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Research paper

Pressure Wave Elimination in Iraqi Crude Oil Pipelines Using Novel Porous Filter and Electronic Control System

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Abstract

The pressure wave is a serious problem in crude oil transportation pipelines. It is generated at the beginning and at the end of crude oil pumping process or as a result of sudden closing of valves. The high turbulence fluid particles in presence of pressure wave resulting in sever stresses on pipe walls needing for maintenance and replacement after a period of time. It is also leading to dissipation of flow energy consuming much more power for oil pumping. The objective of the present work is to decrease and eliminate the pressure wave in Iraqi crude oil pipelines through designing, manufacturing, and testing of a novel pressure wave filter with optimum design. The experimental system consists from: porous filter, oil pipe, pump, AC drive, and digital pressure transducers. The porous filter that was tested to eliminate the pressure wave is composed from various pipes (0.5 inch Perspex pipe, 1 inch PVC pipe, and 2 inches stainless steel pipe) with different porous materials to absorb the pressure energy from the fluid particles. These porous media are (1.5cm, 1cm, 0.4cm glass beads, and glass cylinders of 2cm length, 2cm outer diameter, and 2mm thickness). The experimental results proved the successful of the invented porous filter for eliminating the pressure wave by 99% using optimum design without suppressing the flow rate of crude oil in the pipe. The results obtained are quite significant since it awards a simple and low-cost solution for a real and practical problem in crude oil transportation sector.

Keywords: *Pressure wave; porous filter; crude oil; Fluid flow; Pumping energy.*

1. Introduction

The transportation of crude oil through pipelines is considered as a cheapest and safest method especially when exporting for neighboring countries **[1, 2, 3].** These pipelines suffer from sever pressure wave propagation inside crude oil flow. The pressure wave is generated at the beginning and immediate shut down of crude oil pumping process or as a result of a sudden closing of valves **[4, 5, 6].** The high turbulence and randomness of fluid particles in presence of pressure wave resulting in sever stresses on pipe walls needing for maintenance and replacement after a period of time. It is also leading to dissipation of a crude oil flow energy consuming much more power for oil pumping **[7, 8, 9, 10].** The current techniques that have been used in Iraqi pipelines company are using of tanks for collecting the oil to overcome the pressure wave problem, that means a time delay in oil transportation in addition to inerrability of the method for long transportation pipelines. Another technique is installing of pressure sensors along the pipe to control the pressure and discharging when needed; the method is suitable for internal pipes **[11].** The studies for solving the pressure wave problem are still limited in spite of its importance **[11, 12, 13,] Hyoung Jinkim et al. (2012) [14]** investigated the effect of closing the valve and its control, two pressure waves are produced at each end the first wave propagate to ward to the other end. Also, they studied experimentally and numerically the rapid transients in water distribution system, including back flow prevention assemblies. **Tehuan Chen et al. (2015) [15]** considered a suboptimal limit control trouble for fluid pipe line switch terminal sluice control in order to reduce the pressure oscillation during valve closing, so that mitigating pressure wave effects. The numerical score demonstrated the ability of optimal boundary control to significantly decrease pressure oscillation. **Mohammad Pournazeri et al. (2017) [16]** tested the pressure wave on the pump elevation pipeline system with an air chamber. The Hydraulic transit was simulated using the method of characteristics. The computer program developed was helpful in modeling the optimum parameters. **Tangtao Feng et al. (2017) [17]** studied the pressure wave caused by system apparatus closing or opening. A coupling scheme is put to analyze the pressure wave in a parallel pump-valve frame work. Through the period of pumps start, three pressure waves occurred, and the mechanical loading oscillated constantly after 12 s. **Helio Matos et al. (2018) [18]** used polyurethane of 1:1 volume ratios as a likely energy mitigation mechanism. Two high-speed cameras are utilized to capture the collapse structures while 7dynamic pressure transducers measured the emitted pressure oscillation. The energy of the implosion's high-pressure pulses, existing at the confinement's closed end, was larger than the energy of the fulminatory itself because of the pressure wave impact. **Sławomir Henclik (2018) [19]** studied the influence of dynamic fluid-structure interaction (FSI) onto the course of pressure wave which is important in non-rigid pipeline frame work. The gist of this influence is the dynamic transfer of liquid energy to the pipeline structure and back, that is significant for elastic structures and can be negligible for rigid ones. The transient is created by a fast closing of valve installed at the end of the pipeline. FSI influence is assumed to be present mainly at the valve. Such a system, elastically attached close valve in a pipeline or another, equivalent design can be a true solution applicable in practice. **Sławomir Henclik (2018) [20]** proposed a numerical approach to the four-equation model of pressure wave for fluid–structure interaction (FSI). An algorithm for numerical solution of that model in time domain depends on the method of characteristics (MOC) is proposed. It was set up that proper option of support parameters may produce respectable reduction of pressure wave amplitudes, fundamentally due to effective energy absorption and dispersion at the supports. The aim of the present work is to reduce and eliminate the pressure wave in external Iraqi crude oil pipelines through designing, manufacturing, and testing of a novel porous filter with optimum design installing inside the oil pipe.

2. Pressure Drop Governing Equations

The Bernaulli equation application for a pipe is

$$\frac{dp}{\rho} + gdz + vdv = 0 \qquad (1)$$

for constant density

$$\frac{p}{\rho} + gz + \frac{v^2}{2} = constant \qquad (2)$$

The integration constant called Bernaulli constant

divide Eq. (2) by g yeilds

$$z + \frac{p}{\gamma} + \frac{v^2}{2g} = constant \qquad (3)$$

since

$$\gamma = \rho \times g$$

then

$$z_1 \frac{p_1}{\gamma} + \frac{v_1^2}{2g} = z_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g} \qquad (4)$$

orizontal pipe with no elevation change , thus Eq.(4) For h becomes

$$\frac{p_1 - p_2}{\gamma} - \frac{v_1^2 - v_2^2}{2g} = 0 \qquad (5)$$

Eq.(5) represents the pressure difference between two points in a horizontal pipe.

3. Materials and Methods

3.1 Materials

The materials used in the experimental work are Iraqi crude oil, and porous media. Experimental work was carried out on crude oil supplied from AL-Doura Refinery/ Baghdad- Iraq. The physical properties are shown in table (1).

Table (1): Properties of crude oil supplied from Al-Doura refinery.

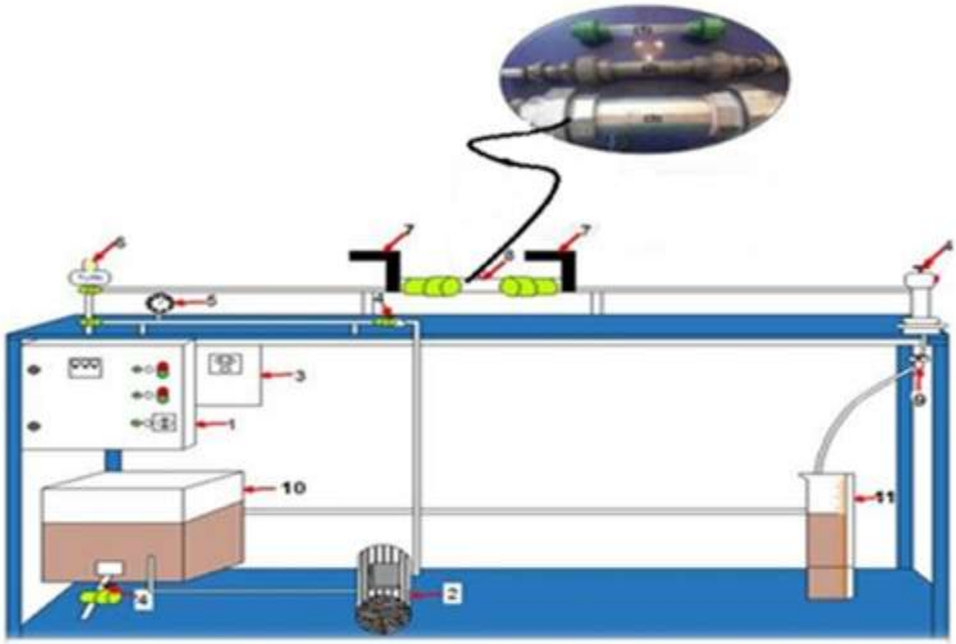
Properties of crude oil	
API Gravity at 15°C	31.6
Specific Gravity at 15°C	0.8676
Density at 15°C (g/cm^3)	0.8671
Kin. Viscosity at 37.8°C (cSt)	7.9
Sediment (vol%)	0.1
Water content (vol%)	Traces

3.2 Experimental System

The experimental system has been made up of: oil pump, oil pipe made from Perspex with inside diameter of 0.5 inches, PVC with 1 inches and stainless steel with diameter of 2 inches, and 2m length, solenoid valve, and control unit (relay, power supply, timer, and digital reader), measuring equipment are digital pressure transducers and graduated cylinder. Their specifications are recorded in table 2. Figure 1, displays the schematic diagram of the experimental rig. In the center of the oil pipe, the porous filter has been installed; it consists mainly from a tube with a diameter of (0.5, 1, and 2 inches) and 18 cm length. Glass beads are placed inside it at different diameters tested as porous material that absorbs the kinetic energy of the liquid particles. Porous materials which were used are: glass beads with diameters of 1.5, 1, and 0.4 cm. Glass cylinder with diameter of 2cm, length 2cm and thickness of 0.2cm was also used and examined. There was a stainless-steel mesh surrounded the porous material in the wave filter. The value of the pressure was measured before and after the filter using high precision sensors that were connected to a device that converts the electrical signal to a pressure reading in bar, which were converted online to the computer as a pressure readings and graphs. Several variables were tested to reach the optimal performance of the system; the filter diameter and optimum diameter selection were tested so that the presence of the filter did not cause a reduction in oil flow rate. AC drive was used to adjust the pumping time to a required value. The experiments have been done to examine the effect of the 3 operating variables (operating pressure: from 1 to 5 bars, oil pumping time: from 2 to 8 seconds using different porous materials. All experiments have been done in constant temperature of about 30 °C.

Table (2): Specifications of experimental devices.

Device	Specifications
Solenoid Valve	
Model	RAO32DA09036000/74505
Air supply	4-8 Bar
Mounting part	ISO 5211
Oil Pump	
Model	WCD75
Flow	50 L/min
Size	25 mm
Head	30 m
Pressure Transducers	
Model	CPC6000/Barometer
Rang	0 -10 bar
Out /Gnd	4 – 20 mA
AC Drive	
Input	200-230 V,1phase, 16 A, 50-60 HZ
Output	0-Input V ,3 phase, 8 A,0.01-400 HZ, 2HP-1.5 KW



1- Control unit, 2- Pump, 3- Ac drive, 4-Valve, 5-pressure gauge, 6- Electrical valve, 7- Pressure transducers, 8- Porous filter (0.5, 1, and 2 inch diameter), 9- Oil valve, 10- Tank, 11-Cylinder.

Figure 1: Schematic diagram of the experimental system.

4. Results and Discussion

A number of variables affecting the operation of the system, such as the diameter of the filter, the type of porous material, as well as the operation time and pressure of the pump have been tested. A large number of practical data have been obtained in order to achieve the optimum conditions for eliminating the pressure wave without adversely affecting the oil flow rate in the pipe. The following are some of the experimental results obtained with discussions.

4.1 Effect of filter diameter and porous material type:

Figure 2, shows the pressure wave in the pipe without installing of porous filter. It can be clearly shown that the pressure wave is obvious and the flow is in high disturbance due to pressure fluctuation when the pressure wave filter is not employed.

Figure 3, shows the pressure readings when installing the pressure wave filter of 0.5 inch diameter and 0.1 cm glass beads porous material. Point 1 and 2 represent filter entering and filter exit locations respectively. From the figure it can be noted a significant fluctuation in the value of pressure with time before entering the filter (p1). After the exit of crude oil from the porous filter, we note the stability in the value of measured pressure (p2), which proves the effectiveness of the innovative pressure filter in eliminating the pressure wave by 100%, but there is a problem of high pressure drop in the flow (about 12 mpa) resulting in flow reduction by 60%.

The pressure wave when using porous filter of 0.5 inch diameter and 2.2 cm glass beads is shown in figure 4. From the figure it can be noted a reduction in pressure fluctuations, which proves the effectiveness of the innovative pressure filter in eliminating the pressure wave by 100%, but there is a problem of high pressure drop in the flow (about 10 mpa) resulting in flow reduction by 50%. Porous filter of 1 inch diameter with glass beads of 11.4 cm resulting lower pressure drop as shown in figure 5. The value of pressure drop is 2 mpa and flow reduction of 30% with pressure wave elimination of 80%. From the results it can be concluded that increasing the filter diameter and using a glass cylinders (outer diameters equal to 2 cm and thickness of 2 mm and length of 2 cm) contributes in decreasing the pressure drop to minimum values and eliminating of the pressure wave by 99% without affecting the flow rate of crude oil in the pipe. The results are shown in figure 6 where this design of the filter is considered as an optimum design. Glass cylinders absorb the pressure energy of liquid particles by affecting as a porous media with minimum flow obstruction and less pressure drop.

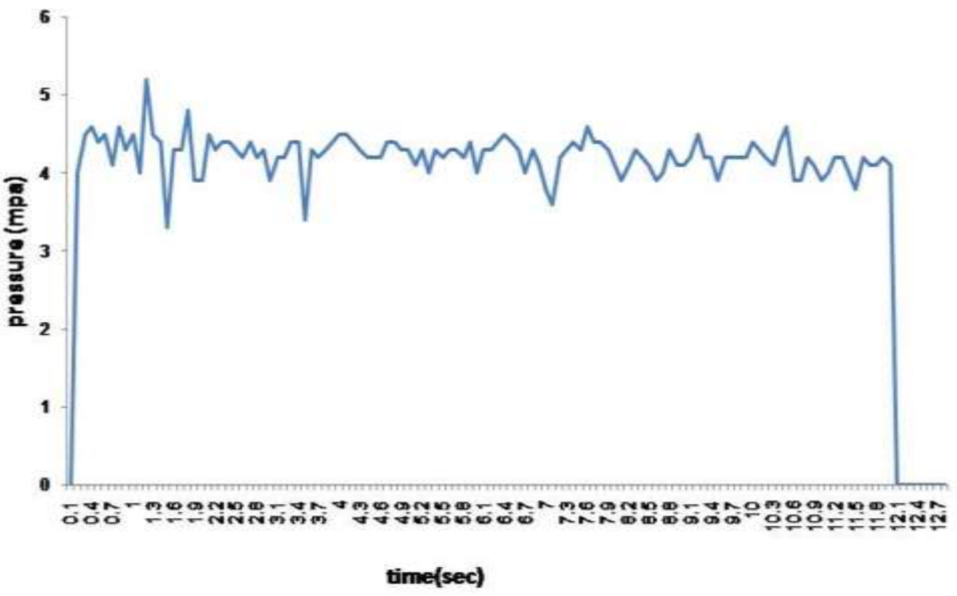


Figure 2: Pressure wave in oil pipe without using pressure wave filter.

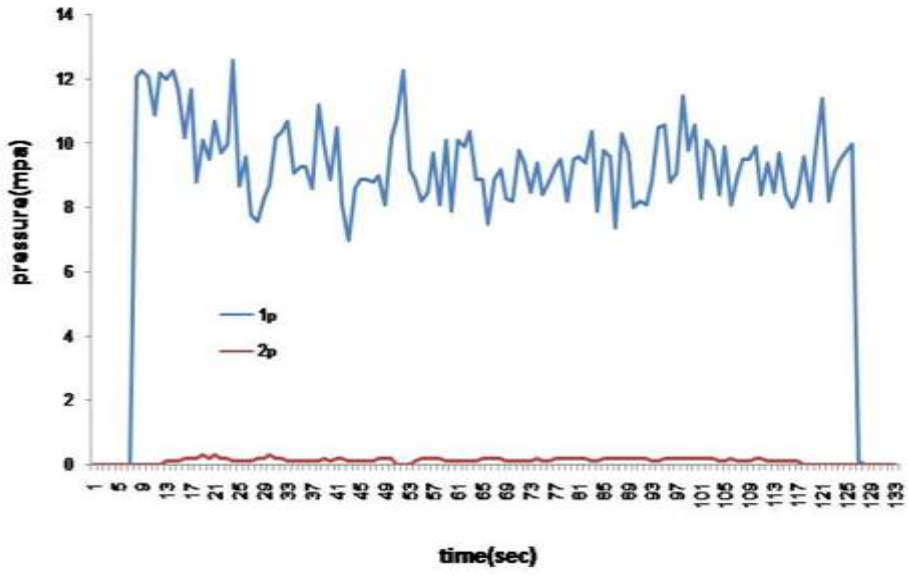


Figure 3: Pressure wave in oil pipe using pressure wave filter of o.5 inch diameter with 1.5 cm glass beads (p1 before filter and p2 after filter) at 1 bar and 2 minutes operating conditions.

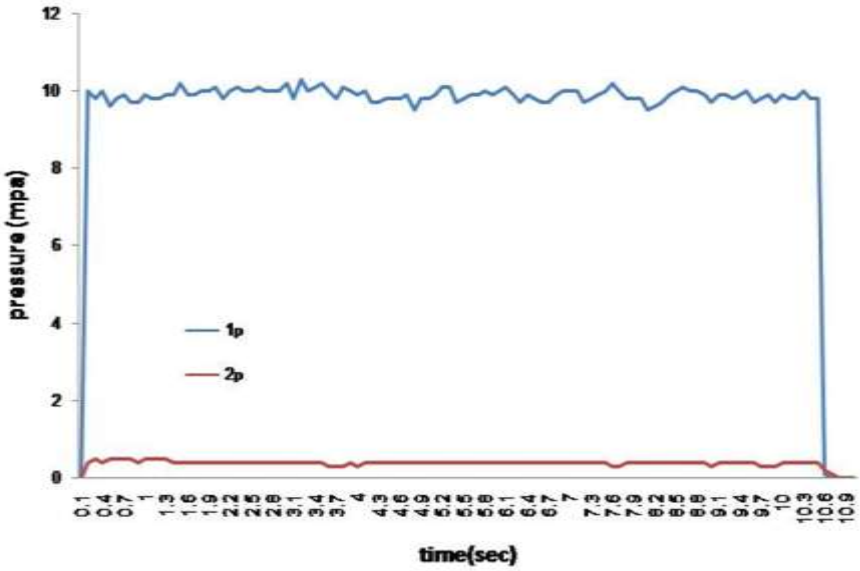


Figure 4: Pressure wave in oil pipe using pressure wave filter of 1 inch diameter with 2.2 cm glass beads (p1 before filter and p2 after filter) at 1 bar and 2 minutes operating conditions.

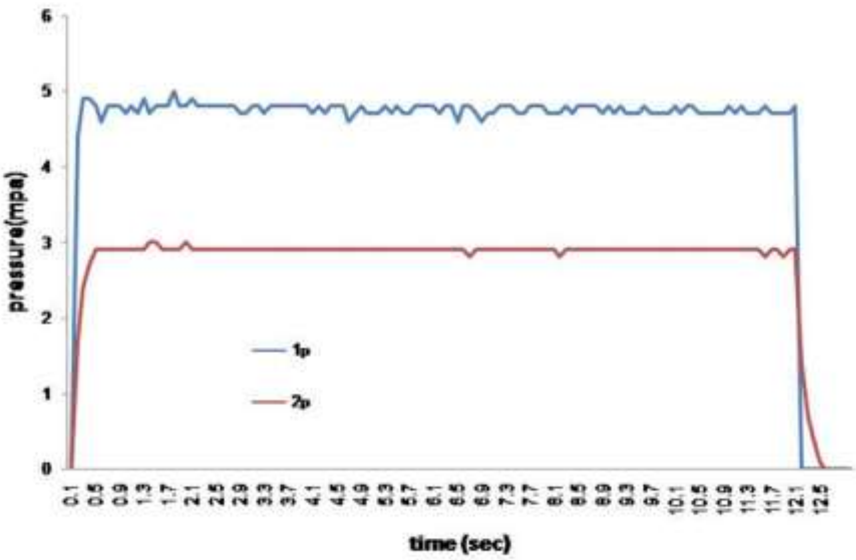


Figure 5: Pressure wave in oil pipe using pressure wave filter of 2 inch diameter with 0.4 cm glass beads (p1 before filter and p2 after filter) at 1 bar and 2 minutes operating conditions.

4.2 Effect of Operating Pressure

The impact of operating pressure on pressure wave elimination has been tested using optimum design. The results are shown in figures (6- 9). From the figures it can be observed that the pressure wave was eliminated by a percent of 99.8% at 1 bar, 98.5% at 2bar, 98% at 3bar, and 98% at 4bar. All results are without any pressure drop and without any impact on flow rate and crude oil pumping power consumption, therefore, the results is acceptable from practical point of view.

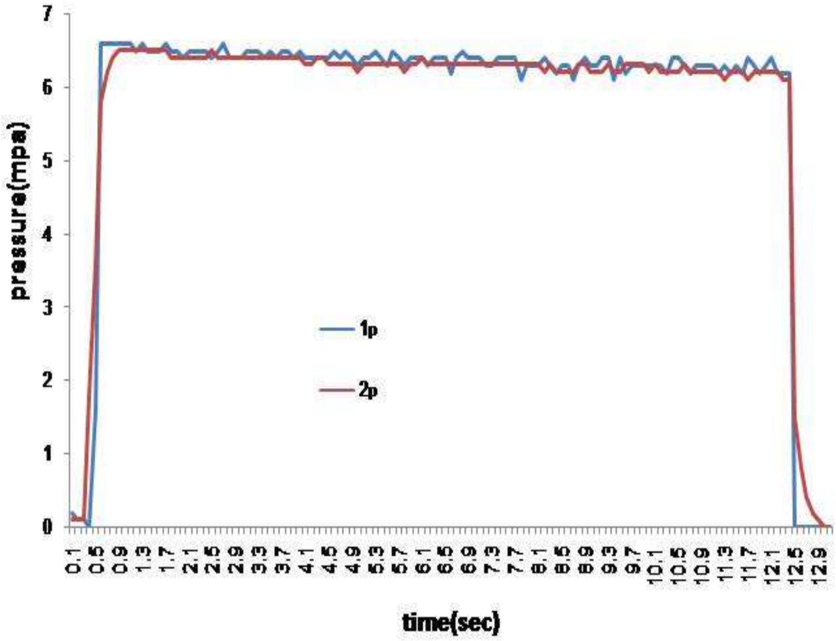


Figure 6: Pressure wave in oil pipe using pressure wave filter of 2 inch diameter with glass cylinders porous material (optimum design) at 1 bar and 2 minutes operating conditions.

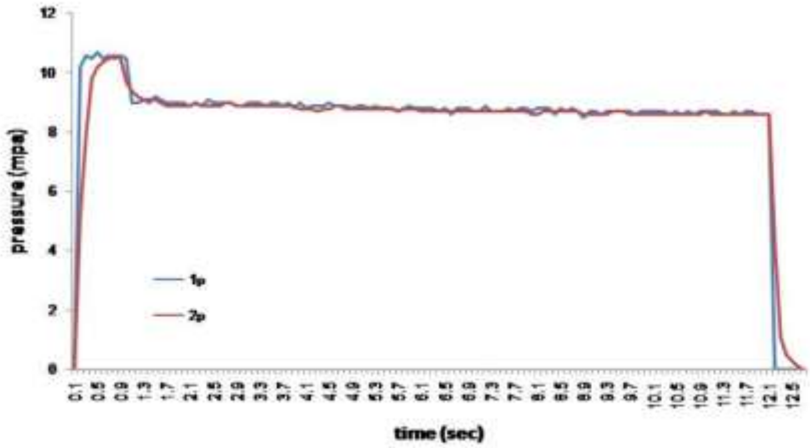


Figure 7: Pressure wave in oil pipe using pressure wave filter of 2 inch diameter with glass cylinders as porous material (optimum design) at 2 bar and 2 minutes operating conditions.

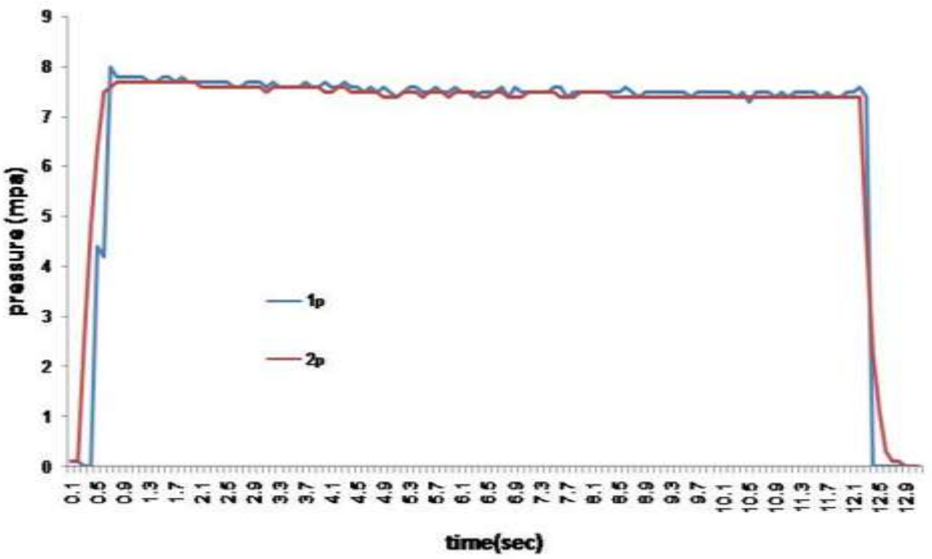


Figure 8: Pressure wave in oil pipe using pressure wave filter of 2 inch diameter with glass cylinders as porous material (optimum design) at 3 bar and 2 minutes operating conditions.

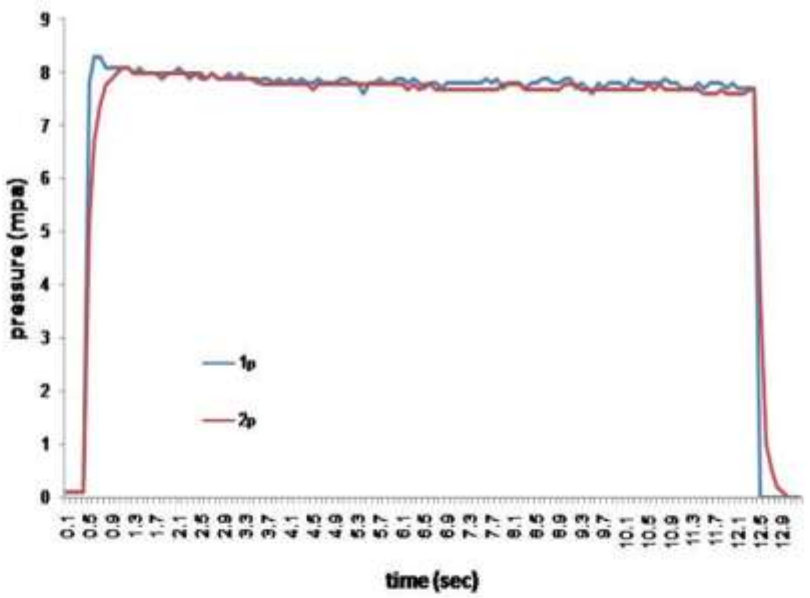


Figure 9: Pressure wave in oil pipe using pressure wave filter of 2 inch diameter with glass cylinders as porous material (optimum design) at 4 bar and 2 minutes operating conditions.

4.3 Effect of Operating Time

The impact of time intervals from 2 minutes to 8 minutes is represented in figures (10-12) for 4bar operating pressure. The results are explained for optimum design; the results show a negative impact of the time for pressure wave elimination at elevated pressure (4bar), since at 2 min, the pressure wave elimination is 95%, while at 4 min, 6 min, and 8 min, the percent is not exceeding 85%.

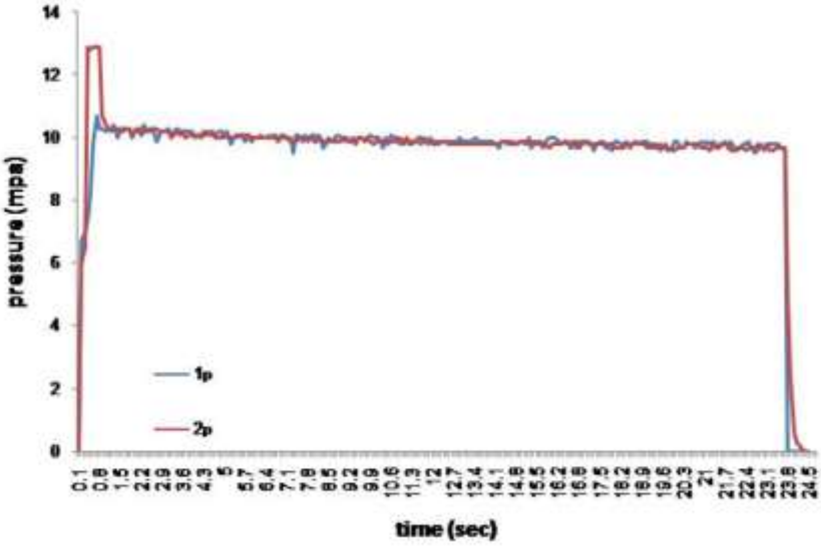


Figure 10: Pressure wave in oil pipe using pressure wave filter of 2 inch diameter with glass cylinders porous material (optimum design) at 4 bar and 4 minutes operating conditions.

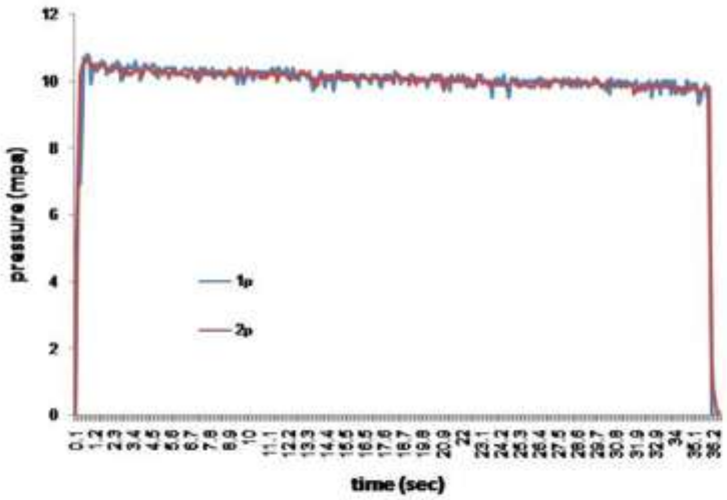


Figure 11: Pressure wave in oil pipe using pressure wave filter of 2 inch diameter with glass cylinders porous material (optimum design) at 4 bar and 6 minutes operating conditions.

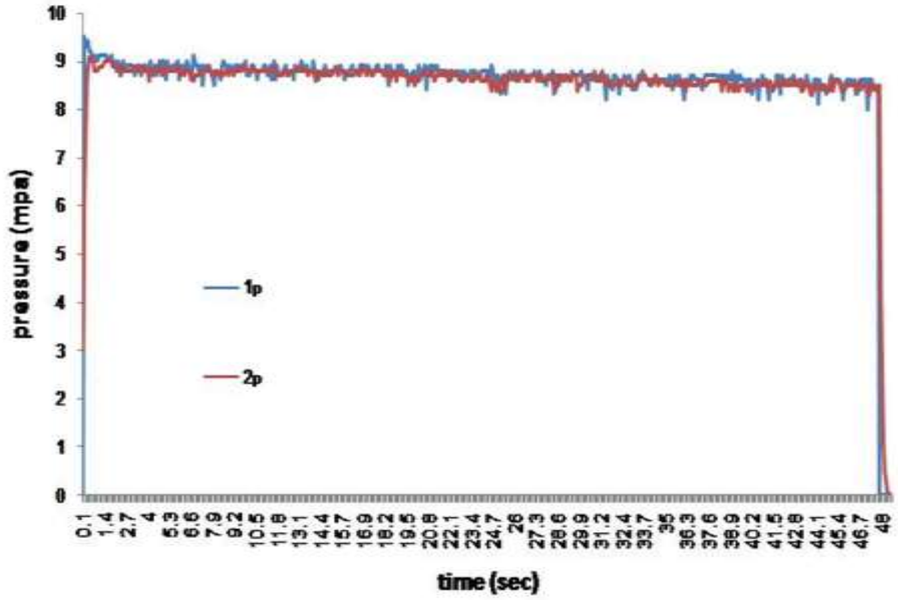


Figure 12: Pressure wave in oil pipe using pressure wave filter of 2 inch diameter with glass cylinders porous material (optimum design) at 4 bar and 8 minutes operating conditions.

5. Conclusions

Pressure wave in external crude oil pipelines has become a serious problem especially in oil exporting pipes whereas considered as major energy consumption for oil pumping and a source of pipe damage. The technologies for pressure wave elimination are almost energy consumer methods. The porous filter with optimum design proposed in this study proved to be a good solution for the problem since it has no energy utilizes and may not cause any delay in oil exporting as compared with recently applied methods. The proposed novel pressure wave filter is able to eliminate the pressure wave in crude oil pipe by 99% without pressure drop in liquid flow. The method is considered as economic and environmentally friendly.

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List of symbols

p	Pressure (dyne/cm^2)
ρ	Density (gm/cm^3)
$\boldsymbol{\upsilon}$	Velocity (cm/s)
g	Gravity acceleration (cm/s^2)
z	Height (cm)

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