STUDY OF LOCAL HEAD LOSSES IN HYDRAULIC SYSTEMS WITH HAWLE FITTINGS

PhD thesis – Summary

for obtaining the Scientific Title of PhD in Engineering from

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in Field of Civil Engineering and Building Services

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The PhD thesis was developed based on the study and research carried out in the Hydrotechnics Department, Civil Engineering Faculty, Politehnica University Timișoara.

The content of the thesis is structured on 6 chapters developed on 150 pages, comprising 46 figures and 128 tables in which information and original results of the research are presented synthetically, as well as a bibliography containing 41 classic and current representative bibliographic titles.

The research topic has its basic objective the experimental and theoretical study of local head losses (hydraulic resistances) generated by HAWLE fittings (gate valves and check valves) used for under pressure water transport systems, and the development on this basis of appropriate methods for the evaluation of local head losses, obtaining tables, graphs, and calculation formulas directly applicable in engineering practice. It should be noted that HAWLE fittings have special characteristics regarding material aspects, such as very smooth surfaces, and geometric shape (BAIO and System 2000 type joints, knife gate valve applicable for underground installation) for which currently does not exist systematic studies of local resistance coefficients.

In order to achieve the basic objective, the following work stages were carried out:

- **1st stage**: Documentation and presentation of the current state of research on the evaluation of local head losses generated by fittings integrated in piping systems

- **2nd stage**: Designing, building and equipping the appropriate facilities for carrying out the proposed experimental program

- **3rd stage**: Preliminary systematic experimental studies in order to determine the position of the pressure outlets upstream and downstream the studied valve, with the aim of eliminating the influence of disturbances on the measurements

- **4th stage**: Systematic experimental studies in order to determine the local resistance coefficients of HAWLE fittings (gate valves, check valves)

- **5th stage**: Synthesis of experimental results, proposals of semi-empirical formulas for the calculation of resistance coefficients, formulation of useful conclusions for future studies

In the **first chapter**, heaving an introductory role, the justification of the research topic is presented, emphasizing the importance of accurate evaluation of local head losses for the sizing of pressurized water systems. Pressure water systems are used for various applications, the actuality of the topic being justified by the fact that the realization and optimization of public water and wastewater systems are priority objectives of investments in Romania, according to directives no. 98/83/CE, 91/271/CEE and 98/15/CE. This chapter also presents the objectives pursued and the structure of the thesis.

In the **second chapter**, entitled "The current stage of the evaluation of local head losses in pipelines", the theoretical basis of the phenomenon of local load losses is presented, as well as the engineering approaches for the evaluation of local head losses, and the specific aspects of the studied valve types, including data regarding the values of the local resistance coefficients identified in the studied literature.

The methods for evaluating local head losses based on the local resistance coefficients, equivalent lengths, and flow coefficients are presented. The relationships between the two mentioned coefficients are also presented, respectively the proposed formula for approximating the local resistance coefficient of a valve manufactured by the same manufacturer, having the same constructive shape, but for an unknown diameter.

The specific aspects of the studied valve types are presented (gate valves and check valves produced by HAWLE). The local resistance coefficients identified in the studied literature are presented and interpreted, keeping in mind the relevant data which, in chapter 5, are used to validate the semi-empirical formulas proposed for the calculation of the local resistance coefficients for partial openings.

Within the Hydrotechnics Department of Politehnica University there is a HAWLE fittings presentation stand made in 2010, as a result of a collaboration between the Faculty of Hydrotechnics, HAWLE-Germany and the AQUADEMICA foundation (Timișoara). The existing installation was adapted with a special section, adequately equipped to ensure the conditions necessary to carry out the experimental measurements in the proposed program.

The design and realization of the experimental stand is presented in the **third chapter**. In addition to the provisions of the regulations regarding the scheme of the test facility and the quality of the measurements, this chapter also presents some problems that arose during the construction of the facility. Factors that can significantly influence water flow stability and/or measurement accuracy are discussed, including recommendations for managing these issues.

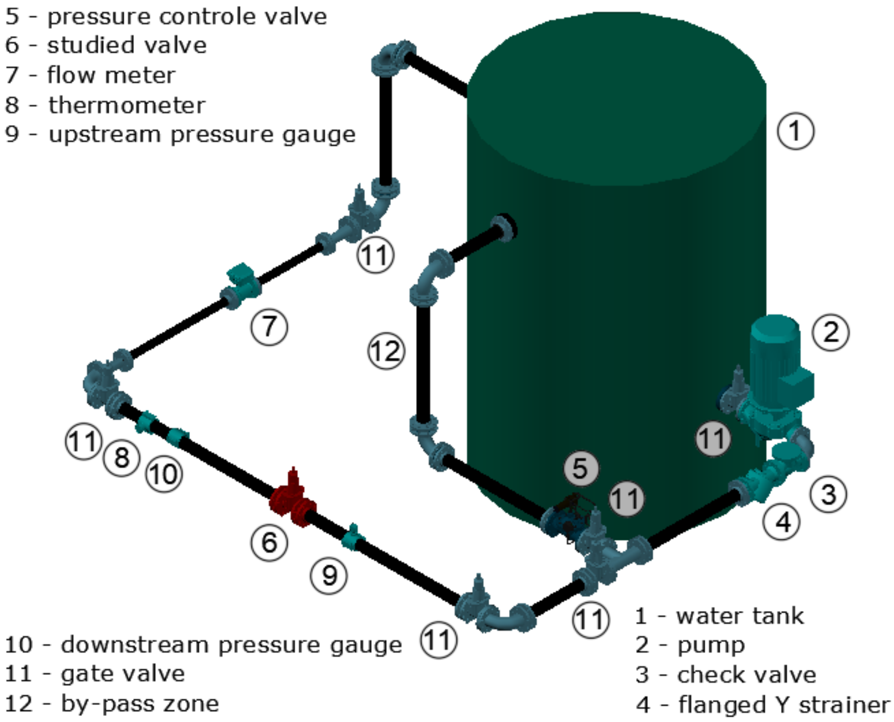

Figure 1. Designed test installation

Also, in this chapter are presented the devices used (manufacturer name, product name), the scheme of the pressure gauges with four taps at the measurement section (designed for carrying out the measurements necessary to determine the local resistance coefficients), and the comparison of the values measured with this kind of pressure gauges, with those measured with pressure gauges with a single tap at the measurement section.

The main components of the test installation and the positioning of the measuring devices are shown in Figure 1, in a simplified form, because apart from the valves and fittings represented, the stand also contains objects belonging to the presentation stand.

In the **fourth chapter**, the carried out experimental studies are presented.

The first stage of the experimental study refers to the determination of the section on which the turbulence caused by the valves occurs. In order to position the gauges of the differential pressure meter at correct distances from the studied valves, it was proposed to determine the distances from which additional local head losses caused by the studied valves no longer occur on the upstream and downstream straight sections for three different flow regimes, respectively for six opening degrees of the valve, between 0.375 and 1.0.

For the study wedge-type gate valves, made of cast iron, with a nominal diameter of 80 mm, with BAIO joints, produced by the Hawle company where used. The three regimes for which measurements were made are characterized by Reynolds numbers between the following ranges:

1. 18 x 10^3 – 20 x 10^3
2. 45 x 10^3 – 53 x 10^3
3. 60x 10^3 – 71 x 10^3

For this experimental study, pressure gauges with a single tap hole were used.

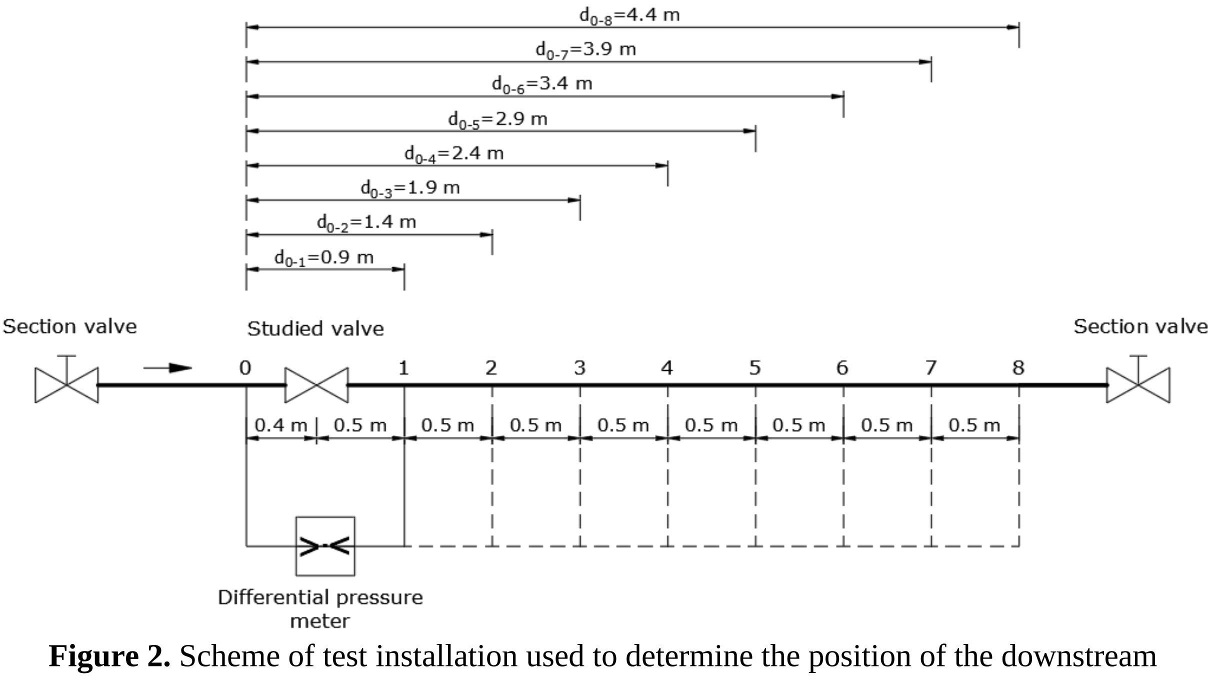

Figure 2. Scheme of test installation used to determine the position of the downstream pressure gauge

Figure 2 shows the scheme of the test installation provided with a reference pressure gauge 0.4 m upstream of the valve and nine pressure gauges mounted 0.5 m from each other on the downstream section.

Since this kind of measurements require a large working space (long measurement sections), the test facility was designed in such a way that the measurements for the upstream and downstream effects are performed in two stages, using practically the same facility, but changing the flow direction, according to Figure 3.

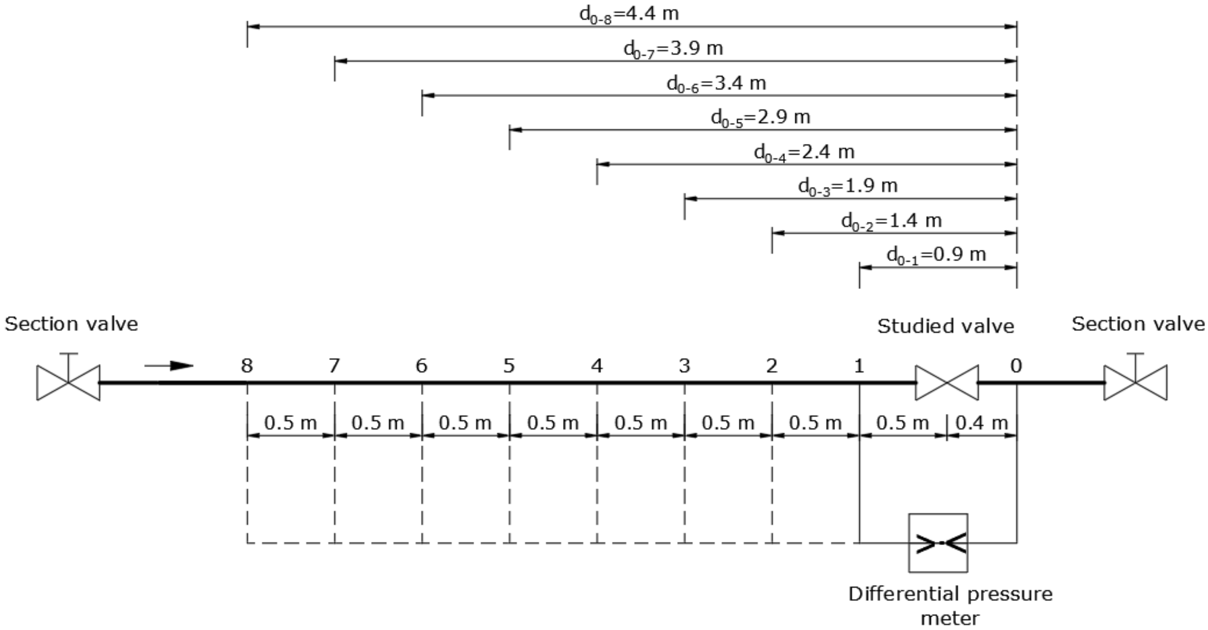

Figure 3. Scheme of test installation used to determine the position of the upstream pressure gauge

To calculate the unit linear head loss the following formula was used:

$$\Delta p_{longitudinal_{unitary}} = \frac{\Delta p_{0,i} - \Delta p_{0,i-1}}{\Delta d_{i-1,i}} \quad (1)$$

The calculation method used includes the following steps:

- Measurement of pressure losses $\Delta p_{0,1}$, $\Delta p_{0,2}$, $\Delta p_{0,3}$ ... $\Delta p_{0,8}$
- Calculation of pressure differences $\Delta p_{0,i} - \Delta p_{0,i-1}$, for i from 2 to 8
- Calculation of unitary longitudinal head losses with formula (1) for i from 2 to 8
- Application of formula (1) using another benchmark established on the basis of the results obtained - if necessary
- Correction of average read values – if necessary
- Identification of the pressure gauge from which additional local pressure losses no longer occur, respectively its distance from the studied valve

In Table 1 the recommended distances for the installation of pressure gauges in the case of the three studied regimes are presented.

Table 1. Summary table of minimum distances for pressure gauges for the studied regimes

Reynolds no.	Opening degree	Upstream distance		Downstream distance	
		(m)	(no. of DN)	(m)	(no. of DN)
18 000..20 000	1.0..0.875	0.46	6	0.96	12
	0.75..0.375	0.96	12	1.96	24.75
45 000..53 000	1.0..0.375	0.96	12	1.96	24.75
60 000..71 000	1.0..0.375	0.96	12	1.96	24.75

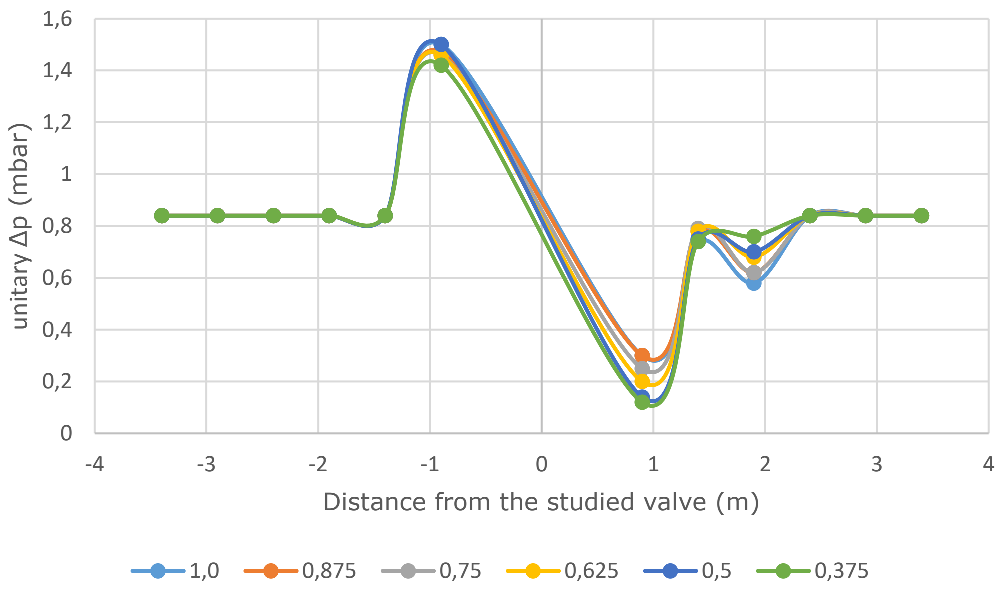

Figure 4. Unitary longitudinal pressure losses, Re 60 000..71 000

In Figure 4 are represented the unitary pressure losses determined in the experimental study for Re 60 000..71 000 at different opening degrees, the 0 value of the abscissa representing the position of the valve axis. A similar allure was identified also in the case of the other regimes studied and presented in the thesis.

As the turbulence caused by the valve develops over a longer area downstream, in that area the fluctuation of the trend caused by the turbulence can be observed, but for a more accurate study of the upstream area, it is needed to use gauges mounted at smaller distances from 0.5 m on a section of at least 1.0-1.5 m. Considering that the upstream area develops over a relatively short distance, in the present study it was not considered necessary to complete the data obtained with additional measurements.

The second experimental study aimed at the experimental study of local pressure losses in gate valves, both for valves dedicated to water and wastewater pressure systems.

The local resistance coefficients were determined by measuring the flow rate (Q), the section length and the pressure loss (Δp measured), respectively the calculation of the Reynolds number, the linear pressure loss (Δp linear), λ (calculated with the formula of Blasius), and the pressure loss due to the valve (Δp valve) (as the difference between the measured pressure loss and the linear pressure loss). Formula (2) was used to calculate the local resistance coefficient (ζ), and ζ_{med} represents the arithmetic mean of the coefficients determined for a certain calculation hypothesis.

$$\zeta = \frac{2\Delta p}{v^2 \rho} \quad (2)$$

The measurements were made at the pressure measured upstream of the calculation section of approx. 2.5 bar.

For the study of gate valves designed for drinking water systems, E2- type wedge gate valves produced by Hawle were used.

Since it was also aimed to verify the dependence of ζ on the type of joint (which can affect the dimensions of the valve body), measurements were made for the following models of gate valves equipped with different joint types:

- Flanged E2-type wedge gate valve, DN 80 mm, made of cast iron
- E2-type wedge gate valve with System 2000 joints, DN 80 mm, made of cast iron

- E2-type wedge gate valve with BAIO joints, DN 80 mm, made of cast iron

The measurements were made using pressure gauges with tapping holes, mounted according to the schemes shown in Figure 7.

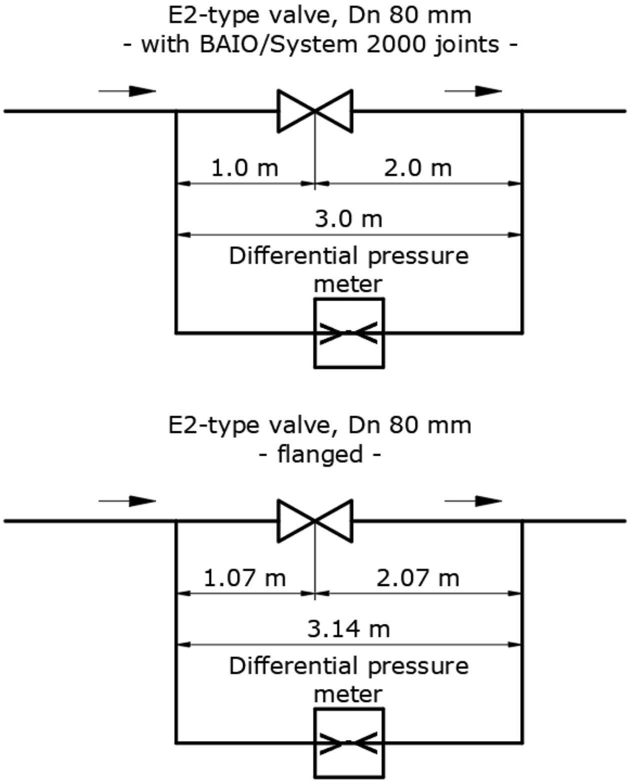

Figure 7. Scheme of measuring section used to determine of local resistance coefficients of wedge gate valves

Table 2. Table of ζ values for E2-type wedge gate valves with different joints

Opening degree	ζ		
	flanged	System 2000	BAIO
1.0	0.021	0.018	0.020
0.875	0.043	0.047	0.045
0.75	0.121	0.143	0.122
0.625	0.297	0.338	0.298
0.50	0.686	0.754	0.673
0.375	1.631	1.740	1.544
0.25	4.511	4.732	4.383

Table 2 shows the ζ values determined for E2-type wedge gate valves with flanged, System 2000 and BAIO joints. It can be observed that the values determined for the flange-type joint and for the one with BAIO-type joints are close (the differences between the values are of at most 5%), but those determined for the System 2000-type joints are higher, except in the case of full opening where the value of ζ is slightly lower than for the other joint types (even equal rounded to two decimal places).

Considering that the values determined for valves with flanged and BAIO-type joints can be considered equal to the average of the experimentally determined values, it is observed that the values determined for the valve with System 2000 type joint are higher by 6..15% compared to the mentioned averaged values, the average difference being around 10%.

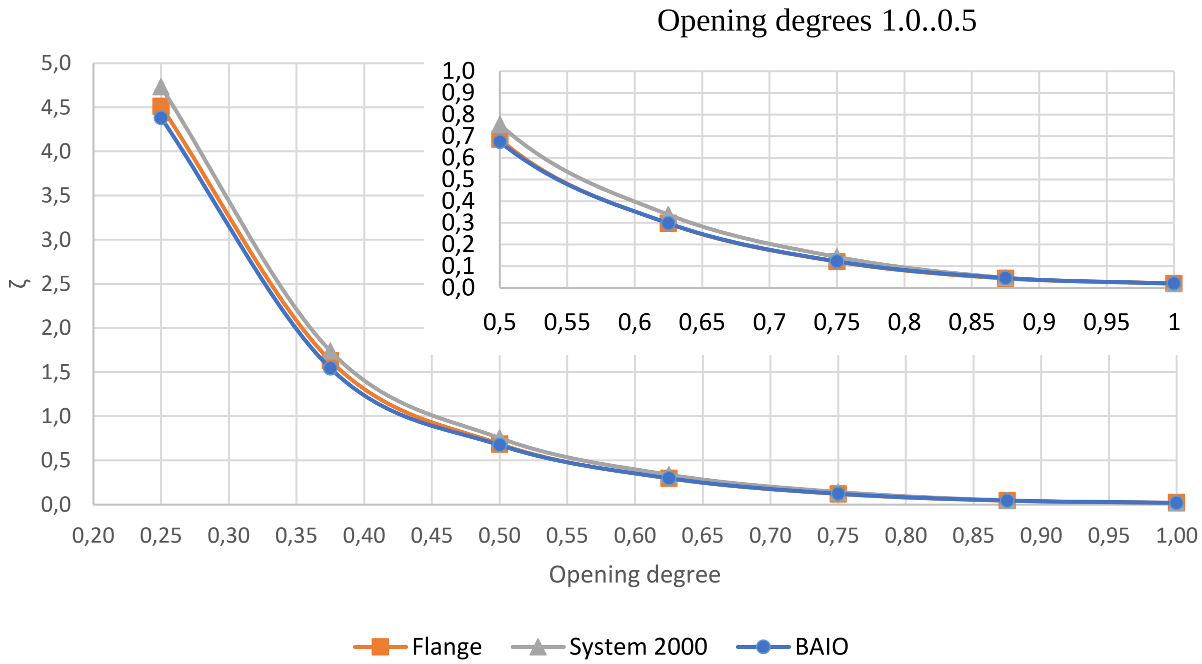

Figure 8. Values of ζ E2-type wedge gate valves with different type of joints

In Figure 8 are presented the local resistance coefficients determined by the own experimental study of wedge gate valves with flanges, BAIO-type and System2000-type joints.

The study of drawer valves designed for under pressure wastewater systems was carried out on the knife gate valve produced by Hawle, with a different construction from the classic one, the valve being designed so that it can be mounted buried directly in the ground.

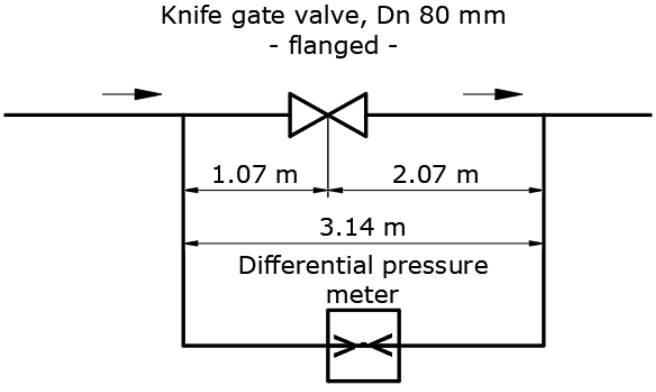

Figure 9. Scheme of measuring section used to determin of local resistance coefficients of knife gate valves

In Figure 9 are represented the positions of the pressure gauges with four tapping holes, mounted in order to make the measurements.

Table 3. Summary table of ζ values for valves designed for water and wastewater systems

Opening degree	ζ		
	Valve - water	**Valve - wastewater**	**Difference %**
1.0	0.018	0.051	65
0.875	0.047	0.055	15
0.75	0.143	0.145	1
0.625	0.338	0.454	26
0.50	0.754	1.611	53
0.375	1.740	5.614	69
0.25	4.732	25.347	81
Average percentual differences			44

Table 3 shows the values of the local resistance coefficients determined for the studied knife gate valve, respectively the differences between these values and those determined for wedge gate valves used for potable water applications. For the comparison of the two types of gate valves, the values related to the valve with System 2000 coupling have been considered, because the local resistance coefficients determined for this type of connection are higher than in the case of the other types of connections studied for wedge gate valves used for potable water applications. It is observed that at lower opening degrees than 0.75 the local head losses caused by knife valves are much higher than in the case of wedge gate valves, but according to the data in Table 3 the difference is also significant in the case of full opening: 65%., the local resistance coefficient of the knife valve being practically almost 2.5 times higher than the maximum value determined for all three types of studied wedge gate valves.

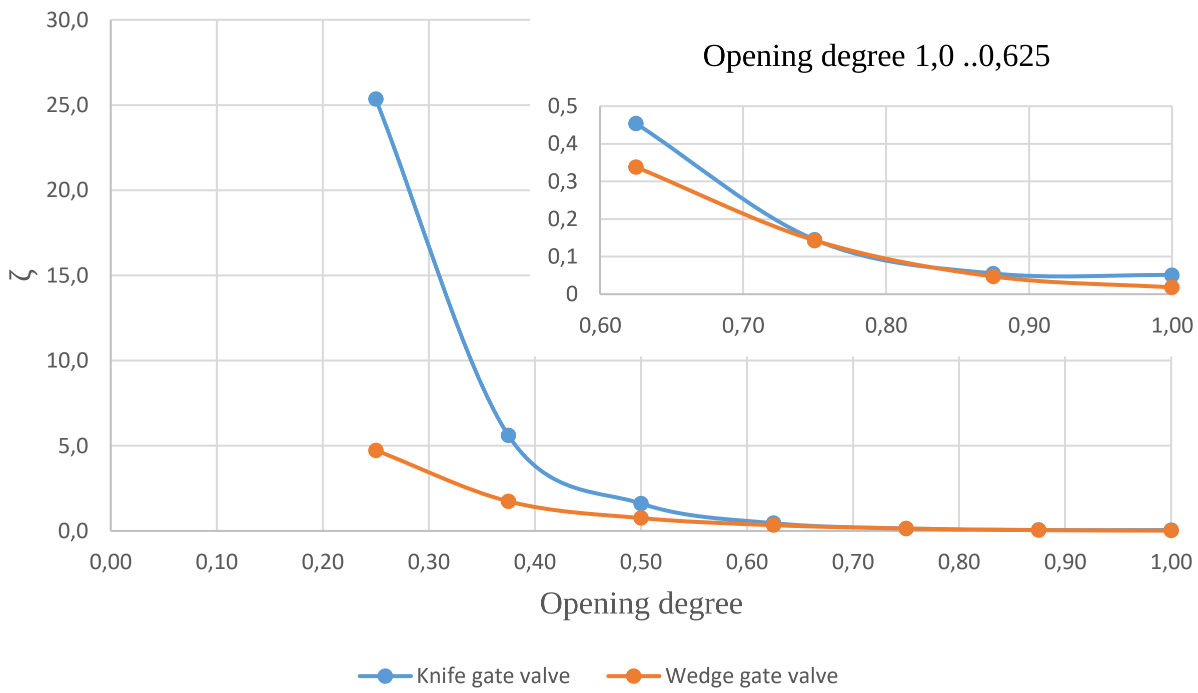

Figure 10. Comparative graph of ζ values for knife valve and wedge gate valve

Figure 10 shows the ζ curves depending on degrees of opening from 1.0 to 0.25, respectively between 1.0 and 0.625. It can be observed that the relationship between the ζ values determined for the different opening degrees present a very different allure compared to that of the gate valves intended for potable water applications.

The last experimental study carried out in the present research refers to the study of local head losses at check valves designed for potable water and wastewater applications.

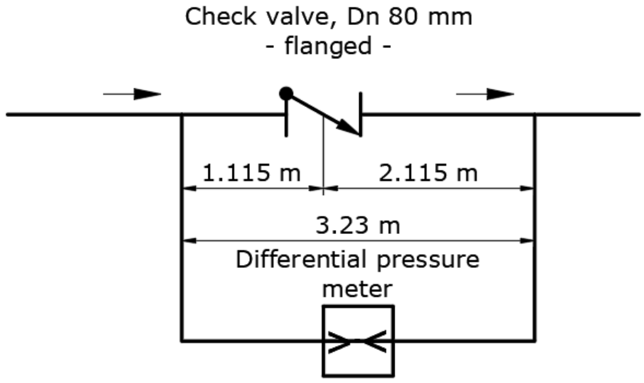

Figure 11. Scheme of measuring section used to determin of local resistance coefficients of check valves

In Figure 11 the positions of the pressure gauges are represented, upstream and downstream of the studied check valves. Given that the two check valves are the same length, the distances of the pressure gauges from the two types of fittings are also identical.

The measurements were made at the pressure measured upstream of the calculation section of approx. 2.5 bar.

In this study two types of check valves were analyzed: swing check valves (without lever and counterweight), which can be used for both drinking water and wastewater systems, and ball check valve for wastewater systems.

For the swing check valve, it was determined an average local resistance coefficient, ζmed = 0.130, resulting a flow coefficient K_v=709 m^3/h, which is very different from the flow coefficient published by the manufacturer for DN 80 mm check valves: 271 m^3/h. It is important to note that for the value published by the manufacturer the exact type of the check valve is not specified.

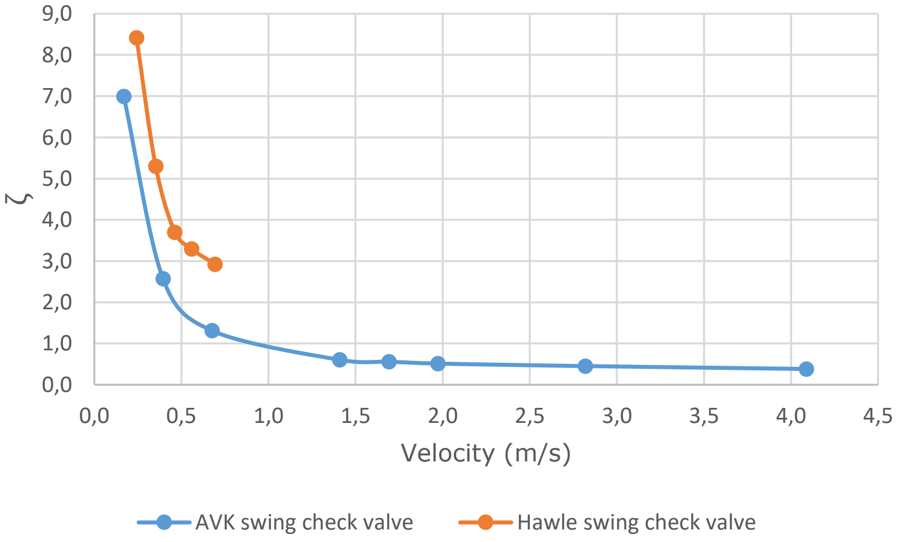

Figure 12. ζ values for ball check valves, depending on the flow velocity

Figure 12 shows the ζ values of ball check valves manufactured by AVK and Hawle, depending on flow velocity. For the ball check valve manufactured by AVK the ζ coefficients were estimated based on the diagram published by the manufacturer. Since for the studied check valve measurements could only be made for velocities below 0.7 m/s, and on this interval the graph obtained has a similar allure to the one referring to the AVK valve, for a more detailed analysis of the phenomenon, in Figure 12 values for velocities up to 4 m/s are also presented.

For the ball valve, three areas of variation of the coefficient ζ can be identified depending on the flow velocity:

- At velocities lower than 0.5 m/s, high values of the ζ coefficient were identified with a very sudden decreasing trend. The difference between the values related to the velocities of 0.24 and 0.56 m/s is approx. 156%. AVK notes that the valve can be considered fully open above 0.5 m/s.

- In the range of velocities about 0.5..1.5 m/s there is a transition zone

- At velocities above 1.5 m/s the decrease of the coefficient ζ becomes much smoother, but even in this zone the difference between the values related to velocities of 1.41 and 4.09 m/s is approx. 58%.

Apart from the dependence of the local resistance coefficient on the flow velocity, another important aspect is that the values determined for the ball check valves are much higher than those determined for the swing check valve. Even the minimum value of the ball check valve determined for the speed of 4.09 m/s is almost 3 times higher than the average value determined for the studied swing check valve.

In the **fifth chapter** there is a summary of the experimental results and semi-empirical formulas are proposed.

Analyzing the dependence of the resistance coefficient for different opening degrees, it can be observed that in the studied literature there is no unanimity about the partial openings for which experimental measurements are made - the exception being the fully open position and the opening degree of 0.5. In many cases, however, manufacturers publish only the coefficient for to the full opening.

It can also be observed that the variation of valve resistance coefficients depending on the opening degree has certain specific characteristics:

- $\lim_{\frac{a}{D}\to 1} \zeta_{\frac{a}{D}}$ tends to very small values (close to 0)
- $\lim_{\frac{a}{D}\to 0} \zeta_{\frac{a}{D}}$ tends to very high values

Based on these observations, the following general form is proposed for the semi-empirical formulas for gate valves:

$$\zeta_{a/D} = \zeta_{1,0} C e^{\sigma\left(1-\frac{a}{D}\right)} \quad (3)$$

where

$\zeta_{a/D}$ represents the local resistance coefficient related to an opening of a/D,

$\zeta_{1,0}$ represents the local resistance coefficient related to the full opening,

$\frac{a}{D}$ represents the opening degree (0 – fully closed, 1 – fully open),

and the coefficients C and σ are determined based on the experimental results.

The validation of the proposed general form was based on the following sources from the studied literature:

For wedge gate valves:

- $\zeta_{a/D}$ coefficients determined by Idel'chik for wedge-type gate valves for openings between 0.25 and 1.0. This source does not specify the diameter of the valve for which the experimental measurements were made.

- $\zeta_{a/D}$ coefficients determined and published in a table in the appendix of the AVK product catalog for openings between 0.3 and 1.0 for valves having DN 80 mm.

For knife gate valves:

- $\zeta_{a/D}$ coefficients determined by Idel'chik for openings between 0.25 and 0.9. The type of gate valve is not specified but it can be assumed that it refers to knife gate valves. This source does not specify the diameter of the valve for which the experimental measurements were made.
- $\zeta_{a/D}$ coefficients determined and published as a diagram in the Erhard product catalog for openings between 0.3 and 1.0 for valves (”ERU K1 knife gate valve) having DN 100 mm.

When choosing the sources, the aim was not to validate the general form strictly for a certain nominal diameter of the valves, but to propose formulas that are valid regardless of it.

The two coefficients, C and σ, from formula (3) were determined for each type of gate valve, analyzing the dependence of the expression $e^{\left(1-\frac{a}{D}\right)}$ of the opening degree. The coefficients were determined using the Microsoft Excel software, by generating trendlines.

The following semi-empirical calculation formulas are presented in the thesis:

1. For wedge gate valves: $\zeta_{\frac{a}{D}} = \zeta_{1,0} 0.92 e^{7.22\left(1-\frac{a}{D}\right)}$ (4)
2. For knife gate valves with classic valve body: $\zeta_{\frac{a}{D}} = \zeta_{1,0} 0.68 e^{8.56\left(1-\frac{a}{D}\right)}$ (5)
3. For knife gate valves with unusual valve body: $\zeta_{\frac{a}{D}} = \zeta_{1,0} 0.23 e^{10.03\left(1-\frac{a}{D}\right)}$ (6)

The first two formulas, (4) and (5), were validated based on the coefficients from the literature mentioned above, resulting an average accuracy of 90% and 91-94%, and formulas (4) and (6) were applied to the coefficients determined by our own experimental studies, resulting an average accuracy of 95% and 89-90%. Thus, it is considered that the proposed formulas represent a practical and useful tool in the evaluation of local load losses related to partial openings, based on local resistance coefficients determined experimentally for the full opening.

In this chapter also the local resistance coefficients determined by the own experimental study are analyzed, in comparison with the data from the studied literature, and the equivalent lengths proposed for the studied valves are presented.

In the **sixth chapter** personal contributions and recommendations regarding the calculation of local head losses at the studied valves are presented.

Among the personal contributions we mention:

- Study of the literature regarding the evaluation of local head losses caused by gate valves and check valves, with the following conclusions and observations:
  - it can be stated that if for fittings dedicated to drinking water applications there is data including at the level of manufacturers' catalogs, for fittings dedicated to wastewater applications there is much less such data
  - it was found that the values published in scientific materials without specifying the exact type of valve are suggestive for understanding the phenomenon, but are not recommended for use at the level of hydraulic modeling. Moreover, for high-precision calculations, coefficients determined exactly for the specific

model (type, diameter, manufacturer's variant) must be used.

- the provisions of the regulations related to the design of valve testing facilities were studied, presenting the aspects identified and clarified through own experience regarding the positioning, mounting and calibration of the necessary measuring devices
- an experimental study was carried out in order to determine the distances of the pressure gauges from the studied valves according to the studied flow regime and opening degree. The experimental study showed that the minimum distances provided by the SR EN 1267 and SR EN 60534-2-3 standards are suitable for determining the local resistance coefficient for fully open gate valves, but if it is desired to determine some coefficients for partial openings, it is recommended to increase the distances of the pressure gauges of the studied valve. It was proposed to mount the upstream gauge at a minimal distance of 1.0 m (equivalent lengths of approximately 12 nominal diameters), and the downstream gauge at a minimal distance of 2,0 m (equivalent lengths of approximately 25 nominal diameters).
- an experimental study was carried out for the local resistance coefficient of gate valves having DN 80 mm
- the influence of the type of joint on the values of the local resistance coefficients was presented, considering that Hawle offers several types of quality joint compared to the classic flanges. If in the case of flanges and BAIO-type joints resulted very close values, for the System 2000 type coupling resulted coefficients with approx. 10% higher values as the other two types of joints.
- it was found that the differences between the values of the experimentally determined coefficients for the different types of joints can be considered minor and negligible, but the lack of accuracy demonstrated in terms of the value of the coefficient published by the manufacturer for the range of diameters between 50 and 150 mm, and the average coefficient determined according to own experiments it is significant. This aspect emphasizes the need of using coefficients determined for a specific product with the same nominal diameter, if a very accurate evaluation of the local head loss is aimed.
- analyzing the dependence of the resistance coefficients on the degrees of partial opening of the gate valves, a general form of the formula for calculating the resistance coefficient of gate valves was proposed. The advantage of the proposed form is that it offers the possibility of determining the values related to any partial opening through a quick calculation, without the need to use diagrams or tabular data, based only on the local resistance coefficient experimentally determined for the full opening.
    - it has been demonstrated that this form of formula is valid both for the experimental coefficients from the studied literature and for the coefficients determined in the present research.
    - the coefficients C and σ must be determined for each type of valve with a specific constructive form. It has been shown that in the case of the valve produced by Hawle for wastewater applications, a valve with a body similar to the wedge gate valves, but with a knife-type closure element, the variation of the resistance coefficients related to the different opening degrees is different both from the variation of the wedge gate valves, as well as the variation of knife gate valves with a flat body (the classic constructive variant). Even in this case, the general formula can be applied, but with coefficients determined specifically for this specific constructive form of the valve.
    - within the thesis, a calculation formula was proposed for the following types of gate valves: wedge gate valve, knife gate valve (with classic, flat body) and knife

gate valve produced by Hawle (which can be buried directly in the ground)

- the knife valve produced by Hawle for under pressure wastewater systems (the constructive variant that can be mounted and buried directly in the ground) can be considered an atypical constructive variant, because in the studied literature there was found no data related to local head loss produced by this type of valve, demonstrating the special importance of carrying out experimental studies for such special constructive variants

- the local resistance coefficient was experimentally determined for the DN 80 mm swing check valve produced by Hawle, which theoretically can also be used for wastewater, and the result was compared with the other studied sources. Also, an experimental study was carried out for the ball check valve manufactured by Hawle, and recommendations were formulated regarding the aspects considered in the evaluation of pressure losses caused by check valves depending on the type of their closure element.

We mention that for the fittings dedicated to wastewater applications, for which our own experimental measurements were made (ball check valve and knife gate valve with atypical constructive form manufactured by Hawle), until the writing of this thesis, there were no other experimental results published.

In this last chapter there are proposed also recommendations regarding the calculation of local head losses at the studied valves both regarding experimental evaluation, respectively numerical evaluation of local head losses, and for new research related to the evaluation of local head losses in the case of under pressure water/wastewater systems.

The thesis also contains four **appendices** related to the main parameters of drinking water, to the analysis of the data published by AVK for wedge gate valves with diameters between 50 and 150 mm, to the proportionality of the local resistance coefficients with a different diameter compared to the experimentally determined one for a certain diameter between 50 and 150 mm, respectively showing pictures of the test facility and the equipment used.