JOURNAL OF ENGINEERING RESEARCH

Refereed and issued twice annually by the Faculty of Engineering - University of Tripoli

Issue 29 March 2020

EFFECTS OF DISTRIBUTION OF AIR VESSELS ON TRANSIENT FLOW ALONG LONG AND HUGE WATER PIPELINES

Othman Al-Muntasser and Elhadi I. Dekam*

ME Department, Azzaitouna University, Tarhoona, Libya,
*Faculty of Engineering, University of Tripoli. Libya.
E-mail: ossman_222@yahoo.com and e.dekam@uot.edu.ly

الملخص

تمثل هذه الورقة دراسة لسيناريوهات متعددة لتدفق عابر على طول شبكة أنابيب مياه ضخمة تربط خزان ترهونة بخزان أبوزيان الذي يشكل جزءًا من الخط الرئيسي لمشروع نهر الصناعي الليبي. هناك محطتين للضخ بها عدد ست مضخات RDLO 400-880A (KSB) تعمل بالتوازي في كل محطة. وترتبط كلتا المحطتان بفرع طوله 4 كيلومترات قطره 1.6 متر من أنابيب الصلب، بينما يربط بين الخزانين فرع طوله 15.9 كم وقطره 2.8 متر. تم النظر في تسعة سيناريوهات مختلفة حيث تمت دراستها، إما عن طريق تغيير مصادر التدفق العابر وذلك بسبب انقطاع التيار الكهربائي الكامل، أو بإغلاق جميع المنافذ لحظياً، أو بسبب انفجار الأنابيب في اثنين من منافذ التدفق، و/أو عن طريق اختيار تدابير مختلفة للسلامة بما في ذلك أخذ أعداد مختلفة من الأوعية الهوائية العاملة مع توزيع مختلف لتلك الأوعية على طول الخط. وتعتبر هذه الحالات في ظل ظروف تشغيل مختلفة من منافذ مغلقة أو مفتوحة.

استخدام برمجية "واندا". وذلك لتحديد سلوكيات خصائص التدفق لكل سيناريو، بما في ذلك توزيعات الضغط المستقر والضغوط الدنيا والقصوى. تم الحصول على خطوط التدرج الهيدروليكي لكل حالة حيث تم تحديد الحالات الأكثر خطورة. وكان الحد الأقصى للضغط الذي تم بلوغه هو 40.2 بار، في حين أن الحد الأدنى للضغط المسجل هو (0.97 -) بار في ظل ظروف محددة. وتتجاوز هذه القيم الحدود المسموح بها، مما يؤدي إلى عمليات غير آمنة. يمكن أن يكون انقطاع التيار الكهربائي الكامل للمضخة المصدر الرئيسي للتدفق العابر في أنظمة شبكة الأنابيب؛ هو أخطر سبب لإلحاق الضرر بمكونات الشبكة، خاصة في شبكة نقل مياه ضخمة مثل منظومة ترهونة أبوزيان للنقل المائي. ويبدو أن الجمع بين 7 صمامات هواء في اتجاه المصب ووعاء هوائي واحد في أعلى مجرى لكل محطة ضخ أمر مقبول جدًا لحماية المنظومة بالنظر للسيناريوهات المدروسة.

ABSTRACT

This paper represents a study of different transient flow scenarios along a real huge water pipeline system connecting Tarhunah reservoir with Abu-Ziyyan reservoir, which forms a part of the Central Branch of the Libyan Man-Made River Project. There are two pumping stations with 6 RDLO 400-880A (KSB) pumps operating in parallel for each station. Both stations are connected by a 4 km section of 1.6 m diameter steel pipe, while a 15.9 km section of 2.8 m diameter pre-stressed concrete circular pipes connects the two reservoirs. Different nine scenarios are considered and studied, either by changing the transient flow sources, due to complete power failure, closing all turnouts instantaneously, or pipe burst in two of the flow turnouts, and/or by selecting different safety measures including taking various numbers of working air vessels with variable vessel distributions along the line. These are considered under different operating conditions of closed or open turnouts.

"WANDA" software package was employed. The profiles were determined for each scenario, including the steady, minimum, and maximum pressure distributions. Hydraulic grade lines are obtained for each case where the most critical situations are identified. The maximum attained pressure was 40.2 bar (gage), while the minimum recorded pressure is 0.97 bar (gage) under specific conditions. These values exceed the permissible limits, leading to unsafe operations. Complete pump power failure could be the main source of transient flow in pipe network systems; it is the most dangerous reason for damaging the network system components, especially in a huge water transport network as Tarhunah Abu-Ziyyan water transport system. The combination of 7 air valves downstream and 1 air vessel upstream of each pumping station seems to be very acceptable for the protection of the system regarding the considered scenarios.

KEYWORDS: Libyan Man-Made River; Transient Flow; WANDA; Water Pipelines.

INTRODUCTION

As well known, a transient pressure in a pipeline is a generic term for a wave phenomenon that accompanies a sudden change in the velocity of the fluid in the pipeline [1]. Authors variously use the term "surge" pressure to denote a transient pressure that has no detrimental effect, whereas the term "water hammer" tends to be used to denote a transient pressure that will have serious consequences if not properly addressed and mitigated. Pressure transients can be positive or negative. The magnitude of these surges is independent of the operating pressure and can attain a value of many times of the normal operating pressures. The transient flow is the response of the fluid to some change in the hydraulic facilities that control and convey the fluid, or in the surrounding environment, that influence the flow. The most common sources of transient pressures are pump operation, pump power failure, control valve operation, sudden changes in demand, air release valve operation, pressure reducing valve operation, pipeline rupture, and filter flushing operations [2, 3].

Transient flow following a pump trip is usually the most severe in the case of pipelines of low frictional resistance. Pump trip is practically instantaneous, especially in pipelines where the pump rotational inertia is negligible. Pump trip can also cause water column separation due to negative pressures. The initial wave is a negative or reduced pressure wave, which travels from the pump discharge end to the downstream end and returns as a positive pressure wave. This also allows for some gases to escape from the liquid solution [4].

LITERATURE SURVEY

There are two types of transient flow, the first type is known as a quasi-steady flow, which is characterized by the absence of inertial effects on the flow behavior. In such flows the variations of flow discharge and pressure with time are gradual. This leads to that the flow appears to be steady over a short time interval [5]. The second type of transient flow is known as the true transient flow, in which the effects of the fluid inertia, the compressibility of the fluid and the elasticity of the pipe are essential factors in the flow behavior. These factors must be considered in order to obtain the full characteristics of the transient flow. If the inertial effects are significant, however the pipe elasticity and the fluid compressibility effects are relatively minor or negligible, then we have a transient flow, which is referred to as a rigid-column flow [5].

Accompanying the high-pressure wave, there is a negative wave, which is often overlooked, can cause very low pressure, leading to the possibility of column separation and contaminant intrusion [6]. Thus, transient flow can be a serious problem in water piping and network systems. It may put potentially extra damaging stress and strain on pipes, joints, valves, pumps and fixtures. The noise associated with water hammer can be a nuisance as well [7].

A variety of controlling methods are available to mitigate transient pressures, generally falling into three categories: alteration of pipeline profile and diameter, valve and pump control procedures, and surge control devices. Different control devices are employed, such as surge tanks, surge pipes, air valves, and air vessels. Air vessels are famous in this regard, generally they alleviate negative pressures more effectively than other forms of transient flow protection components, and they can maintain a positive pressure in the line at all stages following the pump trip. This is accomplished by forcing water out of the vessel into the cavity [8]. The compressed air forces water from the air vessel into the pipeline, allowing the water column travelling up the pipeline to maintain its momentum. Friction and other head losses tend to reduce the water velocity and therefore the subsequent oscillations. Thus, some degree of flow throttling is often used in conjunction with the cushioning effect of air vessels [7].

In order to model the transient flow phenomenon in conduits, it is required to solve a set of continuity and momentum equations. The continuity and momentum equations form a set of non-linear, hyperbolic, partial differential equations which is not easy to be solved by hand. The number of variables required for accurate analysis can be large and some of the variables may have a lesser effect on the results than others. The elastic equations of motion require numerical forms and finite difference subdivision of the pipeline in order to compute the head changes at points along the line. Numerical methods with an initial condition and two boundary conditions are needed [9,10]. For a water distribution system, there are many more parameters needed for solving the transient flow problem. In a water distribution system, every branch of the system requires an additional boundary condition. External boundary conditions take the form of a driving head, or a flow leaving the system. Internal boundary conditions arise in the form of nodal continuity, energy loss between points, head across valves, pumps, and more. The complexity of the problem may require the use of modeling software [11].

The design of reliable hydraulic networks is considered as a significant problem in the modern industry. An important stage of pipe network design is to find the optimum network layout with requirement satisfaction such as pressure, power consumption and demands at different nodes, that minimize cost while meeting a desired performance criterion. The study of unsteady flow analysis in piping networks is certainly dated back to the early in the nineteenth century [7]. However, transient flow analysis, history is more readily documented. Some of the earlier work was done related the flow of blood stream, friction losses, and the propagation of pressure waves in pipes [12].

As cited in Almuntasser 2011, Lowy in (1928) studied resonance caused by periodic valve movement and pressure drop due to a gradual opening of valves and gates. Schnyder in 1929 included complete pump characteristics in his analysis of transient flow in pipelines connected to centrifugal pumps. Silva-Araya and Chaudhry 1993 developed an energy dissipation model for the computation of laminar and turbulent unsteady friction losses and obtained instantaneous velocity profiles to compute the Reynolds stresses in transient pipe flow [7].

Almuntasser 2011, gave a literature review covers development of a mathematical model for the calculation of transient flow considering the energy dissipation, where the transient flow produced by the instantaneous closure of a valve, located at the end of a pipeline connected to a constant head reservoir [7]. Suarez 2005 extends Silva-Araya and Chaudhry's unsteady friction model for transient flow analysis to the series and branching pipe systems [13, 14].

AL-Kishriwi in 2007, based on the method of characteristics, an algorithm for analyses and simulation of different sources of transient in a practical water pipeline network is presented [15]. Gseaa in 2009/10 studied the effects of the characteristics of the network elements such as valve type, pipe material; pump type, friction model and surge protection type [16, 17].

All methods of analysis of unsteady flow in conduits start with the basic flow governing equations. These methods include Arithmetic transient flow, Graphical transient flow, Characteristics method, and Algebraic method. Implicit method, Linear method, and Other methods. All these methods have been applied, although the famous method is the method of characteristics, which provides a technique for solving transient flow equations and has many advantages. Software packages are available and they have been employed effectively. WANDA is a package that is available at the site of the present studied water pipeline system and was used for conducting the desired case study [18].

Referring to the behavior of the possible transient flows from different transient sources under different operating condition for the Tarhunah-Abu-Ziyyan water piping system, one should determine the most critical-danger situations. Evaluation of the performance of different protection procedures, among which different considered devices, including evaluation of the effect of type, number and location of such devices [19]. Introducing alternative protection ways, presenting the behavior of the transient flow with such ways. The case study is fully described in the following section and the selected software package will be introduced.

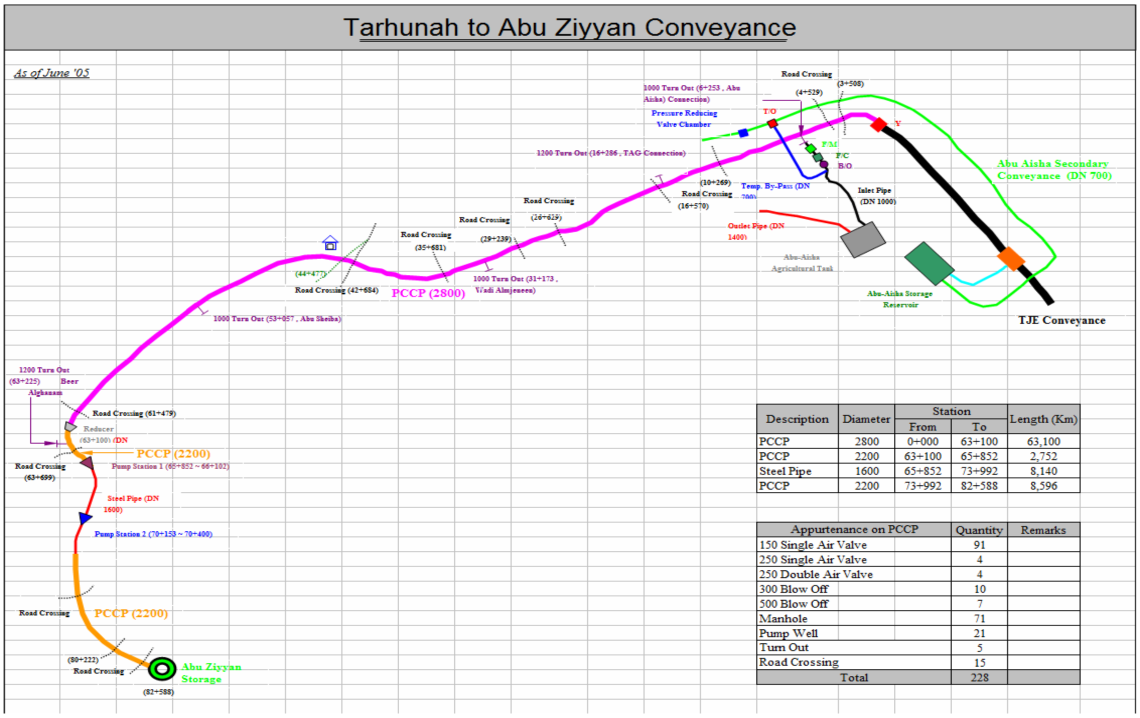
METHODOLOGY

In this paper, the long large water transport pipeline system is to be studied considering nine transient flow scenarios. The system is well defined. The above characteristics and constrains in addition to the topography of the pipeline are the main input data for the design and evaluation processes. “WANDA” computer software package is employed to analyze and evaluate a number of actual and hypothetical geometrical and operating flow conditions for the main TAZ hydraulic system. The full detailed description of the components was introduced as input data to WANDA. Different nine scenarios are applied using WANDA software package, including transient flow and water column separation events that induced in the water piping system due to different transient sources. The gage static pressure and gage static pressure head are simulated, presented, and discussed. The study focuses on the critical cases that are related to the main trigger events in the considered water piping system, where these cases are due to complete power failure and pipe burst in specified turnouts secondary conveyance.

DESCRIPTION OF THE MAIN COMPONENTS

The case study represents the pipeline system connecting Tarhunah Abu-Ziyyan (TAZ) reservoir tanks, which is a stage of the large project Al-Hasaouna-Al-Jfara system.

A map showing the layout of TAZ conveyance is shown in Figure (1). Tarhunah Abu-Ziyyan (TAZ) conveyance forms part of the Central Branch of the Man Made River Project over Libya. TAZ system is designed to transfer 800,000 m³/day of water from the end of Tarhunah to Jefara Plains Extension (TJE) to the Jefara Plains and Abu-Ziyyan. It consists of 66 km of gravity drive pipeline and an 18 km length of pumped main line. Turnouts with an average total demand of 400,000m³/day are located in the gravity line to supply a number of agricultural projects [7].



Description	Diameter	Station		Length (Km)
		From	To	
PCCP	2800	0+000	63+100	63,100
PCCP	2200	63+100	65+852	2,752
Steel Pipe	1600	65+852	73+992	8,140
PCCP	2200	73+992	82+588	8,596

Appurtenance on PCCP	Quantity	Remarks
150 Single Air Valve	91	
250 Single Air Valve	4	
250 Double Air Valve	4	
300 Blow Off	10	
500 Blow Off	7	
Manhole	71	
Pump Well	21	
Turn Out	5	
Road Crossing	15	
Total	228	

Figure 1: Layout and main components of the TAZ conveyance system.

The remaining 400,000 m³/day is lifted approximately 600 m by the two pumping stations to Abu-Ziyyan reservoir. A 15.9 km with 2.8 m diameter pipe on the (TJE) line connects Sidi Sied Regulating Tank to TAZ line. The gravity pipeline section of TAZ is 2.8 m diameter Pre-Stressed Concrete Cylinder Pipes (PCCP). The first of the two pumping stations is to be located at the end of this section. A 4 km section of 1.6 m diameter steel pipe connects the two pumping stations. The second section of 1.6 m diameter steel pipe is used for the next 4 km downstream of the second pumping station. The final 10 km of the pipeline to Abu-Ziyyan is to be constructed from PCCP. The steel pipeline section is required due to the high operating pressures [7].

The huge piping system Tarhunah Abu-Ziyyan consists of different pipe sections as indicated in Table (1). Two large open reservoirs, 2 pumping stations, each running with 6 pumps in parallel, 7 air vessels downstream, and 1 air vessel upstream of each pumping station, and one surge pipe upstream of each pumping station. There are 8 pumps, 6 are on duty and 2 are standby in each pumping station, where the characteristics of the working pumps are included in Table (2). The pumps are grouped to work in parallel permanently all the time. Sidi Sied and Abu-Ziyyan reservoirs are regulating type tanks, where the description of the installed tanks are presented in Table (3).

Table 1: Pipeline lengths, diameters, and roughness's [7].

	Length (km)	Diameter (mm)	Type	e-mm Old pipe	e-mm New pipe
1	15.90	2800	PCCP	0.2667	0.10
2	63.10	2800	PCCP	0.2667	0.10
3	3.000	2200	PCCP	0.2667	0.10
4	7.904	1600	Steel	0.0800	0.03
5	8.584	2200	PCCP	0.2667	0.10

PCCP = Prestressed Concrete Cylinder Pipes

Table 2: Characteristics of the working pumps [7].

Pump Type		RDLO 400-880A (KSB)	
Pump + Motor polar Moment of Inertia	31.34 kg-m²	Reference Head	279 m
Rated Speed	1485 rpm	Suction Flange Diameter	500 mm
Reference flow	2772 m³/h	Discharge Flange Diameter	400 mm

Table 3: Characteristics of the installed tanks [7].

Sidi Sied Regulating Tank	
Location	15.9 km upstream of TAZ
Top Water Level	390.0 m AMSL (above mean sea level)
Bottom Water Level	385.4 m AMSL
Abu-Ziyyan regulating Tank	
Location	82.588 km
Top Water Level	868.5 m AMSL

There are five different turnouts along the gravity flow pipe section. The turnouts are employed to supply agricultural projects located along the pipeline between Sidi Sied regulating tank and the first pumping station. The locations and flow rates of the turnouts are given in Table (4). Because the change in pressure is directly proportional to the change in velocity, the avoidance of sudden velocity changes will generally prevent serious transient pressures from developing. The protection devices employed in the considered piping system are introduced below. The air vessels that installed downstream of both pumping stations are identical. The air vessels are connected to the main pipeline, where water and air volumes, temperature, inflow and outflow coefficients are given in Table (5). There are pipes that are laid in the ground and run to a higher ground along an inclined slope. They are required to release the surge pressures created upstream of the pump stations. The characteristics of the surge pipes are presented in Table (6). The locations of the considered, air vents with their properties are described in Table (7). The pump pressure head, and flow rates are presented in Table (8).

Table 4: Turnout's Locations and Flow rates [7].

Location	Length (m)	Diameter (mm)	Flow (m³/s)	Invert Level (m)
Abu Aisha	6,253	1000	0.857	164.49
Sabha	17,700	1000	1.504	156.95
Wadi Almjeneen	31,173	1000	0.857	188.80
Abu Sheiba	53,057	1000	1.504	227.55
Beer Alghanam	63,225	1200	2.269	281.64

Table 5: Characteristics of air vessels [7].

No. of air vessels/station	7 duty-1 standby	Water volume (downstream of PS2)	21.78 m³
Volume of each	49 m³	Air Volume (upstream of PS2)	33.9 m³
Air volume (downstream of PS1)	34.08 m³	Water Volume (upstream of PS2)	16.1 m³
Water volume (downstream of PS1)	15.92 m³	Water temperature	25ºC
Air Volume (upstream of PS1)	45.65 m³	Polytropic expansion coefficient (k)	1.2
Water Volume (upstream of PS1)	4.35 m³	Inflow coefficient	1000
Air volume (downstream of PS2)	28.22 m³	Outflow coefficient	100

Coefficients are based on a 1600mm diameter pipe.

Table 6: Characteristics of surge pipes [7].

Surge Pipe No. 1	
Location	Upstream of ps1
Centre Line Elevation at connection point	330.18 m AMSL
Diameter of pipe	1.6 m
Termination point Centre Line	411.98 m AMSL
Size of Orifice plate	613 mm in 1600 mm dia. pipe
Inflow coefficient	100
Outflow coefficient	100
Coefficients are based on a diameter of 1.6 m	
Surge Pipe No. 2	
Location	upstream of PS2
Centre Line Elevation at connection point	586.88 m AMSL
Diameter of pipe	1.6 m
Termination point Centre Line	691.15 m AMSL
Size of Orifice plate	443 mm in 1000 mm dia. pipe
Inflow coefficient	350
Outflow coefficient	350
Coefficients are based on a diameter of 1.6m	

Table 7: Characteristics of vent pipe [7].

Location	Downstream of Sidi Sied Regulating
Centre Line Elevation at connection point	365.772 AMSL
Diameter	600 mm
Length of vent pipe	82.40 m
Diameter of vent shaft	1000 mm
Shaft Termination point	398.60 AMSL

Table 8: Pump Characteristics [7].

Q (gpm)	0	1000	2000	3000	4000	5200
Hp (ft)/stage	136	128	117	96	63	0

The design pressure of a pipe at any location is the maximum sustained pressure due to a steady state or zero flow condition measured above the centerline of the pipe [11]. Transient pressure in a pipe is the sustained pressure plus the peak transient pressure due to a surge measured at the height of maximum elevation above the centerline of the pipe. The maximum transient pressure should not exceed the maximum permissible pressure under any condition. The maximum permissible pressure for Pre-Stressed Concrete Cylindrical Pipes is above the nominal rating of the pipes for 6, 8 and 10 bar pipes and 4 bars above the nominal rating of pipe 12 bar or above. For steel pipes, the maximum permissible pressure is the bar rating of the pipe. The minimum transient pressure should not fall below the minimum pressure. The minimum permissible pressure is 0.2 bar above the soffit of the pipe [20].

The wave celerity of Pre-Stressed Concrete Cylindrical Pipes is taken as 1160 m/s. The wave celerity for the steel pipe is taken as 1080 m/s. These values are used in the transient analysis [20]. The maximum allowable velocity in a pipe flowing under full condition for a sustained period is 4 m/s. The maximum allowable velocity in a pipe flowing under conditions for short periods, such as during transient is 8 m/s [21].

APPLICATIONS OF WANDA SOFTWARE PACKAGE

WANDA provides a comprehensive set of design tools to support the hydraulic design from the first schematic diagrams to the evaluation of the control loops during emergency events [18]. WANDA deals with a wide scope of applications that can be covered in three different areas; Engineering for pre-design and detailed design of arbitrary hydraulic systems, Transient for evaluation of the dynamic behavior of the system in normal operation or during emergency events, and control as an extension of WANDA transient for evaluation of the integrated behavior of the hydraulic system and the control loop.

One can model and evaluate any piping system including its control systems or alternatively, design and appraise potential control systems considered suitable for the subject pipeline or pipeline network. Possible operational measures can be assessed. Safety devices such as surge towers, air inlet and relief valves, air vessels and pressure relief valves can be judged for their effectiveness to protect the system. WANDA has many advantages and features in dealing with design and evaluation of hydraulic systems.

WANDA software is for sure tested and evaluated at least by the management of the Man-Made River. This software has been used for designing, evaluating, and optimization stages concerning such large and expensive project in which safety measures are very important including the required effective treatment to the induced surge pressures. Different geometrical and operating scenarios associated with transient pressure head distributions along the pipeline are considered. This software was introduced and tested, elsewhere [7], through the analysis of two famous hydraulic systems along with “Hammer” software package.

APPLIED SCENARIOS

The studied scenarios are defined in Table (9) with the combination of the surge device vent pipe downstream of Sidi-Sied reservoir and a surge pipe upstream of each of the first and second pumping stations. Scenarios are considered under operating conditions of closed or open turnouts. Turnouts specifications and closing time are indicated in Tables (10 and 11). These scenarios are determining the maximum and minimum surge envelopes. A limited number of very lengthy results are presented in detailed graphs for each scenario. The locations that are of concern are identified and the results at these critical locations were summarized.

Table 9: Different Operating Scenarios [7]

Case	**e** (mm)	Turnouts Status	Pump Status	Side Said Water Level	Abu-Ziyyan Water Level	Cause of Transient	Protection measures taken and remarks
1	0.1	Closed	All Pumps stopped	TWL	TWL	Power failure	7 air vessels downstream of each pumping station
2	0.1	Closed	All Pumps stopped	TWL	TWL	Power failure	9 air vessels downstream of each pumping station
3	0.1	Closed	All Pumps stopped	TWL	TWL	Power failure	6 air vessels, 1 upstream and 5 downstream of each pumping station
4	0.1	Closed	All Pumps stopped	TWL	TWL	Power failure	7 air vessels, 1 upstream and 6 downstream of each pumping station
5	0.1	Closed	All Pumps stopped	TWL	TWL	Power failure	8 air vessels, 1 upstream and 7 downstream of each pumping station
6	0.1	2 burst	All Pumps on	TWL	TWL	Burst of Abu Sheiba and Beer Alghanam	8 air vessels, 1 upstream and 7 downstream of each pumping station
7	0.1	2 burst	All Pumps on	TWL	TWL	Burst of Abu Aisha and Esbaeaa	8 air vessels, 1 upstream and 7 downstream of each pumping station
8	0.2667	All open	All Pumps stopped	BWL	TWL	Power failure	8 air vessels, 1 upstream and 7 downstream of each pumping station
9	0.1	Open then closed	All Pumps on	TWL	TWL	All turnouts closed in the same time during 30 min	8 air vessels, 1 upstream and 7 downstream of each pumping station

Table 10: Characteristics of turnouts [7].

Location	Location of turnouts on pipeline (m)	Turnout diameter (mm)	Average flow rate (m^3/s)	Invert level of turnouts on pipeline (m)
Abu Aisha	5,832	1000	0.857	164.49
Esbaeaa	17,700	1000	1.504	156.95
Wadi Almjeneen	31,474	1000	0.857	188.80
Abu Sheiba	53,358	1000	1.504	227.55
Beer Alghanam	63,526	1200	2.269	281.64

Table 11: Closing time for all turnouts [7].

		Model title	Discharge (m^3/h)	Valve position (open) (%)
1	VALVE V-T/01-out	V-T/01-out	3,003	11.58
2	VALVE V-T/02-out	V-T/02-out	5,340	15.64
3	VALVE V-T/03-out	V-T/03-out	3,085	12.01
4	VALVE V-T/04-out	V-T/04-out	5,414	18.61
5	VALVE V-T/05-out	V-T/05-out	8,168	23.68

RESULTS AND DISCUSSIONS

Now, each scenario was analyzed considering the related input data that are found elsewhere [7]. Transient flow results for each scenario are going to be discussed in detail. Referring to the 1st scenario, Figure (2) represents the maximum, minimum, and steady pressure heads along the pipeline. All heads are above the line profile along the pipeline except at pipe 1 at x = 8,100 m, where the minimum pressure head drops below the pipe profile. Here, the calculated pressures and heads are based on "gage" values.

The maximum pressure in the pre-stressed concrete cylindrical pipes located downstream of Sidi-Sied reservoir has a value approximately of 27.4 bars at x = 42,156 m. The minimum pressure was – 0.85 bar occurred approximately at x =8,100 m downstream of Sidi-Seid Reservoir, for details refer to zooming Figures, (3 and 4). This is slightly above cavitation pressure; – 0.97 bar at 20ºC. The maximum pressure in the steel pipeline was estimated to be 40.2 bar as shown in Figure (5). This pressure is above the maximum permissible pressure of the pipe of 40 bar. The negative pressure with a value of – 0.85 bar occurs at a location between the pumping stations. This near negative pressure could lead to a column separation.

In this scenario and others, the power failure is related to all working 12 pumps. This case is considered to be the most severe transient flow scenario, that was generated from the complete power failure compared to partially power failure. Once this is analyzed and safety measures are taken, other scenarios with partial power failure would be covered and the safety measures would be sufficient and hence, the system is protected and safe.

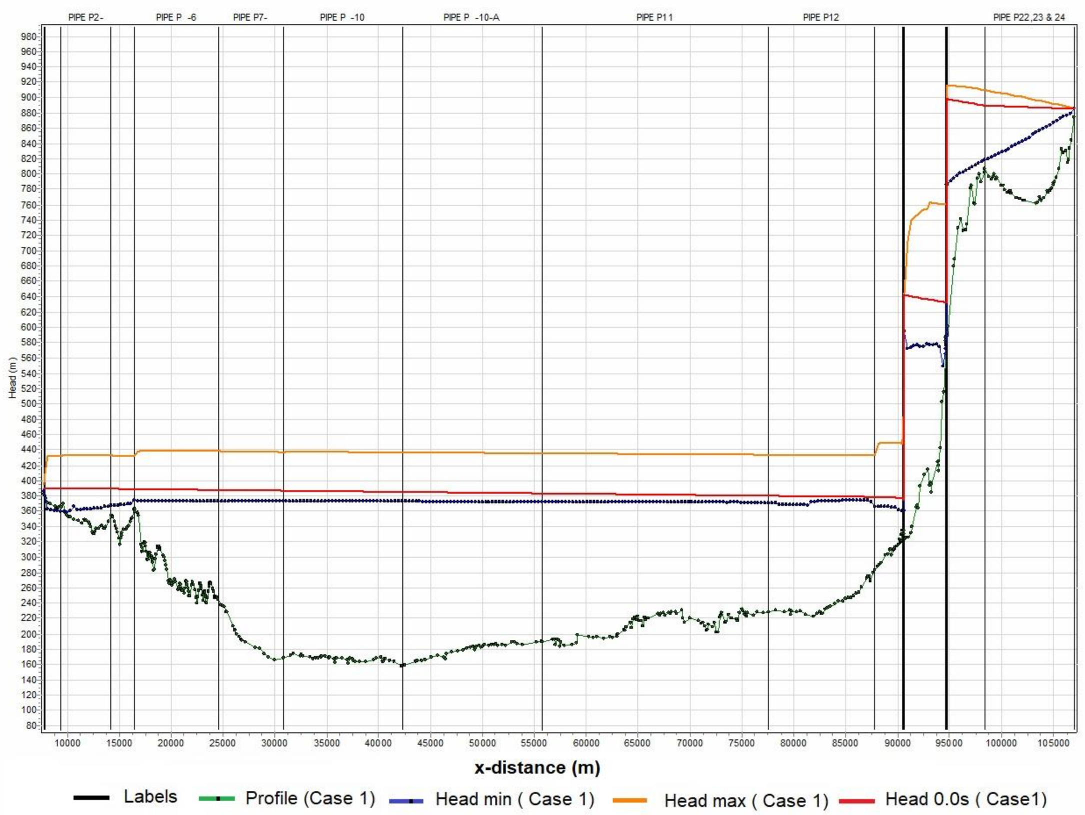


Figure 2: 1st scenario; Static pressure head along pipes 1-24.

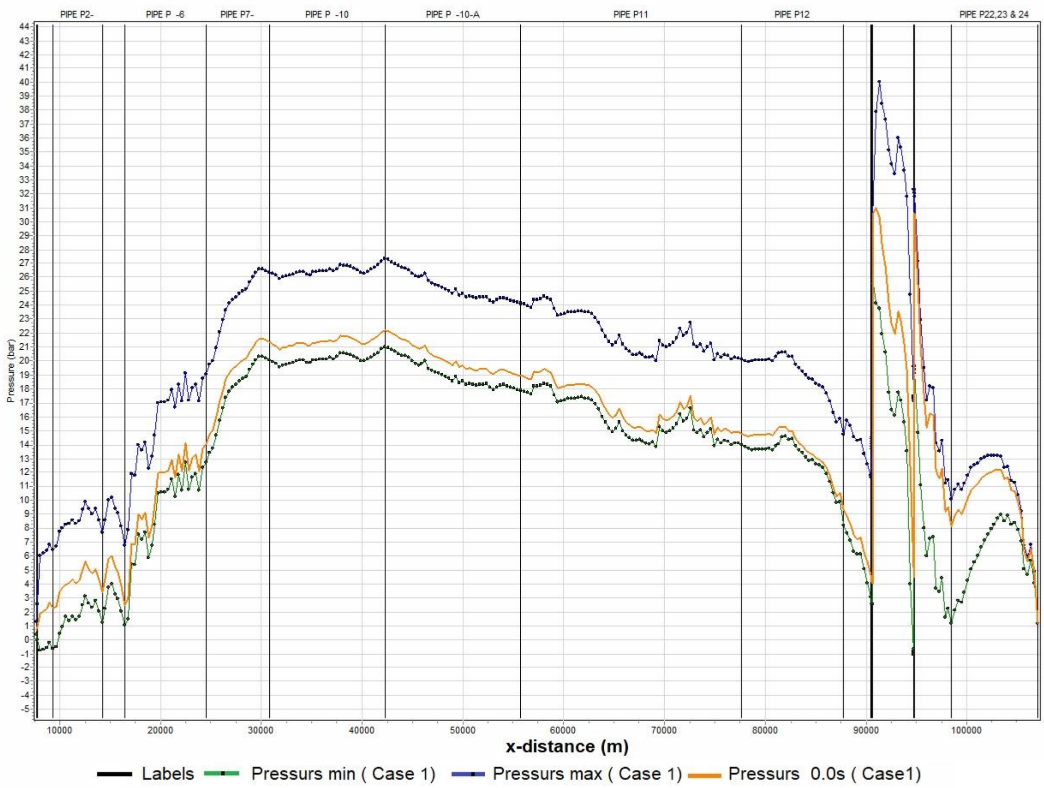


Figure 3: 1st scenario; Static pressure along pipes 1-24

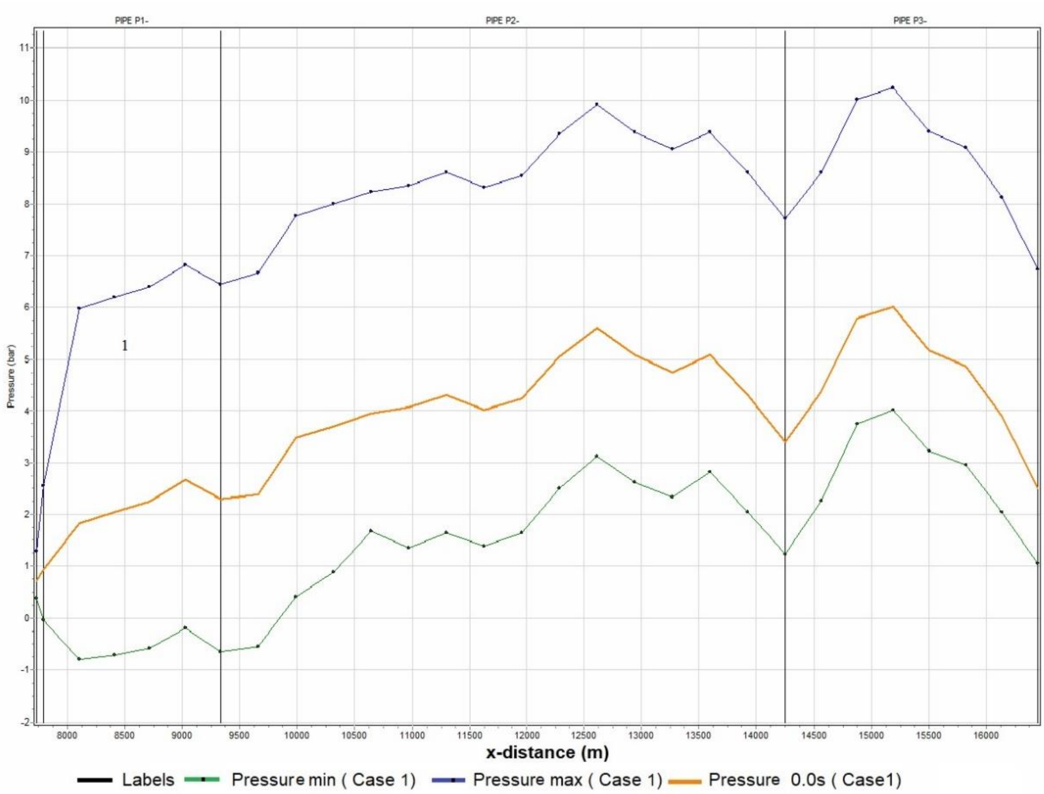


Figure 4: 1st scenario; Static pressure along pipes 1-3

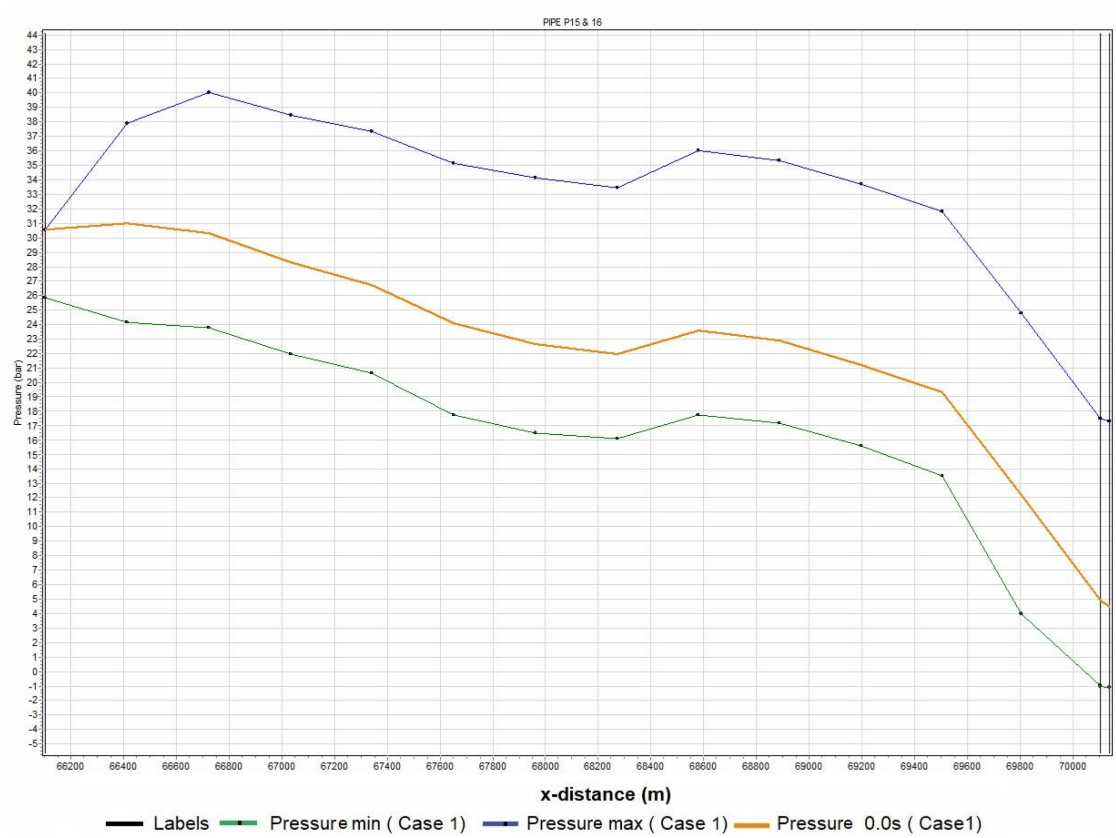


Figure 5: 1st scenario; Static pressure along pipes 15-16.

The 2ndscenario is with 9 air vessels downstream of each pumping station. Referring to Figures (6 and 7), all heads and pressures are above the pipeline profile except at pipe 1 at x=8,100 m. The values of heads and pressures are nearly the same as those obtained in the first scenario related to the seven air vessels. In other words, adding two working air vessels downstream of each pumping station didn't improve the situation. Here, the distribution of the air vessels along the line is very important, that is the location of such vessels determines the trend of the transient flow behavior.

Referring to Figures (8 and 9) related to the 3rd scenario, the minimum head is traced below the pipeline profile at the location of x = 98,500 m. The maximum pressure occurs in the steel pipeline, pipe 19 to pipe 24, with a maximum pressure of 35.1 bar at x = 90,600 m. However, there is a low negative pressure of □0.4 bar occurs in a location between the first and second pumping stations at x = 97,000 m.

Figure (10) represents a zooming view of the pressure distribution along pipe 19 to pipe 24. Therefore, operating only five air vessels downstream plus 1 air vessel at upstream of each pumping station is critical and should be avoided in order to insure the protection of the valuable piping system. The 4th scenario is presented in Figures (11 and 12). The minimum head is so near to the pipeline profile at x = 98,500 m, while the maximum pressure was 35.8 bar at x = 90,500 m which is nearly equal to the maximum permissible pressure of the steel pipe. This value is critical and should be avoided.

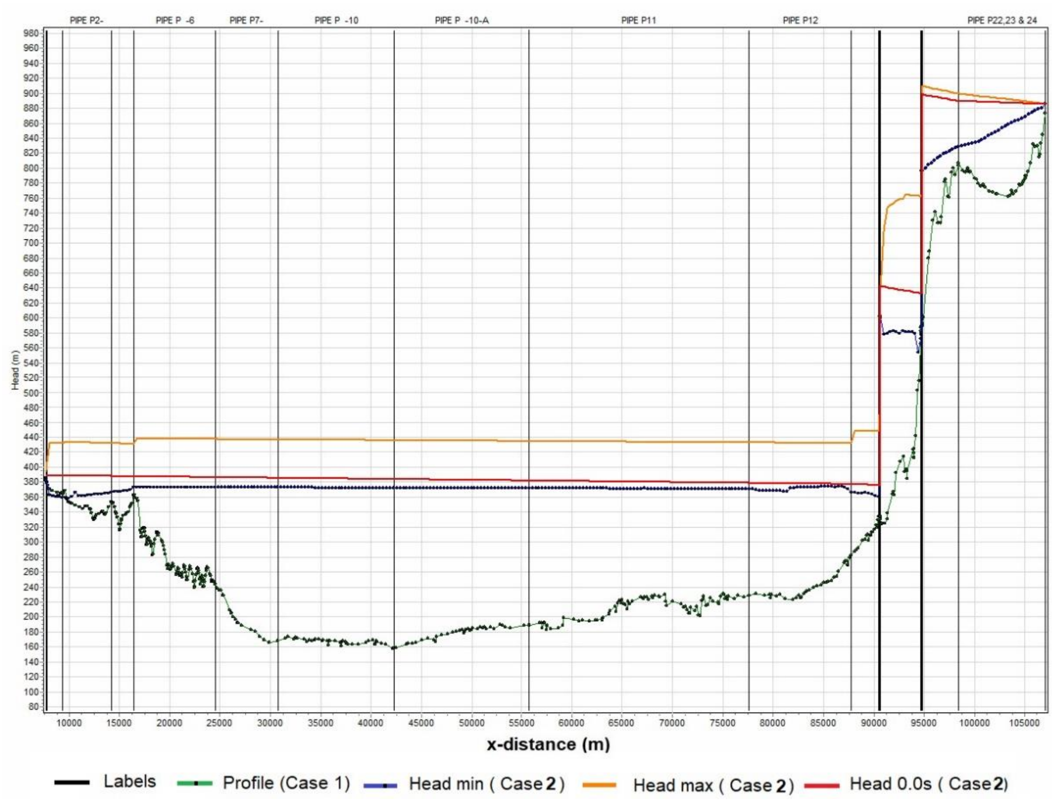


Figure 6: 2nd scenario; Static pressure head along pipes 1-24.

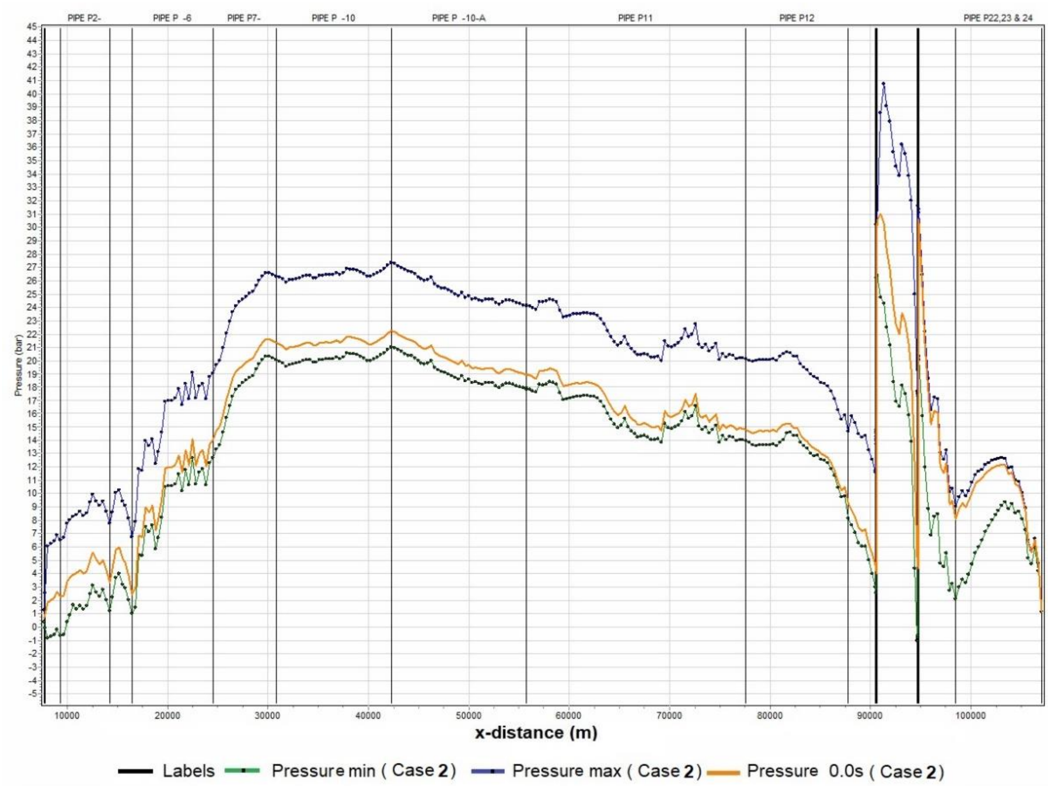


Figure 7: 2nd scenario; Static pressure along pipes 1-24.

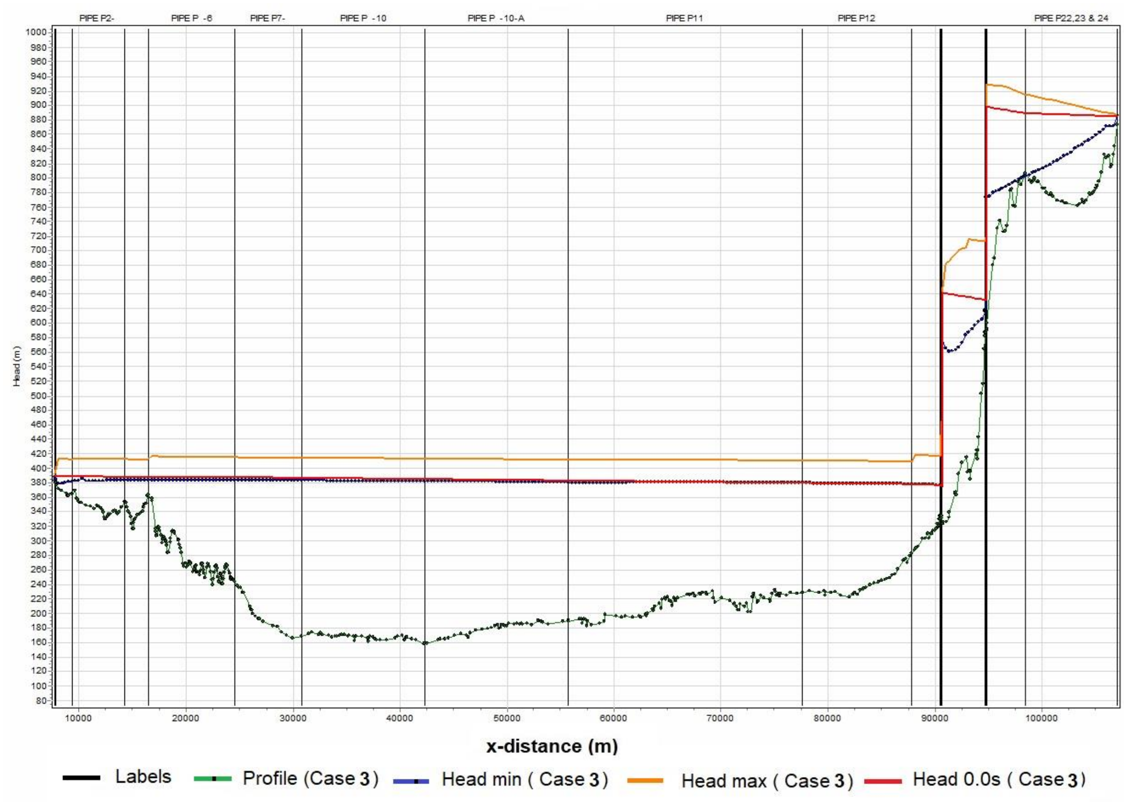


Figure 8: 3rd scenario; Static pressure head along pipes 1-24

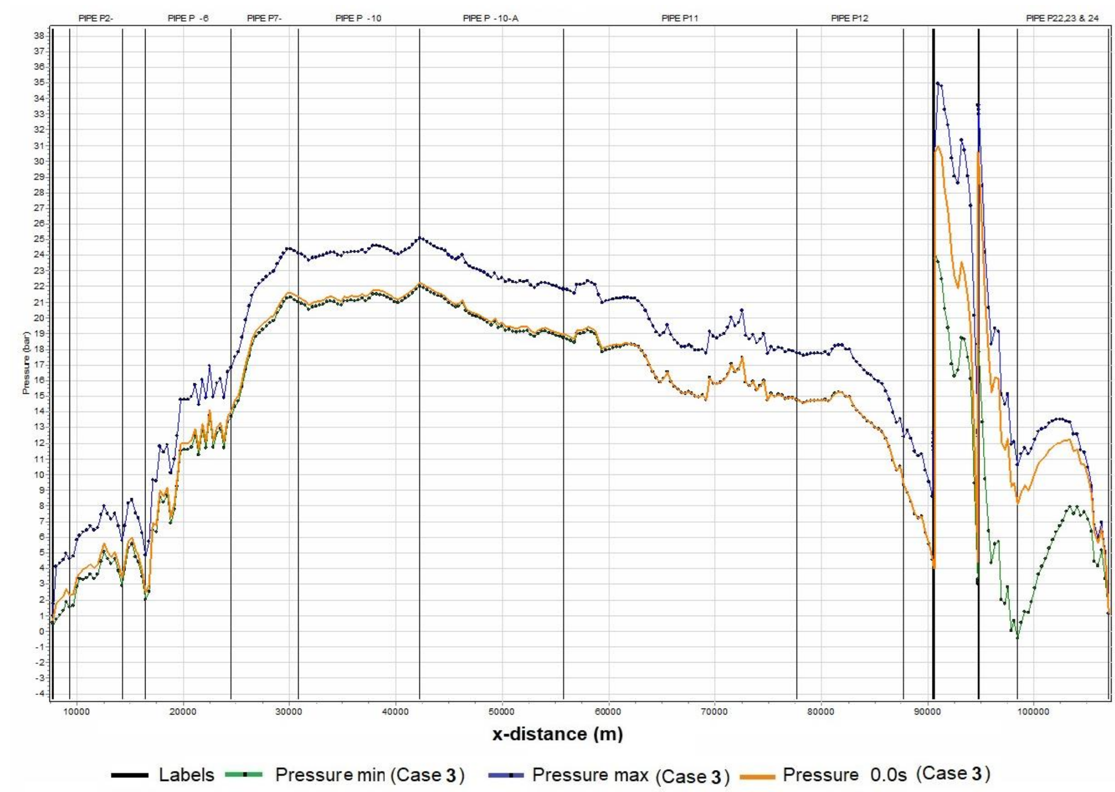


Figure 9: 3rd scenario; Static pressure along pipes 1-24.

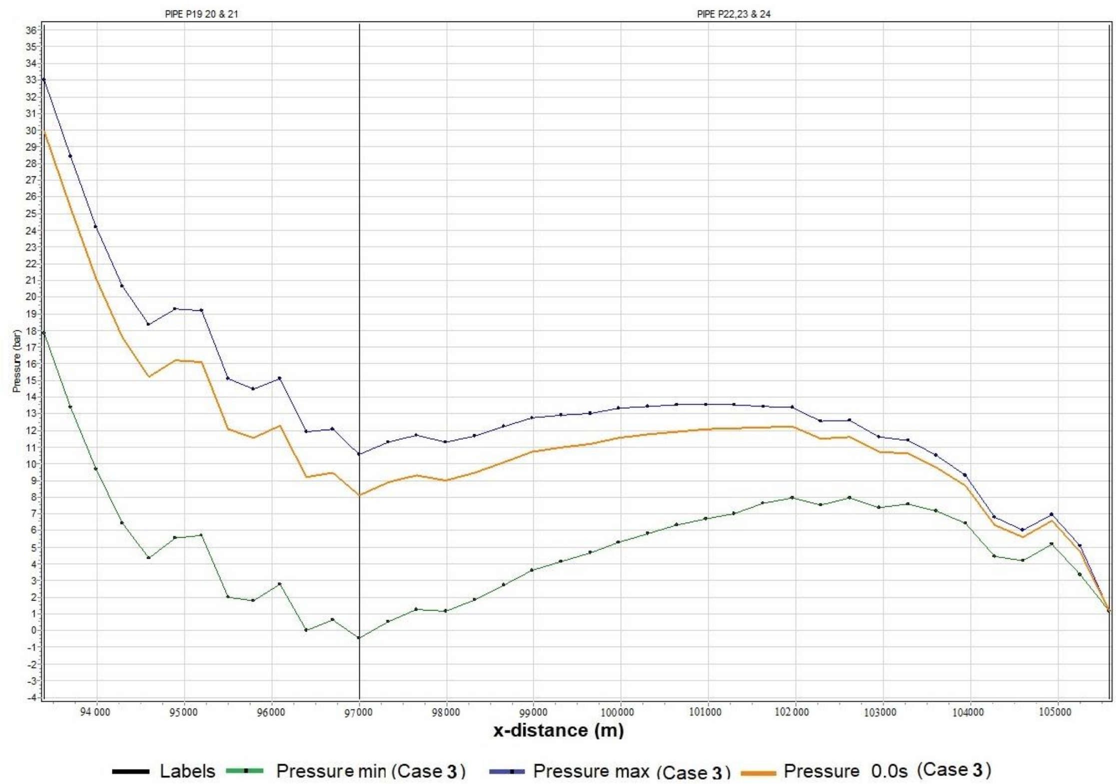


Figure 10: 3rd scenario; Static pressure along pipes 19-24.

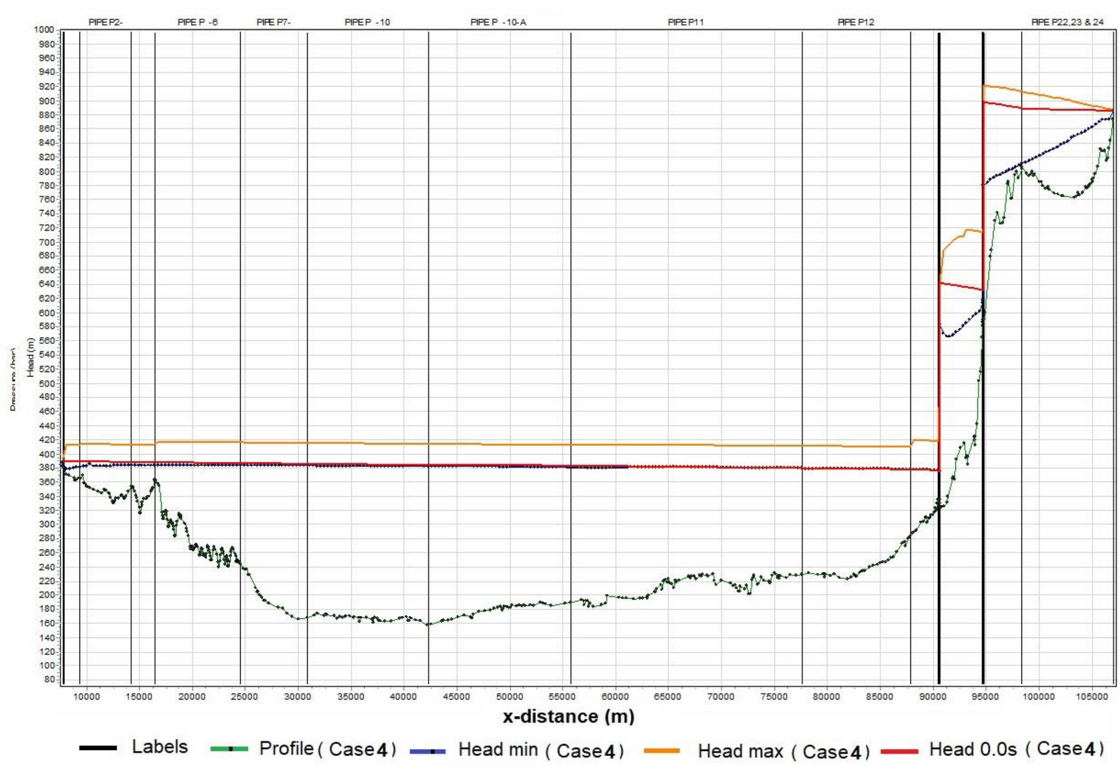


Figure 11: 4th scenario; Static pressure head along pipes 1-24.

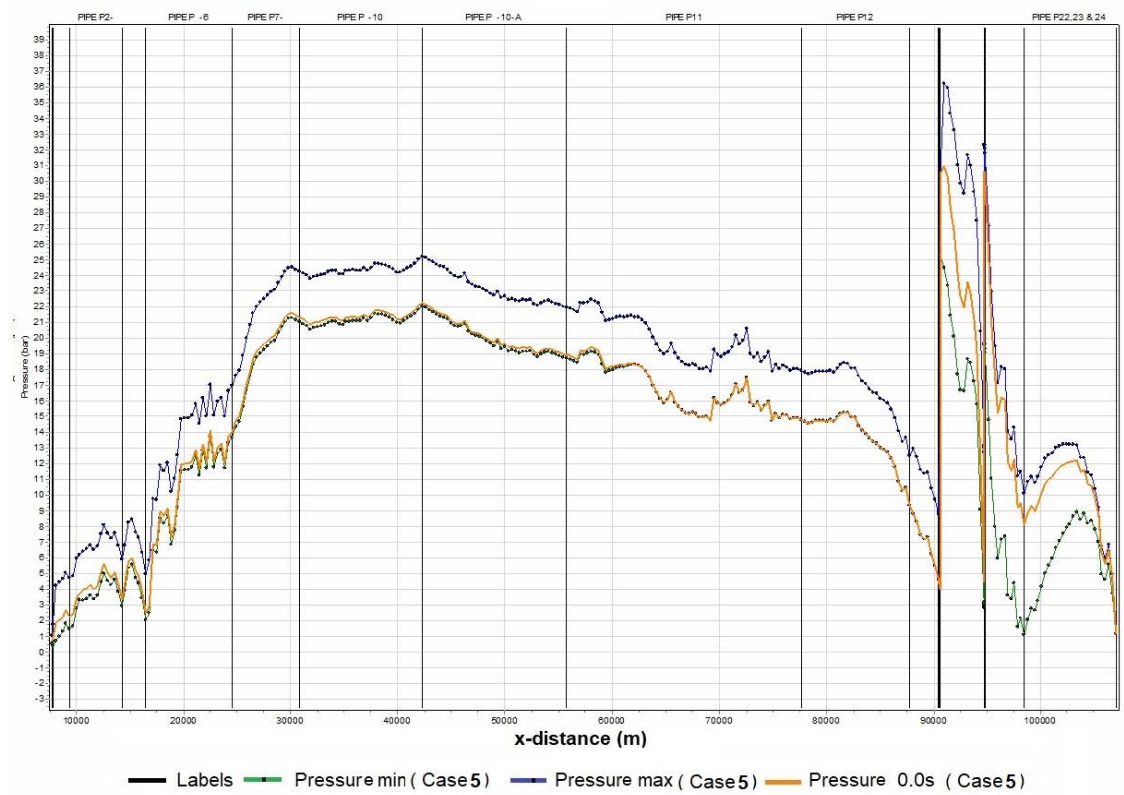


Figure 12: 4th scenario; Static pressure along pipes 1-24.

The 5th scenario seems to give an acceptable transient behavior along the pipeline due to the power failure. One can see that the minimum head is far from the pipeline profile as shown in Figure (13). The peak pressure is reduced to 36 bar instead of 40.2 bar compared to the previous scenario with 7 air vessels. With this scenario, the negative pressure is eliminated along the pipeline as indicated in Figure (14) and no cavitation or column separation is expected.

In the 6th scenario, the transient flow is caused by a burst pipe at two turnouts; Abu-sheiba at x = 5,832 m with 0.857 m^3/s and Beer Alghanam at x = 63,526 m with 2.269 m^3/s. Referring to Figure (15), all pressure heads are above the pipe profile along the whole pipeline. It is found that the minimum pressure head just touches the pipe profile. Figure (16) shows that the maximum pressure found to be 22.25 bars at x = 42156 m in the pre-stressed concrete cylindrical pipes. This pressure is just above the operational desired pressure; 28 bar is less than the nominal rating of the pipes, leading to be considered safe.

Although, the more logical expected scenario was to have only one burst turnout at the time, two burst turnouts are considered to occur at once for the present scenario, which is still possible case. This covers the consequences of the single burst turnout. This situation is still less severe than the scenario of the complete power failure in both pumping stations that related to the 5th scenario, due to the low negative pressure and the expected vacuum regions along the pipeline.

Regarding to the 7th scenario, the transient flow is differently caused by burst pipes at two turnouts; Abu-Aisha at x = 5,832 m with 0.857 m^3/s and Esbaeaa at x = 17,700 m with 1.504 m^3/s, where Esbaeaa turnout is the closest one to Abu-Aisha. Referring to

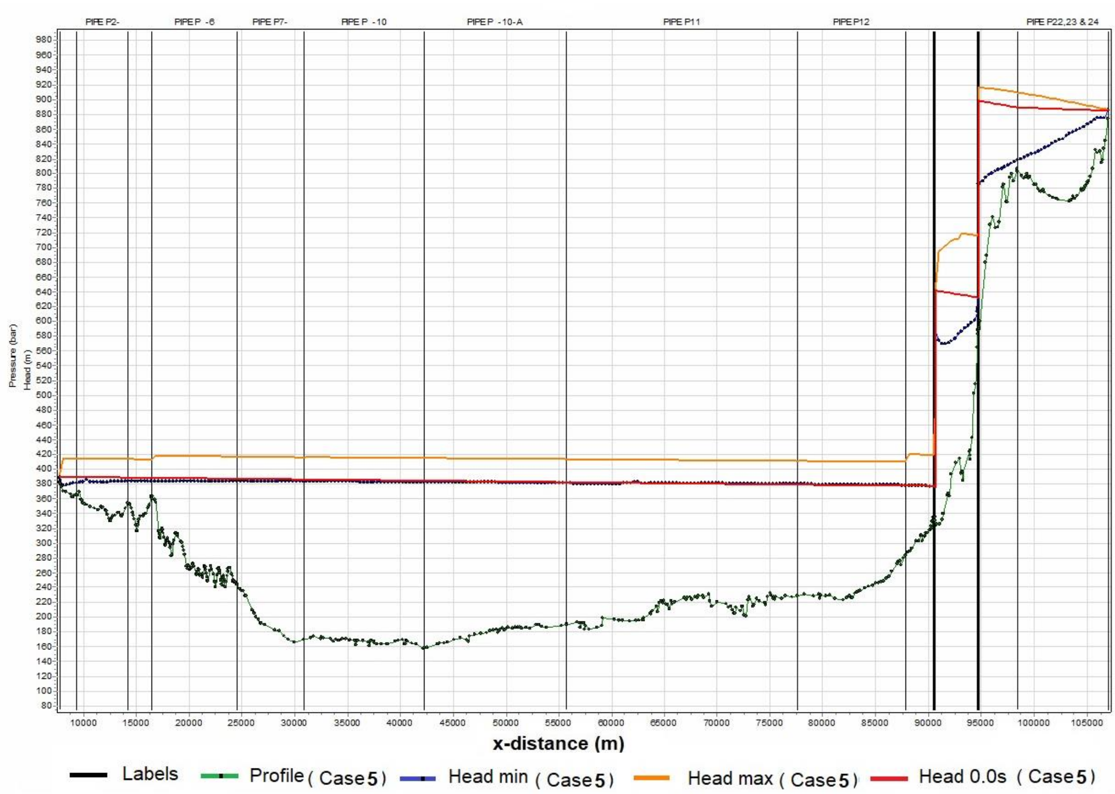


Figure 13: 5th scenario; Static pressure head along pipes 1-24.

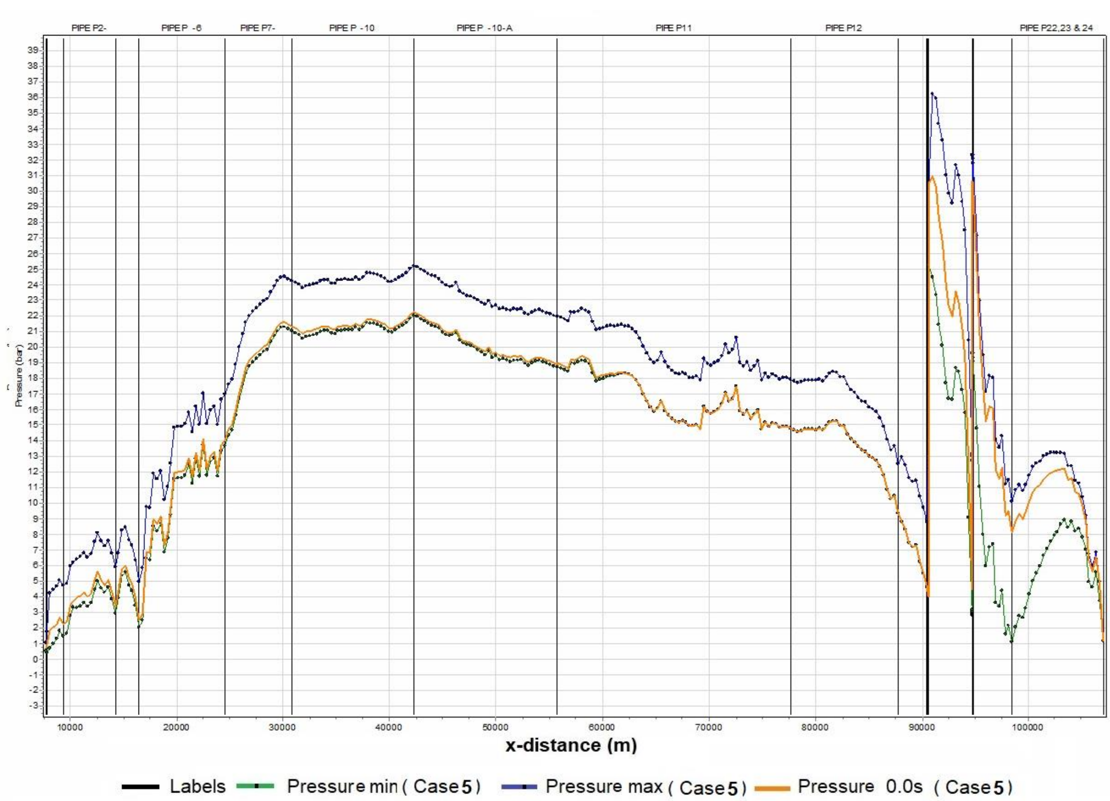


Figure 14: 5th scenario; Static pressure along pipes 1-24.

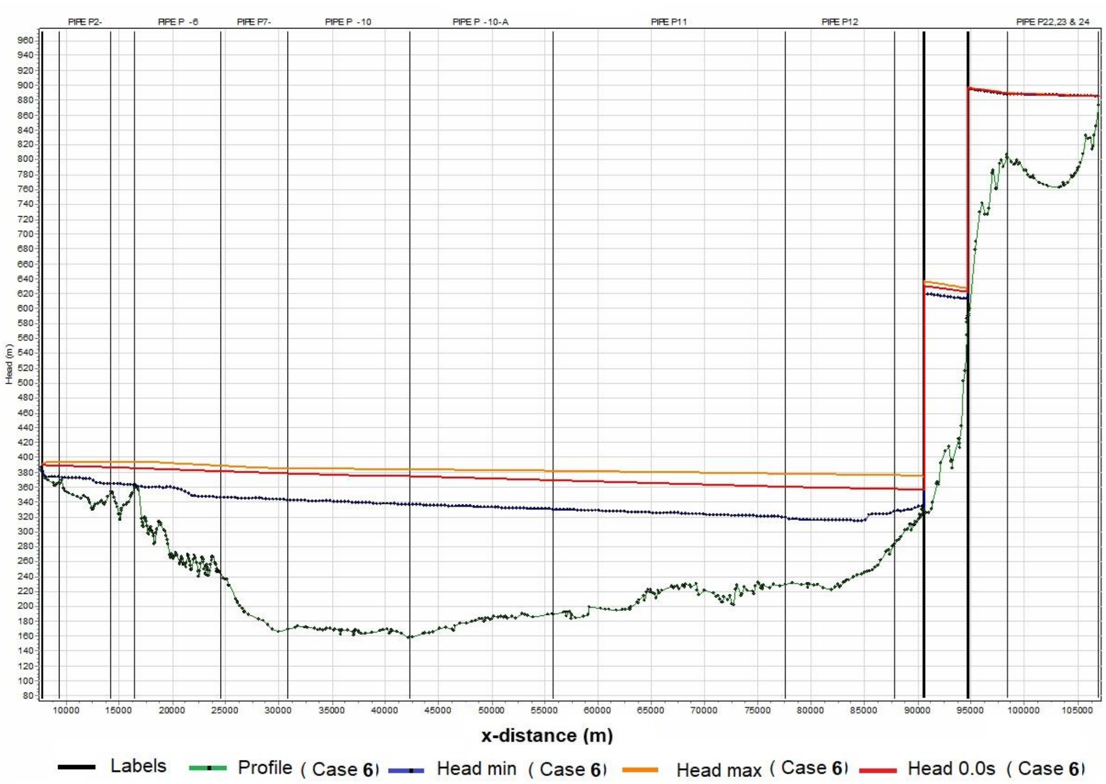


Figure 15: 6th scenario; Static pressure head along pipes 1-24.

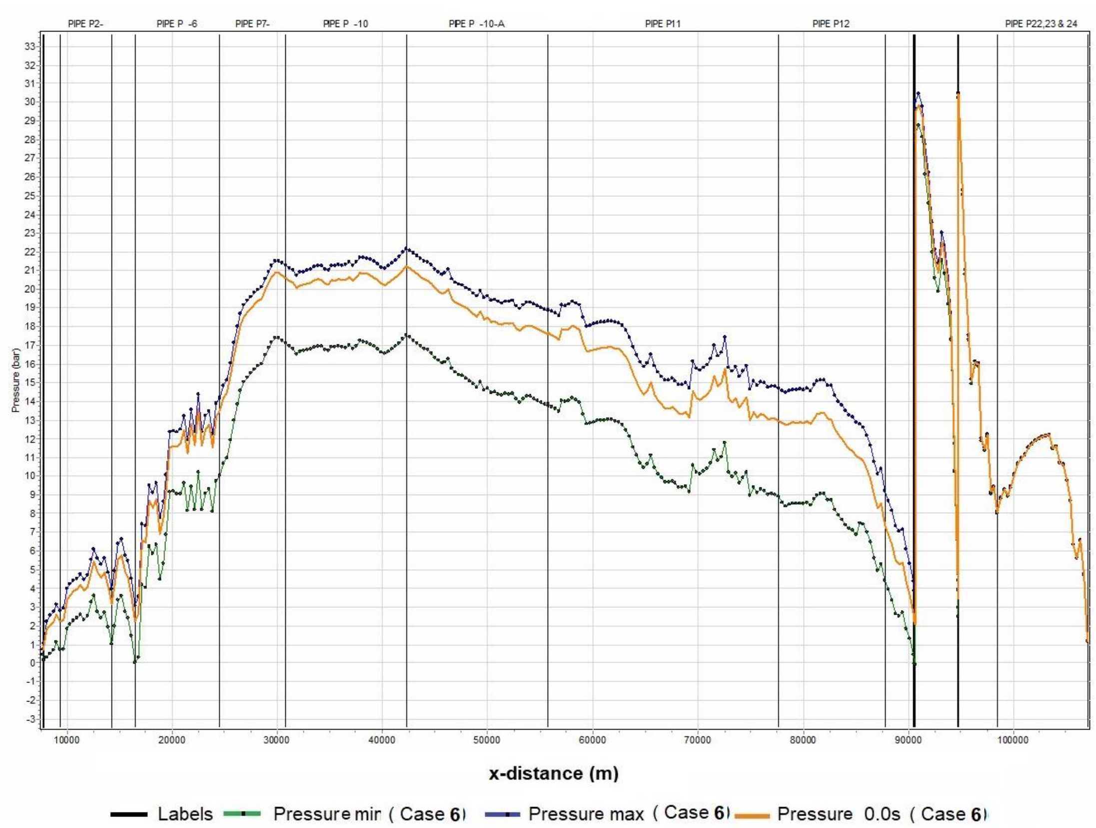


Figure 16: 6th scenario; Static pressure along pipes 1-24.

Figures (17 and 18), the maximum pressure was 21.8 bars at the position of x = 42,156 m, which is less than the operating pressure. While, the minimum pressures are – 0. 25 bar and almost –1. 0 bar in the pre-stressed concrete cylindrical pipes at x = 14,400 and x = 16,660 m, respectively. Here, the case of a burst pipe of the two considered turnouts is accompanied with low negative pressures, and the taken safety measures are not enough and should be raised.

Therefore, regarding to the normal operation, the safety measures, including 7 air vessels at downstream of each pumping station plus 1 air vessel at the upstream of each pumping station, are not enough for the case of burst of two or more turnouts instantaneously. This is due to the expected negative low-pressure regions in a number of locations along the pipeline.

Referring to Figure (19) related to the 8th scenario, the minimum and steady heads are both overlapping from pipe 3 to pipe 12 due to the low water level in Sidi-Seid reservoir. Figure (20) shows that the maximum and minimum pressures are within permissible pressure values. Comparing this scenario with the 7th scenario considering wall roughness differences, one can see the effect of such roughness. The higher roughness tends to decay the behavior of transient wave amplitude that leads to shorten the time required to reach the new steady flow behavior. Using new pipes with higher roughness increases the required pumping power, hence using roughness is not the proper way to achieve an acceptable transient flow behavior.

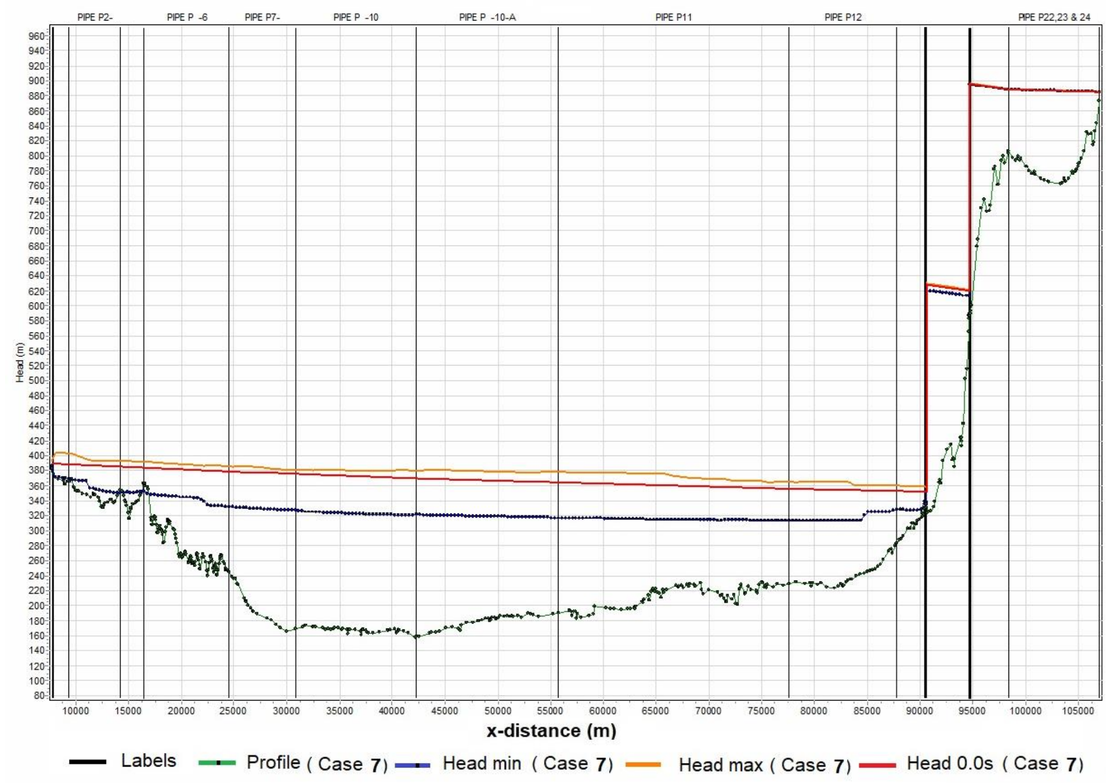


Figure 17: 7th scenario; Static pressure head along pipes 1-24.

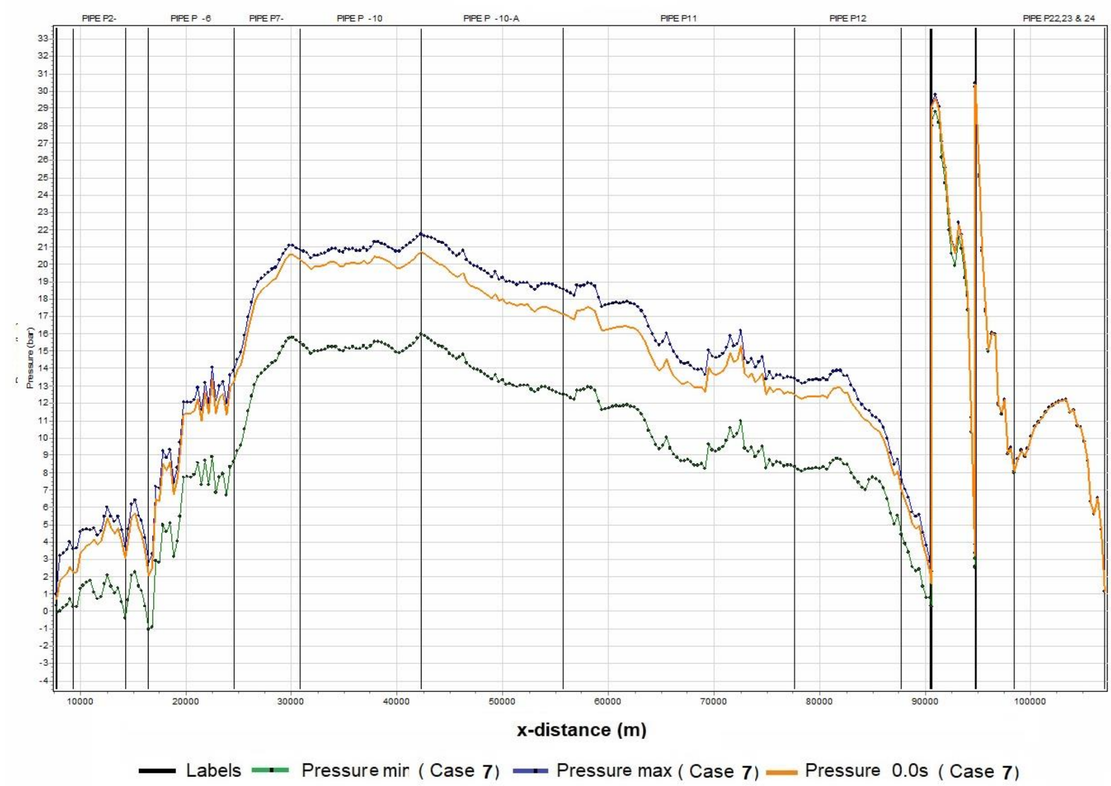


Figure 18: 7th scenario; Static pressure along pipes 1-24.

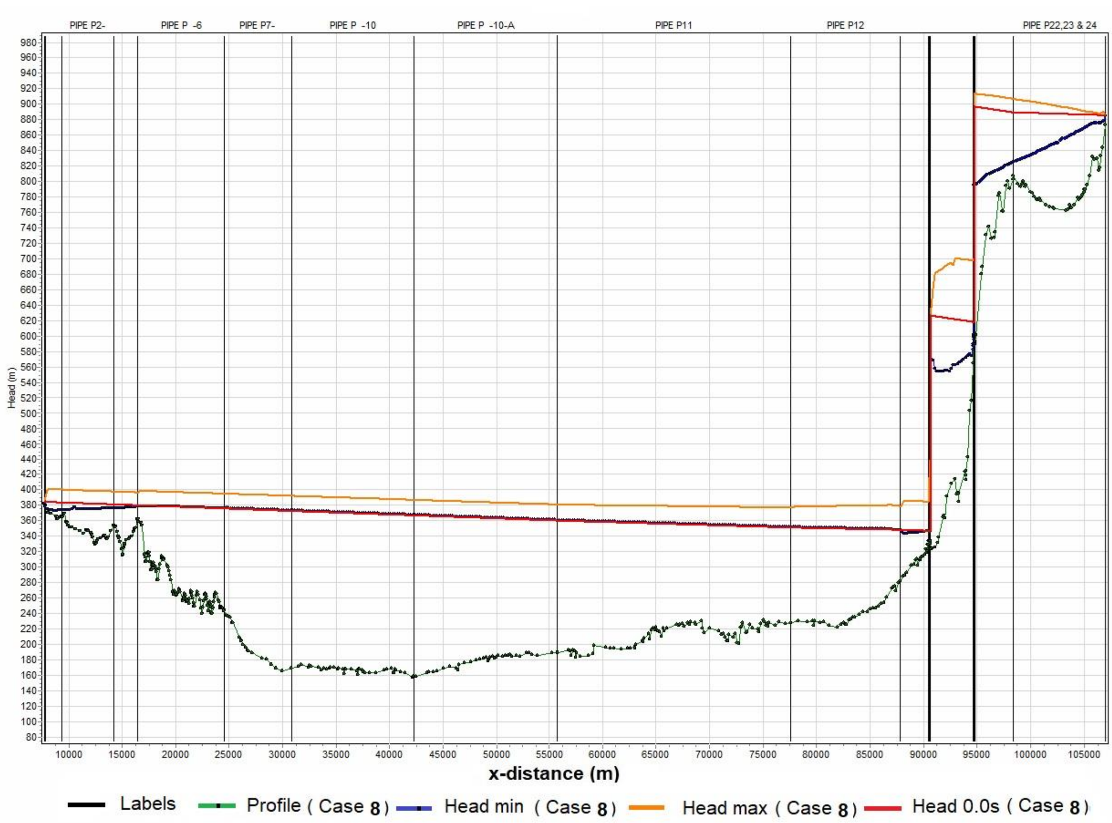


Figure 19: 8th scenario; Static pressure head along pipes 1-24.

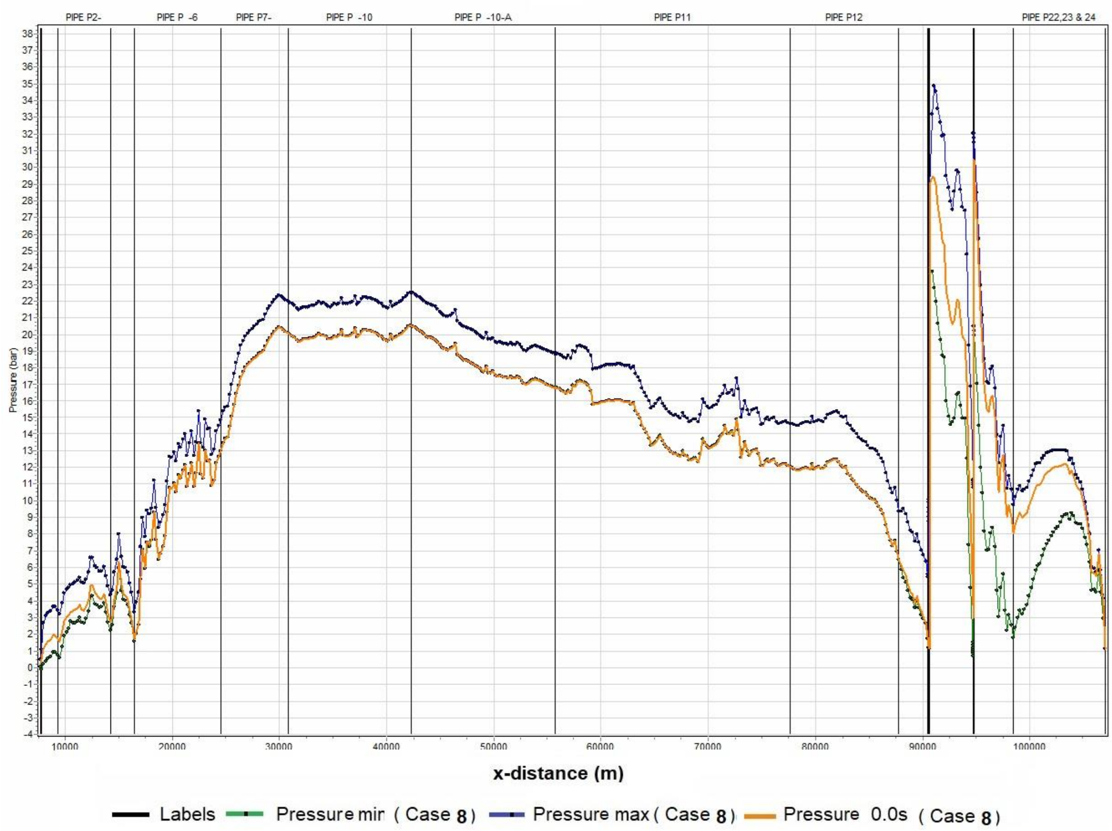


Figure 20: 8th scenario; Static pressure along pipes 1-24.

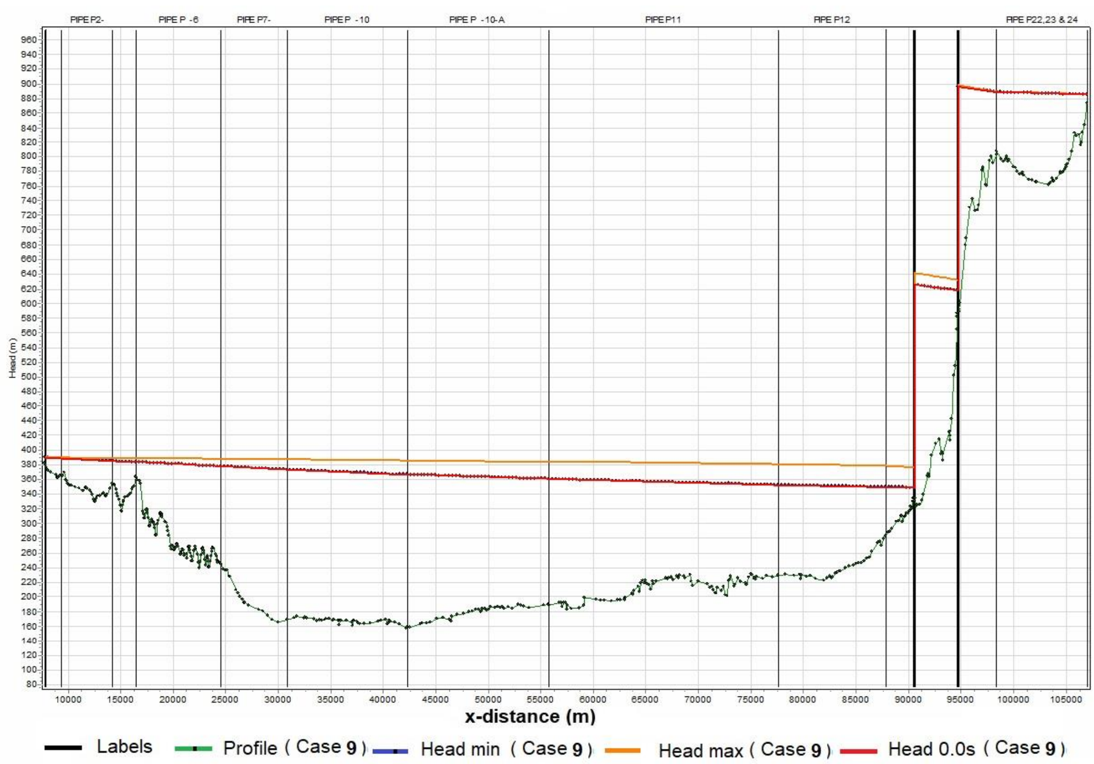


Figure 21: 9th scenario; Static pressure head along pipes 1-24.

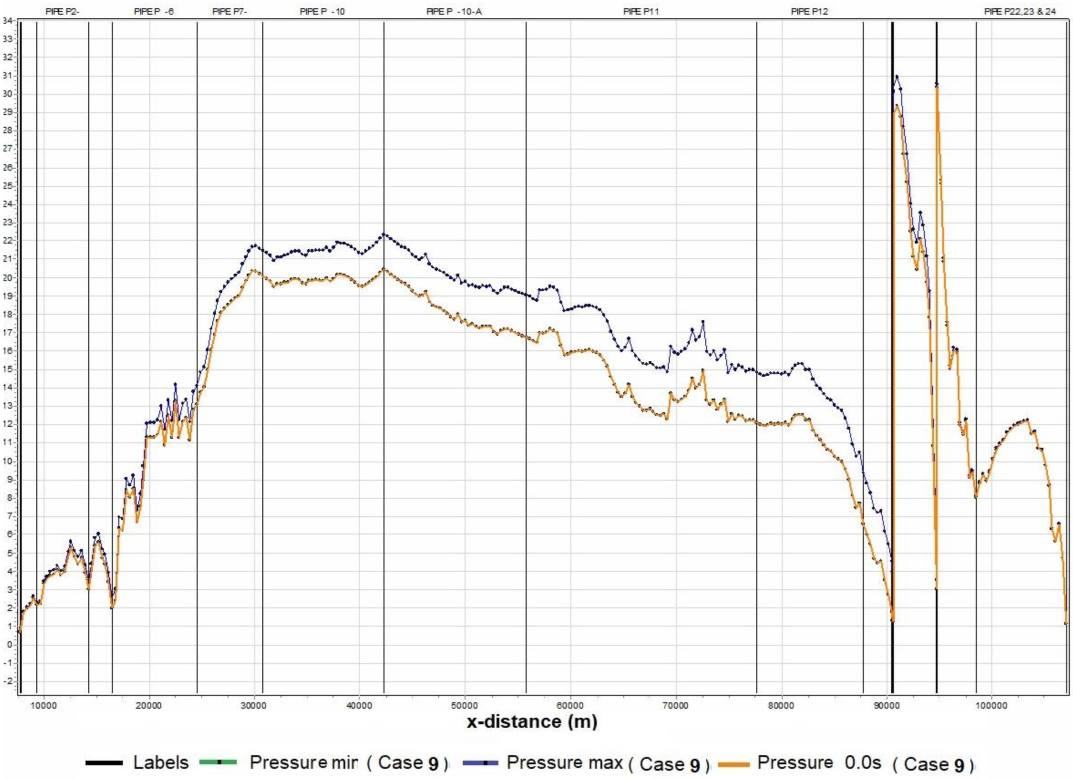


Figure 22: 9th scenario; Static pressure along pipes 1-24.

Regarding the 9th scenario behavior presented in Figures (21 and 22), the steady and minimum pressures are almost overlapped along most of the pipe length. The maximum pressure is within the permissible pressure. There is no indication for any cavitation along the pipeline, according to the low values of the minimum pressure distribution along the pipeline.

Comparing this scenario with the 5th scenario where the transient flow caused by the complete power failure, while keeping the same safety measures, the 5th scenario seems to have larger variations than the 9th scenario. However, both scenarios are considered safe within the permissible limitations.

CONCLUSIONS AND RECOMMENDATIONS

Complete pump power failure could be the main source of transient flow in pipe network systems; it is the most dangerous reason for damaging the network system components, especially in a huge water transport network as the studied project Tarhunah Abu-Ziyyan water transport system. The combination of 7 air valves downstream and 1 air vessel upstream of each pumping station seems to be the acceptable arrangement for the protection of the system for most considered scenarios.

Selection of proper protection system configuration; type, size, characteristics, and site, have great influence on the system performance at transient flow mode. Therefore, care must be taken in this selection process. Study of transient behavior becomes not difficult with the use of commercial modern software packages, such as WANDA. The output results from this software are evaluated and it is proved to have high accuracy in solving transient problems.

The turnouts should not be closed or opened instantaneously, that is each turnout should be closed or opened separately. This will limit the integration of the unwanted flow characteristics. Closing turnouts should be done with the specified low timing rates. This will limit the amplitude of the induced flow waves. The operators should be aware of the transient flow consequences, through continuing educational and training programs. Seminars, reports, discussions, and posters are recommended.

Referring to the design, construction, evaluation, operation procedures, this large piping project deserves to be a study field for many research points. This may include the study of combined sources of transient flow. The study may cover other protection systems against unforeseen disasters, such as floods, and earthquakes, including considering safety measures for the civil activities around the pipeline route against any unwanted expected pipe rupture.

ACKNOWLEDGMENT

The authors are pleased to thank very much the Company of Man-Made River-Libya, for their support conducting this research, including providing the necessary data and giving access to the WANDA software package.

REFERENCES

[1] A. R. David Thorley, Fluid Transients in Pipeline Systems, 2nd edition, City University, London, 2004.
[2] Khairi M. Salem, Sizing Air Vessels for Water Hammer Protection in Water Pipelines, M. Sc. Thesis, ME Department, University of Tripoli, 2013.
[3] Khairi M. Salem, Mohammed E. Mashina, Elhadi I. Dekam, Sizing Air Vessels for Water Hammer Protection in Water Pipelines, Journal of Engineering Research, Mar 2017.
[4] Arris S. Tijsseling and Alexander anderson, Thomas Young's, research on fluid transients: 200 years, Journal of Scientific Computing, January 2008.
[5] Bruce E. Larock, Roland W. Jeppson, Gary Z. Watter, Hydraulics of Pipeline Systems, CRC, 2000.
[6] T.S. Lee, H.T. Low and D.T. Nguyen, "Effects of Air Entrainment on Fluid Transients in Pumping Systems" Journal of Applied Fluid Mechanics, Vol. 1, 2008.
[7] Othman Almuntasser, Evaluation of Tarhunah-Abu-Ziyyan Water Pipeline Transient Flow, M. Sc. thesis, University of Tripoli, 2011.
[8] Bong Seog Jung, Bryan W. Karney, Paul F.Boulos, and Don J. Wood. "The need for comprehensive transient analysis of distribution systems," AWWA 99:1, Journal of the American Water Works Association, January 2007.
[9] Paul F. Boulos, Bryan W. Karney, Don J. Wood, And Srinivasa Lingireddy, Hydraulic Transient Guidelines for Protecting Water Distribution Systems, Journal AWWA, 2005.
[10] Z. Zaraycki and S. Kudzma, Simulation of Transient Flows in a Hydraulic System with a Long Liquid Line, Journal of Theoretical and Applied Mechanics, 2007.
[11] A. R. Simpson and Z. Y. Wu, Computer Modelling of Hydraulic Transient in Pipe Networks and the Associated Design Criteria, the University of Adelaide South Australia, J, 2005.

[12] Incorporated and Haestad Methods Water Solutions, Bentley Institute Press, 2007.
[13] J. Paul Tullis, Hydraulics of Pipelines: pumps, valves, cavitation's, transients, Wiley and Sons, Inc, 1989.
[14] A.R. Lohrasbi and R. Attarnejad, Water Hammer Analysis by Characteristic Method, Journal AWWA, 2008.
[15] Jaime Suarez Acuna, Generalized Water Hammer Algorithm for Piping Systems with Unsteady Friction, M.Sc. thesis, University of Puerto Rico, Mayaguez Campus 2005.
[16] Nuri A. kishrew, Transient analysis and simulation of water transport and distribution networks, M.Sc. thesis, Al-Fateh University, 1997.
[17] Fadel S. Gseaa, Pressure Transient in Networks, Simulation and Analysis, M.Sc. thesis, Al-Fateh University, 2009.
[18] Fadel S. Gseaa, Elhadi I. Dekam, Pressure Transient in Networks, Simulation and Analysis, Journal of Engineering Research, January 2010.
[19] WANDA 3.51 program package, Rotterdamsweg. 177, 2600 MH Delft the Netherlands.
[20] Abd-Algadir Abd-Allah Abd-Algadir, The Study of Air Valves in Water Pipelines, M. Sc. Thesis, ME Department, University of Tripoli, 2013.
[21] Abdel Gawad M. Abdel Bary, Optimization of Water Distribution Systems Subjected to Transient Flow Using Genetic Algorithms, M.Sc. Thesis, Mansoura University, Egypt, 2008.