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RECOMMENDATIONS FOR PIPES SELECTIONS IN HEATING AND COOLING SYSTEMS

BY

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Abstract. The present study finds it's purpose in stressing that pipes selection is not just a matter of „how it is used”, or „how much does it costs” but also a question of „where” . Using experience of other countries, the work has at the basis calculation values from France, USA and UK and recommends selection tables of pipes diameters for low, medium and high pressure drops. Also, it illustrates the diameter choice in two different situations based on the economic criteria.

Key words: Pipe diameter; pipes sizes; pressure drops; head losses.

1. Introduction

It is well known that the sizing of the pipes depends mainly on the flow to be transported, the fluid type, pressure and temperature, the maximum acceptable noise and economic factor, but a pipe diameter is selected as a function of various criteria.

2. Pipe Sizing

The Reynolds number for small diameters is low and in order to avoid intermediate or laminar condition, some people fix a minimum velocity for tubes of coils.

For a Reynolds number of 3,500, the corresponding water flows and velocities are given in Table 1.

Table 1

Minimum Water Flows and Velocities for $\Re e$ *= 3,500*

DN	d_i	Water 80°C		Water 20°C		Water 5°C		Water 5°C + 30% glycol	
mm	mm	l/s	m/s	l/s	m/s	l/s	m/s	l/s	m/s
10	12.5	0.012	0.101	0.034	0.280	0.053	0.428	0.120	0.980
15	16.0	0.016	0.079	0.044	0.219	0.067	0.335	0.154	0.766
20	21.6	0.021	0.058	0.059	0.162	0.091	0.248	0.208	0.567
25	27.2	0.027	0.046	0.075	0.129	0.114	0.197	0.261	0.450

In France, a maximum velocity is recommended depending on the pipe sizes (s. Table 2).

Table 2

Normal Velocities or Design and Corresponding Pressure Drops, [Pa/m] *for* t_s *= 20 °C and Roughness = 0.05; Minimum Velocities During Flushing to Transport Iron Particles of 5 mm in a Horizontal Pipe*

Normal velocities						Minimum velocities for flushing			
DN	d_i	m/s	l/s	l/h	Pa/m	m/s	l/s	l/h	Pa/m
15	16.0	0.55	0.110	398	332	0.96	0.193	694	925
20	21.6	0.70	0.256	923	352	1.00	0.366	1,318	682
25	27.2	0.80	0.464	1,672	337	1.03	0.598	2,153	539
32	35.9	0.90	0.910	3,277	296	1.06	1.072	3,859	401
40	41.8	0.95	1.302	4,689	271	1.08	1.481	5,331	344
50	53.0	1.1	2.425	8,729	265	1.11	2.447	8,807	270
65	70.3	1.3	5.041	18,150	256	1.15	4.460	16,054	203
80	82.5	1.4	7.477	26,917	242	1.17	6.249	22,495	173
100	107.1	1.5	13.501	48,603	200	1.21	10.891	39,207	134
125	131.7	1.5	20.405	73,495	156	1.24	16.877	60,756	109
150	159.3	1.5	29.869	107,528	124	1.26	25.090	90,323	89
200	207.3	1.5	50.581	182,090	90				
250	260.4	1.5	79.812	287,323	68				
300	309.7	1.5	112.893	406,416	55				

However, for pipes installed near to residential apartments, the maximum velocity of water is normally reduced from 1.5 to 1.2 m/s.

These velocities should be compared with the minimum necessary velocities such that 5 mm ferrous particles can be carried in a horizontal section (BSRIA) during the rinsing operation.

Low circulation velocities may reduce circulation noise, pumping energy and differential pressure variations with load, however they also mean a higher investment in pipes and accessories. They also usually cause stagnation of heavy particles that can cause clogging by accumulation. However, particle transport appears to create other operations problems in countries that use high circulation velocities.

In the US, it's quite common to increase the tube diameter when a limiting pressure drop of 400 Pa/m is reached, giving an average head drop in the plant of around 250 Pa/m (25 mm water column/m). Independently of velocity limits, this rule gives the following approximate relations for water at 20 °C

$$d_i > 1.66 q^{0.374}, \tag{1}$$

where d_i, [mm], q, [l/h]

$$d_i > 35.41 q^{0.374}, \tag{2}$$

where d_i, [mm], q, [l/s].

Or, more generally, for other Δp_{max}, [Pa/m], maximum velocity, V_{max}, [m/s], and q, [l/h], following formulas can be used

$$d_i > 5.47 q^{0.374} \Delta p_{max}^{-0.2}, \tag{3}$$

$$d_i > 0.6\sqrt{q/v_{max}}. \tag{4}$$

The following relations are obtained for q, [l/h]:

$$d_i > 117 q^{0.374} \Delta p_{max}^{-0.2}, \tag{5}$$

$$d_i > 36\sqrt{q/v_{max}}. \tag{6}$$

In the United States [2], a minimum velocity of 0.6 m/s is recommended for pipe sizes 2 inches (50 mm) and under. For larger sizes, a minimum pressure drop of 75 Pa/m is recommended, "so air can be entrained in the water and carried to separation units".

In the United Kingdom [3] , the range recommended for velocities are 0.75…1.5 m/s for steel pipes of 50 mm and below and 1.25…3 m/s above 50 mm.

In Scandinavian countries, a maximum pressure drop of 100 Pa/m is sometimes adopted, accepting much lower velocities [1].

Reducing the pipe sizes decreases the investment costs but increases the pumping costs. When the pressure drops in pipes represent more than 75% of the pump head, the differential pressure on some circuits is multiplied at least by 4 at small loads and the authority of the control valves is reduced by the same factor. For this reason it is sometimes preferable to reduce the pressure drops at least in the main pipes or to work with secondary pumps.

3.Recomendations for Pipes Selections in Heating and Cooling Systems

As the rules are quite different from country to country, we suggest three reference tables, for low, medium and high pressure drops.

Table 3

Low Pipe Pressure Drops – Roughness 0.05 – For $\Re e < 3{,}500$ Values in Bold

Pipes		Water flows				Velocities		Δ*p* in pipes, [Pa/m], for water at following temperatures, [°C]:					
DN	d_i	l/s		m³/h		m/s		5		20		80	
mm	mm	min	max	min	max	min	max	min	max	min	max	min	max
10	12.5	0.014	0.03	0.05	0.11	0.11	0.25	**35**	**78**	**23**	**100**	22	89
15	16.0	0.03	0.06	0.11	0.20	0.15	0.28	**29**	**89**	**22**	100	27	80
20	21.6	0.06	0.13	0.20	0.45	0.15	0.34	**16**	**110**	**22**	100	18	80
25	27.2	0.13	0.24	0.45	0.85	0.22	0.41	36	109	33	100	25	81
32	35.9	0.24	0.50	0.85	1.80	0.23	0.49	29	109	26	100	21	83
40	41.8	0.50	0.75	1.80	2.71	0.36	0.55	52	108	48	100	39	83
50	53.0	0.75	1.43	2.71	5.16	0.34	0.65	34	108	31	100	25	85
65	70.3	1.58	3.05	5.70	11.00	0.41	0.79	33	107	30	100	25	86
80	82.5	3.05	4.68	11.00	16.84	0.57	0.88	49	107	46	100	38	87
100	107.1	4.68	9.40	16.84	33.82	0.52	1.04	30	107	28	100	23	88
125	131.7	9.40	16.14	33.82	58.10	0.69	1.18	39	105	36	100	31	88
150	159.3	16.14	26.83	58.10	96.60	0.81	1.35	41	106	39	100	34	89
200	207.3	26.83	53.61	96.60	193.00	0.79	1.59	29	105	27	100	24	90
250	260.4	53.61	97.45	193.00	351.00	1.01	1.83	34	104	32	100	28	90
300	309.7	97.45	155.00	351.00	557.50	1.29	2.06	44	105	42	100	37	91

Table 4

Medium Pipe Pressure Drops – Roughness 0.05 – For $\Re e < 3{,}500$ Values in Bold

Pipes		Water flows				Velocities		Δ*p* in pipes in Pa/m for water at following temperatures					
DN	d_i	l/s		m³/h		m/s		5°		20°		80°	
mm	mm	min	max	min	max	min	max	min	max	min	max	min	max
10	12.5	0.014	0.04	0.05	0.15	0.11	0.34	**35**	**165**	**23**	200	22	159
15	16	0.04	0.08	0.15	0.3	0.21	0.41	**40**	221	**57**	200	47	162
20	21.6	0.08	0.19	0.3	0.67	0.22	0.51	**46**	220	47	200	37	166
25	27.2	0.19	0.35	0.67	1.24	0.32	0.59	72	215	65	200	52	166
32	35.9	0.35	0.73	1.24	2.64	0.34	0.72	56	216	51	200	41	170
40	41.8	0.73	1.1	2.64	3.96	0.53	0.8	103	214	95	200	79	171
50	53	1.1	2.08	3.96	7.5	0.5	0.94	67	214	62	200	52	174
65	70.3	2.3	4.4	8.25	15.9	0.59	1.14	64	212	59	200	50	176
80	82.5	4.4	6.77	15.9	24.37	0.83	1.27	96	212	90	200	78	178
100	107.1	6.77	13.52	24.37	48.67	0.75	1.5	59	211	55	200	47	179
125	131.7	13.52	23.36	48.67	84.1	1	1.71	76	210	72	200	63	180
150	159.3	23.36	38.38	84.1	138.2	1.17	1.93	82	207	77	200	68	180
200	207.3	38.38	77.13	138.2	277.7	1.14	2.29	56	208	53	200	47	182
250	260.4	77.13	133.14	277.7	479.31	1.45	2.5	67	188	64	181	57	164
300	309.7	133.14	188.33	432	678	1.59	2.5	66	153	62	147	55	133

Table 5
High Pipe Pressure Drops – Roughness 0.05

Pipes		Water flows				Velocities		Δp in pipes, [Pa/m], for water at following temperatures, [°C]:					
DN	d_i	l/s		m³/h		m/s		5		20		80	
mm	mm	min	max	min	max	min	max	min	max	min	max	min	max
10	12.5		0.06		0.22		0.5		442		400		330
15	16	0.06	0.12	0.22	0.44	0.31	0.6	121	437	121	400	96	335
20	21.6	0.12	0.27	0.44	0.98	0.33	0.74	102	436	93	400	74	342
25	27.2	0.27	0.5	0.98	1.82	0.47	0.87	141	429	130	400	107	343
32	35.9	0.5	1.06	1.82	3.82	0.5	1.05	111	424	102	400	84	346
40	41.8	1.06	1.6	3.82	5.73	0.77	1.16	200	421	186	400	160	348
50	53	1.6	3.02	5.73	10.86	0.73	1.37	132	425	123	400	105	357
65	70.3	3.32	6.4	11.94	23	0.85	1.65	125	422	117	400	101	359
80	82.5	6.4	9.8	23	35	1.2	1.83	191	423	180	400	159	363
100	107.1	9.8	19.45	35	70	1.09	2.16	116	417	109	400	96	364
125	131.7	19.45	33.41	70	120	1.43	2.45	149	412	142	400	126	363
150	159.3	33.41	55.55	120	200	1.68	2.79	159	417	152	400	137	370
200	207.3	55.55	101.25	200	364.5	1.65	3	112	350	107	337	96	309
250	260.4	101.25	160	364.5	575.17	1.87	3	112	266	107	256	96	235
300	309.7	160	226	575.17	813.57	2.12	3	112	216	107	208	97	191

Fig. 2 illustrates the following situations:

E x a m p l e 1: Pipe *DN* = 80 and water flow 20 m^3/h: Velocity = 1 m/s and Δp = 140 Pa/m.

E x a m p l e 2: Pipe *DN* = 10 and water flow 0.1 m^3/h: Reynolds number being below 3,500, this nomogram is not applicable in this case, as it was established for turbulent condition.

In the case of reverse return systems , the same head loss per meter should be obtained for the entire plant. This is practically impossible as all the calculated tube diameters are not available on the market.

O b s e r v a t i o n. Changing from a given diameter to the next lower diameter can increase the head loss per meter by the order of 250%. For a flow of 32 m^3/h (8.9 l/s), head losses per meter at 20°C are 91 Pa and 335 Pa for diameters *DN*100 to *DN*80 respectively.

4. Economic Criteria

The tube diameter may be selected as a function of economic criteria. The annual cost of the tube is made up of two parts:

a) Fixed costs represented by the amortization of pipe purchase and installation costs over a period of twenty years (for example), including interest on the capital invested. These costs depend only on the diameter of the tube, its insulation and the stresses that it imposes on accessories such as filters, shut off valves, etc.

b) Variable costs which depend on the number of hours of operation per year.

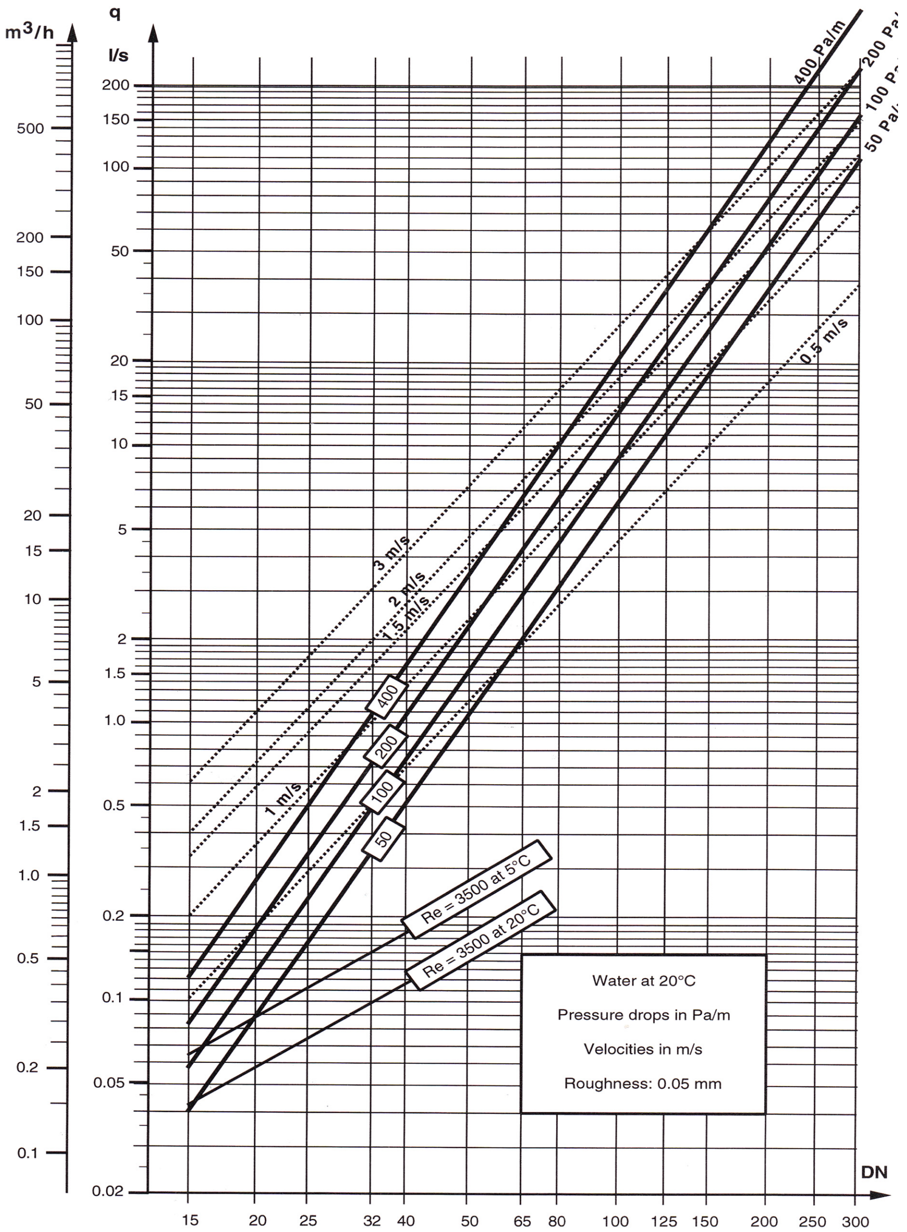


Fig. 1 – Pressure drops and velocities in pipes.

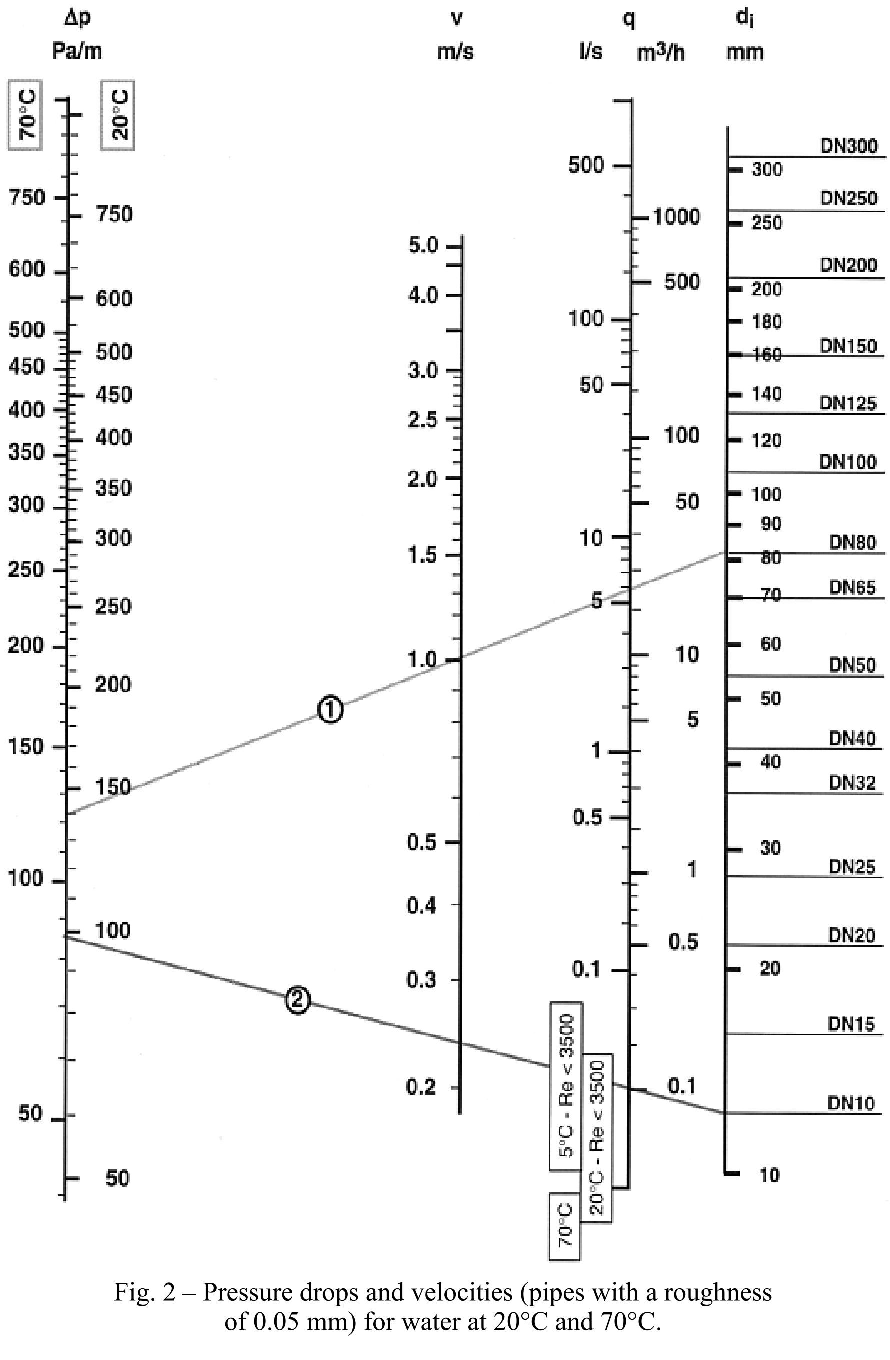


Fig. 2 – Pressure drops and velocities (pipes with a roughness of 0.05 mm) for water at 20°C and 70°C.

These are divided into two parts, namely:

a) Costs associated with the flow rate, such as pumping costs which depend on head losses. In this respect, a distinction is made between heating plants and cooling plants.

In heating, the energy consumption of pumps is not a loss in itself as the energy consumed is essentially transformed into heat in the water. The actual cost of pumping therefore depends on the ratio between the cost of this energy produced electrically and the cost of the same energy produced by a boiler. The real pumping cost can be estimated by the relation 100 – 10 x (cost per liter of fuel/cost per kWh) ~80% of the theoretical pumping cost [4].In cooling process, the entire pumping energy losses and the chillers have to compensate for water reheating. The actual pumping cost then represents approximately 130% of the theoretical pumping cost .

b) Costs associated with diameter, such as heat losses or heat gains. The economic diameter is that which minimizes the annual cost. The head losses obtained may be incompatible with the smooth operation of the plant and limitations have to be adopted. Sometimes higher head losses are used to design favoured circuits in which it is necessary to limit the flow anyway by means of a balancing valve. In this case there is no longer any point in calculating the economic tube diameter as head losses have to be created in one way or another. However, reducing pipe sizes is limited by noise and erosion considerations.

5. Other Head Losses

Losses due to elbows, tees, service valves etc., have to be added to pressure drops in pipes themselves.

They can be estimated by the following formula:

$$\Delta p = 500\xi\gamma v^2, \tag{7}$$

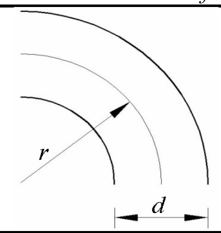
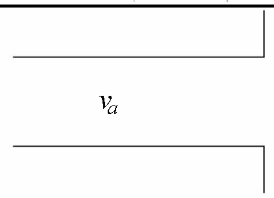
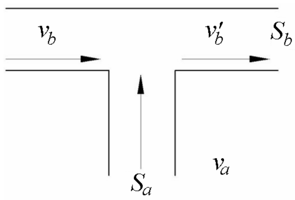
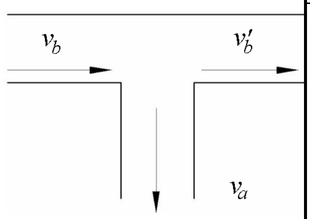
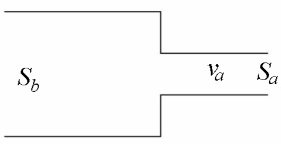
$$v = \frac{0.354q}{d_i^2}, \tag{8}$$

$$v = \frac{1,273q}{d_i^2}, \tag{9}$$

where Δp, [Pa], v, [m/s], d_i, [mm], q, [l/s].

The coefficient ξ (sometimes called *k*-factor) depends on the object. A list of factors is given in specialized books and we will restrict ourselves to the examples given in Table 6.

Table 6
A Few Values of ξ (k factor in UK); S is the Internal Area of the Tube

	r/d	ξ			
	0.5	0.75			
	1	0.35			
	2	0.28			
	→ $\xi_a = 1$			← $\xi_a = 0.34$	
		S_a/S_b			
		0.3	0.5		
	v_a / v_b	ξ_a		v_b / v_b'	ξ_b
	0.5	–	0.5		
	0.6	0.0	0.9	0.6	1.3
	0.7	0.4	1.3	0.7	0.9
	0.8	0.5	1.4	0.8	0.4
	0.9	0.7	1.5	0.9	0.2
	1.0	0.8	1.5	1.0	0.0
	v_a / v_b	ξ_a		v_b' / v_b	ξ_b
	0.3	12			
	0.4	7.0			
	0.5	4.5		0.5	0.50
	0.6	3.5		0.6	0.20
	0.7	3.0		0.7	0.10
	0.8	2.5		0.8	0.05
	0.9	2.2		0.9	0.01
	1.0	2.0		1.0	0.00
	2.0	1.0			
	S_a/S_b	ξ_a			
		$0.34(1–S_a/S_b)$ →		$(1– S_a/S_b)$ ←	
	0.2	0.27		0.64	
	0.4	0.20		0.36	
	0.6	0.14		0.16	
	0.8	0.07		0.04	

Note that some values of ξ are changing with the water flow. When the flow changes, the pressure drop depends on the square of the flow but also on the new value of ξ. Finally, in this case, the pressure drop depends on the flow with an exponent which differ from 2.

Some elements are defined by their coefficient, *Kv*, and pressure drops that they generate can be calculated by the following formulas

$$\Delta p = 0.1\gamma\left(\frac{q}{Kv}\right)^2, \tag{10}$$

$$\Delta p = 0.1\gamma\left(\frac{3,600}{Kv}\right)^2, \tag{11}$$

were Δp, [Pa], q, [l/h].

The value *Kv* can also be converted into γ by relation

$$\xi = \frac{d_i^4}{625\left(Kv\right)^2}. \tag{12}$$

The diameter, d_i, [mm], is the same as the internal diameter of the pipe in which the valve is installed.

5. Conclusions

As seen, pipes dimensioning should take into consideration technical and economic criteria. Whether flow, pressure or cost are not entirely suited based on one criteria, we have to keep in mind that there are various balancing equipments and methods for integrating control loops into a heating or cooling installation in order to obtain the desired indoor climate at minimum operating costs.

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R E F E R E N C E S

1. Petitjean R., *Total Hydronic Balancing*. Edit. Respoustryck, Borås, Sweden, 1997.
2. * * * *Water Distribution Systems Code W.* The Chartered Institution of Building Services Engineers , London, 1993.
3. * * * *HVAC Systems – Applications,* Ch. X: *Hydronic Systems*, SMAGNA (US) 1990.
4. Popovici C., Ignat J., *About Variable Speed Heating and Cooling Pumps*. Bul. Inst. Politehnic , Iaşi, **LV (LIX)**, *2*, s. Constr.Archit. (2009).

RECOMANDĂRI ASUPRA ALEGERII CONDUCTELOR SISTEMELOR DE ÎNCĂLZIRE ŞI RĂCIRE

(Rezumat)

Prezentul studiu îşi propune să sublinieze că determinarea diametrelor conductelor pentru instalaţiile de încălzire, cât şi pentru cele de răcire nu este doar o problemă de „cum o folosim", sau „cât costă" ci şi o chestiune de „unde va funcţiona". Folosind experienţa altor ţări, lucrarea are ca bază valori de calcul din Franţa, SUA, Anglia şi recomandă tabele de selecţie a diametrelor conductelor pentru pierderi de presiune mici, medii şi mari . De asemenea, este exemplificată alegerea diametrelor în două situaţii în baza criteriului economic.