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Experimental investigation into the effect of erosion and corrosion in pipes conveying fluid on its frequencies

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Abstract
Pipes conveying fluid have many uses and the danger increases as the fluid is more likely to burn in the event of contact with the atmosphere, especially in oil installations. Many of the problems occurred due to the erosion and corrosion caused large explosions and many losses. For example, the fire and explosion in Chevron Richmond refinery in California. From this example and others, the idea of detecting erosion was introduced using vibration sensors. In this paper, proposed by the researchers an experimental method for detecting chemical corrosion and erosion caused by the flow of fluid inside the pipe in addition to the effect of external conditions in Al-Najaf Refinery. The examination was carried out by followed pipe (154.06mm) internal diameter, (168.28mm) external diameter and (7.11mm) thickness. The pipe specifications were ASTM\ASME A106 Grade B Sch40, 210Mpa modulus of elasticity and $7.85\times10^3 Kg/m^3$ density. The pipe conveying RCR fluid and fixed with simply-supported ends. The focus was on a 10-meter pipe length. Also, the thickness of the pipe measured by Ultrasonic Thickness Gauge, and the frequency measured by Digital Vibration Meter, and the fluid velocity measured by Ultrasonic Flow-meter. The required values were examined every three months within five years in the same velocity and by keeping it within the limits of laminar flow. By followed up and studied the draw diagrams to find the search results, it has been shown that decreasing the thickness of the pipes over time due to erosion corrosion gives an increase in the frequency of the pipe transmitted fluid. This was evidence of the possibility of getting an indicator of erosion and corrosion through the pipes vibration. Where, the sensitivity of the frequency increase was indicated by the decrease in the thickness of the pipe due to the erosion and corrosion of the pipe wall. The percentage increase of frequency between the standard pipe without erosion and corrosion and the pipe after 5 years is 3.91%.

Keywords: Corrosion; Erosion; Frequency; Pipe thickness.

1. Introduction
There are many uses for pipes transmit fluid for example, oil transport pipelines, water vapor pipes and power plant pipes. In general, most pipes suffer from corrosion due to chemicals and erosion due to fluid flow or both. Through the search in documents of pipelines carrying oil products, we found that there are many large problems due to corrosion erosion, for example, The Chevron Richmond refinery in California. Carriage fuels such as gasoline, diesel and lubrication oils. The refinery capacity 250,000 barrels per day.

The unit of crude was operating usually, the operator was on his usual tour, when he noticed a leakage from an insulated 8-inch pipe of light gas oil pipe. The fluid temperature of 337 C°. The production manager decided not to shutoff the unit due to small leakage. A decision was made to remove the insulation first. After the insulation was removed, hydrocarbon gas began to spread. The corrosion of the pipe thickness was so great that it could not withstand the pressure of the fluid in it, which caused a sudden collapse in the pipe walls after the extinguishing of the firewater as a precautionary measure taken by the officials. Hydrocarbon ignites when mixed with air.

M. R. Ismail [1], noted that this is not the only the factor that affecting on the frequency, there is also the flow of fluid transferred and fixations, and has received on the analytical equations for the extraction of natural frequency of many types of fixations. There was actually a match between mathematical results and practical results.

Kochupillai J. et. al, [2], introduced Finite Element methods to examine the parametric instability of thin pipe containing pulsating fluid flow by using multivariable Floquet–Lyapunov theory for shells.

Qing-fang G. et. al, [3], studied the vortex-induced vibration problem in shell pipes conveying fluid .The fixed- point principle in was employed in the investigation. The existence condition of the periodic solution as well as the region of parameters for instability was given.

A theoretical investigation of the free vibration characteristics of a gas pipeline model was studied by EI-A. El-Kafrawy et. al, [4], the model is supported-end using anchors. The solution is based on the finite element method by the PC software "CAEPIPE". The natural frequencies and 20 mode shapes of a supported-end buried gas pipeline model are calculated. The analysis reveals that the first two mode shapes are the more dangerous natural frequencies of the pipe line system, lies between 30 and 50Hz which can be excited through an excitation of an actual or a real object with the rotating speed between (2000 and 3000) rpm. One can see that these mode shapes present the following types of the piping vibration of lateral, longitudinal and torsion vibration.

A pipe conveying fluid with a sudden contraction and with the effect of heat flux combined with vibration on these pipes was studied by I. M. H. Al-Sodain, [5]. Several end pipe supports (simply, flexible, fixed) were adopted. A mathematical model was developed using the transfer matrix method solved by a computer program in MATLAB 6.5 to show the effect of vibration and the effect of implementing different values of heat flux on pipes conveying fluid with a sudden contraction.

A pipe conveying fluid combined with vibration on these pipes was studied by M. I. Salim, [6]. The effect of support type (flexible, simply and rigid) on the natural frequency and corresponding mode shape of a straight pipe conveying laminar flowing fluid was studied. Also, the effect of some design parameters like pipe diameter, wall thickness, pipe material, and the effect of fluid velocity were investigated for Reynolds number ranging between (250 to 1500).

Finally, at 2017 M. A. Al-Baghdadi et. al, [7], investigation the effect of sand transportation on the erosion severity in 3-D elbow. Where the investigation included study the problem by using CFD technique by using finite element technique. Then, at, 2018, [8], development it paper and investigation the effect for various parameters, as temperature; viscosity; density… etc., on the erosion for elbow. Also, other damage effect on pipe behavior as vibration pipe were investigation by multi researchers with various techniques, as experimentally, [9-10], and analytically, [11], techniques. Then, prediction for pipe defect by variable of frequency for pipe.

Since, the change in structure frequency are given indicate for defect occurred, [12-19], then can be predication for corrosion pipe by measuring the natural frequency of its pipe, and see the change for its frequency. Then, in this paper investigation experimentally the predication for corrosion pipe by change of frequency pipe. Then, evaluated chart given the relation between corrosion pipe and pipe frequency.

Since the results for experimental technique can be dependent to given the behavior for engineering problem, [20-28], and its results did not necessary comparison with other results evaluating by other techniques, [29-36], then, the investigation for pipe frequency with corrosion behavior can be evaluating by using experimental technique only.

2. Experimental work

In this work the R.C.R. fluid is chosen, the pipe was (154.06mm) internal diameter, (168.28mm) external diameter and (7.11mm) thickness. The pipe specifications were ASTM\ASME A106 Grade B Sch40, 210Mpa modulus of elasticity and $7.85\times10^3 Kg/m^3$ density, and fixed with simply-supported ends as shown in Figure 1.

Figure 1. The pipe is fixed with simply-supported ends.

Also, the thickness of the pipe under operation measured by Ultrasonic Thickness Gauge. And the frequency measured by Digital Vibration Meter. And the fluid velocity measured by Ultrasonic Flow Meter. The equipment used is approved by the Iraqi Ministry of Oil to measure quantities. The required values were examined every three months within five years in the same velocity and by keeping it within the limits of laminar flow. The explanation of equipment used in this work was:

2.1 Ultrasonic thickness gauge

The principle of Operation of this device is similar to sonar except it works at much higher frequencies and speed. The transmitter probe contains a short pulse to send ultrasound waves into the material to reverse from the inner surface of it and return to the probe receiver. The gauge measures the entire period of the pulse. The longer the time, meaning the higher thickness of material, and displaying the data of the reading as shown in Figure 2.

2.2 Digital vibration measure

This device initially measuring the amplitude of the vibrating pipe, and then the computer program was used to determine the frequency of the pipe from the device. The device is shown in Figure 3.

Figure 2. Ultrasonic thickness gauge.

Figure 3. Digital vibration meter.

2.3 Ultrasonic flow meter

Ultrasonic flow meter is a device that computing the period of round-trip time of ultrasonic signal which is send into fluid flowing inside a selected pipe. To measure the velocity of the fluid it should installed a pair of transducers on the pipe. The two transducers work alternatively, which both of it transmits and receives the ultrasonic signal. And by reading the different between the two values of time, it can compute the velocity of the fluid. The device is shown in Figure 4. The block diagram of experimental work is shown in Figure 5.

Figure 4. Ultrasonic Flow-meter.

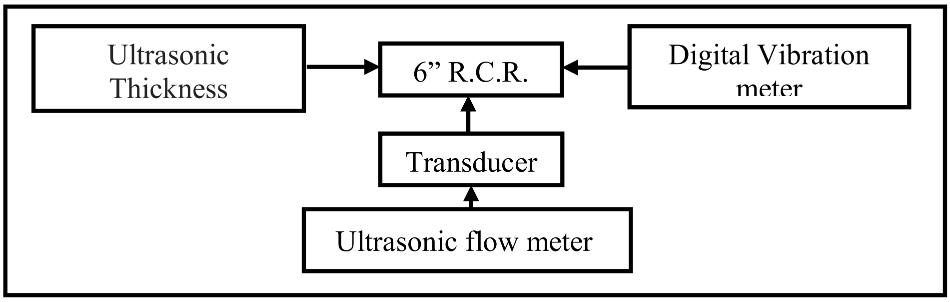

Figure 5. Experimental work block diagram.

3. Results and discussion

Initially 10 points were selected for examination in different position, along about 10 meters from the pipe. It was measured the thickness at these points over time (every three months in five years). The results were as in Table 1.

Table 1. The data which were taken along the pipe once every three months and within five years.

	Point (1) mm	Point (2) mm	Point (3) mm	Point (4) mm	Point (5) mm	Point (6) mm	Point (7) mm	Point (8) mm	Point (9) mm	Point (10) mm	Aver. Thick. mm
Check (1)	7.10	7.00	7.04	7.10	7.05	7.02	7.10	7.08	7.09	7.01	7.059
Check (2)	7.07	6.95	7.01	7.04	7.01	6.96	7.05	7.03	7.06	6.97	7.015
Check (3)	7.02	6.88	6.95	7.00	6.95	6.93	7.03	7.00	7.03	6.93	6.972
Check (4)	6.97	6.85	6.92	6.94	6.92	6.87	6.99	6.95	6.97	6.90	6.928
Check (5)	6.94	6.79	6.88	6.91	6.88	6.84	6.94	6.92	6.94	6.88	6.892
Check (6)	6.91	6.72	6.85	6.85	6.85	6.78	6.91	6.87	6.88	6.83	6.845
Check (7)	6.85	6.68	6.81	6.81	6.8	6.76	6.88	6.85	6.86	6.82	6.812
Check (8)	6.83	6.64	6.76	6.74	6.75	6.71	6.84	6.8	6.82	6.76	6.765
Check (9)	6.78	6.58	6.72	6.71	6.72	6.66	6.80	6.75	6.77	6.74	6.723
Check (10)	6.73	6.52	6.66	6.63	6.68	6.65	6.74	6.70	6.71	6.67	6.669
Check (11)	6.71	6.44	6.64	6.59	6.61	6.59	6.72	6.68	6.68	6.66	6.632
Check (12)	6.64	6.41	6.60	6.55	6.59	6.57	6.65	6.64	6.65	6.60	6.590
Check (13)	6.61	6.35	6.56	6.50	6.54	6.52	6.64	6.62	6.61	6.58	6.553
Check (14)	6.59	6.30	6.52	6.43	6.52	6.47	6.61	6.55	6.56	6.55	6.510
Check (15)	6.53	6.23	6.49	6.41	6.47	6.45	6.55	6.53	6.54	6.54	6.474
Check (16)	6.53	6.21	6.45	6.36	6.44	6.35	6.53	6.47	6.47	6.48	6.429
Check (17)	6.48	6.14	6.43	6.34	6.37	6.34	6.49	6.45	6.44	6.46	6.394
Check (18)	6.44	6.09	6.37	6.25	6.34	6.30	6.48	6.43	6.39	6.42	6.351
Check (19)	6.42	6.02	6.35	6.21	6.31	6.24	6.44	6.37	6.34	6.38	6.308
Check (20)	6.36	5.98	6.26	6.18	6.26	6.20	6.38	6.33	6.30	6.36	6.261
Check (21)	6.30	5.91	6.23	6.11	6.23	6.18	6.32	6.27	6.27	6.31	6.213

The last column in Table 1 represents the rate of thickness whose data are taken each time along the pipe. It is also noted that the rate of reduction in thickness is about 0.167 mm per year, which is relatively high rate that is may be due to the high proportion of sulfuric acids in our oil wells.
The pipe reduction was clear as example, the average thickness of standard pipe is 7.059mm, while the average of the pipe thickness at the end of period of five years is 6.213mm. Thus, the reduction into this thickness is 11.98%.
Figure 6 represents a chart of the previous table data (Table 1). The zigzag lines at the top are the data taken at the beginning of the mentioned period, and the last line represent the data at the end of the period. Thus, the inclusion of top-down lines shows the condition in which the metal is corroded as a result of the flow and chemical effects of the transferred fluids.
In the meantime, reading the frequencies resulting from the vibration of the pipe due to flow in the same period of time (every three months in five years). Table 2 showing the comparison between the thickness of the pipe and the reduction in the thickness from the original and the degree of vibration.

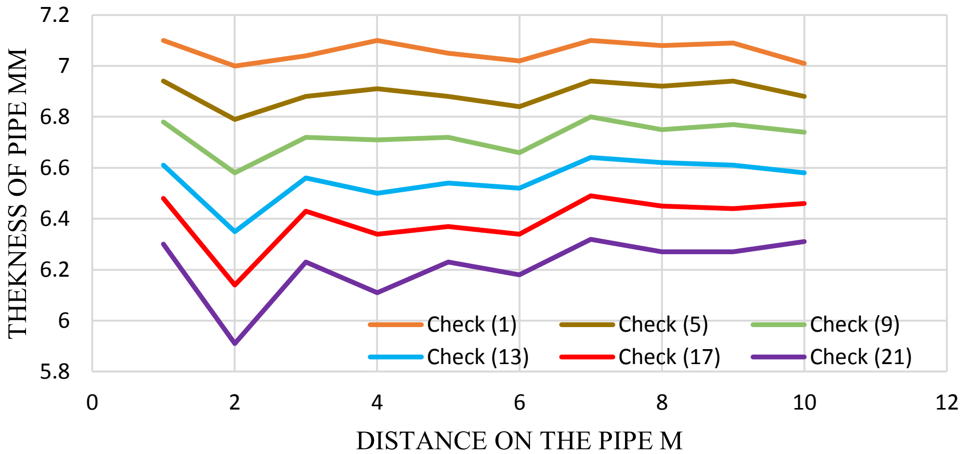

Figure 6. The condition in which the metal is corroded due to the flow over time (every one year).

Table 2. The comparison between the thickness of the pipe and the reduction in the thickness from the original and the degree of vibration.

	Average Thickness mm	Thickness Reduction mm	Frequency Rad/sec
Check (1)	7.059	0	712
Check (2)	7.015	0.044	714
Check (3)	6.972	0.087	715
Check (4)	6.928	0.131	716
Check (5)	6.892	0.167	718
Check (6)	6.845	0.214	719
Check (7)	6.812	0.247	720
Check (8)	6.765	0.294	722
Check (9)	6.723	0.336	723
Check (10)	6.669	0.39	725
Check (11)	6.634	0.425	726
Check (12)	6.590	0.469	728
Check (13)	6.557	0.502	729
Check (14)	6.510	0.549	730
Check (15)	6.474	0.585	732
Check (16)	6.429	0.630	733
Check (17)	6.394	0.665	734
Check (18)	6.351	0.708	736
Check (19)	6.308	0.751	738
Check (20)	6.261	0.798	739
Check (21)	6.213	0.846	741

From Table 2, the frequency increase due to the reduction in thickness as it clears in Table 2. For example, the average thickness of check (1) is 7.059mm, while the frequency is 712rad/sec, the average thickness of check (7) is 6.812mm and the frequency 720rad/sec. thus, the percentage increasing of frequency is 1.12%. Also, the percentage increase of the frequency is 2.46% between check (1) and (14) with 6.510mm average thickness and 730 Rad/sec frequencies. The highest value of the percentage increase in frequency was recorded between the frequency produced by the first case (check (1)) with 712 Rad/sec frequencies and the last case (check (21)) with 741 Rad/sec frequencies, which was the amount 3.91%.
The relationship between the thickness of the pipe and the degree of vibration was being as in Figure 7, where the less thickness increased vibration. As example, at baseline, there was no decrease in pipe thickness and the frequency was normal. After the period of time and began to take the tests was observed decrease in the tube and the use of equipment for testing was found the effect of this shortage in the thickness of the pipe on the frequency Figure 8.
If the degree of vibration is compared with time (the time period in which the test was performed), the graph showed in Figure 9.

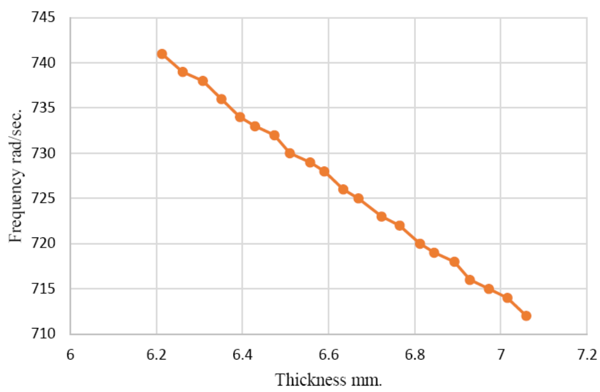

Figure 7. The reduction in the thickness of the pipe increases the value of frequency.

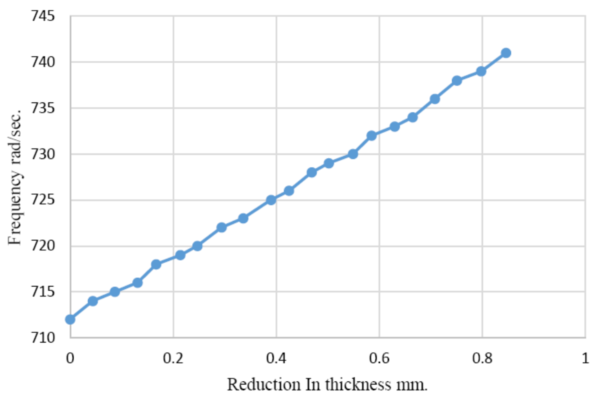

Figure 8. The relationship between the reduction in the thickness of the pipe and the value of its vibration is as positive.

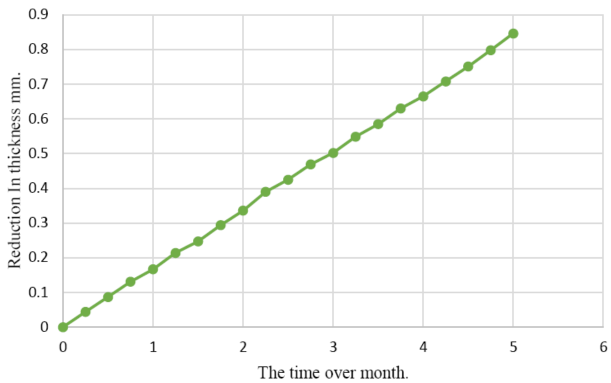

Figure 9. The value of the pipe thickness reduction with the time.

4. Conclusions

From the results, the following conclusions are listed,

1. The decrease in the thickness of pipe increase the frequency of the pipe experimentally.
2. The percentage increase of frequency between the standard pipe without corrosion and the pipe after 5 years is 3.91%.
3. The percentage reduction of pipe thickness from the first check to the last one is 11.98%.
4. Non-activation of quality control of imported materials resulting from poor specifications of pipes used.

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