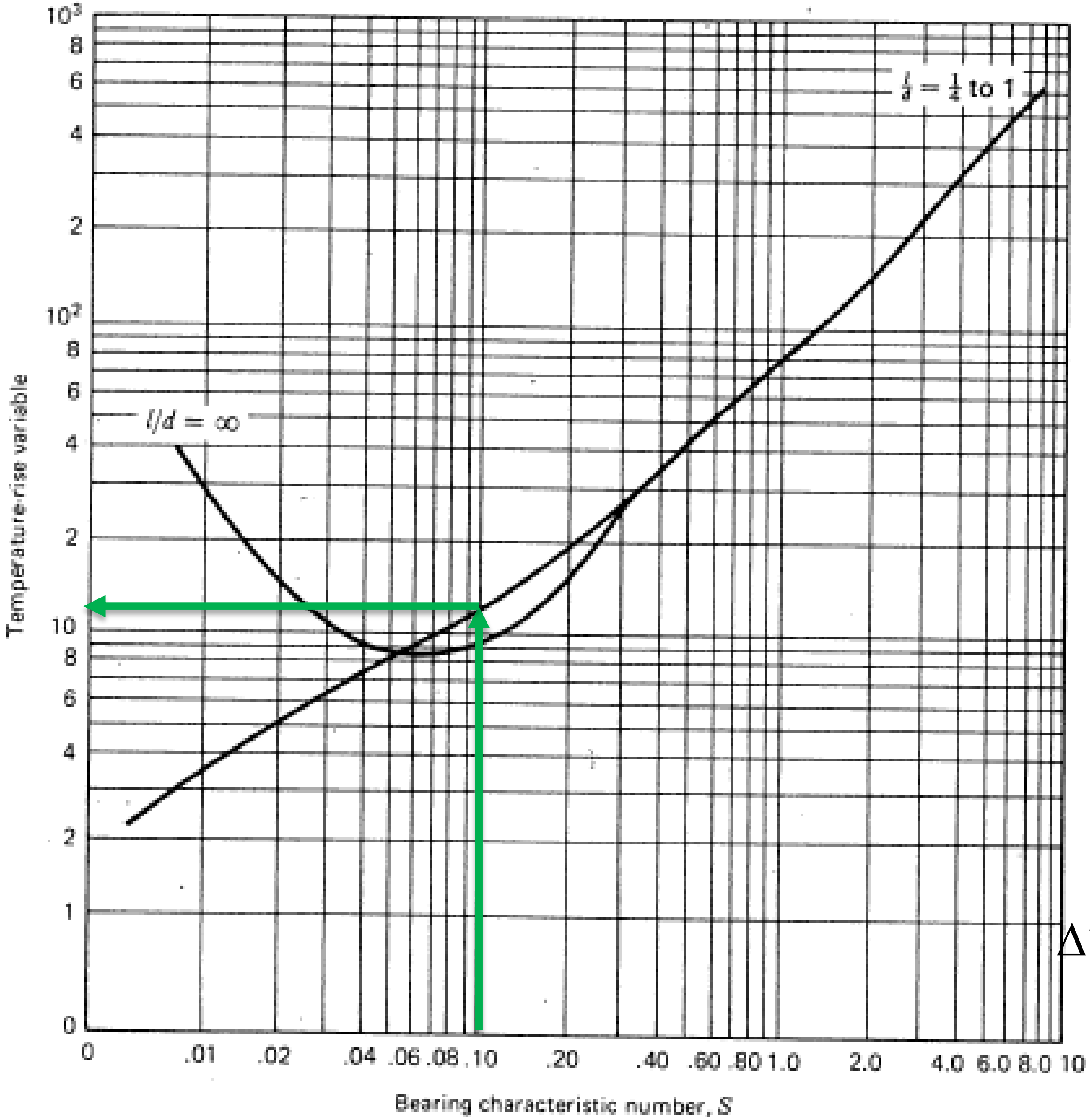


FIGURE 12-12 Chart for temperature-rise variable $T(\text{var}) = \gamma C_H \Delta T/P$. In plotting this chart it was found that the curves for $l/d = \frac{1}{4}, \frac{1}{2}$, and 1 were so close together that they could not be distinguished from a single curve.

Based on eqn.

$$\Delta T_{o_C} = T_{\text{var}} \frac{P}{\gamma \times C_H}$$

S= 0.1, l/d=1/2

T_{var} =14

P= 0.6 MPa

861kg/m3

1760J/kg-C

$$\Delta T_{o_C} = 14 \times \frac{0.6 \times 10^6}{861 \times 1760} = 5.5\ {}^oC$$

EXAMPLE 4.6:

A journal which is **turned steel** and operates in **bored and reamed cast bronze** bearing has a diameter of 50 mm and a length of 25 mm.
The speed of journal is 1200 rpm. If SAE 20 oil of an inlet temperature of 45 ºC is used for optimum (minimum) power loss.
Determine:
a)The temperature rise of the oil
b)The maximum load that can be supported by this bearing.
c)Total oil flow and the side flow.
d)The coefficient of friction.
e)The maximum oil pressure and its angular location.
f)The terminating position of the oil film.
g) Minimum oil film thickness

Solution:

Turned journal
Bored and reamed cast bronze bearing
d=50 mm l=25 mm → l/d= 1/2
N= 1200 rpm = 20 rps
SAE 20 oil T_i =45 º C

a) From the graph for minimum power loss

For $\dfrac{l}{d}=\dfrac{1}{2}$

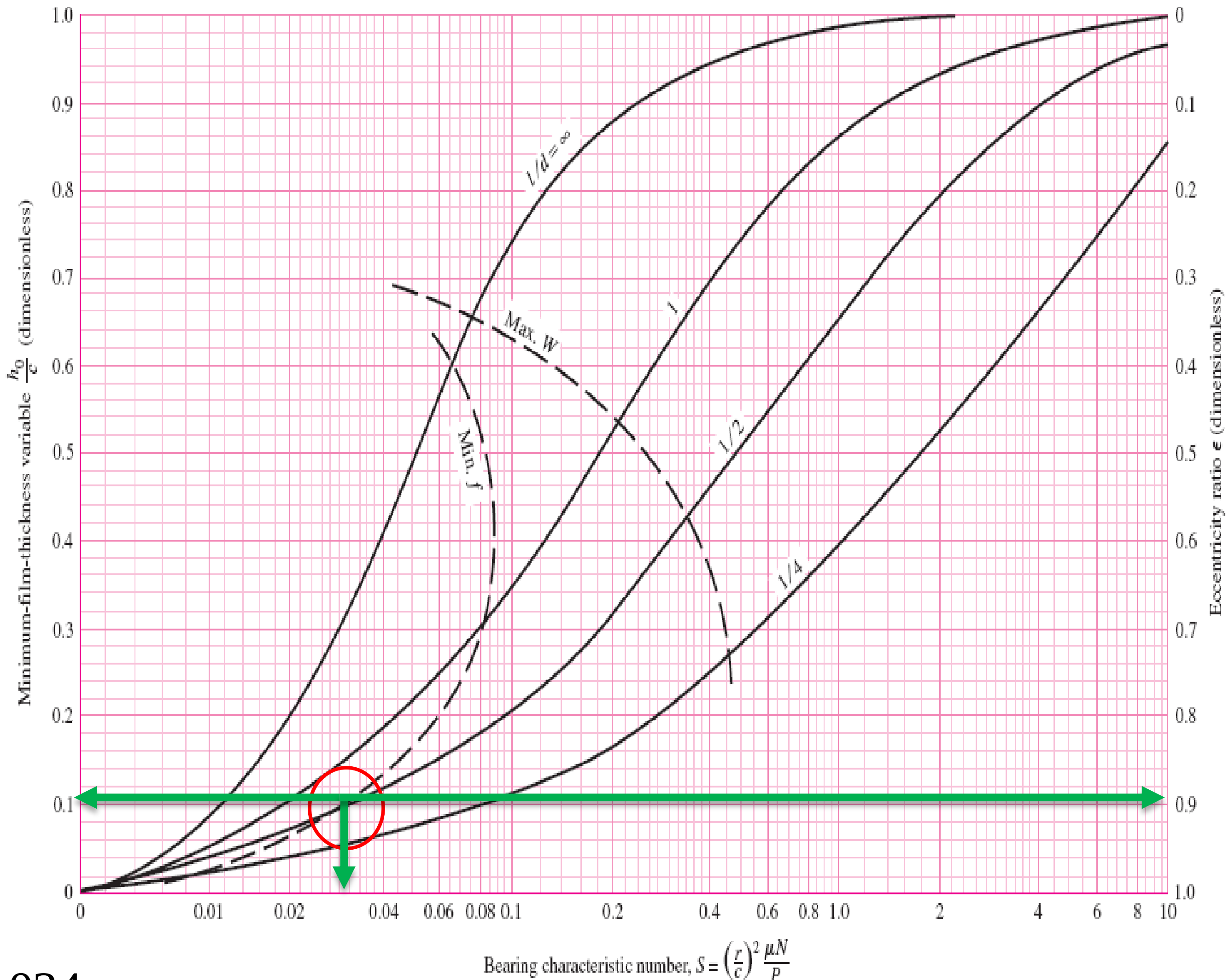
$$\frac{h_0}{c}=0.11 \quad \text{and} \quad S=0.034$$

$$\Delta T_{o_C}=\frac{8.30\times P}{\left[1-\frac{1}{2}\times\frac{Q_s}{Q}\right]}\times\frac{\frac{r}{c}f}{\frac{Q}{rcNl}} \qquad \text{or} \quad \Delta T=T_{\text{var}}\frac{P}{\gamma C_H}$$

For $S=0.034$

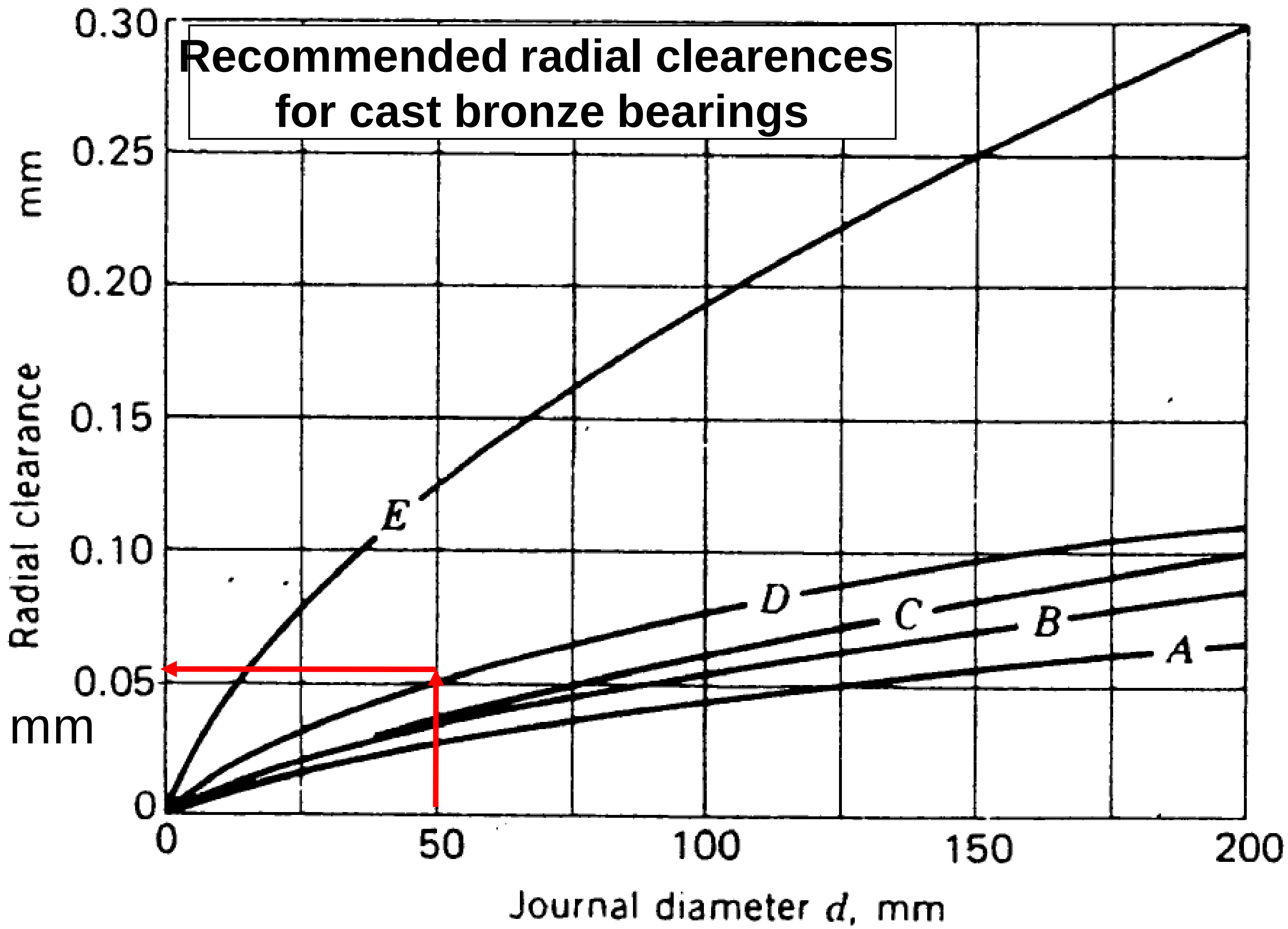
$$\frac{l}{d}=\frac{1}{2} \qquad \frac{r}{c}f=1.7 \quad \& \quad \frac{Q}{rcNl}=5.65 \quad \& \quad \frac{Q_s}{Q}=0.94$$

From the graph for minimum power loss



For $\dfrac{l}{d} = \dfrac{1}{2}$

$$\frac{h_0}{c} = 0.11 \quad \text{and} \quad S = 0.034$$


Recommended radial clearences
for cast bronze bearings
0.30
0.25
0.20
0.15
0.10
0.05
0
mm
Radial clearance
E
D
C
B
A
0
50
100
150
200
Journal diameter d, mm

C_{min} =0.05 mm

FIGURE 12-27. Recommended radial clearances for cast-bronze bearings. The curves are identified as follows:

A—precision spindles made of hardened ground steel, running on lapped cast-bronze bearings (0.2- to 0.8-μm rms finish), with a surface velocity less than 3 m/s

B—precision spindles made of hardened ground steel, running on lapped cast-bronze bearings (0.2- to 0.4-μm rms finish), with a surface velocity more than 3 m/s

C—electric motors, generators, and similar types of machinery using ground journals in broached or reamed cast-bronze bearings (0.4- to 0.8-μm rms finish)

D—general machinery which continuously rotates or reciprocates and uses turned or cold-rolled steel journals in bored and reamed cast-bronze bearings (0.8- to 1.6-μm rms finish)

E—rough-service machinery having turned or cold-rolled steel journals operating on cast-bronze bearings (1.6- to 3.2-μm rms finish)

Since ΔT depends on P ; $\Delta T = T_{\text{var}} \dfrac{P}{\gamma C_H}$

and also P depends on μ $P = \left(\dfrac{r}{c}\right)^2 \dfrac{\mu N}{S}$

and μ depends on ΔT $T_{ave} = T_{in} + \dfrac{\Delta T}{2}$

we will use trial & error method for ΔT ^{o}C

let ΔT =16 ^{o}C → $T_{ave} = 45 + \dfrac{16}{2} = 53 \ ^{o}C \rightarrow$

$$\mu = 24 \times 10^{-3} \ Pa - \sec \quad \text{for SEA 20 oil}$$

Then $$P = \left(\frac{50/2}{0.05}\right)^2 \frac{24 \times 10^{-3} \times 20}{0.034} = 3.525 \ MPa$$

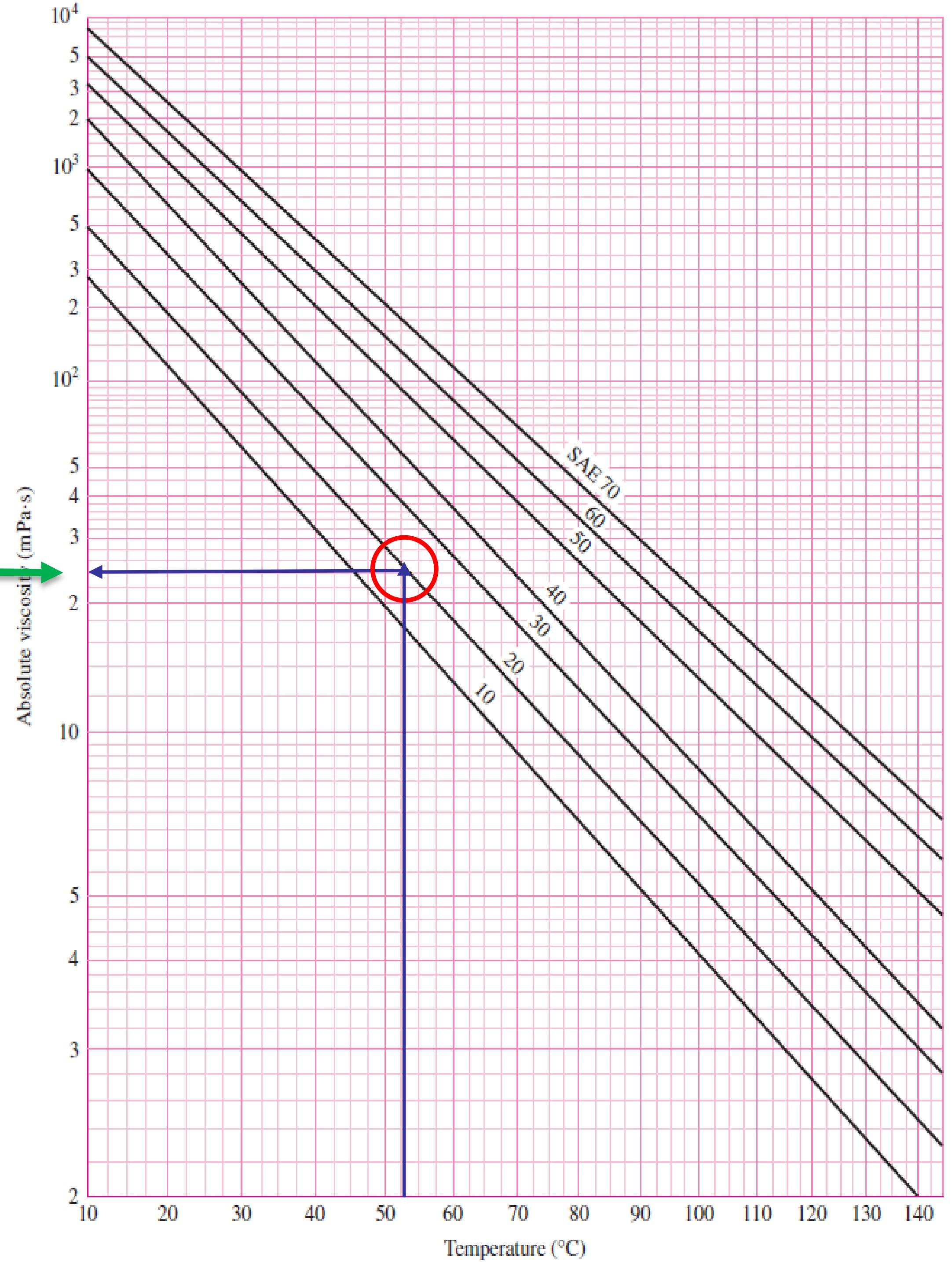
$$\Delta T_{^{o}C} = T_{\text{var}} \frac{P}{\gamma C_H} = 7 \times \frac{3.525 \times 10^6}{861 \times 1760} = 16.6 \ ^{o}C \cong \text{assumed } \ \Delta\text{T} \ \text{ OK}$$

Now from chart Fig. 12.12 pp. 534 (Fig. 12.10 pp. 435)

SAE 20 Oil

$$T_{ave} = 53\ ^{o}C$$

$$\rightarrow \mu = 24 \times 10^{-3}\, Pa - \sec$$



For $\dfrac{l}{d}=\dfrac{1}{2}$

$S = 0.034$ T_{var} =7 ^oC.

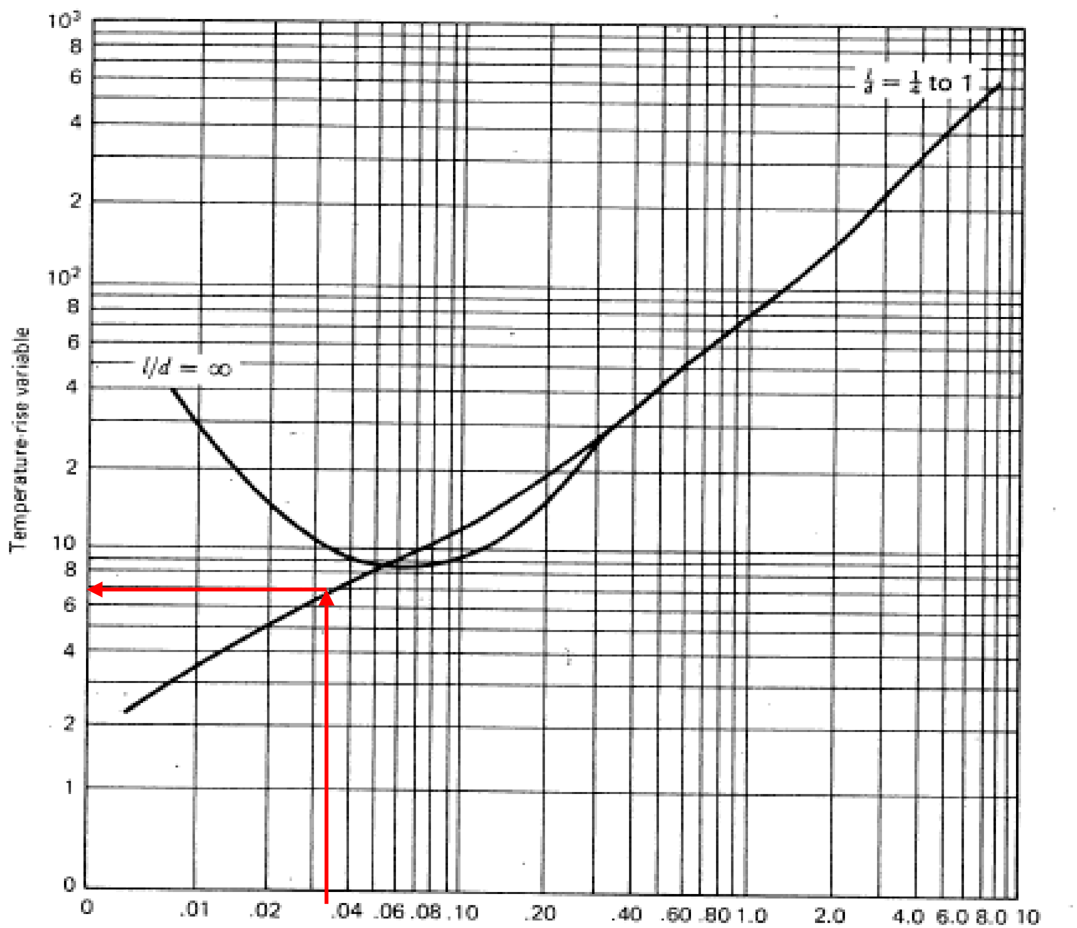
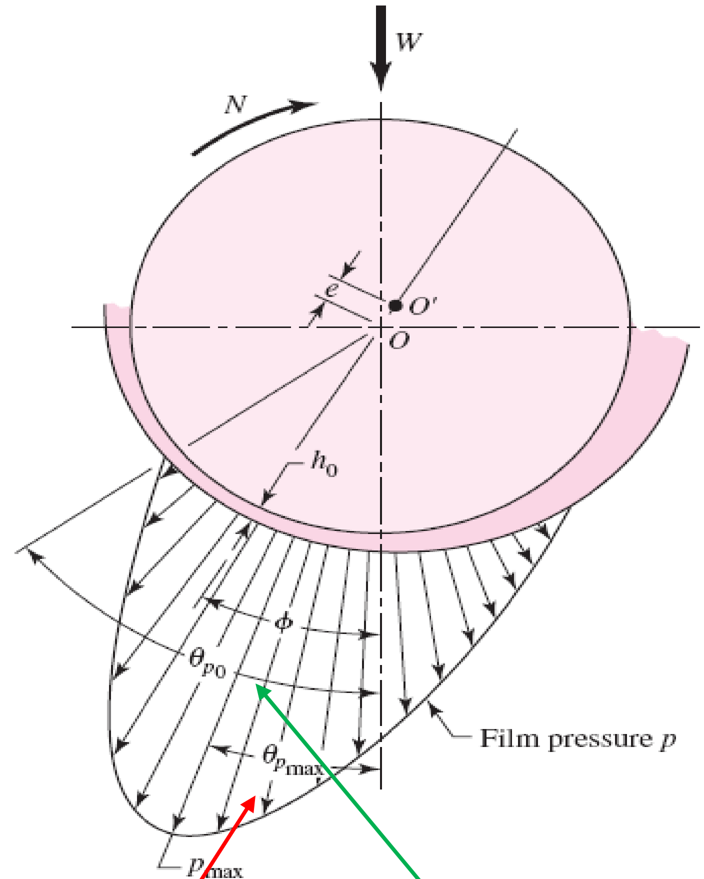


FIGURE 12-12 Chart for temperature-rise variable $T(\text{var}) = \gamma C_H \Delta T/P$. In plotting this chart it was found that the curves for $l/d = \frac{1}{4}$, $\frac{1}{2}$, and 1 were so close together that they could not be distinguished from a single curve.



$\theta_{P_{\max}} \cong 12^o$

$\theta_{P_0} \cong 34^o$

b) $W = ?, = P \times (l \times d) = 3.525 \times 10^6 \times (0.025 \times 0.05)$

$W = 4406 \ N$

c) Q=?
Qs=?

For $S = 0.034$

$\frac{l}{d} = \frac{1}{2}$

$$\frac{Q}{rcNl} = 5.65 \rightarrow Q = 5.65 \times 25 \times 0.05 \times 20 \times 50 = 3528 \ mm^3/\sec$$

$$\frac{Q_s}{Q} = 0.94 \quad \rightarrow Q_s = 0.94 \times 3528 = 3317 \ mm^3/\sec$$

d) $\frac{r}{c} f = 1.7 \quad \rightarrow \quad f = 1.7 \frac{0.05}{25} = 0.0034$

e) $\frac{P}{P_{\max}} = 0.2 \quad \rightarrow P_{\max} = \frac{P}{0.2} = \frac{3.528}{0.2} = 17.64 \ MPa$ $\qquad \theta_{P_{\max}} \cong 12^o$

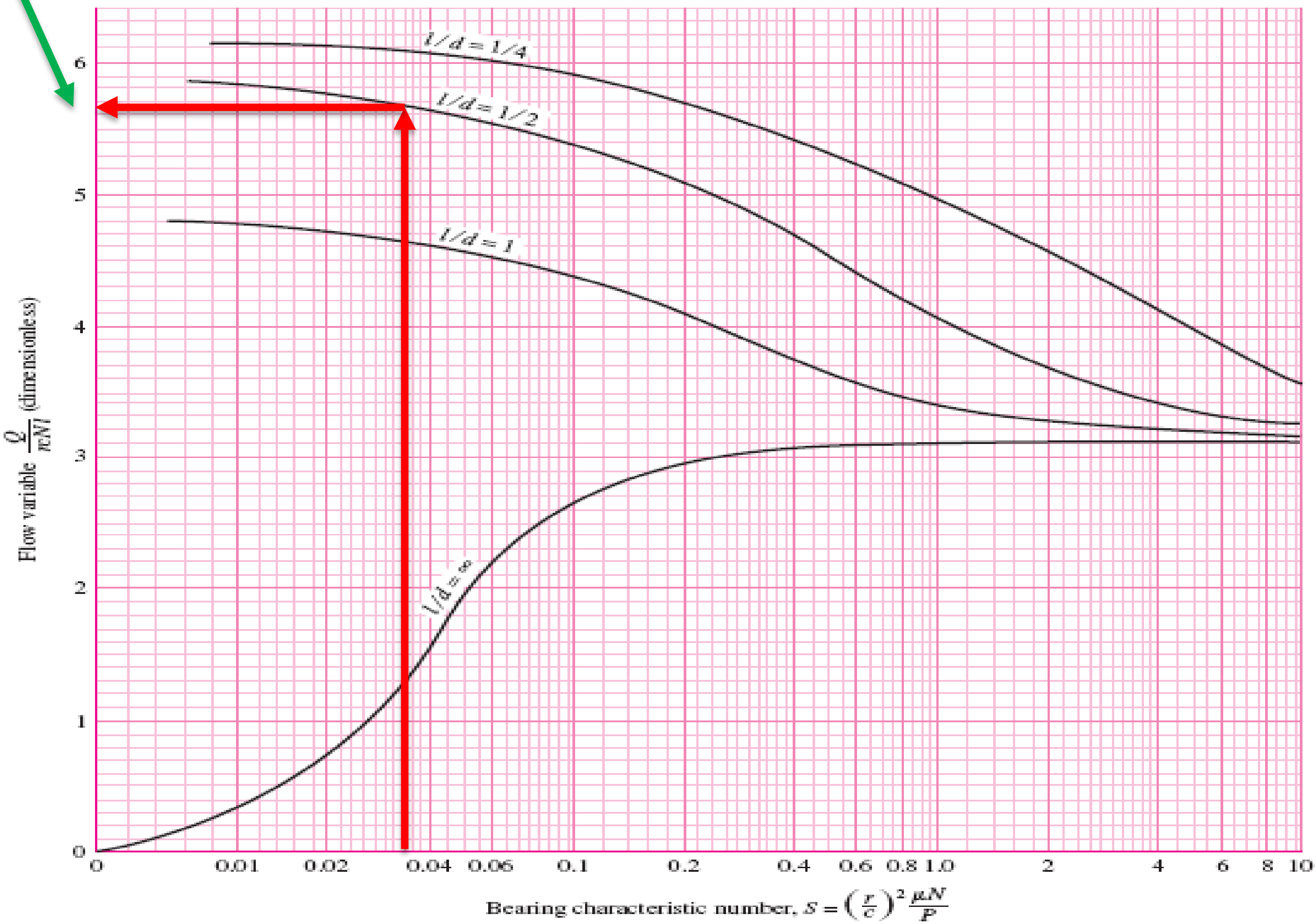
f) $\theta_{P_0} \cong 34^o$

g) $h_0 = ? \quad \frac{h_0}{c} = 0.11 \rightarrow h_0 = 0.11 \times 0.05 = 0.0055 \ mm$ $\qquad \underline{\underline{h_0 = 5.5 \ \mu m}}$

$$\frac{Q}{rcNl} = 5.65 \quad (p541)(p445)$$

$$For \;\; S = 0.034$$

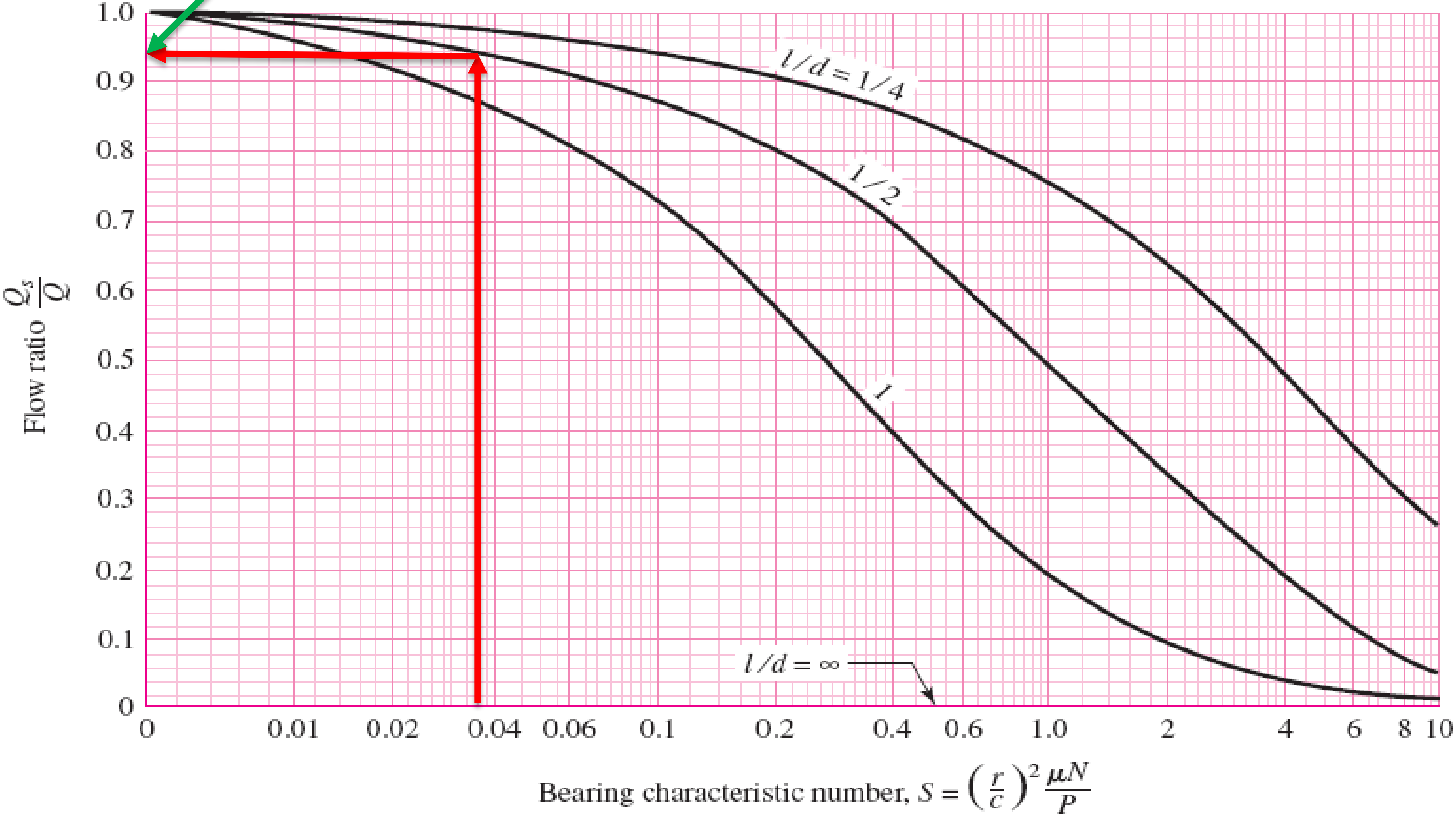
$$\frac{l}{d} = \frac{1}{2}$$



$$\frac{Q_s}{Q} = 0.94 \quad (p542)(p446)$$

$$For \;\; S = 0.034$$

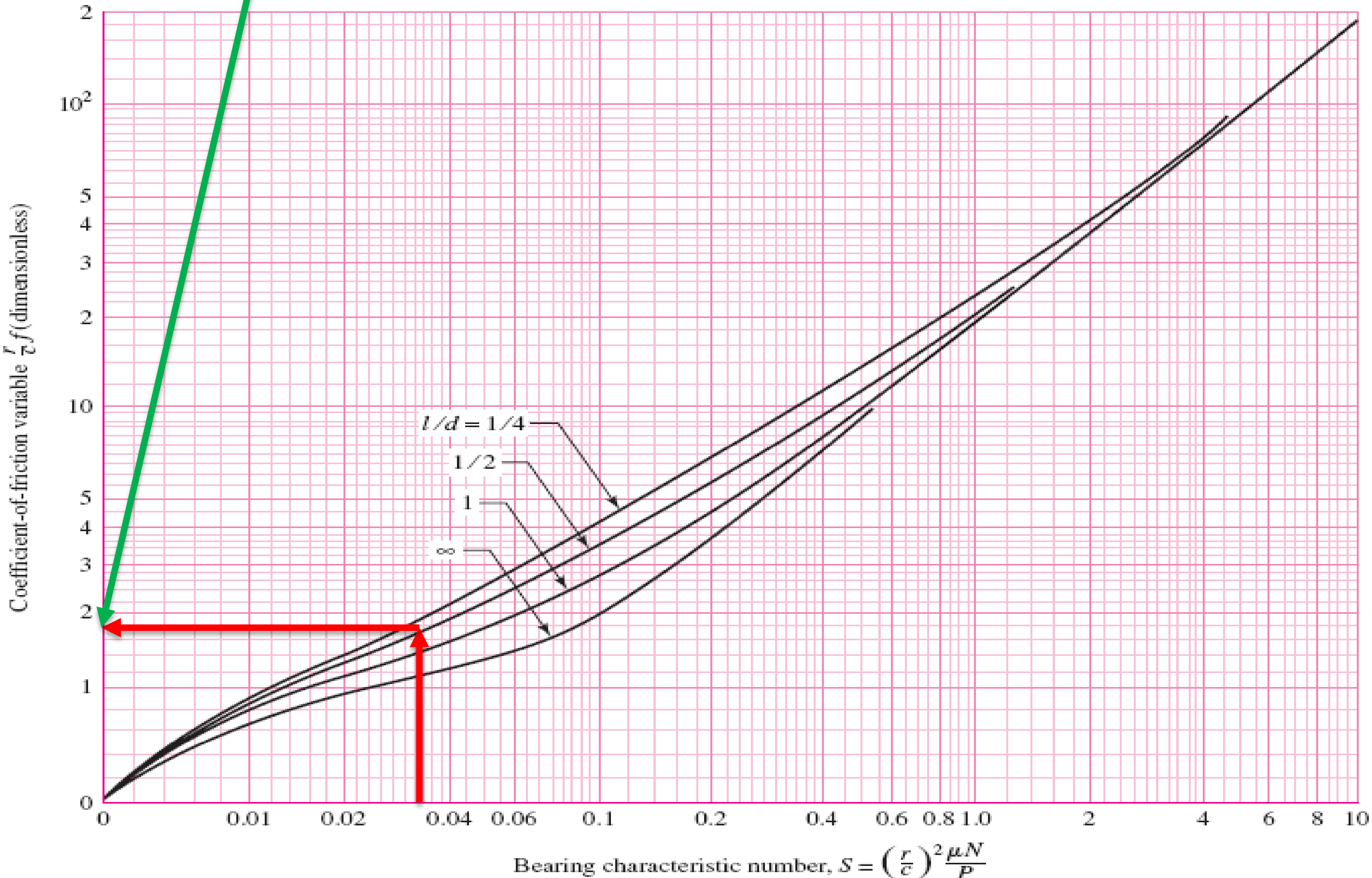
$$\frac{l}{d} = \frac{1}{2}$$



$$\left(\frac{r}{c}\right)f = 1.7 \quad (p540)(p444)$$

$$For \;\; S = 0.034$$

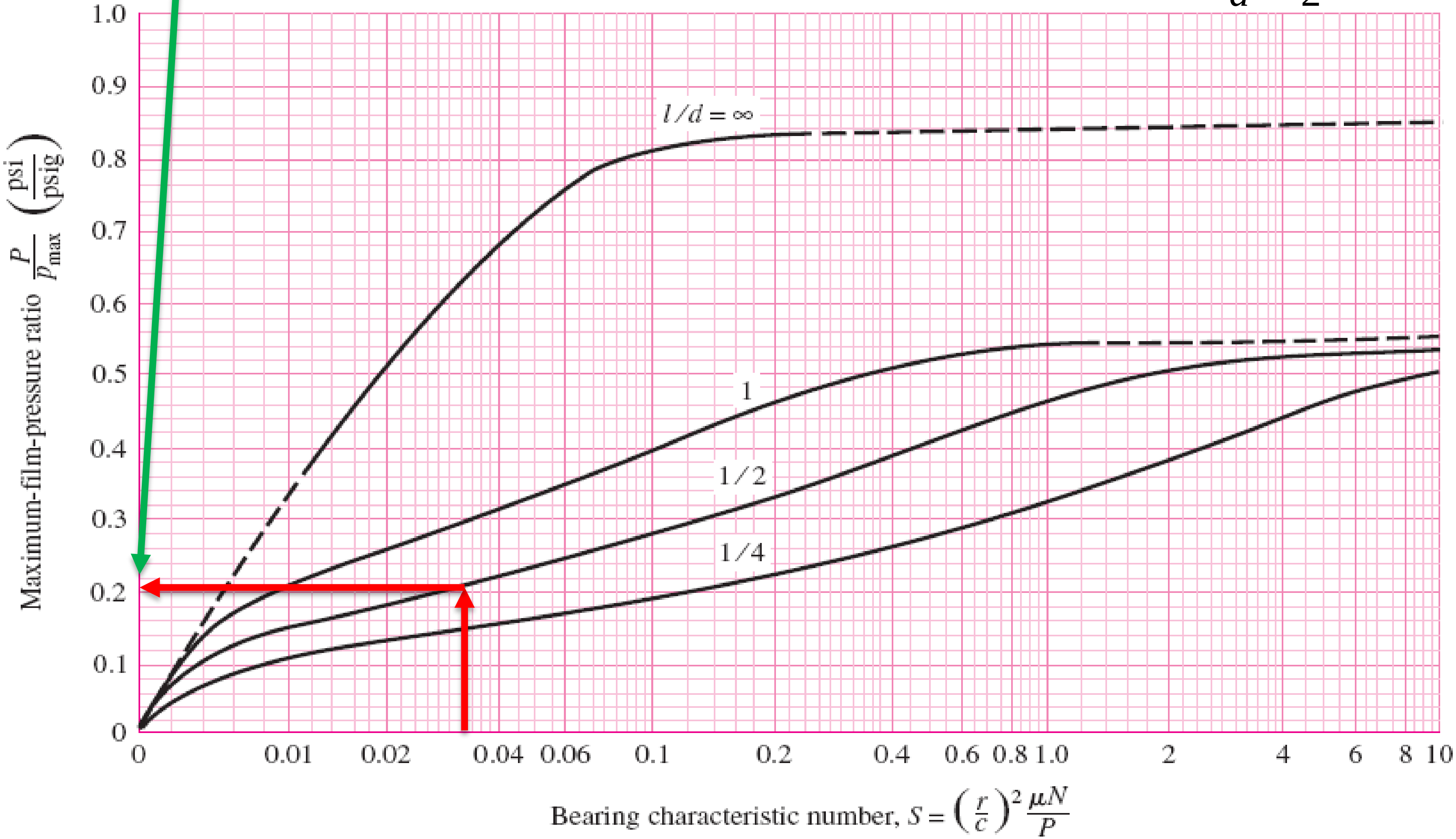
$$\frac{l}{d} = \frac{1}{2}$$



$$\frac{P}{P_{\max}} = 0.2$$

For $S = 0.034$

$$\frac{l}{d} = \frac{1}{2}$$

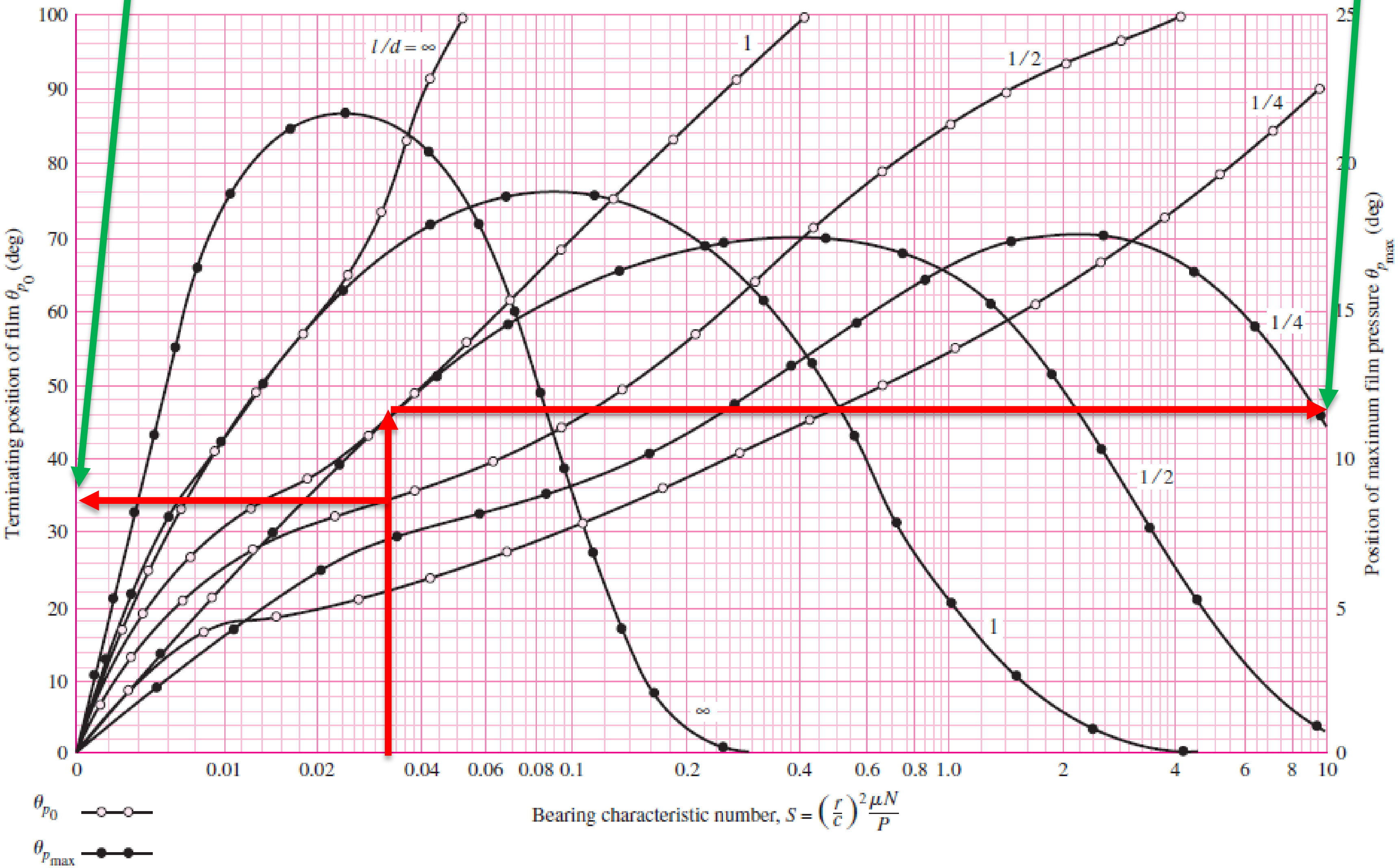


For $S = 0.034$

$$\frac{l}{d} = \frac{1}{2}$$

$\theta_{P_0} \cong 34^o$

$\theta_{P_{\max}} \cong 12^o$



For $S = 0.034$

$$\frac{l}{d} = \frac{1}{2}$$

$$\frac{h_0}{c} = 0.11$$