

Solutions for Water Hammer Phenomenon in the Low Lift Pump Station Located on Tigris River

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ABSTRACT

The goal of this research is to find the proper solutions of curing the water hammer which the suddenly shutdown of the electricity that supply the power to the pumps occurs it, where this case make the water return to the pumps with very high speed approach the pumping speed which make surge wave, usually the pumps and the pipes and valves would crushed according to this surge wave. When the studied hydraulic data was taken from the pump station located on Tigris river and also from the knowledge of the pumping capacity and the velocity of the pumps used in this station and input this data to (Bentley Software) specialized in studying and locating the position of the water hammer support to locate the right place to put the surge tank which can absorbs the surge wave and finally to prevent the water from returning with very high speed to the pumps and to save the pumps, pipes and valves from crushing even when the electricity suddenly shutdown and depend on the standby generators to generate the electricity , the putting of surge tanks in the place of highest point of pressure make the pressure decreased from (22bar) up to (7 bar) approximately .

Keywords: pump station, low lift, surge, tank, water hammer.

ايجاد الحلول لظاهرة المطرقة المائية في محطة السحب الواطئ الواقعة على نهر دجلة

الخلاصة

الهدف من هذا البحث هو ايجاد الحلول المناسبة لكيفية معالجة ظاهرة المطرقة المائية والتي تحصل عادة بسبب الانقطاع المفاجئ للتيار الكهربائي المغذي للمضخات مما يؤدي الى رجوع المياه اليها بسرعة قد تصل الى نفس السرعة التي تم ضخه بها مشكلا صدمة قوية جدا قد تؤدي احيانا الى تحطم هذه المضخات وايضا الانابيب الناقلة للماء الخام والاقفال. وبعد تحليل المعطيات الهيدروليكية التي تم استحصاليها من موقع المحطة المشيدة على نهر دجلة وايضا من خلال معرفة قدرة وسرعة ضخ المياه بالمضخات المستخدمة ضمن هذه المحطة تم ادخال هذه المعطيات في برنامج الحاسوب (Bentley Software) المتخصص في مجال دراسة وتحديد موقع الصدمة المائية وبالتالي تحديد المكان المناسب لوضع خزانات المطرقة المائية والتي من الممكن استخدامها في امتصاص موجة الصدمة مما قد يمنع من رجوع الماء المضخ بسرعة عالية جدا وعلى شكل صدمة الى المضخات وبالتالي عدم تحطمها هي والانابيب والاقفال مما يؤدي الى استمرارية عمل المحطة بصورة صحيحة حتى حين انقطاع التيار

الكهربائي بشكل مفاجئ والاعتماد على المولدات الكهربائية الاحتياطية لاعادة توليد هذا التيار ، وان وضع هذه الخزانات في مكان اعلى نقطة للضغط قد ساعد على تخفيض الضغوط من (22bar) الى (7 bar) تقريبا .

INTRODUCTION

Surge tanks are most commonly used to protect systems from changes in fluid levels; they act as a reservoir that stores and supply excess fluid. In addition, the tanks shield the systems from dramatic changes in pressure, temperature, and concentration. They can also allow one unit to be shut down for maintenance without shutting down the entire plant.

The principle demand on a surge tank is to compensate the mass oscillation of the water flow in the pressure tunnel of load changes of turbines and/or pumps, whereas the construction type in connection with a suitable throttling device should effect in a most powerful damping of the amplitude already in the very first period of oscillation.

Avoiding Pressure Surge Damage in Pipeline System presented by Geoffrey D Stone CP Engineering FIE Aust [1], [11], G. V. Aronovich, N. A. Kartvelishvili and Ya. K. Lyubimtsev [2], [13], [16], studeied the fatigue failure of the pipeline, supports, instrumentation, equipment and components. Steyrer Peter [3], [12], [17], worked on an economic surge tank design for hydraulic system of high-head, peak-load storage power plants. Kim Sang – Hyun [4], [6], [10], design of surge tank for water supply systems using the impulse response method with the GA algorithm, D. S. Shavelev, I. A. Chernyatin, I. P. Andreeva and V. L. Kuperman [5], [7], [8], analyzed the surge in tanks by using the numerical equations.

Partial or full-load rejection leads to an upsurge oscillation, whereby the maximum pressure is limited by the bearable stress of the concrete lining of the power tunnel.

Load demand, however is followed by a down surge oscillation and the damping effect of the throttling device should avoid reaction on the turbine or pump. In this case the minimum pressure must not come below the elevation of the power tunnel, [9].

EXPERIMENTAL WORK

The data was taken from Low Lift Pump Station (LLPS) located on Tigris River; the initial design of the flow is 352000 cubic meters per day or 4.444 m³/s. The low lift pump station equipped with 9 pumps (6 duties & 3 standbys) conveys 16000 m³/hr of the raw water from the river to the treatment plant through twin separate 1500mm diameter pipe lines. Each 3 pumps convey 8000 m³/hr through each pipeline.

These data was analyzed and studied with using the Bentley Hammer model. This model is a complete Windows-based framework for analysis of water hammer and surge transients in closed conduit systems. It can simulate all the hydraulic elements that influence water hammer including pumps, control and check valves, surge tanks, vacuum breakers, surge relief valves, and hydro pneumatic tanks (air chambers). Hammer simulates column separation and collapse, as well as air intake and discharge at vacuum breakers and air release valves.

Sections between Pumping station and its downstream tank are simulated individually. All the hydraulic system affecting the flow was simulated and nodes were included in the pipeline at the high and low points. This includes the pipe between the hydro pneumatic tank and the pipeline.

The surge control was achieved by using hydro pneumatic tank located on the discharge side of each pumping set and double acting valves located at the critical high points of the pipelines. The hydro pneumatic tanks were optimized to limit the maximum surge pressure at the pump discharge valve to no more than 15% of the working pressure during power failure. For this purpose surge pressure shall be taken as the pressure rise due to surges. The working pressure is defined as the " the level of the maximum receiving (pumping system) or discharging (gravity system) reservoir free water surface or the steady state grade line at maximum flow, whichever is greater, minus the center line level of the pipe. The limit of the negative pressures have been limited to be less than -5m in the event of the worst case of total power failure while all pumps are operating.

Simulations were done at the low lift pump station with instantaneous pump stop without back flow.



Figure (1) Low Lift Pump station (Pump House under construction).

LOW LIFT PUMP STATION MODELING:

LLPS Transient Analysis (without protection):

Figure. (2) Shows a schematic diagram for the water pumps that pump the water through the pipes network from the suction well (SW) to the receiving well (RW).

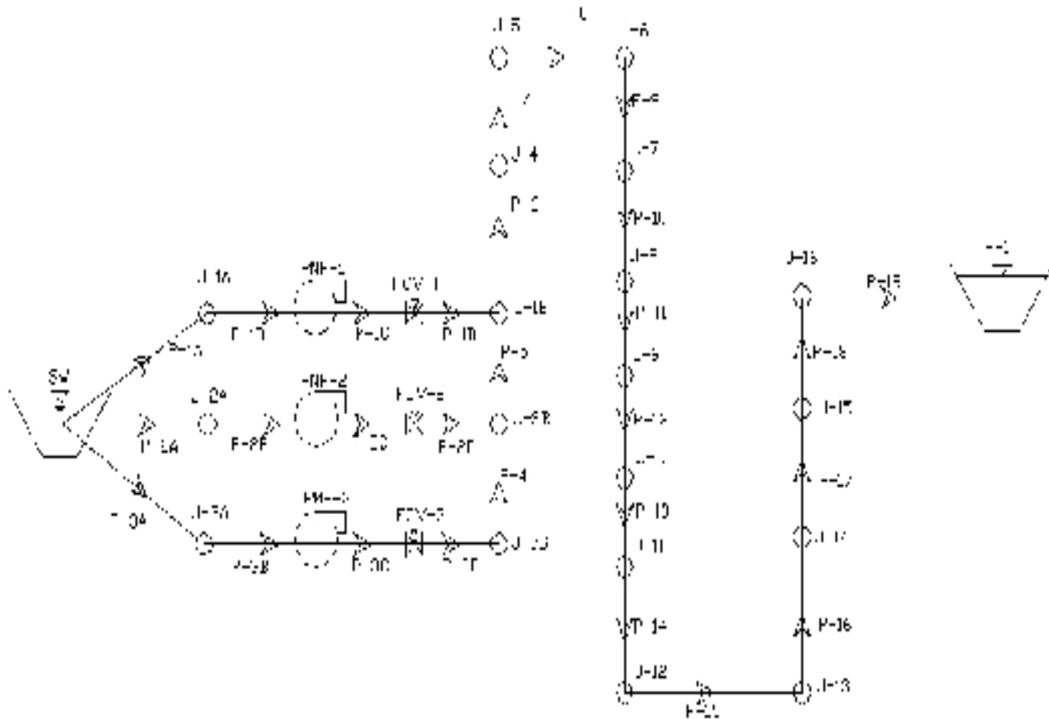


Figure (2) LLPS schematic diagram (without surge control)

Figure (5) Shows the transients head distribution along the profile when the pumps shut down, as shown in the graph the pressure raises up to 22 bars and column separation occurs at junction J-9, and vacuum occurs along the pipeline as shown in color blue in the graph.

LLPS Transient Analyses (with protection)

To protect the pump station and the pipeline a hydro pneumatic tank had been added at the joint J-4 and double acting valves had been also added to the point J-9 to avoid column separation.

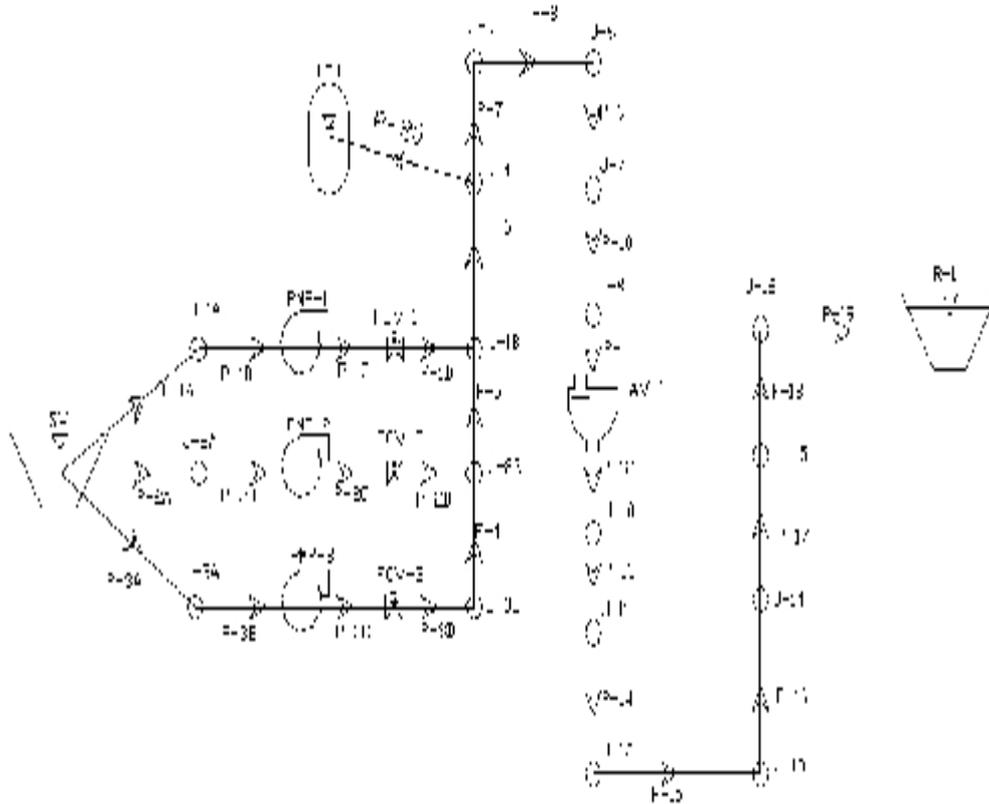


Figure (3) LLPS Model Schematic Diagram (with surge control)

PROTECTION EQUIPMENTS

Hydro Pneumatic Tanks

For the hydro pneumatic tank the model give the minimum and maximum air volumes in the tank during a power failure transient. Based on these, the hydro pneumatic tanks were sized. Each tank will have compressor on and off levels, an alarm level, and an air release level. As shown in the figure (4).

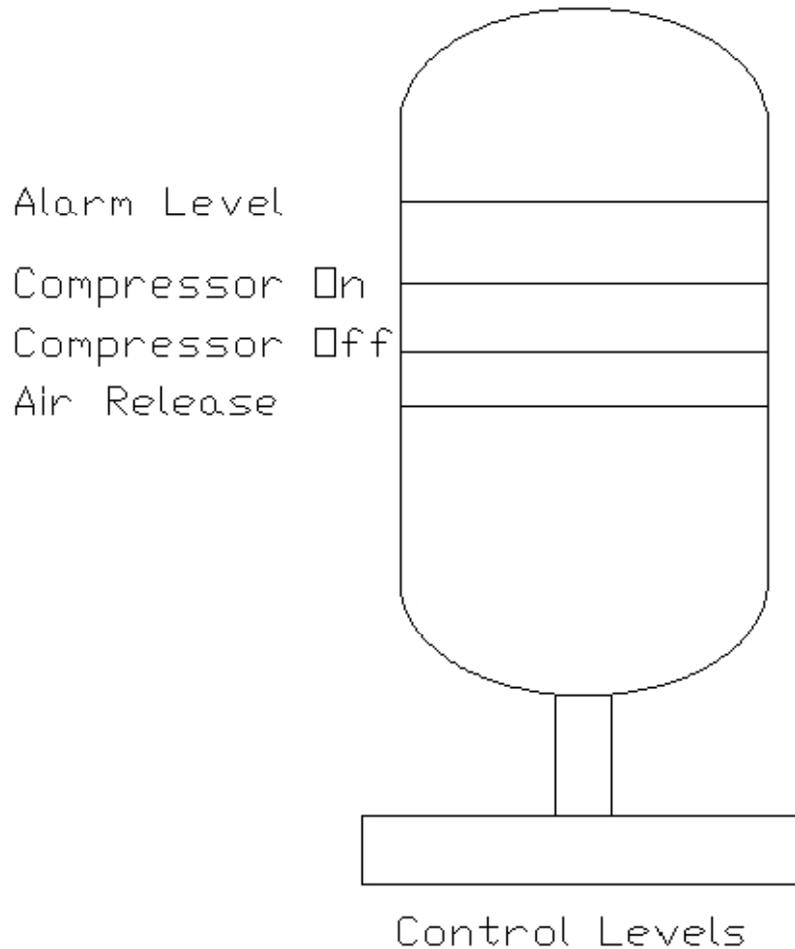


Figure (4) hydro pneumatic tank control levels.

The following criteria were used to size the tanks and establish the control levels:

- The Alarm level will be at the 1.05 times the minimum air volume level calculated by the model.
- The Compressor On level will sufficiently below the alarm level to avoid alarm activation during successive start-up of pumps.
- The Compressor Off level will be 0.1 m below the compressor on level.
- The Air Release level will be 0.1 m below the off level.

The total tank volume will be 1.05 times the expanded air volume corresponding to an initial air volume at the "Air Release" level. This will ensure that air will not be lost into the pipe.

Hydro pneumatic Tank volumes and pressures are summarized in Table(1).

Table (1) hydro pneumatic tanks dimensions.

LLPS

Receiving Tank high water level (m)	Z_d	276.65
Pipe Invert Level at Pump Outlet (m)	Z_o	222.86
Static Head (m)	$P_s = Z_d - Z_o$	53.79
Flow for $C=130 \text{ m}^3/\text{hr}$	$Q =$	8400.00
Head at Pump Outlet with $C=130$	$H_o =$	278.00
Working Pressure with $C=130$ (m)	$P_o = H_o - Z_o$	55.14
No. of Tanks	$N =$	1.00
Tank Diameter (m)	$D =$	3.00
Tank cross section Area (m^2)	$A =$	7.07
Required Air Volume (m^3)	$V_{REQ} =$	15.00
Expansion Ration	$re =$	1.85
Margin of Safety	$Ms =$	0.05
Alarm air Volume of Tank	$VAL = (1 + Ms)V_{REQ}/N$	15.75
"AL" - "ON" Distance (m)	$HAL-ON = \text{select}$	0.30
Air volume at "ON"	$VON = VAL + A * HAL-ON$	17.87
Pump start-up interval (min)	Δt_s	5.00
Air input rate (m^3/min)	$Q_{AIR} =$	0.02
water level drop due to air input (m)	$\Delta h_{AIR} = 4 * Q_{AIR} * \Delta t_s / NA$	0.04
Maximum Pressure (m)	$P_{max} = P_o$	55.14
Polytrophic Constant	$n =$	1.20

Minimum Air Volume During Startup	$V_{min}=V_{on}(P_s/P_{max})^{1/n}$	17.50
water level rise during start up	$\Delta h = [(V_{on}-V_{min})/A]-\Delta h_{air}$	0.01
Max water level below alarm level (m)	HAL-ON - $\Delta h =$	0.29
"ON" - "OFF" Distance(m)	HON-OFF	0.10
"Off" - " Air Release" Distance (m)	HOFF-AR	0.10
Air Volume at "Air Release"	$V_{AR}=V_{on}+A(HON-OFF+HOFF-AR)$	19.28
Expanded " Air Release" Volume	re VAR	35.67
Max Volume Safety Factor	b=	0.05
Water depth in tank after expansion from Air Release level (m)	$\Delta h=b*re*VAR/A$	0.25
Tank Volume $m^3=$	$V_{TANK}=(1+b)*re*Var$	37.46
Pipe Inlet / Outlet Diameter (mm)		500.00

Double Acting Valves

LLPS Double Acting Valves Summary Table:

POINT	VAPOUR OR AIR	MAX. VOL (m^3)	CURR. VOL (m^3)	CURR. FLW (cms)
P – 12 : AV – 1	Air	322.668	322.668	1.464
P – 11 : AV – 1	Air	10.862	7.993	0.141

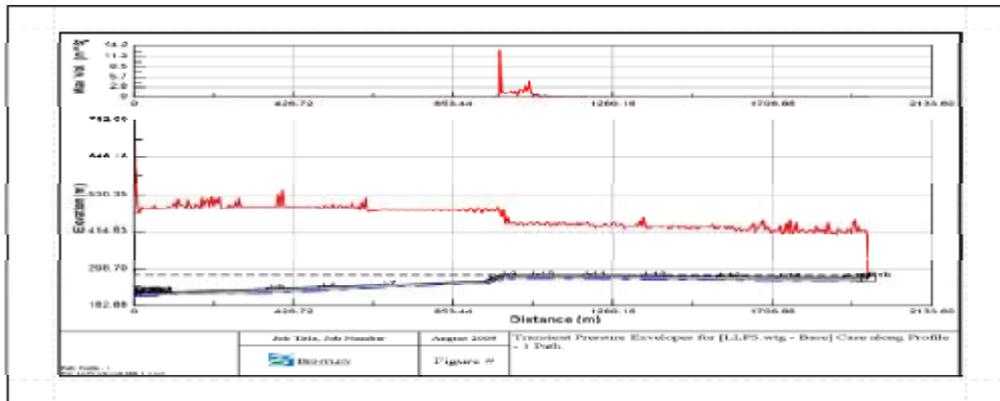


Figure (5) HLPS – BS1 transient pressure envelopes (without surge control).

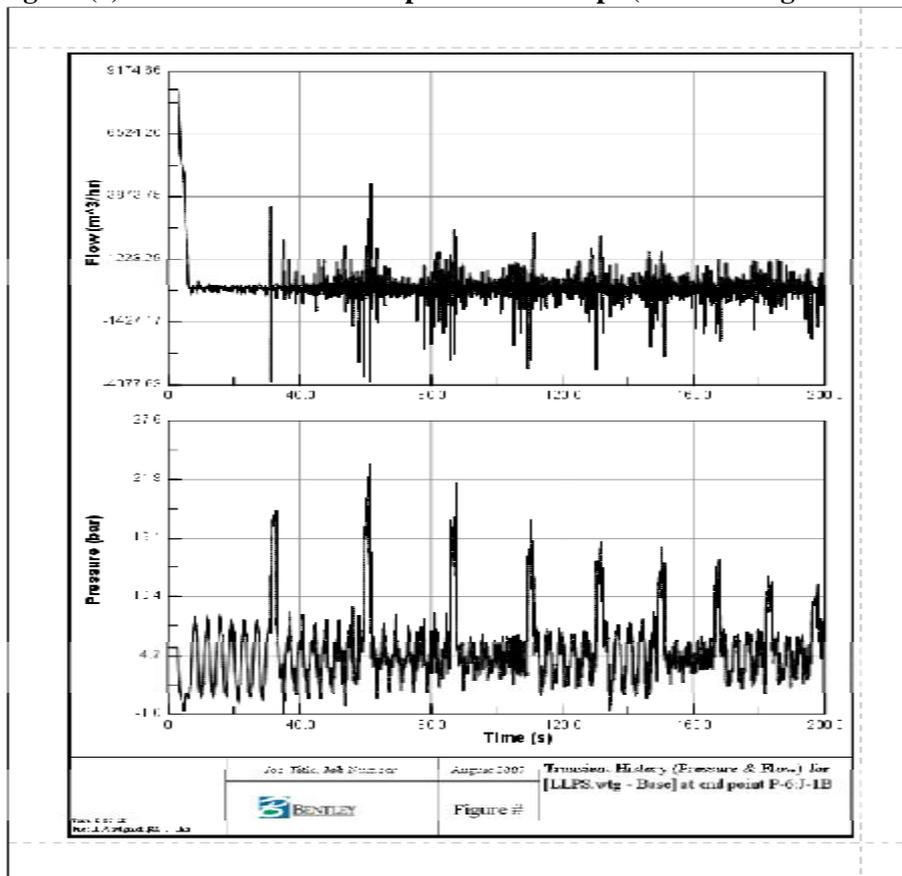
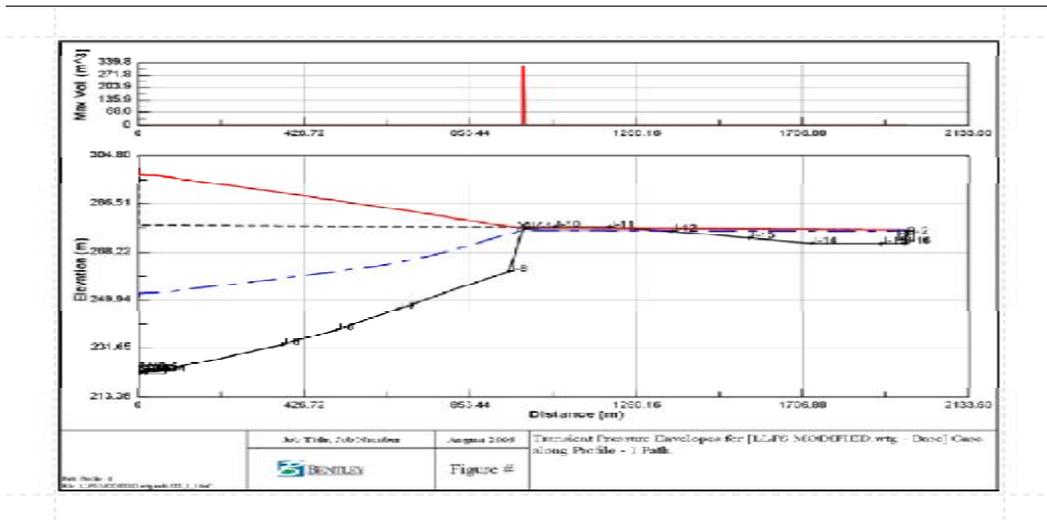


Figure (6) LLPS transient pressure & flow at the inlet of the pipe P-6 as shown in the graph a column separation occurs at 35, 60, 85, 110, 135sec. (without surge control).



Figure(7) LLPS Transient Pressure envelopes (with surge control).

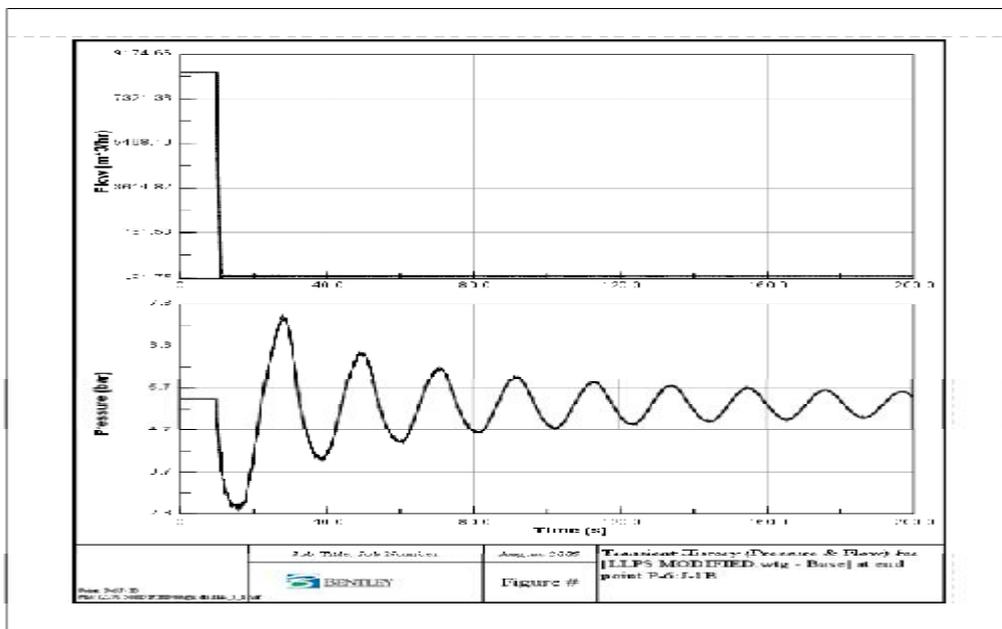


Figure (8) LLPS transient pressure & flow at the inlet of the pipe p-6 as shown in the graph the pressure is damping smoothly. (With surge control).

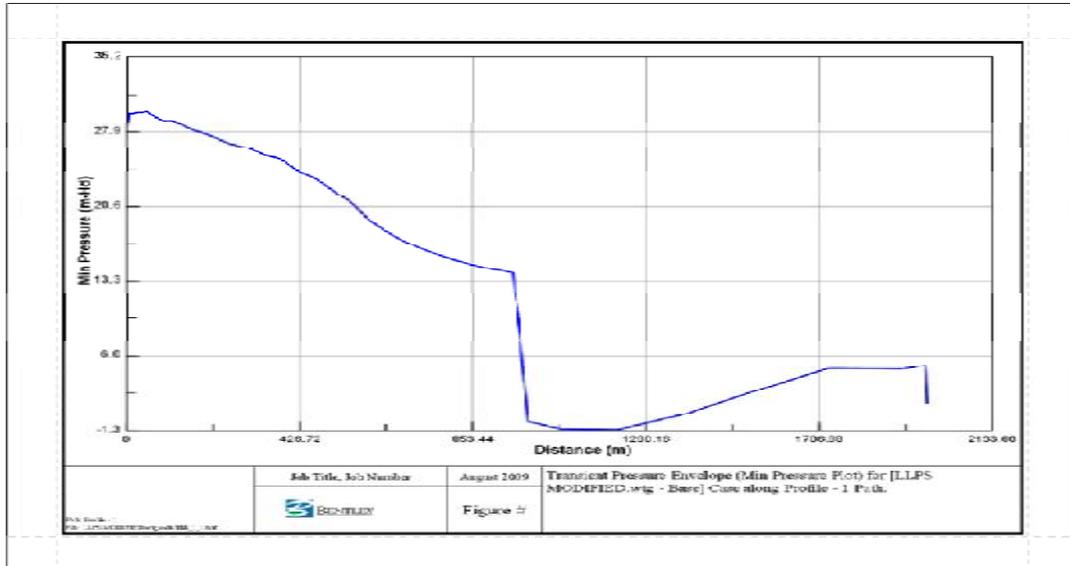


Figure (9) LLPS minimum pressure along the pipeline shows that the minimum is about 1.3 bars (with surge control).

RESULTS AND DISCUSSION

When designing any pumping station (low lift or high lift) must consider the phenomenon of surge wave in the mechanical design which occur to the suddenly electricity provider shutdown or according to a break in the transmission pipeline network.

By making a schematic diagram as shown in (Figure 2) for the transmission pipeline network, then input all the collected data (pumps head, pumps discharge, pipes diameter, pump station elevation...etc.) to the (Bentley Software), and analyze it, got (Figure 5) that shows the pressure envelopes according to the elevation and distance, also noticed that the pressure and the flow would be variable and not constant according to the time as shown in (Figure 6) when not use the surge protection.

Bentley software can locate the right place to put the surge wave protection from knowing the maximum pressure point in the pipes network which here would be at joint (J-9) as shown in (Figure 3) , to protect the system use double acting valves at joint(J-9) and pneumatic tank at joint (J-4) to avoid the column separation, also noticed that after using the surge wave protection the pressure envelopes would be more constant as shown in (Figure7), also the relation between the pressure and flow according to the time would be more constant as (Figure 8) shows that the pressure will damping smoothly after using the surge controls.

The pressure would be decreased along the distance and reach the zero point as shown in (Figure 9), the pressure damping about 1.3 bar.

The using of water hammer protection is very important, to reduce the pressure, make the flow constant and prevent the pipes, pumps crashes because of the surge wave.

Bentley software can specify the right volume of the surge tank must be used to contain the capacity of the surge wave when occurs, and in this search the tank volume required is approximately 40 m³, also the program can specify the shape and tank dimension as shown in the output table above , figure. (4) Shows the shape of the surge tank required.

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