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AN APLICATION FOR THE SELECTION AND SIZING OF CONTROL VALVE FOR CONTROL LOOP

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ABSTRACT

The paper presents the research of the author in developing an application for sizing and selection of control valves for typical process control applications. The proper sizing, selection, installation, and maintenance of control valve are all significant to obtain precise control performance.

The paper has three parts. The first part describes the steps necessary to size and selection control valve based on the specific standards. The second part is destined to present the application developed by the author using Python programming language. In the last part, the author has presented and analyzed the numerical results of selection control valve using data from a real process.

Keywords: control valve, pipe, numerical results

INTRODUCTION

The increased complexity of the industrial process has imposed additional requirements to the control valve as new constructive solution implicitly a more precision sizing and selection. The control valve is an essential component of the control loop. To compensate the disturbance and keep the process variables to the set point, the control valve manipulates a flow water, gas, liquid, steam). The main components of the control valve are an electronic-pneumatic converter, actuator element and control element [1, 2, 3]. The selection of the control valve consists in two steps: the selection of actuator element and selection of the sizing of the control element with seat.

The author of this paper has focused on selection and sizing of control elements which depend on the fluid type (compressible or incompressible fluid), flow regime (turbulent or laminar) and operated data of process. Based on these issues and specific standards [4, 8, 9], the author has developed an application using the Python programming language to calculate the flow coefficient *Kv* or *Cv* which allows to select a control valve from catalogues of the specialized firms.

Some software for control valve design are found in the specialty literature. One of them is CONVAL® program which is used to select the plant refinery control valve [3]. The main components that form the basis of the CONVAL software are the model of control valve, thermodynamic elements, and industrial database of control valve [10]. The software developed by Ruhr University of Bochum, is used to verify the 38 control valves of the plant.

Another way to calculate the size control valves is the Valve Sizing Calculator, a web-software created by HIT VALVE [11]. This software calculates the valve specific using the process data and the medium given by the user and providing information about the operating circumstances and the noise level for the selected valve and the specified application.

The Baker Hughes company proposes a multi-configurator called ValSpec software for the selection and sizing of control valves, the choice of regulators and related accessories within the applications [13]. This application is created based on ISA/IEC standards [9].

Based on the specific standards of the selection of valves [6, 9], the Ciclo software company proposes the Control valve software application for the selection and sizing control valves [12]. This software is based on a database for the properties of liquids, gases, steam, which allows the realization of very different operating conditions and the most correct choice.

SIZING CONTROL ELEMENT DETERMINATION STEP

The first step in control valve sizing is collecting relevant process data. The process data such as: flowrate (minim and maxim), operating pressure (minim and maxim), inlet pressure, outlet pressure, operating temperature, viscosity, density, piper sizing, vaporization pressure.

The second step involves the determination of the flow coefficient *Cv* or *Kv* and is expressed as the flow of water in p.m. U.S(m^3/h) for a pressure drop of 1 psi (1 bar) across a flow passage (*Cv*=1.156**Kv*). The calculation of the flow coefficient depends primarily on the flow regime (non-choked turbulent, choked turbulent and laminar). Secondly, the constructive elements (reducers or fittings) that are attached to the control valve, in many kinds of industrial applications, have a significant influence on the nominal flow coefficient. The equations of flow coefficient according with the specific standard [6, 7, 8, 9] for each flow regime and the nature of fluid are present in the following sections.

A. *Incompressible fluid*

A1. *The control valve without attached fitting*

Based on value of differential pressure between upstream and downstream pressure, the flow regime is established [6, 9]:

$$\Delta P \geq F_L{}^2 \cdot (P_1 - F_F \cdot P_V)\,; \tag{1}$$

where F_L – a control valve's liquid pressure recovery factor without attached fittings, P_1 - inlet pressure measured, F_F - factor of liquid critical pressure ratio, P_v – liquid's absolute vapor pressure at inlet temperature.

Base on relation (2) is calculated the liquid critical pressure ratio:

$$F_F = 0.96 - 0.28 \cdot \sqrt{\frac{P_V}{P_C}} \tag{2}$$

where P_c -critical pressure.

If the condition (1) is fulfilled, we have a choked turbulent regime and flow coefficient is calculate with relation (3)

$$C_v = \frac{Q}{F_L}\sqrt{\frac{\frac{\rho_1}{\rho_0}}{P_1 - F_F \cdot P_V}} \; ; \tag{3}$$

If the condition (1) is not fulfilled, the regime is non-choked and flow coefficient is determinate with relation (4)

$$C_v = Q \cdot \sqrt{\frac{\frac{\rho_1}{\rho_0}}{\Delta P}} \; ; \tag{4}$$

where the Q – volumetric flow rate [m^3/h], $\frac{\rho_1}{\rho_0}$ - relative density.

In case on ΔP is very small, the section of pipe is big and the R_{ev} <1000, the regime is laminar, and flow coefficient is

$$C_v = \frac{Q}{F_R}\sqrt{\frac{\rho_1/\rho_0}{\Delta P}} \; ; \tag{5}$$

where F_R – Reynolds number factor, R_{ev} - valve Reynolds number.

A2. *The control valve with attached fitting*

If the condition (6) is fulfilled the regime is choked turbulent and the flow coefficient is calculated with relation (7)

$$\Delta P \geq \left(\frac{F_{LP}}{F_P}\right)^2 \cdot (P_1 - F_F \cdot P_V) \; ; \tag{6}$$

$$C_v = \frac{Q}{F_{LP}}\sqrt{\frac{\rho_1/\rho_0}{P_1 - F_F \cdot P_V}} \; ; \tag{7}$$

where F_{LP} - a control valve with associated fittings' combined liquid pressure recovery factor and piping geometry factor, F_P - factor of the piping geometry.

If condition (6) in not fulfilled the regime is non-choked turbulent and flow coefficient is determinate base on relation [6, 9]

$$C_v = \frac{Q}{F_P}\sqrt{\frac{\rho_1/\rho_0}{\Delta P}} \; ; \tag{8}$$

If the regime is laminar the effect of reducers or fittings is unknown, and a control valve control valve with diameter equal to diameter of pipe is suggested.

B. *Compressible fluid*. Because the flowrate of compressible fluids can be measured in either mass or volume units, the equations must be developed to compensate for both circumstances [5, 9].

B1. *The control valve without attached fitting*.

The condition for determinate the flow regime is:

$$x < F_\gamma \cdot x_T \; ; \tag{9}$$

where x - represented the rapport between pressure differential and absolute pressure ($\Delta P/P_1$), x_T - pressure differential ratio factor in choked flow condition for a valve without attached fittings, F_γ-specific heat ratio factor [6, 9].

The specific heat ration factor is called with next relation:

$$F_\gamma = \frac{\gamma}{1.4} \tag{10}$$

If the condition (9) is fulfilled, we have a choked turbulent regime and flow coefficient is calculate with relations (11-14)

$$K_v = \frac{W}{3.16 \cdot 10^1 \cdot Y \cdot \sqrt{x \cdot P_1 \cdot \rho_1}}\ ; \tag{11}$$

$$K_v = \frac{W}{1.10 \cdot 10^2 \cdot Y \cdot P_1 \cdot \sqrt{\frac{T_1 \cdot Z}{x \cdot M}}}\ ; \tag{12}$$

$$K_v = \frac{Q}{2.46 \cdot 10^3 \cdot Y \cdot P_1 \cdot \sqrt{\frac{M \cdot T_1 \cdot Z}{x}}}\ ; \tag{13}$$

$$K_v = \frac{Q}{4.82 \cdot 10^2 \cdot Y \cdot P_1 \cdot \sqrt{\frac{G_g \cdot T_1 \cdot Z}{x}}} \tag{14}$$

where M - molecular mass of the flowing fluid [kg/Kmol], T_1 - inlet absolute temperature [K], P_1 - inlet absolute pressure measured at upstream pressure tap [bar]; Z - compressibility factor - ratio of ideal to actual inlet specific mass, W - mass flowrate, Y - expansion factor, G_g - gas specific gravity.

If the condition (9) is not fulfilled, the regime is non-choked and flow coefficient is determinate with relation (16 – 18)

$$K_v = \frac{W}{3.16 \cdot 10^1 \cdot F_P \cdot Y \cdot \sqrt{x \cdot P_1 \cdot \rho_1}}\ ; \tag{15}$$

$$K_v = \frac{W}{1.10 \cdot 10^2 \cdot F_P \cdot P_1 \cdot Y \cdot \sqrt{\frac{T_1 \cdot Z}{x \cdot M}}}\ ; \tag{16}$$

$$K_v = \frac{Q}{2.46 \cdot 10^3 \cdot F_P \cdot P_1 \cdot Y \cdot \sqrt{\frac{M \cdot T_1 \cdot Z}{x}}}\ ; \tag{17}$$

$$K_v = \frac{Q}{4.82 \cdot 10^2 \cdot F_P \cdot P_1 \cdot Y \cdot \sqrt{\frac{G_g T_1 \cdot Z}{x}}}\ ; \tag{18}$$

B2*. The control valve with attached fitting.*

If the condition (19) is fulfilled the regime is choked turbulent and the flow coefficient is calculated with relations (19-23)

$$x < F_\gamma \cdot x_{TP}\ ; \tag{19}$$

$$K_v = \frac{W}{0.667 \cdot 3.16 \cdot 10^1 \cdot \sqrt{F_\gamma \cdot x_T \cdot P_1 \cdot \rho_1}}\ ;\ ; \tag{20}$$

$$K_v = \frac{W}{0.667 \cdot 1.10 \cdot 10^2 \cdot P_1 \cdot \sqrt{\frac{T_1 \cdot Z}{F_\gamma \cdot x_T \cdot M}}}\ ; \tag{21}$$

$$K_v = \frac{Q}{0.667 \cdot 2.46 \cdot 10^3 \cdot P_1 \cdot \sqrt{\frac{M \cdot T_1 \cdot Z}{F_\gamma \cdot x_T}}}\ ; \tag{22}$$

$$K_v = \frac{Q}{0.667 \cdot 4.82 \cdot 10^2 \cdot P_1 \cdot \sqrt{\frac{G_g \cdot T_1 \cdot Z}{F_\gamma \cdot x_T}}}; \tag{23}$$

If condition (19) in not fulfilled the regime is non-choked turbulent and flow coefficient is determinate base on relations [6, 9]

$$K_v = \frac{W}{0.667 \cdot 3.16 \cdot 10^1 \cdot F_P \cdot \sqrt{F_\gamma \cdot x_{TP} \cdot P_1 \cdot \rho_1}}; \tag{24}$$

$$K_v = \frac{W}{0.667 \cdot 1.10 \cdot 10^2 \cdot F_P \cdot P_1 \cdot \sqrt{\frac{T_1 \cdot Z}{F_\gamma \cdot x_{TP} \cdot M}}}; \tag{25}$$

$$K_v = \frac{Q}{0.667 \cdot 2.46 \cdot 10^3 \cdot F_P \cdot P_1 \cdot \sqrt{\frac{M \cdot T_1 \cdot Z}{F_\gamma \cdot x_{TP}}}}; \tag{26}$$

$$K_v = \frac{Q}{0.667 \cdot 4.82 \cdot 10^2 \cdot F_P \cdot P_1 \cdot \sqrt{\frac{G_g \cdot T_1 \cdot Z}{F_\gamma \cdot x_{TP}}}}; \tag{27}$$

where X_{TP} - pressure differential ratio factor of a control valve with attached fittings at choked flow.

APPLICATION FOR SELECTION AND SIZING CONTROL VALVE

The author has elaborated an application for determining the sizing of control valve using Python programming language structured in three categories: liquid, gases and steam (figure 1). The structure of the application developed contains a mathematical model of the control valve based on ISA-75.01.01 and IEC 60534 8-3 and IEC 60534 8-4 [6, 9].

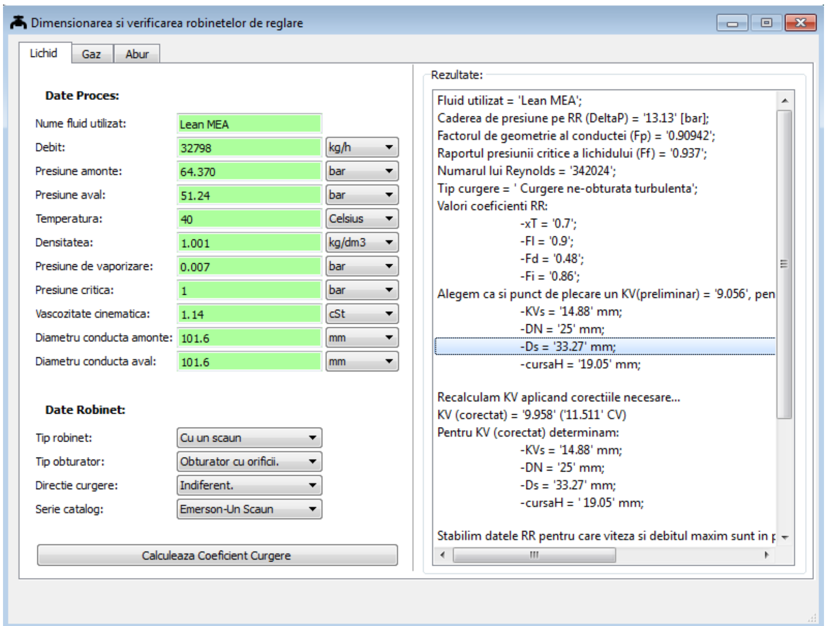

***Fig.1**. Informatics system for sizing and determination of control valve.*

For an adequate dimensioning, the minimum necessary data are divided into two sections:

- the process data area, which contains data such as flowrate, upstream and downstream pressure, temperature, etc.
- the control valve data area, from which we list data of the control valve type shape, shutter type, etc.

The generated results are displayed in the area on the right of the graphic interface, but also by writing all the input data and the informational flow within the application in a data file, thus making it easy to return to previous results.

NUMERICAL RESULTS

The real process data used to validate the application for sizing control valve are presented in table 1. In table 2 is a comparison between calculated flow coefficient and flow coefficient from the process. The result has validated the developed application. A comparative graphic between calculated flow coefficient with the flow coefficient form the process is shown in figure 3.

Table 1. Process data.

No tag		**122FV**	**002LV**	**121LV**	**127LV**	**139LV**	**141LV**
Fluid	**Working conditions**	Lean MEA	Gas oil impure	Rich MEA	Lean MEA	Naphtha	Stripper heavy
Flowrate [kg/h]	**min**	15537	937.5	16477	15537	810	1091
	normal	32798	1563	34784	32798	3643	1818
	max	36269	1717	38465	36269	4370	2500
Downstream pressure[bar]	**min**	67.87	7.19	52.74	2.98	6	2.18
	normal	64.37	3.78	47.72	1.76	5.6	2.17
	max	62.18	0.71	47.20	1.76	5.3	2.12
Upstream pressure[bar]	**min**	48.19	0.02	5.9	0.43	4.51	0.2
	normal	51.24	0.3	6.05	1.35	4.57	0.2
	max	51.27	0.3	6.02	1.35	4.53	0.2
Temperature [^{0}C]		40	70	38.25	40	43.3	43.3
Density [kg/dm^3]		1.001	1	0.98	1.001	0.702	1
Vaporization pressure[bar]		0.007	0.007	0.06	0.06	2.9	0.1
Critically pressure [bar]		1	0.1	1	1	3	1
Viscosity [cSt]		1.14	1.640	0.650	1.19	0.363	0.6
Upstream diameter pipe [m]		101.6	50.8	76.2	101.6	76.2	50.8
Downstream diameter pipe [m]		101.6	50.8	76.2	101.6	76.2	50.8

Table 2. Comparative analysis of the flow coefficient.

No. Tag	Fluid	Working condition	Flow coefficient C_v	
			Industrial data	Calculated
122FV	Lean MEA	Minimum	4.052	4.105
		Normal	10.47	11.51
		Maximum	12.706	14.689
137FV	Gas oil impure	Minimum	0.416	0.451
		Normal	0.970	1.047
		Maximum	3.108	3.1
121 LV	Rich MEA	Minimum	2.818	2.899
		Normal	6.299	6.564
		Maximum	6.970	7.301
132 -LV	Lean MEA	Minimum	11.259	12.845
		Normal	59.27	59.49
		Maximum	66.36	65.85
139-LV	Naphtha	Minimum	0.919	0.645
		Normal	4.96	3.5
		Maximum	6.881	4.9
141-LV	Striper heavy	Minimum	0.89	0.98
		Normal	1.49	1.67
		Maximum	2.08	2.4

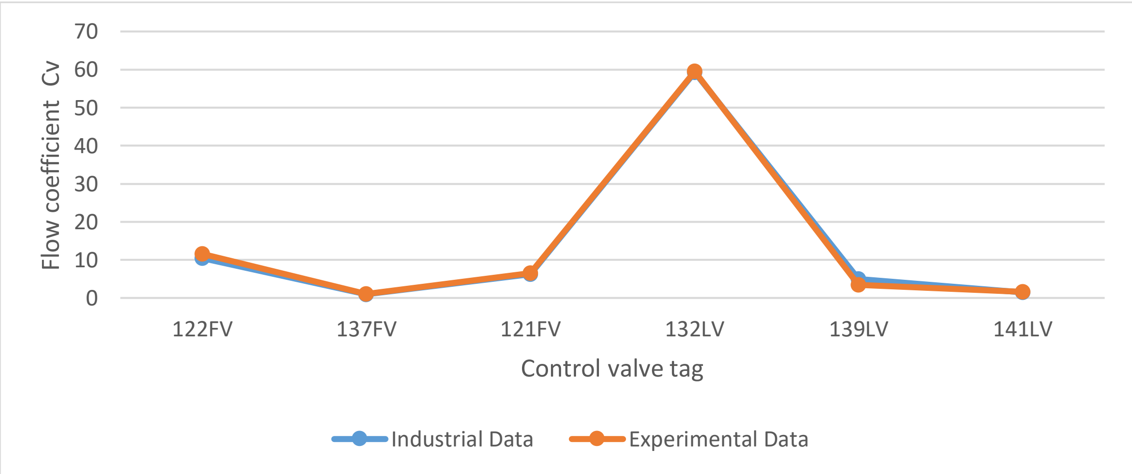

***Fig.2**. Comparative graphic between flow coefficient calculated and experimental data.*

CONCLUSIONS

The paper has presented the following:

- the main steps necessary to size and selection control valve;
- an application for selection and sizing control valve;
- the simulation of the application and the results of the simulation.

The main step supposed collecting data for industrial determination of the flow coefficient C_v or K_v for each flow regime and the nature of fluid. The flow coefficients are calculated based on equation presented in specific standard.

To apply the relationships for determining the flow coefficient in the different flow regimes, we created an application in which we implemented the algorithm for calculating the flow coefficient, in the Python programming language.

To verify the accuracy of the results generated within the application, based on the industry data, we performed a comparative analysis of the flow coefficient calculated with the existing one. Based on the analysis of the results, we deduced an absolute error of 0.015%.

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