SONDERDRUCK aus
Professional Papermaking
Nr. 1/2008

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Practice-oriented Test Procedures to Determine the Service Life and Life Cycle Costs of Valves and Fittings in the Pulp System

Summary

In the last few decades valves and fittings for water and pulp suspension management within pulp and paper mills have become high-tech-equipment. They are not only expected to be highly reliable, precise and easy to maintain but should also have a long operating life. Consequently the criteria for selecting these tools for a given task should not only be based on functionality and costs but should also take into consideration potential cost which might arise due to increased expenses in maintenance or even production interruptions, i. e. the real "life-cycle-costs".

Experience gave evidence that seemingly economic valve solutions might in the long run turn into very costly decisions, if potential losses in production stability, machine availability or even product quality had not appropriately been taken into account.

This paper presents the basic methods of life-cycle-cost calculation and a few case studies which show what consequences might occur in the wake of valve failure in a modern, high-speed paper production plant.

It also reports about a recently developed test apparatus which might provide a much better and sound basis for the prediction of whether a specific valve is the best solution for a given job – including its performance throughout the whole life-cycle. This mobile apparatus has been designed, developed and commissioned in co-operation between the professorship for paper technology at Dresden University of Technology and Stafsjö Armaturen and Ebro Armaturen. In a preliminary test series in which 6 different valve types were subjected to both, water and paper pulp suspension flows the influence of the valve geometry on hydrodynamics and pressure drop were investigated. First results will be reported and discussed.

Shut-off and adjustment valves Pulp gate valve with / without V-diaphragm, butterfly valves, spherical valves	all Media
Regulating valves and fittings Spherical segment valves, flap valves	all Media
Non-return valves and fittings Butterfly valves, check valves	all Media except pulp
Sampling valves and fittings Sampling valve, spherical valves	Pulp, filtrate
Safety devices Filtrate Safety valves, sniffer valves	Compressed air, vapour, pulp
Special valves and fittings White water valves for bone-dry cross profile regulation, zone regulating valves in vapour blow box	Filtrate, vapour

Fig. 1: Main valves and fittings used in the pulp and paper industry

Fig. 2: Knife gate valves, butterfly and control valves

1. Introduction

The demands placed on valves and fittings for the pulp and paper industry have become increasingly complex during the last few years, on account of the increased use of recycled pulp, the increasing restriction of water circuits, higher contents of minerals, foreign particles and salts in the suspensions and circuit waters, as well as the general increase in production speeds[1].

The valves and fittings primarily used to shut off and regulate medium flows, for ventilation, evacuation of plant parts, protection – for example against excessive pressure in the system –, communication with controls and PLS etc., are shown in *Fig. 1*.

Valves and fittings in pipe systems are used to seal lines and tanks, control pulp flows and regulate volume and mass flows, as well as for precise dosing of process and product additives, control in water and waste water systems, and for the discharge of rejects. *Fig. 2* shows examples of the product diversity of the valves and fittings used.

Valves and fittings, in interaction with pipe networks and process control, are extremely important components in a production plant in order to achieve reliable overall operations. It is therefore expected that these – generally not particularly cost-relevant components – will operate reliably and fault-free, as in the event of malfunctions they generate failure costs that can many times exceed their own value. Valves and fittings to control water and stock flows today represent high-tech products, from which not only high reliability, precision and ease of maintenance are expected, but also a long service life. Therefore, the decision criteria for the selection of valves and fittings in pipelines include not only their functionality and acquisition costs, but also any follow-on costs due to high maintenance expenditure or even production failures, i. e. the actual "life cycle costs" (LCC). Experience has shown that savings made with regard to the overall purchase price

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of such components at the expense of operational reliability or plant up-time, the cost efficiency of the overall process (pump operation etc.) or even the product quality can prove to be a very expensive in the long term.

The results presented in this study, particularly the influence of the shut-off geometry on the flow behaviour and the pressure loss of the valves, were presented and discussed at the PTS Symposium "Chemical Technology of Paper Production" in Munich/Germany (2006).

2. Life cycle cost analysis

2.1 Definitions

In operating practice, divergent requirements in relation to purchase and technology must often be taken into account when procuring production equipment. Despite the availability of functional specifications, it is usually very difficult or even impossible to make a comparative assessment of alternative means of production in respect of their total costs, because costs that arise during the usage phase due to defined system characteristics are often only included in the decision process as "soft facts"[2].

Both manufacturer and operator therefore are particularly interested in determining the true "life cycle costs" of a defined means of production. Before examining further details of life cycle costing, a few important concepts must be defined:

Life cycle costs refer to the overall costs caused by a system during its life cycle. From the manufacturer's perspective these include the cost of generating the product idea, development, production, service and recycling or disposal if necessary. From the customer's viewpoint, these primarily include the pre-sales phase, product use and the after-sales phase.

DIN EN 60300[3] defines the ***calculation of life cycle costs*** as the process of financial analysis to estimate the total procurement, ownership and disposal costs of a product. It is based on the allocation of costs to corresponding phases in the life cycle and also includes a subdivision into one-off and recurring costs or initial and follow-on costs.

2.2 Methods for calculating life cycle costs

Before a life cycle cost analysis can be started, the question of whether the expenditure and scope of this cost analysis are justified at all must be answered. VDI directive 2884 formulates a series of questions for this purpose. Positive answers to these are justification for compiling the LCC model.

- Does the means of production cause high recurring costs and follow-on costs in proportion to the one-off procurement costs?
- Does the means of production have a long planned service life?
- Do any cost-relevant consequences become more significant with progressive service life of the means of production?
- Does the means of production require a high capital expenditure beyond the service life?
- Can a cost reduction potential be assumed, which can be identified through the use of LCC?

The number of investment goods of the same design to be procured is an argument for using LCC. The profitability of performing an LCC analysis increases as the expected usage for the number of procurement objects multiplies. Access to relevant data is simpler here, due to increasing use of IT systems and more pronounced customer orientation by manufacturers. The individual work steps of the LCC in the area of the procurement process are shown in *Fig. 3*.

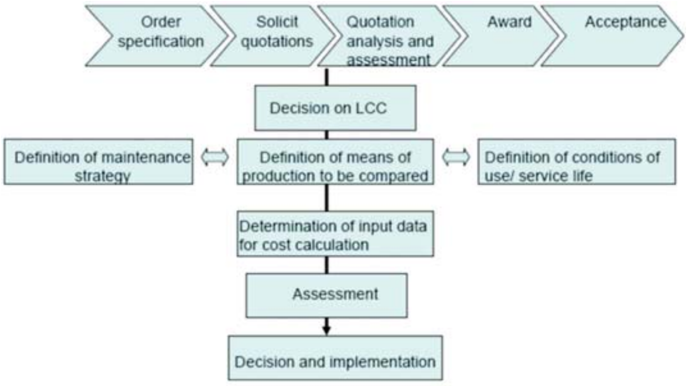


Fig. 3: Life cycle costing in the procurement process [4]

The result of a life cycle cost analysis is heavily dependent on the quality and scope of the analysed parameters. The determined costs are periodically calculated over the analysis period and discounted to a common reference point with the help of dynamic investment calculation processes, thus becoming comparable. A distinction is made here between one-off costs (procurement, commissioning), regularly recurring costs (operation, inspection) and irregularly recurring costs (repairs, plant failures).

To determine these costs, assessment methods such as the MTBF value (Mean Time Between Failures), which specifies the average time between two failure events of a means of production, or the failure mode and effects analysis (FMEA) are available. The latter pursues the goal of systematically identifying potential errors, error consequences and error causes for components for which no empirically assured MTBF values are present[4].

For industrial valves, the specification of the parameters to be compared after definition of the performance requirements and conditions of use may look like this[4].

- Procurement costs (cost prices for valve and actuator, packaging, freight, customs, administration, stock keeping, exchange rate differences etc.)
- Commissioning costs (installation in the pipeline, manufacture of connections, documentation of commissioning, emission protection measures)
- Operating costs (electric actuator: energy costs, pneumatic actuator: instrument air costs, manual actuator: personnel costs etc.)
- Maintenance (inspection, maintenance, repair, spare parts, cleaning, etc.)
- Failure costs (plant stoppages, product loss, etc.)
- Follow-on costs (personal injuries, environmental damages, etc.)
- Costs for decommissioning (disassembly from the pipeline, cleaning, disposal, residual value, etc.)

The result of the analyses provides an overview of the expected costs throughout the life cycle for each alternative. It should be noted that the calculated failure and product loss costs must be very specifically coordinated with the respective use of the valve/fitting. With the same energy consumption, the failure of a regulating valve immediately before the headbox (no possibilities for alternative product guidance) is far more dramatic than the failure of the same valve in a non-critical location, and consequently the result of the LCC analysis is completely different.

Fig. 4 shows the development of the individual costs and the total life cycle costs for a supposed cycle duration of 5 years, using the example

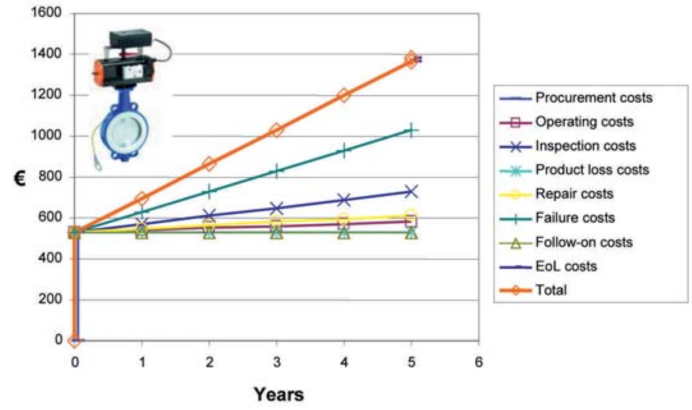


Fig. 4: Resulting valve life cycle

of a regulating valve with nominal width DN200. The analysed valve is deployed in a brewery, where it is used in the wort boiling area. Due to the different discounts, the specified values can only be regarded as notional.

2.3 Case studies

The potential follow-on cost-generating failure scenarios for valves are very diverse. They extend from minor system faults, through impairments in the quality of the end product, to production stoppage. A minor system fault does not result in a production fault, but only shows unintentional deviations from the nominal parameters of the plant, e. g. leaks from a shut-off valve. As long as the parameters are still within the tolerance parameters, the financial damage is kept within limits.

The consequences are more detrimental if it is only possible to continue manufacturing with reduced quality, so if – with the same costs – the revenue is reduced or production even has to be cancelled. It can become even more problematic if the delivered finished product subsequently has to be rejected.

Examples of this are hydraulic faults caused by valves in the constant section, which manifest themselves as pressure fluctuations in the headbox, where they lead to fluctuations in the pulp output speed. The results are instability in the web drainage and – resulting from this – unstable or poor longitudinal and cross profiles of grammage, ash, fibre orientation, strength characteristics and generally poor formation. This can ultimately result in waviness, bubbles and curling of the product.

Such consequences can occur e. g. due to excessive play in the actuator of a control valve in the vacuum line of the wet end, if the control loop surges and oscillations result in the vacuum. These oscillations affect the drainage and can retroact on the actuator[5].

In the worst-case scenario, a fault in a valve results in immediate interruption of the production process with all additional costs. This then includes not only the costs of recommissioning the valve itself, but also the costs of unplanned shut-down operations, safeguards and recommissioning together with ramp-up of the system until the nominal parameters are reached. A very graphic example of this would be a valve for regulating the grammage before the mix pump which suddenly jams, so that the quantity of pulp fed to the headbox can no longer be adapted to the current production requirements. In this case, shut-down of the plant to repair the affected valve is unavoidable.

- Unfavourable flow conditions cause pressure pulsation
- Unfavourable positioning influences operating mode of pumps, cleaners and sorters
- Influence of gas accumulations in the area of valves and fittings results in hydraulic instability
- Dirt and pulp deposits in the area of gas accumulations cause losses of quality and running efficiency in the paper machine
- Separation and depositing in the area of valves and fittings results in paper profile fluctuations and associated quality faults

Fig. 5: Hydraulic instability caused by valves and fittings in the constant section and associated faults

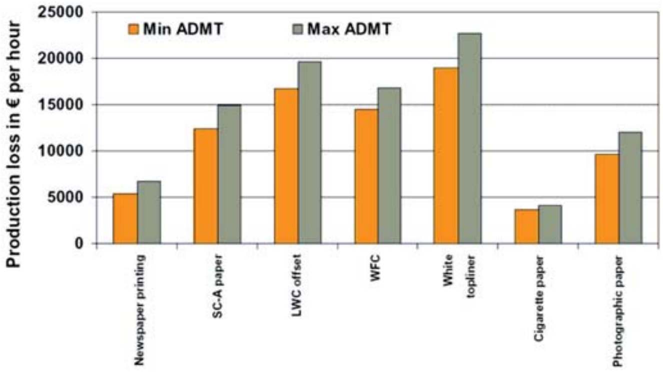
B. Stibi[6] has summarised the following potential faults caused by valves *(Fig. 5).*

As a result of the increasing speed and dimensional width of paper- and cardboard-making machines during the last few years, and the increasing prevalence of online production plants, the costs resulting from production faults have risen considerably. There can be no doubt that these trends will continue.

The production loss according to paper grade in the event of a shutdown is determined on the basis of the profit margin (€/ADMT "Absolute Dry Metric Ton": 200–500 €/t), which for example with newspaper printing with 100 % de-inked pulp lies between 200–250 €/t and in the case of special papers such as cigarette paper, bible printing paper, photographic paper etc. lies between 350–500 €/t. The production loss per metre of working width and hour is determined by means of the grammage of the product and the production speed[7]. *Fig. 6* shows typical production losses according to paper and board grades, as well as manufacturing conditions. Losses occurring due to restarting and adjustment processes until reaching the nominal values are not yet included. The following rule is available for determining the numeric values:

$$V = \frac{60}{1000000} \cdot m_A \cdot b \cdot v \cdot D$$

with:
V = Loss in €/h
m_A = Grammage in g/m²
b = Working width of the PM in m
v = Working speed of the PM in m/min
D = Profit margin in €/t



	Newspaper printing	SC-A paper	LWC offset	WFC	White topliner	Cigarette paper	Photographic paper
Speed m/min.	1600	1700	1800	1600	1200	1000	1000
PM width m.	6,26	8,7	9,2	6,3	7	5	5
Base weight g/m2	45	56	60	80	150	30	80
€ ADMT (min./max.)	200/250	250/300	280/330	300/350	250/300	350/450	400/500

Fig. 6: Production losses per hour of downtime

Generally, a valve fault has a greater impact on costs, the closer it is located to the production process of the end product and the fewer bypass systems are present. So the loss due to the failure of a g.s.m.

substance regulating valve before the mix pump in the manufacture of LWC paper with a grammage of 60 g/m^2 at a production speed of 1,800 m/min and a working width of 9.2 m and a repair time (downtime) of approx. 2.5 hours is between 40,000 € and 50,000 € .

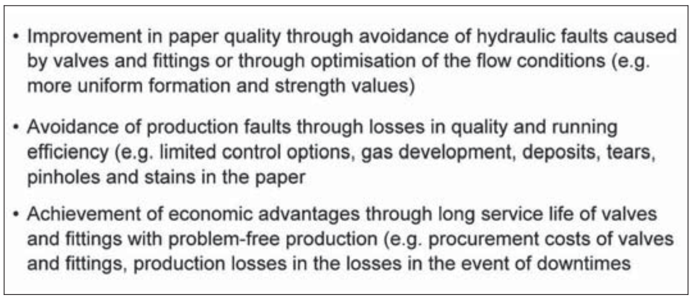
In addition to the cited production-relevant faults, however, there are also faults which jeopardise the safety of the plant, which likewise require immediate interruption of the plant operation, at least until provisional repair.

Against this background, the professorship at the Dresden University of Technology in conjunction with the companies Stafsjö Armaturen and ERBO Armaturen have designed and implemented a flexible test facility for the development and optimisation of valves for the paper industry, which delivers particularly informative data on the suitability of valves for specific applications, thanks to its very practical approach.

3. Test plant

The test facility described below should make significant contributions to the optimisation of existing and the development of new valves, and thus to the achievement of the objectives specified in *Fig. 7.*

The test plant has a modular design and can be operated either in a laboratory or pilot plant station with model suspensions or in a mobile capacity, in the bypass line of a large scale industrial plant. The base areas of the individual modules correspond to the standard Euro pallet (1200 x 800 mm), thus permitting problem-free transport. The energy supply for all plant parts is provided centrally. The valves to be tested can be equipped with both pneumatic and electric actuators. Opening and closing processes as well as opening intervals can be preset as desired and automatically shut down[8].



- Improvement in paper quality through avoidance of hydraulic faults caused by valves and fittings or through optimisation of the flow conditions (e.g. more uniform formation and strength values)
- Avoidance of production faults through losses in quality and running efficiency (e.g. limited control options, gas development, deposits, tears, pinholes and stains in the paper
- Achievement of economic advantages through long service life of valves and fittings with problem-free production (e.g. procurement costs of valves and fittings, production losses in the losses in the event of downtimes

Fig. 7: Objectives of the test plant

A test design is possible within the following parameters:

- Pipeline cross-section: DN 100,
- Pulp density: 0–3 (4) %,
- Flow speed: 0.3–5 m/s,
- Temperature range: up to 60 °C

Fig. 8 provides an overview of the entire plant. Starting from a receiving vat (storage volume = 1000 l), which is also equipped with a powerful agitator, the model suspension is conveyed by the pump into the experimental field. The pressure drop is continuously measured above the test valve. A glass tube for visualisation of the flow processes is directly connected to the test valve. This can be replaced by a robust stainless steel tube for application in an industrial production environment. The bypass increases plant reliability and enables setting of defined flow situations (low flow speed with stable pump operating point).

The demonstrated test facility is to enable realisation of the cited goals. It offers the following options for characterisation of the behaviour of a valve under given operating conditions:

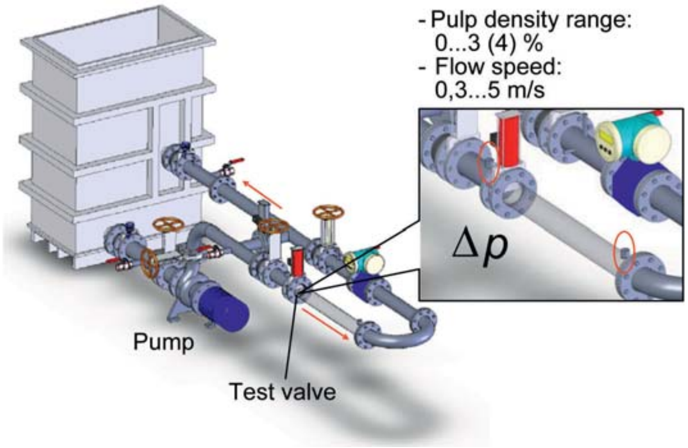


Fig. 8: Test plant

- Determination of the pressure drop and energy losses above the valve,
- Determination of the tightness of the valves when closed,
- Optimisation of the flow conditions (pressure pulsations, turbulence formation),
- Determination of flow limits and performance curves,
- Assessment of corrosion, wear and cavitation under real conditions.

3.1 Test design and test performance

In initial test series on the plant, which had only been recently commissioned, six valves from the current product range were tested in a real pulp suspension - Canadian pine sulphate pulp with a degree of beating of 28 °SR.

With a constant volume flow of 70 m^3/h (or a superficial velocity of 2.5 m/s), the pressure drop above the test valve was measured for pure water and for the specified pulp with pulp densities of 2.3 % and 1.3 %. *Fig. 9* provides an overview of the tested valves. Three gate valves and three butterfly valves were tested. The fields of application of the individual valves will be discussed subsequently in connection with the determined measured values.

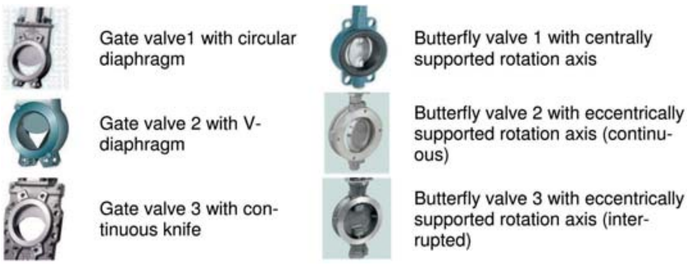


Fig. 9: Tested valves

4. Results and discussion

Fig. 10 shows the determined pressure losses for the three different gate valves as a function of the degree of opening. The degree of opening corresponds linearly to the stroke of the knife actuator. A value of 100 % means a completely opened valve. It is clearly evident that, under the described test conditions, the gate valve with circular diaphragm produces the smallest pressure loss in the pipeline. However, for use as a control element in a pulp flow with a high pulp consistency, the gate valve with continuous diaphragm is generally pre-

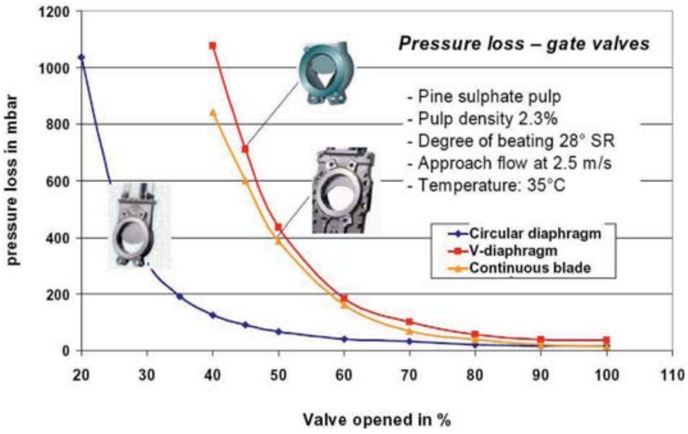


Fig. 10: Pressure loss in gate valves

ferred. The inversion of the knife geometry has the advantage that no small angles occur in which fibres or dirt can settle. Moreover, high local flow speeds occur in the small angle areas, which then result in a higher abrasion risk. With the same stroke, the gate valve with continuous knife produces a higher pressure loss. The operator must accept this fact in return for the reduced obstruction and wear risk.

The gate valve with V-diaphragm is similar in design to the gate valve with circular diaphragm. The purpose of the V-diaphragm is to influence the characteristic curve of the gate valve so that this valve tends towards a more favourable control behaviour – but again, for the price of a higher pressure loss and thus increased energy costs (pump capacity).

The pressure losses of the individual butterfly valves determined in the new test plant are shown in *Fig. 11*. The measured curves only differ relatively slightly and do not permit any comprehensive interpretation of the results at this point. A differentiated picture will appear later, with another form of representation.

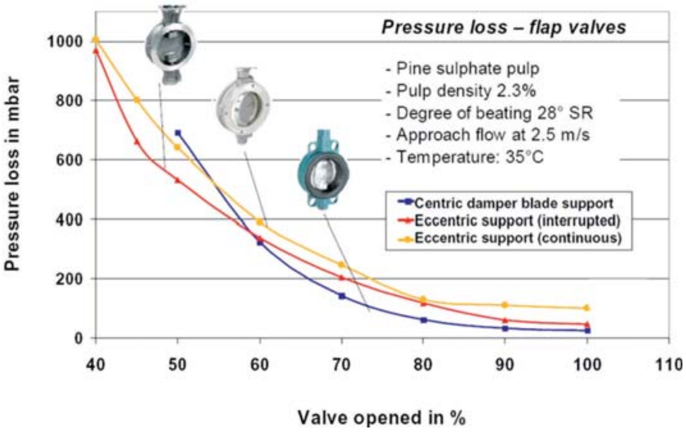


Fig. 11: Pressure loss in butterfly valves

A high pressure loss above a pipeline element is always also synonymous with an energy loss and the conversion of the loss energy into heat[9]. The energy loss can be easily quantified as the product of volume flow and pressure drop. In these localised areas, physical state changes increasingly result (changes of state), and consequently a gas accumulation in the area of the valves due to the "outgassing" of dissolved gas in the form of gas bubbles. The action chain is demonstrated again in *Fig. 12*.

The influence of gas content on the running and quality characteristics in paper production has long been known and is described in detail in literature[10]. Due to the high contents of calcium carbonate as a filler and coating pigment, CO_2 is released, particularly with the use of aluminium sulphate or other auxiliary agents and the resulting decomposition of calcium carbonate. Because of the long-term increase in the use of calcium carbonate in paper production and paper upgrading and the associated increase in dissolved and free carbon dioxide in pulp systems, it should no longer be just air content which is discussed, but rather gas content, the more so as CO_2 is far more easily soluble in water than air. Measurements have shown that CO_2 gas contents up to over 5 % can arise.

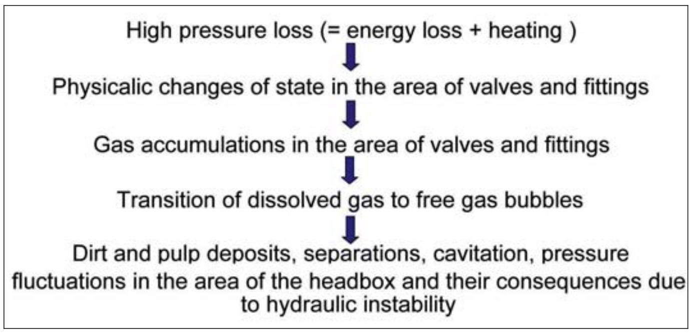


Fig. 12: Influence factors that can lead to valve faults and their effects

Gas can be present in the following forms in a pulp suspension:

- Dissolved in the liquid,
- In gaseous form as free bubbles,
- Adsorbed in solid matter, such as pulp, filler, etc.

Bubble formation in pulp suspensions is all the more intensive, the higher the content of fibres and hydrophobic substances. It is also encouraged by high flow speeds and shear rate in pumps, valves and pipelines. The previously mentioned physical state changes in valves are induced by periodically changing pressures, temperatures and flow speeds. In respect of production and product quality, the resulting free gas bubbles have the following negative effects:

- Decreasing pump performance,
- Deposits in the circuit,
- Undesirable flotation/increased foaming,
- Concentration of hydrophobic pulps (local contamination islands),
- Breakage, caused by floating, tacky, resin-rich pulps,
- Drainage problems.

Loss of quality in the finished paper due to high air or gas contents:

- Stains,
- Pinholes/holes,
- Impaired formation, porosity and printability,
- Loss of strength.

Although the pressure loss is a palpable and easy to interpret variable, for the control engineering design and pump dimensioning of a plant a further characteristic value, the so-called K_v-value, is generally used, which links different process parameters together. This value is defined as the water volume that flows through a valve per hour at a temperature of 15 °C in relation to 1bar pressure loss.

On the basis of the K_v-value, a modified characteristic value K was determined during the first test series, in accordance with the following rule.

$$K = \dot{Q} \cdot \sqrt{\frac{\rho}{\Delta p}}$$

with:
$\dot{Q}$ = Volume flow in m³/h
ρ = Density in kg/m³
Δp = Pressure loss in mbar

Fig. 13 and *Fig. 14* show the curves calculated according to this model.

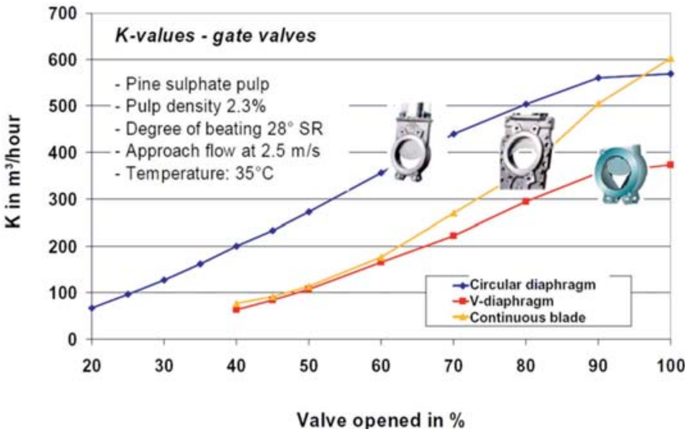


Fig. 13: Characteristic flow values of gate valves

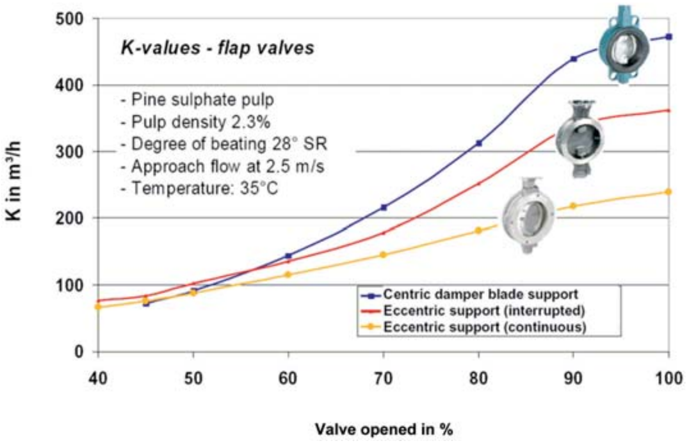


Fig. 14: Characteristic flow values of butterfly valves

In the case of the gate valves it quickly becomes clear that the low pressure loss of the gate valve with circular diaphragm also results in high flow values. It is also clear that the characteristic flow values of the gate valve with circular disk and those of the gate valve with continuous disk must coincide for the 100 % opening state.

The lower characteristic flow values of the gate valve with V-diaphragm coincide with the high pressure loss values and have already been discussed above. This fact must be accepted in order to achieve better control behaviour of the valve.

In contrast to the pressure loss curves for the butterfly valves, the individual valves can be differentiated more successfully with the help of the characteristic flow value (K-value).

The butterfly valve with central support offers the least resistance to the flow and thus also achieves the highest characteristic flow values. This butterfly valve model is designed in such a way that its tightness is achieved by positioning the blade against a rubber seal. However, this limits the field of application of this butterfly valve to temperature ranges below 200 °C and moderate pressures. In order to also be able to offer valves that can withstand both high temperatures and high pressures, butterfly valves with a double eccentric support and a different sealing material have been introduced. In this case, sealing occurs as metal on metal, thus requiring a different design. The resulting reductions in cross-sectional area with their unfavourable effect on the fluidics, are expressed, as expected, in lower characteristic flow values. On the basis of a shaft bearing mounted at the back of the blade, this was interrupted to optimise the fluid mechanics. The improvement is evident in considerably higher characteristics flow values (Fig. 14).

5. Summary

Life cycle costing is a method for optimising the total costs and revenue of a technical system over its life cycle. Life cycle costs include the total costs of a technical system over its lifetime.

The life cycle cost analysis, increasingly practised for many large investments, is also becoming an interesting tool for typical wearing parts in the context of procurement strategy, in view of the necessary continuous efforts to further reduce production costs in paper production.

The informative value of life cycle costing for pipeline valves particularly depends on the quality of the incoming information. Due to the multitude of influencing parameters and the complexity of their interrelationships, the assessment of a valve's suitability for a specific application still largely defies any analytical approach.

The described test facility has created the prerequisites for producing reliable information on the behaviour of valves with justifiable expense – in both laboratory or pilot plant station and in a real production environment - which provides a solid basis for the calculation of their life cycle costs.

Studies with the test facility to date provide an initial orientation and introduction to the metrological characterisation of pipeline valves in real pulp flows. For precise assessment and characterisation of pipeline valves, however, extensive studies are still required with a far larger range materials, valves and operating conditions.

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