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1. General

DPharp low flow transmitters are designed to measure infinitesimal flow rates (water-equivalent flow rates ranging from approximately 0.016 to 33 liters per minute [L/min] or air-equivalent flow rates from 0.45 to 910 L/min) and transmit a 4 to 20 mA DC signal responsive to the flow rate. A DPharp low flow transmitter consists of a differential pressure transmitter and an integral flow orifice manifold. The orifice plate can be replaced by removing only the manifold from the piping without removing the transmitter.

The integral flow orifice manifold is directly mounted in-line on a nominal 0.5-inch (25 mm) process pipe, and hence there is no need of a separate detector or of lead pipes.

The upstream and downstream pressures across the orifice are directed to the low- and high-pressure side chambers, respectively, and the differential pressure is converted into an electric signal of 4 to 20 mA DC.

Six orifice plates are available in different bore sizes from 0.508 to 6.530 mm in diameter. A choice from these six different orifice plates and the variable settings of the measurement range of the differential pressure transmitter enables a wide range of extremely low flow rates to be measured.

The difference between the upstream and downstream pressures across the orifice, $P_1 - P_2$, has the following relationship with the flow rate Q:

$$Q = kd^2 \sqrt{\frac{P_1 - P_2}{\rho}}$$

where

k = Proportionality factor

$P_1 - P_2$ = Differential pressure

ρ = Specific density of the process fluid

d = Diameter of the orifice bore

Use of an integral orifice requires the process fluid to be so clean that it contains no suspended matter or solids, and the fluid temperature must not exceed 120°C.

2. Standard Specifications

Measurement Ranges:

Air equivalent flow: 0.45 to 910 NL/min
(at 0°C, 1 atm)

Water equivalent flow: 0.016 to 33 L/min
(at 4°C, 1 atm)

Orifice Bores and Parts Number:

	Bore (mm)	Part Number*	
		EJ115 (S1 & S2) EJ135 (S1 & S2) EJA115 (S1 & S2) EJB115 (S1 & S2)	EJ115 (S3) EJ135 (S3) EJA115 (S3) EJB115 (S3) EJX115A (S1)
A	0.508	D0117BW	F9340NL
B	0.864	D0117BX	F9340NM
C	1.511	D0117BY	F9340NN
D	2.527	D0117BZ	F9340NP
E	4.039	D0117CA	F9340NQ
F	6.350	D0117CB	F9340NR

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* The part numbers for the individual orifice plates differ depending on the style code of the transmitter combined. "S1" to "S3" in the table above indicate the style codes.

Applicable Transmitters:

EJ115, EJ135, EJA115, EJB115, and EJX115A

Orifice Plate Material: 316 SST

Manifold Material: 316 SST

Spacer Material: 316 SST

Orifice Gasket Material: PTFE

Ambient Temperature Limits of Transmitters:

- 40° to 85°C (general-use type)
- 30° to 80°C (with integral indicator)
- 20° to 60°C (TIIS flameproof type)
- 10° to 60°C (TIIS intrinsically safe type)

Maximum Working Pressure (Integral Flow Orifice Assembly)

Applied transmitter code	Maximum working pressure
-V, -X	16 MPa
-W, -Y	42 MPa

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Differential Pressure Span of Transmitter:

- Model EJ115
 - L capsule: 1 to 10 kPa
 - M capsule: 1.3 to 130 kPa
 - H capsule: 14 to 210 kPa
- Models EJA115, EJB115, and EJX115A
 - L capsule: 1 to 10 kPa
 - M capsule: 2 to 100 kPa
 - H capsule: 20 to 210 kPa
- Model EJ135
 - M capsule: 3.3 to 130 kPa
 - H capsule: 18 to 210 kPa

Process Connections:

Rc 1/2 females or 1/2 NPT females (must be the same as those of transmitters)

Accuracy:

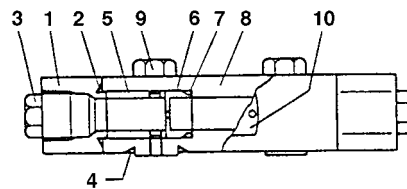
±5% of span (including accuracy of transmitter)

3. Model and Suffix Codes of Integral Flow Orifice

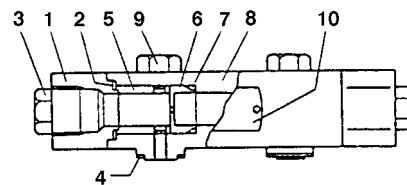
Model	Suffix Codes	Description
IFO	Integral flow orifice attachment
	- S	Manifold material: 316 SST
	4	Process connection: 1/2 NPT female
	2	Process connection: Rc 1/2 female
	1	With 1 orifice plate
	6	With 6 orifice plates of different bore sizes
	S	Orifice material: 316 SST
	-V ...	For mounting onto the EJ115 [S1 or S2], EJA115 [S1 or S2], or EJB115 [S1 or S2]
	-W ...	For mounting onto the EJ135 [S1 or S2]
	-X ...	For mounting onto the EJ115 [S3], EJA115 [S3], EJB115 [S3], or EJX115A [S1]
	-Y ...	For mounting onto the EJ135 [S3]

Example: IFO-S21S-X

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Integral Flow Orifice for EJ115/EJA115/EJB115/EJX115A



Integral Flow Orifice for EJ135

1. Process connectors (2 pieces)
2. Gaskets for process connector (2 pieces)
3. Process connector mounting bolts (4 pieces)
4. Gaskets for transmitter (2 pieces)
5. Spacer (1 piece)
6. Orifice plate (1 piece)
7. Orifice gasket (1 piece)
8. Manifold (1 piece)
9. Manifold mounting bolts (4 pieces)
10. Nameplate (1 piece)

4. How to Choose Orifice Bore Size

When selecting the most suitable orifice bore size and determining the differential pressure range, firstly, the 100% process flow rate must be converted to the equivalent air flow rate at 0°C and 1 atm if the process fluid is a gas, or to the equivalent water flow rate at 4°C and 1 atm if the process fluid is a liquid. This conversion can be performed by applying the appropriate formula from Table 1, 2, or 3. In case of gas applications, the relationship between P₁ and P₂ must satisfy the following equation;

$$\frac{P_2}{P_1} > 0.75$$

where values of P₁ and P₂ are in absolute. Next, using the graph in Figure 1 or 2, choose the most suitable bore size. Carry out this procedure in reference with the following exercises. Lastly, calculate the Reynolds number of the flow, and using Figure 3 or 4, locate the corresponding point on the flow coefficient (K_a/K_a) curve for the selected bore size. If it is found that the resulting point is not on the part of the curve in which the flow coefficient is constant, then a correction is needed for the calculated differential pressure at the 100% flow rate.

Exercise 1

Fluid: Nitrogen (N₂) gas
100% flow rate: 20 m³/h
Normal temperature: 30°C
Normal pressure: 100 kPa
Normal relative humidity: 0%

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Step 1: In reference material showing the specific density of typical gases, find the specific density of the gas in question at 0°C and 1 atm. For nitrogen gas, it is 1.251 kg/Nm³. Based on this, calculate the specific density ρ_{fg} at 30°C and 100 kPa as follows:

$$\begin{aligned} \rho_{fg} &= 1.251 \times \frac{273.15}{273.15 + 30} \times \frac{101.325 + 100}{101.325} \\ &= 2.240 \text{ kg/m}^3 \end{aligned}$$

Step 2: By applying the lower formula in Table 1, calculate the equivalent air flow rate at 0°C and 1 atm, as follows:

$$\begin{aligned} Q_{0a} &= 0.8794 Q_{fg} \sqrt{\rho_{fg}} \\ &= 0.8794 \times 20 \times \sqrt{2.240} \\ &= 26.3 \text{ Nm}^3/\text{h} = 438.7 \text{ Nl}/\text{min} \end{aligned}$$

Step 3: Using Figure 2, select the most suitable orifice bore and obtain the differential pressure at the calculated flow rate. They should be as follows:

Orifice bore: 6.350 mm
Differential pressure: 45 kPa*

* The actual differential pressure range should be set up in accordance with the result of the calculation performed by Yokogawa.

Exercise 2

Fluid: Liquid
100% flow rate: 0.3 m³/h at 40°C
Normal temperature: 40°C
Normal pressure: 300 kPa
Specific density under normal operating conditions:
980 kg/m³

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Step 1: By applying the upper formula in Table 3, calculate the equivalent water flow rate at 4°C and 1 atm, as follows:

$$\begin{aligned} Q_{4w} &= 0.03162 Q_{fg} \sqrt{\rho_{fg}} \\ &= 0.03162 \times 0.3 \times \sqrt{980} \\ &= 0.297 \text{ m}^3/\text{h} \\ &= 4.95 \text{ l}/\text{min} \end{aligned}$$

Step 2: Using Figure 1, select the most suitable orifice bore and obtain the differential pressure at the calculated flow rate. They should be as follows:

Orifice bore: 4.039 mm
Differential pressure: 28 kPa

or

Orifice bore: 6.350 mm
Differential pressure: 4.7 kPa

5. Differential Pressure Correction Due to Reynolds Number

In the same manner as for generic orifice flowmeters, check whether the Reynolds number of the flow in question is within the band in which the flow coefficient is constant. If it is not, correct the calculated differential pressure at the 100% flow rate as follows:

$$Re_d = 354 \frac{W}{\mu \times d}$$

where

W = normal mass flow rate [kg/h]

d = orifice bore diameter [mm]

μ = viscosity [mPa·s]

Using Figure 3 or Figure 4, locate the corresponding point on the flow coefficient (K_{af}/K_a) curve for the selected bore size. If it is not on the part of the curve in which the flow coefficient is constant, then the calculated differential pressure at the 100% flow rate needs to be corrected in accordance with the equation below.

$$\Delta P = \left(\frac{1}{K_{af} / K_a} \right)^2 \times \Delta P_0$$

where

K_f = constant flow coefficient intrinsic to each orifice

K_{af} = flow coefficient under normal operating conditions

ΔP_0 = calculated differential pressure at 100% flow

ΔP = corrected differential pressure

Set the differential pressure range of the transmitter to the value of ΔP thus obtained.

6. Permanent Pressure Loss

When a fluid passes through an orifice, a great number of vortices are generated between the pipe wall and the spouted jet discharged from the orifice, and these vortices spread in the downstream of the orifice until the jet spreads to the same as the pipe's inner diameter. The energy consumed by these vortices results in a permanent pressure loss of the fluid.

The permanent pressure loss of a liquid with relatively low viscosity, such as water, or of a gas can be calculated using the empirical formula below.

$$\Delta P = (P_1 - P_2) (1 - \beta^2)$$

where

ΔP = permanent pressure loss

$P_1 - P_2$ = differential pressure

β = orifice bore ratio

The orifice bore ratio ranges from 0.00143 through 0.25 for integral flow orifices. Hence, an integral flow orifice causes a pressure loss equivalent to that of an edge orifice, which is approximately 75 to 100 percent of the differential pressure set.

Table 1. Formulas for Calculating Equivalent Air Flow Rate (of Dry Gases)

Conditions	Equivalent Air Flow Rate at 0°C, 1 atm	Parameters [and their Units]
Where the specified scale is based on normal operating conditions (at t °C, p kPa)	$Q_{0a} = 0.8794Q_{fg} \sqrt{\rho_{fg}}$ $\rho_{fg} = \rho_{Ng} \times \frac{273.15}{273.15 + t} \times \frac{101.325 + p}{101.325} \times \frac{Z_{Ng}}{Z_{fg}}$	<p>Q_{0a}: Equivalent volumetric air flow rate at 0°C, 1 atm [Nm³/h]</p> <p>Q_{fg}: Volumetric flow rate of the given gas under normal operating conditions (at t °C, p kPa) [m³/h]</p> <p>Q_{Ng}: Volumetric flow rate of the given gas under standard conditions (0°C, 1 atm) [Nm³/h]</p> <p>ρ_{fg}: Specific density of the given gas under normal operating conditions (at t °C, p kPa) [kg/m³]</p> <p>ρ_{Ng}: Specific density of the given gas under standard conditions (0°C, 1 atm) [kg/Nm³]</p> <p>Z_{Ng}: Compression factor of the given gas at 0°C, 1 atm [nondimensional]</p> <p>Z_{fg}: Compression factor of the given gas under normal operating conditions (at t °C, p kPa) [nondimensional]</p>
Where the specified scale is based on standard conditions (at 0°C, 1 atm)	$Q_{0a} = 0.5356Q_{Ng} \sqrt{\rho_{Ng} \times \frac{273.15 + t}{101.325 + p} \times \frac{Z_{fg}}{Z_{Ng}}}$	

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Table 2. Formulas for Calculating Equivalent Air Flow Rate (of Wet Gases)

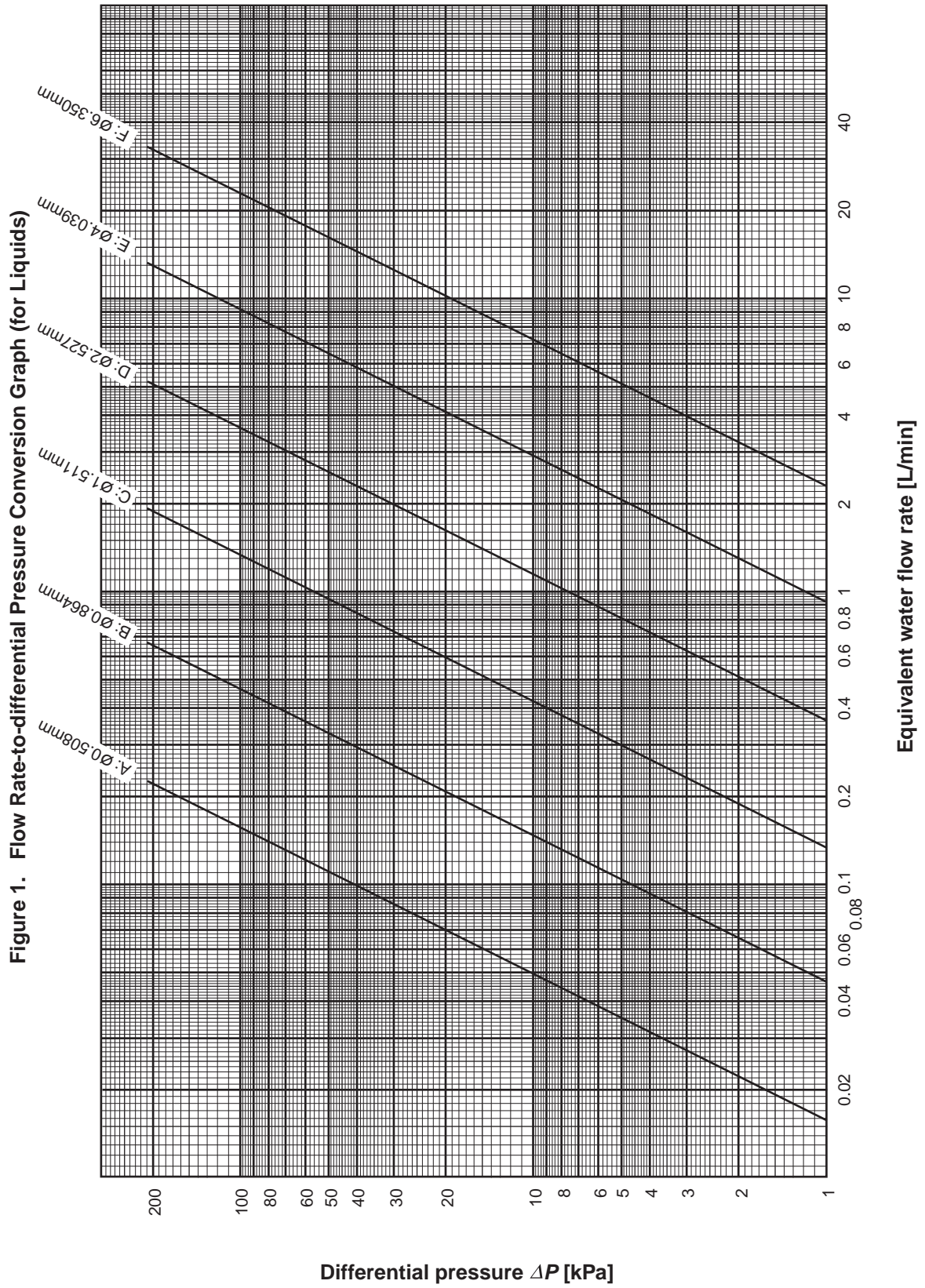
Conditions	Equivalent Air Flow Rate at 0°C, 1 atm	Parameters [and their Units]
Where the specified scale is based on normal operating conditions (at t °C, p kPa)	$Q_{0a} = 0.8794Q_{fg} \sqrt{\rho_{fg}}$ $\rho_{fg} = \rho_{Ng} \times \frac{273.15}{273.15 + t} \times \frac{(101.325 + p) - \varphi P_{fs}}{101.325} \times \frac{Z_{Ng}}{Z_{fg}} + \varphi \rho_{fs}$	<p>Q_{0a}: Equivalent volumetric air flow rate at 0°C, 1 atm [Nm³/h]</p> <p>Q_{fg}: Volumetric flow rate of the given gas under normal operating conditions (at t °C, p kPa) [m³/h]</p> <p>Q_{Ng}: Volumetric flow rate of the given gas under standard conditions (0°C, 1 atm) [Nm³/h]</p> <p>ρ_{fg}: Specific density of the given gas under normal operating conditions (at t °C, p kPa) [kg/m³]</p> <p>ρ_{Ng}: Specific density of the given gas under standard conditions (0°C, 1 atm) [kg/Nm³]</p> <p>φ: Relative humidity [%]</p> <p>ρ_{fs}: Specific density of saturated water vapor under normal operating conditions (at t °C, p kPa) [kg/m³]</p> <p>P_{fs}: Saturated water vapor pressure under normal operating conditions (at t °C, p kPa) [kPa-abs]</p> <p>Z_{Ng}: Compression factor of the given gas at 0°C, 1 atm [nondimensional]</p> <p>Z_{fg}: Compression factor of the given gas under normal operating conditions (at t °C, p kPa) [nondimensional]</p>
Where the specified scale is based on standard conditions (at 0°C, 1 atm)	$Q_{0a} = 0.3262Q_{Ng} \times \frac{(273.15 + t)}{(101.325 + p) - \varphi P_{fs}} \times \frac{Z_{fg}}{Z_{Ng}} \sqrt{\rho_{fg}}$ $\rho_{fg} = \rho_{Ng} \times \frac{273.15}{273.15 + t} \times \frac{(101.325 + p) - \varphi P_{fs}}{101.325} \times \frac{Z_{Ng}}{Z_{fg}} + \varphi \rho_{fs}$	

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Table 3. Formulas for Calculating Equivalent Water Flow Rate (of Liquids)

Conditions	Equivalent Water Flow Rate at 4°C, 1 atm	Parameters [and their Units]
Where the specified scale is based on normal operating conditions (at t °C, p kPa)	$Q_{4w} = 0.03162Q_{ft} \sqrt{\rho_{ft}}$	<p>Q_{4w}: Equivalent volumetric water flow rate at 4°C, 1 atm [m³/h]</p> <p>Q_{ft}: Volumetric flow rate of the given liquid under normal operating conditions (at t °C, p kPa) [m³/h]</p> <p>ρ_{ft}: Specific density of the given liquid under normal operating conditions (at t °C, p kPa) [kg/m³]</p>
Where the specified scale is based on standard conditions (at 0°C, 1 atm)	$Q_{4w} = 0.03162Q_{Nt} \times \rho_{Nt} \sqrt{\frac{1}{\rho_{ft}}}$	<p>Q_{Nt}: Volumetric flow rate of the given liquid at 0°C, 1 atm [Nm³/h]</p> <p>ρ_{Nt}: Specific density of the given liquid at 0°C, 1 atm [kg/Nm³]</p>

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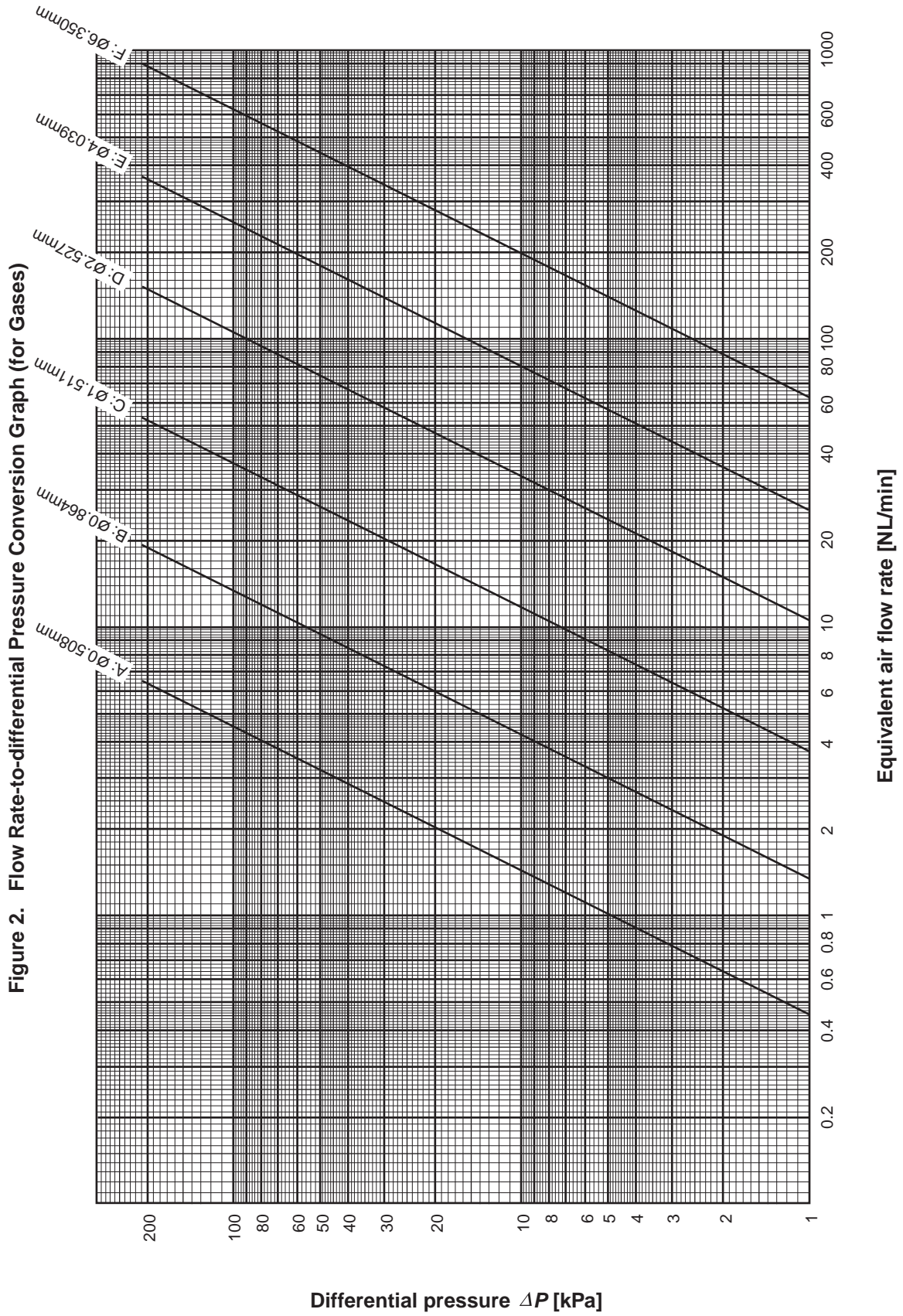


Figure 3. Reynolds Number-to-flow Coefficient Ratio Graph for Checking Need of Correction
 (Applicable to Models EJ115 [S1 & S2], EJ135 [S1 & S2], EJA115 [S1 & S2], and EJB115 [S1 & S2])

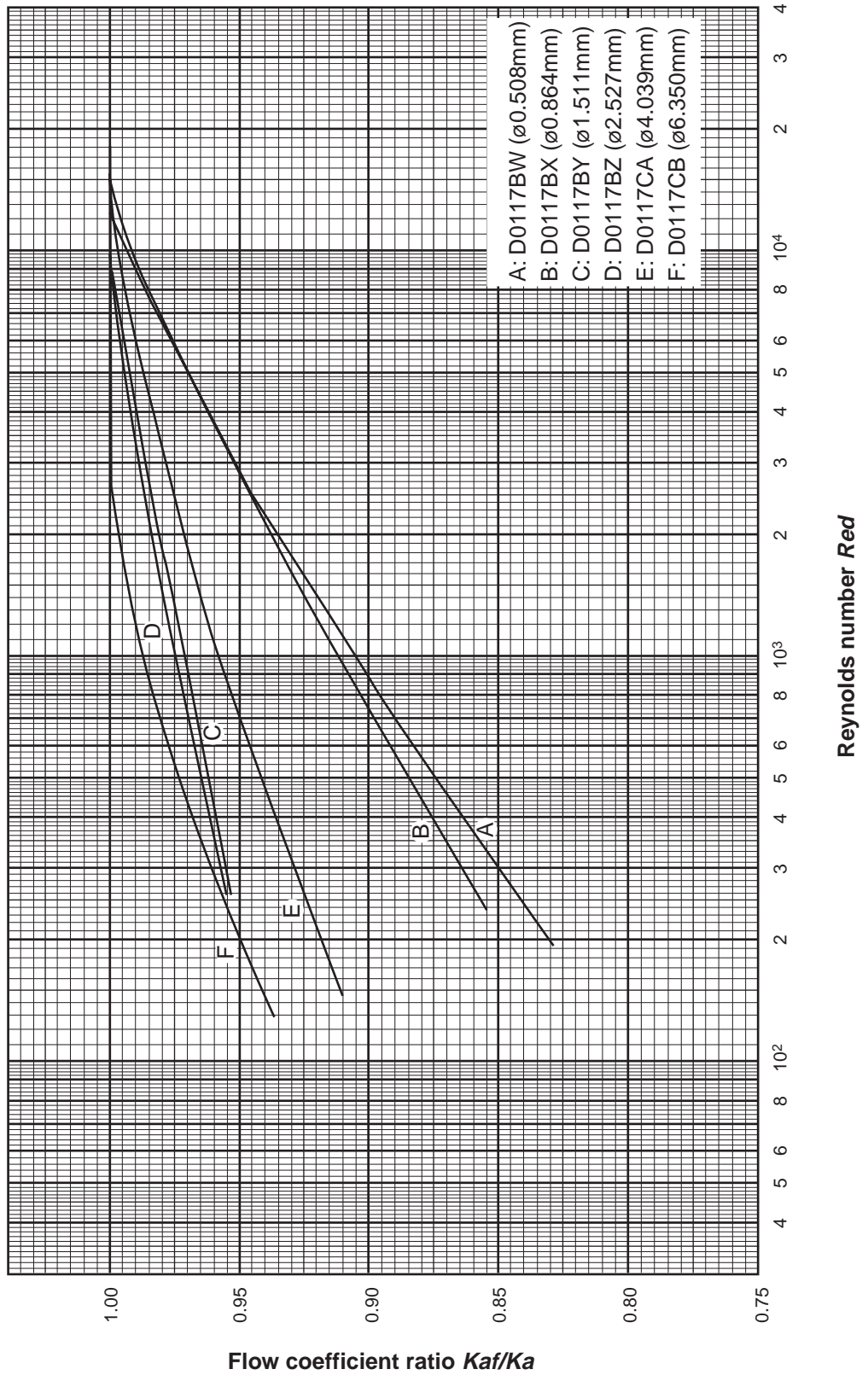


Figure 4. Reynolds Number-to-flow Coefficient Ratio Graph for Checking Need of Correction
(Applicable to Models EJ115 [S3], EJ135 [S3], EJA115 [S3], EJB115 [S3], EJ115A [S1])

