Water transmission schemes are used around the world to transport water from the production sites towards the distribution networks. These transmission schemes start with a pumping station, where tanks, pumps, and surge vessels are installed; see Figure 1 for an example of surge vessels. The next part is a long transmission pipeline, which runs from the pumping station to a valve station after which the water is discharged into tanks or reservoirs.

To ensure the safety of the pipelines, surge vessels are installed just downstream of the pumps, see figure 2 for an example schematic of a pumping station. After a full pump trip due to, for example, a power failure, these surge vessels start to supply water to the pipeline. This makes the transition from full flow to zero flow smoother, thus reducing the minimum pressure reached after the full pump trip. The surge vessels are designed in such a way that the minimum pressure is acceptable and that the surge vessel does not drain.

The basic working principle of the surge vessel is the expansion and compression of the air inside the vessel. This dampens the pressure waves and therefore reduces the extreme pressures within the system. The bigger the air cushion the better the downstream system is protected from pressure surges. In this lies the need for optimizing the size of the surge vessel, since a bigger surge vessel will be more costly. Water hammer simulation software plays an important role in the optimization of the surge vessels. In this type of software, the physics of the functioning of the surge vessel is taken into account in a simplified way. In reality, the behavior of the air inside the vessel is more complex. For example, the air will cool down when expanding. This can start a flow of heat from the outside air into the surge vessel, the amount of which depends on the temperature difference, the wall thickness of the material of the surge vessel, and on the dimensions of the surge vessel. However, it is difficult to account for this heat transfer, and therefore in most water hammer software programs, two extreme cases are considered: no heat transfer and constant air temperature equal to the outside temperature (i.e. instantaneous and unrestricted heat transfer). These two extremes lead to a simple equation known as the ideal gas law. The behavior of the air is described by the so-called Laplace coefficient or adiabatic index.

When using the ideal gas law, these two extreme cases need to be considered. The case that there is no heat transfer is also known as an adiabatic process, for which the Laplace coefficient of air is 1.4. This leads, in general, to the lowest pressure in the system. The other case is also known as isothermal expansion, with a Laplace coefficient of 1.0. This leads to the lowest water level in the surge vessel. To come to a safe and reliable design both need to be considered. It is not possible to exclude one or the other since it is not known beforehand which of the two will be the dominant process. As it has been shown [1], this leads to a conservative design of the
surge vessel. A 20% reduction in surge vessel volume can be obtained when the behavior of the air or Laplace coefficient is known beforehand, as can be seen in Figure 3 [1] which shows the required surge vessel volume for different values of the Laplace coefficient ranging from isothermal expansion (1.0) to adiabatic expansion (1.4). This figure is created by finding for the different surge vessel volume the acceptable C-value (product of initial air volume and initial air pressure). This is done for the minimum water level in the surge vessel and for the minimum acceptable pressure in the system. This results in two lines for every Laplace coefficient, the area between the lines (white part in figure 3) represents acceptable combinations of surge vessel volume and C-value. From figure 3 it can be seen that a surge vessel volume of about 575 m³ (blue dot in figure 3) is required. If the Laplace coefficient would be 1 the total required volume would reduce to 475 m³. The actual, more realistic Laplace coefficient can be predicted if the heat transfer is considered in the modelling of the surge vessel [2, 3].

The heat transfer from the outside air to the inside air and the heat transfer due to the condensation of the water vapor needs to be modelled. The difficulty is the estimation of the heat transfer coefficient, which dictates how much heat is transported from the outside air into the air inside the surge vessel. Two processes play a role in this. One of them is the heat transfer through the wall, which depends on the material (steel in most cases) and the wall thickness, both of which are known. The second process is the heat transfer inside the surge vessel, where the air is at a standstill and the heat conducted through the wall increases the temperature of the air close to the wall. Then, due to collisions of the air molecules the heat is slowly transported towards the center of the surge vessel, i.e. through diffuse heat transport. Next, free convection is induced, a motion of the air molecules driven by the density difference, resulting from the temperature difference of the air inside the surge vessel. This process depends upon the geometry (size, orientation) of the surge vessel, the temperature difference between the air inside the surge vessel and the ambient temperature. It can be modelled by calculating an overall heat transfer coefficient with the help of the Nusselt number, the ratio between the overall heat transfer and the heat transfer by conduction. Several relations for different geometries can be found in literature [3] but, there is none for heat transfer inside a cylinder.

A comparison between 3D CFD simulations and simulations with extended rational heat transfer model (eRHT) model [2], which estimates the rate of heat transfer using the Nusselt relation for an infinite flat plate, shows a significant overestimation of the heat transfer compared to the 3D CFD simulations [3] (see Figure 4). This is the subject of ongoing research, whose main goal is to develop a relationship that can predict the heat transfer inside the surge vessel. 3D CFD simulations are used for this purpose. Next, the surge vessel model needs to be validated against measurements. For this purpose, laboratory and field measurements are planned.

The new and improved model for the air expansion in a surge vessel is still under development. When finished, it is expected to help reduce significantly the required volume of surge vessels, thus reducing their construction costs. The main focus of the ongoing research is the heat transfer modelling and the validation of the model with measurement data.

References