WHITE PAPER

Validation of BLOWDOWN™ Technology in V9 of Aspen HYSYS®

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Executive Summary

BLOWDOWN software technology, developed by Professor Stephen Richardson of Imperial College London and Dr. Graham Saville formerly of Imperial College London, was acquired by Aspen Technology on 12 March 2015. BLOWDOWN software technology has been used in hundreds of studies in the oil and gas and chemical industries to identify locations in a system where temperatures can decline dramatically during depressurization. The BLOWDOWN software technology has been incorporated into Aspen HYSYS® V9 in order to provide an accurate determination of these low temperatures, which is a critical activity in the design and operation of every process plant as it can reduce capital cost, but more importantly, improve the safety of the plant. This white paper validates the new BLOWDOWN™ Technology in Aspen HYSYS against published experimental data.

Introduction

A major challenge in the process industry today is controlling the capital cost of both greenfield and brownfield projects, while ensuring regulatory standards are met. Simulation is widely used during the design and revamp of pressure relief systems; therefore, accurate models are required. Although conservative approaches are often desirable for safety considerations, uncertainties and inaccuracies can lead to gross overdesign.

One common method for limiting the consequences associated with a process emergency is the rapid depressurization or blowdown of a vessel. By evacuating the contents of a vessel in certain emergency situations, such as a fire, overpressure and stress rupture of the vessel can be avoided. However, this blowdown process comes with its own challenges. During depressurization, the temperature of the fluid can drop significantly. The heat transfer between the fluid and the vessel wall leads to a reduction in the temperature of the wall, which can lead to a fracture if the wall temperature falls below the ductile-brittle transition temperature of the steel. It is therefore critical to accurately determine the lowest temperatures that can be reached during blowdown so that the proper construction materials can be selected.

Modeling a system during depressurization can be quite complex. During blowdown, a multiphase mixture of gas, liquid and aqueous phases flow through the vessel, valve and any associated piping. As the fluid flows, heat transfer between the fluid and vessel wall, as well as between the different fluid phases, will occur. An accompanying mass transfer between the phases as liquid evaporates and vapor condenses will also occur. Both the fluid mechanics and heat and mass transfer effects are time-dependent and three-dimensional. Additional modeling complexity is introduced for high pressure systems, where the thermodynamic trajectory during the depressurization takes the fluid near or through the critical region.

A rigorous approach to modeling the blowdown process was developed at Imperial College London by Dr. Graham Saville and Professor Stephen Richardson. This computer program, known as BLOWDOWN software technology, can dynamically simulate the flow of hydrocarbons from multiple depressurizing vessels and pipelines. The program utilizes a thermodynamic package based on corresponding states that is very accurate for hydrocarbon systems, particularly at near-critical conditions. Additionally, a heat and mass balance is performed on each phase (gaseous hydrocarbon, liquid hydrocarbon and free water), therefore no equilibrium assumptions and adjustable parameters are necessary. Consequently, the model is predictive and has been validated against many experimental measurements, most of these at full-scale.

BLOWDOWN software technology was acquired by Aspen Technology on 12 March 2015 and was subsequently integrated within Aspen HYSYS. Dr. Saville and Professor Richardson served as consultants during the project by recommending restrictions and assumptions made in the single vessel with a piping template provided within BLOWDOWN Technology in Aspen HYSYS. In addition, they gave guidance for this validation white paper by providing additional information that was not published, nor can be released due to the proprietary nature of the experiments.

Comparison of BLOWDOWN Technology in Aspen HYSYS with Experimental Data

Comparisons were made between the results from simulations using BLOWDOWN Technology in Aspen HYSYS with experimental measurements that were published in the following articles:

- Haque, M. A., et al. "Rapid Depressurization of Pressure Vessels." *J. Loss Prev. Process Ind.*, Vol 3 (1990). Print.
- Haque, M. A., et al. "Blowdown of Pressure Vessels: II. Experimental Validation of Computer Model and Case Studies." *Trans IChemE*, Vol 70, Part B (1992). Print.

The experiments above covered different vessel sizes and orientation and choke sizes while using fluid compositions representative of upstream oil and gas systems. It should be noted that not all of the experimental parameters and conditions were published in the literature due to the proprietary nature of some of the experiments. Consultation with the original authors provided some of the unpublished data, but these cannot be disclosed in this document.

Imperial College Experiments

Blowdown experiments were performed at Imperial College in a bunker or blast cubicle using the vessel described in Table 1 below. For safety reasons, nitrogen was used as the representative gas and carbon dioxide was used as the representative condensable phase. Fifteen experiments modified the fluid composition, blowdown directions and choke sizes. The blowdown times were on the order of 100 seconds.

Inside Diameter	0.273 m
Length	1.524 m
Head Type	Flat Ends
Wall Thickness	25 mm

Table 1: Vessel dimensions for experiments at Imperial College.

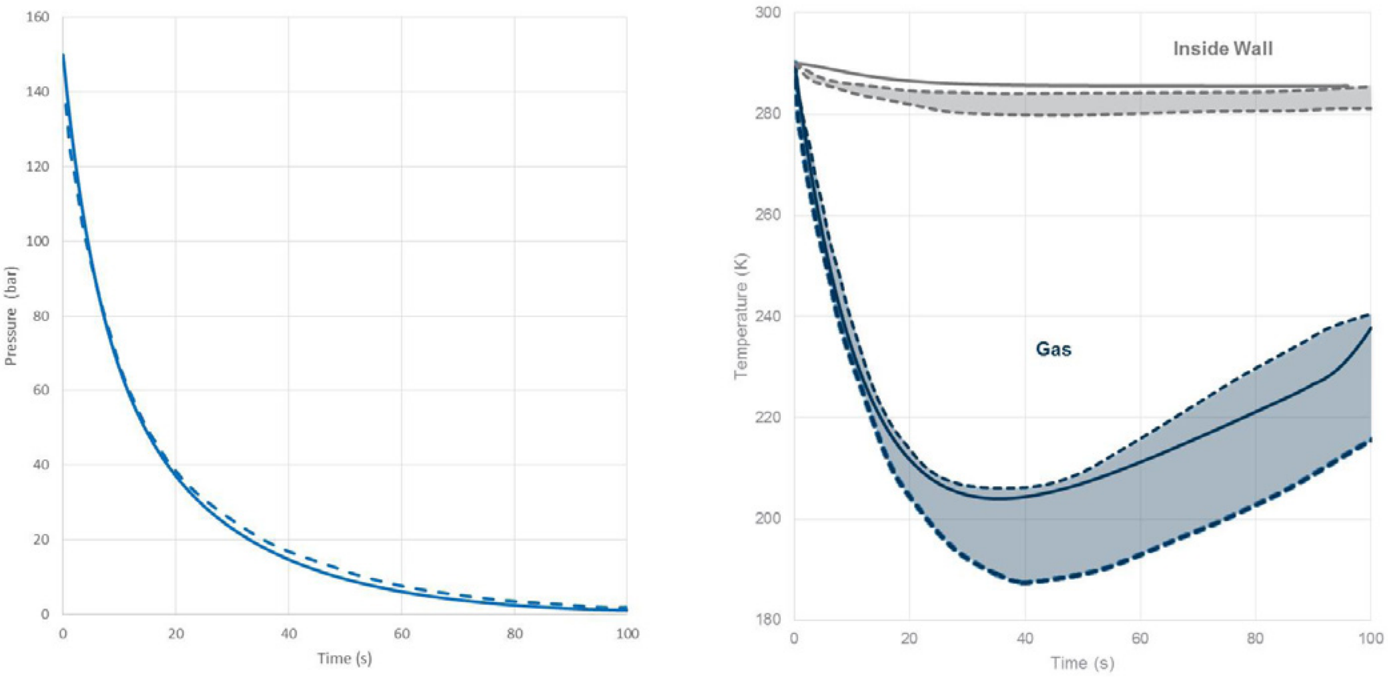
I1: Blowdown of Pure Nitrogen

The "I1" experiment considered the blowdown of pure nitrogen from the top of a vertical vessel. The additional experimental conditions and parameters are defined in Table 2.

Composition	100.0 % N_2
Initial Pressure	150 bar
Initial Temperature	290 K
Vessel Orientation	Vertical
Orifice Diameter	6.35 mm
Blowdown Direction	Top
Back Pressure	1.01325 bar
Ambient Temperature	290 K
Orifice K_d	0.8

Table 2: Experimental conditions for the "I1" experiment at Imperial College.

The variations with the time of the pressure, bulk gas temperature and inside wall temperature are shown in Figure 1. The vessel depressurized to atmospheric pressure in approximately 100 seconds, and the gas rapidly cooled during this expansion. Heat was transferred between the fluid and the wall; however, the wall temperature does not decline nearly as much as the fluid does. The experimental results show a range of temperatures as there are some spatial variations in those temperatures.



(a) (b)

Figure 1: The variations of (a) the vessel pressure and (b) the bulk gas and inside wall temperature with time for the "I1" case. The dashed lines indicate experimental measurements, while the solid lines are the predictions of BLOWDOWN Technology in Aspen HYSYS.

The simulation of this blowdown experiment using BLOWDOWN Technology in Aspen HYSYS predicted the pressure variation in the vessel with time that is in good agreement with the experiment, as shown in Figure 1. Unlike the experimental results, BLOWDOWN Technology in Aspen HYSYS assumes that the bulk fluid temperatures are spatially uniform within each phase and that the temperatures of the wall, in contact with each phase, vary only through the thickness of the wall. Therefore, there is a single prediction for the bulk gas temperature and the inside wall temperature. It can be seen that the predicted temperatures are close to the experimental values in that the minimum average bulk gas temperature and the minimum inside wall temperature are predicted within less than 4K.

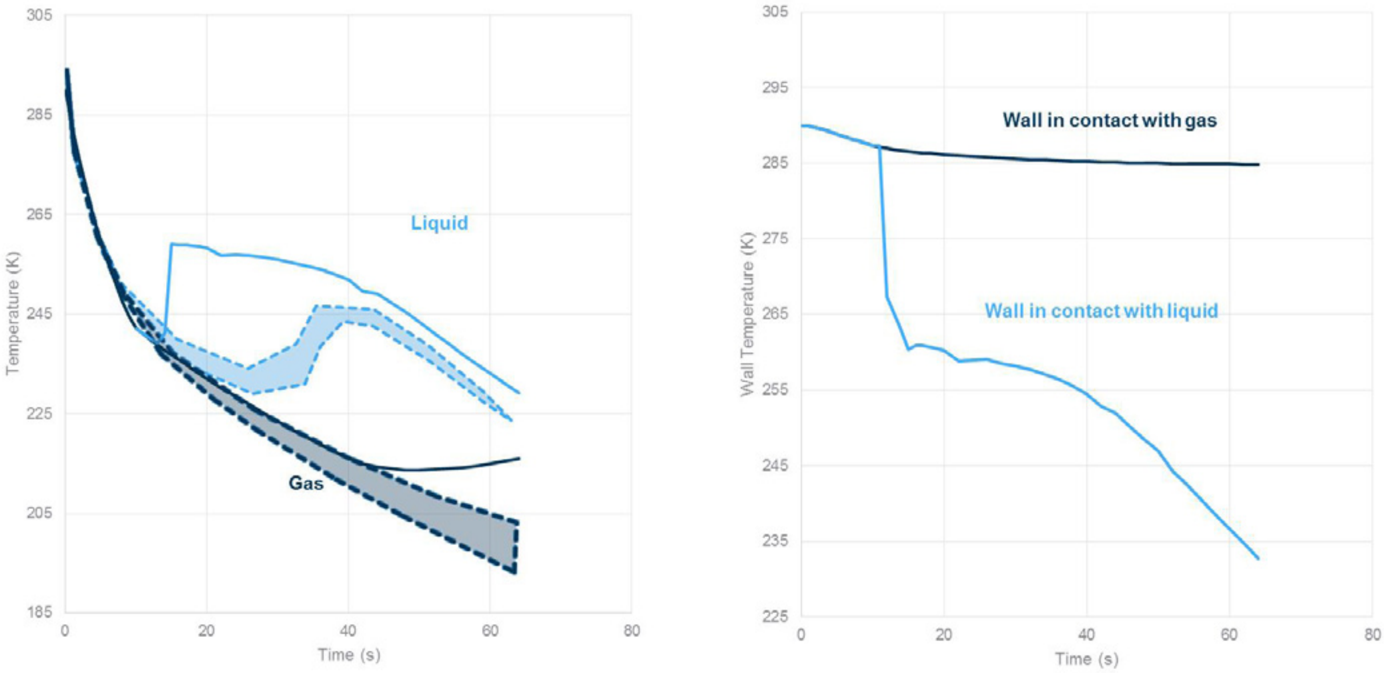
I7: Blowdown of a Nitrogen-Carbon Dioxide Mixture

In the "I7" experiment, the vessel initially contained a 70% nitrogen/30% carbon dioxide mixture on a molar basis. At the initial conditions of 150 bar and 290K, this mixture was a single gas phase. The additional experimental conditions and parameters are defined in Table 3.

Composition	70.0 % N_2 and 30.0% CO_2 (mole percent)
Initial Pressure	150 bar
Initial Temperature	290 K
Vessel Orientation	Vertical
Orifice Diameter	6.35 mm
Blowdown Direction	Top
Back Pressure	1.01325 bar
Ambient Temperature	290 K

Table 3: Experimental conditions for the "I7" experiment at Imperial College.

The predictions of BLOWDOWN Technology are also shown in Figure 2, which displays good agreement with the experimental data. As blowdown proceeded, liquid started to condense causing a variation in the fluid temperature between the top and bottom zones, as shown in Figure 2(b). BLOWDOWN Technology predicted the formation of liquid, including the initial rise and steady fall of the liquid temperature. As explained in the original paper, "Rapid Depressurization of Pressure Vessels", referenced on page 3, this behavior was due to the small amount of liquid that initially formed, which then came in contact with the relatively warm bottom wall of the vessel, leading to a partial evaporation. As the gas continued to expand, more liquid condensed and fell to the bottom of the vessel, forming a pool of liquid that cooled the vessel wall. Only a few centimeters of liquid formed in the pool, which was sufficient to reduce the inner wall temperature that was in contact with the liquid much more significantly than that at the top of the vessel. Therefore, the prediction and location of liquid formation is critical for identifying the low temperature points in the vessel.



(a) (b)

Figure 2: The variations of (a) the bulk gas and liquid temperatures and (b) the inside wall temperatures with time for the "I7" case. The dashed lines indicate experimental measurements, while the solid lines are the predictions of BLOWDOWN Technology in Aspen HYSYS.

Spadeadam Experiments

Blowdown experiments were performed at the British Gas test site at Spadeadam using the vessel defined in Table 4. These experiments used mixtures of methane, ethane, propane and nitrogen. The composition contained trace amounts of higher molecular weight hydrocarbons, in particular butane, which were not reported in the literature. In addition, there were slight variations in the composition between individual experiments. Eighteen experiments modified the fluid composition, blowdown directions and choke sizes. The blowdown times were on the order of 1,500 seconds.

Inside Diameter	1.130 m
Length	3.240 m (2.250 m tan-to-tan)
Head Type	Torispherical Ends
Wall Thickness	59 mm

Table 4: Vessel dimensions for Spadeadam experiments.

S9: Blowdown of a Hydrocarbon Mixture

In the "S9" experiment, a vertical vessel was blown down from the top. The experimental parameters and conditions are given in Table 5.

Composition	85.5 % C1 , 4.5 % C2 and 10.0% C3 (mole percent)
Initial Pressure	120 bar
Initial Temperature	303 K
Vessel Orientation	Vertical
Orifice Diameter	10.0 mm
Blowdown Direction	Top
Back Pressure	1.01325 bar
Ambient Temperature	293 K

Table 5: Experimental conditions for the "S9" experiment at Spadeadam.

Figures 3 and 4 show the experimental variation that includes the time of the pressure in the vessel, the bulk gas temperature and the temperatures of the inside wall in contact with the gas and liquid. The bulk liquid temperature was not measured in this experiment. Initially, the fluid in the vessel was only gas. As the blowdown proceeded, the pressure and temperature of the gas decreased. After approximately 100 seconds, liquid condensate formed and the droplets fell to the bottom of the vessel to form a pool of liquid. Droplets continued to condense as the bulk gas temperature decreased during blowdown. As heat was transferred (it is easier to transfer to liquid than to gas from the vessel wall), the initial liquid temperature was higher than that of the gas. However, as the blowdown continued, the depressurization rate decreased and therefore the bulk gas temperature did not decrease as rapidly. Eventually, the bulk gas temperature started to rise as heat was gained from the vessel wall more quickly than it was lost due to expansion. Consequently, the bulk liquid temperature became lower than the bulk gas temperature, therefore the vessel wall had a lower temperature when in contact with the liquid.

The simulation results using BLOWDOWN Technology in Aspen HYSYS are also shown in Figure 3. There is very good agreement between the simulation and experiments. The minimum average bulk gas temperature is predicted within 2K and the minimum inside wall temperature is predicted within 3K.

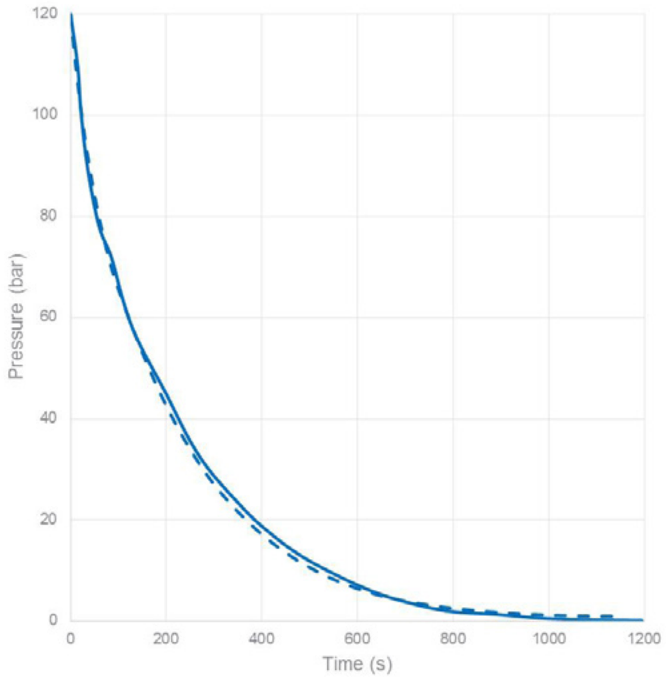


Figure 3: The variations of the vessel pressure with time for the "S9" case. The dashed lines indicate experimental measurements, while the solid lines are the predictions of BLOWDOWN Technology in Aspen HYSYS.

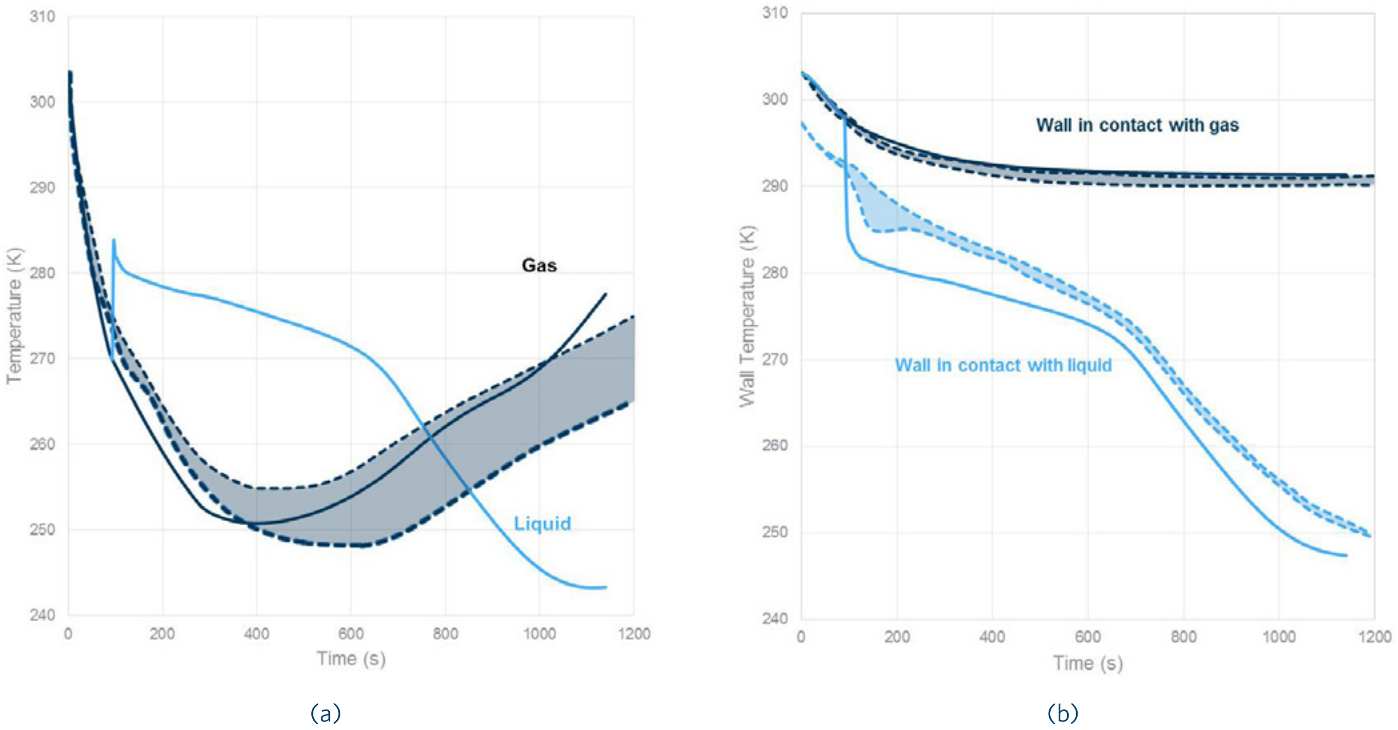


Figure 4: The variations of (a) the bulk gas and liquid temperatures and (b) the inside wall temperatures with time for the "S9" case. The dashed lines indicate experimental measurements, while the solid lines are the predictions of BLOWDOWN Technology in Aspen HYSYS.

S12: Blowdown of a Hydrocarbon Mixture

In the "S12" experiment, a vertical vessel was blown down from the top with an initial composition that was different from the previously described "S9" experiment. The experimental parameters and conditions are given in Table 6.

Composition	66.5 % C1 , 3.5 % C2 and 30.0% C3 (mole percent)
Initial Pressure	120 bar
Initial Temperature	290 K
Vessel Orientation	Vertical
Orifice Diameter	10.0 mm
Blowdown Direction	Top
Back Pressure	1.01325 bar
Ambient Temperature	293 K

Table 6: Experimental conditions for the "S12" experiment at Spadeadam.

Figures 5 and 6 show the experimental variation with time of the pressure in the vessel, the bulk gas and liquid temperatures and the temperatures of the inside wall in contact with the gas and liquid. Compared to the "S9" experiment, significantly more liquid condensed from the gas in the "S12" experiment. This lead to lower temperatures of the bulk liquid and of the inside wall that was in contact with the liquid at a later time. In addition, the larger amount of liquid allowed the bulk liquid temperature to be monitored as a function of time. As shown in Figure 6(b), there was very little spatial variation in the bulk liquid temperature as there was for the bulk gas temperature. The original authors attributed this to the intense boiling in the liquid phase, which resulted in rapid mixing and thermal equilibrium in the phase. Therefore, it is essential to include this phenomenon in the model.

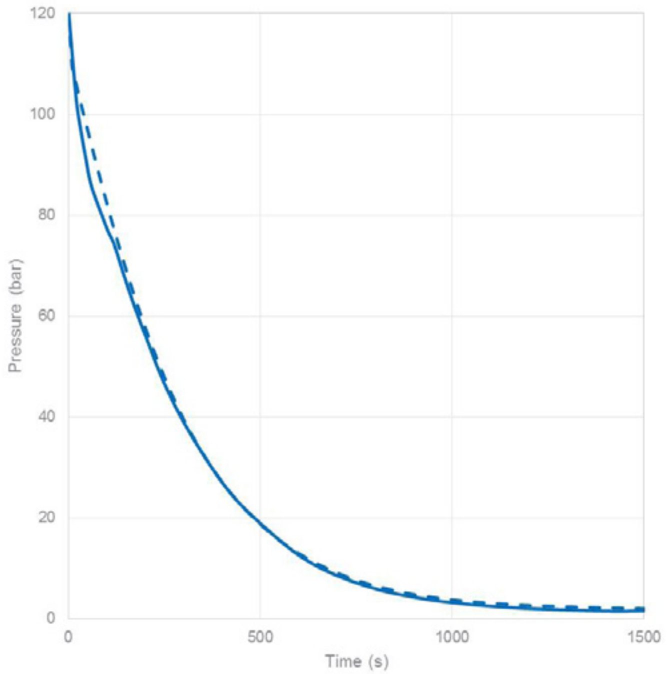
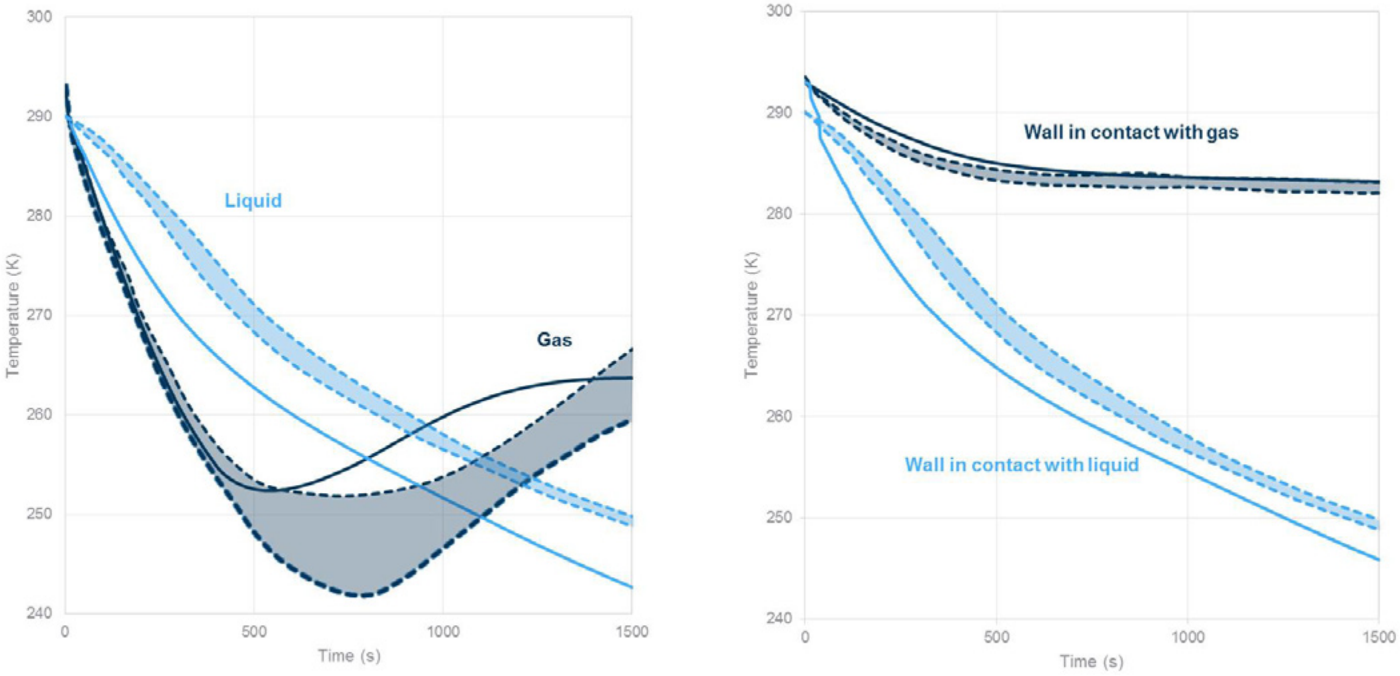


Figure 5: The variations of the vessel pressure with time for the "S12" case. The dashed lines indicate experimental measurements, while the solid lines are the predictions of BLOWDOWN Technology in Aspen HYSYS.



(a)

(b)

Figure 6: The variations of (a) the bulk gas and liquid temperatures and (b) the inside wall temperatures with time for the "S12" case. The dashed lines indicate experimental measurements, while the solid lines are the predictions of BLOWDOWN Technology in Aspen HYSYS.

Conclusion

Ensuring adequate design of depressurization systems is vital for safe asset operation. The design and rating of your depressurization system is not a trivial task, due to the modeling complexity of simulating a dynamic depressurization analysis. On top of this, accurately predicting vessel and pipe wall temperatures requires even greater modeling complexity. Conservative depressurization analysis can result in high project costs, but contracting the work to a niche consultant for a more accurate analysis can ruin the project timeline. **With industry-leading BLOWDOWN Technology** now available in Aspen HYSYS, low temperature concerns in a depressurization system can be assessed using a technology that has been validated across hundreds of projects over the past several decades.

AspenTech is a leading supplier of software that optimizes process manufacturing — for energy, chemicals, engineering and construction, and other industries that manufacture and produce products from a chemical process. With integrated aspenONE® solutions, process manufacturers can implement best practices for optimizing their engineering, manufacturing, and supply chain operations. As a result, AspenTech customers are better able to increase capacity, improve margins, reduce costs, and become more energy efficient. To see how the world's leading process manufacturers rely on AspenTech to achieve their operational excellence goals, visit **www.aspentech.com**.

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