

Innovative air vessel design for long distance water transmission pipelines

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Abstract

The Shuweihat Water Transmission Scheme (SWTS, UAE) consists of a twin DN1600 DI PN25 pipeline transmitting 150 MIGD over 250 km from Shuweihat Desalination plant to Mussafah (Abu Dhabi city). The Scheme is divided in two subsequent systems, each with a tank farm and a pump station delivering water to downstream terminal reservoirs and direct consumers. The first system (Lot A) transmits water from Shuweihat to Mirfa (100 km). The second (Lot C) is from Mirfa to Mussafah (150 km). The pipeline follows roughly the UAE coastline and the profile is generally flat with a few local high points.

The surge study of the Lot C system investigated a large number of scenarios and resulted in the design of surge protection equipments and control systems. The surge protection equipment consists of 16 x 121 m³ (1936 m³) innovative vertical non-vented air vessels, invented by Deltares. The innovation includes a passive air release valve at a strategic elevation on the air vessel. This air release valve opens if the water level drops below the float level. At this water level the air pressure is super-atmospheric so that air is released from the air vessel to prevent draining. This innovation was driven by the initial findings of the surge analysis where it became apparent that 22 x 220 m³ (4840 m³) air vessels would have been required. These large vessels were the result of a double constraint. On the one hand, the initial air mass had to be sufficient to allow a proper expansion of the vessels and thus the protection of the pipeline against excessive negative pressures. On the other hand, a very small initial air mass was required due to the lack of backpressure. This meant that the air pocket was expanding by a factor exceeding 20, resulting in the emptying of the vessels.

In this paper, we will describe the hydraulic model of the hybrid air vessel, detail the benefits of the new design and discuss the cost savings compared to conventional air vessels. It is concluded that the hybrid air vessel has saved over 50% of the required air vessels total volume. Considering the size of air vessels initially required, the costs savings in terms of surge protection of the SWTS Lot C system were cut in excess of 60%.

Introduction

The Shuweihat Water Transmission Scheme (SWTS), United Arab Emirates, consists of two ND1600 Ductile Iron pipelines transporting distilled water from the Shuweihat desalination plant to Mussafah (Abu Dhabi area), via the Mirfa tank farm and its desalination plant. The purpose of the pipeline is to transport the entire Shuweihat distillate production of 150 MIGD to the major population centers in the UAE as well as remote desert dwellings along the coastline.

The Transmission and Despatch Company of Abu Dhabi (TRANSCO) owns and operates the pipeline system. The main contractor was Marubeni Taisei Consortium (MTC) and the consultant of the owner was Tebodin Middle East (TME).

The scheme is divided in several lots of which the description is given in the following table.

Lot	Description
'A'	Dual Transmission line (approx. 100 km) from Shuweihat to Mirfa, including Shuweihat pumping station. Pipeline A: Transmission line / Pipeline B: Distribution line
'B'	Dual Transmission line (approx. 150 km) from Mirfa to Mussafah Pipeline A: Transmission line / Pipeline B: Distribution line Single transmission line between Mussafah and Unit IV (13 km)
'C'	Mirfa City and pumping station
'D'	Mussafah City and pumping station
'E'	Single transmission line (approx. 100 km) from Shuweihat to Sila

Deltares (formally known as WL | Delft Hydraulics) was commissioned by MTC to perform the hydraulic study of all lots. The study includes pipelines from Mirfa to Mussafah (pipeline A and B) and from Mussafah to Unit IV (single line) with their respective pumping stations. The Mirfa, Mussafah and Unit IV tank farms are also included in the study.

This paper focuses on the air vessels design of Lot C (Mirfa to Mussafah).

Objectives

The objectives of the study of the Shuweihat Water Transmission Scheme (SWTS) are:

1. to determine the unsteady flow conditions (pressure and head) occurring in the system during emergency or most critical conditions.
2. to design safety devices in order to prevent unacceptable pressures during emergency or most critical conditions. This includes the design of air vessels at the pumping station, the sizing of air valves, and the closure / opening patterns of the various control valves.

Surge protection approach and Acceptance criteria

Two sets of acceptance criteria have been used for the project depending on the availability of the SCADA system and the Fiber Optic Cable (FOC).

In the case of a healthy control system, stringent acceptance criteria have been used. These are the maximum pressure below 25 barg and the minimum pressure above atmospheric pressure (0 barg). In order to achieve such criteria, the surge protection approach relies on the coordinate action of the pumps and the downstream control valves. In case of full pump trip, the control stations close in a controlled manner to prevent negative pressures. In this case, the air vessels are providing a sufficient damping as to allow for smooth pressure variations. On the other hand, in the case the receiving stations are closed (simultaneously), the pump station will trip in a timely manner in order to limit the maximum pressure surge. In all cases, the restart after trip was to be made against a fully pressurized pipeline thereby resuming normal operation in the shortest possible time.

In the case of an unhealthy control system or fiber optic cable, the client did not wish to reduce the maximum capacity of the pipeline. Yet, safe operation was to be maintained even if communication between the various stations (pump station, distribution receiving station and terminal receiving station) was interrupted. In such case, the acceptance criteria were somewhat relaxed with the maximum pressure to be maintained below 30 barg and the minimum pressure above -0.5 barg. The approach was to safeguard the pipeline from any damages while allowing some air pockets to enter the pipeline. The restart procedure is in such case longer than with a healthy control system as the air pockets need first to be vented.

Software

WANDA 3.71 was used to perform the simulations. This software has been developed by Deltares (formerly WL | Delft Hydraulics) in the Netherlands. WANDA is an interactive software package for hydraulic analyses of pipeline systems. WANDA includes three modules, Engineering, Transient and Control, to support the entire life cycle of a pipeline system: basic design, detailed design, commissioning, operation, maintenance procedures and temporary and permanent modifications.

1. WANDA Engineering focuses on steady state simulation and efficient operation of pumping stations.
2. WANDA Transient focuses on simulation of pressure surges during emergency and normal operations.
3. WANDA Control integrates hydraulic transients and advanced control systems for the proper evaluation of control systems. Finally, WANDA Control can be linked to a real PLC or control software in order to assess the performance of the actual control systems during a Factory-Acceptance-Test (FAT) or Site-Acceptance-Test (SAT).

WANDA is the successor of WILMA, which has been developed and applied since the 1970s. Many individual component models of WANDA have been validated against laboratory and field data. A subset of representative scenarios has been collected in a validation report (Pothof, 2006), which has been updated on a regular basis (Zwan, 2008; Tukker 2012). The default WANDA license contains a number of

air vessel models, including vented, non-vented, horizontal and vertical air vessels. The innovative hybrid air vessel has been developed during the project.

Description of the model

Pumps and design flow rates

Moment of inertia		100 kgm ²			No. of pumps in operation	Total Discharge (m ³ /h)	Head at the Pump Station	Pressure at the Pump Station
Flow rate per pump (m ³ /h)	Flow rate per pump (GPM)	Head (m)	Speed (RPM)					
Rated	4,735	25	203	994	3	14,205	232 m	22 barg
Future	5,682	30	191	994	2	11,365	161 m	15 barg

Pipeline Profile and Hydraulic Grade Line

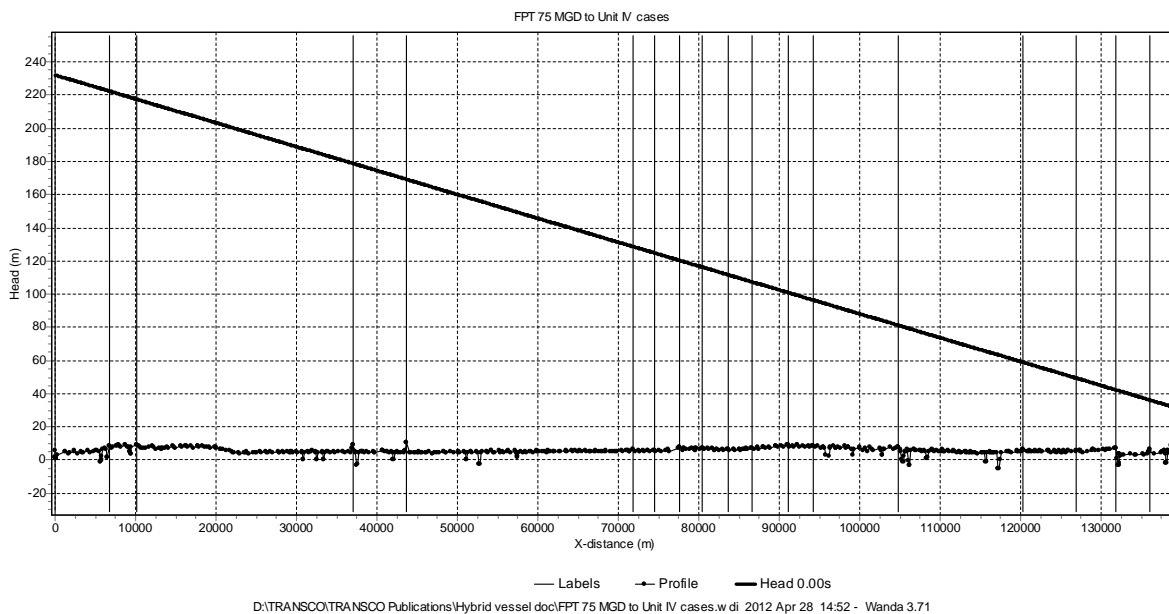


Figure 1 HGL of Mirfa to Unit IV (140 km) at 75 MGD

Air vessels

Design criteria

At the client's request, and based on the consultant's design requirements, the air vessel design had to meet the following design criteria:

Criteria	Comments
Design surge scenario	Full pump trip at maximum flow with control valve "As Is",

Minimum pressures in the pipeline	no Fiber Optic Cable available, no local DCS
Total number of vessels	Above -0.5 barg
Maximum level in the vessels	n+1 basis allowing for maximum flow
Minimum level in the vessels	At least 1 meter clearance from the ceiling of the vessels to protect the instruments from water
Laplace coefficient	Vessels must remain filled at all times, no air release during surge is allowed.
Control mode of the vessels	From 1.0 [-] to 1.4 [-]
Control range	Level control (from High High Water Level to Low Low water level)
Installation of the vessels	At least 1 meter between HHWL and LLWL vertical none vented vessels above ground level

Photos of the air vessels



Air vessels properties

Air vessels	Initial Design	Hybrid vessels	Comments
Total Air vessel volume	5280 [m ³]	1942.4 [m ³]	n+1 basis with Level control
Total volume of vessel	220 [m ³]	121.2 [m ³]	
Number of vessels	11	8	Per pipeline

Laplace coefficient	1.0 to 1.4 [-]	1.0 to 1.4 [-]	
Initial air volume	HHWL: 15.62 [m ³] LLWL: 25.24 [m ³]	HHWL: 20.00 [m ³] LLWL: 28.00 [m ³]	Air / Water ratio of 20% Air / Water ratio of 30%
Initial water volume	HHWL: 204.4 [m ³] LLWL: 194.8 [m ³]	HHWL: 101.20 [m ³] LLWL: 93.02 [m ³]	
Initial water operating level	28.09 [m ADD] 27.09 [m ADD]	19.50 [m ADD] 18.50 [m ADD]	
Top level of vessel	33.28 [m ADD]	22.0 [m ADD]	
Bottom level of vessel	6.85 [m ADD]	6.85 [m ADD]	
Air outlet level	n/a	10.0 [m ADD]	Hybrid vessel type
Chamber area	9.62 [m ²]	8.00 [m ²]	
Chamber diameter	3.7 [m]	3.2 [m]	Maximum limited to 3.4 [m]
Differential inlet / outlet	not required	not required	

The need to innovate

The analysis of the design criteria, as defined by the client's consultant showed directly that some major difficulties would be encountered during the design phase. It was observed that the initial steady state pressure and the profile of the pipeline would be particularly challenging. The initial steady state is calculated to be 22 barg at the pumping station at full flow. The pipe profile is flat without any significant intermediate high points. The highest point along the pipeline and relatively close to the pump station is 9.2 m and that is only 4.6 m above the pump station level. The terminal tank, 140 km away from the pump station is at a levels of 12.8 m.

One can directly conclude that after a full pump trip when the terminal control valves are not allowed to close, the pipeline pressure will stabilize at around 12.5 m, and that this will result in a pressure of 0.8 barg at the pump station. Considering the air pocket in the air vessels, it will expand in accordance with the polytropic gas law ($P_1 V_1^\lambda = P_2 V_2^\lambda$) with Lambda representing the Laplace coefficient (from isothermal, $\lambda = 1.0$, to adiabatic, $\lambda = 1.4$).

In the isothermal case, the final air volume will expand to 11 times the initial volume (22 bar(a) / 2 bar(a)) while this is only a factor 5.5 in the adiabatic case. Although the Laplace coefficient to be applied during the surge event (measured in minutes) can be subjected to much discussion, there is no doubt that once the system is at rest for several hours awaiting restart, there will be plenty of time for heat transfer between the water surface, the vessel wall and the air pocket. The long term Laplace of a non-insulated air vessel can only be taken as 1.0 [-] and thus factor 11 air expansion ratio must be considered.

Considering an air vessel installed at ground level and of 20 meter height, the maximum initial air volume could not exceed 11.5% of the total volume if air expansion was to be fully happening within the vessel.

The issue related with the initial air volume caused difficulties beyond the scope of mere expansion ratios. Indeed, the initial air volume has a direct impact on the effectiveness of the vessel at delivering water when needed. The smaller the volume, the less efficient is the vessel as the “spring” of the compressed air is reduced. This is further reduced by the possible adiabatic behavior of the vessel during the surge event requiring a designing at Laplace of 1.4 [-]. Based on the initial air volume of 11.5%, a preliminary design showed that a total air volume of 22x220 [m³] was required to meet the acceptance criteria of the client. These large vessels had a weak spring effect, delivering water poorly to the pipeline. Their size was extraordinary with a height of 22.8 m and a diameter of 3.5 m. Their weakness in performances was however compensated by their shear number and size.

Unfortunately, air vessel volumes in excess of 140 m³ are difficult and costly to manufacture. Furthermore, diameters above 3.5 m pose serious manufacturing and logistical problems to the point that the contractor considered moving the production to site rather than the product. Obviously, such large vessels were not foreseen in the front end design and would have thus caused an unacceptable financial and schedule strain on the project.

This provided the opportunity and strong incentive to develop an innovative design in the form of the hybrid air vessel.

Analysis of the behavior of the Hybrid vessel

The analysis of the conventional air vessels functioning showed that the water in the vessels was used in two distinct phases. The initial phase is where the vessels need to supply quickly large amount of water to protect the pipeline against large pressure variation due to the pump trip. The pressure drops from 22 barg to 4 barg in approximately 200 seconds. This phase accounted for approximately 40% of the total volume. The second phase is where the air expands due to the lack of backpressure and where pressure variations in the pipeline are small. The pressure drops from 4 barg to 1 barg in 800 seconds and account for the final 60% of the vessel volume.

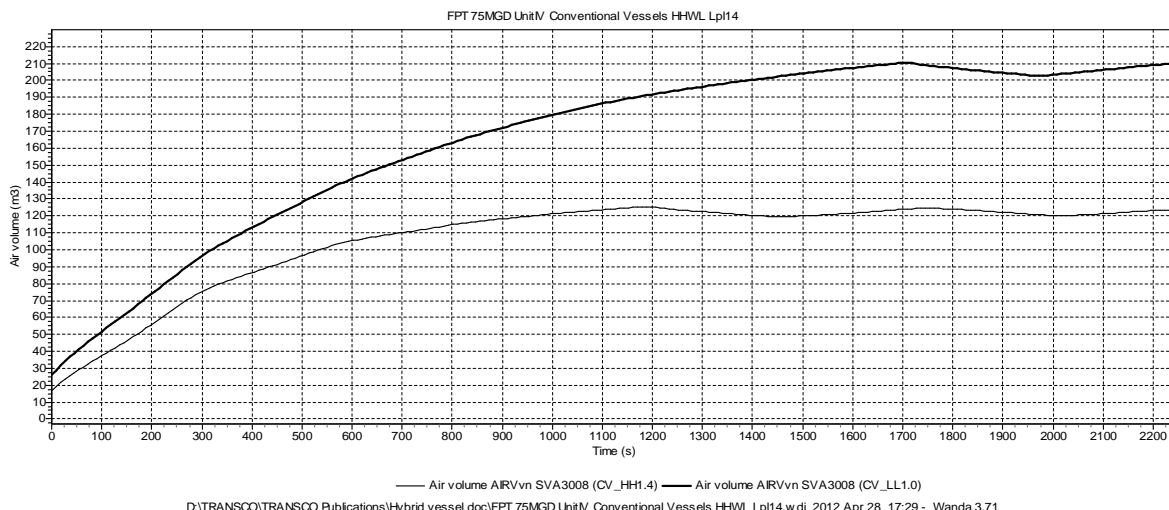


Figure 2 Conventional (220 m³) air vessel, Air volume time series at HHWL (Laplace 1.4, label CV_HH1.4) and LLWL (Laplace 1.0, label CV_LL1.0)

It is clear that more than 60% of the conventional vessel volume is not used for protection purposes but only to absorb the expansion of the air pocket. It is a volume that could be suppressed provided that the expansion of the air is taken care of in another manner.

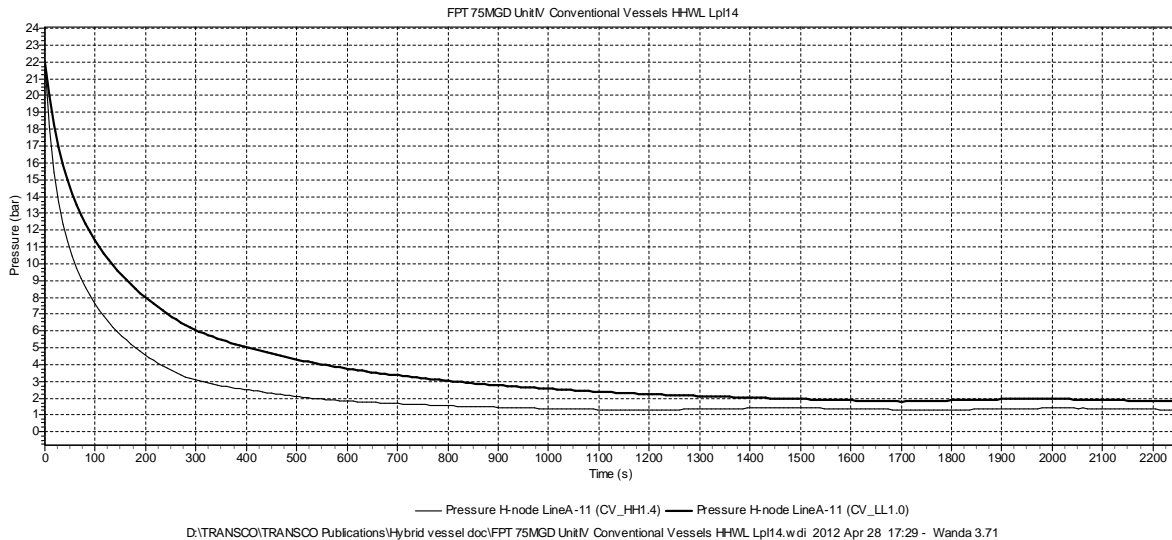


Figure 3 Conventional (220 m3) air vessel, Pump Station pressure at HHWL (Laplace 1.4) and LLWL (Laplace 1.0)

The hybrid air vessel was developed in order to provide the maximum spring effect in the first wave periods and then to release air once the pressure fluctuation in the pipeline are small. The expansion of the air pocket is absorbed through release rather than expansion. This means that the initial air charge of the hybrid air vessel should be at least 20% and that an air release system is strategically located near to the bottom of the vessel.

This design is different from a conventional vented air vessel (a.k.a. Dipping tube surge vessel) since the air pocket of the hybrid air vessel is “super” charged compared to the vented vessel. When pumps trip, the large initial air volume will be efficient in sustaining the pressure in the pipeline as a strong spring effect can be achieved by over charging the air pocket. The vessel is designed to supply water for the first pipe period (approximately 240 seconds) at which point the pressure has dropped from 22 barg to 4 or 6 barg (depending on the initial air charge). At this point, the fluid level in the vessel has reached the level of the air release valve (10 m ADD) which will open to release the air. Since air is being released from the surge vessel at 4 to 6 barg, the numerical model must be able to handle both supercritical and subcritical air flows, as detailed in (Streeter, 1993) or the WANDA User Manual (Deltares, 2008). Furthermore, the float of the air valve must not remain shut at the typical opening pressures of 4 to 6 barg.

When the air is released from the vessels, the water flow to the pipeline slows down. This creates a secondary surge event in the pipeline which is of small amplitude. The pressure in the pipeline drops further from 4 to 6 barg down to 0 barg in approximately one pipe period. The rate of change of the head due to the secondary pressure wave is a parameter entirely controlled by the design of the air

release valve. This is integrated in the design and the air release valve is sized so that this secondary surge pressure meets the acceptance criteria.

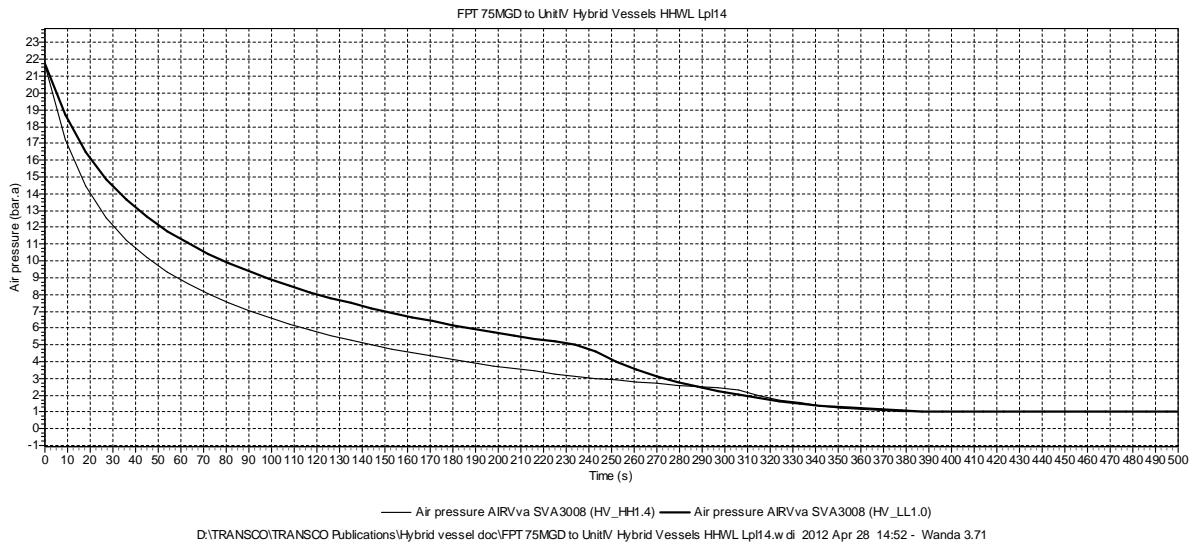


Figure 4 Hybrid Air vessel (121 m3): air pressure in the vessel at HHWL (Laplace 1.4) and LLWL (Laplace 1.0)

The opening of the air valve at approximately 240 seconds (HV_LL1.0) is taking place at 5 bar(a) and thus with a differential pressure of 4 bar compare to the atmosphere. In the case of HHWL (HV_HH1.4), the air valve opens later at about 300 seconds, as the higher Laplace and smaller air pocket create a stiffer spring, so that the float opens later during the transient event. The vessels finally settle at the atmospheric pressure which opens the way to reduce the Laplace range from 1.4 to possibly 1.2 [-] since long term heat transfers do not need to be considered. This is a further development which was not considered in this paper where the full range of Laplace is used.

On Figure 5, the air release valve is located at the 10 m elevation mark. The fluid level drops below this level since the capacity of the air release valve mounted on the vessel is designed to slowly release the extra air volume. This needs to be designed in order to avoid a too severe secondary surge.

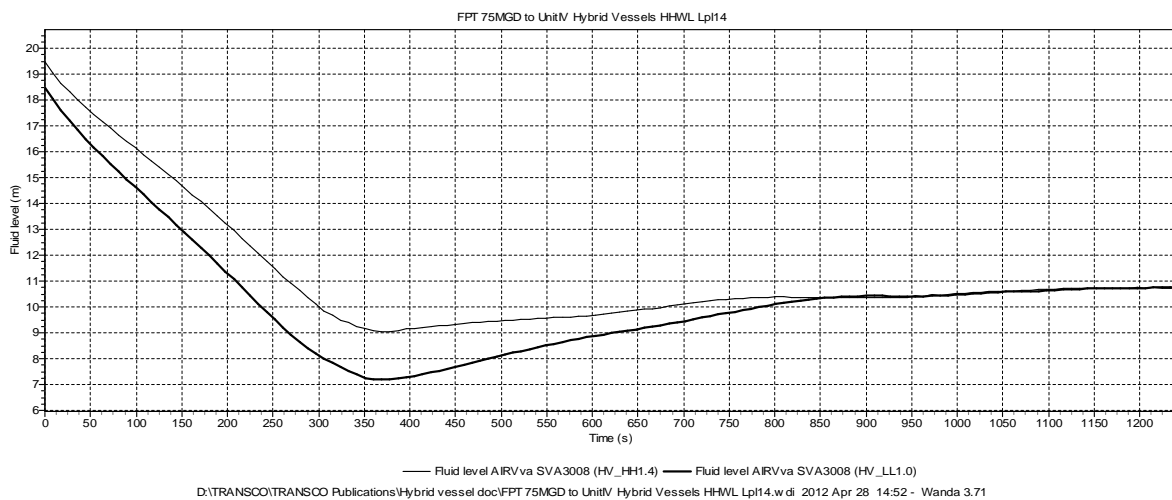


Figure 5 Hybrid Air vessel (121 m3); fluid level at HHWL (Laplace 1.4) and LLWL (Laplace 1.0)

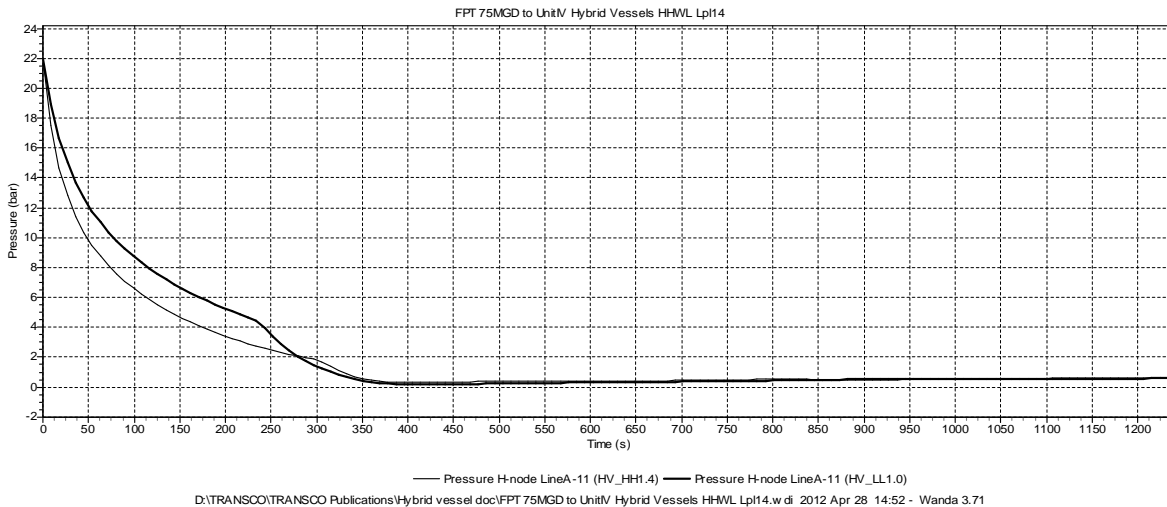


Figure 6 Hybrid Air vessel (121 m³); Pressures at the pump station at HHWL (Laplace 1.4) and LLWL (Laplace 1.0)

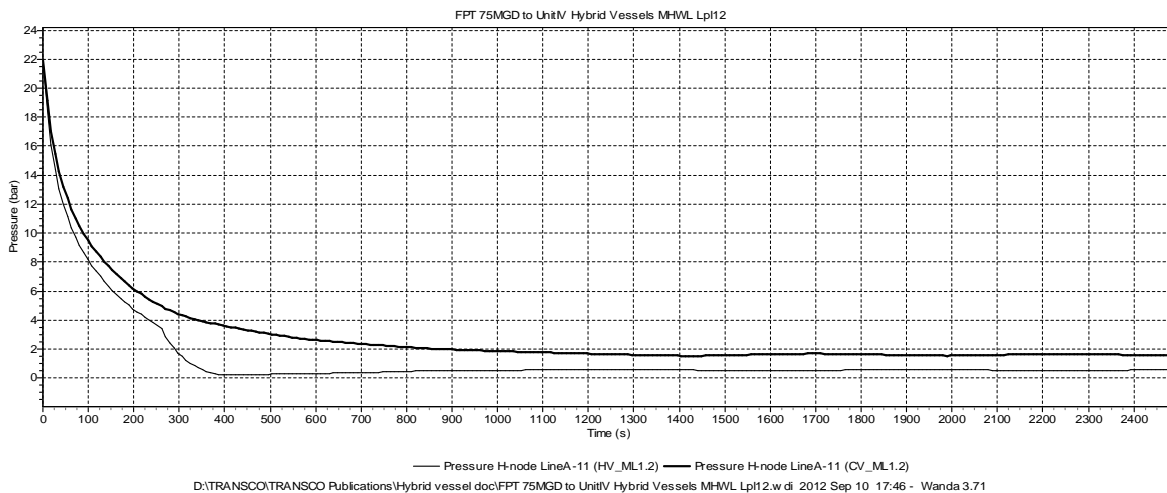


Figure 7 Pressure at the pump station; comparison of Hybrid and Conventional at medium level, medium Laplace

Figure 7 shows the combined behavior of the hybrid 8 x 121 m³ vessels (968 m³ total volume) and the conventional vessels 11 x 220 m³ (2,420 m³ total volume). After 200 seconds (pipe period is 240 seconds), the air release valve on the hybrid vessel opens and creates a secondary surge. The pressure difference between the hybrid and conventional vessel is then 1.5 barg only. Figure 8 shows the pressure envelopes along the pipeline. The pressure gradient across the pipeline is similar in the case of the hybrid and the conventional vessels.

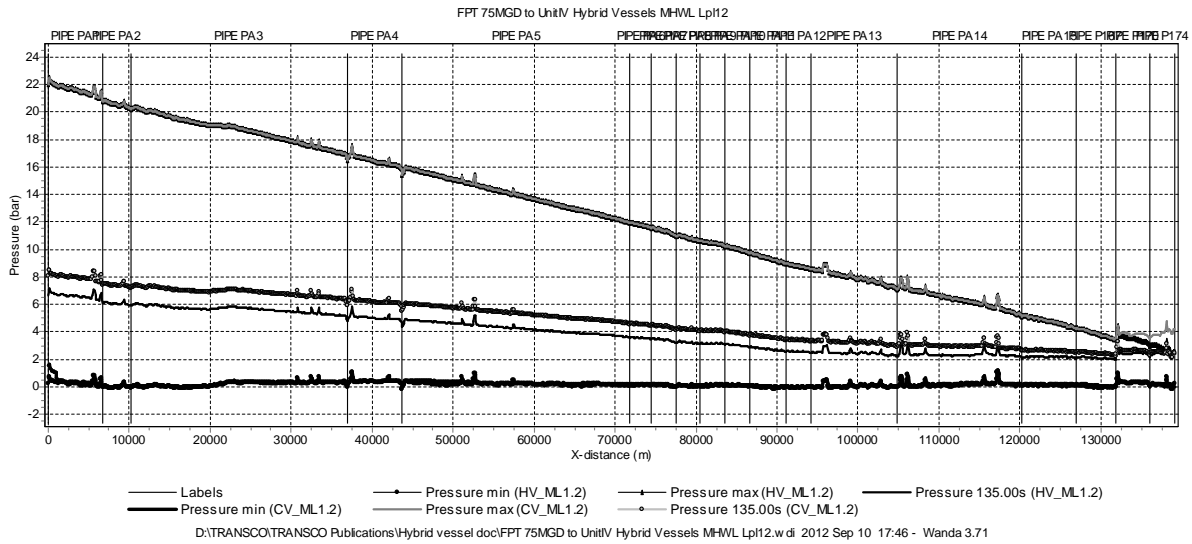


Figure 8 Pressure envelop: Hybrid (HV) and Conventional (CV) vessel. Results after 135 seconds and extrema

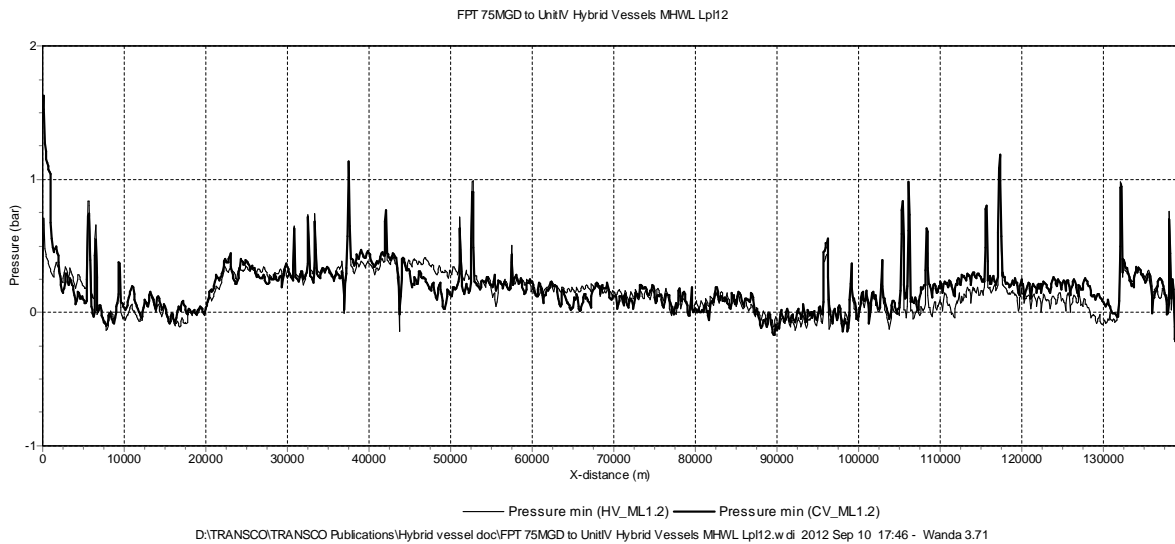


Figure 9 Minimum Pressure envelop; Comparison of Hybrid and Conventional vessels; Zoom on minimum extrema

Figure 9 shows that there is no difference in the pipeline minimum pressures between the hybrid and the conventional vessels. In both cases, the air valves are required in order to sustain the pressure in the pipeline and in both cases, the minimum pressure is well within the acceptance criteria of -0.5 barg. The comparison of the discharge between the hybrid and conventional vessel show that in the first 220 seconds, both systems are behaving identically and start only to differ significantly once the air release system is open.

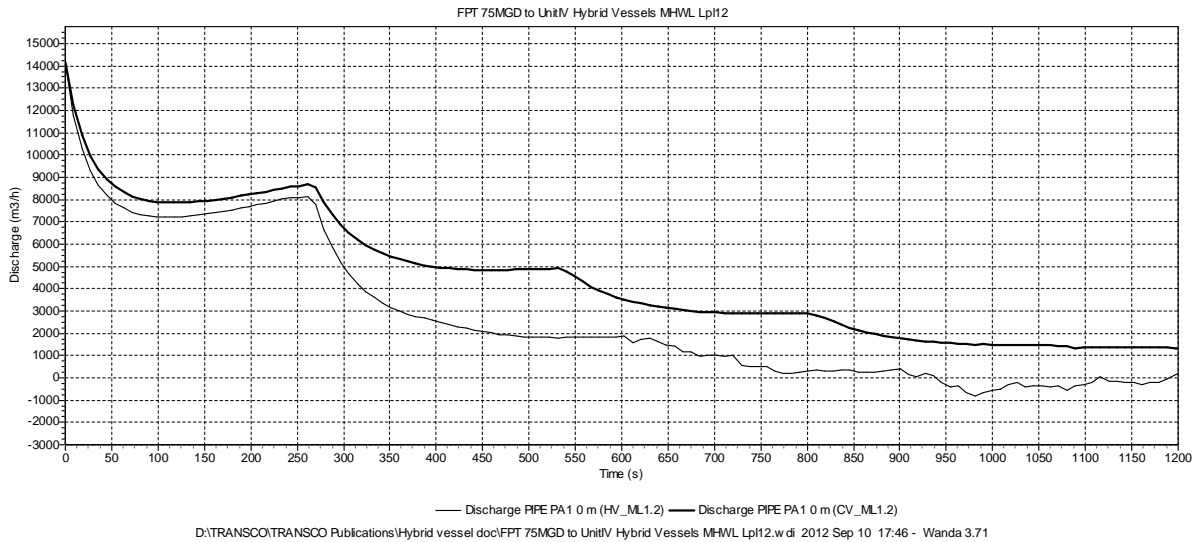


Figure 10 Discharge at the Pump station; Comparison of Hybrid and Conventional vessels

Model of the Hybrid vessel

The hybrid air vessel has been developed as a special component in WANDA 3.71 based on the existing vented air vessel model, combined with the advanced air valve model that accounts for supercritical and subcritical air flows.

When the water level is above the float level for air release/inlet, the hybrid vessel acts like a non-vented surge vessel. When the water level drops below the float level, the hybrid air vessel acts like a WANDA air valve component, taking into account the absolute air pressure, the water level and super- and subcritical air release or inflow. When the water level rises again above the float level, the model automatically returns back to the surge vessel state. The model also tracks the total air mass inside the hybrid vessel, such that multiple switches between the surge vessel state and the air flow state are processed correctly; see the WANDA User Manual for further information (Deltares, 2008).

The table beside is a print of the WANDA software input table. It shows the input parameters of the hybrid air vessel.

AIRVva SVA3008	
Name	SVA3008
Comment	18.5 to 19.5
Keywords	PS
User name	verhuur leruth NE011843
Modified	2012 Apr 29 13:48
Type	Airvessel vertical hybrid
Model name	
Sequence number	0
Disuse	No
Reference id	
Top level (m)	22.0000
Bottom level (m)	6.85000
Air inlet level (m)	10.0000
Chamber area (m2)	8.000
Air quantity by	Fluid level
Initial fluid level (m)	18.0000
Laplace coefficient (-)	1.200
Ambient air temperature (°C)	52.00
Air discharge coeff. (-)	1.000
Air discharge area (m2)	0.004000

Construction and Operation issues

Air valve opening pressure

The main difficulty encountered in the construction of the hybrid air vessel is related to the pressure at which the air valve needs to open. Normal air valve open when the pressure in the pipeline is lower than the surrounding atmospheric pressure (approximately -0.02 bar difference). At this point, the force exerted by gravity of the air valve ball is greater than the force due to air pressure or suction to the rim and the ball falls in its seat thereby opening the air valve orifice. During the operation of the air valve, the maximum pressure difference across the air valve is not usually exceeding 0.5 bars.

In the case of the hybrid air vessel, the air valve needs to open with a pressure difference of 5 bar as, depending on the initial air charge, the fluid level of the air valve was reached with an internal air pressure between 4 to 6 bar(a).

This created a significant challenge to manufacturer since the air pressure exerted on the ball at 6 bar(a) was such that it could not drop under its own weight. To ballast the ball created problems of buoyancy during closure as, upon restart, the air valve needed to close at ambient pressure and only through buoyancy.

The solution was proposed by Vent-O-Mat (South Africa) which had on its catalogue a triple action air valve with rings instead of balls. The orientation of the rings, perpendicular to the orifice cancelled the effect of the large air pressure. At the same time, the closure characteristics where not affected and the air valve was closing through its own buoyancy.





The photo show that double air release system were installed on each vessels at the level of 10 m ADD (the bottom of the vessel is at 6.85 m ADD).

Air Compressor Requirements

The hybrid air vessel is a compressed air vessel which depends on a compressed air system to load and control the air pocket. Such compressor systems can be expensive and are difficult to maintain which may appear to somewhat off-set the benefit of the hybrid air vessel.

Indeed, in the case of full pump trip, the air charge is totally lost to the atmosphere which means that a large compressor system is required to reload before restart. However, this lengthy procedure is required only in the case of catastrophic full pump trip, when the SCADA and control system of the pipeline is not operational and the system is operated at full flow. In such extreme conditions, the purpose of the hybrid air vessels is to maintain the integrity of the pipeline and prevent damage.

Normal conditions call for a healthy SCADA and control system when the system is operated at full flow. If a full pump trip occurs, the control valve at the downstream end of the pipeline close automatically thereby providing back pressure to the pipeline. The elevation of the air release valve was designed so that the pressurization wave (positive surge wave) from the control valve could reach the pump station before air release. In this case, the system could be restarted almost immediately.

Testing and validation of the equipment

The air release valve is a critical component of the hybrid air vessel design. The first part of the testing was performed by the manufacturer in factory. The air valve was installed in an air rig that could simulate the pressure condition forecasted by the surge software. The proper operation of the air valve was verified for both its opening under large pressure difference and its closure under small pressure differences. The tests were satisfactory and the air valve was shipped and installed on the hybrid air vessels.

The hybrid air vessel was subjected to a validation campaign together with the rest of the Shuwei hat Water Transmission Scheme. The results of the simulations with WANDA were compared to the reading of the SCADA system for critical cases up to the maximum design flow.

The minimum pressure prediction within the pipeline showed that the hybrid air vessel was protecting efficiently the pipeline against negative pressure and that the air valve was efficiently releasing the air. The air vessels minimum level was recorded at 8 m or 1.15 m above the bottom of the vessel (level drop of 12 m). The surge model built in the WANDA software proved to be accurate in the prediction of the discharge and head in the pipeline as illustrated in the figures below.

The measured fluid levels in the air vessels showed an erratic behavior during the opening phase of the air release valve. The problem lies with the set-up of the level recording instruments on the air vessel. These are connected to the side rail of the vessel where the air release valves are also located. The rapid air flow exiting the vessel though the air valve has disturbed the readings causing possibly water surges within the rail and in any case rapid fluctuations. Instrumentation failure is further supported by the pressure and flow modeling in the pipeline which shows a close match with modeling and the fact that the level reading stabilizes again during the relatively quite refilling phase of the surge vessel.

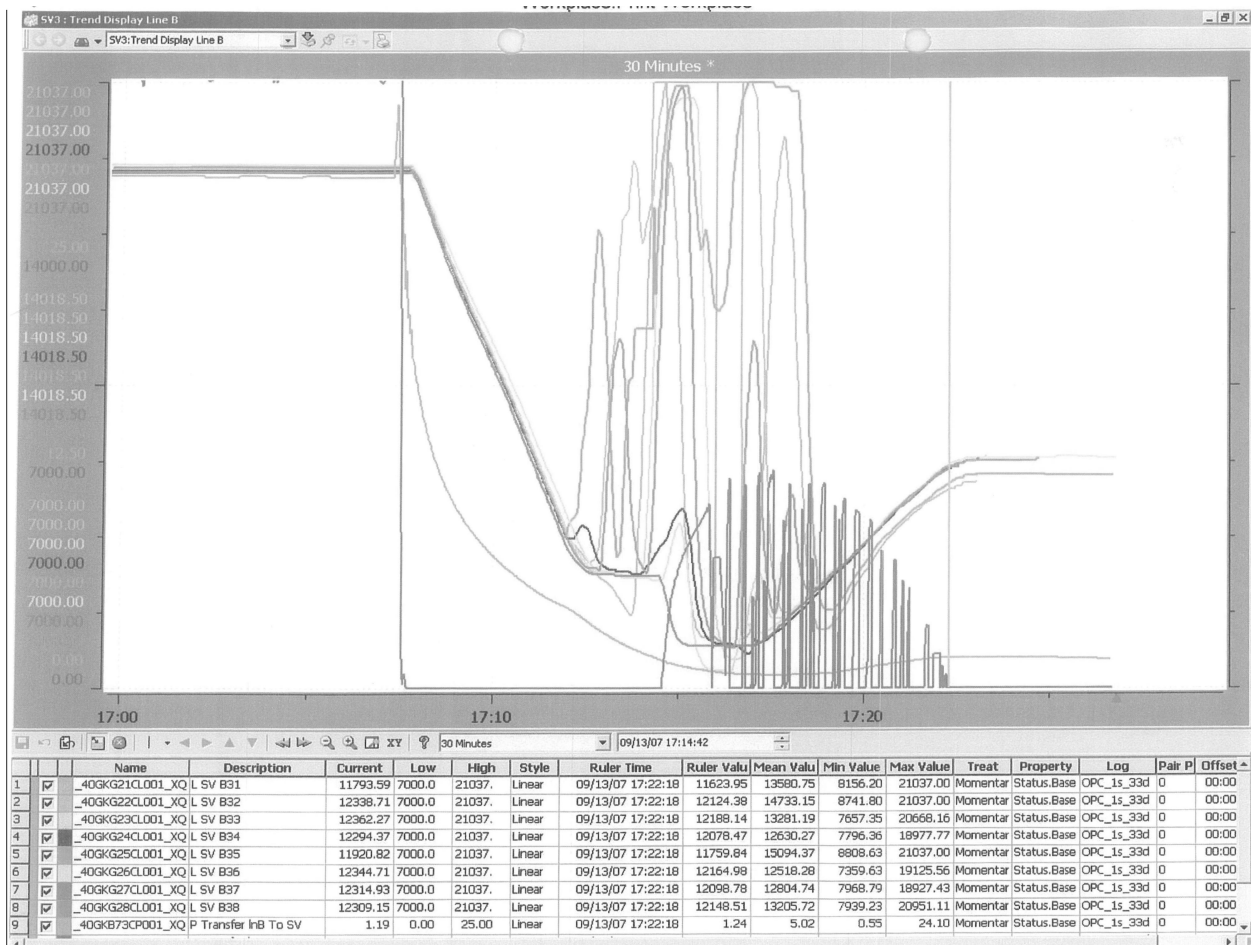


Figure 11 Full Pump trip at 75 MGD, Recorded fluid level in the vessels, Pressure in the pipeline and Discharge in the pipeline measured upstream of the vessels

During the trial operation, the Laplace coefficient of the air vessels was adjusted to match the observed maximum fluid level drop. The best fit was obtained for a Laplace coefficient of 1.05 [-] which is almost isothermal. This may seem surprising for a vessel of 121 m³ as one would expect that the air pocket expansion is somewhat more adiabatic. Apparently, the time scale of the heat transfer is similar to the time scale of the transient event, so that the best fit of the Laplace coefficient is reasonably close to the isothermal value of 1.0. Additional data is required on the air vessels (such as air temperature) to allow further work on the heat transfer flux within the vessel. This is required to fully understand the air expansion processes and improve modeling.

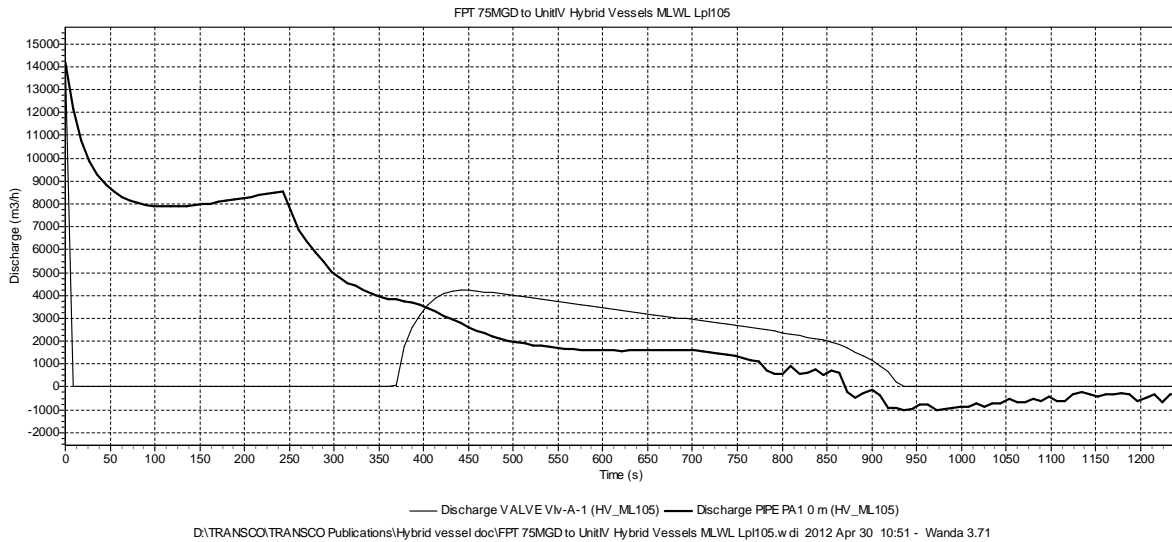


Figure 12 FPT at 75 MGD; Discharge upstream and downstream of the air vessels

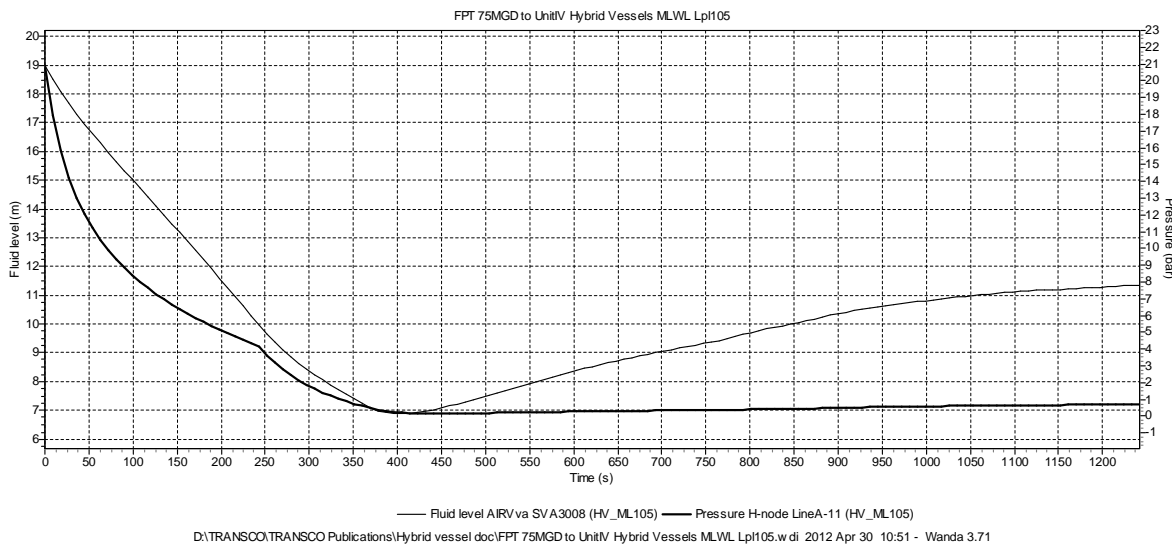


Figure 13 FPT at 75 MGD; Pressure in the pump station and fluid level in the Hybrid Vessels based on a medium initial water level (19 m) and best fit Laplace (1.05 [-])

Conclusions

The hybrid air vessel allowed for a reduction of 60% of the total installed vessel size while providing a comparable level of protection to the pipeline. This was achieved by the innovative addition of an air release valve near the bottom end of the hybrid vessel designed to release the air pocket. This allowed retaining the strong spring effect provided by a large initial charge while at the same time limit the size of air vessels. This renders an efficient and compact design. The design of the hybrid air vessel is expected to bring benefits in particular for long pipeline systems with no or little residual pressure.

The hybrid air vessel was constructed and tested on site where its efficiency at protecting the pipeline is demonstrated by the reading of pressure and flow at the pump station. The reproduction of these two parameters in the WANDA software was very accurate. The recording of the fluid level in the vessels during the air release valve opening phase are not useable due to the installation of the air release valve on the rail shared with the level recorder.

The Laplace coefficient of the hybrid air vessel was evaluated based on an approximate recorded maximum level drop. The best fit was obtained for a Laplace of 1.05 [-]. Apparently, the time scale of the heat transfer is similar to the time scale of the transient event, so that the best fit of the Laplace coefficient is reasonably close to the isothermal value of 1.0. The current data does not allow making a clear judgment on this coefficient and that opens the door for future data collection campaigns (air temperature and accurate water levels during transient events).

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