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Finite Element Analysis For Prediction Hydraulic Performance Of A Rectangular Flap Valve

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ABSTRACT

Flap Valves are designed for use on the discharge end of pipes to prevent backflow or intrusion into the pipe. Typical applications include discharges to reservoirs, ponding basins and standpipes. A flap valve is simple, one-way valve that allows the flow of gases or fluids in one direction while preventing flow in the opposite direction. The valve accomplishes this objective with a spring loaded or weighted flap placed across the opening of a pipe, tube, or duct. The valve flap releases in the direction of the desired flow and is either forced open by the flow or by remote means. When the flow ceases or the remote actuation releases, the spring or weight of the flap closes it against a seal, effectively preventing fluid or gas from flowing back into the pipe. The flap valve also prevents undesirable foreign objects from entering the pipe or channel to which it is attached.

The present study is dealing with the hydraulic parameters of a rectangular wall mounted flap valves. These valves are widely used at the end of delivery pipe or channel of pumping stations. The flap valve parameters are determined by FEM computation in function of opening angle. Real turbulent flow has been considered. The flow coefficients and the torque coefficients have been evaluated for normal and reverse flow direction and for different water levels. The computational fluid dynamics (CFD) velocity distributions have been made also for normal and reverse flow. The model results can be applied to calculate the hydraulic loss of the flap valve in steady state condition and can be the basis of dynamic simulation when the pump stops and the valve is closing in reverse flow. The results indicate that the characteristics of flap valves with help of FEM seem to be effective and very useful.

Key word: valve - hydraulic parameter – backflow – flow coefficient – stationary - transient

1. Introduction

Check valves are often used in piping system to avoid the fluid to flow backwards. However they can also cause hydraulic loads when they close. An ideal check valve closes exactly when the flow is reversed. However in reality, this is not always the case. Due to non-ideal properties of the valve some back flow often occurs. When the valve slams shut a pressure surge occurs. The severity of this pressure surge is largely dependent on the back flow prior to the closing. For the hydraulic load calculations the modeling of the check valve closure is very important [1]. There has always been widespread disagreement among valve manufacturers regarding which flow equation should be used. During the 1950s, some users in the process industries began to realize that the gas flow formulas then in use gave incongruous results that could lead to serious sizing errors [2]. The cause of the problem was that valves that had the same flow coefficient rating but were different shapes could have radically different choked gas flow characteristics. It became apparent that a single experimentally determined coefficient was insufficient to describe gas flow through valves over the full range of pressure drops. Another goal of using any flow coefficient calculation is to predict pressure drop. Predicting pressure drop is more difficult than predicting flow rate because of the iterative nature of the solution. Fortunately, modern computer programs make this once difficult calculation simple. The ISA equation for pressure drop is a function of observed flow rate, inlet pressure and temperature, pressure drop, published flow coefficient, gas-specific heat, and expansion factor, which itself is a function of pressure drop and published choked flow coefficient [3]. Categorizing check valves is not easy since different manufacturers have different specifications. However the most common types can be divided into: swing, lift, tilting disc, duo/double disc, stop and nozzle [4]. Usually the flow transient in the piping system is not affected by the check valve until the valve is almost completely closed. This feature makes it possible to study the closing behavior of the check valve independently of the piping system. In other words, the flow transient affects the valve but the valve does not affect the system flow until it is almost completely closed. This is however not true for damped check valves.

2. Valve parameters

The actual flap component of a flap valve may also be made of a flexible material such as neoprene or silicone. The only real requirement for the effective operation of this type of valve is that the flap opens when subjected to the normal flow through the duct and forms a good seal when closed. The valves in the human heart are classic examples of a flap valve, amply demonstrating the great simplicity and reliability of the design The valve model arrangement is shown on Fig. 1.

The flow coefficient of a device is a relative measure of its efficiency at allowing fluid flow. It describes the relationship between the pressure drop across an orifice, valve or other assembly and the corresponding flow rate. When flow goes through a valve or any other restricting device it loses some energy. The flow coefficient is a designing factor which relates head drop (Δh) or pressure drop (ΔP) with the flow rate (Q) [5].

$$Q = K \cdot \sqrt{\frac{\Delta P}{SG}}$$

Q: Flow rate , ΔP: Pressure Drop, Sg: Specific gravity , K: Flow coefficient Kv or Cv

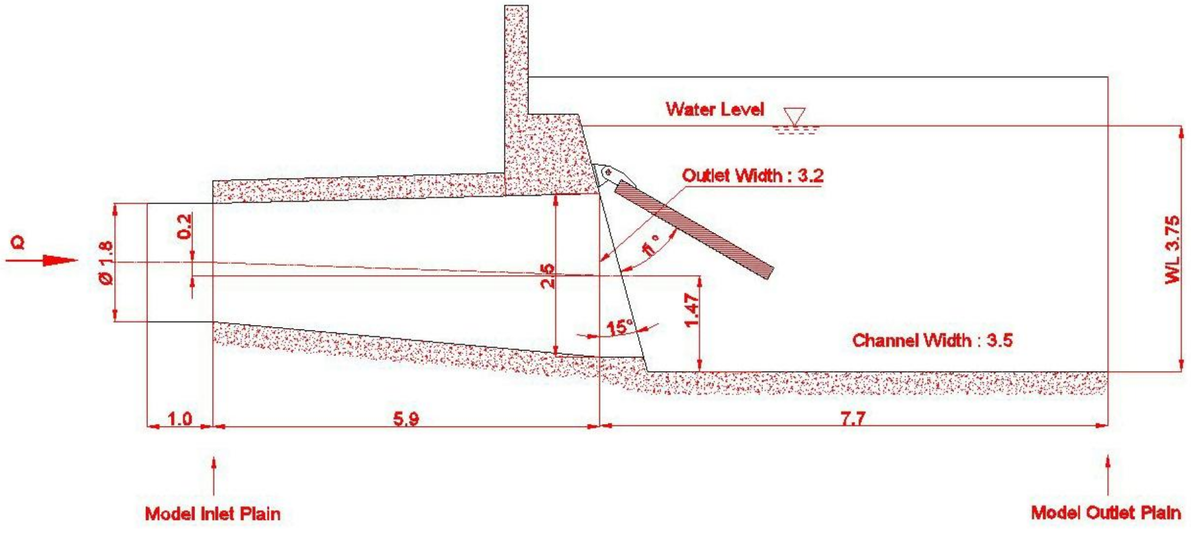


Figure 1. The valve model arrangement

The hydraulic parameters are the head loss and the torque acting on the flap. The hydraulic loss:

$$h' = \zeta(\varphi)\frac{v_1^2}{2g}sign(v_1)$$

Where $\zeta(\varphi)$ is the loss coefficient, v_1 is the velocity in the channel before the valve and g is the gravity acceleration. The loss coefficient is ∞ at $\varphi = 0$ so it is more comfortable to use it in another form. [2]. Considering Borda-Carnot type loss, the loss coefficient is:

$$h' = \frac{v_1^2}{2g}\left(\frac{A_1}{A_{\min}} - \frac{A_1}{A_2}\right)^2$$

Where A_1 is the cross section of the channel before the valve, A_{min} is the minimal contracted cross section and A_2 is the cross section after the valve. When the valve is built inside a pipe: $A_1 = A_2$ and then a kind of flow coefficient can be defined:

$$K_\zeta(\varphi) = \frac{A_{\min}}{A_1} = \frac{1}{1+\sqrt{\zeta}}$$

When the valve is closed, $K_\zeta(\varphi) = 0$. An open channel follows the flap valve here ($A_1 \neq A_2$) however this simple expression may be used [6] [7].
The torque acting on the flap valve in dimensionless form:

$$K_m(\varphi) = \frac{M_h}{\rho g h' D_e^3}$$

Where M_h is the hydraulic torque, ρ is the density of water, D_e is the equivalent diameter of the valve.

This expression has been used originally for circular shape flap valve. The equivalent diameter of the valve gives the same cross section as follows:

$$D_e = \sqrt{ab\frac{4}{\pi}}$$

Where a, and b are the rectangle sides.
In steady state condition the torque of the flap weight $M_w(\varphi)$ is equal to the hydraulic torque $M_h(\varphi)$. Considering that the volume flow expressed with the velocity is:

$$Q = v_1\frac{D_e^2\pi}{4}$$

One can get for the steady state condition the expression as follows:

$$Q = \left[\frac{1}{K_\zeta(\varphi)} - 1\right]\sqrt{\frac{\pi M_w(\varphi)}{2\rho K_m(\varphi) D_e}}$$

When K_ζ, K_m and M_w are known in function of φ, the steady state Q can be calculated also in function of φ. The expression is valid, if $K_m>0$, this is the situation in a range from $\varphi = 0$ and for normal flow direction (Q>0).

In case of reverse flow direction $h' < 0$. A distinction is needed at the $K_\zeta(\varphi)$, $K_m(\varphi)$ functions. These are denoted finally as:
$K_{\zeta+}$, $K_{\zeta-}$, K_{m+}, K_{m-}

Each valve has its own flow coefficient. This depends on how the valve has been designed to let the flow going through the valve. Therefore, the main differences between different flow coefficients come from the type of valve, and of course the opening position of the valve.

Flow coefficient is important in order to select the best valve for a specific application. If the valve is going to be most of the time opened, probably there should be selected a valve with low head loss in order to save energy. Or if it is needed a control valve, the range of coefficients for the different opening positions of the valve should fit the requirements of the application. At same flow rate, higher flow coefficient means lower drop pressure across the valve. Depending of manufacturer, type of valve, application the flow coefficient can be expressed in several ways. The coefficient can be non-dimensional or with units if parameters such as diameter or density are considered inside the coefficient or just in the equation.

Most of valve industry has standardized the flow coefficient (K). It is referenced for water at a specific temperature, and flow rate and drop pressure units. Same model valve has different coefficient for each diameter.

Kv is the flow coefficient in metric units. It is defined as the flow rate in cubic meters per hour [m3/h] of water at a temperature of 16º celsius with a pressure drop across the valve of 1 bar.
Cv is the flow coefficient in imperial units. It is defined as the flow rate in US Gallons per minute [gpm] of water at a temperature of 60º fahrenheit with a pressure drop across the valve of 1 psi.

3. Dynamic behaviour of flap valve

In case of transient phenomenon the flap valve parameters may be different, however when the change is not very fast, we can use the stationary parameters as approximation completed with two new elements:
During the stop of pumping the flap turning velocity governed by the equation of motion:

$$\frac{d\varphi}{dt} = \frac{M_h - M_w}{\Theta_{fl} + \Theta_{add}}$$

where Θ_{fl} is the inertia of the flap body related to the shaft centre and Θ_{add} is the inertia of additional water mass moving together with the flap (roughly a sphere of water with the diameter D_e).
The head loss is calculated with a modified velocity:

$$h' = \zeta(\varphi)\frac{(v_1 - v_x)^2}{2g} sign(v_1 - v_x)$$

where v_x is the velocity component of moving flap centre in the channel direction. The other approach for the dynamic relations is the method of return velocity [5], [6], [8]. The v_r return velocity is the velocity of closing body centre at the last moment before reaching the valve seat. The approximation is that the return velocity at a given valve is the function of dv_1/dt acceleration only. The return velocity is an important parameter as the water hammer pressure jump generated by the sudden closure is [9], [10]:

$$\Delta h = \frac{w \Delta v_1}{g}$$

Where w is the wave velocity and Δv_1 is the velocity jump from v_r to zero. Sometimes the manufacturer can give the return velocity characteristic curve.

4. Results

4.1. The flap valve stationary parameters commuted with FEM

Solid Works software has been applied for computation. Real turbulent flow has been considered. The flow coefficients *Kv* and the torque coefficients *Km* have been evaluated for normal and reverse flow direction and for the water levels 3.25 m, 3.75 m and 4.25 m. The *Kv* and *Km* curves are shown here on Fig 2 and Fig. 3. as examples. The results are correlated well with previous research a shown in Figure (4), [11]. The complete results can be found in the Appendix A.

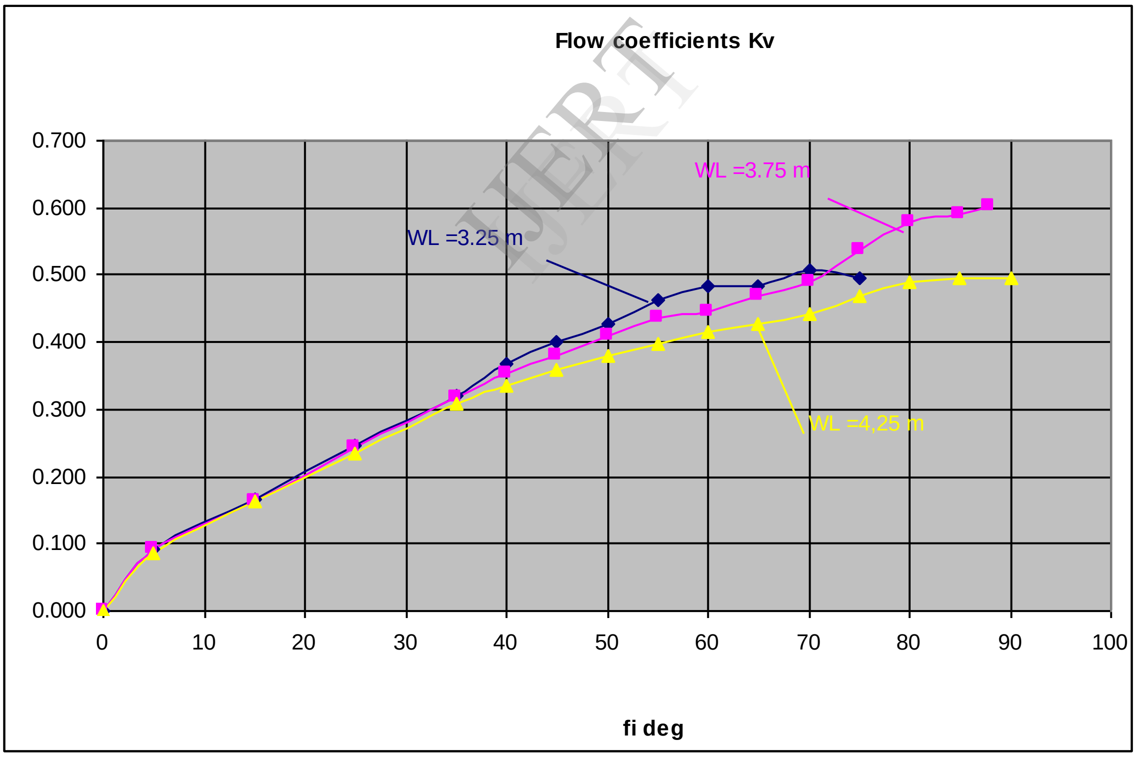


Figure 2. The flow coefficients Vs different water levels

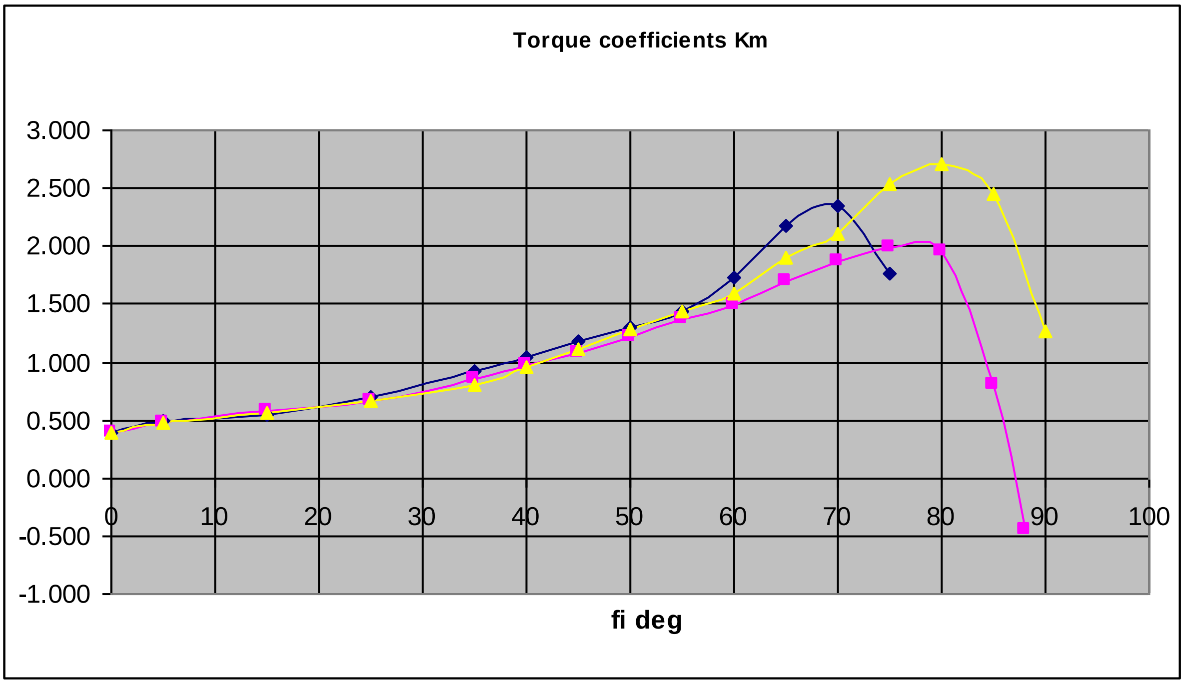


Figure 3. The torque coefficients Vs different water levels

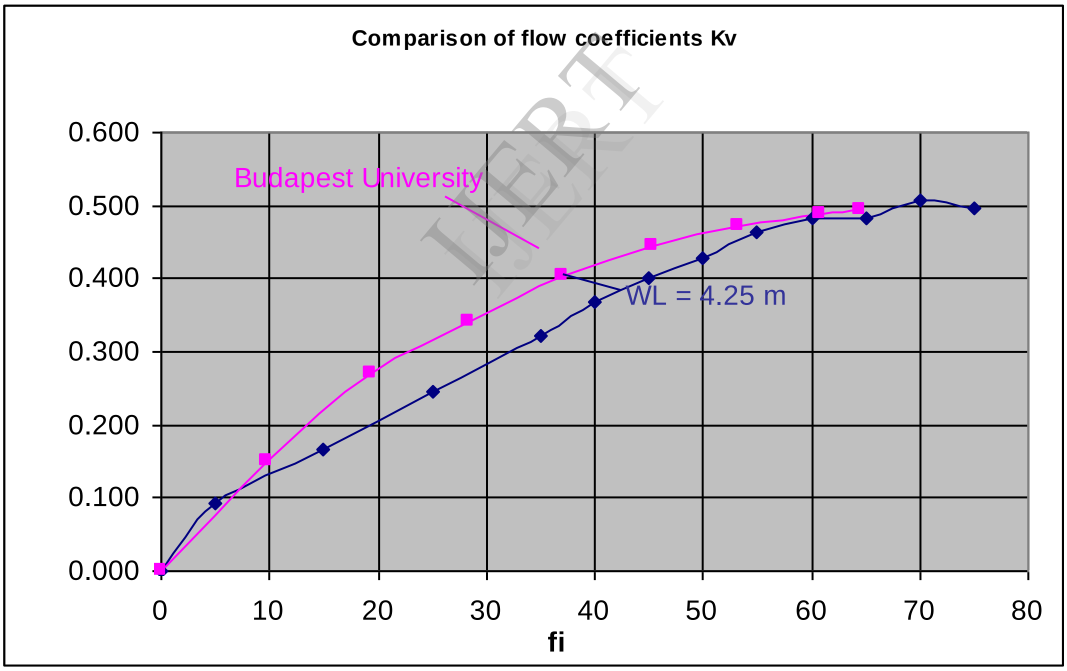


Figure 4. The flow coefficients Vs different water levels and comparison with other research

The coefficients change in function of water level; however, the difference is significant on higher opening angle (fi > 45°) only. There is a small scattering in the computed values in this region due to the very low hydraulic loss of the valve.

The flow coefficient *K*v curve with *W L = 4.25 m* has been compared to the measured curve in where the model size was 200x364 mm and the flap valve was somewhat convex seeing from the pump side. There was not any wall near the flap outlet. The result is shown on. There is a well-determined difference between the curves due to the geometries; however the basic character is the same.

4.2. The velocity fields

The CFD velocity distributions have been made also for normal and reverse flow. The discharge is Q = 5.0 m3/s. The pictures for fi = 45° flap angle can be seen here, the complete set of pictures. In particular the large field of low velocity in the diffuser at normal flow and the reverse flow lines on the side edges and around the upper edge of flap valve are interesting as shown in figs. 5, 6, and fig. 7 . The complete results can be found in the Appendix B.

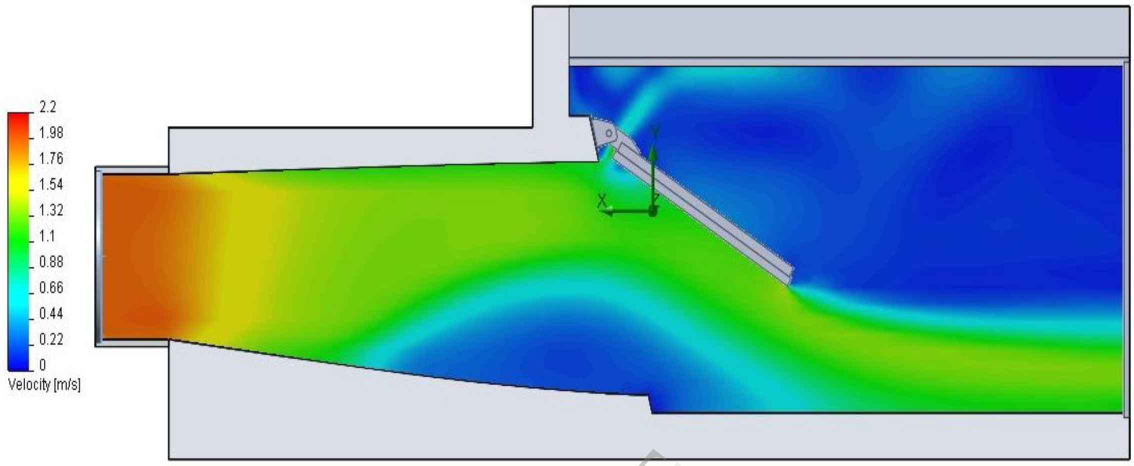


Fig.5 **Velocity fields at angle (**fi) 45° normal flow

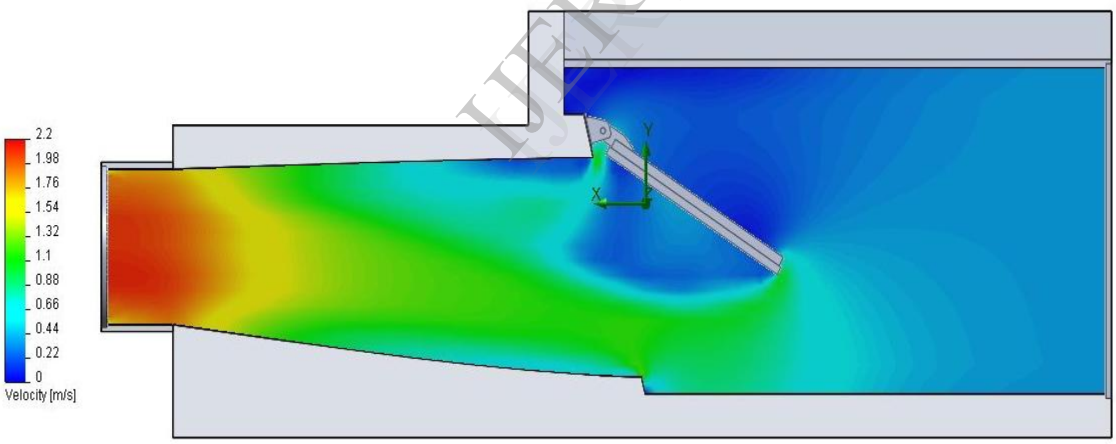


Fig **Velocity fields at angle (**fi) 45° reverse flow

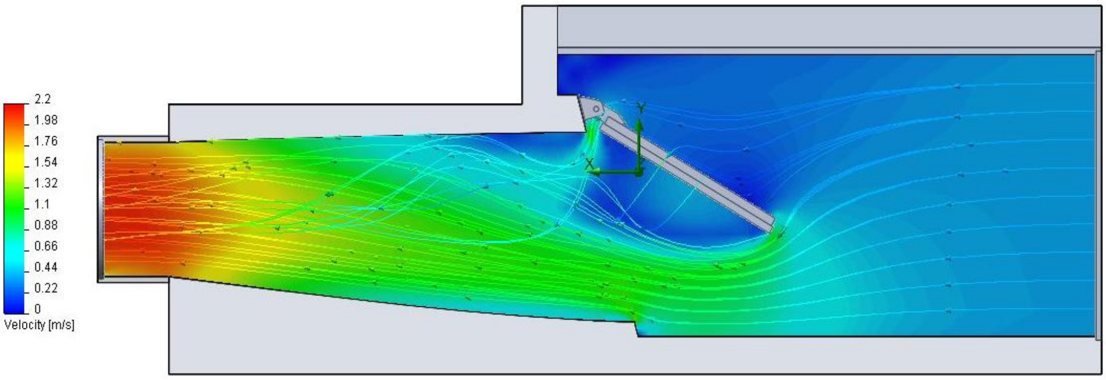
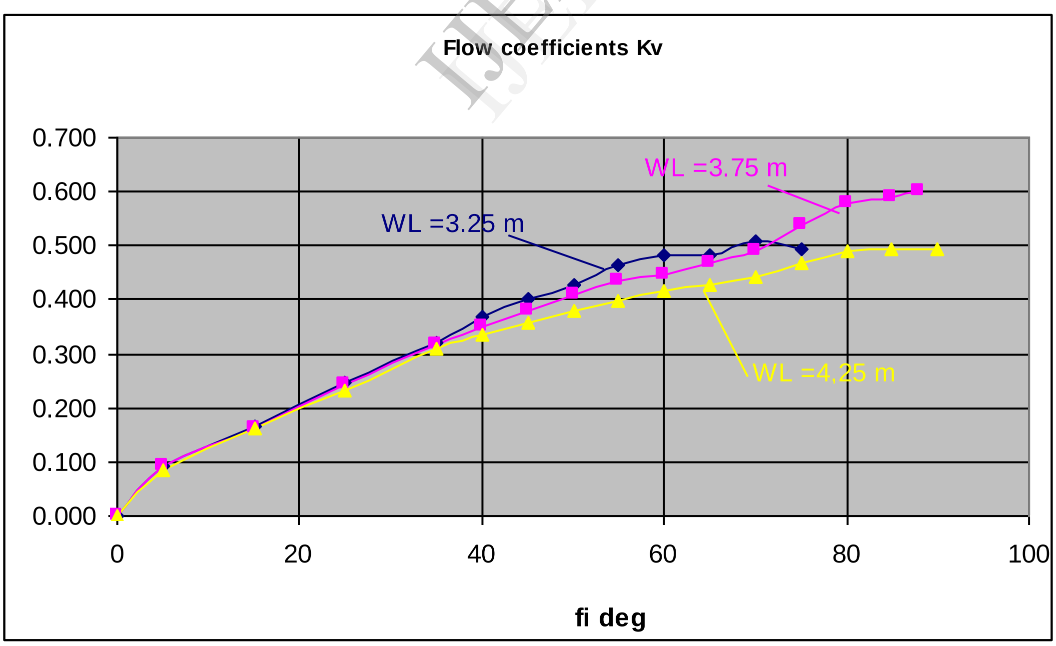


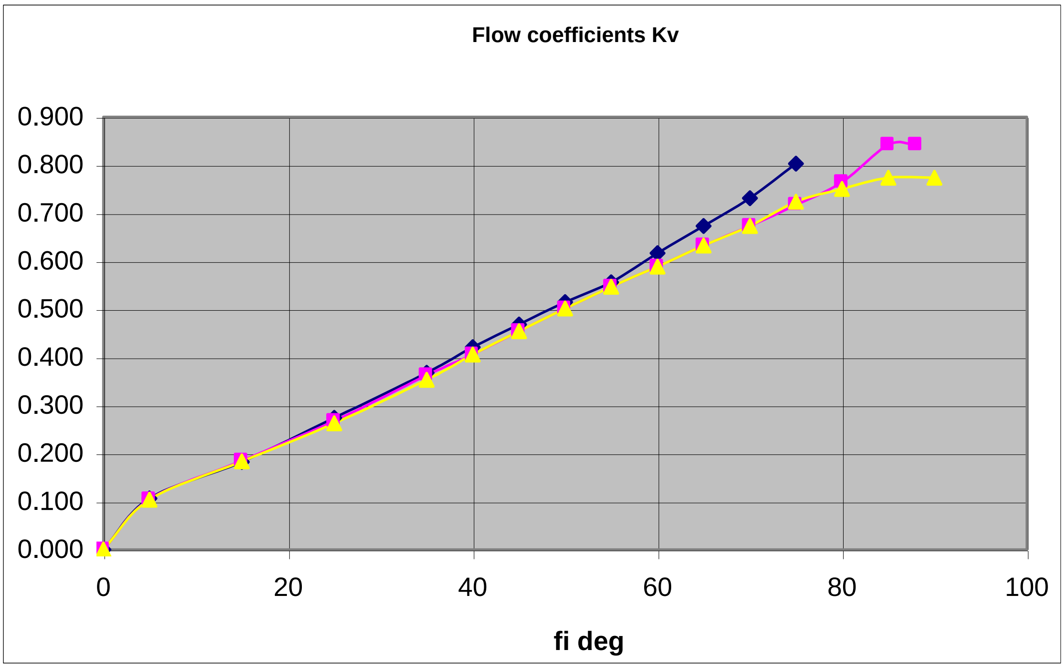
Fig. 7. **Velocity fields at angle (**fi) 45° Reverse flow with flow lines

5. Conclusions

The characteristics of flap valves with help of FEM seem to be effective and very useful. With the help of these results, the steady state and dynamic behaviour of flap valves can be followed**.** In order to make the CFD calculation completes, further work should be made regarding the complete closure of the check valve.

APPENDIX A




Flow coefficients Kv
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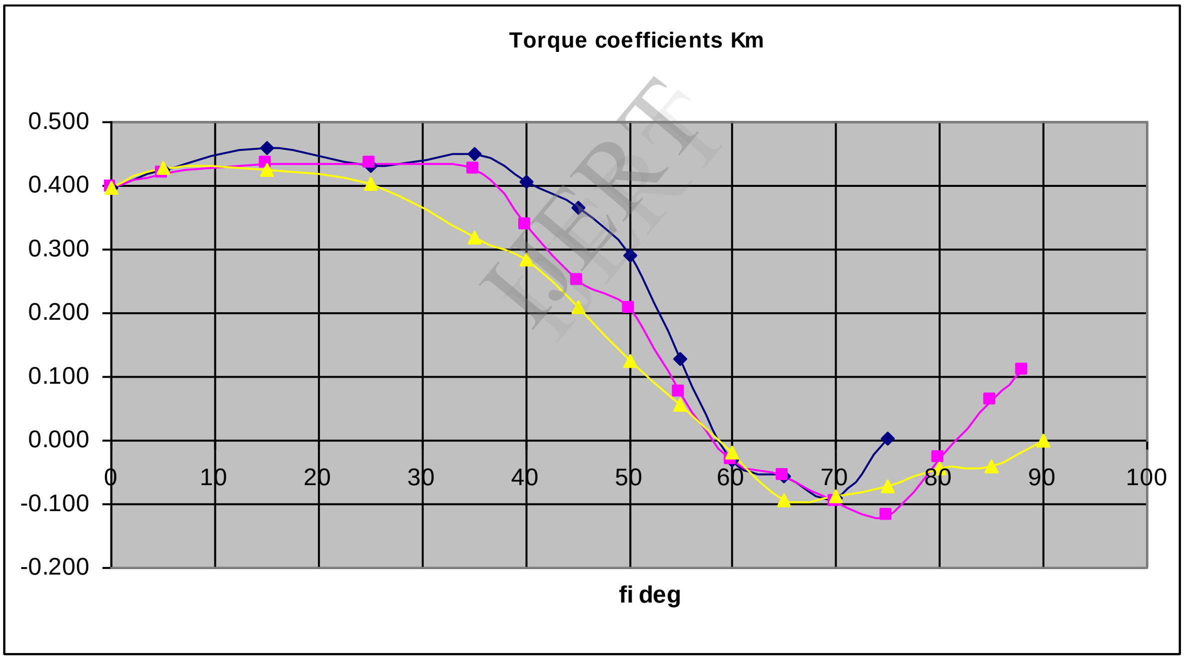
Torque coefficients Km
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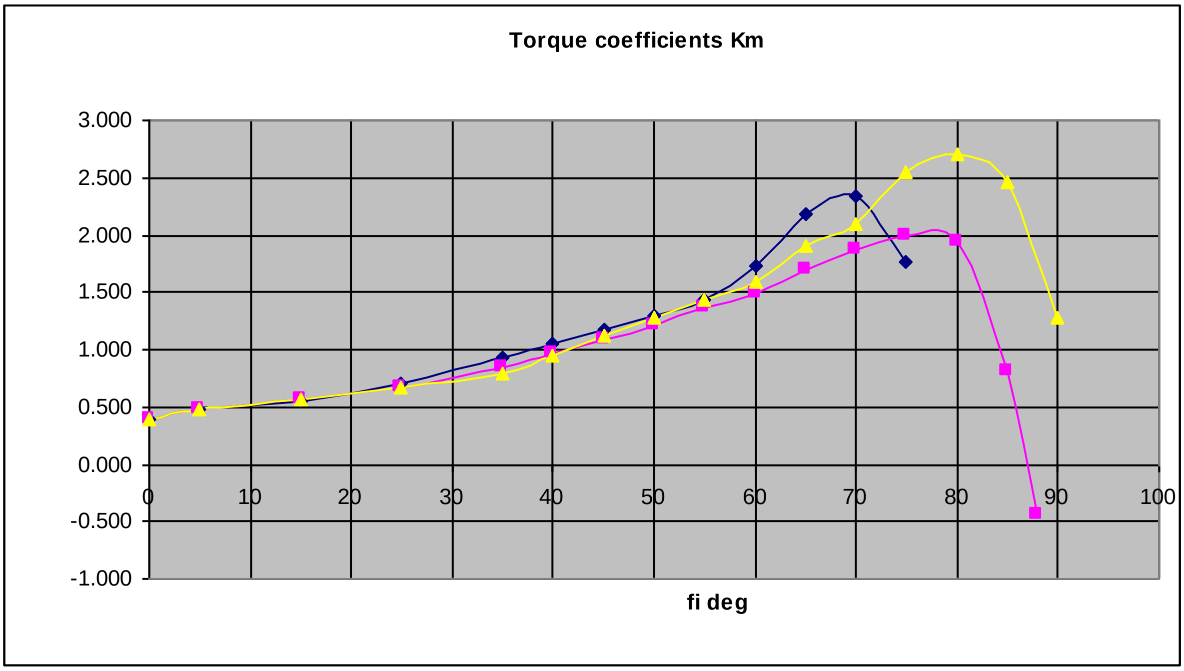
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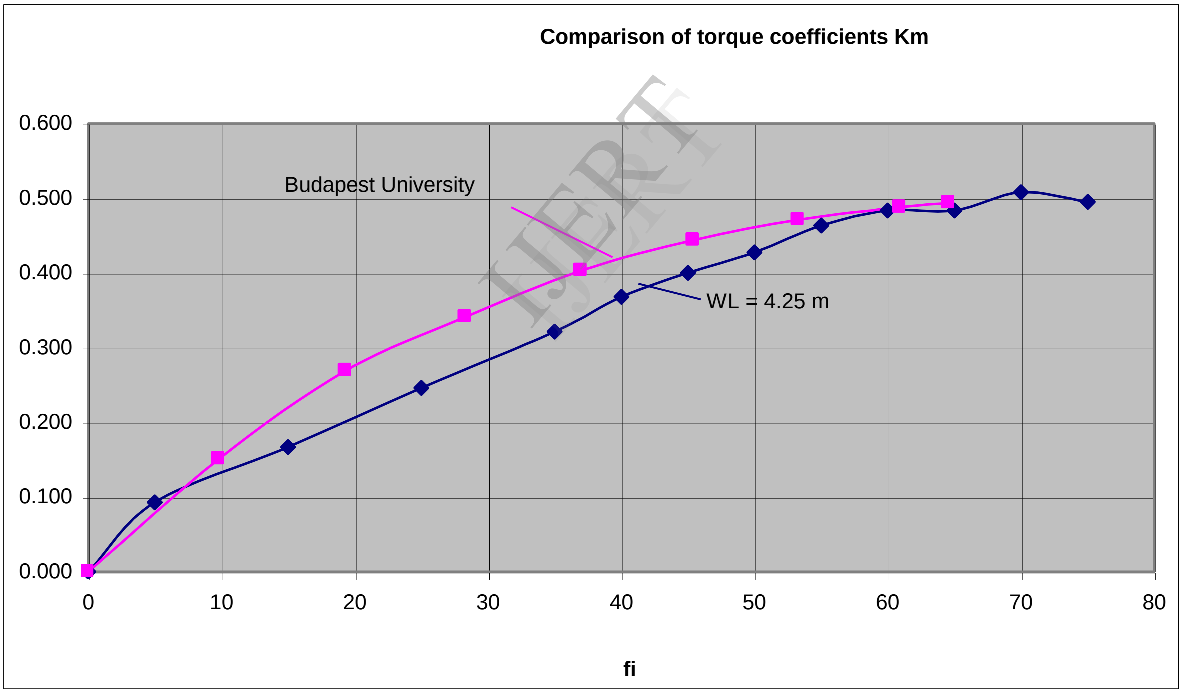
Comparison of torque coefficients Km
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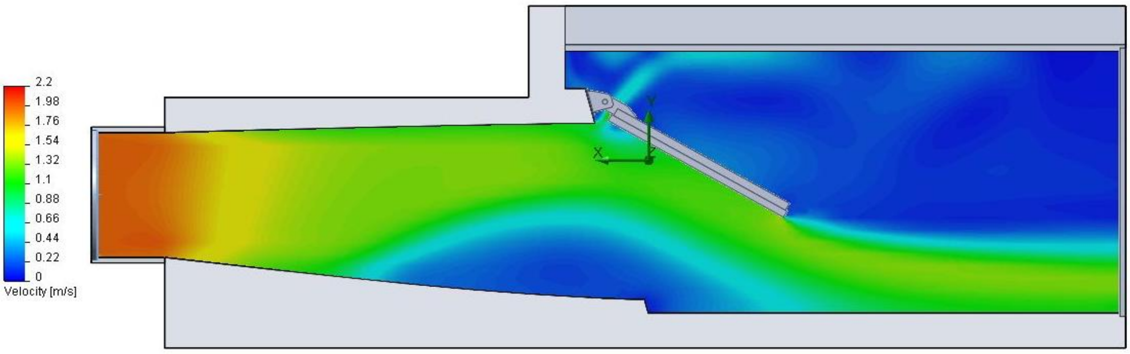
APPENDIX B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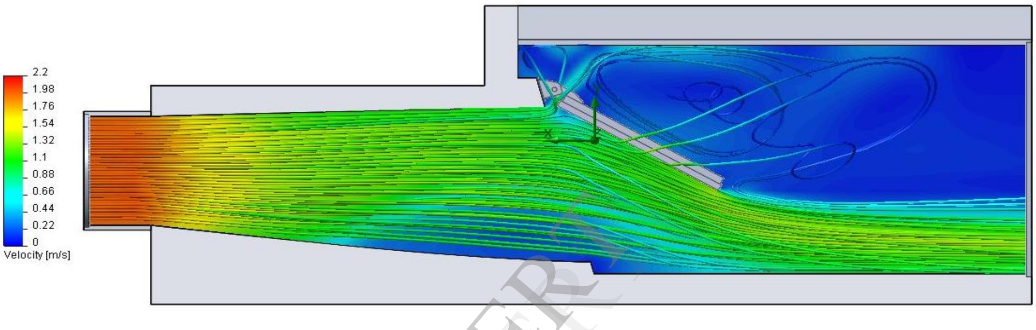
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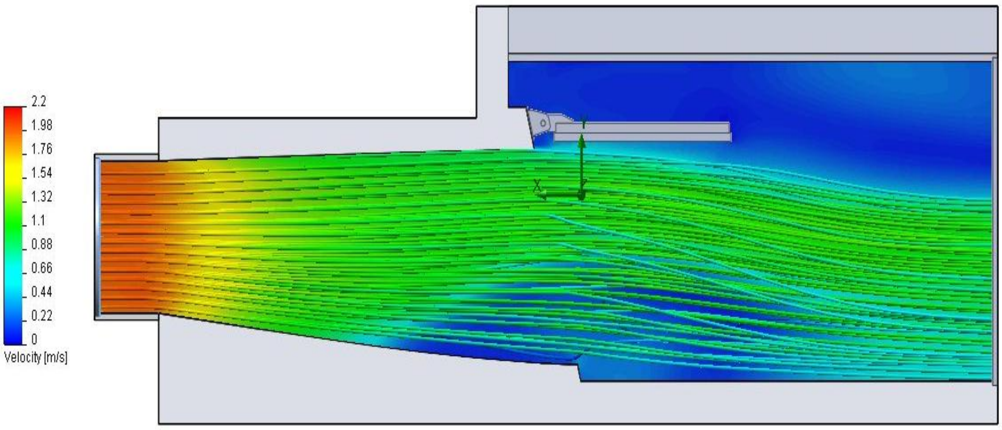
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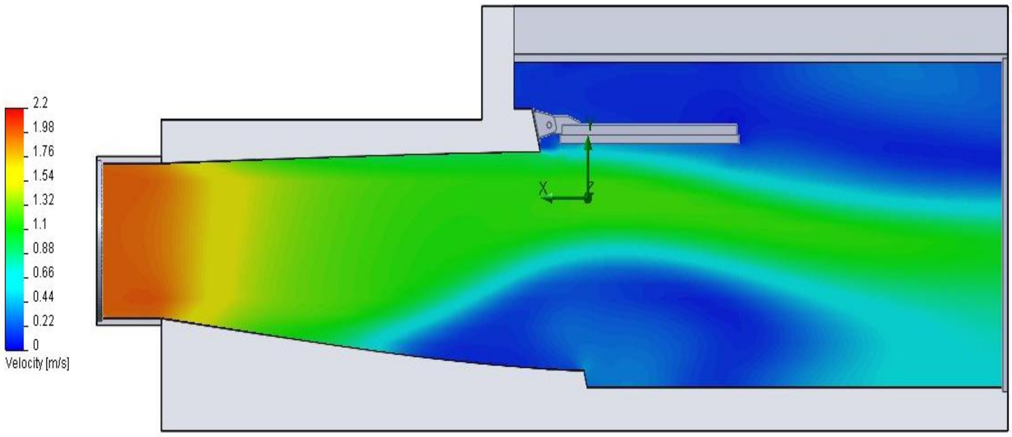
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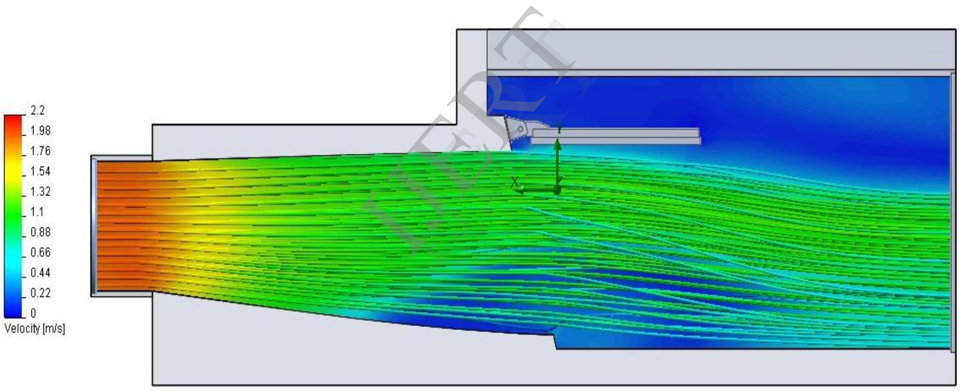
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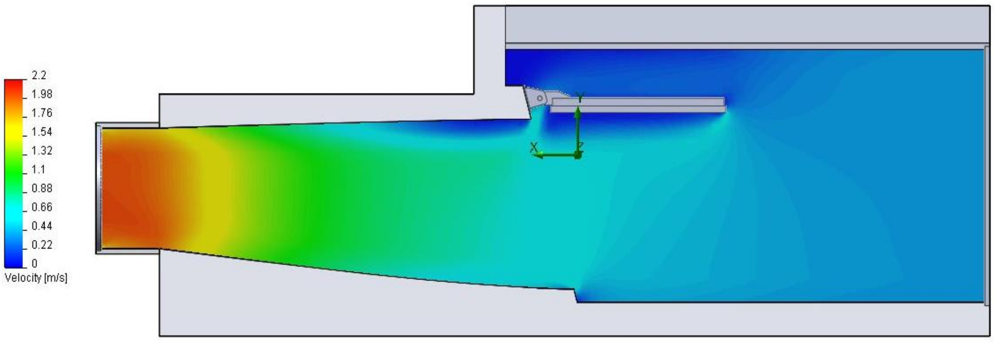
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Velocity [m/s]
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