Surge Pressure Effect on Crude Oil Export Pipelines to Petroleum Ports

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Abstract

Pressure surges in pipelines are created by a change in momentum of the moving stream (e.g. valve closure). The occurrence of pressure surges should be determined by transient pressure analysis .Surge pressures are particularly critical for pipelines transporting liquid fluids, because of the high density and lower compressibility compared to gaseous fluids. Although damping of the pressure wave initiated at the point of blockage occurs as it travels upstream, surge may in some cases result in the highest pipeline pressure at a location well upstream of the point of origin. This may occur in particular for liquid pipelines in hilly terrain.
Methods of preventing the generation of unacceptably high surge pressures including valve closure speed reduction or special fast-response pressure relief systems close to the point of surge initiation. If not sufficient, strict adherence to well formulated operating procedures should be implemented.

In our research we presented the factors that may contribute in the happening of surge phenomenon and with the use of computer calculations and experimental work we gave some solutions to prevent it. Depending on Joukowsky equation we noticed that for crude oil that each time when decreasing the valve opening the pressure will increase .in experimental part we also made tests on gas oil by using a system in petroleum research and development center the results showed that as the valve closed the pressure increase where we get maximum pressure of 42 psi.

Introducrion

Pressure surges occur in all fluid pipeline systems. There arise two types of damage from the surge phenomenon, fatigue and catastrophic failure. Pressure surges in pipelines are also created by a change in momentum of the moving stream (e.g. valve closure).

Surge pressures are particularly critical for pipelines transporting liquid fluids, because of the high density and lower compressibility compared to gaseous fluids. Although damping of the pressure wave initiated at the point of blockage occurs as it travels upstream, surge may in some cases result in the highest pipeline pressure at a location well upstream of the point of origin. This may occur in particular for liquid pipelines in hilly terrain [1].

The pipeline system shall be designed such that surge pressures cannot exceed MAIP at any point along the pipeline, and will not trigger the system for overpressure protection from the upstream facility if fitted [2].

Pressure surges are often divided into two categories: transient surges and cyclic surges. Cyclic surging is a regularly occurring pressure fluctuation produced by action of such equipment as reciprocating pumps, undamped pressure control valves or interacting pressure regulating valves, oscillating demand, or other cyclic effects. Cyclic surges may cause fatigue damage and should be designed out of the system. Transient surges are just that transient in nature, occuring over a relatively short time and between one steady state and another. A transition surge may occur, and the system then returns to the same steady state as before the surge. Transient surges are usually not cyclic in nature although they may be repetitive.

There are two categories of damage that arise from surge events, these are:

• Catastrophic failure of the pipeline or equipment

• fatigue failure of the pipeline, supports and/or of equipment components

The objective of this work is to investigate experimentally the surge phenomenon under different operating parameters such as diameter of the pipeline, velocity of flowing fluid, and valve closing time [3, 4].

Theory

Critical time

Different criteria have to be adopted to avoid surge waves in pipelines namely:

1- The transportation time required by wave can be written as:

Critical time = 2L/a

Where:

L is pipe length (m)

a is speed of sound in oil (m/s)

2- The Valve or pump closure time should be greater than critical time.

3- The last 20% of valve closure most critical. Very dependent on type of valve.

Figure (1) shows the implemented wave speed at different critical times to show its effect on the surge happening.

Wave speed pressure

Wave speed depends on many factors such as:

For fluid: (Bulk modulus of elasticity of the fluid, density)

For pipe material: (Bulk modulus of elasticity of the pipe walls, diameter, pipe thickness) [9].

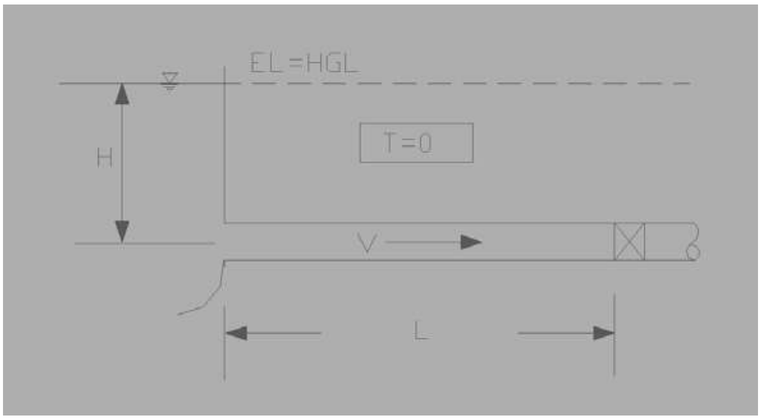
$$\Delta h = \frac{a}{g} * \Delta v \qquad \text{.................1}$$

Where:

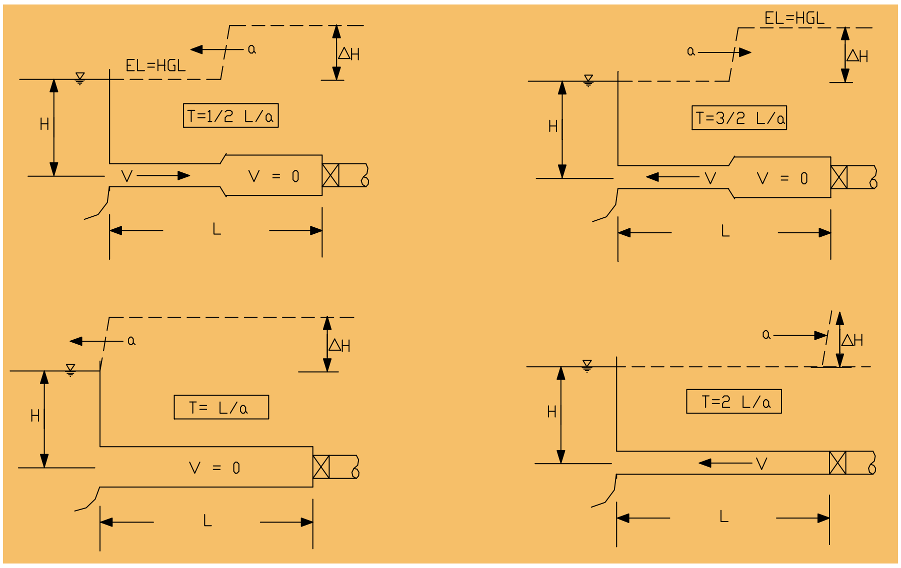
Δh = change in pipe pressure head

a = wave speed

g = speed of gravity



(a)



(b)

Fig. (1) Wave speed at different critical times, (a) Wave Diagram t=0 to 2L/a, (b) Wave Diagram t= 2L/a to 4L

Δv = change in velocity

Also by using the following equation to calculate pressure wave speed [5]:

$$a = \frac{\left[\frac{K}{\rho}\right]^{0.5}}{\left[1+\left(\frac{K}{E}\right)\left(\frac{D}{t}\right)C\right]^{0.5}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where:

K - Bulk modulus of elasticity of fluid,

E - Modulus of elasticity of pipe material,

D - Inside pipe diameter (m),

t - Pipe wall thickness (m),

C-pipe supporting factor,

This factor (C) depends on the following cases:

- Fixed pipes from one side C= 1.25-α
- fixed piped from both sides C= 1- α^2
- all long supports C=1

α- Poisson ratio for pipe material for carbon steel pipe =0.3 [10].

by using computer program we have concluded this relation which is illustrated in figure (2) for different for three cases pipe supporting then we supposed that pipe diameter is (1.22) m .also we can observe that wave speed is proportional to thickness (i.e. when the thickness of pipe increases the wave speed increases) .In this case we get the wave speed of approximately 502m/sec. The pipe supporting factor(C) reaches it's lowest value (0.91) when the wave speed increase with the thickness pipe material .

When the wave speed and the pipe length are known, it will become easy to calculate the critical time depending on general speed equation see figure (1).

Estimating surge pressure

At the beginning we will use Joukowsky equation to estimate the pressure change Δp_{Jou} in a fluid caused by an instantaneous change in flow velocity Δv as follows:

$$\Delta p_{Jou} = \rho . a . \Delta v \qquad \text{.................}3$$

Δv: Flow velocity change in (m/s).

ρ: Density of the fluid in (kg/m^3).

a: Wave propagation velocity through the fluid in the pipeline in (m/s), where a= (L/t).

Δp_{Jou}: pressure change in (N/m^2).

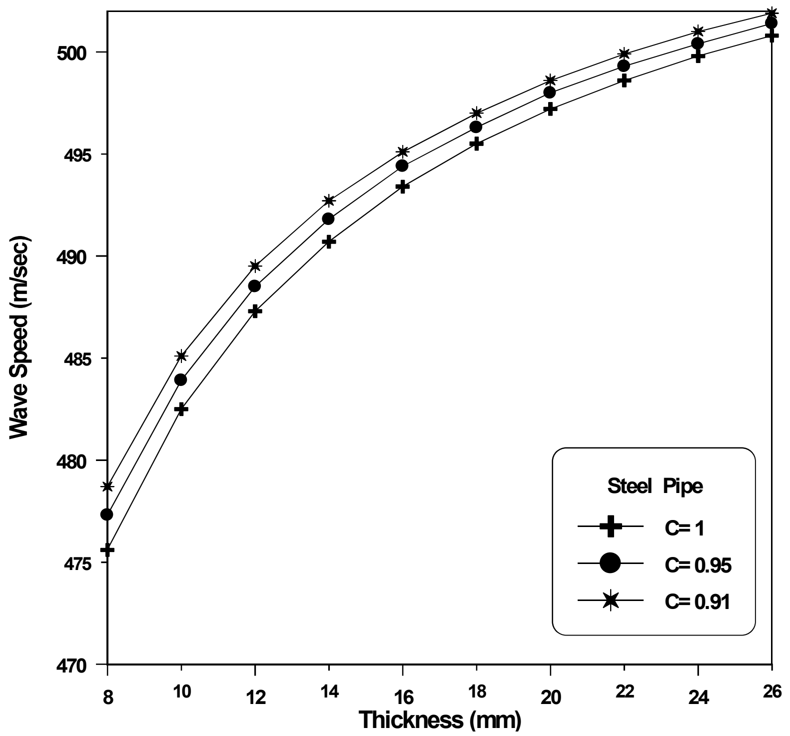


Fig. (2) The Relation between Wave Speed and Thickness for Carbon Steel Pipe

The Δp_{Jou} formula is referred to as the Joukowsky equation. As well as Δv, equation (3) contains the density ρ and wave propagation velocity a. The relationship only applies to the period of time in which the velocity change Δv is taking place. If Δv runs in opposite direction to the flow, the pressure will rise, otherwise it will fall.

Joukowskys equation was used to determine the pressure surge as in case (1) where the following values were assumed: ρ=850 kg/m^3, L=100 km, u=2.5, s2, 1.5/sec, Δp (bar)

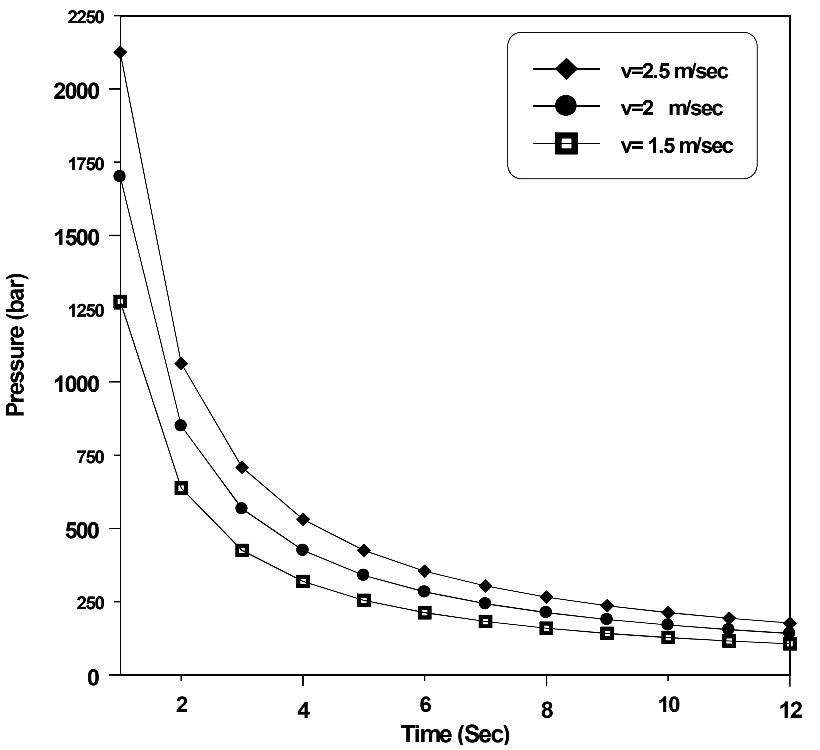


Fig. (3) The relation between time and pressure at different velocities

It can be seen from figure (3) that as the time of closing increases the pressure will decrease at constant length and different velocities also three different velocities were taken the maximum was 2.5 (m/sec) then the surge pressure reached higher values approximately above 2000 bar and at minimum velocity 1.5

(m/sec) the pressure decreased gradually which indicates that when the velocity is decreasing we can mitigate or avoid the surge pressure phenomenon.

Experimental Part

System description:

The length of system is 6 m , it contains 7 pressure gauges , there is 55 cm distance between each gage and 2 gauges before the main gage .the system also contains: two tanks the volume of each tank is 30L ,two pumps the flow rate of each one is 55 (L/min) , three pipes each pipe is 6 m length with three diameters (1”, 3/4”, 1/2’’) respectively and there is main valve to control the pumped fluid as shown in figure (4).

Fig. (4) The Experimental System

Procedure

1. 60 L of crude oil was prepared after the system was cleaned then we began to record the results
2. 0.5 inch pipe diameter was used, the readings were taken while the valve was opened (0%, 25%, 50%, 75%, 100%) from the pipe diameter.
3. 0.75 inch pipe diameter was used, the readings were taken while the valve was opened (0%, 25%, 50%, 75%, 100%) from the pipe diameter.
4. 1inch.pipe diameter was used, the readings were taken while the valve was opened (0%, 25%, 50%, 75%, 100%) from the pipe diameter.
5. 60 L of gas oil was prepared. after the system was cleaned the gas oil in it then we begin to record the results
6. 0.5inch.pipe diameter was used, the readings were taken while the valve was opened (0%, 25%, 50%, 75%, 100%) from the pipe diameter.
7. 0.75inch. pipe diameter was used, the readings were taken while the valve was opened (0%, 25%, 50%, 75%, 100%) from the pipe diameter.
8. 1inch.pipe diameter was used, the readings were taken while the valve was opened (0%, 25%, 50%, 75%, 100%) from the pipe diameter.

Results and discussion

The experimental work was achieved on two stages:-

The first stage included taking 60L of crude oil and its description in table (1). The tables (2-4) shows the test results of crude oil for the three different pipe diameters ½ (3/4,1) inch pipe diameter ,from these results we can see that the pressure increase when the valve opening is decrease as for gas oil the results are shown in tables from (5-8).

Table (1) The Standard Analysis of Crude Oil

No.	Test	Results		Price ID/ Test
		Sample No.		
		1	لا تاكدية الفحص	
1	Density @15.6° C gm/ cm^3	0.93848	± 0.00002	
2	Density @25°C gm/ cm^3	0.93242	± 0.00001	
3	Density @30°C gm/ cm^3	0.92641	± 0.00002	
4	API	19.126		
5	Viscosity @ 40 °C (cst)	60.98138		
6	Viscosity @ 100 °C (cst)	8.639088		

Crude oil

Table (2) Pressure gradient according to percentage valve opening for ½inch.pipe diameter

Pressure Grad.	% valve opening				
	100%	75%	50%	25%	Closed
P1	16 Psi	17 Psi	22 Psi	34 Psi	41 Psi
P2	16 Psi	17 Psi	23 Psi	35 Psi	43 Psi
P3	14 Psi	16 Psi	23 Psi	36.5 Psi	45 Psi
P4	12 Psi	14 Psi	22 Psi	35 Psi	44.5 Psi
P5	10 Psi	13 Psi	21.5 Psi	35 Psi	44 Psi
P6	8 Psi	12 Psi	21 Psi	35 Psi	44 Psi
P7	7 Psi	11 Psi	21 Psi	35 Psi	44 Psi
P8	5.5 Psi	9 Psi	20 Psi	33.5 Psi	43.5 Psi

Crude oil

Table (3) Pressure gradient according to percentage valve opening for 3/4inch.pipe diameter

Pressure Grad.	% valve opening				
	100%	75%	50%	25%	Classed
P1	9 Psi	non Psi	non Psi	non Psi	non Psi
P2	9 Psi	non Psi	non Psi	non Psi	non Psi
P3	7 Psi	10 Psi	18 Psi	27.5 Psi	38 Psi
P4	6 Psi	9 Psi	16.5 Psi	26 Psi	37 Psi
P5	5 Psi	8 Psi	16 Psi	25 Psi	36 Psi
P6	3 Psi	6 Psi	15 Psi	24 Psi	36 Psi
P7	2 Psi	6 Psi	15 Psi	24 Psi	36 Psi
P8	2 Psi	6 Psi	15 Psi	24 Psi	36 Psi

Crude oil

Table (4) Pressure gradient according to percentage valve opening for 1inch.pipe diameter

Pressure Grad.	% valve opening				
	100%	75%	50%	25%	Closed
P1	non Psi	non Psi	non Psi	non Psi	non Psi
P2	5 Psi	6 Psi	9 Psi	22 Psi	35 Psi
P3	3 Psi	3 Psi	7.5 Psi	21 Psi	35 Psi
P4	4 Psi	4 Psi	9 Psi	23 Psi	37 Psi
P5	2 Psi	3 Psi	7.5 Psi	22 Psi	36 Psi
P6	0 Psi	0.5 Psi	6 Psi	2 0 Psi	35 Psi
P7	0 Psi	0.5 Psi	6 Psi	20 Psi	35 Psi
P8	0 Psi	0.5 Psi	6 Psi	20 Psi	34 Psi

Gas oil

Table (5) Pressure gradient according to percentage valve opening for ½inch pipe diameter

Pressure Grad.	% valve opening				
	100%	75%	50%	25%	Closed
P1	8 Psi	13 Psi	20 Psi	30 Psi	40 Psi
P2	8 Psi	13 Psi	20 Psi	30 Psi	40 Psi
P3	7 Psi	12 Psi	20 Psi	30 Psi	40 Psi
P4	6 Psi	12 Psi	18 Psi	29 Psi	39 Psi
P5	6 Psi	12 Psi	18 Psi	29 Psi	39 Psi
P6	5 Psi	10 Psi	16 Psi	29 Psi	39 Psi
P7	4 Psi	9 Psi	16 Psi	29 Psi	39 Psi
P8	3 Psi	8 Psi	15 Psi	28 Psi	38 Psi

Gas oil

Table (6) Pressre gradient according to percentage valve opening for 3/4inch pipe diameter

Pressure Grad.	% valve opening				
	100%	75%	50%	25%	Closed
P1	2 Psi	8 Psi	25 Psi	38 Psi	40 Psi
P2	2 Psi	8 Psi	25 Psi	38 Psi	40 Psi
P3	1 Psi	8 Psi	25 Psi	38 Psi	40 Psi
P4	1 Psi	8 Psi	24 Psi	37 Psi	40 Psi
P5	1 Psi	7 Psi	24 Psi	37 Psi	40 Psi
P6	0 Psi	6 Psi	24 Psi	36 Psi	40 Psi
P7	0 Psi	6 Psi	23 Psi	36 Psi	39 Psi
P8	0 Psi	6 Psi	22 Psi	35 Psi	39 Psi

Gas oil

Table (7) Pressure gradient according to percentage valve opening for 1inch.pipe diameter

Pressure Grad.	% valve opening	
	75%	50%
P1	2 Psi	8 Psi
P2	2 Psi	8 Psi
P3	1 Psi	6 Psi
P4	1 Psi	6 Psi
P5	0 Psi	5.5 Psi
P6	0 Psi	5.5 Psi
P7	0 Psi	4 Psi
P8	0 Psi	4 Psi

Gas oil

Table (8) Pressure gradient according to percentage valve opening for 1/2inch pipe diameter

Pressure Grad.	% valve opening	
	25%	closed
P1	20 Psi	40 Psi
P2	20 Psi	40 Psi
P3	19 Psi	49 Psi
P4	22 Psi	42 Psi
P5	20 Psi	41 Psi
P6	20 Psi	41 Psi
P7	19 Psi	40 Psi
P8	19 Psi	40 Psi

Conclusion

1. From the experimental part, it is observed that when the pipe's hole is decreasing, the pressure will increase above the maximum allowable pressure. For crude oil and gas oil for different pipe diameters for example (for 1inch pipe diameter for crude oil) when the valve was closed the pressure reached its maximum value 35 psi and when it was fully opened the pressure decreased to 5psi.
2. The valve closing time and velocity of flowing fluid are important elements of controlling surge, when the time of closing increases the pressure will decrease at constant length and different velocities.
3. Surge can also increase depending on wave speed which will in turn increase with increase of pipe thickness and decreasing pipe supporting factor.
4. Using Devices in the System to Mitigate Surge is necessary as: surge relief valve, accumulators …ect.
5. Controlling fluid speed from not becoming too high to avoid wave speed through closing the valve, the appropriate velocity is (2-2.5) m/sec.
6. Avoid sudden closure of valves and practicing gradual opening and closing to avoid surge pressure.

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