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Effect of Age of Pipes on Performance of Natural Gas Transmission Pipeline Network System

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Abstract: The development of steel pipes allowed greater quantities of gas to be transported to satisfy the ever growing demand. However, as the age of the pipe increases the roughness of the pipe tends to increase due to the accumulation of various elements around the internal surface of the pipe, which results a decrease in performance of the pipeline network systems. This paper discusses the use of simulation model for the analysis of the effect of age of pipes on the performance of the pipeline network system of natural gas. The flow equations which govern the simulation were modified to take into account the effect of the age of pipes. Analysis was made based on branched pipeline network system serving five power plant customers. The performance of three groups of pipes i.e., new, 10 and 20 years old were evaluated and compared. The results of the simulation analysis showed that a decrease in flow capacity of 2.16 and 4.35% were observed for the 10 and 20 years old pipes, respectively. To certain extent the model is capable of evaluating the effect of the age of pipe on the performance of the gas transmission system. In order to establish firm relationships between the age of the pipes and performance of the pipeline network system, further research is required.

Key words: Pipeline networks, pipe roughness, corrosion, natural gas, simulation

INTRODUCTION

Corrosion of steel pipes is one of the serious challenges which affect the performance of the transmission pipeline network systems. Corrosion is the destructive attack to a metal due to chemical or electrochemical reaction with its environment. The phenomenon of corrosion involves reactions which lead to the creation of ionic species by either loss or gain of electrons. Corrosion of material depends on several factors. Some of them includes: nature of the material or alloy, surface condition/roughness, composition, moisture absorptivity, environment, temperature, humidity and corrosive elements (Revie and Uhlig, 2008).

It has been reported that an increase in ages of the pipes resulted higher pipe roughness due to the accumulation of various elements around the internal surface of the pipe (Worthingham *et al*., 1993). An increase in roughness has major effect on the performance of the transmission system i.e. lower flow rate capacity and high-pressure drop (Menon, 2005).

There are many studies conducted on corrosion of pipelines for both single phase flow and two phases gas-liquid mixtures flow (Ferrira *et al*., 2004; Riemer, 2000; Zhou, 1993; Nestic *et al*., 2004). The importance of internal corrosion management in the design of offshore pipeline network system based on simulation for wet gas production field was discussed by Ferrira *et al*. (2004). Riemer (2000) discussed on the effect of cathodic protection system for pipeline networks based on mathematical model. The effects of flow conditions and fluid properties on flow characteristics and corrosion rates were studied (Zhou, 1993). An integrated CO_2 corrosion-multiphase flow model was developed by Nestic *et al*. (2004) based on mechanistic model assumptions. However, the above studies did not establish the relationships between the age of the pipes and performance of the gas transmission system.

This study focuses on evaluating the effect of the age of the pipes on the performance of the pipeline network system based on the simulation model developed by Woldeyohannes and Majid (2008) by modifying the flow equations to incorporate the effect of the age of the pipes. The simulation model was used to create a system that analyzed pipeline network with different configurations to get pressure and flow parameters. Based on the variables obtained, the performance of the pipeline network system was analyzed.

MATERIALS AND METHODS

Simulation is becoming one of the important tools for analyzing the performance of systems and making operating or resource policy decisions in natural gas

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transmission pipeline network systems (Nimmanonda *et al*., 2002; Abbaspour, 2005; Hoeven, 2003; Abdolahi *et al*., 2007; Osiadacz, 1987; Woldeyohannes and Majid, 2009). It is used to predict the behavior of the transmission pipeline network systems (TPNS) under different conditions which can be used as a guide for decisions regarding the design and operation of the real system.

Simulation analysis of TPNS could be a complex process depending on the extent of the network configurations (gunbarrel, branched, looped, etc.), the nature of the gas (single phase dry gas, two-phase gas liquid mixture) and other factors like temperature of the gas and pipe corrosion.

TPNS consists of pipes and non-pipe elements like compressors, regulators, valves, scrubbers, etc. The simulation of TPNS without non-pipe elements is relatively easier to handle and developed in previous study (Osiadacz, 1987). The addition of non-pipe elements makes the simulation of TPNS more complex. Some authors perform the pipeline network simulation analysis by neglecting the non-pipe elements of the network or oversimplifying their effect (Osiadacz, 1987; Letniowski, 1993; Nimmanonda, 2003). Since compressor station is the key element in TPNS, the incorporation of all its parameters (speed, suction pressure, discharge pressure, flow rates, suction temperatures) is essential for a complete simulation of gas networks. Woldeyohannes and Majid (2008) developed a TPNS simulation model by incorporating the detailed parameters of the compressors. However, the effects of other non-pipe elements like valves, regulators, scrubbers, etc. were neglected during modeling. Furthermore, the flow equations neglected the effect of the ages of the pipe during analysis. The TPNS simulation model by Woldeyohannes and Majid (2008) was used as basis for studying the effect of the age of the pipes on the performance of the gas transmission network system by modifying the flow equations.

The TPNS simulation model: The TPNS simulation model developed by Woldeyohannes and Majid (2008) was enhanced here in order to integrate effect of the ages of the pipe on flow equations.

Flow modeling: A new solution scheme was developed to incorporate the age of the pipe on flow modification. Fig. 1 illustrates the general procedure to incorporate the effect of corrosion with age of the pipe and flow modification.

Data of roughness of the coated pipe with service life of the pipe (Worthingham *et al*., 1993) was used for developing the correlation between the service life of the pipe and roughness. Based on the data points, exponential function for approximating the relationship between the roughnesses of the pipe with that of the service life is obtained to be:

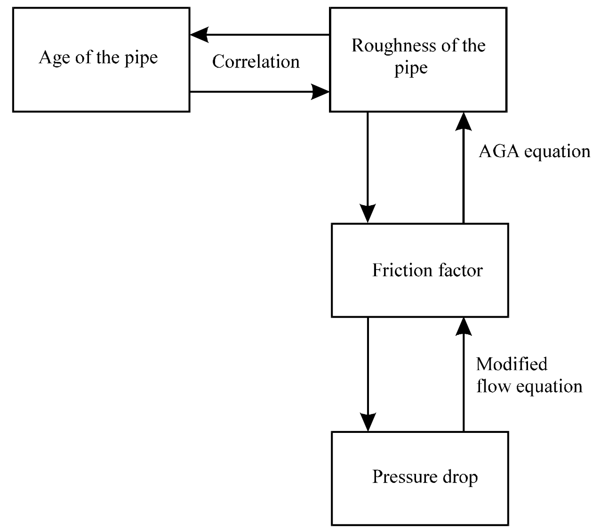

Fig. 1: The effect of age of the pipe on flow equations

$$r = 0.00353\exp(0.03802y) \quad (1)$$

where, r is the roughness of the pipe in mm and y is age of the pipes in year.

Most gas pipelines operate in the turbulent zone. For the fully turbulent zone, American Gas Association (AGA) recommends using the following formula for calculating the transmission factor which is based on the relative roughness and independent of the Reynolds number as stated by Menon (2005):

$$F = 4\mathrm{Log}_{10}\left(\frac{3.7D}{r}\right) \quad (2)$$

where, F is the transmission factor, r is the roughness of the pipe and is the diameter of the pipe.

The relationships between the transmission factor and friction factor can be express by Menon (2005):

$$F = \frac{2}{\sqrt{f}} \quad (3)$$

Substituting (3) in (2) and rearranging gives:

$$f = \frac{1}{\left[2\mathrm{Log}_{10}\left(\frac{3.7D}{r}\right)\right]^2} \quad (4)$$

Equation 1 and 4 indicate the relationships between friction factor and age of the pipe.

The general flow equation for a single flow used by Woldeyohannes and Majid (2008) was modified based on the friction factorin f (4) in order to integrate the effect of the age of the pipe on the pressure drop. For any pipe, connecting the upstream node i, downstream node j and the flow through pipe q, the single flow equation with corrosion relating the two nodes can be represented as:

$$P_i^2 - P_j^2 = K'_{ij} f Q^2 \quad (5)$$

where, K_{ij} is pipe flow resistance whose value depends on the pipe physical attributes as defined by Woldeyohannes and Majid (2008).

Compressor stations equations: The basic quantities related to a centrifugal compressor unit is inlet volume flow rate Q, speed n, adiabatic head H and adiabatic efficiency η . Based on the normalized parameters of the centrifugal compressors (Gresh, 2000) and the principles of polynomial curve fitting (Abbaspour, 2005; Wu *et al*., 2000), the governing simulation equation for the compressor is given as:

$$(P_d / P_s)^m = \frac{mn^2}{ZRT_s}[A_1 + A_2(Q/n) + A_3(Q/n)^2 + A_4(Q/n)^3] + 1 \quad (6)$$

where, A_1, A_2, A_3, A_4 and B_1, B_2, B_3, B_4, are constants which depend on the units. The detail derivation for equ. 6 is presented by Woldeyohannes and Majid (2008).

Based on the performance map of the compressor used from Kurz and Ohanian (2003), simulation analysis was performed to determine the coefficients of the mathematical approximation which represents the characteristics of the compressor. The coefficients for the mathematical approximation of the compressor were determined to be:

$$A_1 = 1.08 \text{ E - } 06$$
$$A_2 = 1.96 \text{ E - } 08$$
$$A_3 = 4.71 \text{ E - } 10$$
$$A_4 = -5.83 \text{ E - } 12$$

Formulation of mass balance equations: The mass balance equations were obtained based the principle of network. The detail on mass balance formulation can be obtained from Woldeyohannes and Majid (2008).

RESULTS AND DISCUSSION

The enhanced TPNS simulation model was used to evaluate the gas transmission pipeline network shown in Fig. 2. The problem instance was taken from Woldeyohannes and Majid (2008). The network was analyzed under single phase gas flow analysis with no corrosion and single-phase flow analysis with corrosion based on pipe data given in Table 1. The analysis was done based on source pressure of 3500 kPa and demand pressure requirement 4500 kPa. The temperature of the gas is assumed to be constant. Two compressors were working for the system. It was assumed that the speed of the compressor was 8800 rpm.

Single phase flow analysis without corrosion: The results for the unknown pressure variables and flow variables were obtained with less than ten iterations with relative percentage error of 1.76979E-15. Figure 3 shows the convergence of nodal pressures solution for the first ten iterations to the final pressure The convergence of the corresponding flow parameters are shown in Fig. 4 and 5.

Single phase flow analysis with corrosion: The same pipe data and compressor parameters were used as in the case of with no corrosion to analyze the pipeline network shown in Fig. 2 by considering corrosion. The age the pipes could vary to give the corresponding friction coefficient.

Table 1: Pipe data for single CS and five customers

Pipe nodes			
Start node	End node	Diameter (km)	Length (mm)
0	1	900	100
2	3	900	80
3	D1	600	70
3	4	900	80
4	D2	600	90
4	5	900	70
5	D3	600	80
5	6	900	90
6	D4	600	70
6	D5	600	80

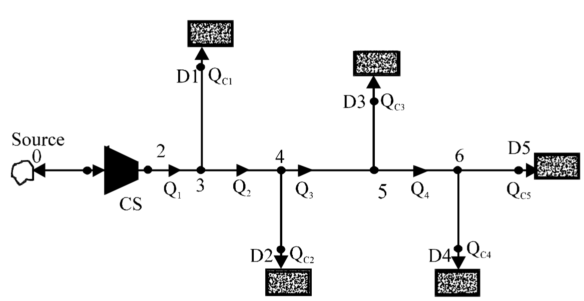

Fig. 2: Branched pipeline network system

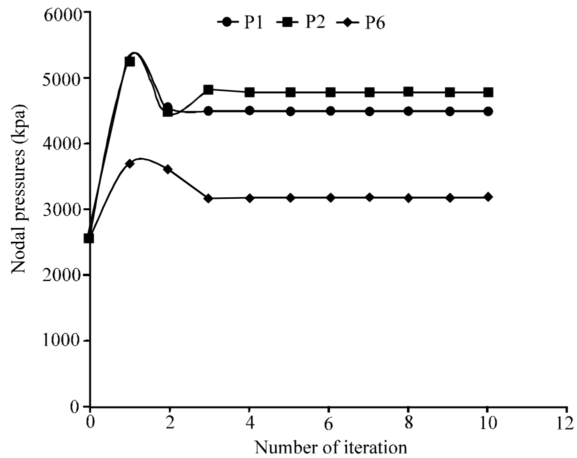

Fig. 3: Convergence of pressure variables without corrosion

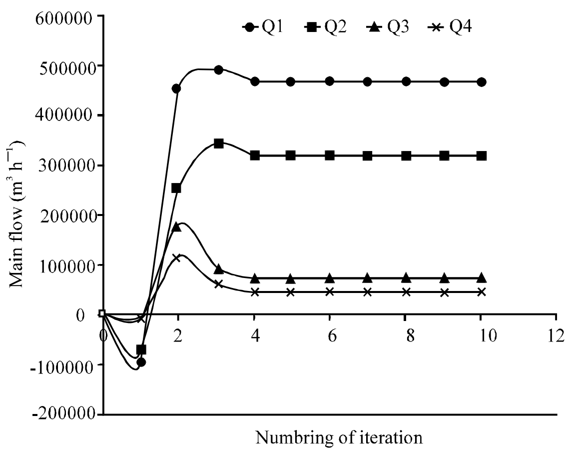

Fig. 4: Convergence of main flow variables without corrosion

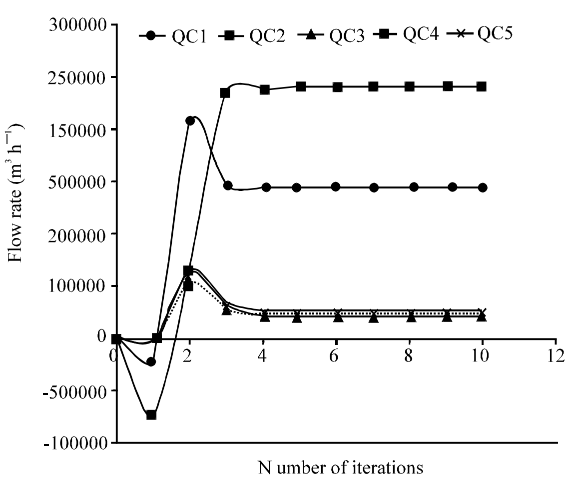

Fig. 5: Convergence of lateral flow variables without corrosion solution for the first ten iterations.

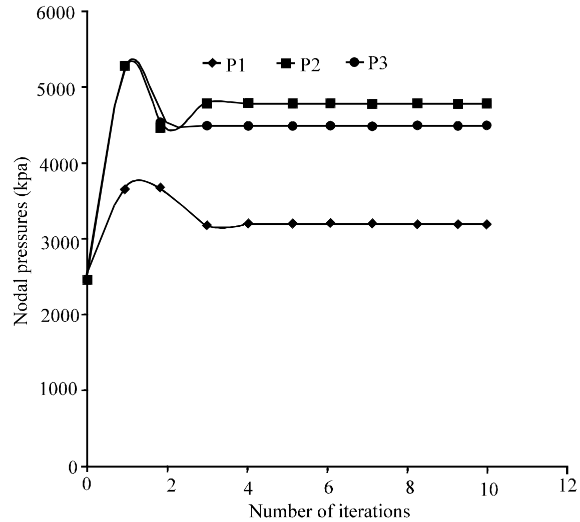

Fig. 6: Convergence of pressure variables with corrosion

The convergences of the pressure and flow variables were studied based on ten years old pipes. The convergence of some of nodal pressure variables is shown in Fig. 6.

The convergence of flow parameters through main pipes is shown in Fig. 7. Figure 8 shows the convergence of flow variables through the branch pipes. Similar to the convergences of the nodal pressures and flow variables through main pipes shown for without corrosion, the TPNS simulation converged almost to the final solution at the end of the 4^{th} iteration for the flow variables through lateral pipes.

The results obtained for the case of neglecting corrosion were compared with the results obtained by considering the effect of corrosion for various ages of the pipe.

By maintaining the same source pressure and demand pressure requirements similar to the case with no corrosion, simulation study was conducted to analyze the effect of the age of the pipe on the performance the TPNS. Compression ratio and the flow rate Q_1 were studied for Fig. 9 shows the variation of the compression ratio of the system with age of the pipes at different compressor speeds. As it seen from the figure, compression ratio of the system increased with increase in the age of the pipes. As the age of the pipes increased, the friction factor and pipe flow resistance increased which increase the pressure drop of the system to result in higher compression ratio.

The variation of flow variables with ages of pipes is shown in Fig. 10. It is observed that corrosion had a significant effect on flow capacity of the pipes. The results of the simulation analysis

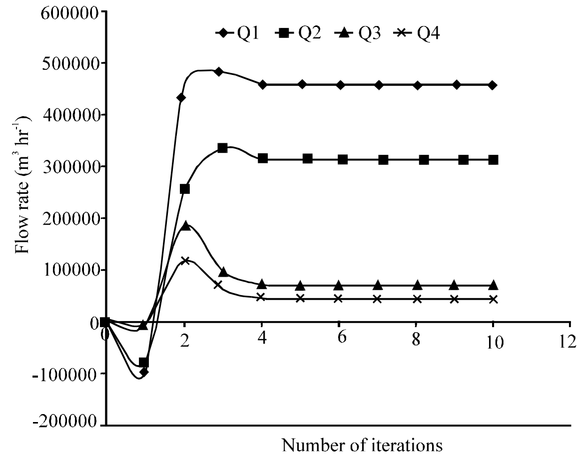

Fig. 7: Convergence of flow through main pipes with corrosion

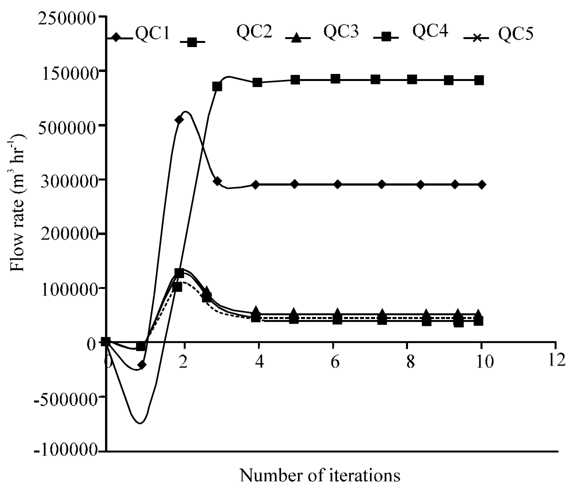

Fig. 8: Convergence of flow through lateral pipes with corrosion

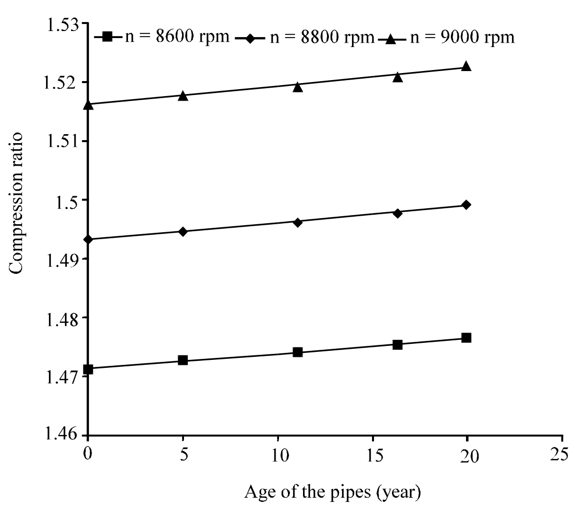

Fig. 9: Compression ratio variations with ages of pipes

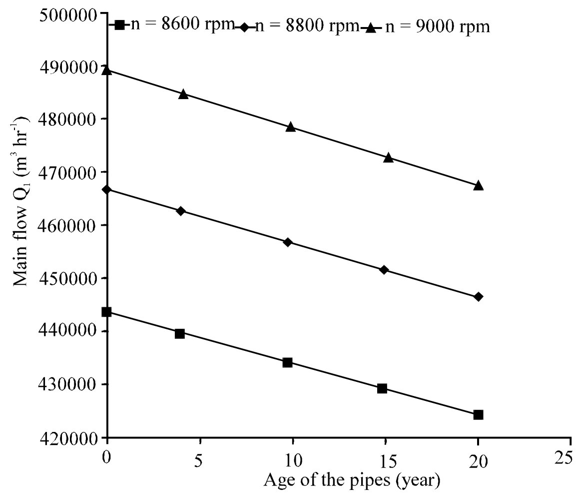

Fig. 10: Flow through pipes for different ages of pipes

Table 2: Variation of flow with ages of pipes

Age (year)	Friction	Pipe flow resistance	Flow ($m^3\ h^{-1}$)
0	0.007003	9.01E-06	466683
10	0.007407	9.53E-06	456596
20	0.007847	1.01E-05	446371

showed that a decrease in flow capacity of 2.16 and 4.35% were observed for the 10 and 20 years old pipes, respectively when the compressors run at speed of 8800 rpm.

Table 2 shows the results of the simulation study conducted on pipe joining node 0 and 1 of the pipeline network system shown in Fig. 2. The friction factor, pipe flow resistance and the flow through the pipe were studied under three age groups. As the age of the pipes increased, the friction factor and pipe flow resistance increased. Based on flow equations, for fixed pressure at the start and end node of the pipe, an increase in flow resistance of the pipe reduced the flow capacity.

CONCLUSIONS

The effect of the age of pipes on performance of the transmission pipe line network system was analyzed by enhancing the simulation model to integrate the age of the pipes to the flow equations. Analyses of branched pipeline network showed that significant effects on the performance were observed for the three groups of pipes studied. The performance of three groups of pipes i.e. new, 10 and 20 years old were evaluated and compared. The results of the simulation analysis showed that a decrease in flow capacity of 2.16 and 4.35% were observed for the 10 and 20 years old pipes, respectively. To certain extent the model was capable of evaluating the effect of the age of pipe on the performance of the gas transmission system. In order to establish firm relationships between the age of the pipes and performance of the pipeline network system, further work is required. The developed simulation model could be easily extended to be applied for performance analysis of pipeline network systems for other petroleum products. Transient model is another important problem to be addressed from the simulation perspective.

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