T.C.
MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES IN
PURE AND APPLIED SCIENCES

EXPERIMENTAL ANALYSIS OF THE PERFORMANCE COEFFICIENTS OF THE BUTTERFLY VALVES

Mehmet SANDALCI

THESIS
FOR THE DEGREE OF MASTER OF SCIENCE
IN
MECHANICAL ENGINEERING PROGRAMME

SUPERVISORS
Asst. Prof. Dr. Ebru MANÇUHAN
Asst. Prof. Dr. Kurtul KÜÇÜKADA

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ACCEPTANCE AND APPROVAL DOCUMENT

The jury established by the Executive Board of the *INSTITUTE FOR GRADUATE STUDIES IN PURE AND APPLIED SCIENCES* on April, 27, 2009 (…………...................) has accepted Mr Mehmet SANDALCI 's thesis titled "EXPERIMENTAL ANALYSIS OF THE PERFORMANCE COEFFICIENTS OF THE BUTTERFLY VALVES" as Master of Science thesis in mechanical engineering.

Advisor : Asst. Prof. Dr. Ebru MANÇUHAN

1. Member of the jury : Prof. Dr. Galip TEMİR
2. Member of the jury : Asst. Prof. Dr. Emre ALPMAN

.

Date : ....

APPROVAL

Mr .... has satisfactorily completed the requirements for the degree of Master of Science in .... at Marmara University. The Executive Committee approves that he be granted the degree of Master of Science on……………… (Resolution no:)

DIRECTOR OF THE INSTITUTE
Prof. Dr. Sevil ÜNAL

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June, 2009 **Mehmet SANDALCI**

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ABSTRACT

EXPERIMENTAL ANALYSIS OF THE PERFORMANCE COEFFICIENTS OF THE BUTTERFLY VALVES

In the present work, two different butterfly valves, DN65 and DN80, were tested according to standard testing method ANSI/ISA-75.02-1996. The tests were performed at different flow rates such as 2, 3 and 4 m/s and at different valve opening angles such as 0, 10, 20, 30 and 40°. The opening angle 0° was considered as the fully open valve. The flow area percentages, ϕ , were calculated for different valve openings as 100, 82.64, 65.80, 50 and 35.72% and pressure drops, ΔP, were recorded for different valve openings at different velocities.

Using the experimental data the loss and flow coefficients, K and C_v, were calculated and correlations were developed to give K and C_v as a function of the flow area percentage, ϕ. Uncertainty analysis was performed to show the effect of the measurement uncertainties on the performance coefficients.

The proposed correlations provide an effective way to determine the performance coefficients of two different sizes of butterfly valves. The loss coefficient is independent of the inlet velocity but it is dependent of the valve size at the lower flow area percentage. However, when flow area percentage is more than 65% the proposed correlations, $K = 1.074 \times 10^5 \phi^{-2.514} \pm 3\%$ or $K = 0.244 \times 10^5 \phi^{-2.269} \pm 3\%$, can be used for two valve sizes.

Flow coefficient is independent of the inlet velocity but it is dependent on the valve size. The proposed correlations giving the flow coefficients as functions of the flow area percentage are $C_V = 49.053 \exp(0.0195\phi) \pm 1.5$ and $C_V = 34.334 \exp(0.018\phi) \pm 3.35$ for DN80 and DN65 valves, respectively.

Correlations for K and C_v which are given are appropriate for practical use. Manufacturer or designer of butterfly valves can find easily the corresponding K and C_v values for different valve opening.

Keywords: Butterfly valve, Loss coefficient, Flow coefficient, Uncertainty analysis.

June, 2009 **Mehmet SANDALCI**

ÖZET

KELEBEK VANALARDA PERFORMANS KATSAYILARININ DENEYSEL OLARAK İNCELENMESİ

Bu çalışmada, DN65 ve DN80 öçlülerindeki iki farklı vana, standart test metodu ANSI/ISA-75.02-1996'ya uygun olarak test edilmiştir. Bu test farklı akış hızlarında (2, 3 and 4 m/s) ve farklı açıklık açılarında (disk açılarında) (0, 10, 20, 30 and 40°) gerçekleştirilmiştir. 0° açıklık açısı tam açık vana konumu olarak kabul edilmiştir. Farklı açıklık açılarına tekabül eden akış alan yüzdeleri hesaplanmış, farklı akış hızlarında ve farklı vana açıklıklarındaki basınç kayıpları kaydedilmiştir.

Deneysel veriler kullanılarak K ve C_v değerleri hesaplanmış ve K ve C_v değerlerini akış alan yüzdelerine bağlı fonksiyon şeklinde veren korelasyonlar geliştirilmiştir. Ölçüm belirsizliklerinin, performans katsayıları üzerindeki etkisini göstermek için belirsizlik analizi yapılmıştır.

Sunulan korelasyonlar, iki farklı kelebek vananın performans katsayılarının belirlenmesinde etkin bir yöntem sağlar. Kayıp katsayısı, akışkanın, vanaya giriş hızından bağımsızdır. Fakat düşük akış alan yüzdelerinde vana çapına bağlıdır. Buna rağmen , $K = 1.074 \times 10^5 \phi^{-2.514} \pm 3\%$ or $K = 0.244 \times 10^5 \phi^{-2.269} \pm 3\%$, şeklinde sunulan korelasyonlar, %65' den daha büyük akış alan yüzdelerinde, iki farklı vana çapı için kullanılabilir.

Debi katsayısı akışkan giriş hızından bağımsızdır fakat vana çapına bağımlıdır. DN65 ve DN80 ölçüsündeki vanalar için sunulan korelasyonlar; $C_V = 49.053 \exp(0.0195\,\phi) \pm 1.5$ ve $C_V = 34.334 \exp(0.018\,\phi) \pm 3.35$, akış alan yüzdeleri cinsinden debi katsayılarını verir.

K ve C_v için verilen bu korelasyonlar, pratik kullanımlar için kabullenilir. Kelebek vana üreticileri ve tasarımcıları, farklı vana açıklık değerlerine göre, K ve C_v ‘ yi kolayca bulabilirler.

Anahtar kelimeler: Kelebek vana, Kayıp katsayısı, Debi katsayısı, Belirsizlik analizi

Haziran, 2009 **Mehmet SANDALCI**

LIST OF SYMBOLS

A_0 valve flow area (m^2)

A_v valve cross section area (m^2)

Q volumetric flow rate (m^3/s or gal/min)

C_v flow coefficient (US gal/min)

K loss coefficient (-)

P_{in} upstream pressure (psi)

P_v downstream pressure (psi)

r_v valve radius (m)

V flow velocity (m/s)

U_K Uncertainty for loss coefficient (-)

U_{Cv} Uncertainty for flow coefficient (gal/min)

$U_{\Delta P}$ Uncertainty for the pressure drop (N/m^2 or psi)

U_Q Uncertainty for the volume flow rate (m^3/s or gal/min)

Greek Letters

ΔP pressure drop (N/m^2)

ΔP_0 reference pressure drop (N/m^2)

ρ density (kg/m^3)

ρ_0 density of reference fluid (kg/m^3)

θ disc rotation angle (degree)

ϕ flow area percentage (%)

Subscripts

DN nominal diameter

PN nominal pressure

i initial

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PART I

INTRODUCTION

Valves are the most important types of fittings commonly used on installations. Man's desire to control fluids, led the development and designation of valves for various purposes. Widely used valves, generally function only as tools to turn on and off, but sometimes they are used for difficult tasks such as protecting the entire enterprise and its personnel. The diversity of purposes led the development of different types of valves in various designs.

Thanks to countless research and development efforts, it was understood that the ability of controlling fluids depends on the characteristic of a valve; in other words depends on the fluid controlling ability and working performance of a valve. These characteristics and performance values vary according to each manufacturer's design and play important roles when choosing valves. Actually, different types of valves can be chosen depending on the operating conditions, place and purpose of use, while on the other hand, the availability of too many options for the same purpose might lead us to indecisiveness. If this is the case, the fitting that has the lowest resistance against the fluid should be preferred. Wrong choice for the installation will cause a great loss of energy. Today, the energy cost appears as the highest cost component for enterprises. Since energy saving would lower costs, valve manufacturers design and manufacture valves to provide minimum resistance against fluids. These features sell the product well in foreign markets and the important valve users ask such characteristics and performance data thereof.

I.1 OBJECTIVE OF THE PRESENT WORK

The aim of this study is to measure and observe variations of performance coefficients (loss coefficient and flow coefficient) of DN65 and DN80 butterfly valves for different flow conditions. These two different sizes being DN65 and DN80 are the most commonly used sizes in industrial applications. The flow conditions refer to 3 different Reynolds numbers for two different sizes of the valves at 5 different valve flow area percentage (100%, 82.64%, 65.80%, 50%, 35.72%) corresponding to 0°, 10°, 20°, 30°, 40°, regarding the fully open position (100% open) as 0°. The Reynolds number changes from 1.555×10^5 to 3.12×10^5 for DN80 and from 1.255×10^5 to 2.52×10^5 for DN65 sizes of valves. These values of the Reynolds number correspond to 3 different velocities such as 2, 3 and 4 m/s.

I.2 THESIS OUTLINE

A simple information about the valves as introduction, and objective of the present work were defined shortly in chapter 1.

Chapter II introduces valve world. This chapter is divided into three sections. In section II.1, the valves are described. In section II.2, categorization and classification of the valves depending on their design and use are defined. Finally, the use and design parameters of the butterfly valves are explained in section II.3.

In chapter III, valve performance and performance coefficient definition are mentioned. This chapter is divided into three sections. In section III.1, loss coefficient, in section III.2, flow coefficient and in section III.3, cavitation index are described.

In chapter IV, literature surveys about the valve performance are shared.

Chapter V presents experimental method for measuring the parameters to calculate valve performance values. This chapter is divided into four sections again. In section V.1, experimental test setup is expressed. In section V.2, simulation of a butterfly valve flow area is shown. In section V.3, results of the measurement are presented. In section V.4, information about uncertainty analysis is given.

Chapter VI, the last section, includes results and conclusion. Results and the purpose of the results are presented briefly. This chapter is divided into four sections again. In section VI.1 and VI.2, experimental measurement is given in the form of tables and graphics. In section VI.3, comparison of the results with the results found from the previous literatures and handbooks is done. In section VI.4 conclusion and suggestions are given.

PART II

THE VALVES

II.1 DEFINITON OF A VALVE

Valves are an essential devices of any piping system that regulate liquids, gases, vapors, slurries by opening, closing or partially obstructing various ports or passageways. Valves are used in a wide range of application including industrial, commerical, residential, military, transportation and many more. Common types of valves include globe, gate, butterfly, ball, check, plug, diaphragm, pinch, pressure relief, and control valves (Figure II.2). Each of these types has various categories and designs, each offering different properties and functional capabilities (Table II.1). They have certain inherent advantages and disadvantages.Understanding these differences and how they effect the valve's application or operation is necessary for the successful operation of a facility.Although all valves have same essential components, parts and the method of controlling the flow.

In general, there are four methods of controlling flow through a valve(Figure II.1).

1) Move a disc, or plug into or against an orifice as globe and needle valves
2) Slide a flat, spherical or cylindiricalsurface across an orifice as gate and plug valves
3) Rotate a disc or ellipse about a shaft extending across the diameter of an orifice as ball and butterfly valves
4) Move a flexible material into the flow passage as diaphragm and pinch valves

Each method has different characteristics that makes it the best choice for a given application of function.

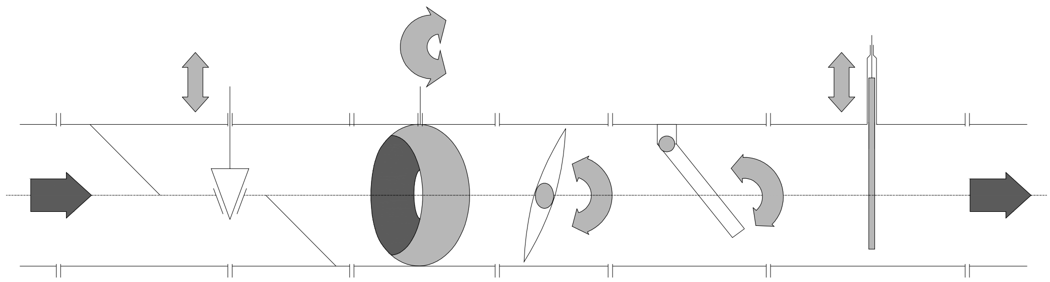


Figure II.1. Various flow control methods

Valves can be designed for liquid or gas applications.They can be operated manually, electrically, pneumatically, mechanically, hydraulically, or by combinations of these methods. In general valves are characterized by their types, sizes, and pressure classes.

The valve nominal size is an alphanumerical reference to identify parts and fittings used in a pipe system. This value is expressed with the letters DN, the abbreviation of nominal diameter, and with numbers equal to the physical size of the fitting hole in mm (e.g. DN200). However, this value is not used in calculation unless otherwise stated. Below are the standard nominal sizes given in ascending order.

DN10, DN15, DN20, DN25, DN32, DN40, DN50, DN65, DN80, DN100, DN125, DN150, DN200, DN250, DN300, DN350, DN400, DN450, DN500, DN600, DN700, DN800, DN900, DN1000, DN1100, DN1200,DN1400, DN1500, DN1600, DN1800, DN2000, DN2200, DN2400, DN2600, DN2800, DN3000, DN3200, DN3400, DN3600, DN3800, DN4000

Nominal sizes are given in “inches” in the American system (according to ANSI) as listed blow in ascending order:

1/4’’, 3/8’’, 1/2’’, 3/4’’, 1’’, 11/4’’, 11/2’’, 2’’, 21/2’’, 3’’, 4’’, 5’’, 6’’, 8’’, 10’’, 12’’, 14’’, 16’’, 18’’, 20’’, 24’’, 30’’, 36’’, 42’’, 48’’

The valve nominal pressure is an alphanumerical reference to identify parts and fittings used in a pipe system. This value is expressed with the letters PN, the abbreviation of nominal pressure and the maximum pressure value in “bars” allowed for the fitting used (e.g. PN16). However, as it is given in the following chapters the allowed operational pressure of a valve depends on the fitting’s PN level, material, structure, and the fluid’s temperature. Since the material resistance decreases in higher temperatures, working pressure values decrease in inverse proportion. Below are the standard nominal pressures given in ascending order:

PN2.5, PN6, PN10, PN16, PN25, PN40, PN63, PN100

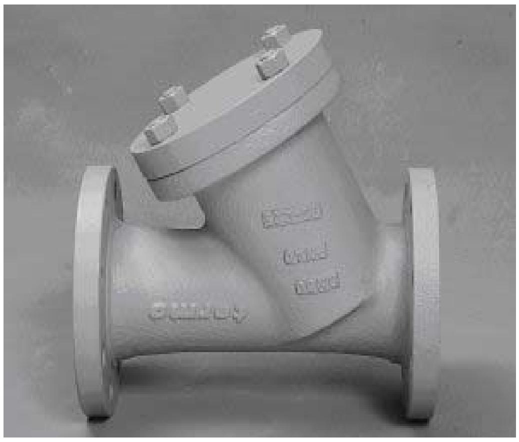
In order to select a suitable valve for a particular application, the user must evaluate the valve characteristics, including the design features, materials of construction, and performance, in light of specific application requirements: flow medium, process design requirements, piping design criteria, and economic factors.By nature of their design, function, and application, valves come in a wide variety of styles, sizes, and pressure classes.

Lastly valves come in various materials to meet individual requirements. These materials include plastic, carbon and stainless steel, ductile or cast iron, brass, and, bronze.Valves were standardized by several enterprise like ANSI, API, ASME, AWWA, BSI, DIN, and MAA for global usage and compatibility in installation sector.

Ball valve

Check valve

Butterfly valve



Strainer

Bellow sealed globe valve

Safety valve

Figure II.2. Common armatures used on installations

Table 2.1. Description of common valve types

NAME	DESCRIPTION
Gate	Flat faced vertical barrier (disc or gate) that slides down through valve to blockflow
Globe	Stem adjust linearly (up and down) to vary position of plug with respect to matching horizontal seat
Butterfly	Flow controlling disc rotates with a wing-like action, at right angles to the flow
Ball	Solid ball with section removed is rotated to adjust flow
Check	Automatically prevent the reversal of flow in a pipeline system. Design to control the direction of flow, rather than throttling and isolating
Pinch	Flexible element, such as rubber tube, pinched to shut off flow
Needle	Similar in principle to a globe valve except valve closure is achieved by lowering a slender point fitting into a conical or needle seat
Diaphragm	Vary flow by forcing a flexible diaphragm down into a seat

II.2 VALVE CLASSIFICATION

2.2.1 Valve Classification According to Function

Thanks to the wide technical knowledge and creativity of the valve designers, various types of valves and fittings for various industrial purposes have been developed. Diversity of products and many different variations of those products caused valves to be classified in many categories.

Basically, valves are classified into four main groups according to their tasks or functions (Figure II.3):

1) **On – Off Valves :** They let the flow to be turned on or off. Besides, they allow or prevent mixing of the liquid. They are expected to minimize pressure loss in the on position, and not to exceed a certain leakage value in the off position.
2) **Throttling Valves :** They regulate or keep the flow rate of fluids passing through the installation constant, at the desired level. Throttling valves can be used as on – off valves, but on – off valves can not be used as throttling valves.
3) **Control Valves :** Control valves: They regulate flow rate and temperature of fluids manually or by an actuator. They also function as keeping the value of a parameter constant under variable process conditions by controlling the effective factors.
4) **Safety Valves :** They prevent and compensate extreme and sudden pressure increases that pose danger.

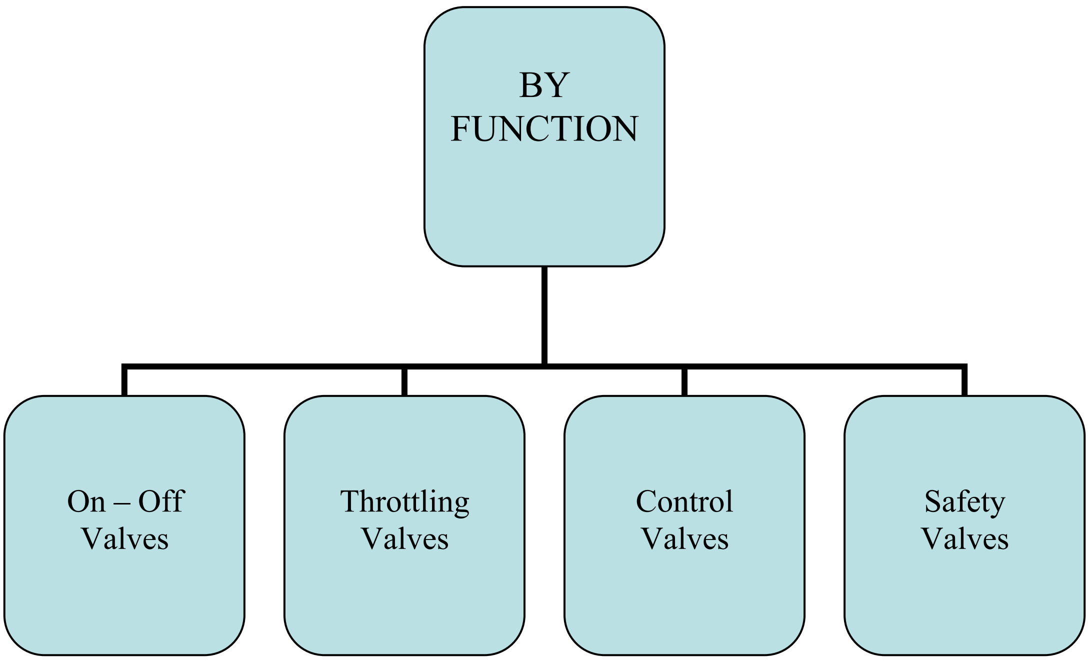


Figure II.3. Valve classification according to function

2.2.2 Valve Classification According to Mechanical Motion

Based on the mechanical or cyclical motion of the valve closure member, valves are classified as follows (Figure II.4). Linear motion valves in which the closure member, as in gate, globe, diaphragm, pinch, and lift check valves, moves in a straight line to allow, stop, or throttle the flow. When the valve-closure member travels along an angular or circular path, as in butterfly, ball, plug, eccentric-and swing check valves, the valves are called rotary motion valves. Some rotary motion valves are called require approximately a quarter turn, 0 through 90 degree, motion of the stem to go to fully open from a fully closed position.

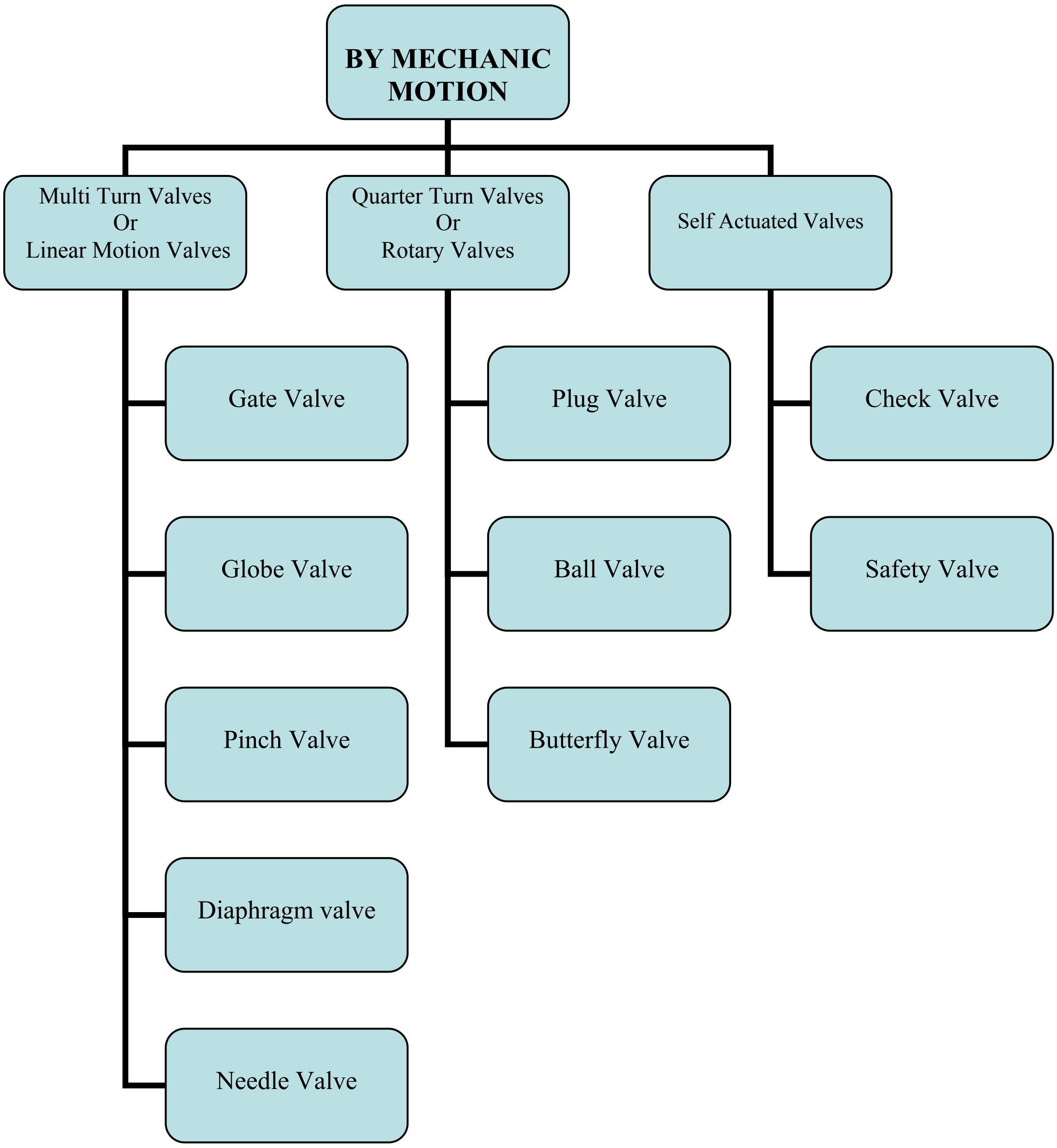


Figure II.4. Valve classification according to mechanic motion

II.3 BUTTERFLY VALVES

Butterfly valves are a member of quarter turn valve family and used to control, regulate or throttle flow. They are generally specified for most compressible and incompressible fluid applications as air, gas, steam, and water. Butterfly valves are suitable high or low pressure and temperature applications. The most important properties of them are having low pressure drop and high pressure recovery factor. Because of that butterfly valves are mostly used in large water distribution and transmission lines.

Butterfly valves are produced in sizes ranging from DN40 to aver DN5000. Majority, butterfly valves from DN40 to DN200 are controlled by handle or lever, but over DN200 they are controlled by gearbox or actuators. They are usually manufactured in flanged, wafer, and lug, or single-flange-type designs. Wafer style valves are installed "sandwiched" between two flanges. This style of valve is easier to replace or install. However, replacing a wafer valve requires the conveying line to be drained. Once the valve is removed, there is nothing to seal material either downstream or upstream from the removal point. Lug style valves contain tapped holes that allow them to be bolted directly to a mating flange. In the closed position, the valve independently seals material to the upstream and downstream side. Because of this independent sealing, lug type valves may be used to isolate downstream equipment that may require replacement or maintenance.

2.3.1 Structure of Butterfly Valves

In general, a butterfly valve is made up from 6 main components (Figure II.5). These components are;

1. Body
2. Seat
3. Disc
4. Stem
5. Lever or actuator.

Each component part is available in a variety of materials called "trim features." Properly combining trim features to address material handled and environment is important in selecting the correct model valve for its intended service.

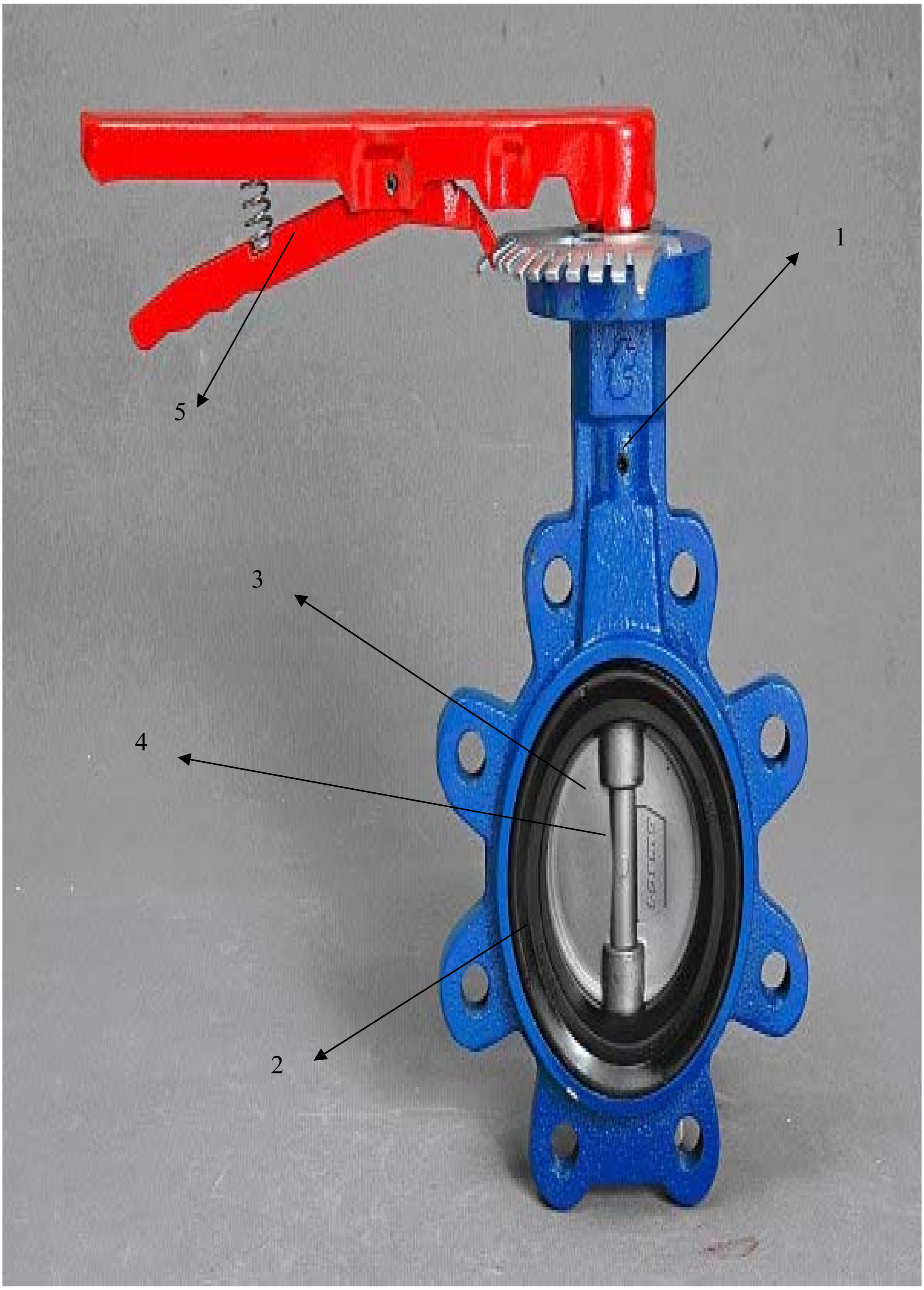


Figure II.5. Essential parts of butterfly valves

1. **Body**

   A butterfly valve body can be made of cast iron, ductile iron, aluminum, carbon steel, stainless steel and exotic metals.

2. **Seat**

   Resilient seated valves are the most commonly used types. The interior of the valve body is lined with an elastomer seat. Seats may be made of EPDM, buna, viton, Teflon, natural rubber, carbox, chlorbutyl, white buna, or white neoprene as well as other materials. Choice of seat material depends on temperatures, pressures and material handled. The seats of some inexpensive butterfly valves are typically molded into the body and cannot be repaired or replaced. Precision butterfly valves typically contain removable seats that are repairable or replaceable.

3. **Disc**

   The valve disc (controlled by the actuator) regulates the flow of material within the conveying line. Disc materials are available to meet a variety of application demands: stainless steel, aluminum/bronze, ductile iron, ductile/epoxy coated, ductile/nickel plated, ductile/nylon II coated as well as others. As the disc is directly in the material flow stream, care must be taken in specifying the proper material of construction and disc shape. Some discs are designed to allow increased flow patterns through the piping.

4. **Stem**

   The stem passes through the center of the valve, attaches to the actuator, and positions the disc for material flow control and shut off. Depending on the application and valve size, stems may be one or two-piece construction. Typical materials of construction include carbon steel and different grades of stainless steel.

5. **Actuator or lever**

   A variety of actuators are available for butterfly valves: manual handle, gearbox, electric, pneumatic and hydraulic actuators

2.3.2 Advantages and Disadvantages of Butterfly Valves

Important advantages accompanied by some disadvantages of butterfly valves, widely used in industrial applications, are well known. Their outstanding advantages in comparison to other valves are: they are smaller in volume, lighter in weight, and are manufactured in a wider size range (from DN40 to DN 5000). Technically, these valves have low pressure drop under high pressure working conditions.

Beside there are many advantages offered by butterfly valves compared to other types of valves including an inherently simple, economic design that consists of fewer parts, which makes butterfly valves easy to repair and maintain. The wafer-shaped body and relatively light weight offer a savings in the initial cost of the valve and installation costs -- in person-hours, equipment and piping support.

However, cavitation and choked flow are the common problems experienced on installations with butterfly valves. Due to their insufficient leakage capability, they are not preferred in critical fluid applications.

Butterfly valves are suitable for these systems:

1. Cooling water, air, gases, and other similar applications
2. Pump lines
3. Food processing, chemical services
4. Slurry services
5. High-pressure and high-temperature water and steam services
6. Throttling service
7. Vacuum service

PART III

VALVE PERFORMANCE

Characteristic behaviors of a valve under various working conditions are called the valve's performance. In other words, valve performance is a valve's optimum working capability under the conditions it is operated. Valve performance is one of the important criteria for choosing valves. The right fitting used properly at the right place will increase the efficiency of our installations, and hence the productivity of our facility. Therefore, the valves and fittings, which we are to use on our installations, should be deeply surveyed.

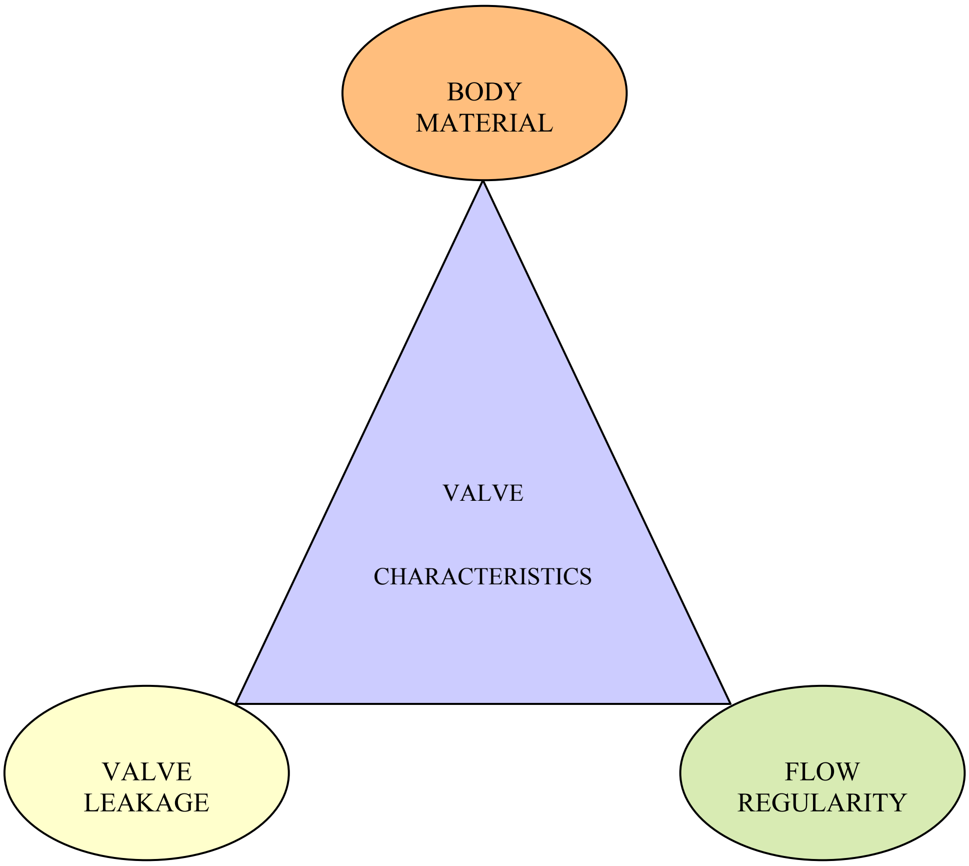


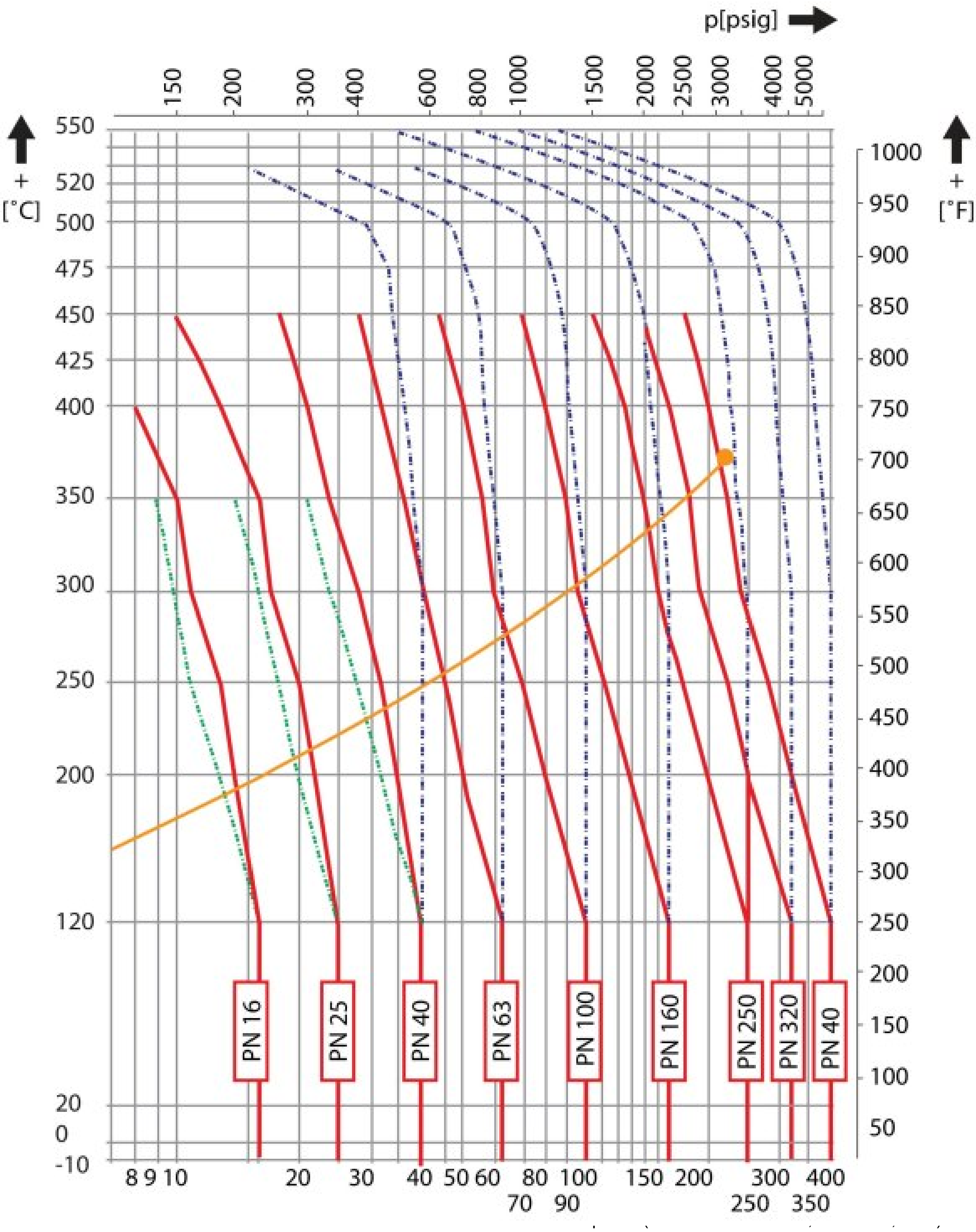
Figure III.1. Classification of valve characteristics

Basically, valve characteristics can be classified into three main groups (Figure III.1):

1. Valve Body Material characteristics
2. Valve Leakage characteristics
3. Valve Flow-regime characteristics

Material characteristics are the response of the body and internal components of a valve to temperature, pressure and fluid characteristics. Having determined the type of valve to be used on the installation, one of the important steps to be taken is determining the material of the valve's body. Cast iron (GG25), ductile iron (GGG40.3), steel (GSC-25), carbon steel (C 22.8) , high alloy steel (G17 CrMo 5-5 or 13 CrMo 4-5) , stainless steel, bronze and brass are used as body materials by the industry kullanılır. Each material offers different characteristics under different temperature and pressure values. These characteristics are given in details, in table...
As it is seen, temperature and pressure are the main parameters. These two important parameters are insignificant on their own. Selecting a body material only by means of temperature or pressure is definitely the incorrect way. Both of them should be taken into account.

The most significant conclusions we can draw from the diagram (Figure III.2) are:
Materials' nominal pressure values are lowered above 120°C. For instance, ductile iron valve with the nominal pressure of PN25 can be used only at 20 bars when the temperature is raised to 200°C, while it can be used up to 120°C at 25 bars. Operating pressure is lowered as the temperature rises. A material with higher strength properties should be preferred, if pressure remains constant. Body material should be decided very carefully and special alloy steel should be preferred, if the temperature rises up to 450°C.



Saturated steam (critical point: 705,47 °F/3207,4 psig)

Set pressure p (bar/bar g)

_ _ _ _ _ _ _ G17 CrMo 5-5, 13 CrMo 4-5   _ _ _ _ _ _ _ GG 25

———— GP 240 GH, C 22.8
(t > 400 °C: nach/acc. DIN EN 10213-2)

———— Sattdampflinie (kritischer Punkt: 374,15 °C/221,2 bar)
Saturated steam (critical point: 705,47 °F/3207,4 psig)

———— GGG 40.3

Figure III.2. Valve body material selection diagram

Seals are materials preventing leakage of materials of any kind between moving or non-moving machine parts. Leakage characteristics are the response of seals -just like the valve body material- used in valves under the same working conditions with the same valves.

Valve leakage can be classified into two groups:

1) Valve Outer Sealing
2) Valve Seat Leakage (Seat leakage)

The sealing between a valve and external environment is known as the outer sealing and generally provided by using seals between body & lid, shaft & cover, or connection flange against possible leakage (Figure III.3).
The materials commonly used for this purpose:

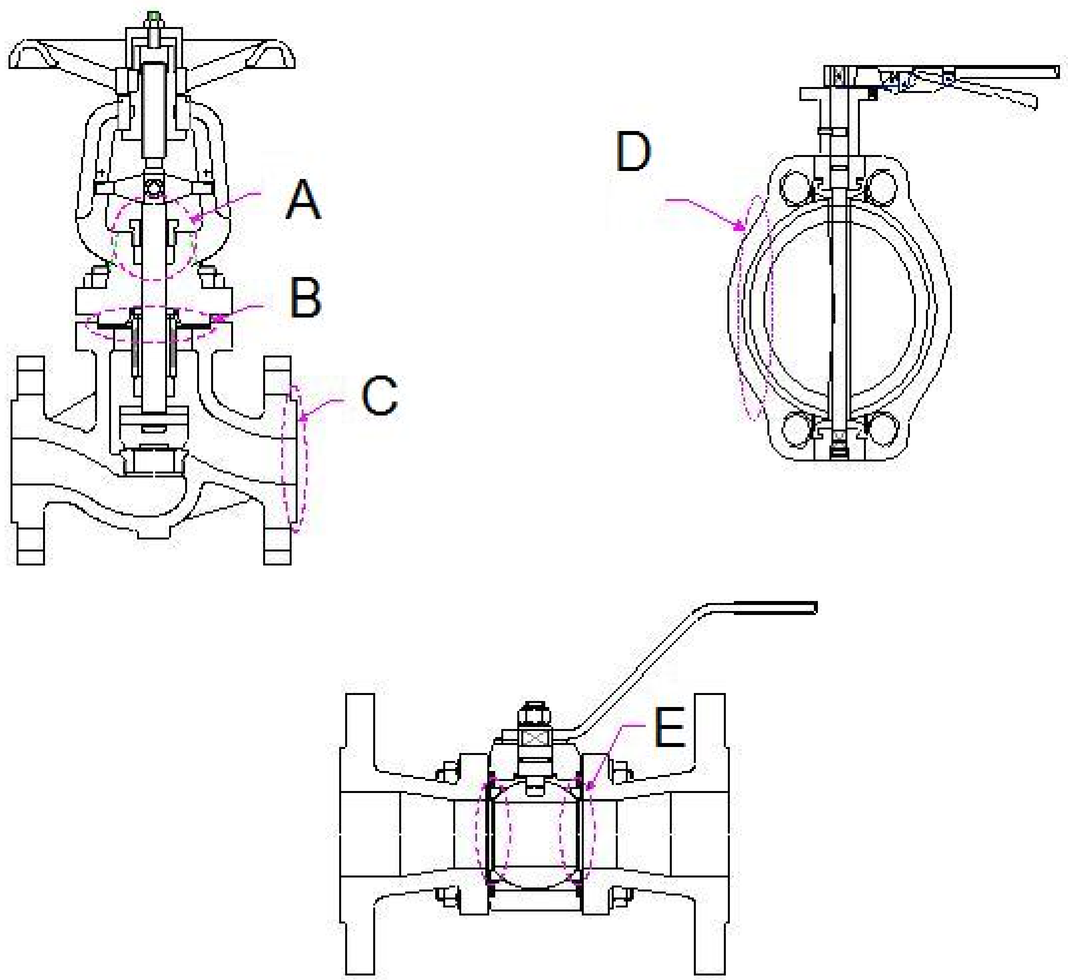
- IT seal
- Nonasbestos seal
- Graphite seal
- Metal seal
- P.T.F.E
- P.T.F.E packing
- Graphite packing

Valve, not allowing the fluid to pass is called seat leakage. Fluid passage throughout the valve is prevented by a seal placed between the flap or disc and the seat. There is also another sealing method, in which no sealing material is used. This method called metal-to-metal sealing, and requires high quality surface improvement (peening). This method is mainly preferred when high pressure is in question.

Commonly used materials for seat leakage are

- P.T.F.E (polytetrafluoroethylene)
- EPDM (ethylene propylene diene M class rubber)
- NBR (nitrile butadiene rubber)
- VITON
- NEOPRENE
- FLUORCEL
- HYPALON

and they are mainly used in spherical and throttle valves.



III.3. Valve seat leakage and outer sealing surfaces

A good seat leakage does not only depend on the structure and characteristics of the seal used. It depends on the level of excellent fitting between the flap and seat or the seal, and their harmonious operation. Desired valve leakage performance is obtained when these requirements are met. A statement such as “100% leakage proof” is never spoken in valve industry. Certain levels of leakage are allowed and tolerated. Valve leakage tests are conducted with suitable fluids at desired temperature and pressure, and in accordance with the tolerance limits specified by the norms.

There are actually six different seat leakage classifications (Table III.1) as defined by ANSI/FCI 70-2 1976(R1982) .

Class I

Identical to Class II, III, and IV in construction and design intent, but no actual shop test is made. Class I is also known as dust tight and can refer to metal or resilient seated valves.

Class II

Intended for double port or balanced singe port valves with a metal piston ring seal and metal to metal seats.

• 0.5% leakage of full open valve capacity.

• Service dP or 50 psid (3.4 bar differential), whichever is lower at 50 to 125^{o}F.

• Test medium air at 45 to 60 psig is the test fluid.

Typical constructions:

• Balanced, single port, single graphite piston ring, metal seat, low seat load

• Balanced, double port, metal seats, high seat load

Class III

Intended for the same types of valves as in Class II.

• 0.1% leakage of full open valve capacity.

• Service dP or 50 psid (3.4 bar differential), whichever is lower at 50 to 125^{o}F.

• Test medium air at 45 to 60 psig is the test fluid.

Typical constructions:

• Balanced, double port, soft seats, low seat load

• Balanced, single port, single graphite piston ring, lapped metal seats, medium seat load

Class IV

Intended for single port and balanced single port valves with extra tight piston seals and metal to-metal seats.

• 0.01% leakage of full open valve capacity.

• Service dP or 50 psid (3.4 bar differential), whichever is lower at 50 to 125^{o}F.

• Test medium air at 45 to 60 psig is the test fluid.

Typical constructions:

• Balanced, single port, Teflon piston ring, lapped metal seats, medium seat load

• Balanced, single port, multiple graphite piston rings, lapped metal seats

• Unbalanced, single port, lapped metal seats, medium seat load

• Class IV is also known as metal to metal

Class V

Intended for the same types of valves as Class IV.

• The test fluid is water at 100 psig or operating pressure.

• Leakage allowed is limited to 5 x 10 ml per minute per inch of orifice diameter per psi differential.

• Service dP at 50 to 125 ^{o}F.

Typical constructions:

• Unbalanced, single port, lapped metal seats, high seat load

• Balanced, single port, Teflon piston rings, soft seats, low seat load

• Unbalanced, single port, soft metal seats, high seat load

Class VI

Class VI is known as a soft seat classification. Soft Seat Valves are those where the seat or shut-off disc or both are made from some kind of resilient material such as Teflon. Intended for resilient seating valves.

• The test fluid is air or nitrogen.

• Pressure is the lesser of 50 psig or operating pressure.

• The leakage limit depends on valve size and ranges from 0.15 to 6.75 ml per minute for valve sizes 1 through 8 inches.

Table III.1. Valve seat leakage testing procedures

LEAKAGE CLASS DESIGNATION	MAXIMUM LEAKAGE ALLOWABLE	TEST MEDIUM	TEST PRESSURE	TESTING PROCEDURES REQUIRED FOR ESTABLISHING RATING
I	X	X	X	No test required
II	0.5% of rated capacity	Air or water at 50-125 °F	45-60 psig or max. Operating differential whichever is lower	45-60 psig or max. Operating differential whichever is lower
III	0.1% of rated capacity	As above	As above	As above
IV	0.1% of rated capacity	As above	As above	As above
V	0.0005 ml per minute of water per inch of port diameter per psi differential	Water at 50-125 °F	Max. Service pressure drop across valve plug not to exceed ANSI body rating	Max. Service pressure drop across valve plug not to exceed ANSI body rating
VI	Not to exceed amounts shown in the table above	Air or nitrogen at 50 to 125°F	50 psig or max. Rated differential pressure across valve plug whichever is lower	Actuator should be adjusted to operating conditions specified with full normal closing thrust applied to valve plug seat

The most common used are CLASS IV and CLASS VI in valve sector. CLASS IV is also known as metal to metal, CLASS VI is known as a soft seat classification as before I said.

As we mentioned before, leakage is an important matter that needs to be focused on. It is more important in installations, in which toxic and chemical materials and materials hazardous to environment and living organisms are used.
The most important factors to be considered when choosing a seal are

1. Temperature
2. Pressure
3. Medium

P-T (Figure III.4) diagrams play important roles in choosing seals, just like in choosing body materials. These diagrams are different for each manufacturer and product. Therefore, each seal behaves specifically different under various working conditions. Such characteristic behaviors somehow indicate the products performance.

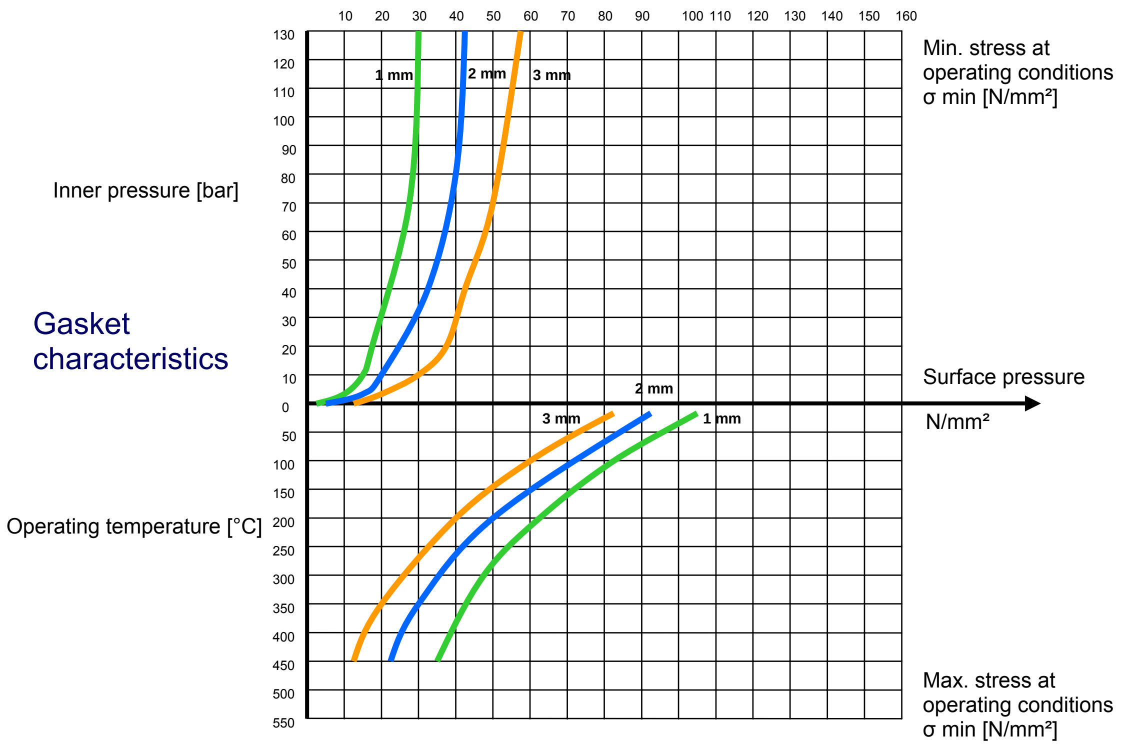


Figure III.4. Gasket characteristics vs. Pressure and temperature

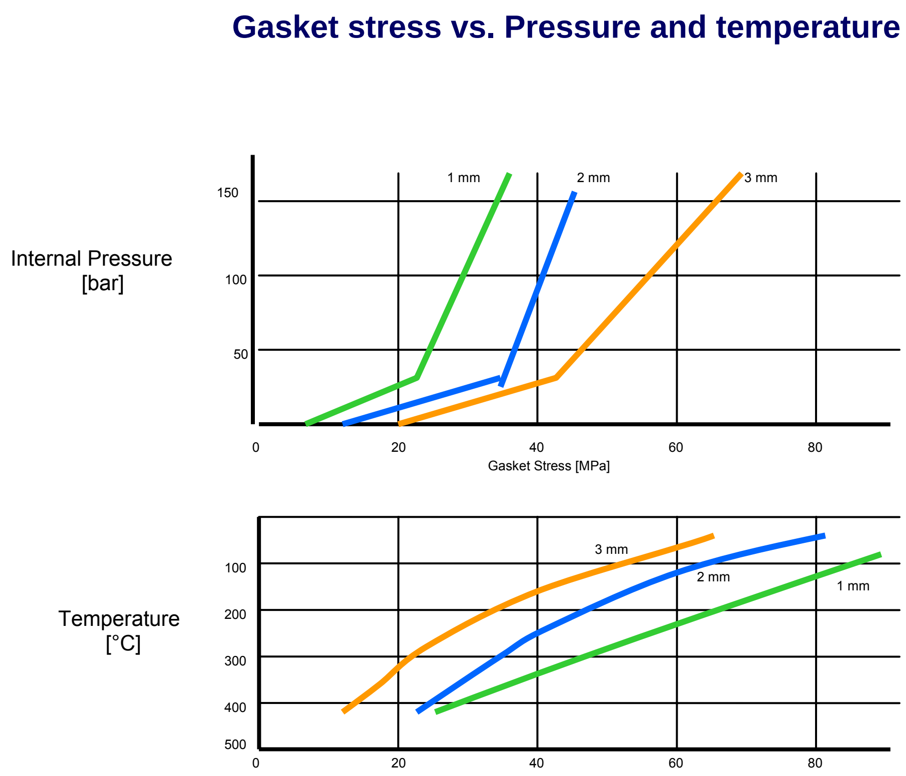


Figure III.5. Seal thickness according to temperature and pressure

Diagrams that help us on choosing seals and define their characteristics are given in Figure III.5. Knowing only the temperature and pressure might not suffice especially for choosing seals for critical applications. Many other parameters (compressibility, recovery, stres relaxation, increase in thickness, gas tightness etc.) as Figure III.6, should be considered. Computer based professional analysis should be made, as well.

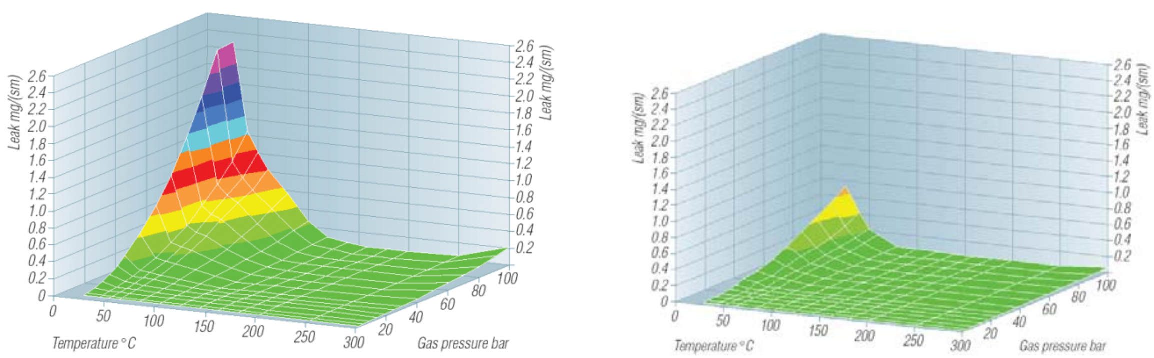


Figure III.6. Professional analysis of performance of a sample seal

Flow – regime characteristic shows the valve's capability level of not disturbing the flow order and obstructing the flow in the pipeline. The above mentioned material and leakage characteristic is generally permanent that can not be improved while the flow – regime characteristic is directly related to valve design, and can be improved constantly. For this reason, valve flow characteristic and its effects on valve performance are especially studied in our project. These are given in details under the following headings.

Valve flow – regime characteristic is directly related to the performance of a valve and generally denoted by 3 characteristic coefficients. The first one of them is the coefficient (K), showing the energy loss caused by the valve. It can be denoted as

$$K = \frac{\Delta P}{\frac{1}{2}\rho V_i^2} \qquad \text{(III.1)}$$

The second is the flow coefficient (C_V), defining the fluid leakage capability of the valve. It is defined as

$$C_V = Q\left(\frac{\Delta P_0}{\Delta P}\frac{\rho}{\rho_0}\right)^{1/2} \qquad \text{(III.2)}$$

The third and the last one, the cavitation index (C_{CS}), analyses the cavitation.

$$C_{CS} = \frac{\Delta P}{P_{in} - P_v} \qquad \text{(III.3)}$$

III.1 PERFORMANCE COEFFICIENTS

III.1.1 Loss Coefficient

The loss coefficient is unique to each type of valve and it is a dimensionless parameter giving the ratio of the pressure drop to the kinetic energy of the fluid. The loss can be given as follows for any valve geometry:

$$K = \frac{\Delta P}{\frac{1}{2}\rho V^2} = \frac{1}{V^2}\frac{2\,\Delta P}{\rho} \qquad \text{(III.4)}$$

In Eq. (III.4), v is the inlet velocity, ρ is the density of the fluid and ΔP is the pressure drop measured between 2 diameters in front of the valve and 6 diameters behind the valve as shown Fig. III.7

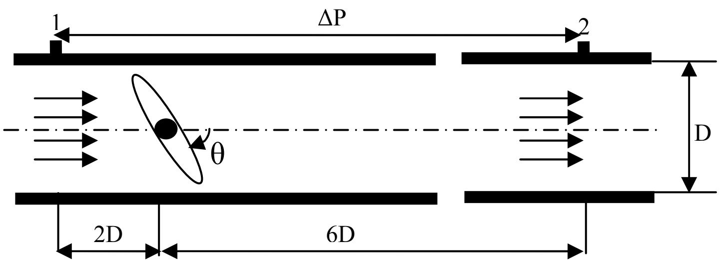


Figure III.7. Measurement points on the test setup

Normally, loss coefficient values can be calculated with this formulas but for some requirements we can use approximate acceptance values for each armature or fitting as shown Table III.2.

Table III.2. Generally accepted K values

Product	Type of component	"K" value
Tee	Line flow, flanged	0.2
	Branch flow, flanged	1
Elbow	Regular 90º, flanged	0.3
	Long radius 90º, flanged	0.2
	Long radius 45º, flanged	0.2
Valves	Globe valve, fully open	10
	Butterfly valve, fully open	2
	Gate valve, fully open	0.15
	Gate valve, ½ closed	2

III.1.2 Flow Coefficient

The flow coefficient is defined as the flow capacity of a valve at a standard temperature between 5 and 40°C corresponding to a unit pressure drop, ΔP_0, at an opening position. The value of ΔP_0 is 1 psia or 1 N/m^2 depending on the units of Q being U.S. gal/min or m^3/s. In the below equation, ρ_0 represents the density of the reference fluid which is water and it is taken as 62.4 lb/ft^3 or 1000 kg/m^3 depending on the units of Q.

$$C_V = Q\left(\frac{\Delta P_0}{\Delta P}\frac{\rho}{\rho_0}\right)^{1/2} \qquad \text{(III.5)}$$

The flow coefficient is generally given in U.S. gal/min and it is given for a reference temperature of 60°F and for a reference pressure loss, ΔP_0, of one pound per square inch at a specific opening position. When ΔP_0 and ρ/ρ_0 are taken as unity the above equation reduces to:

$$C_V = Q\left(\frac{1}{\Delta P}\right)^{1/2} \qquad \text{(III.6)}$$

In the above equation when the volume flow rate, Q, and the pressure drop are used in units of U. S. gal/min and psia, the flow coefficient, C_v, is obtained in U.S. gal/min, Perry & Zappe [14,21].

III.1.3 Cavitation Index

Cavitation is a phenomenon that happens in liquids. As impurities travel through the vena contracta, the fluid velocity will increase and the pressure decreases below the vapor pressure of the liquid creating a "bubble" around this impurity. The "bubble" will travel downstream, the velocity of the fluid slows and the pressure rises above the vapor pressure causing the "bubble" to collapse or implode. If these implosions contact any solid surfaces, the material will become pitted.

These implosions can have shock waves as high as 100,000 psi. Over time, this erosion can cause severe structural damage.

Cavitation occur under these conditions

1. Upstream and downstream of the vena contracta must be in the liquid state.
2. The liquid can not be in a saturated state, and high upstream pressure.
3. In the vena contracta, the pressure must fall below the vapor pressure of the fluid.
4. The downstream pressure must recover above the fluid's vapor pressure.
5. Entrained gases or impurities in fluid.

If all above conditions are present, then cavitation is ocuring inside the valve.

In general, cavitation index is denoted as

$$C_{CS} = \frac{\Delta P}{P_{in} - P_v} \qquad \text{(III.7)}$$

ΔP = Pressure drop across valve (psi)

P_{in} = Upstream pressure (psi)

P_V = Vapor pressure (psi)

PART IV

LITERATURE SURVEY

The research on butterfly valves concerned the investigation of valve performance for various valve and pipe configurations. The effect of the downstream of an elbow on the valve performance was investigated by Morris & Dutton [13]. The effect of the valve/elbow interactions on the pressure drop and flow coefficient was investigated using air as the working fluid for a butterfly valve of 76.2 mm in diameter. They also investigated the effect of two butterfly valves mounted in series on the valve performance Morris &Dutton [12].

Pressure losses were measured by Fester et al for 5 different sizes of diaphragm valves of diameters ranging from 40 mm to 100 mm using both Newtonian and non-Newtonian fluids for laminar, transitional and turbulent flow. Empirical correlations were derived to calculate the loss coefficients for each diaphragm valve in the fully open position [8].

Perry gives loss coefficient data for butterfly valves in the nearly fully open (5°) and 10°, 20°, 40°, 60°open position. But, there is no mention of a diameter effect [14]. The effect of the two different disk configurations such as perforated and solid disk plates on the loss coefficient was investigated by Eom for a butterfly valve of 100 mm in diameter for position of every 10° from 0° to 90° [7].

The performance, flow patterns and cavitation phenomena of a ball valve (d=50.8 mm) are studied experimentally by Chern [5]. Various patterns of flows in and downstream the ball valves with respect to different valve openings (100, 88.9, 77.8, 66.7, 55.6, and 44.4%) and inlet velocities (2, 3, 4 and 5 m/s) are visualized using a particle tracking flow visualization method. In addition, cavitation phenomena are observed under certain conditions. Performance coefficients (flow coefficient, loss coefficient and cavitation index) of the valve are determined by pressure and flow rate measurements. Variation of circulation length behind the ball valve, variation of loss coefficient, flow coefficient and cavitation index were shown in figures. The correlations between the valve performance and the flow patterns are presented.

The butterfly control valve flow characteristics was investigated by Wojtkowiak [19]. Flow characteristics, flow patterns and pressure distributions in the disc vicinity have been shown. Steady-state, three-dimensional, laminar and turbulent flows ($10^3 \langle \mathrm{Re} \langle 2 \times 10^4$) have been analyzed. Based on the results an improved flow characteristics equation $K = f(d/D, \alpha, \mathrm{Re})$ valid for $d/D = 0.947$ has been proposed.

The water flow past the butterfly valve was investigated by Chaiworapuek [3]. A numerical simulation of flow past the butterfly valve in static and dynamic analysis using commercial fluid Dynamics software FLUENT. The characteristic of loss coefficient and torque behavior of the DN150 and DN300 butterfly valves. As a result, it was found that the loss coefficient and torque values increased when the disc angle was increased. By increasing the water speed, the loss coefficient remained constant while torque value increased. In dynamic analysis of both angular speeds, the maximum torque occured 70-80º in closing turn and 100-110º in opening turn.

PART V

EXPERIMENTAL METHOD

ANSI / ISA -75.02 – 1996 is a Standard has been prepared as part of the service of ISA, the international society for measurement and control for giving information about control valve capacity test procedures.

The main objective of this standard made for both valve manufacturers and valve users is to explain valve capacity testing procedures and hence to help on calculating performance, capacity and characteristics such as

Valve flow coefficient (Cv)
Liquid pressure recovery factors (F_L and F_{LP})
Reynolds number factor (F_R)
Liquid critical pressure ratio factor (F_F)
Pipping geometry factor (F_P)
Pressure drop ratio factor (X_T and X_{TP})

The procedure that should be followed for compressible and incompressible fluids before the above mentioned calculations, are explained separately and different calculation methods are given for each. This test Standard utilizes the mathematical equations outlined in ANSI / ISA – 75.01 The structure of experimental configuration that will help on the measurement of required parameters is given in details.

V.1 EXPERIMENTAL TEST SETUP

Tests were configured according to ANSI/ISA-75.02-1996 in which valve performance test procedures are defined, at the testing station of the company, STANDART POMPA, and outlined schematically in figure V.1.

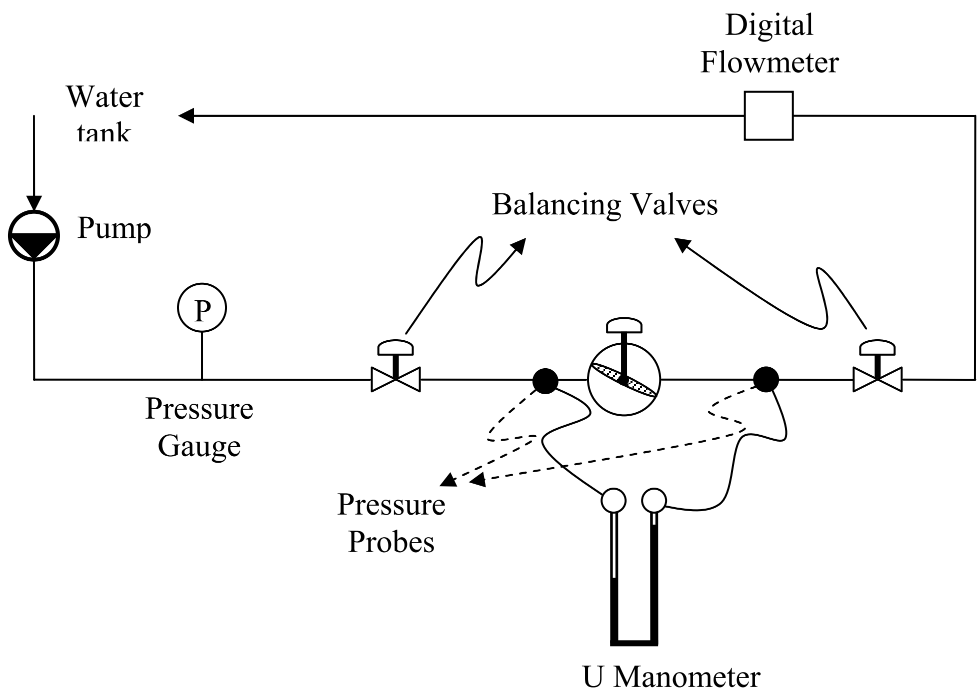


Figure V.1. Schematic view of experimental test setup

TERMO, DN 65 and DN 80 wafer-type butterfly valves are used as test valves. These valves are chosen as the fittings, sizes of which are mostly preferred by the construction industry in TURKEY. These valves were mounted on BORUSAN steel pipeline of 2½" and 3", and the necessary water was supplied by 1000 lt water tank, and STANDART , 18.5 kW, inline centrifuge pump with frequency converter. The line was a closed system with counterclockwise flow direction. DN65 and DN80 (2 of each) STAF model, TOUR & ANDERSSON (T.A), flow regulating valves to control the flow rate in the pipeline, and DN80 KHRONE, digital flowmeter were used to verify the flow rate.

Additionally, one PAKKENS manometer and thermometer to measure flow temperature and pressure, and U-tube mercury manometers mounted on the probes located at the back and front of the valves within certain distances were used to measure input and output pressure differences.

V.2 SIMULATION OF A BUTTERFLY VALVE FLOW AREA

Our purpose in this study is to measure, and observe variations of performance figures (loss coefficient and flow coefficient) of DN65 and DN80 butterfly valves at different rates and different valve opening ratios.

As it is known, butterfly valves are fittings operated by a circle profiled flap or disk in central or eccentric bearing rotated 90° in a tube. Besides, flow rate of is controlled with different valve opening ratios by moving the disk between 0° and 90°. The correlation between working principle of a butterfly valve, rotation angle of the disk and valve opening are simply given in Figure V.2.

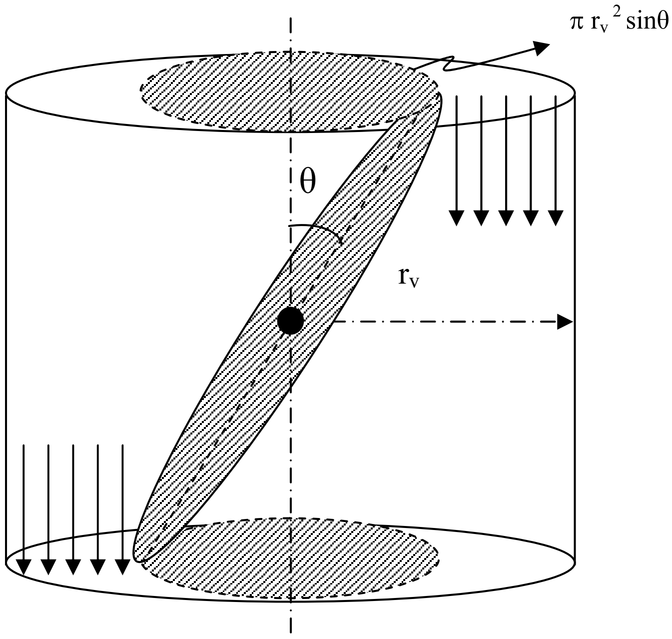


Figure V.2. Geometrical diagram for simulation of turning of disc in a butterfly valve

Cross section area of the fully open valve, in which the fluid flows, is calculated with the following equation.

$$A_v = \pi \, r_v^2 \tag{V.8}$$

Valve flow area ,A_0, and flow area percentage ,Φ, are calculated for the disc rotation angle , θ , using the following equations:

$$A_o = \pi \, r_v^2 - \pi \, r_v^2 \sin\theta = \pi \, r_v^2 (1 - \sin\theta) \tag{V.9}$$

$$\phi = \frac{A_o}{A_v} x100 \tag{V.10}$$

Valve flow area or valve opening values and flow area percentages for 5 different positions (0^0, 10^0, 20^0, 30^0, 40^0) of the disc rotation angle , θ , from fully open , $\theta=0^0$, to partially open , $\theta=40^0$, for DN80 and DN65 butterfly valves, are given in Table V.1.

Table V.1. Valve flow area and flow area percentages corresponding to different disc rotation angle of DN80 and DN65 valves

Rotation angle, θ (Degrees)	0	10	20	30	40
Rotation angle, θ (Radians)	0	π/18	π/9	π/6	2π/9
Valve flow area for DN80 (m^2)	0.00478	0.00395	0.00314	0.00239	0.00171
Valve flow area for DN65 (m^2)	0.00312	0.002576	0.00205	0.00156	0.00112
Flow area percentage (%)	100	82.64	65.80	50	35.72

Flow area and flow area ratio variation of DN80 butterfly valve per 100 degrees rotation angle during the change from fully open ($\theta=0^0$) to fully closed ($\theta=90^0$) are given in Figure V.2.

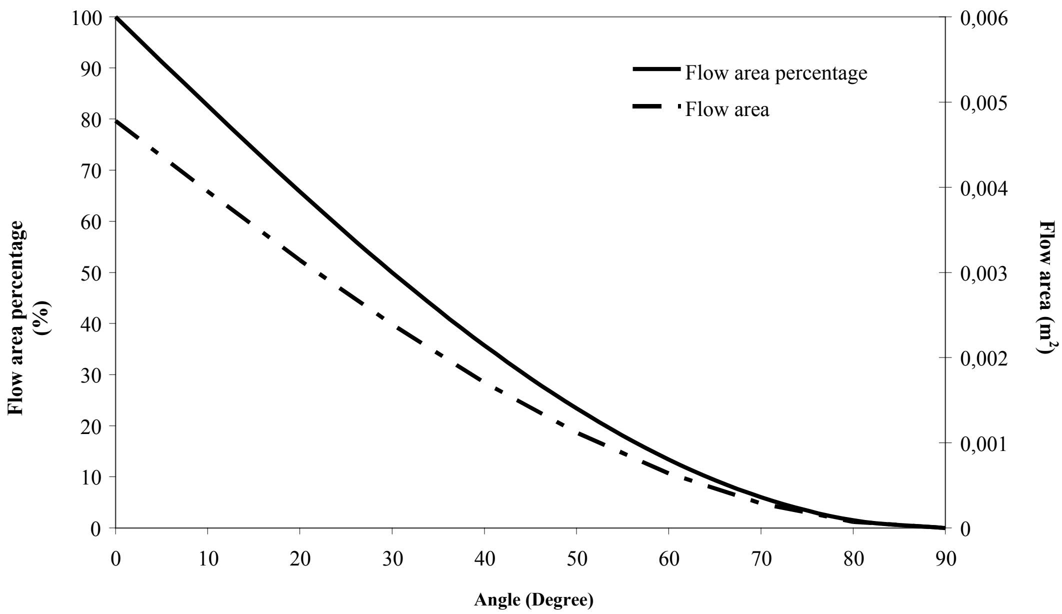


Figure V.2. Variation of butterfly valve flow area and flow area percentage versus disc angle (DN80)

V.3 MEASURED PRESSURE DROP VALUES

These pressure difference values are measured at the flow velocities of 2, 3, 4 m/s and at valve opening ratios (100%, 82.64%, 65.80%, 50%, 35.72%) corresponding to 0°,10°, 20°, 30°, 40°, regarding the full open position (100% open) as 0°. Flow rate and loss coefficient values of DN65 and DN80 butterfly valves are figured by placing pressure differences measured at different flow velocities and disk angles into the formulas as per ANSI/ISA-75.02-1996. Each measurement is taken 3 times and the said performance values are figured by using arithmetic mean of the measured values in formulas as required by the relevant standard. These figures are given in details in appendix B.1, B.2, B.3, B.4. Measured values are given in details in Table V.3.

Table V.3. ΔP mm-Hg values measured at different velocities and flow area ratios

Size	DN80					DN65				
Angle (θ)	**0**	**10**	**20**	**30**	**40**	**0**	**10**	**20**	**30**	**40**
Flow area ratio(ϕ)	**100.0**	**82.64**	**65.80**	**50**	**35.72**	**100**	**82.64**	**65.80**	**50**	**35.72**
Velocity (m/s)										
2	25	34	44	95	280	24	27	36	80	216
	24	32	45	94	280	25	29	37	77	221
	26	34	45	95	277	25	28	38	78	218
Avarage ΔP (mmHg)	**25.0**	**33.3**	**44.7**	**94.7**	**279.0**	**24.7**	**28.0**	**37.0**	**78.3**	**218.3**
Velocity (m/s)										
3	43	58	80	185	535	56	60	81	156	479
	43	56	80	185	525	57	58	80	160	482
	45	57	81	187	535	58	59	79	160	480
Avarage ΔP (mmHg)	**43.7**	**57.0**	**80.3**	**185.7**	**531.7**	**57.0**	**59.0**	**80.0**	**158.7**	**480.3**
Velocity (m/s)										
4	70	98	140	320	920	90	99	138	297	997
	67	99	141	323	895	91	98	140	295	1000
	70	100	143	324	922	90	100	141	298	998
Avarage ΔP (mmHg)	**69.0**	**99.0**	**141.3**	**322.3**	**912.3**	**90.3**	**99.0**	**139.7**	**296.7**	**998.3**

V.4 UNCERTAINTY ANALYSIS

In the calculation of the performance coefficients such as the flow and loss coefficients there are uncertainties due to the uncertainties in the pressure drop and flow rate measurements. The reading accuracy of the manometer and the flowmeter is around ±3% and ±0.1%, respectively. Therefore, the uncertainty in the pressure drop is ±3% while the uncertainty in the flow rate ±0.1%. Using these values the uncertainties in the flow and loss coefficients were calculated and given in Table 2. The uncertainty analysis was performed using the method described by Taylor et al [17]. The procedure for calculating the uncertainties in the loss and flow coefficients was explained in detail in the Appendix A.

The percent relative uncertainties for K and C_v values are the ratio of the uncertainties at different angles to the values of K and C_v, such as U_K/K and U_{Cv}/C_v, respectively. Then the percent relative uncertainty in the loss coefficient is ±3.0 % for two different sizes of valves. However, the percent relative uncertainty in the flow coefficient is ±1.35 % for DN80 while it was found to be ±3.35 % for DN65 size of valve.

Table V.3. Uncertainties in the loss and flow coefficients for two different valve sizes

Rotation angle(deg.)	θ	**0**	**10**	**20**	**30**	**40**
Flow area percentage (%)	ϕ	**100.0**	**82.64**	**65.80**	**50.00**	**35.72**
DN80	$K \pm U_K$	1.15±0.035	1.65±0.050	2.36±0.071	5.38±0.16	15.2±0.46
	$C_V \pm U_{CV}$	291.2±3.94	243.1±3.29	203.5±2.75	134.7±1.82	80.08±1.08
DN65	$K \pm U_K$	1.51±0.045	1.65±0.050	2.33±0.070	4.95±0.15	16.7±0.50
	$C_V \pm U_{CV}$	149.5±5.01	142.8±4.79	120.2±4.03	82.47±2.77	44.96±1.51

PART VI

RESULTS AND DISCUSSIONS

The pressure drop measurements for five different valve openings and for three different velocities were used to calculate the flow and loss coefficients. The calculations were done for two different sizes of butterfly valves being DN65 and DN80. In the following sections, the loss and flow coefficients obtained using experimental measurements will be presented.

VI.1 THE LOSS COEFFICIENT

The variation of the loss coefficient with the flow area percentage at three different velocities was shown in Fig. VI.1.

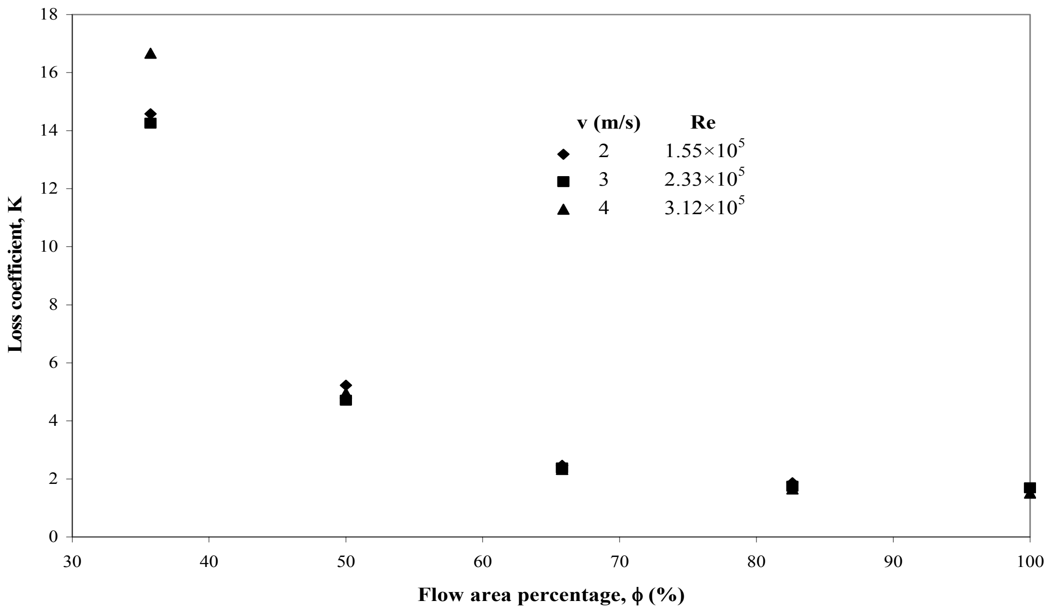


Figure VI.1. Loss coefficient for DN65 versus flow area percentage at three different velocities

As it can be seen the dependence of the loss coefficient on the velocity is negligible and it is a strong function of the flow area percentage. Fig. VI.1. shows that the loss coefficient is not affected by the Reynolds number in turbulent flow but the flow area percentage of the butterfly valve.

The relations can be given to relate the loss coefficient to the flow area percentage, ϕ. The loss coefficients for a velocity of 4 m/s, and for DN80 and DN65 butterfly valves are $K = 1.074 \times 10^5 \phi^{-2.514} \pm 3\%$ and $K = 0.244 \times 10^5 \phi^{-2.269} \pm 3\%$, respectively and they are shown in figures VI.2. and VI.3.

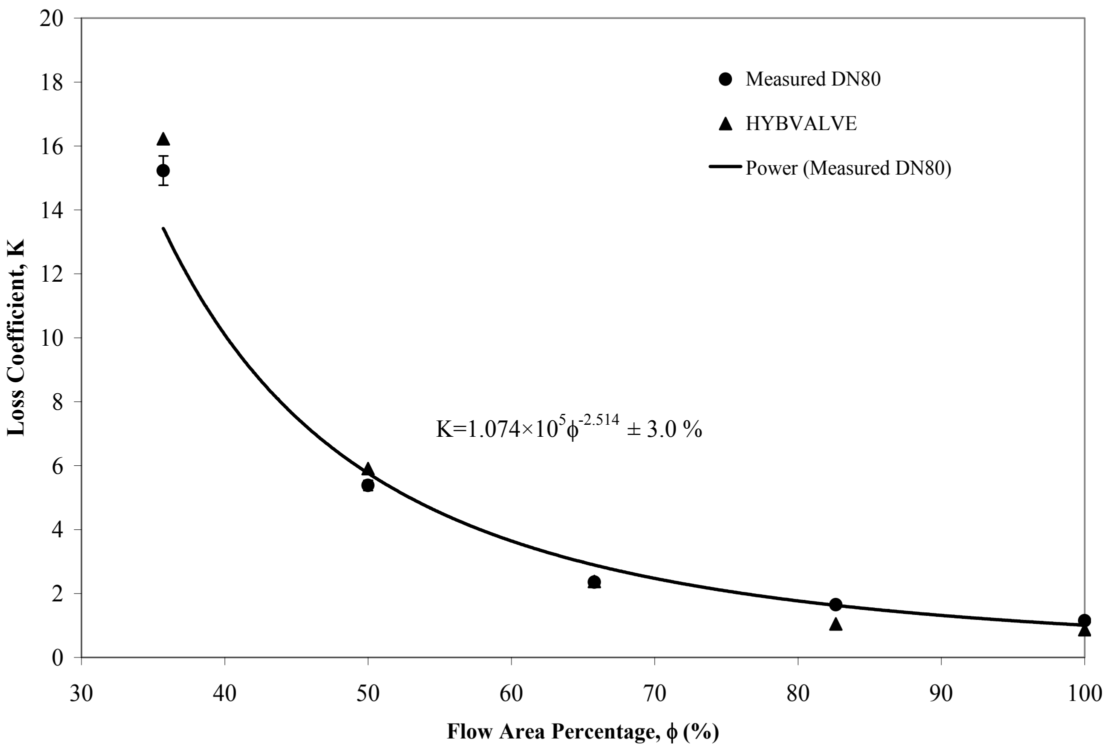


Figure VI.2. Comparison of calculated K values at 3.12x10^5 Reynolds number with the other literature data (DN80)

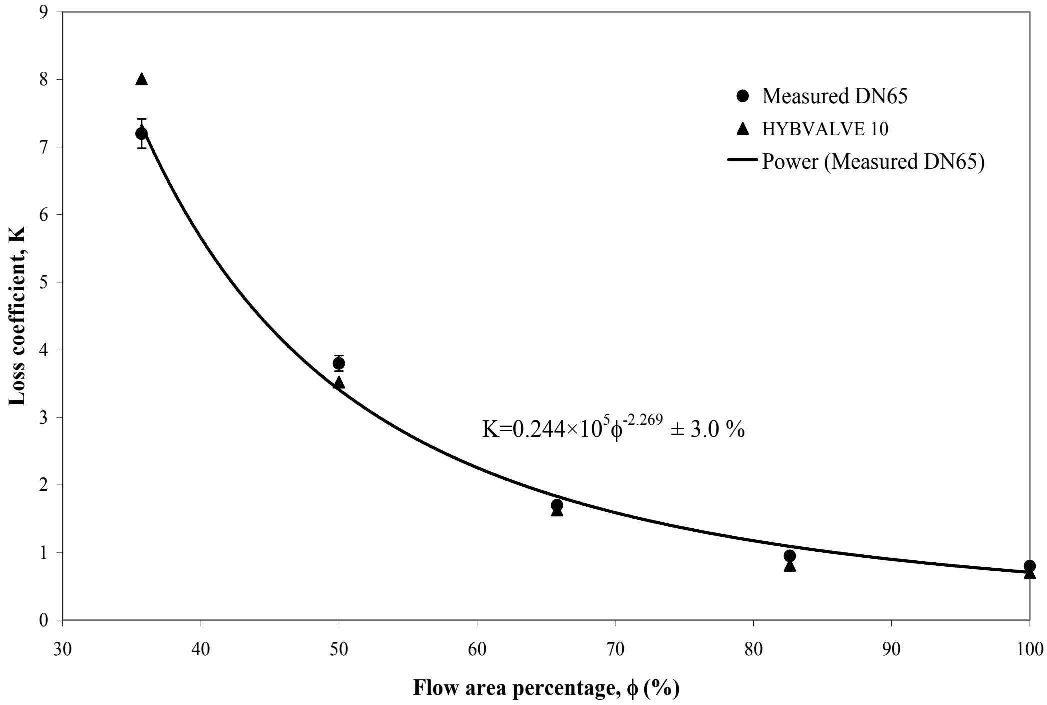


Figure VI.3. Comparison of calculated K values at $2.52x10^5$ Reynolds number with the other literature data (DN65)

It was observed that the loss coefficient is not affected by the flow rate of the working fluid, but the opening angle of butterfly valve. It was observed that value of K decreases as the disk angle moves form partially closed position, $\theta=40^o$ or ϕ= 35.72%, to fully open position, $\theta=0^o$ or ϕ= 100%.

VI.2 THE FLOW COEFFICIENT

Variation of flow coefficient, C_v, is the indicator of the flow rate at a certain pressure drop as a function of the valve opening. The computed values of the flow coefficient with respect to the flow area percentage at different velocities for DN65 valve size were given in Fig. VI.4.

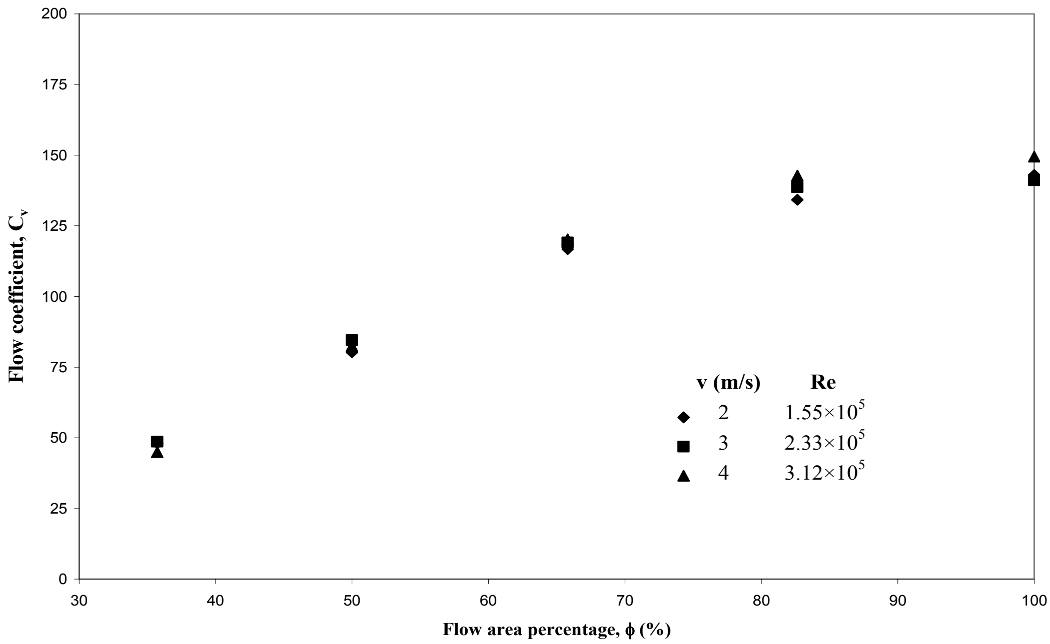


Figure VI.4. Flow coefficients for DN65 versus flow area percentages at three different velocities

It was observed that the flow coefficient increases as the flow area of the valve increases. However, the effect of the velocity is negligible. Variation of the flow coefficient with the flow area percentage is not linear but an exponential function as shown in Fig. VI.5 and VI.6.

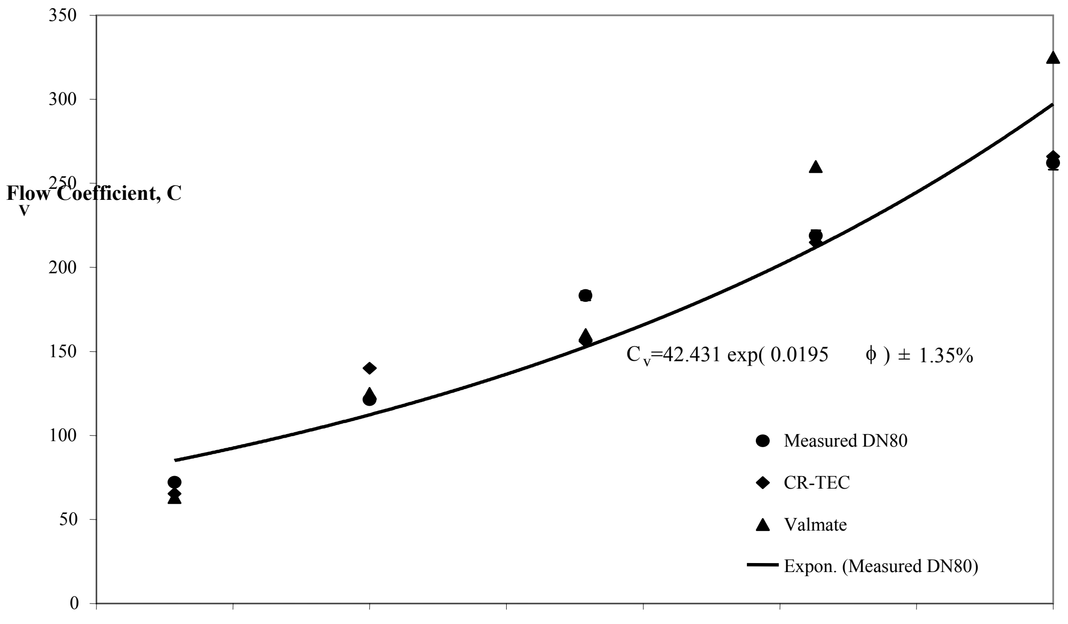


Figure VI.5. Comparison of calculated C_v values with the other literature data for $3.12x10^5$ Reynolds number (DN80)

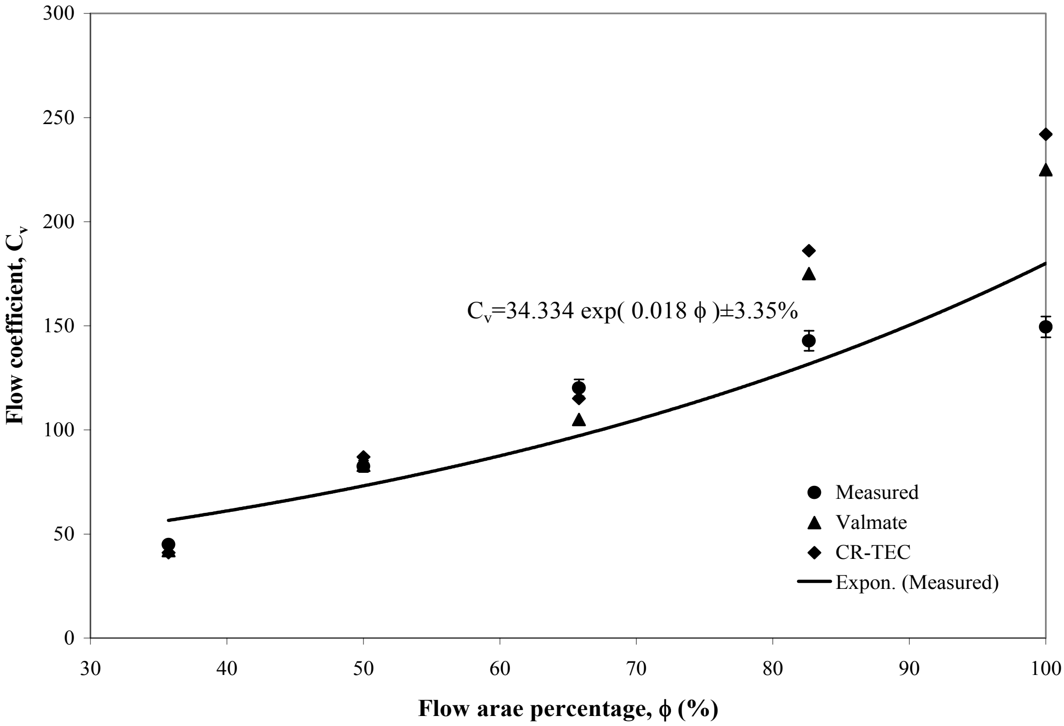


Figure VI.6. Comparison of calculated C_v values with the other literature data for 2.52×10^5 Reynolds number (DN65)

For two different sizes of butterfly valves such as DN80 and DN65 the flow coefficients are $C_V = 42.431 \exp(0.0195\,\phi) \pm 1.35$ and $C_V = 34.334 \exp(0.018\,\phi) \pm 3.35$, respectively. The results were compared to obtained data from Valmate and Crtec manufacturers [25,22]. Differences between the computed results from experimental data and the results given in the literature were observed at higher flow area percentages.

VI.3 COMPARISON OF THE LOSS AND FLOW COEFFICIENTS FOR TWO DIFFERENT SIZES OF THE VALVES

The variation of the loss coefficient, K, and the flow coefficient, C_v, with respect to the flow area percentage, ϕ, for both valves, DN80 and DN65, were shown in figures VI.7. and VI.8

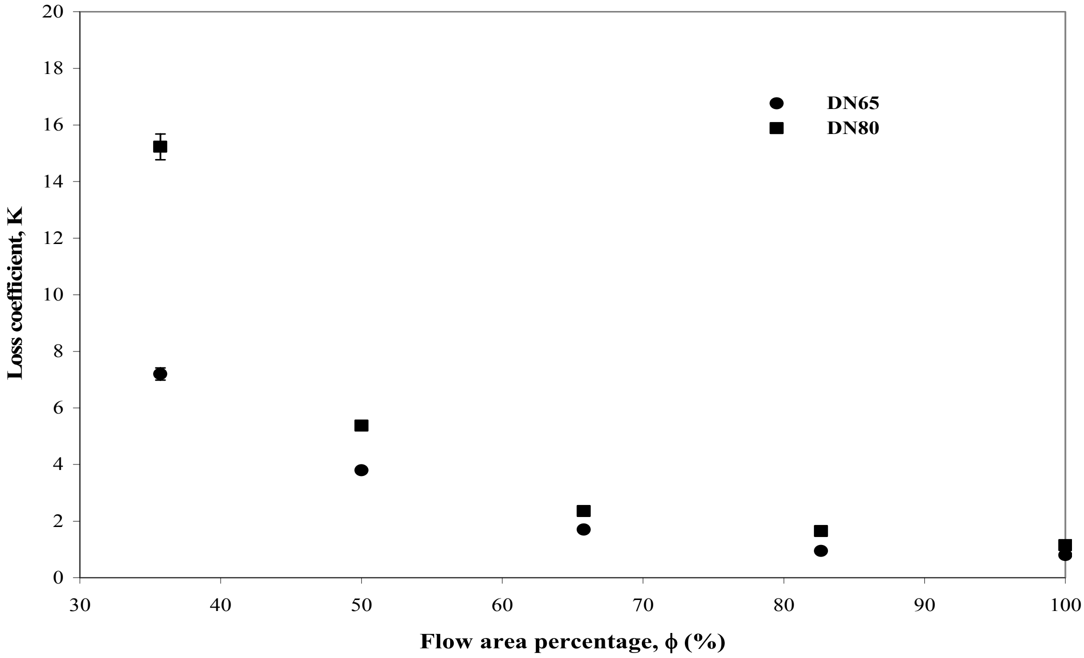


Figure VI.7: The change of K values versus flow area percentages for DN65 and DN80 at the 4 m/s velocity

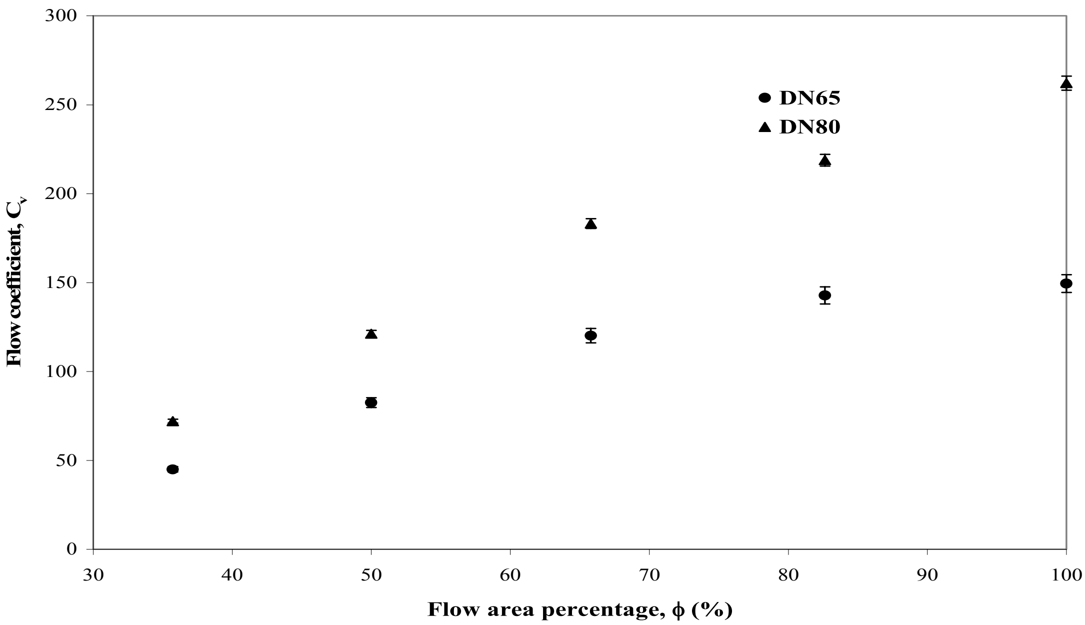


Figure VI.8. The change of C_v values versus flow area percentages for DN65 and DN80 at the 4m/s velocity

It was observed that the flow coefficient is a function of the valve size; however, the loss coefficient is independent of the valve size at the higher flow area percentage. But dependent of the valve size was observed that at the lower flow area percentages (about $\phi < 65\%$ or $\theta < 0^o$).

VI.4 CONCLUSIONS AND RECOMMENDATIONS

The valve performance can be determined by using the loss coefficient K, and the flow coefficient C_v, using the pressure loss and volume flow rate information from the experimental data.

- The loss coefficient is independent of the inlet velocity for turbulent flow but it is dependent of the valve size at the lower flow area percentage. However, when flow area percentage is more than 65% the proposed correlations, $K = 1.074 \times 10^5 \phi^{-2.514} \pm 3\%$ or $K = 0.244 \times 10^5 \phi^{-2.269} \pm 3\%$, can be used for two valve sizes.
- Flow coefficient is independent of the inlet velocity for turbulent flow but it is dependent on the valve size. The proposed correlations giving the flow coefficients as functions of the flow area percentage are $C_V = 49.053 \exp(0.0195\phi) \pm 1.35$ and $C_V = 34.334 \exp(0.018\phi) \pm 3.35$ for DN80 and DN65 valves, respectively.
- Correlations for K and C_v which are given above are appropriate for practical use. Manufacturer or designer of butterfly valves can find easily the corresponding K and C_v values for a given valve opening angles.

For future work, it is recommended that this approach can be applied different sizes of butterfly valves such as DN50 and DN100. Thus, a general correlation can be obtained for the most used valve sizes in industrial applications.

The proposed correlations can be used for turbulent flow for two valve sizes. But, correlations are derived to calculate the performance coefficients for laminar and transitional flow regimes.

Cavitation index values, C_{cs}, can be determined by the pressure loss data. The critical conditions of inception of cavitation can be found by using experimental data for different valve openings.

APPENDIX A

THE PROCEDURE FOR CALCULATING THE UNCERTAINTIES IN THE LOSS AND FLOW COEFFICIENTS

The set of input parameters are directly related to the measured variables in uncertainty analysis. The computed performance coefficients are obtained using the experimental measurements. Uncertainties in the performance coefficients such as K and C_v, are determined using the uncertainties in the flow rate Q, and pressure drop ΔP.

The loss coefficient K, and flow coefficient C_v can be calculated for any valve by using the below given equations:

$$K = \frac{1}{V^2}\frac{2\Delta P}{\rho} = \frac{\pi^2 D^4}{8\,Q^2}\frac{\Delta P}{\rho}, \qquad C_V = Q\left(\frac{1}{\Delta P}\right)^{0.5} = \frac{Q}{\sqrt{\Delta P}} \tag{A.1}$$

The uncertainty in the pressure drop $U_{\Delta P}$ and the uncertainty in volume flow rate, U_Q are used to be ±3% and ±0.1%, respectively.

The partial derivatives of K with respect to measured Q and measured ΔP are called the sensitivity coefficients and they are given as:

$$\frac{\partial K}{\partial Q} = -\frac{\pi^2 D^4}{4Q^3}\frac{\Delta P}{\rho} \qquad \frac{\partial K}{\partial \Delta P} = \frac{\pi^2 D^4}{8Q^2\,\rho} \tag{A.2}$$

Similarly, the sensitivity coefficients for C_V can be written as:

$$\frac{\partial C_V}{\partial Q} = \frac{1}{\sqrt{\Delta P}} \qquad \frac{\partial C_V}{\partial \Delta P} = -\frac{Q}{2(\Delta P)^{3/2}} \tag{A.3}$$

The uncertainty in the loss coefficient in terms of the uncertainties and sensitivity coefficients is given as:

$$U_K = \left[\left(\frac{\partial K}{\partial Q}U_Q\right)^2 + \left(\frac{\partial K}{\partial \Delta P}U_{\Delta P}\right)^2\right]^{1/2} \tag{A.5}$$

Similarly the uncertainty in the flow coefficient due to uncertainties in the pressure drop and volume flow rate:

$$U_{C_V} = \left[\left(\frac{\partial C_v}{\partial Q}U_Q\right)^2 + \left(\frac{\partial C_v}{\partial \Delta P}U_{\Delta P}\right)^2\right]^{1/2} \tag{A.6}$$

APPENDIX B

B.1 MEASURED FLOW COEFFICIENT VALUES FOR DN65 BUTTERFLY VALVES

Table VI.1.a Measured flow coefficient values for DN65 butterfly valves

								FLOW COEFFICIENTS				
Angle		0	10	20	30	40		0	10	20	30	40
Flow Area		0.003117	0.00302325	0.002753	0.002338	0.001829		0.003117	0.002576	0.002051	0.001559	0.001114
Flow Area Fraction		100	96.984631	88.30222	75	58.68241	ϕ	100	82.63518	65.79799	50	35.72124
Test_1	ΔP1 mmHg	24	27	36	80	216	**2 m/s**	**161,06**	**151.85**	**131.50**	**88.21**	**53.69**
Test_2	ΔP2 mmHg	25	29	37	77	221	**2 m/s**	**157.80**	**146.52**	**129.71**	**89.92**	**53.08**
Test_3	ΔP3 mmHg	25	28	38	78	218	**2 m/s**	**157.80**	**149.11**	**128.00**	**89.34**	**53.44**
Avarage	ΔP4 mmHg	24.67	28.00	37.00	78.33	218.33	**2 m/s**	**158.87**	**149.11**	**129.71**	**89.15**	**53.40**
	V1=3m/s											
Test_1	ΔP1 mmHg	56	60	81	156	479	**3 m/s**	**158.16**	**152.79**	**131.50**	**94.76**	**54.08**
Test_2	ΔP2 mmHg	57	58	80	160	482	**3 m/s**	**156.76**	**155.40**	**132.32**	**93.57**	**53.91**
Test_3	ΔP3 mmHg	58	59	79	160	480	**3 m/s**	**155.40**	**154.08**	**133.16**	**93.57**	**54.02**
Avarage	ΔP4 mmHg	57.00	59.00	80.00	158.67	480.33	**3 m/s**	**156.76**	**154.08**	**132.32**	**93.96**	**54.00**
	V1=4m/s											
Test_1	ΔP1 mmHg	90	99	138	297	997	**4 m/s**	**166.34**	**158.60**	**134.33**	**91.57**	**49.98**
Test_2	ΔP2 mmHg	91	98	140	295	1000	**4 m/s**	**165.42**	**159.41**	**133.37**	**91.88**	**49.90**
Test_3	ΔP3 mmHg	90	100	141	298	998	**4 m/s**	**166.34**	**157.80**	**132.89**	**91.41**	**49.95**
Avarage	ΔP4 mmHg	90.33	99.00	139.67	296.67	998.33	**4 m/s**	**166.03**	**158.60**	**133.53**	**91.62**	**49.94**

APPENDIX B

B.2 MEASURED LOSS COEFFICIENT VALUES FOR DN65 BUTTERFLY VALVES

Table VI.1.b Measured loss coefficient values for DN65 butterfly valves

								LOSS COEFFICIENTS				
Angle		0	10	20	30	40		0	10	20	30	40
Flow Area		0.003117	0.00302325	0.002753	0.002338	0.001829		0.003117	0.002576	0.002051	0.001559	0.001114
Flow Area Fraction		100	82.63518	65.79799	50	35.72124	ϕ	100	82.63518	65.79799	50	35.72124
Test_1	ΔP1 mmHg	24	27	36	80	216	**2 m/s**	**1.60**	**1.80**	**2.40**	**5.34**	**14.42**
Test_2	ΔP2 mmHg	25	29	37	77	221	**2 m/s**	**1.67**	**1.94**	**2.47**	**5.14**	**14.76**
Test_3	ΔP3 mmHg	25	28	38	78	218	**2 m/s**	**1.67**	**1.87**	**2.54**	**5.21**	**14.56**
Avarage	ΔP4 mmHg	24.67	28.00	37.00	78.33	218.33	**2 m/s**	**1.65**	**1.87**	**2.47**	**5.23**	**14.58**
	V1=3m/s											
Test_1	ΔP1 mmHg	56	60	81	156	479	**3 m/s**	**1.66**	**1.78**	**2.40**	**4.63**	**14.21**
Test_2	ΔP2 mmHg	57	58	80	160	482	**3 m/s**	**1.69**	**1.72**	**2.37**	**4.75**	**14.30**
Test_3	ΔP3 mmHg	58	59	79	160	480	**3 m/s**	**1.72**	**1.75**	**2.34**	**4.75**	**14.24**
Avarage	ΔP4 mmHg	57.00	59.00	80.00	158.67	480.33	**3 m/s**	**1.69**	**1.75**	**2.37**	**4.71**	**14.25**
	V1=4m/s											
Test_1	ΔP1 mmHg	90	99	138	297	997	**4 m/s**	**1.50**	**1.65**	**2.30**	**4.96**	**16.64**
Test_2	ΔP2 mmHg	91	98	140	295	1000	**4 m/s**	**1.52**	**1.64**	**2.34**	**4.92**	**16.69**
Test_3	ΔP3 mmHg	90	100	141	298	998	**4 m/s**	**1.50**	**1.67**	**2.35**	**4.97**	**16.66**
Avarage	ΔP4 mmHg	90.33	99.00	139.67	296.67	998.33	**4 m/s**	**1.51**	**1.65**	**2.33**	**4.95**	**16.66**

APPENDIX B

B.3 MEASURED FLOW COEFFICIENT VALUES FOR DN80 BUTTERFLY VALVES

Table VI.2.a Measured flow coefficient values for DN80 butterfly valves

								FLOW COEFFICIENTS				
Angle		0	10	20	30	40		0	10	20	30	40
Flow Area		0.004778	0.003949	0.003144	0.002389	0.001707		0.004778	0.003949	0.003144	0.002389	0.001707
Flow Area Fraction		100	96.984631	88.30222	75	58.68241	ϕ	100	82.63518	65.79799	50	35.72124
Test_1	ΔP1 mmHg	25	34	44	95	280	**2 m/s**	**241.89**	**207.42**	**182.33**	**124.09**	**72.28**
Test_2	ΔP2 mmHg	24	32	45	94	280	**2 m/s**	**246.88**	**213.81**	**180.30**	**124.75**	**72.28**
Test_3	ΔP3 mmHg	26	34	45	95	277	**2 m/s**	**237.20**	**207.42**	**180.30**	**124.09**	**72.67**
Avarage	ΔP4 mmHg	25.00	33.33	44.67	94.67	279.00	**2 m/s**	**241.89**	**209.49**	**180.97**	**124.31**	**72.41**
	V1=3m/s											
Test_1	ΔP1 mmHg	43	58	80	185	535	**3 m/s**	**276.66**	**238.22**	**202.83**	**133.38**	**78.43**
Test_2	ΔP2 mmHg	43	56	80	185	525	**3 m/s**	**276.66**	**242.43**	**202.83**	**133.38**	**79.18**
Test_3	ΔP3 mmHg	45	57	81	187	535	**3 m/s**	**270.45**	**240.30**	**201.58**	**132.67**	**78.43**
Avarage	ΔP4 mmHg	43.67	57.00	80.33	185.67	531.67	**3 m/s**	**274.54**	**240.30**	**202.41**	**133.14**	**78.68**
	V1=4m/s											
Test_1	ΔP1 mmHg	70	98	140	320	920	**4 m/s**	**289.12**	**244.35**	**204.44**	**135.22**	**79.75**
Test_2	ΔP2 mmHg	67	99	141	323	895	**4 m/s**	**295.52**	**243.11**	**203.71**	**134.59**	**80.86**
Test_3	ΔP3 mmHg	70	100	143	324	922	**4 m/s**	**289.12**	**241.89**	**202.28**	**134.39**	**79.66**
Avarage	ΔP4 mmHg	69.00	99.00	141.33	322.33	912.33	**4 m/s**	**291.21**	**243.11**	**203.47**	**134.73**	**80.08**

APPENDIX B

B.4 MEASURED LOSS COEFFICIENT VALUES FOR DN80 BUTTERFLY VALVES

Table VI.2.b Measured loss coefficient values for DN80 butterfly valves

								LOSS COEFFICIENTS				
Angle		0	10	20	30	40		0	10	20	30	40
Flow Area		0.003117	0.00302325	0.002753	0.002338	0.001829		0.004778	0.003949	0.003144	0.002389	0.001707
Flow Area Fraction		100	82.63518	65.79799	50	35.72124	ϕ	100	82.63518	65.79799	50	35.72124
Test_1	ΔP1 mmHg	25	34	44	95	280	**2 m/s**	**1.67**	**2.27**	**2.94**	**6.34**	**18.70**
Test_2	ΔP2 mmHg	24	32	45	94	280	**2 m/s**	**1.60**	**2.14**	**3.00**	**6.28**	**18.70**
Test_3	ΔP3 mmHg	26	34	45	95	277	**2 m/s**	**1.74**	**2.27**	**3.00**	**6.34**	**18.50**
Avarage	ΔP4 mmHg	25.00	33.33	44.67	94.67	279.00	**2 m/s**	**1.67**	**2.23**	**2.98**	**6.32**	**18.63**
	V1=3m/s											
Test_1	ΔP1 mmHg	43	58	80	185	535	**3 m/s**	**1.28**	**1.72**	**2.37**	**5.49**	**15.88**
Test_2	ΔP2 mmHg	43	56	80	185	525	**3 m/s**	**1.28**	**1.66**	**2.37**	**5.49**	**15.58**
Test_3	ΔP3 mmHg	45	57	81	187	535	**3 m/s**	**1.34**	**1.69**	**2.40**	**5.55**	**15.88**
Avarage	ΔP4 mmHg	43.67	57.00	80.33	185.67	531.67	**3 m/s**	**1.30**	**1.69**	**2.38**	**5.51**	**15.78**
	V1=4m/s											
Test_1	ΔP1 mmHg	70	98	140	320	920	**4 m/s**	**1.17**	**1.64**	**2.34**	**5.34**	**15.36**
Test_2	ΔP2 mmHg	67	99	141	323	895	**4 m/s**	**1.12**	**1.65**	**2.35**	**5.39**	**14.94**
Test_3	ΔP3 mmHg	70	100	143	324	922	**4 m/s**	**1.17**	**1.67**	**2.39**	**5.41**	**15.39**
Avarage	ΔP4 mmHg	69.00	99.00	141.33	322.33	912.33	**4 m/s**	**1.15**	**1.65**	**2.36**	**5.38**	**15.23**

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AUTOBIOGRAPHY

I was born on May 29, 1978 in Mersin, grew up in İstanbul. After I had graduated from Kenan Evren High School at 1995, I started studying mechanical engineering in Erciyes University.

I completed my military service in Anadolukavağı as a lietuenant at the end of 2003 after graduated. I worked in KAYALAR Construction as a project engineer about 1 year. I started master in science at Marmara University, Mechanical Engineering Department at 2005 and I have been working at GEDİK Casting and Valve Company as a sales and marketing engineer for 3 years.