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# Influence of gas desorption in a safety relief valve undergoing cavitation

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**Abstract.** In this study, the characterization of the flow through a safety relief valve (SRV) is performed in presence of cavitation and gas desorption. For this purpose, a transparent safety relief valve model is used on an experimental facility in which the flow conditions (mass flow rate, fluid temperature, and pressure upstream and downstream the valve) can be accurately monitored. For two different valve openings, the characteristic curves are measured while flow visualization is performed on the transparent model. The results show that choked flow conditions are reached only for the smallest valve opening, with a remarkable repeatability. In order to take into consideration the gas saturation level of the working fluid, the vacuum system used to adjust the pressure downstream is also used for gas desorption by storing the liquid under vacuum conditions, a process known as vacuum degasification. In saturated liquids the evolved gas bubbles modify the flow properties, such as the speed of sound, and this may have an influence in the cavitation inception and the occurrence of choked flow. This study proves that gas saturated water in standard conditions (atmospheric pressure and 293 K) has the same behavior that fully deaerated water, both under the same cavitating conditions. It is thus not necessary to take the saturation level of the liquid into account when in standard conditions. The same is not expected in pressurized saturated liquids, which is currently under study.

## 1. Introduction

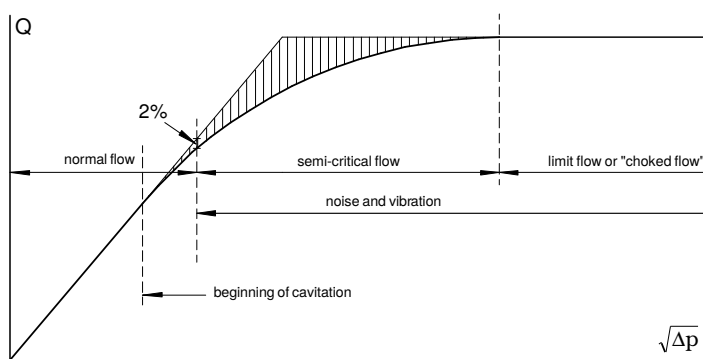
In valves and hydraulic pumps, the phenomenon of cavitation takes place when the static pressure of an accelerating flow falls below a threshold value. Depending on this value, many authors [1, 2, 3] distinguish between vaporous cavitation and gaseous cavitation. Vaporous cavitation takes place when the pressure drops below the liquid vapor pressure, which is traditionally the only phenomenon taken into consideration when studying cavitation. On the other hand, gaseous cavitation, also known as gas desorption, takes place when the pressure falls below the saturation pressure of the gas dissolved in the liquid. In a liquid + gas mixture, the gas remains dissolved unless its temperature is raised or its pressure is lowered below the saturation pressure, since both circumstances reduce the gas solubility. When gas release takes place, small bubbles come out of the solution, and they are carried away by the flow. When cavitation is involved, the presence of entrained gas in suspension in the liquid, even in very small quantities, have an influence in the cavitation inception. Furthermore, evolved gas is responsible for reducing the velocity in the medium and for attenuating the pressure peaks due to the added compressibility of the gas, as described by Wylie and Streeter [4].

Cavitation in valves has gained great attention in the last decades due to more demanding requirements in terms of safety and operation of industrial valves. The flow rate through a valve



in single phase conditions is proportional to the square root of the pressure drop but this is not true anymore when the flow undergoes cavitation. Figure 1 shows the three flow regions that can be found during valve operation.

- Normal flow: In absence of cavitation, the flow rate is proportional to  $\sqrt{\Delta P}$ .
- Semi-critical flow: Beyond cavitation inception, the flow rate does not increase linearly with  $\sqrt{\Delta P}$  anymore.
- Limit flow or choked flow: The intensity of cavitation is such that the speed of sound in the resulting two-phase flow reaches the flow velocity, resulting in a choked flow similar to that in compressible flows. The flow rate does not increase anymore with  $\sqrt{\Delta P}$ .



**Figure 1.** Flow rate diagram of an incompressible fluid through a valve according to IEC 60534-2-3[5]. Extracted from [6].

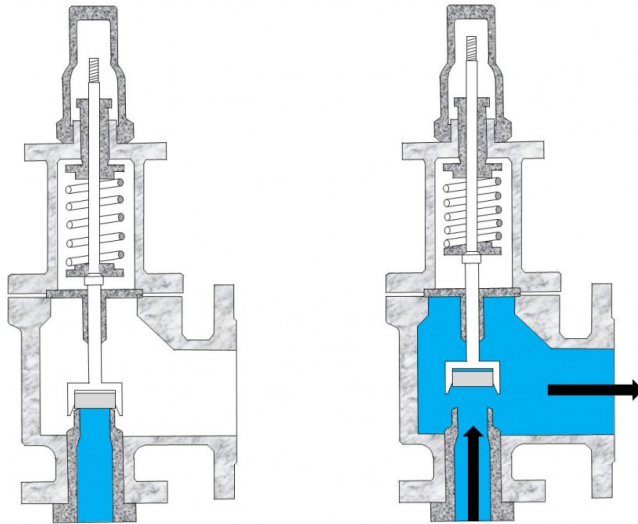
Valve operation with cavitation can be unsafe since the maximum flow rate is limited by the choked flow conditions, and this can be critical in the case of safety relief valves (SRV). This type of valves are used in hydraulic systems as the last protection against overpressures. As figure 2 illustrates, SRVs are kept closed by means of a spring, which is adjusted to counterbalance the maximum pressure in the line. When the static pressure in the line rises above this value, the pressure force on the valve disk is higher than the force applied by the spring and the valve opens. SRVs must be extremely reliable in order to evacuate the necessary flow fast enough to avoid permanent damage to the system, and this can not be ensured if the valve undergoes cavitation during flow discharge. It is thus fundamental to characterize the behavior of such valves in the extreme range of cavitating flow.

Several authors have studied cavitating flows in SRVs, both experimentally ([7, 8, 9, 10]) and numerically ([11]). In all these studies, the influence of gas desorption was always left unanswered. The purpose of this paper is to study the influence of this parameter, continuing the work by Pinho et al.([8]) and taking into consideration the level of deaeration and saturation of the test liquid. To do so, an experimental facility was designed and built to allow the two-phase flow characterization through valves, with an accurate setting of the test conditions, including the saturation level of the test liquid.

## 2. Experimental facility

The experimental facility designed for this study is dedicated to test valves working under adverse cavitating conditions, following the recommendations given by the international standard IEC 60534-2-3[5]. The facility design is shown in figure 3, where the flow is induced in a closed loop by means of a variable-frequency drive pump that takes water from a 700 L tank, setting the necessary flow rate through the test valve. In order to attenuate the turbulence generated by the pump, a second tank of 50 L is mounted before the test valve, referred to as “calming tank”. The whole facility is built in stainless steel AISI 316L to avoid corrosion. Since the liquid can warm up during testing, the main tank is equipped with an electric resistance to heat up the

liquid in order to reach a constant working temperature where the radiated heat to the ambient balances the heat provided by the resistance and the viscous friction.



**Figure 2.** Safety relief valve operation: Closed (left), relieving (right).

Cavitation is generated by accelerating the liquid through the flow restriction created by the test valve. If the cavitating conditions need to be set for lower flow rates, a vacuum pump connected to the main tank can be used to reduce the back pressure downstream the test valve.

The SRV used in this study is the same used by Pinho et al.[8], which is based on an API 1 1/2G3 SRV and built in methacrylate, as shown in figure 4. Instead of using a spring to close the valve, the model allows the adjustment of the disk at any fixed desired lift.

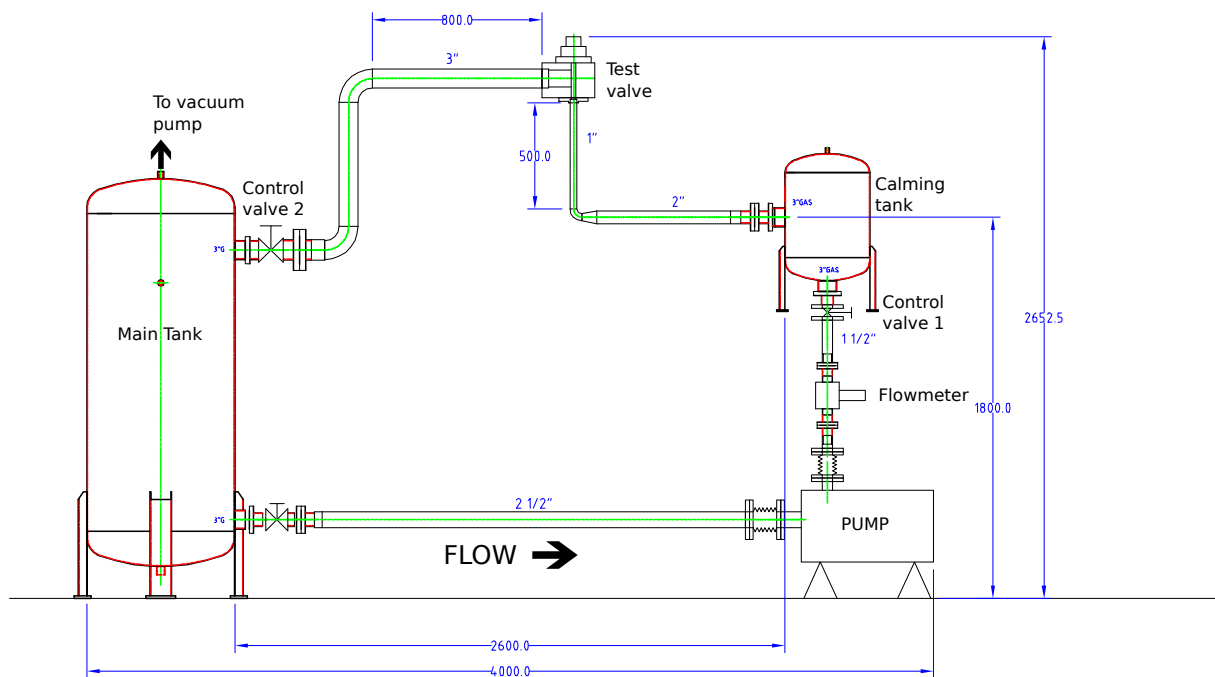
### 2.1. Measurements techniques

The sensors used to set the flow conditions and characterize the valve are listed in table 1. The pressure transducers to measure the pressure differential through the test valve are installed following the recommendations of IEC 60534-2-3: the upstream and downstream sensors are mounted respectively two and six pipe diameters before and after the valve, while ensuring more than 20 diameters and 10 diameters of straight pipe line upstream and downstream the valve, as sketched in figure 5. A type K thermocouple is mounted in the calming tank to measure the liquid temperature before reaching the test valve, and the ultrasonic flowmeter is located after the pump. Finally, the flow visualizations are done with a Phantom camera than can sample at a maximum rate of 650,000 images per second.

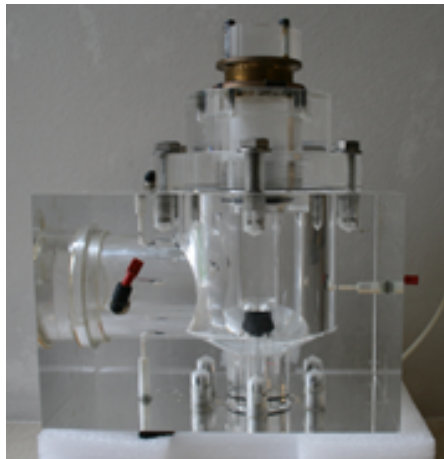
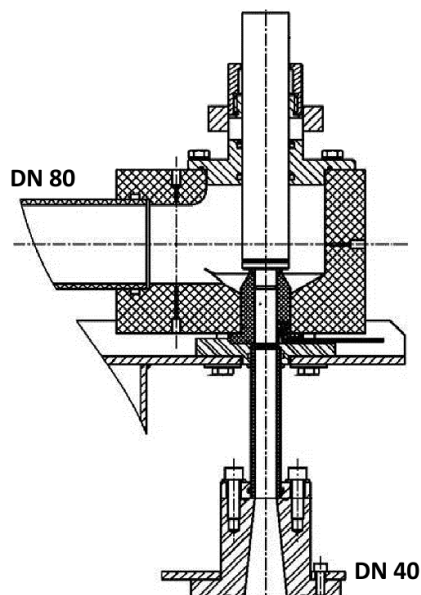
### 2.2. Experimental procedure

The valve characterization is performed by setting a constant total pressure upstream the valve for a given valve opening. Two different opening configurations have been used in this study: 3 mm and 6 mm. The pressure drop across the valve and the flow rate are set by means of control valves 1 and 2 (see figure 3) and, if necessary, decreasing the pressure downstream the valve by means of the vacuum pump or even changing the pump rotation velocity.

In this study, two types of experiments are undertaken: with fully deaerated water and with saturated water at atmospheric pressure. The deaerated condition is set by applying a degasification process to the test liquid, as described by Lema et al.[3]. This is achieved by



**Figure 3.** Experimental facility.

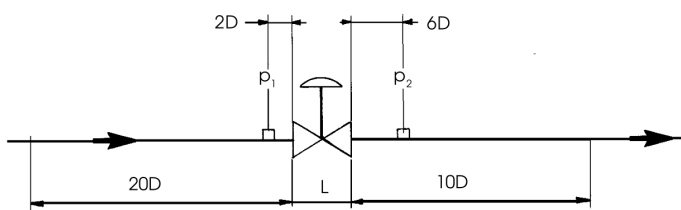


**Figure 4.** Transparent model of API 1 1/2G3 valve.

keeping the liquid under reduced pressure, often referred to as vacuum degasification. This process allows reducing the gas solubility by reducing the partial pressure and, as stated by Henry's law, a less soluble gas will desorb from the liquid + gas solution. The final partial pressure applied to the solution during the vacuum degasification is always kept slightly above

**Table 1.** Measurement techniques

Transducer	Description
Pressure (3 units)	OMEGA PXM219. Range (absolute pressure): 100 - 600 kPa(upstream), 0 - 300 kPa (downstream), 0 - 100 kPa (main tank).
Temperature	OMEGA thermocouple, type K
Flow	COMAC CAL FLOW33 Ultrasonic flowmeter. Range: 0 - 54 $m^3/h$
High speed camera	Phantom Miro 310

**Figure 5.** Pressure transducers installation according to IEC 60534-2-3 standard.

the liquid vapor pressure to avoid the boiling of the liquid and the massive arrival of vapor to the vacuum pump. Since the vapor pressure of water at 293 K is 2.3 kPa, the minimum vacuum pressure for degasification was set to 5 kPa resulting a gas mass fraction of  $4.8 \cdot 10^{-7}$ . Once the water was deaerated, the pressure in the main tank was kept constant and equal to 5 kPa to avoid liquid gas saturation in the main tank during testing. On the other hand, with saturated conditions the pressure in the tank was always the atmospheric pressure, resulting a gas mass fraction of  $1.9 \cdot 10^{-5}$ . One should keep in mind that in both test conditions, the total upstream pressure (static pressure measured by the transducer plus the dynamic pressure computed with the flow velocity at the same location) was always kept constant and equal to 250 kPa. Table 2 summarizes the test conditions used in the present study.

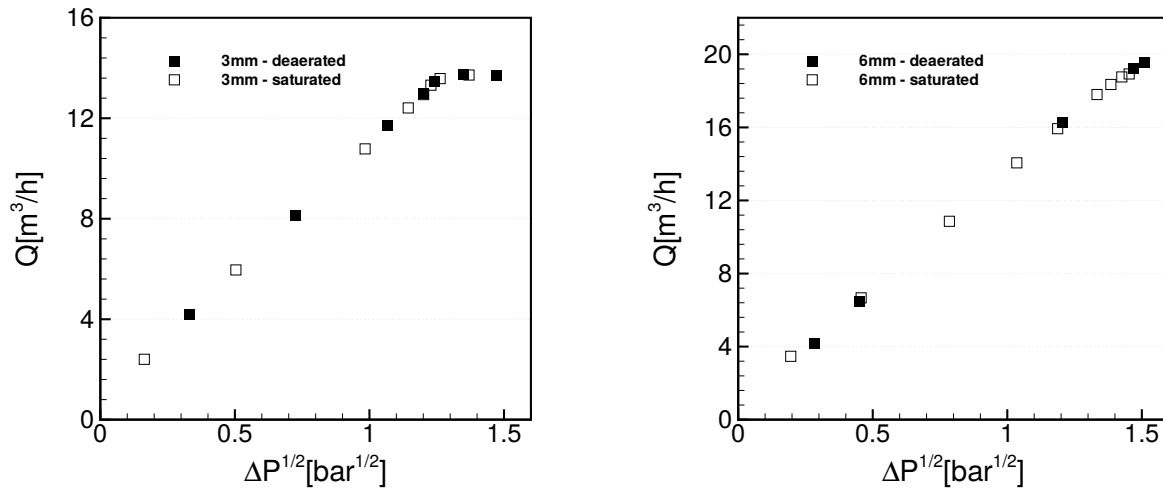
**Table 2.** Test conditions

Total pressure upstream	250 kPa
Pressure drop	[2kPa....230kPa].
Valve opening	3mm and 6mm
Flow rate	[ $2m^3/h$ .... $20m^3/h$ ]
Test liquids	<ul style="list-style-type: none"> <li>Fully Deaerated water, <math>X_{air} = 4.8 \cdot 10^{-7}</math></li> <li>Saturated water at normal conditions, <math>X_{air} = 1.9 \cdot 10^{-5}</math></li> </ul>

### 3. Results and discussion

For every test condition, the experiments are repeated three times, with a good test repeatability of less than 2%. Figure 6 shows the flow rate evolution against the square root of the pressure drop through the valve for the two valve openings considered in this study. According to the results shown in figure 6, deaerated and saturated conditions give the same results. This was obviously expected in normal flow conditions, but it is remarkable how in cavitating conditions

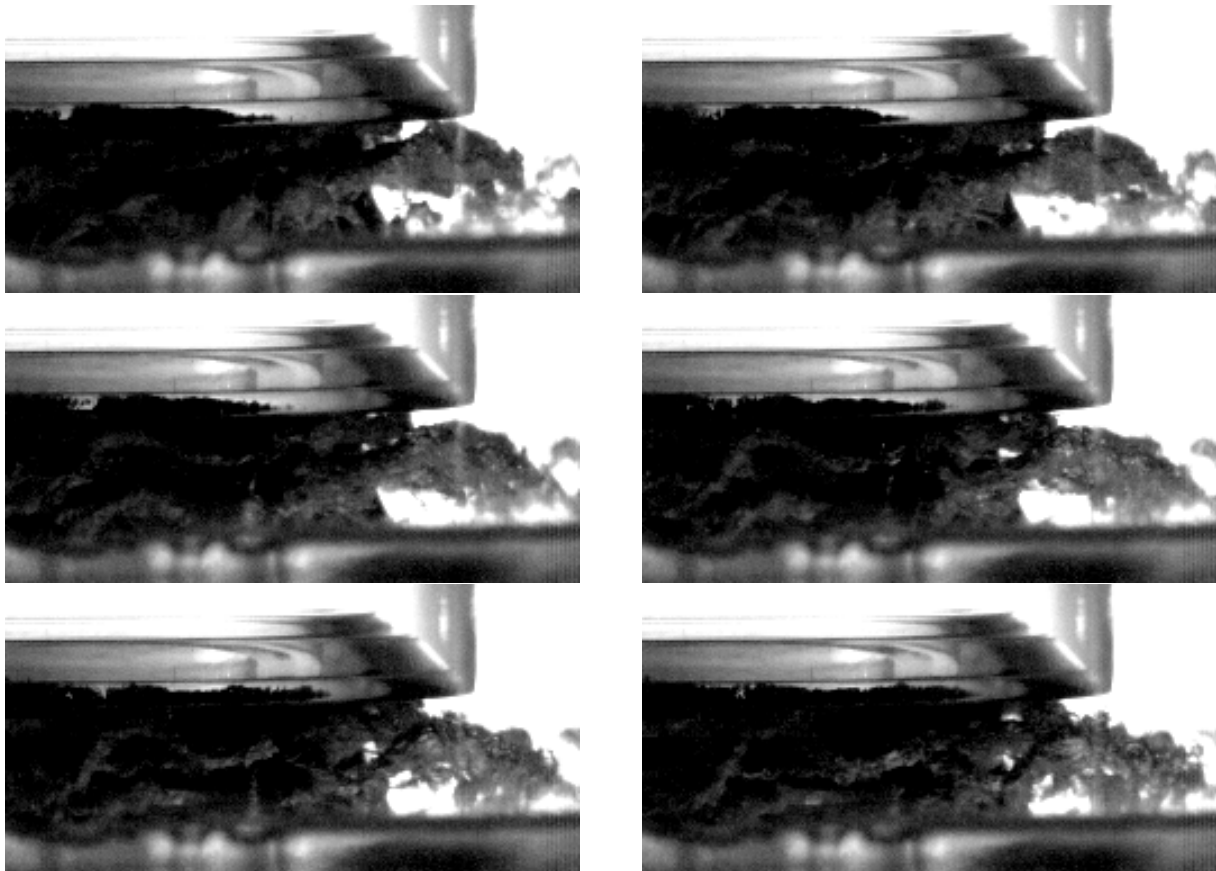
the flow rate through the valve remains the same for both liquids. For instance with a 3 mm valve lift, choked flow conditions can be clearly detected above  $\Delta P^{1/2} = 1.2 (bar)^{1/2}$  without any difference in the flow rate evolution. Similar results are obtained with a 6 mm lift, except that choked flow conditions cannot be reached for this opening.



**Figure 6.** Flow rate versus pressure drop for different valve openings.

It is well known that in saturated liquids, when the local pressure decreases, the evolved gas bubbles change the flow properties, such as density and speed of sound. Moreover, the growing amount of gas bubbles should reduce the mass flow rate through the valve with an earlier start of the choked flow. However, the results obtained in the present study show that for both deaerated and saturated conditions, the gas phase dissolved in water in standard conditions does not make a difference in the flow through the valve under cavitating conditions. In the study by Lema et al. [3], where the waterhammer in a pipe line was under consideration, the saturated conditions were reached at 2 MPa. Under these circumstances, the deaerated and saturated results were completely different in terms of wave velocity and pressure peak levels during waterhammer occurrence. It is therefore probable here that at higher saturation pressure levels, the influence of gas desorption during cavitation would be more important. This is currently under study, but care should be taken in the experimental procedure because the maximum working pressure in the transparent valve cannot exceed 350 kPa. It is not excluded that an industrial valve is used instead of the transparent model.

The intensity of cavitation can hardly be characterized by other means than flow visualization, using a high speed camera. Acoustic techniques are not necessarily reliable, especially in industrial conditions. For this study a Phantom camera, Miro 310 model, is used, with a multi LED illumination system synchronized with the camera. The sampling rate was set to 77,000 images per second with a resolution window of  $256 \times 128$ . Figure 7 shows snapshots separated by a time interval of  $65 \mu s$  obtained with the 3 mm valve lift and saturated water. One can observe the vapor bubbles formation in the valve restriction, which is the space left between the valve disk and the valve seat. The corresponding flow conditions are the ones at choked flow inception ( $\Delta P^{1/2} = 1.2 (bar)^{1/2}$  and  $Q = 13.6 m^3/h$  in figure 6) and the same was done with deaerated water. The qualitative comparison does not reveal any difference between the two test conditions, in agreement with the valve characteristic curves in figure 6.



**Figure 7.** Cavitating flow in the API 1 1/2G3 valve: Lift 3 mm and saturated water at atmospheric pressure. Images sequence: from left to right and from top to bottom.

#### 4. Conclusions

This study aimed at characterizing the influence of gas desorption in a safety relief valve undergoing cavitation. For that purpose, experiments were performed on a transparent SRV valve model, using deaerated water on the one hand and saturated water at atmospheric pressure as test liquids. A dedicated facility was designed and constructed, following the IEC 60534-2-3 norm. This flow loop allows characterizing virtually any type of valve under cavitating conditions, and proved to offer an excellent repeatability, which is usually difficult to reach in such installation.

For two different valve openings, the valve characteristic curves were measured, while flow visualization was performed on the transparent model. The experimental results show that choked flow conditions are reached only for the smallest valve opening, with a remarkable consistency. The evolution of the flow rate against the pressure drop show that water under saturated conditions gives almost the same results than the ones obtained with deaerated conditions. It appears that gas saturation in water in standard conditions has no influence on the flow through the valve under cavitating conditions. Therefore, under these circumstances the water saturation level can be ignored when defining the test conditions. At higher gas saturation pressures, the influence of this parameter is expected to be more important, and this is currently under study.

## Acknowledgment

The authors would like to thank Dr. Jorge Pinho from Bosch Termotecnologia SA (Portugal) and Dr. Saïd Chabane from Fluide-Méca (France) for their help in the design of the experimental facility. The API 1 1/2G3 SRV transparent model has been lent by the von Karman Institute for Fluid Dynamics (Belgium) and the Centre Technique des Industries Mécaniques (France), which are gratefully acknowledged.

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