How to choose a proper sealing system for rotary shaft applications

Particulary with reference to fugitive emissions during service

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Fugitive emissions are an important aspect in running a chemical or petrochemical plant. Apart from their environmental impacts, fugitive emissions are responsible for loss of medium during the production process. Due to this plant efficiency is reduced and a higher capital expenditure is required.
Three common types of sealing systems are compared: compression packings, mechanical seals and magnetic couplings. The criteria used for this comparison are leakage rates under operating conditions. As additional criteria operating expense, behaviour on failure and durability will also be considered. As a result plant operators and engineers should be able to choose the proper sealing system for their particular application.

1 About this work

Rotary shaft seals are a common component in almost every chemical or petrochemical plant. Due to increasingly stringent emission regulations and the need to improve reliability the choice of the best suitable sealing system is of great importance for the plant operators.
In this paper an overview will be given about which criteria should be considered. It is based on literature research and on a survey by plant operators as well as manufacturers of such sealing systems.

2 Rotary shaft sealing systems

Because of the widespread use of rotary shaft sealing systems and the numerous sealing devices available, this paper concentrates on only three types of rotary shaft sealing systems. These types are:

- **compression packings**

Compression packings consist of a number of rings manufactured and engineered with specially treated yarns and fibres incorporating additive products, such as lubricants, densifiers, protection and anti-corrosion agents. These rings are inserted into the annular space between the rotating shaft and housing of the device to be sealed. By tightening the packing gland against the outer ring, pressure is transmitted to the packing set. This expands the rings radially against the side of the stuffing box and the rotating shaft, effecting a seal.

- **mechanical seals**

A mechanical seal consists basically of three components. A rotating component, known as rotary seal ring, a stationary seal ring and a spring. The material typically used for the faces of the rings are for example stainless steal or Silicon carbide. The ring faces are pressed together by the spring. This way the space inside the device is sealed against the environment.

- **magnetic couplings**

Magnetic couplings work in a very different way. With this type of seal the end of the rotating shaft is surrounded by a containment shell. A cylinder encloses the containment shell, leaving only a small gap between containment shell and the surrounding cylinder. The torque is transmitted by the use of magnetic force.

The widespread use of these three types of rotary shaft seals involves also a wide range of applications, e. g. pressure range or different media. In order to compare these three sealing devices it is necessary to concentrate on applications where any type of seal could be used. However due to the numerous special constructions available no universally valid statement can be made. Nevertheless Table 1 is an attempt to specify the limits of application for each sealing type. This table is by no means complete.

To compare the sealing systems mentioned above, we have restricted the application range to:

pressure difference:	0 to 25 bar
medium:	water
temperature of medium:	20 °Celsius

<table>
<tr><td colspan="2"></td><td>compression packing</td><td>mechanical seal</td><td>magnetic coupling</td></tr>
<tr><td colspan="2">temperature</td><td>- 200 ÷ + 500 °C</td><td>-100 ÷ + 450°C</td><td>-100 ÷ +450 °C</td></tr>
<tr><td colspan="2">pressure</td><td>1 ÷ 40 bar</td><td>high vacuum ÷ 450 bar</td><td>vacuum ÷ 40 bar</td></tr>
<tr><td colspan="2">max. sliding velocity/rotation</td><td>40 m/s</td><td>> 100 m/s</td><td>3600 1/min</td></tr>
<tr><td colspan="2">torque</td><td>no limit</td><td>no limit</td><td>315 Nm</td></tr>
<tr><td rowspan="4">media</td><td>liquid</td><td>√</td><td>√</td><td>√</td></tr>
<tr><td>gaseous</td><td>√</td><td>√</td><td>-</td></tr>
<tr><td>pulpy</td><td>√</td><td>-</td><td>-</td></tr>
<tr><td>abrasive</td><td>√</td><td>-</td><td>-</td></tr>
<tr><td colspan="2">aprupt failure</td><td>-</td><td>√</td><td>√</td></tr>
<tr><td colspan="2">large diameters</td><td>√</td><td>-</td><td>-</td></tr>
</table>

Table 1 : Operating limits

A DIN-standardized pump has been chosen as typical sealing device. For the characteristic data see Table 2.

Note, that the following comparison of these sealing systems is based on the set of parameters mentioned above. Therefore any changes in these set of parameters may cause great differences in the results

rotary pump DIN / EN 22 858; 50-32-160	
Speed	3000 1/min
Q	12,5 m³/h
H	32 m
η_P	0,8
Shaft Diameter at seal	33 mm

Table 2 : DIN-standardized Pump

3 Criteria to select a sealing system

The best suitable sealing system for a particular application has to meet several needs. First of all it is important to know the amount of leakage during service. Another point to be considered is the loss of power due to friction. Costs are also an important factor. Therefore not only the cost to purchase the desired sealing system but also the costs for maintenance during service time and any additional operating costs have to be taken into account. The life span of the selected sealing system and its behaviour on failure have to be taken into consideration as well. A brief discussion of each point follows

3.1 Leakage rate

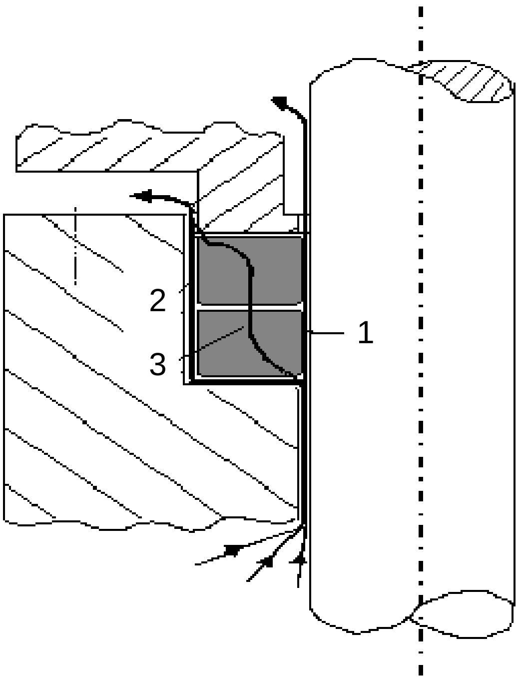
The sealability of the sealing system during service is an important criterion, due to the continual loss of medium. Such impacts are for example:

- no compliance with environmental regulations
- loss of valuable medium

Therefore it is essential for plant operators to get an estimation of the leakage rate they have to expect.

Compression packings

Compression packings require leakage to dissipate frictional heat between packing rings and rotating shaft. Three pathways can be detected.



Picture 1 : Pathways of leakage flow for compression packings

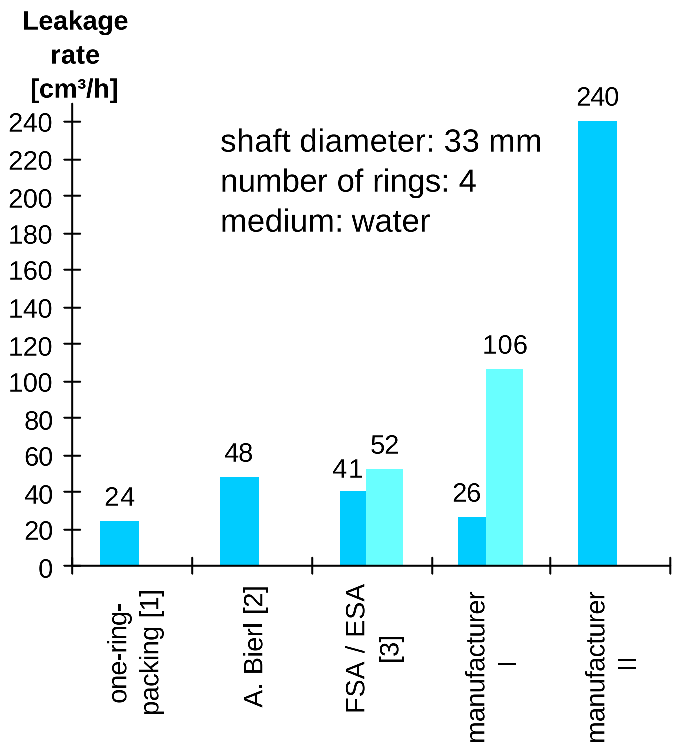
Obviously there is a small channel between the inner surface of the packing rings and the shaft. Another possibility is a medium flow between the outer surface and the casing of the sealed device. And to a smaller extent the flow of medium through the packing material itself. Picture 1 illustrates the leakage paths mentioned above.

Despite of many attempts to calculate the leakage rate, no suitable calculation method could be ascertained because of the great number of parameters to be considered. Thus the only help for users to estimate the amount of leakage is to fall back on informations by manufactures or publications of organisations working in the field of fluid sealing. These data are only a rough estimation and can not consider the real circumstances. Picture 2 gives an overview of the available data.

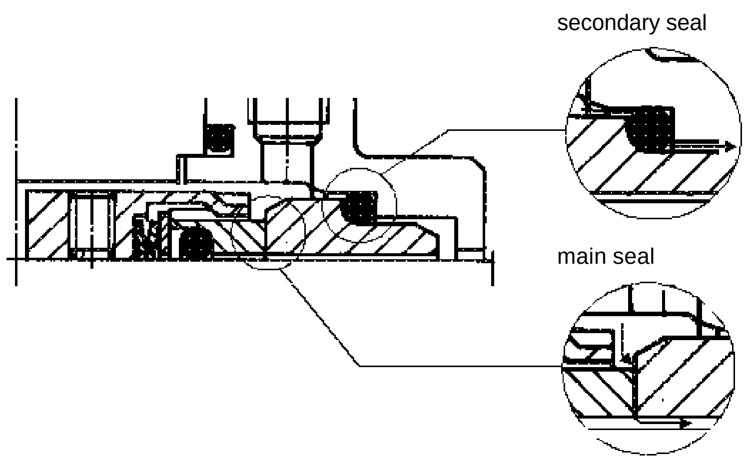
As a prerequiste for low leakage rates during service careful assembly and sufficient warm up are indispensable.

Mechanical seals

Because of fluid pressure, there will be some leakage through the gap between the rotating face and the stationary face. This loss of medium is necessary to dissipate the heat in the gap resulting from friction. Other leakages in the secondary seals of a mechanical seal are not to be considered in this paper. The secondary seals, which are mostly O-ring seals, have a static load only. Therefore the possible leakage will be so little that it can be ignored. For details see picture 3.

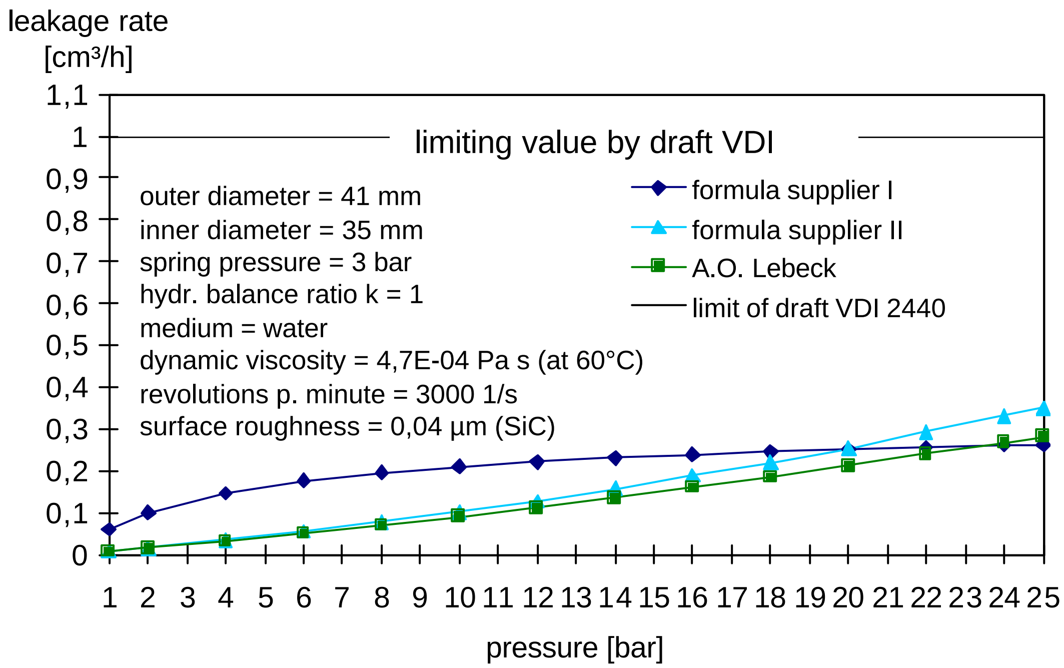


Picture 2 : Leakage data for compression packings



Picture 3 : Pathways for leakage flow for mechanical seals

The calculation of leakage of a mechanical seal requires the consideration of complex relations, for example the existing lubrication, the existing gap form or gap width. To solve this problem Lebeck [4] developed a method of calculation for iterative determination of these values. This method of calculation is the base of the calculation rules given by manufacturers. It is important to know that the decisive factor - the width of the gap - is to be determined by diameter ratio or is to be assumed as known. For comparison picture 4 shows the expected quantity of leakage following three different calculation rules. The method of Lebeck is compared to formulas of manufacturers [5]. To apply one of these calculation rules the user needs to know the gap width.



Picture 4 : Leakage data for mechanical seals

For the petrochemical industry the permissible amount of leakage is defined in the draft of VDI-Norm 2440 as 1 g/h.

Magnetic coupling

For industrial use the magnetic coupling is regarded as hermetically tight.

3.2 Costs

Apart from the expected leakage during service the cost factor is important for the selection of a suitable sealing system. The plant operator not only has to take into consideration the purchasing costs but also the operating costs.

3.2.1 Purchasing costs

The purchasing costs of the selected sealing system for a standard pump are shown in table 3. The prices of a double mechanical seal and components are added.

compression packing	mechanical seal	magnetic coupling	double mechanical seal with additional equipment (1500 DM)
15 DM	1050 DM	4300 DM	3600 DM

Table 3 : Purchasing costs

3.2.2 Service life

The service life of a compression packing is decisively influenced by the permissible quantity of leakage, the medium and the care of assembly. The average working life of a compression packing during normal operation can be estimated at 39 weeks, data is given within the range of 3 weeks up to one year. Whereas a mechanical seal has an average life time of three years in the same operating conditions. The life time of a magnetic coupling can be estimated at approximately 10 years.

3.2.3 Operating costs

Apart from the purchasing costs there are additional costs during the whole operating time. These ensue from the installation of the sealing system, from continuous control, regular maintenance, performance loss due to friction in the sealing system and from downtime. It is difficult to quantify the amount of these costs, especially if the costs for storage of spare parts and training of assembly staff are also to be considered. The costs for additional equipment (e.g. heater, cooler etc.) are difficult to quantify as well.
That is why in this investigation only the performance loss due to friction and the costs of control and maintenance are to be considered.

3.2.3.1 Loss of performance

Loss of performance in sealing systems are essentially caused by friction. The only exception is the magnetic coupling because there friction loss is negligible. But eddy currents can occur in the magnetic field which have to be compensated by increased power supply.

Compression packing

Caused by radial pressure of the packing rings there are frictional forces across the whole packing length. The resulting frictional torque depends essentially on the coefficient of friction, the given leakage rate and the radial pressure distribution across the packing length [6]. The coefficient of friction for PTFE can be assumed as 0.04. For an estimation, the distribution of the surface pressure can be assumed to be linear. To achieve good sealability it must be greater than the fluid pressure which has to be sealed up and is therefore assumed as 1.1 times the fluid pressure in our example.

Mechanical seal

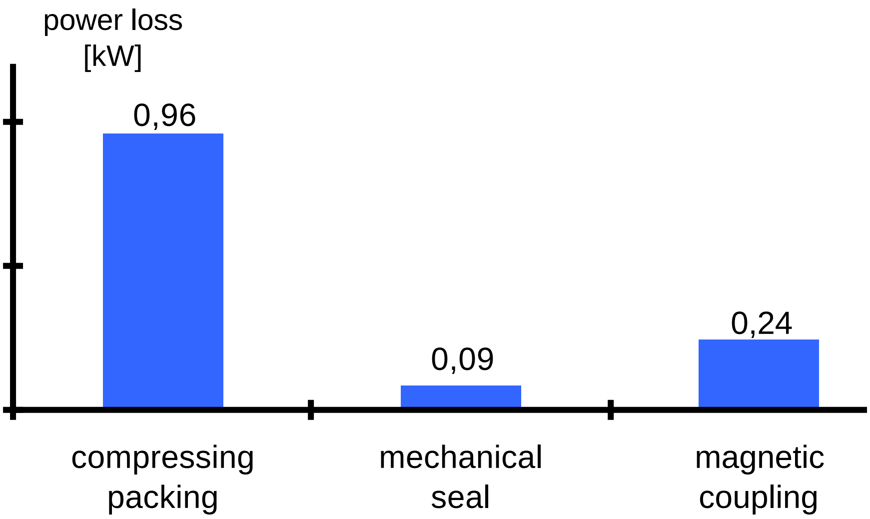
The frictional forces working in the gap between the rotating ring and the stationary ring lead to a certain performance loss. The essential values are frictional coefficient, the contact pressure of the spring and the sliding velocity.

Magnetic coupling

The frictional losses in the bearings of a magnetic coupling can be neglected compared to the losses caused by the occurring eddy currents. For a common magnetic coupling they can be assumed as approximately 10 to 20 percents of the power supply. For the selected standard pump with a power supply of 1,65 kW and a presupposed efficiency of the magnetic coupling up to 15 % the loss of power will be 244 watt [7].

Picture 5 shows the assumed loss of power of all three types of sealing systems caused by friction or eddy currents. The base of the calculation are the selected standard pump and the operating conditions as defined above. It should be noted, that these results are mainly due to the high rotating velocity. Therefore different input parameters, e. g. shaft diameter or rotating velocity, will cause great variations.

For the determination of energy costs an annual operating time of 4500 hours is assumed and the cost of electricity is calculated as 0,12 DM/kWh.



Picture 5 : loss of power

3.2.3.2 Costs of control and maintenance

Other important cost factors are the expenses for control during operation and regular maintenance. There are great differences in this for the three types of sealing systems.

Compression packing

A compression packing requires regular control at short intervals for examination of the gland adjustment. In contrast to this the effort to replace a compression packing is low. The reason is that the cost of material is low and the replacement of the compression packing can take place without removing the pump from the plant.

Mechanical seal and magnetic coupling

Both kinds of sealing system work almost without maintenance during normal operation and require only a inspection at regular intervals. The carrying out of the inspection requires the removal of the pump from the plant which causes higher costs.

By means of a survey at users and manufactures the costs of control and maintenance were determined. The result of this survey is shown in table 4.

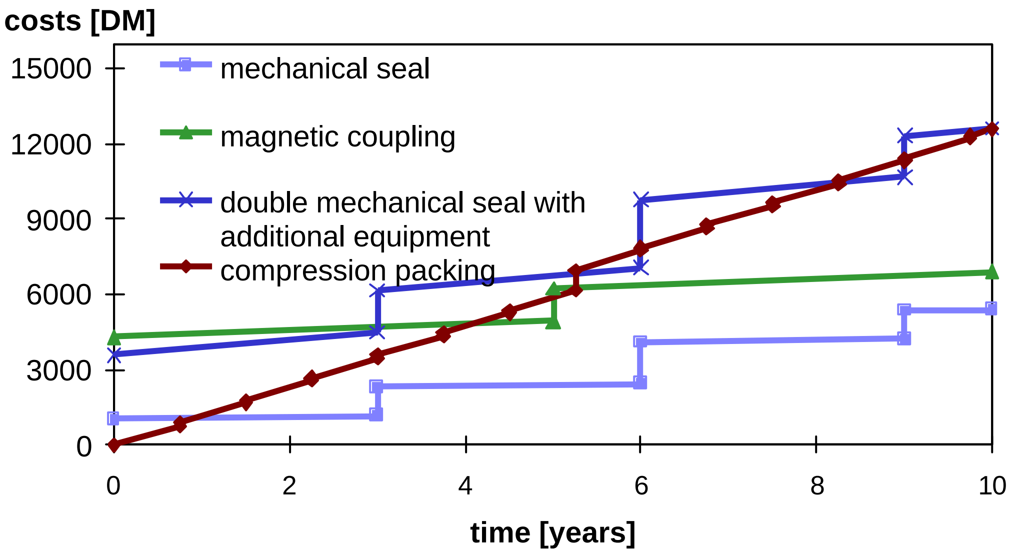
	controlling & maintenance			energy costs
	interval	staff [h] (100 DM/h)	material costs [DM]	costs / year [DM/year]
compression packing				
controlling	1 week	0,1	-	
packing exchange	0,75 years	1	27,-	518,-
sleeve exchange	5 years	3	527,-	
mechanical seal				
controlling	3 years	6	525,-	
exchange	6 years	6	1050,-	46,-
magnetic coupling				
cleaning	5 years	30 % of purchase		258,-
double mechanical seal				
controlling	3 years	6	1050,-	
exchange	6 years	6	2100,-	92,-
additional equipment	10 % of purchase			210,-

Table 4 : Maintenance costs

3.2.3.3 Total operation cost

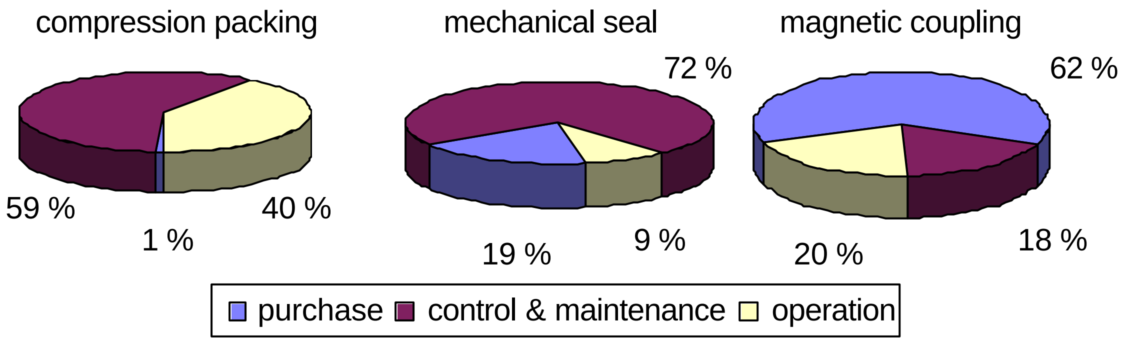
The examination of such individual expenses is not very meaningful. The sum of all costs which are caused by the sealing system during the whole operating time give a much better picture. For the selected standard pump the total costs of its operating life time are shown in picture 6.

In picture 6 the costs caused by a double mechanical seal during its total working life are given in addition.



Picture 6 : Total operating costs

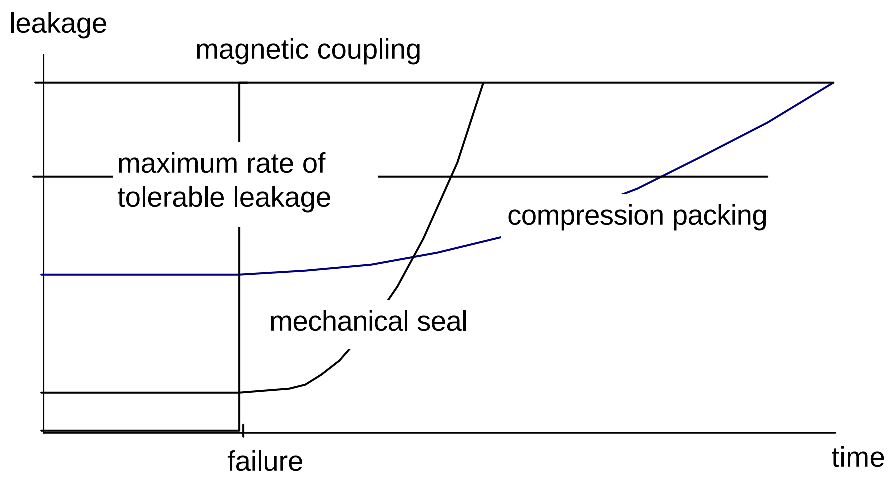
The percentage share of the different kinds of costs are shown in picture 7.



Picture 7 : Shares of costs

3.3 Failure

Great differences can be seen comparing the failure of the three types of sealing systems. If the sealing system does not work e.g. due to damage or wear the leakage increases. Picture 8 shows the temporal increase of leakage of the three types of sealing systems.

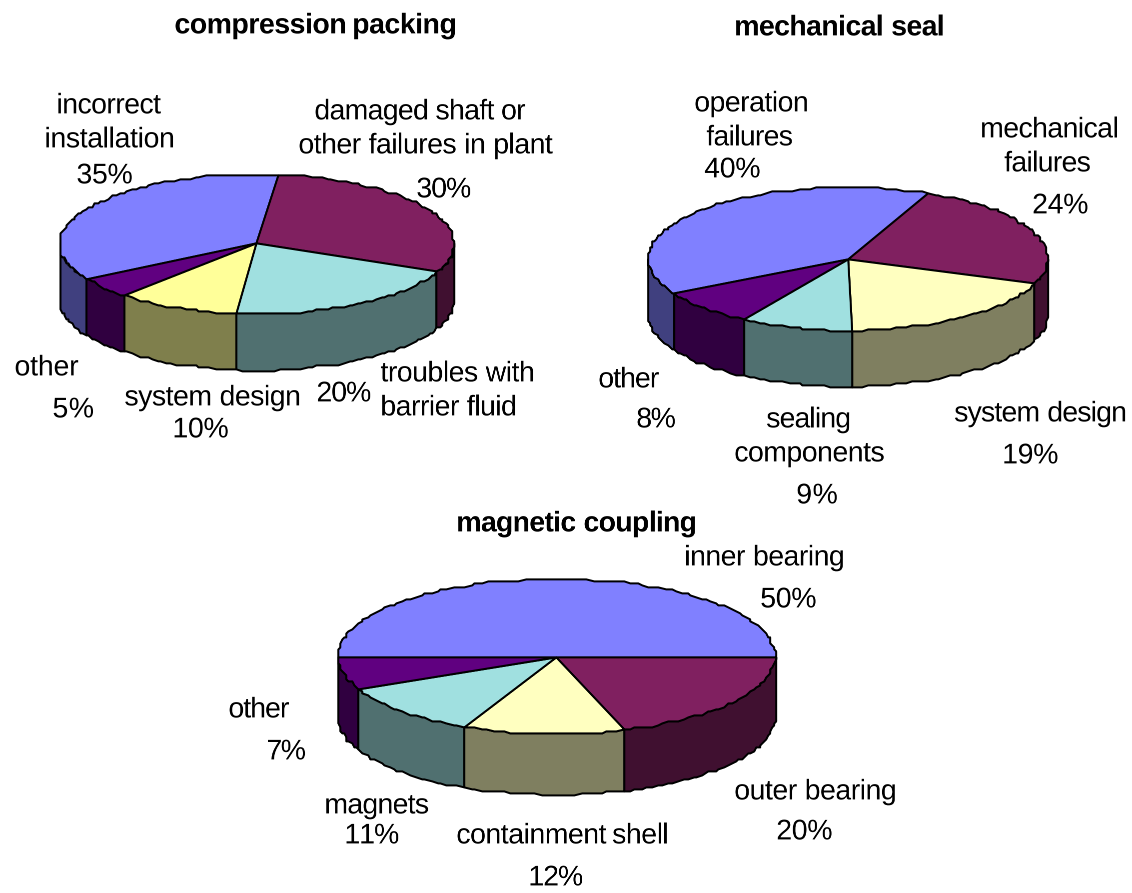


Picture 8 : Behaviour on failure

Using a compression packing the amount of leakage will increase continuously from the beginning of the breakdown. A mechanical seal will continue to work as well but the increase will be much more steep. Whereas using a magnetic coupling there is an immediate excessive loss of medium.

Additionally it should be mentioned, that due to the required permanent control of a compression packing the probabilitiy of an unexpected failure is much lower than for the other two sealing systems.

Picture 9 shows an overview of the percentage shares of the causes of damages [8] [9].



Picture 9 : Causes of failure

3.4 Summary

In summary there is no general recommendation for the choice of a sealing system. Because any changes in the numerous input parameters will affect the results or even lead to totally different ones.

If leakage during operation is permissible, the choice will be between two sealing systems, compression packing or mechanical seal. If the application demands very high standards of tightness, there is no choice but using a magnetic coupling or a double mechanical seal. For decision-making a comparison as done in this investigation, applied to the actual application, can be of some help. Further information about the best sealing system can be supplied by the various manufacturers.

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