

# Flow Characteristics of Check Valves and Energy Losses in Pipelines

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## INTRODUCTION

Check valves (or "non-return" valves) are a substantial part of numerous accessories applied in water supply and other hydraulic systems<sup>(1)</sup>. The application of these valves is aimed to prevent reverse flow under different conditions. This is necessary, for example, to prevent emptying of pipelines after pump shutdown and work of a pump as a turbine at intolerable high rotation speed due to backflow<sup>(2)</sup>. The application of check valves may also be connected with the waterhammer phenomena, e.g., the valves at the pump discharge providing slow closure after pump normal switching-off, or after an energy supply interruption; the valves in by-pass lines of pumps, etc.<sup>(3)</sup>.

One of the requirements to the check valves' operation in the main pipelines is low hydraulic resistance in the open position. This requirement is substantial for energy saving, taking into consideration the great number of the check valves in pipeline systems (tens of thousands of the valves are applied in Israel's water supply pipelines). The selection of the check valves during the design phase of the pipeline project must be based on analysis of the different valve characteristics, including energy losses. The method and examples of the energy losses analysis are described in this paper.

### Main types of check valves

Energy losses in pipelines related to hydraulic resistance of check-valves depend on their type, design and adjustment. The simple and very often used design of the check valves is based on the use of flow action on the valve without application of external energy source (Fig. 1). The plate closing/opening of the water passage is under action of pressure and friction forces from the liquid flow and the moment of these forces is under steady flow conditions in equilibrium with the moment of counterweight and friction forces in the bearing. Swing type check valves and valves with tilting discs (Fig. 1-2) if the counter weights are applied, both are the direct control action valves<sup>(1,2,5)</sup>. The check valve design

in which a spring is used for the valve closure as an alternative to the weight belongs also to this type of the valves<sup>(5)</sup>.

The direct control action valve opening and hydraulic losses at the fixed flow rate depend on adjustable moment of counter weight. The change of the counter weight moment influences both the hydraulic resistance in the open position and dynamic properties (for example, time of the closure). Hydraulic cylinders may be used in the direct control valves as damping devices to prevent slamming and to reduce waterhammer pressure loads<sup>(5)</sup>. The necessity of the weights or springs forces, providing the closing moment in the open position of the valve after liquid flow interruption (or decrease), limits opportunities of these valves hydraulic resistance reduction.

Positively controlled check valves, using external source of energy, may provide under the same conditions, a reduction of the energy expenses due to the following reasons.

- The full opening of the valve may occur without providing in open position the water flow action on the valve with the moment equal to counter-weight moment (which must be sufficient for the valve closure in the case of flow interruptions). This reason enables designing the valve with smaller hydraulic losses in the full open position.
- The full opening of the valve may be provided in all interval of working flow rate (the opening of the valve controlled by flow decreases at smaller flow rates increasing hydraulic losses).

The valves using external control provide higher opportunities for flow control and smaller hydraulic losses, but these valves are more complicated and expensive. The utmost part of the check valves, which is now being used in pipelines of water supply systems, are direct control action valves.

### **Hydraulic head and energy losses in an open check valve**

The pipeline may work at different flow rates  $Q$  in interval  $Q_{min} \leq Q \leq Q_{max}$ . Changes of the flow rate may be (for example) due to diurnal changes of water supply and corresponding changes of the number of working pumps. The direct control action check valve will change its disc (flap) position under these conditions increasing hydraulic

resistance coefficient at smaller opening. This increase is not necessary in the described situation and leads to the additional energy losses. The external controlled valves enable to avoid these losses. The power corresponding to the hydraulic head loss  $h$  (for an open check valve) may be calculated using equation:

$$N = g\rho hQ \quad (1)$$

where:

$g$  – gravity acceleration

$\rho$  – liquid density

The function  $h(Q)$  is necessary for the power calculation and it is usually determined by check valve producer (an example of the function is shown in Fig. 4).

Energy losses  $E_T$ , during the time  $T$ , can be determined if the diurnal changes of flow rate,  $Q(t)$  are known:

$$E_T = g\rho \int_T hQdt \quad (2)$$

An example of diurnal water consumption changes and changes of a pump station discharge for a municipal water supply is shown in Fig. 5<sup>(4)</sup> (differences between water supply and consumption during 24h are compensated by water reservoirs).

Expenses related to check valves application may be estimated if the prices of energy are known. The price of energy unit  $C$  may depend on season and change during the day time (24h), and may be different for working days (see Table 1) and for holidays.

The annual expense for energy relating to a check valve work in a pipeline may be calculated using the following equations:

$$C_{T_y} = g\rho \int_{T_y} chQdt \quad (3)$$

or

$$C_{T_y} = g\rho \left[ \int_{T_{wd}} chQdt + \int_{T_{hd}} chQdt \right] \quad (4)$$

where

$C_{T_y}$  – annual expenses;

$T_y$  – sum working time during the year;

$T_{wd}$  – part of  $T_y$  related to working days;

$T_{hd}$  – part of  $T_y$  related to holidays ( $T_y = T_{wd} + T_{hd}$ ).

It may be necessary to determine the sum of expenses  $C_{T_y}$  related to application of several check valves in a pipeline. For this case,

$$C_{T_y} = g\rho \left[ \int_{T_{wd}} c \left( \sum_{i=1}^{n_{ch}} h_i Q_i \right) dt + \int_{T_{hd}} c \left( \sum_{i=1}^{n_{ch}} h_i Q_i \right) dt \right] \quad (5)$$

where

$n_{ch}$  – number of check valve used in a pipeline.

Times  $T_{wd}$  and  $T_{hd}$  may be divided on several intervals where product  $chQ = \text{constant}$  and integrals in eq. (5) may be calculated as sums. The simple case is where check valves used in the same pipeline do not differ. The sum expenses for this case may be expressed, taking into consideration different periods for energy prices (Table 1):

$$C_{T_y} = g\rho n_{ch} \sum_{k=1}^{n_{se}} y_k \quad (6)$$

where

$n_{se}$  – number of periods.

For period number  $k$ :

$$y_k = n_{wk} \sum_{j=1}^{n_{iwk}} c_{kj} h_{kj} Q_{kj} \Delta t_{kj} + n_{hk} \sum_{j=1}^{n_{ihk}} c_{kj} h_{kj} Q_{kj} \Delta t_{kj} \quad (7)$$

where

$n_{wk}$  – number of working days

$n_{hk}$  – number of holidays

$n_{iwk}$  – number of time intervals  $\Delta t_{kj}$  during working day (24h)

where  $c_{kj} h_{kj} Q_{kj} = \text{constant}$

$n_{ihk}$  – number of time intervals  $\Delta t_{kj}$  during a holiday (24h),

where  $c_{kj} h_{kj} Q_{kj} = \text{constant}$

It can be assumed that  $g = 9.81 \text{ m/s}^2$ ,  $\rho = 998 \text{ kg/m}^3$  and the following units will be used:  
 $C [\text{NIS/kwh}]$ ,  $h[\text{mH}_2\text{O}]$ ,  $Q[\text{m}^3/\text{h}]$ ,  $\Delta t[\text{h}]$ .

Then eq. (6) may be presented in the form:

$$C_{T_y} = 0.00272 n_{ch} \sum_{k=1}^{n_{se}} y_k \quad (8)$$

Energy losses during work days ( $n_w$ ) of one year may be calculated using equation:

$$E_{T_{wy}} = 0.00272 n_w n_{ch} \sum_{j=1}^{n_{iw}} h_j Q_j \Delta t_j \quad (9)$$

where  $n_{iw}$  - number of time intervals  $\Delta t_j$  during working day (24h), in which

$h_j Q_j = \text{constant}$  and dimensions:  $h_j[\text{m}]$ ,  $Q_j[\text{m}^3/\text{h}]$ ,  $\Delta t_j [\text{h}]$  and  $\sum_{j=1}^{n_{iw}} \Delta t_j = 24\text{h}$ .

The losses during holidays ( $n_h$ )

$$E_{T_{hy}} = 0.00272 n_h n_{ch} \sum_{j=1}^{n_{ih}} h_j Q_j \Delta t_j \quad (10)$$

The actual energy losses and expenses can be now calculated if efficiencies of the pump, driving engine and transmission are known ( $\eta_p$ ,  $\eta_{de}$ ,  $\eta_{tr}$ ). The actual energy expenses in the case where the coefficients of efficiency may be assumed constant:

$$C_{T_y}^{(a)} = C_{T_y} / (\eta_p \eta_{de} \eta_{tr}) \quad (11)$$

where  $C_{T_y}$  is determined by equation (6).

### **Energy expenses calculation example**

Five check valves ( $n_{ch} = 5$ ) with tilting disk are used in the pipeline  $d = 500 \text{ mm}$  (20"). It is necessary to calculate energy expenses for cases of the valves controlled by flow action and valves using external control.

Initial data for calculations of energy expenses during working days (greater part of expenses) are as follows:

- Average flow rate:  $Q_{av} = 750 \text{ m}^3/\text{h}$ .
- Flow rate change during 24h according to Fig. 4.

Time intervals:	0 - 6h	6h - 19h	19h - 24h
Flow rate per one hour			
in % of day (24h) supply:	2%	6%	2%
in $\text{m}^3/\text{h}$ :	360	1080	360

- Prices of high voltage energy for consumers in working days-according to Table 1.
- Hydraulic losses dependence on flow rate

Flow rate, $\text{m}^3/\text{h}$ :	360	1080
Hydraulic loss, m:	0.24	0.6

- Efficiency of the pump, driving engine and transmission (product)  $\eta_p \eta_{de} \eta_{tr} = 0.8$

It is convenient for calculations of sums in eq. (7) to present the data in the table with time intervals where  $chQ = const$  (Table 2).

Calculations of actual energy expenses during all working days of one year using eqs. (7-8,11) and the data yields: 12967 NIS. The energy losses during the same time are calculated using eq. (9):  $E = 32638 \text{ kwh}$  and the actual energy losses  $E^{(a)} = 40797 \text{ kwh}$ . It was the case of the flow controlled check valves without external source of energy.

The energy expenses in case of positively controlled valve application may be calculated using the same initial data with correspondent change of hydraulic losses.

It may be assumed in this example for flow rate  $Q = 360 \text{ m}^3/\text{h}$  head loss  $h = 0.0124 \text{ m H}_2\text{O}$ , and for flow rates  $Q=1080 \text{ m}^3/\text{h}$  head loss  $h = 0.1116 \text{ m H}_2\text{O}$ .

The calculations of the energy expenses during all the working days of one year yields in this case: 2305 NIS, that is 17.8% from the expenses in the first case (application of direct flow controlled valves).

The obtained results show that in this case, application of positive controlled valves, besides other advantages (reduction of waterhammer loads, etc.), provides also reduction of the energy expenses.

## **REFERENCES**

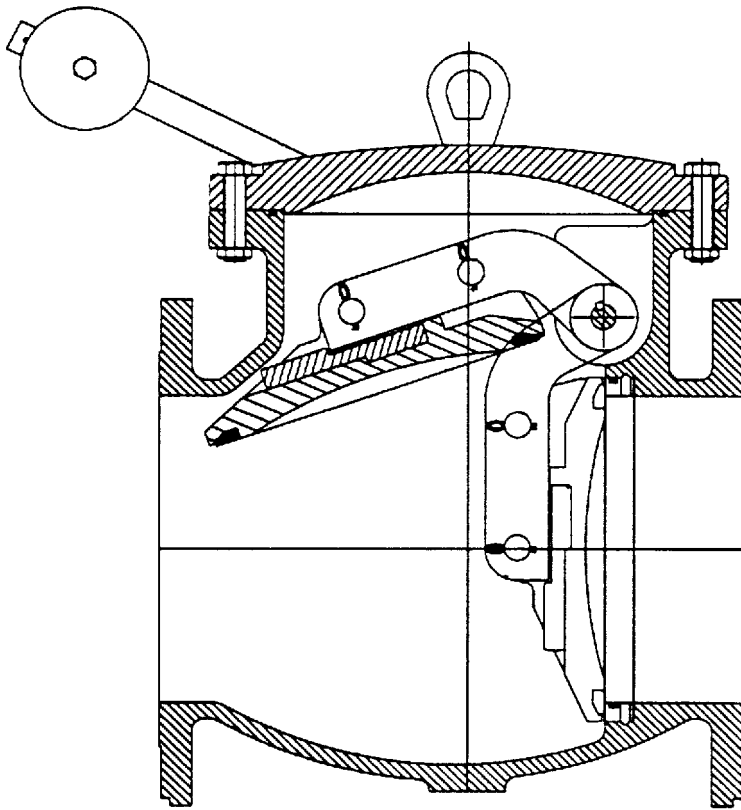
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**Table 1. Prices of high voltage electric energy for consumers in working days (2000)**

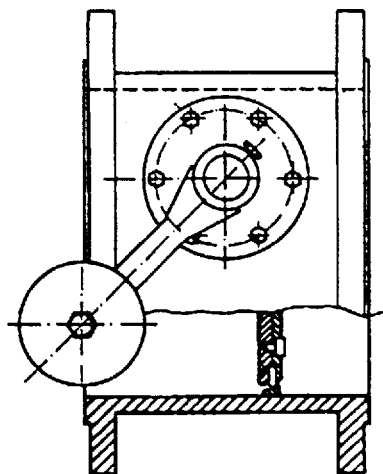
Phase	Months	06, 07, 08, 09	12, 01, 02	03, 04, 05, 10, 11
"Pick"	Time h	8 <sup>00</sup> - 16 <sup>00</sup>	17 <sup>00</sup> - 21 <sup>00</sup>	17 <sup>00</sup> - 21 <sup>00</sup>
	Price NIS/kwh	0.468	0.6557	0.3823
"Brow"	Time h	16 <sup>00</sup> - 21 <sup>00</sup>	7 <sup>00</sup> - 17 <sup>00</sup>	7 <sup>00</sup> - 17 <sup>00</sup>
	Price NIS/kwh	0.3088	0.2857	0.2898
"Wold"	Time h	21 <sup>00</sup> - 8 <sup>00</sup>	21 <sup>00</sup> - 7 <sup>00</sup>	21 <sup>00</sup> - 7 <sup>00</sup>
	Price NIS/kwh	0.1442	0.1469	0.1360

**Table 2. Data for energy expenses calculation**

Months: 06, 07, 08, 09 ; Number of working days: n <sub>w1</sub> = 86						
Time intervals, h	0 - 6	6 - 19			19 - 24	
		6-8	8-16	16-19	19-21	21-24
Price NIS/kwh	0.1442	0.1442	0.468	0.3088	0.3088	0.1442
Flow rate m <sup>3</sup> /h	360	1080	1080	1080	360	360
Hydraulic loss mH <sub>2</sub> O	0.24	0.6	0.6	0.6	0.24	0.24
Months: 12, 01, 02 ; Number of working days: n <sub>w2</sub> = 63						
Time intervals, h	0 - 6	6 - 19			19 - 24	
		6-7	7-17	17-19	19-21	21-24
Price NIS/kwh	0.1469	0.1469	0.2857	0.6557	0.6557	0.1469
Flow rate m <sup>3</sup> /h	360	1080	1080	1080	360	360
Hydraulic loss mH <sub>2</sub> O	0.24	0.6	0.6	0.6	0.24	0.24
Months: 03, 04, 05, 10, 11 ; Number of working days: n <sub>w3</sub> = 107						
Time intervals, h	0 - 6	6 - 19			19 - 24	
		6-7	7-17	17-19	19-21	21-24
Price NIS/kwh	0.136	0.136	0.2898	0.3823	0.3823	0.1360
Flow rate m <sup>3</sup> /h	360	1080	1080	1080	360	360
Hydraulic loss mH <sub>2</sub> O	0.24	0.6	0.6	0.6	0.24	0.24



**Fig. 1. Swing type check valve with counter weight (A.R.I., Israel)**



**Fig. 2. Check valve with tilting disc and counter weight (A.R.I., Israel)**

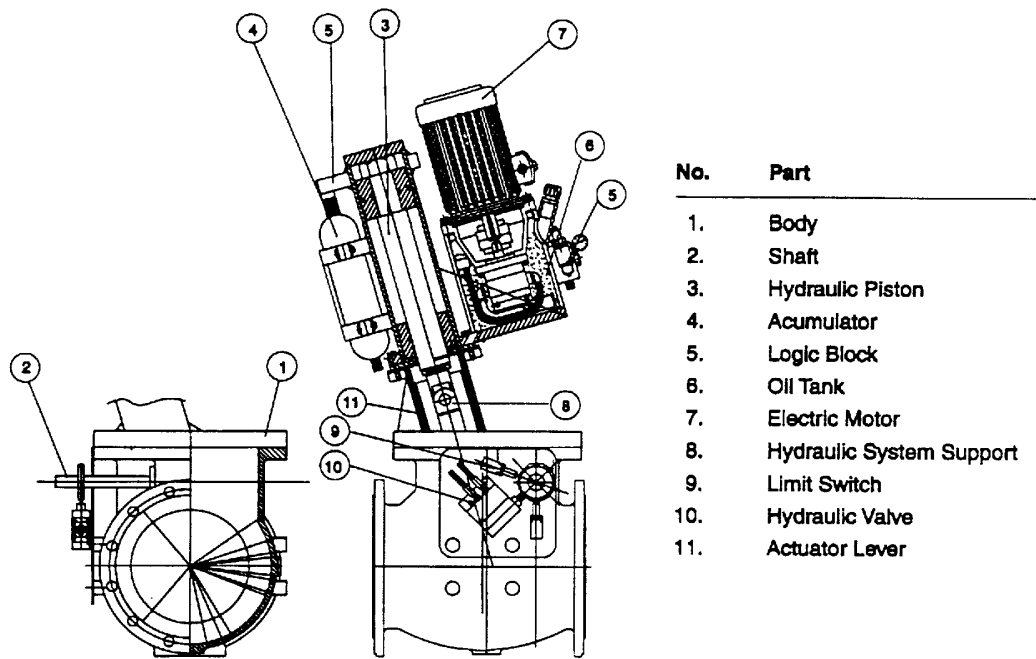


Fig. 3. Check valve using external source of energy (A.R.I., Israel)

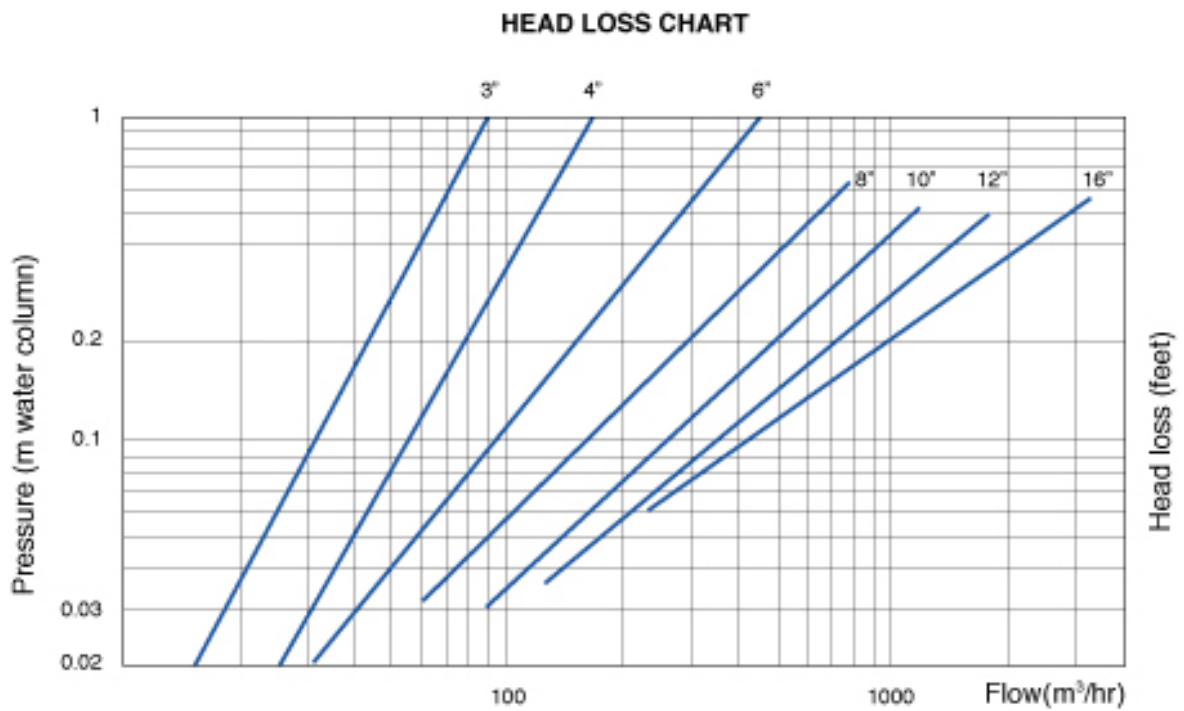
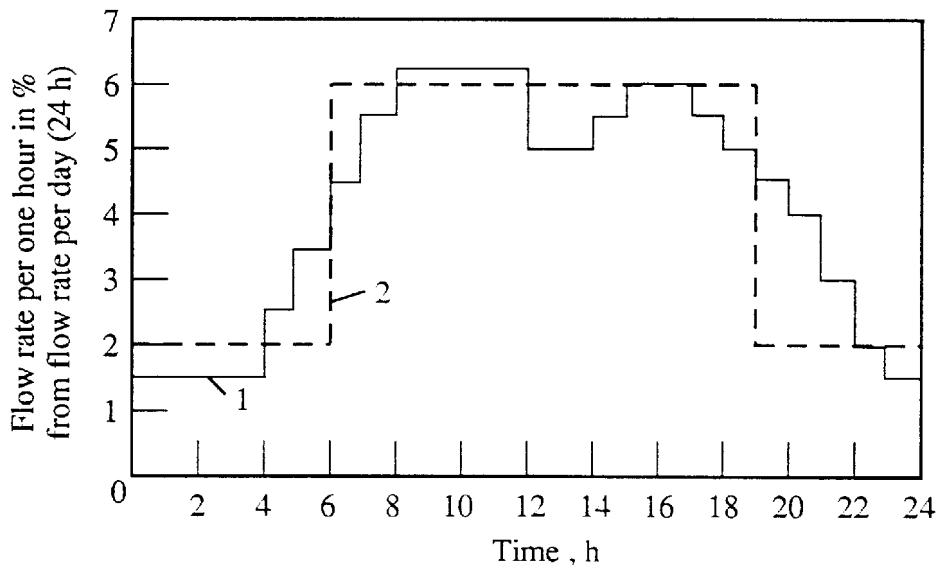


Fig. 4. Head loss chart of

Fig. 4. Head loss chart of swing type check valves (A.R.I., Israel)



**Fig. 5. Municipal water consumption and pump station discharge  
1-water consumption, 2-pump station discharge**

Hd/ra/staff/Tarshish5/195 flow charac