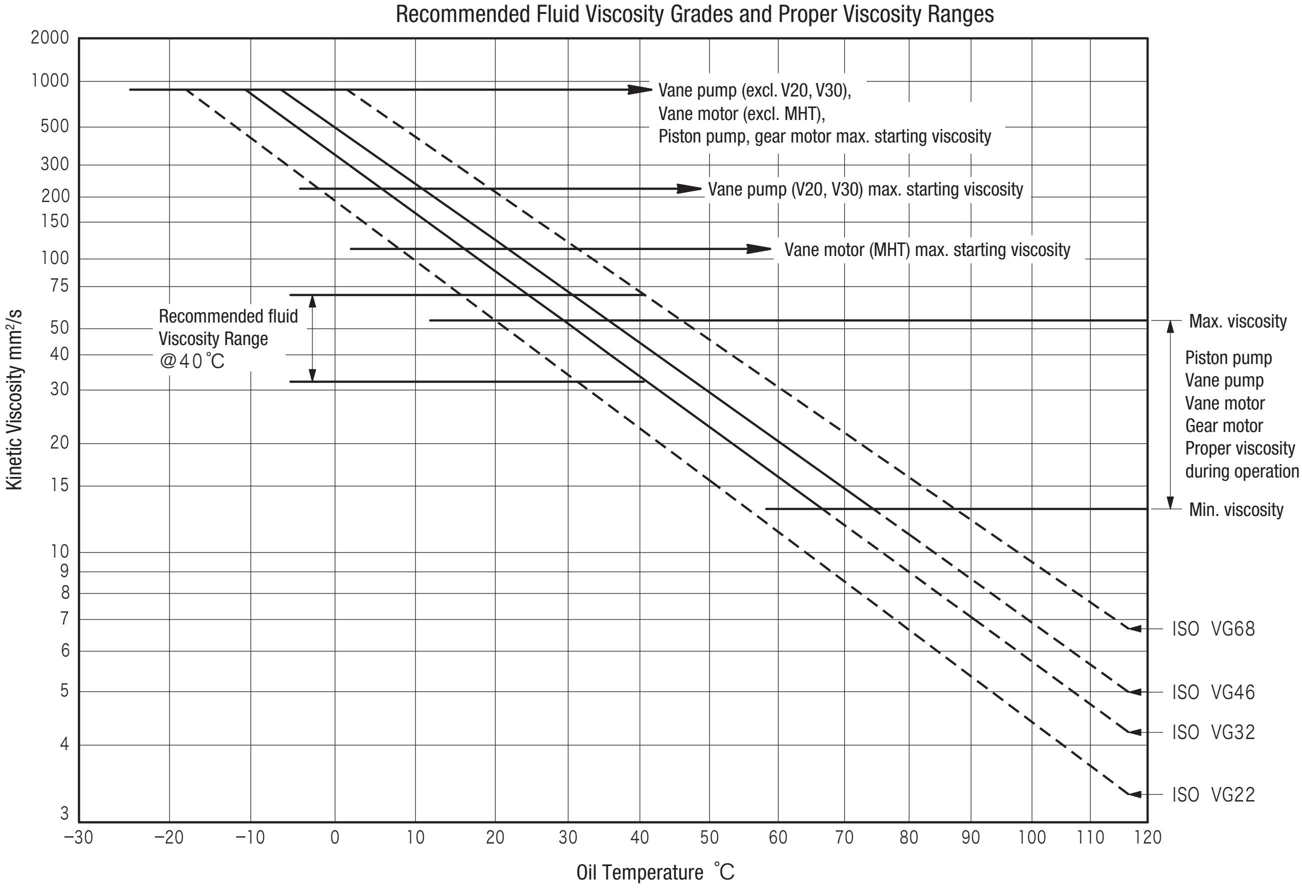
Technical Information

Contents

Recommended Fluid Viscosity Grades and Proper Viscosity Ranges



Hydraulic fluid

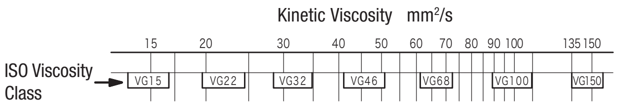
Fluid in hydraulic systems performs the dual function of lubrication and transmission of power. Careful selection of hydraulic fluid should be made with the assistance of a reputable supplier. Proper selection of oil assures satisfactory life and operation of system components with particular emphasis on hydraulic pumps and motors. Almost any fluid selected for use with pumps or motors is acceptable for use with valves. However care should be paid regarding such use as water glycol fluid may not be used with certain control valves.

Hydraulic Fluid Viscosity

Viscosity is the measure of resistance to flow and is an important factor which determines performance of the hydraulic system. It is important to maintain a proper viscosity range to ensure adequate sealing of friction surfaces, lubricity, erosion, and to cope with noise and vibration of hydraulic components due to cavitation. Refer to the table below and select fluid which meets requirements of the system including the pump and motor.

Hydraulic Equipment	Viscosity Class	Viscosity Range mm²/s	
		During Operation	During Startup (Max.)
Vane pump (V20, V30)	VG32-68	13～54	220
Piston pump Vane pump (excl. V20, V30) Vane motor (excl. MHT) Gear motor			860
Vane motor (MHT)			110

● Viscosity range at 40ºC for each viscosity class is shown below.



● SAE10 equivalent fluid is companion to VG32 and VG46 and SAE20-20W is nearly equivalent to VG68.
● The following tables shows the relationship of temperature and viscosity range for each of the above VG classes.

Viscosity Class	Standard Viscosity mm²/s @40 ˚C	Standard Viscosity Fluid Temp. Limits ºC			
		During Operation	During Startup (Min. Temp.)		
		54 mm²/s～ 13 mm²/s	860 mm²/s	220 mm²/s	110 mm²/s
VG32	32	27～62	-12	6	14
VG46	46	34～71	- 6	12	22
VG68	68	42～81	0	19	29

● Refer to recommended oil viscosity grade and proper viscosity range graph on previous page.
● Consult Tokyo Keiki for mobile applications.

Properties of Hydraulic Fluids

Fluid properties or satisfactory operation of hydraulic equipment are as follows.
● Good lubricity and anti-wear properties
● Suitable viscosity in the working temperature range with little change at high and low temperature.
● Stability in oxidation and shearing.
● Rust inhibiting
● Should not react with metals, elastomers, and paints used in hydraulic equipment, piping, and fittings.
● Good antifoaming characteristics.
● Good separation and demulsification characteristics when water, etc., present.

Hydraulic Fluid Types

Hydraulic fluid categories are as follows.

- Hydraulic fluid
  - Mineral oil based fluid
    - Anti-wear type fluids
  - Synthetic fluids (Fire resistant fluids)
    - Phosphate ester fluids
    - Fatty acid ester fluids
  - Water containing fluids (Fire resistant fluids)
    - Water glycol fluids
    - Water-in oil fluids (W/O emulsions)
    - Oil-in water fluids (O/W emulsions)

Hydraulic Fluid and General Characteristics

Property \ Type	Mineral Oil Based	Phosphate Ester	Fatty Acid Ester	Water-Glycol Based	W/O Emulsion	O/W Emulsion
Spec. Gravity (15/4˚C)	0.87	1.1 to 1.3	0.90	1.04 to 1.1	0.93	1.0
Viscosity	Small to very large	Small to large	Medium	Small to large	Small	Small
Viscosity Index (VI)	70 to 150	Low to high 30 to 180	High	High 140 to 170	High 130 to 170	Very high
Evaporation pressure	Small	Small	Small	Large	Large	large
Mineral Oil Mixture	—	3%	Possible	3%	Possible	Not possible

Mineral Oil Based Fluid

The following type of mineral oil fluid is recommended.
● Anti-wear fluids
Anti-wear fluids include additives which improve wear resistance. Such fluids generally have been tested to ASTM-D2882 standards.

Fire Resistant Fluids

Fire resistant fluids such as synthetics and fluids containing water are used when hydraulic equipment operate in locations which may be a fire hazard. Compared with mineral oil fluids however there are some drawbacks as follows.
● Poorer lubricity in many cases
● Greater incompatibility with metals and elastomers
● Greater chances of sludge formation, separation, and change in properties due to the mixture of substances
● Greater chances of cavitation due to water of water containing fluids boiling and electrolysis-caused corrosion

1. Lubricity
The following table which is based on experience, provides a reference regarding the degree to which fire resistant fluids compare with mineral oil based fluids (with mineral oil: 1) in terms of life.

Phosphate ester	Fatty Acid Ester	Water-glycol based	w/o Emulsion	o/w Emulsion
0. 75～1	0. 75～1	0. 5～0. 7	0. 7～0. 8	0. 4～0. 6

2. Material Compatibility
The following table outlines fluid compatibility with seal materials, metals, and paints.

Material \ Type		Phosphate Ester	Fatty Acid Ester	Water-Glycol Based	W/O Emulsion	O/W Emulsion
Seal Material	Compatible	Fluorocarbon rubber Silicone rubber Butyl rubber Ethylene propylene rubber Fluoro-resin Leather	Nitrile rubber Fluorocarbon rubber Silicone rubber Ethylene propylene rubber Urethane rubber Fluoro-resin Chloroprene Leather	Nitrile rubber Fluorocarbon rubber Butyl rubber Ethylene propylene rubber Fluoro-resin Chloroprene	Nitrile rubber Fluorocarbon rubber Fluoro-resin Chloroprene	
Seal Material	Non-Compatible	Nitrile rubber Urethane rubber Chloroprene	Butyl rubber	Silicone rubber Urethane rubber Leather	Silicone rubber Butyl rubber Ethylene propylene rubber Urethane rubber Leather	
Non-Compatible Metal		Aluminum		Zinc Cadmium Aluminum Magnesium	Zinc Cadmium Copper	Aluminum
Paint		Consider no paint, or consult paint manufacturer and use compatible epoxy-based or urethane-based resin paints.				

3. Working Temperature Limits
For longer life of fire resistant fluids, such fluids should generally be used within the temperatures shown in the table.
Water containing fluids especially, should be selected according to oil manufacturer recommendations, with operating temperatures controlled and properties periodically checked.

Type	Phosphate Ester	Fatty Acid Ester	Water-Glycol Based	W/O Emulsion	O/W Emulsion
Operating Limit Low-High Temp ℃	-20〜100	-5〜100	-30〜50	0〜50	0〜50

4. Maintenance of Fire Resistant Fluids
Fire resistant fluid properties differ from those of mineral oil fluids. When using fire resistant fluids, it is recommended that the user consult fluid manufacturer and conduct periodic fluid checks. The following are some general checkpoints.

- When selecting fluid, confirm their compatibility with tanks, piping, and filter materials and with internal paints and coatings.
- Fluids have greater specific gravity compared to mineral oils and care should be paid because of increased resistance to pump suction and flow.
- Beware of clogging of filters as properties of the fluids make them prone to sludge formation.
- Thoroughly flush system when replacing with new fluids or when changing from mineral oil based fluids to fire resistant fluids and insure that they do not mix.
- Antifoaming characteristics are poor compared to mineral oil fluids and oil tanks should be of larger capacity. Circuit should also be designed so that air bubbles are not drawn into the pump.
- In the case of synthetic fluids, caution should be paid regarding metal corrosion from water mixtures due to condensation of water vapor on tank walls, water leakage from cooler, etc.
- With water containing fluids, care should be paid to fluid temperature during operation. The fluid water ratio should be checked periodically and water replenished when necessary to compensate for evaporation. Care should also be paid as repeated freezing and melting of stored fluid may cause fluid separation.

Fluid Replacement

To ensure long term functioning of hydraulic systems, it is necessary to always monitor fluid quality and cleanliness. Fluid manufacturer should be requested to periodically check and analyze fluid and results should be recorded. Fluid replacement is recommended when fluids exceed the limits in the following table.

● Replacement criteria based on fluid properties

Checkpoints	Replacement Limits
Change in viscosity (@40℃)	±10%
Neutralization value mg KOH/g	1.0 (anti-wear fluid)
Precipitate (% weight)	0.1
Water (% weight)	0.05
Difference between normal nonsoluble pentane and nonsolubale benzene (% weight)	0.02
Level of cleanliness	Refer to the table below.

* Milky fluid indicates presence of large quantity of water and fluid should be replaced immediately.

● Recommended cleanliness level and filtration

ISO Code Recommended Cleanliness Level	Hydraulic System	Recommended Filtration (absolute) μm
20/18/15	General hydraulic systems operating at 15 MPa and below	25
19/17/14	General industrial and mobile machinery hydraulic systems operating at 15 to 25 MPa	10〜25
17/15/13	High pressure systems operating at 25 MPa and above	5〜10
16/14/11	High pressure or high reliability systems, including servo valves, for aircraft, precision machine tools, etc.	Less than 5

* ISO 4406 is the relevant ISO code for cleanliness level which defines contamination level of hydraulic fluid according to particle size and number in it.
The values for cleanliness level in the above table is the contamination level when an automatic particle counter is used.
Level "20/18/15" signifies level 20 for the number of contaminant particles of a size greater than 4 μm (C), level 18 for the number of contaminant particles of a size greater than 6 μm (C), and level 15 for the number of contaminant particles of a size greater than 14 μm (C).

The cleanliness level code in the above table is classified according to the number of contaminant particles found in 1 mL of fluid and is categorized in the following table.

Cleanliness Level	No. of Particles (max. no. in 1 mL)
20	10, 000
19	5, 000
18	2, 500
17	1, 300
16	640
15	320
14	160
13	80
11	20

Selection of oil flow velocity and pipe sizes in a hydraulic system

Category			Pump Suction Pipe					Return Pipe		Pressure Pipe										Maximum Working Pressure					
Nominal Diameter			JIS G3454 Carbon Steel Pipe for Pressure Piping STPG370 Schedule 40							JIS G3454 Carbon Steel Pipe for Pressure Piping STPG370 Schedule 80					JIS G3455 Carbon Steel Pipe for High Pressure Piping STS370 Schedule 160					7 MPa		14 MPa		21 MPa	
A	B	Outer Diameter mm	Thickness mm	Inner Diameter mm	Pipe Area cm^2	Flow Velocity m/s	Flow L/min	Flow Velocity m/s	Flow L/min	Thickness mm	Inner Diameter mm	Pipe Area cm^2	Flow Velocity m/s	Flow L/min	Thickness mm	Inner Diameter mm	Pipe Area cm^2	Flow Velocity m/s	Flow L/min	Threaded	Welded	Threaded	Welded	Threaded	Welded
6	1/8	10.5	1.7	7.1	0.4	Approx.0.6 to 1.2	1 ~ 3	Approx.2 to 4.5	5 ~ 11	2.4	5.7	0.3	Approx.2 to 4.5	3 ~ 7						Schedule 80	Schedule 80	Schedule 80	Schedule 80	Schedule 80	Schedule 80
8	1/4	13.8	2.2	9.4	0.7		2 ~ 5		8 ~ 19	3.0	7.8	0.5		6 ~ 13											
10	3/8	17.3	2.3	12.7	1.3		5 ~ 9		15 ~ 34	3.2	10.9	0.9		11 ~ 25											
15	1/2	21.7	2.8	16.1	2.0		7 ~ 15		24 ~ 55	3.7	14.3	1.6		19 ~ 43	4.7	12.3	1.2	Approx.2 to 4.5	14 ~ 32					Schedule 160	
20	3/4	27.2	2.9	21.4	3.6		13 ~ 26		43 ~ 97	3.9	19.4	3.0		35 ~ 80	5.5	16.2	2.1		25 ~ 56						
25	1	34.0	3.4	27.2	5.8		21 ~ 42		70 ~ 157	4.5	25.0	4.9		59 ~ 133	6.4	21.2	3.5		42 ~ 95			Schedule 160			
32	1-1/4	42.7	3.6	35.5	9.9	Less than approx. 1.5	~ 89		119 ~ 267	4.9	32.9	8.5		102 ~ 230	6.4	29.9	7.0		84 ~ 190					×	Schedule 160
40	1-1/2	48.6	3.7	41.2	13.3		~ 120		160 ~ 360	5.1	38.4	11.6		139 ~ 313	7.1	34.4	9.3		112 ~ 251						
50	2	60.5	3.9	52.7	21.8		~ 196		262 ~ 589	5.5	49.5	19.2		231 ~ 520	8.7	43.1	14.6		175 ~ 394						
65	2-1/2	76.3	5.2	65.9	34.1		~ 307		409 ~ 921	7.0	62.3	30.5		366 ~ 823	9.5	57.3	25.8		309 ~ 696						
80	3	89.1	5.5	78.1	47.9		~ 431		575 ~ 1290	7.6	73.9	42.9		515 ~ 1160	11.1	66.9	35.2		422 ~ 949						
90	3-1/2	101.6	5.7	90.2	63.9		~ 575		767 ~ 1730	8.1	85.4	57.3		687 ~ 1550	12.7	76.2	45.6		547 ~ 1230				Schedule 160		
100	4	114.3	6.0	102	82.2		~ 740		986 ~ 2220	8.6	97.1	74.1		889 ~ 2000	13.5	87.3	59.9		718 ~ 1620						×
125	5	139.8	6.6	127	126		~ 1133		1510 ~ 3400	9.5	121	115		1380 ~ 3090	15.9	108	91.6		1100 ~ 2470						

Note: Pipe size is determined by flow velocity in pipe. General guidelines are 0.5 - 1.5 m/s for pump suction pipes, 2.5 - 6 m/s for pressure pipes, and 1.5 - 4 m/s for return pipes.
Please use this pipe selection table taking into consideration the points described below in the case of using petroleum oil of suitable viscosity range.
Consult Tokyo Keiki in cases of other conditions, including environmental, installation, flammable conditions, etc.

Pump suction pipe
- Confirm that total pressure loss including losses through tank filter, pump suction head, and pressure loss through pipes is within the +35 to -16.7 kPa range. In cases of fluid other than Mineral oil based fluid, confirm that gauge pressure is within +35 to -10.1 kPa.
- A safety margin should also be considered to prevent cavitation due to inertial forces of the oil in the pipes when variable displacement pumps such as inline piston pumps are used.

Return pipe
- Consideration should be paid to prevent excessive back pressure, surge pressures caused by valve shifting, and keeping flow velocities low relative to the length of piping.

Pressure pipe
- Approx. 2 m/s for equipment operating pressure of less than 3 MPa.
- Approx. 4 m/s for general equipment.
- Approx. 6 m/s where some pressure loss is acceptable.
- In case of relatively small diameter pipes, keep flow velocity as small as possible in consideration of pressure loss.

Hydraulic formulas

Pumps — SI unit system

1 Shaft input of pump L_S

$$L_s = \frac{P \cdot Q}{60\eta} \times 10^2 \left(= \frac{2\pi \cdot T \cdot N}{6 \times 10^4} \right) \text{(kW)}$$

- P : Discharge pressure (MPa)
- Q : Discharge rate at discharge pressure P (L/min)
- T : Shaft torque (N•m)
- N : Speed (min^{-1})
- η : Total efficiency of pump (%)

2 Hydraulic power of pump L_P

$$L_p = \frac{P \cdot Q}{60} = \eta \cdot L_s \times 10^{-2} \text{ (kW)}$$

- P : Discharge pressure (MPa)
- Q : Discharge rate at discharge pressure P (L/min)
- L_s : Shaft input (kW)
- η : Total efficiency of pump (%)

3 Total efficiency of pump η

$$\eta = \eta_v \cdot \eta_t \times 10^{-2} \text{ (\%)}$$

- η_v : Volume efficiency of pump (%)
- η_t : Torque efficiency of pump (%)

4 Volume efficiency of pump η_v

$$\eta_v = \frac{Q}{Q_{th}} \times 100 \approx \frac{Q}{Q_0} \times 100 \text{ (\%)}$$

- Q : Discharge rate at discharge pressure P (L/min)
- Q_{th} : Theoretical discharge rate (L/min)
- Q_0 : Discharge rate at discharge pressure P≈0 (L/min)

5 Efficiency of driving motor η_e

$$\eta_e = \frac{L_s}{L_e} \times 100 \text{ (\%)}$$

- L_s : Output power of driving motor ≈ shaft input of pump (kW)
- L_e : Input power of driving motor (kW)

Hydraulic motors — SI unit system

6 Theoretical displacement volume of hydraulic motor D_{th}

$$D_{th} = \frac{2\pi \cdot T}{P \cdot \eta_t} \times 10^2 \text{ (cm}^3\text{/rev)}$$

- T : Output shaft torque (N•m)
- P : Difference in pressure between inlet and outlet (MPa)
- η_t : Torque efficiency of hydraulic motor (%)

7 Output power of hydraulic motor L_s

$$L_s = \frac{2\pi \cdot T \cdot N}{60000} = \eta \frac{P \cdot Q}{60} \times 10^{-2} \text{ (kW)}$$

- T : Output shaft torque (N•m)
- N : Speed (min^{-1})
- P : Difference in pressure between inlet and outlet (MPa)
- Q : Fluid inflow to hydraulic motor (L/min)
- η : Total efficiency of pump (%)

8 Input power of hydraulic motor L_m

$$L_m = \frac{P \cdot Q}{60} \text{ (kW)}$$

- P : Difference in pressure between inlet and outlet (MPa)
- Q : Fluid inflow to hydraulic motor (L/min)

9 Volume efficiency of hydraulic motor η_v

$$\eta_v = \frac{D_{th} \cdot N}{Q} \times 10^{-1} \text{ (\%)}$$

- D_{th} : Theoretical displacement volume of hydraulic motor (cm^3 /rev)
- Q : Fluid inflow to hydraulic motor (L/min)
- N : Speed (min^{-1})

Hydraulic motors — SI unit system

10 Torque efficiency of hydraulic motor η_t

$$\eta_t = \frac{2\pi \cdot T}{P \cdot D_{th}} \times 10^2 \text{ (\%)}$$

- T : Output shaft torque (N•m)
- P : Difference in pressure between inlet and outlet (MPa)
- D_{th} : Theoretical displacement volume of hydraulic motor (cm^3/rev)

11 Total efficiency of hydraulic motor η

$$\eta = \eta_v \cdot \eta_t \times 10^{-2} = \frac{L_s}{L_m} \times 10^2 = \frac{2\pi \cdot T \cdot N}{P \cdot Q} \times 10^{-1} \text{ (\%)}$$

- η_v : Volume efficiency of hydraulic motor (%)
- η_t : Torque efficiency of hydraulic motor (%)
- L_s : Output power (kW)
- L_m : Input power (kW)
- T : Output shaft torque (N•m)
- N : Speed (min^{-1})
- P : Difference in pressure between inlet and outlet (MPa)
- Q : Fluid inflow to hydraulic motor (L/min)

12 Moment of inertia (acceleration/deceleration torque) T_A

$$T_A = I \cdot \frac{d\omega}{dt} = \frac{GD^2}{4} \cdot \frac{d\omega}{dt} = \frac{N \cdot GD^2}{38t} \text{ (N·m)}$$

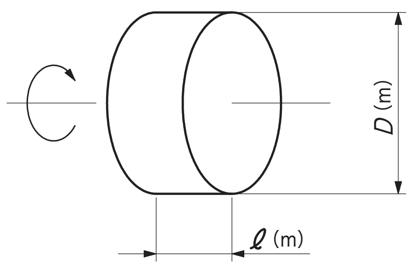
- I : Moment of inertia of rotating body (kg•m^2)
- $\frac{d\omega}{dt}$: Angular acceleration (rad/s^2)
- GD^2 : Flywheel effect (kg•m^3/s^2)
- g : Gravitational acceleration = 9.8 (m/s^2)
- t : Acceleration/deceleration time (s)
- N : Motor speed after acceleration/deceleration (min^{-1})

$$GD^2 = 4g \cdot I = \frac{mg \cdot D^2}{2} = \frac{\pi}{8} \cdot g \cdot D^4 \cdot \ell \cdot \rho \text{ (kg·m}^3\text{/s}^2\text{)}$$

- m : Weight of rotating body (kg)
- D : Diameter of rotating body (m)
- ℓ : Length of rotating body (m)
- ρ : Density of rotating body (kg/m^3)

When the rotating body is made of steel

$$GD^2 = 3 \times 10^4 \cdot D^4 \cdot \ell \text{ (kg·m}^3\text{/s}^2\text{)}$$



13 Flywheel effect of output shaft of hydraulic motor when using speed reduction gear GD^2

$$GD_2 = GD_M^2 + \Sigma GD_N^2 \left(\frac{N_N}{N_M} \right)^2$$

- GD_M^2 : Hydraulic motor separate flywheel effect
- GD_N^2 : Flywheel effect of speed reduction gear shafts
- N_M : Speed of hydraulic motor
- N_N : Speed of speed reduction gear shafts

Cylinders — SI unit system

14 Pressure required to move cylinder P_1

$$P_1=\frac{1}{A_1}\cdot\left(\frac{F}{\eta_c}+P_2\cdot A_2\times10^2\right)\times10^{-2}\ \text{(MPa)}$$

A_1 : Pressure-bearing surface area on inflow side (cm^2)
A_2 : Pressure-bearing surface area on outflow side (cm^2)
P_2 : Pressure on outflow side (MPa)
F : Cylinder thrust (N)
η_c : Thrust efficiency of cylinder (0.9 to 0.95)

15 Flow required to move cylinder Q

$$Q=A_1\cdot v\times10^{-1}+Q_L\quad\text{(L/min)}$$

v : Speed of cylinder (m/min)
A_1 : Pressure-bearing surface area on inflow side of cylinder (cm^2)
Q_L : Internal leaks of cylinder (L/min)

* The amount of the leaks from the control valves inside the hydraulic circuit must be taken into account as far as the pump discharge rate is concerned.

16 Thrust of cylinder F

(1) Acceleration force F_1

$$F_1=m\cdot\alpha=m\cdot\frac{v}{t}\quad(N)$$

m : Weight of load (kg)
α : Acceleration (m/s^2)
t : Acceleration time (s)
v : Speed after acceleration (m/s)

(2) Static frictional resistance F_2

$$F_2=\mu_s\cdot m\cdot g\quad\text{(N)}$$

μ_s : Coefficient of static friction
m : Weight of load (kg)
g : Gravitational acceleration = 9.8 (m/s^2)

(3) Dynamic frictional resistance F_3

$$F_3=\mu_d\cdot m\cdot g\quad\text{(N)}$$

μ_d : Coefficient of dynamic friction
m : Weight of load (kg)
g : Gravitational acceleration = 9.8 (m/s^2)

Electric motors — SI unit system

17 Efficiency of electric motor η_e

$$\eta_e=\frac{L_s}{L_e}\times100\ (\%)$$

L_s : Output power of electric motor = shaft input of hydraulic pump (kW)
L_e : Input power of electric motor (kW)

18 Average power of electric motor L_e

$$L_e=\sqrt{\frac{\Sigma t_N\cdot L_N^2}{T}}\ \text{(kW)}$$

T : Required time per cycle (s)
t_N : Required time for each process during one cycle (s)
L_N : Required power for each process during one cycle (kW)

Approximate maximum value of overload capacity for each process (%)

Rated Output (kW) \ Rated Time (min)	5	15	30
0.2～0.75	150	120	115
1.5～7.5	150	130	115
11～37	150	140	120

Accumulators — SI unit system

19 Discharge rate of accumulator V

$$V=V_0\cdot e\cdot\eta_a\cdot f(a)\quad\text{(L)}$$

V_0 : Volume of gas charged (nominal capacity of accumulator) (L)
e : Gas charging pressure ratio = $\frac{\text{Gas charging pressure}}{\text{Minimum working pressure}}$

(Pleated bladder type e = 0.8 to 0.85
Bellows bladder type e = 0.6 to 0.65)

η_a : Accumulator efficiency ≈ 0.95
$f(a)$: Discharge coefficient
a : Working pressure ratio = $\frac{\text{Maximum working pressure}}{\text{Minimum working pressure}}$

○Isothermal change (when the accumulator operation is performed at gradual changes, and the heat exchange with the outside is performed adequately)

$$f(a)=1-\frac{1}{a}$$

○Adiabatic change (when the accumulator operates rapidly, and there is no allowance for the heat exchange with the outside to be performed)

$$f(a)=1-\left(\frac{1}{a}\right)^{\frac{1}{m}}$$

m : Polytropic index = 1.3 to 1.4

○Gradual compression, rapid expansion (general usage method where the pressure oil, which has gradually accumulated in the accumulator, is suddenly discharged)

$$f(a)=\frac{a^{\frac{1}{m}}-1}{a}$$

m : Polytropic index = 1.3 to 1.4

Hydraulic fluids — SI unit system

20 Viscosity of hydraulic fluid μ

$$\mu=\rho\cdot\nu\times10^{-6}\quad(\text{N}\cdot\text{s/m}^2)$$

ν : Dynamic viscosity of hydraulic fluid (mm^2/s)
ρ : Density of hydraulic fluid (kg/m^3)

21 Compressibility of hydraulic fluid

(1) Amount of compression of hydraulic fluid by pressurization ΔV

$$\Delta V=\Delta P\cdot\frac{V}{K}\times10^{-3}\ (\text{cm}^3)$$

ΔP : Pressurization (MPa)
V : Volume prior to pressurization (cm^3)
K : Modulus of volume elasticity of hydraulic fluid (GPa)

Modulus of volume elasticity of hydraulic fluids K (GPa)

Type of Hydraulic Fluid	K
Mineral oil based	1.6
Phosphate ester	2.9
Water-glycol based	3.4
W/O emulsion-based	2.25

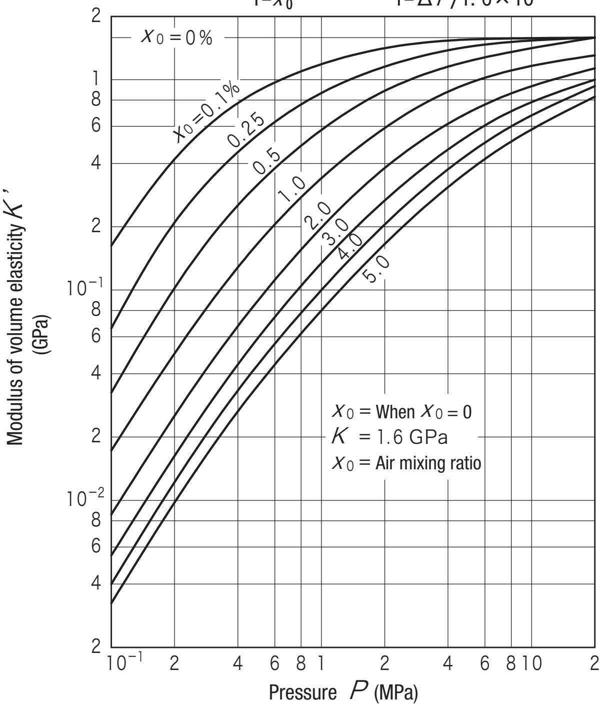
Hydraulic fluids SI unit system

(2) Modulus of volume elasticity of mineral oil based hydraulic fluid with air bubbles mixed in K'

$$K' = \frac{K_1 \cdot K_2}{K_2 + x\,(K_1 - K_2)}$$

K' : Apparent modulus of volume elasticity
K_1 : Modulus of volume elasticity of hydraulic fluid
K_2 : Modulus of volume elasticity of air (K_2 = 1.4P)
x : Volume mixing ratio of air at absolute pressure P
x_0 : Volume mixing ratio of air in atmosphere

$$x = 1 - \frac{1}{1 + \frac{x_0}{1 - x_0} \times \frac{1 - \Delta P/1.4P}{1 - \Delta P/1.6 \times 10^3}}$$



Modulus of volume elasticity of mineral oil based hydraulic fluid with air bubbles mixed in

Pressure losses and other formulae SI unit system

22 Equipment pressure loss ΔP
If the pressure loss with flow Q_0 (L/min) is ΔP_0 (MPa), then pressure loss ΔP with flow Q (L/min) will be:

$$\Delta P = \Delta P_0 \left[\frac{Q}{Q_0}\right]^2 \quad \text{(MPa)}$$

23 Pressure loss of pipes (straight pipes)
○Pipe flow velocity v

$$v = \frac{Q}{6A} \times 10^2 = \frac{2Q}{3\pi \cdot D^2} \times 10^2 \quad \text{(m/s)}$$

Q : Rate of through flow (L/min)
A : Cross-sectional area of pipe inside diameter (mm^2)
D : Pipe inside diameter (mm)

○Reynolds number Re

$$Re = \frac{v \cdot D}{\nu} \times 10^3$$

v : Pipe flow velocity (m/s)
D : Pipe inside diameter (mm)
ν : Dynamic viscosity of hydraulic fluid (mm^2/s)

Pressure losses and other formulae SI unit system

○Fluid fiction factor
When Re ≤ 2000 (streamline flow)

$$\lambda = \frac{64}{Re}$$

When 2000 < Re < 8000 (turbulent flow)

$$\lambda = 0.3164\ Re^{-\frac{1}{4}}$$

○Pressure loss ΔP

$$\Delta P = \frac{\lambda \cdot v^2 \cdot \rho \cdot \ell}{2000D} \quad \text{(MPa)}$$

λ : Fluid friction factor
v : Pipe flow velocity (m/s)
ρ : Density of hydraulic fluid (kg/m^3)
ℓ : Pipe length (m)
D : Pipe inside diameter (mm)

Density of hydraulic fluids at 38°C ρ (kg/m^3)

Type of Hydraulic Fluid	Density
Mineral oil based	864
Phosphate ester	1275
Water-glycol based	1060
W/O emulsion-based	916

24 Pressure losses of elbows and T-shaped pipes ΔP

$$\Delta P = k \cdot \frac{\rho \cdot v^2}{2} \times 10^{-6} \quad \text{(MPa)}$$

k : Loss factor
(90° elbow k = 1.2; T-shaped pipe k = 1.5)
ρ : Density of hydraulic fluid (see section 23) (kg/m^3)
v : Flow velocity (m/s)

25 Suction flow resistance of pump ΔH

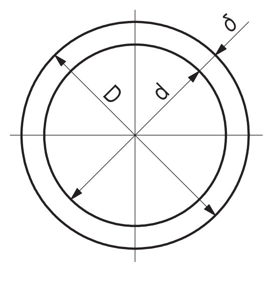
$$\Delta H = \Delta H_E + \Delta H_L + \Delta H_H$$

ΔH_E : Pressure loss of filter element
ΔH_L : Pressure loss of pipe
ΔH_H : Head loss (negative head loss in case of overhead tank)

26 Flow passing through annular clearance Q

$$Q = \frac{1.57\,\Delta P \cdot \delta^3 \cdot d}{\rho \cdot \nu \cdot \ell} \times 10^7 \quad \text{(L/min)}$$

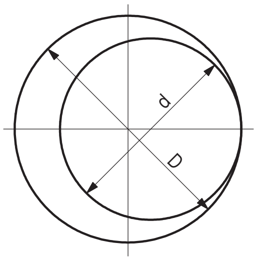
ΔP : Difference in pressure before and after annular clearance (MPa)
D : Outside diameter of annular clearance (mm)
d : Inside diameter of annular clearance (mm)
δ : Clearance = $\frac{D-d}{2}$ (mm)
ν : Dynamic viscosity of hydraulic fluid (mm^2/s)
ℓ : Length of annular clearance (mm)
ρ : Density of hydraulic fluid (kg/m^3)



Pressure losses and other formulae SI unit system

The maximum flow Q_{max} when eccentricity has been induced as shown in the figure below is:

$Q_{max} \approx 2.5Q$ (L/min)



27 Flow passing through orifice Q

$$Q = 60k \cdot A\sqrt{\frac{2}{\rho} \cdot \Delta P} = \frac{30\pi}{2} \cdot k \cdot D^2 \cdot \sqrt{\frac{2}{\rho} \cdot \Delta P}$$

(L/min)

- k : Flow coefficient = 0.6 to 0.7
- A : Cross-sectional area of orifice (mm^2)
- D : Orifice diameter (mm)
- ΔP : Difference in pressure before and after orifice (MPa)
- ρ : Density of hydraulic fluid (see section 23) (kg/m^3)

28 Surge pressure ΔP

$$\Delta P = \sqrt{10\rho \cdot K} \cdot v \times 10^{-2} \text{ (MPa)}$$

- ρ : Density of hydraulic fluid (see section 23) (kg/m^3)
- K : Modulus of volume elasticity of hydraulic fluid (see section 21) (GPa)
- v : Flow velocity before flow is cut off (m/s)

Basic characteristics of noise SI unit system

29 Noise level at distance r_2 from distance-based attenuation and simple point sound source L_2

$$L_2 = L_1 - 20\log_{10}\left(\frac{r_2}{r_1}\right) \text{ (dB)}$$

- L_1 : Noise level at distance r_1 (dB)
- r_1 : Distance from the simple point sound source to the measurement point (m)
- r_2 : Distance from the simple point sound source to the point where the noise level is to be calculated (m)

30 Noise level when noise level L_1 is composed of N types of noise L_N

$$L_N = L_1 + 10\log_{10}N \text{ (dB)}$$

- L_1 : Noise level per type of noise (dB)

31 Estimated noise level of hydraulic unit L_u

$$L_u = 10 \cdot \lambda_p \cdot \left\{\log_{10}\left(10^{\frac{Lm}{10}} + 10^{\frac{Lp}{10}}\right) + \log_{10}N + \log_{10}R_f\right\}$$

(dB)

- L_m : Noise level of electric motor (dB)
- L_p : Noise level of pump (dB)
- λ_p : Pipe condition factor
- N : Number of systems used
- R_f : Effects of reflected noise (non-reflection R_f = 1, one reflection R_f = 2)

Pipe condition factor λ_p

Material	No. of Systems (N) \ Pipe Size	1/4B〜1/2B	3/4B〜1B	1-1/4B〜2B
Steel pipe	1	1.07	1.06	1.05
	2	1.08	1.07	1.06
	3	1.09	1.08	1.07
Rubber hose	1	1.047	1.037	1.027
Rubber hose + muffler	1	1.017	1.012	1.007