Burckhardt Compression

HEAT DISSIPATION FROM PISTON ROD SEALING SYSTEMS

DIFFERENT CONCEPTS WITH CONSIDERATION OF THE API 618

Dr. Norbert Feistel, Dr. Georg Samland, Besim Fejzuli

Compressors for a Lifetime™

Dr. Norbert Feistel received his degree in Mechanical Engineering (Dipl.-Ing.) from the University of Karlsruhe, Germany in 1987. He began his professional career as a design engineer with Mannesmann Demag Fördertechnik in Offenbach/Main, Germany.
In 1988 N. Feistel joined the R&D Group of Burckhardt Compression in Winterthur. After approximately two years, in which N. Feistel's activities concentrated mainly on the labyrinth piston compressors, his responsibilities are now for the development of oil-free sealing systems. In 2002 he gained a Ph.D. at the University Erlangen-Nuremberg, Germany, with a thesis on the operational behavior of dry-running sealing systems in crosshead compressors.

Dr. Georg Samland received his degree in aerospace engineering (Dipl.-Ing.) in 1987 from the Technical University in Stuttgart, Germany. He then started his professional career at the "Staatliche Materialprüfungsanstalt Stuttgart" where he was engaged in several research projects. In 1991 he graduated as a Dr.-Ing. in power engineering at the Technical University in Stuttgart, Germany. In 1991 he joined the Research & Development (R&D) group of Burckhardt Compression in Switzerland. Since 1997 he is the head of the R&D department. His main projects are in the field of finite element analysis, computational fluid dynamics and mechatronic.

Besim Fejzuli received his degree in Mechanical Engineering (Technician TS) in 1999 from the Technical Graduate School Zurich, Switzerland. He then started his professional career at the SLM AG where he was engaged as head of process engineering (AVOR).
In 2001, he joined the Design and Manufacturing (D&M) group of Burckhardt Compression in Switzerland. Since 2003 he is the team leader of the design department and is responsible for the project execution of process gas compressors.

The need for cooling piston rod sealing systems (packings) has recently been a subject of more intense discussion. This has been accompanied by developments of new cooling systems permitting more efficient heat dissipation. These activities are motivated by a general susceptibility of commonly used cooling systems as well as their poorer heat dissipation properties compared with cylinder cooling. An analysis of these two shortcomings has led to a new configuration of cooling channels. Operators now have at their disposal a robust, reliable and easily maintainable cooling system which also complies with the recommendations of the future, fifth edition of API 618.

CHAPTER 1

INTRODUCTION

Of late, two different trends have been evident as regards heat dissipation from piston rod sealing systems (packings): Attempts on one hand to dispense entirely with liquid cooling wherever possible are accompanied on the other hand by commercial introductions of new systems with supposedly improved cooling properties. These efforts are geared primarily to eliminate two main shortcomings of contemporary cooling systems for piston rod seals: their susceptibility to leakages, clogging etc., and their restricted heat dissipation capability in comparison with cylinder cooling. Furthermore, the cost-benefit ratio of cooling systems needs to be examined critically.

The guidelines[2] formulated in API 618 as regards the design of cooling systems for piston rod seals are intended, in particular, to ensure the operational reliability of the latter. The upcoming, fifth edition will contain yet stricter versions of these guidelines. API 618 also stipulates criteria when to use a cooling for dry-running and oil-lubricated piston rod sealing systems.

The plastic sealing elements preferably used today are influenced significantly by temperature, not only in terms of physical and mechanical properties but also the tribological characteristics comprising friction and wear. A rise in the counter surface temperature notably increases the wear rate of the sealing elements, this increase assuming exponential proportions in the worst case. Consequently, heat removal from the friction surfaces decisively influences the operating conditions and especially the service life of piston rod sealing systems.

The following overview of common concepts of cooling piston rod sealing systems describes their advantages and disadvantages. The different conditions governing heat removal from friction surfaces compared with cylinder cooling make it possible to ascertain the performance limits of such cooling systems. These findings, especially as regards susceptibility of systems currently in use, have led to a new configuration of the cooling channels. The performance of the resultant robust, reliable and easily maintainable cooling system for piston rod seals is to be compared with that of common designs.

CHAPTER 2

DESIGNS AND APPLICATIONS OF VARIOUS SYSTEMS FOR DISSIPATING HEAT FROM PISTON ROD SEALS

2.1 UNCOOLED PISTON ROD SEALING SYSTEMS

The basic question arising during the design of a piston rod sealing system is whether or not to use liquid cooling. In the case of dry-running piston rod sealing systems comprising non-metallic sealing elements, API 618 recommends liquid cooling from a pressure of 1.7 MPa onward. Below this pressure, piston rod seals should at least provide for cooling.

Tests have shown[3] that cooling might indeed be necessary below a pressure of 1.7 MPa. Depending on its design, a dry-running sealing system can generate critically high frictional powers especially at high average piston velocities, so that cooling might be needed to ensure reliable operation and maximize service life.

However, the additional requirement for an upgrade to a cooling system can hinder an optimization of uncooled piston rod sealing systems, their design having been focused on a minimization of heat transfer resistance. Of special importance here is a complete avoidance of any gaps and a use of materials possessing a high thermal conductivity. At the same time, an attempt is made to minimize friction power by optimizing sealing element design. A key parameter in this context is the sealing elements' axial width, whose reduction results in a corresponding decrease in friction power without any notable deterioration in sealing efficiency[4].

Given otherwise identical conditions, the shorter distance to the heat sink permits a cooled sealing system to achieve more favourable thermal conditions for sealing elements compared with an uncooled system. Whether the complexity this entails is justified needs to be decided individually.

2.2 COOLED PISTON ROD SEALING SYSTEMS

Whereas piston rod seals subjected to low loads may be able to dispense with a cooling system in some cases, high load parameters in the form of large pressure differences and/or high average piston velocities need cooling to ensure reliable operation coupled with adequately long service life. Some typical concepts of cooling piston rod sealing systems are presented in the following.

Fig. 1
Piston rod sealing system with heat dissipation via a cooling jacket surrounding the packing cups

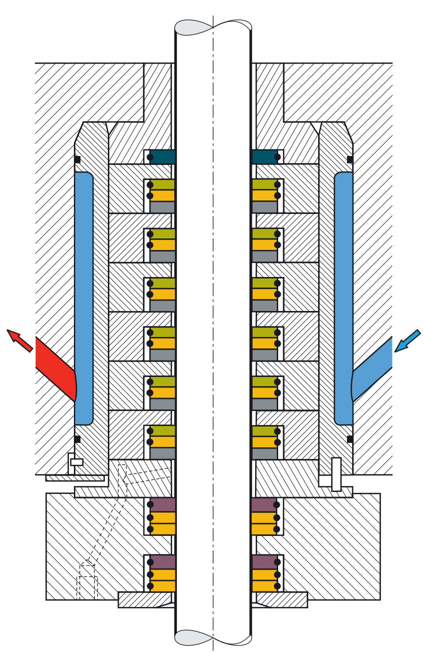


Fig. 2
Piston rod sealing system with heat dissipation by means of packing cups with "open" cooling channels

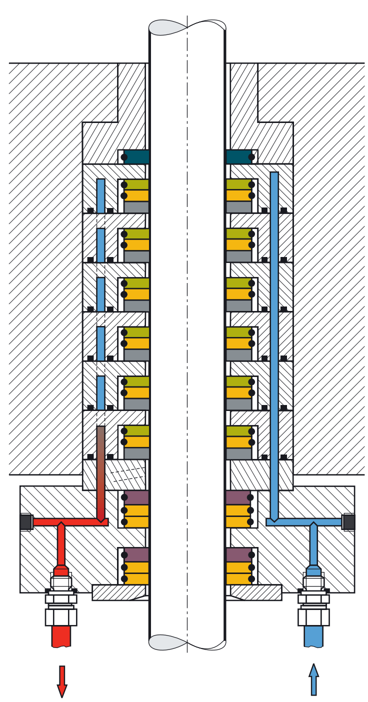
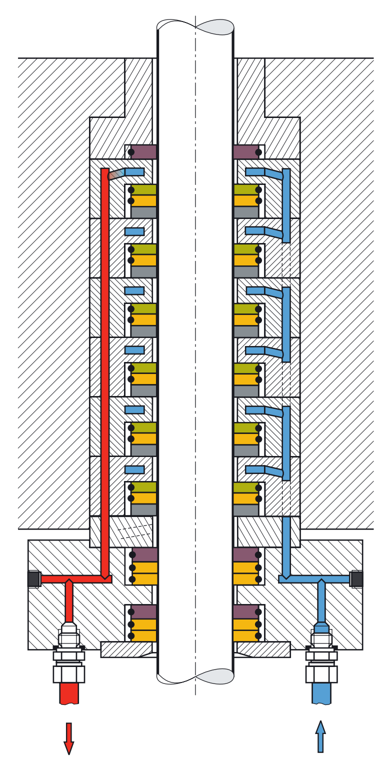


Fig. 3
Piston rod sealing system with heat dissipation via packing cups with totally enclosed cooling channels



2.2.1 COOLING JACKET

A technically very simple method of heat removal by means of a fluid is provided by a cooling jacket which surrounds all packing cups of the sealing system and whose coolant inlets and outlets are usually directly connected to the cylinder cooling. **Fig. 1**
The small number of gastight sealing elements over which the pressure difference is distributed results in a sealing system of widely differing load zones, the maximum values frequently occurring at the packing boundaries. One disadvantage of heat dissipation via a cooling jacket is that its design does not ensure a directional flow, supplying an adequate quantity of coolant to zones subjected to high thermal loads. A problem similar in principle was revealed by theoretical investigations of heat dissipation from the cylinder[5].

Another disadvantage of this heat dissipation concept results from the additionally necessary heat transfer from the packing cups to the cooled sleeve. Depending on design complexity, a small gap also needs to be overcome here by means of free convection, which impairs heat dissipation to a correspondingly high degree. Consequently, heat dissipation via cooling jackets is restricted almost entirely to oil-lubricated piston rod seals or to dry-running packings subjected to low load parameters. Advantages of this design are its simple design and very low risk of coolant leakage into the sealing element chambers.

2.2.2 PACKING CUP WITH OPEN COOLING CHANNEL

In this heat dissipation concept, the packing cups are furnished with a ring-shaped cooling channel, each successive cup closing one side of the channel. **Fig. 2**
The coolant is supplied by an axial bore and leaves the ring-shaped channel after flowing around the piston rod via an additional connecting channel to enter the next packing cup. In this manner, the coolant flows through all packing cups at a constant, clearly definable flow rate, but alternately in clockwise and anti-clockwise directions. **Fig. 6**

One advantage of this cooling channel configuration is its easy accessibility for the purpose of cleaning (refer to 3.2). Furthermore, the packing cups can be made very narrow in the axial direction, thus permitting a correspondingly large number of sealing elements to be integrated over the total length of the sealing system. Generally, the open side of the cooling channel is sealed by means of two O-rings surrounding the piston rod. The latent risk of damaged, wrongly inserted or missing O-rings permitting coolant to enter the sealing element chambers or gas to leak into the coolant channels must be regarded as a disadvantage of this cooling channel arrangement. Accordingly, the fourth edition of API 618 approves O-rings surrounding the piston rod only from a pressure of 13.5 MPa onward. The upcoming fifth edition will advise entirely against a use of circumferential O-rings. A confined arrangement of such rings in a pressure-balanced environment will continue to be permissible only for axial connecting channels (for a better overview, these components are not shown in the following illustrations).

2.2.3 PACKING CUP WITH TOTALLY ENCLOSED COOLING CHANNEL

For dry-running packings at pressures of 1.7 MPa or more and oil-lubricated designs at pressures of 3.5 MPa or more, API 618 recommends liquid-cooled packing cups with totally enclosed cooling channels. To improve the cooling efficiency, the cooling channels are usually integrated directly into the web of the packing cup, right between the sealing elements in each case, in order to minimize the heat transport distance. **Fig. 3**

Compared with the previously described variant involving open cooling channels, however, integration into the packing cup web can result in a larger axial dimension of the packing cups, possibly necessitating at least an elimination of a sealing element over the total length of the system. **Fig. 4**

Fig. 4
Open (left) and closed configuration of cooling channels in the packing cup and the resulting influence on the axial dimension l_{ax}

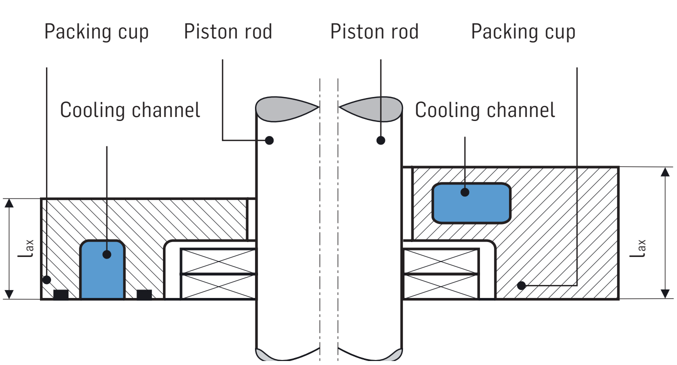
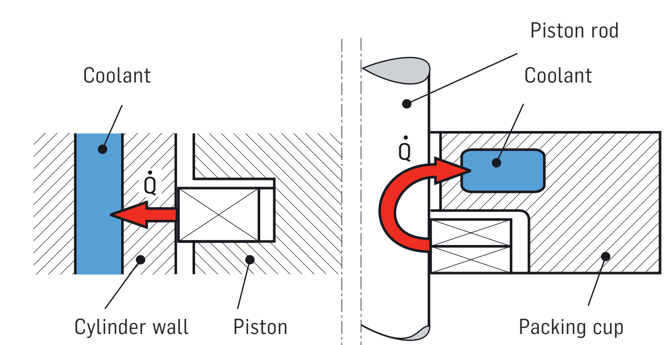


Fig. 5
Differences in heat transport from the sealing elements' friction surfaces to the coolant: directly in the cylinder (left) and indirectly in the piston rod sealing system



The outer edge of the packing cups in some designs is equipped with screw plugs allowing the channels to be cleaned. In the case of the more widespread designs without cleaning apertures, the cooling channels are very awkward to maintain.

CHAPTER 3

EFFICIENCY AND SHORTCOMINGS OF COOLING SYSTEMS FOR PISTON ROD SEALS

3.1 LIMITATIONS OF HEAT DISSIPATION FROM A PISTON ROD SEALING SYSTEM

In the cylinder, friction heat is transferred from the sealing surfaces of the piston rings to the cooling water directly via the cylinder wall which has a high thermal conductivity. To achieve comparably good conditions for the sealing elements of a piston rod sealing system, the cooling channels should be placed directly into the piston rod. As described previously, however, these channels are at best integrated in the packing cups. The heat conductivity of roughly 0.5 W/mK of plastic materials – such as a typical PTFE, filled with carbon/graphite – commonly used for sealing and rider rings reveals that heat conductivity cannot play a major role in heat dissipation. In contrast to the conditions prevailing in a cylinder, heat in a piston rod sealing system is accordingly transferred indirectly from the friction surfaces to the cooling channels: First to the piston rod, then by means of convection to the metallic packing cups and from there to the coolant. **Fig. 5**

The bottleneck forming part of the overall heat transfer resistance from the friction surfaces to the cooling channels comprises convective heat transfer from the piston rod via the leakage gas to the metallic packing cups, the leakage rate playing an important role here. The limitations imposed on the cooling of a piston rod sealing system by indirect heat dissipation have already been investigated in Heinrichs and Strümkes calculations[1] by means of a theoretical model for calculating sliding surface temperatures. Variations in the temperature difference between the sealing elements and chamber wall do not significantly influence the temperature of the friction surfaces.

Consequently, measures to improve the packing cup region have only a very negligible effect on the overall heat transfer efficiency. Accelerating flow or making use of turbulence mechanisms, for example, mainly serves to just increase the friction losses of the coolant. However, API 618 specifies a maximum permissible coolant pressure drop through the packing case of only 0.17 MPa. The original goal, i.e. a notable reduction in the temperature of the friction surfaces, is not achieved with such measures. Nor were tests conducted with different flow rates of cooling water able to reveal any further drop in piston rod temperature above a critical minimum value[3].

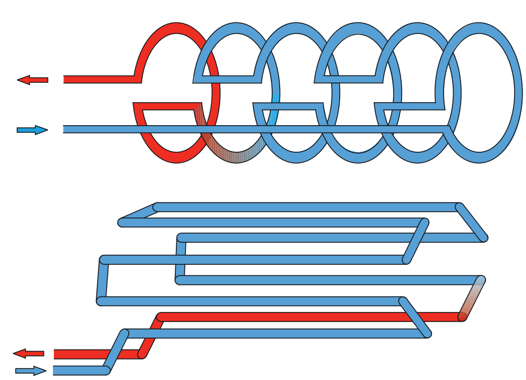
3.2 SHORTCOMINGS OF CONTEMPORARY COOLING SYSTEMS FOR PISTON ROD SEALS

Even before the compressor is started, liquid cooling can pose considerable problems if faulty assembly enables coolant to penetrate into the sealing element chambers. Following contact with the coolant, at least dry-running sealing elements no longer guarantee proper functionality, making their use inadvisable. This problem is compounded by elaborate cleaning required in the region of the sealing element chambers and leakage gas piping. Particularly sensitive to this type of damage are packing cups with open cooling channels if, during the assembly of the packing, O-rings were either left out or damaged.

During operation, the gas pressure is normally higher than the coolant pressure. Especially in the case of packing cups with open cooling channels, negligent assembly can therefore cause process gas to enter the cooling system. If a closed cooling circuit has been employed, leakages of flammable, explosive or toxic gases can pose problems. Special attention needs to be paid here to piston rod sealing systems designed to handle high pressure differences in hydrogen compressors.

Especially dry-running piston rod seals subjected to high loads depend on a perfectly functioning cooling system in spite of the latter's limited efficiency. However, the coolant employed here is often of low quality and purity, use sometimes even being made of perfunctorily cleaned river water. Furthermore, operation may result in a deposition of contaminations, lime etc. in the channels, thus gradually impairing heat dissipation and ultimately leading to a thermal failure of the sealing system. Compared with packing cups possessing a closed cooling channel, the design with an open cooling channel here proves advantageous: The cooling channels' condition is immediately apparent during servicing and any required cleaning can be carried out relatively easily.

Fig. 6
Conventional flow through a piston rod sealing system (top) compared with the longitudinal channels of the new cooling system (bottom)



CHAPTER 4

THE CONCEPT OF LONGITUDINAL COOLING

Compared with the cylinder, indirect heat transfer via the piston rod on the one hand limits the efficiency of heat dissipation from the sealing elements' friction surfaces, and on the other hand does not allow the piston rod temperature to be reduced significantly through improvements to the packing cup region. Accordingly, developments in piston rod sealing systems should be geared primarily toward eliminating the fault susceptibility of the cooling systems. One important boundary condition here is not to fall short of the efficiency which can be achieved by cooling systems commonly used today. Finally, the recommendations of the future, fifth edition of API 618 need to be considered as well.

These objectives were achieved through a new configuration of the cooling channels in the longitudinal direction, parallel to the piston rod, as opposed to the commonly employed circular flow around each individual packing cup. Tangential bores in the two packing cups at the ends of the sealing system divert the flow in the circumferential direction, permitting a reversal of the coolant at either end. This alternation continues until the entire piston rod has been enclosed. **Fig. 6, 7**

The spaces holding gas are sealed by means of a defined metallic ring-shaped surface directly adjoining the sealing element chambers. Optimization of this surface achieves a very tight seal, making it possible to dispense with an O-ring surrounding the piston rod, as required by API 618. If, nevertheless, small leakages of gas should occur, the pressure-balanced region adjoining the sealing surface effectively prevents gas from entering the cooling channels.

The commonly employed, circular arrangement of cooling channels around the piston rod encourages a deposition of solids, since the centrifugal forces occurring during deflection result in a separation of the coolant from the soiling it contains. This problem is avoided by longitudinal flow. Furthermore, the bores in the packing cups can be inspected very easily for soiling and cleaned without any trouble if necessary. The tangential channels for diverting the flow are sealed by means of screw plugs which also permit easy inspection and cleaning. This offers operators an API 618 compliant, reliable and easily maintainable cooling system for piston rod seals. Table 1 lists the properties of the new longitudinal cooling system compared with those of some other cooling systems commonly used today. **Table 1**

Fig. 7
Piston rod sealing system with heat dissipation via longitudinal cooling channels

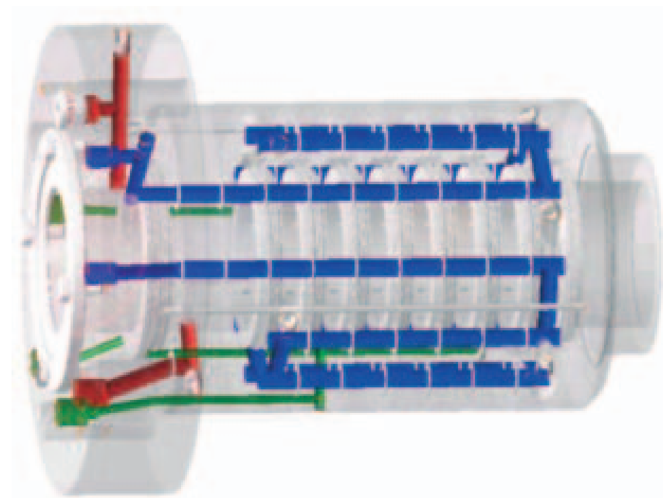


Table 1
Properties of the new longitudinal cooling system compared with those of some other cooling systems commonly used today

	Cooling jacket	Open cooling channel	Enclosed cooling channel	Longitudinal cooling
O-Rings required that span the piston rod	no	yes	no	no
Gas leaking into the distance piece	possible	no	possible	possible
Gas leaking into the coolant	no	possible	no	no
Coolant leaking into the sealing element chambers	no	possible	no	no
Risk of clogging	low	moderate	high	low
Axial dimension of packing cup	low	low	large	low

CHAPTER 5

INVESTIGATION OF THE EFFICIENCY OF DIFFERENT COOLING SYSTEMS

As already mentioned, the previously described advantages of the new, longitudinal-flow cooling system may not reduce heat dissipation efficiency. Consequently, the new system's performance needed to be evaluated in comparison with two widespread designs involving open and enclosed cooling channels. The temperature of the piston rod served as a criterion for rating efficiency.

The dry-running piston rod sealing system used for these tests consisted of a throttle ring and five polymer-blend sealing elements of the step bridge design combined with a three-piece radially cut cover ring. The sealing-ring pairs with an axial dimension of 14 mm were inserted – together with an anti-extrusion ring made of modified PEEK – into chambers possessing an axial dimension of 18 mm in all the investigated cooling systems. The packing cups with open channels as well as those of the longitudinal-flow cooling system each had an axial dimension of 30 mm. However, for the packing cups with totally enclosed cooling channels, the integration of the channels into the stem entailed an increase in the axial dimension to 36 mm. The tests were conducted with hydrogen at a suction pressure of 1.6 MPa, a discharge pressure of 4.0 MPa and an average piston velocity of 3.19 m/s.

An infrared sensor was used to measure the piston rod temperature during operation[3]. One problem posed by such comparative tests is that the large number of variables influencing the piston rod temperature makes it very difficult to achieve similar experimental conditions. Gas leakages through the sealing system play a very influential role here. Fig. 8 shows the piston rod temperatures and gas leakages (measured in standard cubic meters per hour) ascertained for the new longitudinal cooling system at a cooling-water flow rate of 150 l/h. These temperature values comprise averages of the temperature distribution along the stroke of 160 mm[3]. Clearly evident is a drop in temperature as the leakage rate increases. **Fig. 8**

Since the leakage values were not constant during the three comparative tests, a decision was made to represent the piston rod temperature as a function of the leakage rate. For the three examined cooling systems, Fig. 9 shows the piston rod temperatures measured at a cooling-water flow rate of 150 l/h at intervals of 5 minutes over a test period of 70 hours in each case. All measured values are located within a temperature bandwidth of roughly 7 K, the absolute values decreasing with the leakage rate. The variations in temperature clearly indicate that apart from the leakage rate, other factors such as the running-in period and the pressure distribution inside the sealing system also exert a major influence on the piston rod temperature. However, none of the three cooling systems turned out to have any exceptional advantage. In particular, no clear advantage was revealed by the design comprising closed cooling channels

Fig. 8
Influence of gas leakage on piston rod temperature

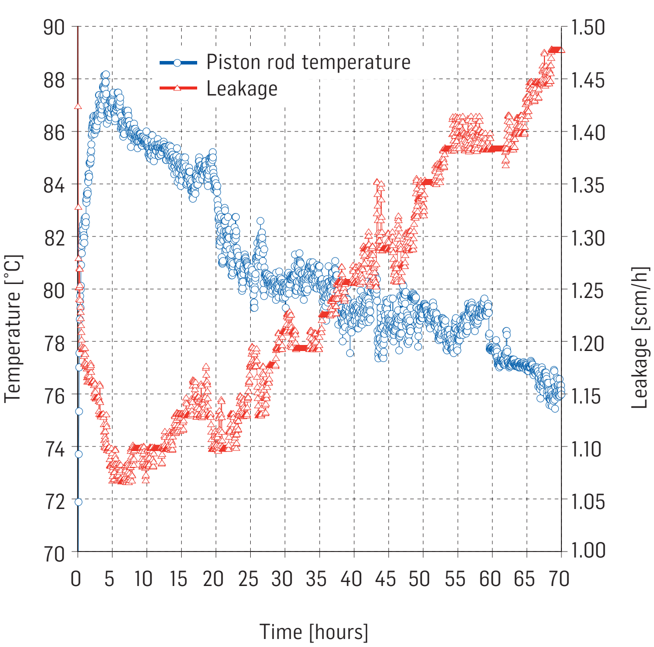
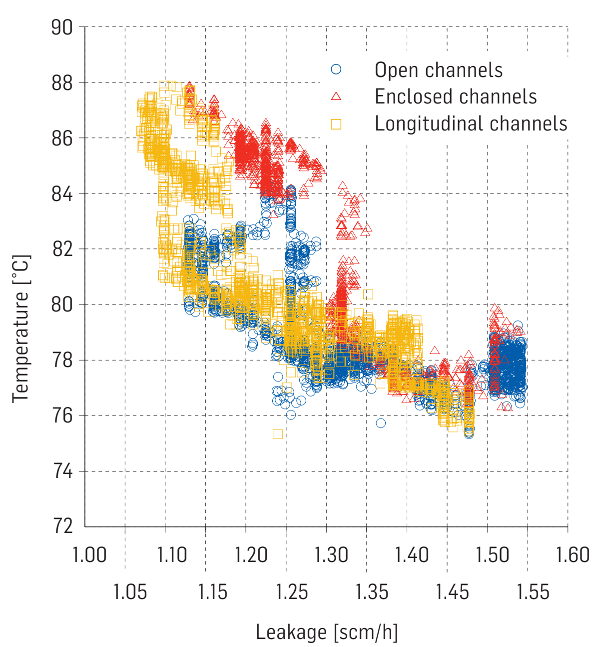


Fig. 9
Piston rod temperature as a function of gas leakage rate for packing cups with open and enclosed cooling channels and the new longitudinal-flow variant



integrated directly in the packing cup web. Had the overall length of the sealing system been limited to 150 mm, the large axial dimension of their packing cups would only have permitted a use of four sealing elements. However, since an integration of cooling channels into the packing cup web does not improve piston rod temperature, the sealing system's service life would be shortened in comparison with the remaining two cooling systems. **Fig. 9**

CHAPTER 6

SUMMARY

The highest resistance arising during heat transfer from the friction surfaces to the cooling channels is offered by convective heat transfer from the piston rod via the leakage gas to the metallic packing cups. Measures to improve the packing cup region accordingly have a very negligible effect on overall heat transfer efficiency. Therefore, development activities should be geared primarily toward eliminating the fault susceptibility of systems for cooling piston rod seals. Important criteria here are an avoidance of gas and coolant leakages, minimization of the risk of clogging and maximization of accessibility for the purpose of inspecting and cleaning the cooling channels.

These objectives have been achieved through a new configuration of the cooling channels in the longitudinal direction, parallel to the piston rod, as opposed to the commonly employed ring-shaped flow around the individual packing cups. Operators now have at their disposal a robust, reliable and easily maintainable cooling system which also complies with the recommendations of the future, fifth edition of API 618. Comparative tests with cooling systems commonly used today have shown that these advantages are not accompanied by any drops in heat transfer efficiency.

Notation

PTFE polytetrafluoroethylene
PEEK polyetheretherketone
l_{ax} axial dimension of the packing cup
$\dot{Q}$ heat flow

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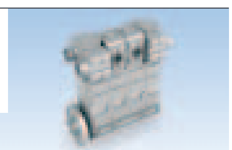

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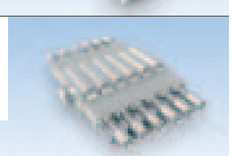

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