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State-of-the-art Review on Measurement of Pressure Losses of Fluid Flow through Pipe Fittings

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Appendix: Summary of literature with original pressure loss data of fluid flow through pipe fittings

Author (year)	Fluid	Fitting types*	Size† [mm (in.)]	Material	Connection type	Velocity range [m/s]	Re range† [×10^5]	Temperature [°C]
Vogel (1926)	Water	Right-angle pipe branches (tees)	M: 43, B: 15, 25	Steel	n/a	n/a	0.04 – 9	n/a
Giesecke (1926)	Water	90° long radius, 90° short radius, 45° ells	25.4 – 76.2 (1 – 3)	n/a	Threaded	0.3 – 0.9	n/a	10.6 – 29.4
Vogel (1928)	Water	Right-angle pipe branches (tees)	M, B: 43	Steel	n/a	n/a	0.04 – 9	n/a
Petermann (1929)	Water	Sharp-, round-edged and conical transition 45° oblique-angled pipe branches (tees)	M: 43, B: 15, 25, 43	Red brass	Flanged	n/a	n/a	n/a
Giesecke and Badgett (1931)	Water	Tees	25.4 (1)	Cast iron	n/a	n/a	n/a	21.1
Kinne (1931)	Water	45°, 60°, 90° pipe branches (tees)	M: 43, B: 15, 25, 43	Red brass	Flanged	n/a	n/a	Ambient conditions
Giesecke and Badgett (1932a)	Water	Ells and tees	19.1, 25.4, 31.8, 38.1 (¾, 1, 1 ¼, 1 ½)	Copper	Couplings	0.4 – 2.2 ‡	n/a	28.9
Giesecke and Badgett (1932b)	Water	Tees	25.4 (1)	Cast iron	n/a	n/a	n/a	n/a
Keulegan and Beij (1937)	Water	Smooth-walled, large-radius curved pipes	9.5 (⅜)	Drawn brass	Couplings	n/a	0.005 – 0.6	n/a
Beij (1938)	Water	90° pipe bends	101.6 (4)	Steel	Butted by friction clamps and bolts	n/a	0.2 – 4 ‡	n/a
Freeman (1941)	Water	Ells, tees, reducing tees, couplings, reducers, and enlargements	6.35 – 203.2 (¼ – 8)	Wrought iron, cast-iron	Screwed, flanged	0.08 – 8.5	0.008 – 11	14.7 – 24.7
Hoopes et al. (1948)	Water, oil	Tees	25.4 (1)	Galvanized malleable iron	Threaded	n/a	0.03 – 0.4 ‡	n/a
McNown (1954)	Water	Combining and dividing manifold flows (sharp-edged tee junctions)	M: 50.8 (2), B: 12.7, 25.4 (½, 1)	Brass	n/a	n/a	n/a	n/a
Gardel (1957a, 1957b)	Water	45° to 135° tees	M: 150, B: 60, 100, 150	Cement	n/a	n/a	n/a	n/a
Itō (1960)	Water	Smooth pipe bends, 45°, 90° ells	34.65 − 45.36	Brass casting	Screwed (ells), flanged	n/a	0.1 – 4 ‡	n/a
Blaisdell and Manson (1963)	Water	15° to 165° sharp-edged pipe junctions (tees)	M: 50.8 (2), B: 12.7 – 50.8 (½ – 2)	Transparent plastic	O-ring couplers	0.6, 1.5, 3, 4.6	0.2 – 2.9	23
Benedict et al. (1966)	Water, air	Enlargements, contractions	n/a	Acrylic	n/a	n/a	n/a	n/a
Astarita and Greco (1968)	Water, glycerol	Sharp-edged pipe contraction	Upstream: 9.8, Downstream: 3.94	n/a	n/a	n/a	0.0002 – 0.02 ‡	n/a
Iwanami et al. (1969)	Water	Sharp-edged right-angled fitting (tees)	M: 21, B: 15, 21	Synthetic resin	n/a	n/a	0.005, 0.01, 0.02, 0.025	n/a
Iwanami and Suu (1969)	Flyash, sand slurry	Sharp-edged right-angled fitting (tees)	M: 53.2, B: 28, 42.1, 53.2	Drawn steel	n/a	1 – 6 ‡	0.8 – 4.3 ‡	20
Gardel and Rechsteiner (1970)	Water	45° to 135° tees	M: 150, B: 100, 125, 150	Asbestos cement	n/a	n/a	n/a	n/a
Ruus (1970)	Water	45°, 60°, 90° wyes, ells in manifold arrangement	95.3, 133.4, 148.6, 190.5 (3.75, 5.25, 5.85, 7.5)	Acrylic ‡	Flanged	n/a	0.8 – 4	n/a
Miller (1971)	Air	90° tees	203.2, 304.8 (8, 12)	Plywood, acrylic ‡	n/a	n/a	7.5 – 10	n/a
Müller and Stratmann (1971)	Air	35°, 45°, 55°, 65° branch pipes (tees)	M: 141, 163, B: 82	n/a	n/a	n/a	3.5 – 3.6 (flow ratios = 0 – 0.6)	n/a
Itō and Imai (1973)	Water	90° pipe junctions (tees)	35	Gunmetal casting	Flanged	n/a	n/a	n/a
Jeppson (1973)	Water	Ell, tee, reducing tee	101.6, 152.4 (4, 6)	PVC ‡	Gasketed	0.17 – 5.0	0.15 – 4.4	n/a
Itō et al. (1984)	Water	90° wye	27.7	Gunmetal	Flanged, screwed	n/a	0.5, 1, 2	n/a

Author (year)	Fluid	Fitting types*	Size† [mm (in.)]	Material	Connection type	Velocity range [m/s]	Re range† [×10^5]	Temperature [°C]
Reimann and Seeger (1986)	Air, water, steam	Tee junctions	50	Acrylic	n/a	n/a	n/a	n/a
Bullen et al. (1987)	Water	Pipe contraction	40 – 110	n/a	Flanged	n/a	0.4 – 2	n/a
Katsaounis (1987)	Air, water	Tee junctions	M: 45, 203, B: 19, 82	n/a	n/a	Liquid: 0.2 – 1.4 Gas: 0.03 – 2	n/a	n/a
Serre et al. (1994)	Water	90º sharp-edged combining pipe junction (tee junctions)	M: 444, B: 63.5 – 203.2	Transparent plastic	n/a	n/a	n/a	n/a
Iwasaki and Ojima (1996)	Air	90° ell pipes	50, 75, 100, 150, 200, 250, 300	PVC	n/a	5.5 – 33	0.34 – 6.0	n/a
Oka et al. (1996)	Water	Sharp-edged combining tees	M: 54.03, B: 12.83, 15.97	Gunmetal casting	Flanged	n/a	0.24, 0.3	n/a
Maia et al. (1998), Maia et al. (2000)	Water	90º sharp-edged tee junction	n/a	Acrylic	n/a	n/a	0.05 – 0.32	15 – 20
Rahmeyer (1999)	Water	Ells, reducing ells, reducers	50.8, 101.6 (2, 4)	Malleable iron and wrought steel	Threaded, socket	0.3 – 3.7	n/a	12.8
Rahmeyer (1999)	Water	Tees	50.8, 101.6 (2, 4)	Malleable iron and wrought steel	Threaded, socket	0.6 – 3	n/a	12.8
Dent (2000)	Water	Ells, expansions/reducers, tees	254, 304.8, 406.4, 508, 609.6 (10, 12, 16, 20, 24)	Wrought steel	Butt-welded	0.6 – 6	n/a	Ambient conditions
Rahmeyer (2002)	Water	Close-coupled ells	50.8, 101.6 (2, 4)	Malleable iron and forged steel	Threaded, socket	0.3 – 6	n/a	12.8
Rahmeyer (2002)	Water	Ells, reducers, expansions	304.8, 406.4, 508, 609.6 (12, 16, 20, 24)	Wrought steel	Compression union	0.6 – 6	n/a	n/a
Rahmeyer and Dent (2002)	Water	Tees	304.8, 406.4 (12, 16)	Wrought steel	Compression union	1.2 – 3.7	n/a	12.8
Rahmeyer (2003)	Water	Fabricated injection-molded tees	50.8, 101.6, 152.4, 203.2 (2, 4, 6, 8)	Schedule 80 PVC	Socket, solvent weld	n/a	n/a	17.4 – 18.3
Rahmeyer (2003)	Water	Ells, reducers, expansions	50.8, 101.6, 152.4, 203.2 (2, 4, 6, 8)	Schedule 80 PVC	Socket and solvent weld	0.6 – 6	n/a	17.4 – 18.3
Spedding et al. (2004)	Air	90° ell bend	26	PVC	n/a	n/a	0.02 – 0.4 ‡	n/a
Ding et al. (2005)	Water	90° long ells, reducing/expansion ells, tees, reducing tees, concentric reducers, expansions	152.4, 203.2, 254 (6, 8, 10)	Steel	Wrought butt-welded	0.6 – 6	n/a	n/a
Oka and Itō (2005)	Water	45°–135° sharp-edged tees	M: 54.03, B: 15.97	Gunmetal casting	Flanged	n/a	M: 0.3, B: 1	n/a
Costa et al. (2006)	Water	90° sharp-edged and round-edged tee junctions	30.1	Acrylic	n/a	n/a	0.05 – 0.32	n/a
Crawford et al. (2007)	Air	90° ell bends, 90° tee junction	25.4	Aluminum	n/a	n/a	0.20 – 1.3	21.9 – 26.9
Sharp et al. (2009)	Water	Cross junctions	279.4	Carbon steel	n/a	0.3 – 4	0.3 – 4.5	n/a
Crane (2013)	Water, steam	Valves, ells, tees	150	n/a	n/a	Water: 0.6 – 6 Steam: 0.05 – 0.2	n/a	n/a
Al-Tameemi and Ricco (2018)	Water, air	90° sharp-angled miter ells	11, 16, 21	Acrylic	Flanged	n/a	0.005 – 0.6	25
Coombs (2019)	Water	90° mitered ell, reducing mitered ell	50.8, 76.2, 101.6 (2, 3, 4)	Steel	Welded, flanged	0.6 – 6	n/a	n/a
Klein (2021)	Water	Ells, tees, couplings	3.2 – 25.4 (⅛ – 1)	Copper, PEX, CPVC	Push-to-connect, screwed, press, expansion	0.6 – 3	n/a	n/a

Notes:
* Original terminology used by the study authors, text in parenthesis indicates potential alternative terminology.
† M: main line; B: branch line
‡ Factor was estimated based on information from the paper.