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Genetic Algorithm Approach for optimizing looped gas pipeline networks

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Abstract : Optimization of gas pipeline networks is a crucial task that needs to be implemented in design and operation phase of pipeline networks. Optimization of pipeline networks has saved millions of dollars in the past and still a search of finding a robust technique for finding best solution remains. The present paper utilizes one of the popular techniques referred to as Genetic Algorithm for pipeline optimization. The objective is to minimize natural gas consumption in compressors. The results obtained have been compared with one of the other popular technique for optimization referred to as Generalized Reduced Gradient technique. Result shows that utilizing Genetic Algorithm technique helps in reducing fuel consumption in pipeline networks. This further helps in minimizing the cost expense in running up the compressors.
Keywords: Genetic Algorithm, Pipeline hydraulics, Compressor station, energy consumption minimization, Generalized Reduced Gradient Technique.

Introduction

The gas after being produced from gas wells is treated and is then sent to the end users through high pressure pipelines, medium pressure pipelines and subsequently low pressure pipelines. Industries utilize a vast pipeline network consisting of pipes, compressors, valves, city gas stations, metering section to deliver the gas to the users. The users' fixes up the pressure required at the terminal station. Depending on the end pressure requirement, the supply pressure is calculated through various equations available in the literature**[1]**. However, it is observed that presence of friction, irregular terrain and temperature difference causes huge loss in pressure and energy. This loss of energy has to be compensated to deliver the gas at the correct pressure at delivery station. Compressors are utilized in gas pipeline networks to provide energy to the gas moving in pipeline networks. The compressors in turn also require energy to run. This energy is obtained either by burning natural gas in pipeline networks or by using the electric energy. Compressors utilizing natural gas for running are referred to as "Natural Gas Run Compressors" while those utilizing electric energy are referred to as "Electric Run Compressors". Due to the easy availability of natural gas from pipeline most of the industries rely on Natural Gas Run Compressors. The compressor utilize about 3-4 percent of gas moving in pipeline as energy source**[2].**A small saving of only one percent results in huge saving in cost**[3].**Present paper focuses on minimizing the energy used in compressors.

Methods used for pipeline optimization

Numerous techniques have been used in the past for optimizing pipeline operations. Goldberg, in 1983, introduced genetic algorithmic methods for optimizing pipeline networks**[4].**The technique remains quite popular even today for optimization in pipeline as well as process industries. Numerous researcher and scholar like Mantri, Renji, Ryan and Wilson continued to develop new optimization techniques for getting an improved solution in terms of minimizing fuel consumption**[5-8].**The researchers not only focused on developing new algorithms but also tried to improve the optimization model. Carter, in 1998, found that utilizing dynamic programming methods yielded a faster solution to a typical non linear optimization problem**[9].** However the technique was found to be unsuccessful in terms of time saving when the pipeline network was large. By the end of the twentieth century numerous works were done in pipeline optimization. Some other techniques like Simulated Annealing was utilized by Mahlke,to find the optimal arrangement of compressors**[10].** Heuristic approach was utilized by Summing et al.,to find the optimum combination of compressors to achieve the desired flow rate**[11].**Mora,used Genetic algorithm to optimize pipeline networks**[12]**. Reduction technique was utilized by Rios Mercado to optimize gas pipeline network**[13]**. Arya & Honwadutilized Ant Colony optimization technique for minimizing fuel consumption in alinear gas pipeline network**[14].**

Nevertheless, significant techniques have been developed and utilized for optimization, but still owing to the scope and huge benefits obtained, search for a robust technique still remains. The present paper focuses on utilizing a robust Genetic Algorithm technique for optimization. The coding of problem formulation has been done in MATLAB 2010a.

Optimization model for minimizing fuel consumption

The model has been presented by Aryaet. al in full detail. Here the important equations utilized in the model for optimization have been presented.

Objective Function

The objective function is to minimize fuel consumption in compressors given by equation 1.

$$f = \sum_{i=1}^{6} m_f = \sum_{(i,j \in A_c} \frac{\left(m_{ij} \times h_{ij}\right)}{\left(\frac{\eta_{is}}{100}\right) \times \left(\frac{\eta_m}{100}\right) \times \left(\frac{\eta_d}{100}\right) \times H_m} \quad (1)$$

Average molecular weight

The natural gas flowing in the pipeline contains Methane and ethane. Its average molecular weight is obtained from eqn. (2)

$$M = M_1 \times y_1 + M_2 \times y_2 \quad (2)$$

Critical Temperature and Critical Pressure of Gas

The critical temperature and critical pressure of natural gas is calculated from eqn. 3 & 4.

$$T_c = Tc_1 \times y_1 + Tc_2 \times y_2 \quad (3)$$

$$P_c = Pc_1 \times y_1 + Pc_2 \times y_2 \quad (4)$$

Heat Content of Gas Mixture

Heat content of natural gas is obtained from eqn. (5)

$$H_m = \frac{M_1 \times y_1 \times H_1 + M_2 \times y_2 \times H_2}{M} \quad (5)$$

Calculation of Isentropic Exponent:

Isentropic Exponent is obtained from eqn. (6)

$$k = \frac{C_{p1} \times y_1 \times C_{P2}}{C_{p1} \times y_1 \times C_{P2} - R} \tag{6}$$

Average Pressure in Pipeline Networks

Average pressure in a pipe is obtained from eqn. (7)

$$P_{ij} = \left(\frac{2}{3}\right) \times \left(P_i + P_j - \frac{P_i \times P_j}{P_i + P_j}\right) \tag{7}$$

Calculation of Compressibility Factor:

Compressibility factor accounts for the deviation of real gas from ideal gas behavior. For natural gas it is obtained from eqn. (8).

$$Z_i = 1 + \left(0.257 - 0.533 \times \frac{Tc}{T}\right) \times \left(\frac{P_{ij}}{Pc}\right) \tag{8}$$

Calculation of Compressor Isentropic Head Calculation:

Isentropic head of compressors is obtained from eqn. (9). $h_i = \left(\frac{Z_i \times R \times T}{M}\right) \times \left(\frac{k}{k-1}\right) \times \left[\left(\frac{P_j}{P_i}\right)^{\frac{k-1}{k}} - 1\right]$ (9)

Equations for Calculation of Friction Factor:

Friction factor is calculated from eqn. (10).

$$f_i = -2 \times \log_{10}\left(\frac{e}{3.7 \times D}\right)^{-2} \tag{10}$$

Equation of Motion:

Pressure drop incurred in pipeline is obtained from eqn. (11).

$$P_i^2 - P_j^2 = \frac{32 \times m_i^2 \times Z_i \times R \times T \times \log_{10}\left(\frac{P_i}{P_j}\right)}{3.14^2 \times D^4 \times M} - \frac{16 \times f_i \times Z_i \times R \times T \times L_i}{3.14^2 \times D^5 \times M} \tag{11}$$

Calculation of Efficiency of Gas Compressor:

Efficiency of gas compressors is a function of discharge pressure and suction pressure and is obtained from eqn. (12).

$$\eta_i = \frac{\left(\frac{P_j}{P_i}\right)^{\frac{k-1}{k}} - 1}{\left(\frac{P_j}{P_i}\right)^{\frac{n_p-1}{n_p}} - 1} \tag{12}$$

General Equations for calculating velocity of gas in pipelines:

Velocity of gas at standard conditions in pipeline is obtained from the eqn. (13)

$$v_i = 14.7359\left[\frac{q_i \times 24 \times 3600}{(100 \times D_i - 2 \times t_i \times 100)^2}\right] \times \left(\frac{P_b}{T_b}\right) \times \left(\frac{100 \times Z_i \times T}{P_{ij}}\right) \quad (13)$$

Calculation for Maximum Allowable Pressure:

The maximum allowable pressure in gas pipeline is obtained from eqn. (14).

$$P_{MAOP} = \frac{2 \times t_i \times S \times E \times F \times T}{D} \quad (14)$$

Erosional Velocity of Gas

The erosional velocity of gas is obtained from eqn.(15).

$$v_e = 122 \times \sqrt{\frac{Z \times R \times T}{P_{ij} \times M}} \quad (15)$$

Choking and Surging in Compressors:

To avoid choking in pipelines the flow rate at the inlet of compressors has to be kept lower than the value obtained from eqn. (16)

$$q_i \succ \left(\frac{3.14 \times D^2}{4}\right) \times c_i \times \left(\frac{2}{k+1}\right)^{\frac{k+1}{2(k-1)}} \quad (16)$$

$$.\, c_i = \sqrt{\frac{k \times Z \times R \times T}{M}} \quad (17)$$

Case Study

For minimizing the fuel consumption, a case study from A French Company "Gaz De France' has been chosen. Tabkhi, (2007) first utilized the network for fuel consumption minimization using GAMS software's, GRG module. For description of the network, readers may refer the Tabkhi thesis **[15].**

Optimization Method

Present paper utilizes Genetic Algorithm for optimization. The coding was done in MATLAB 2010 environment. Details of the technique used can be found in Deb, K **[16].**

Result and Discussion

As discussed above in the present paper Genetic Algorithm has been used for optimization. The population size chosen=100; maximum generations=300;

GA was run 10 times with different values of pressure variables. It was seen taking different values of pressure values time taken was also different, but each time the minimum value of fuel consumed in compressors was same.A comparison of the variables obtained utilizing Genetic Algorithm and GRG have been presented in this section.

Comparison of Pressure Obtained at different Pipe nodes

Figure 1 compares pressure obtained by using GA and GRG at forty five pipe nodes. It can be clearly seen that pressure obtained utilizing GA remains higher at most of the pipe nodes as compared to GRG method.

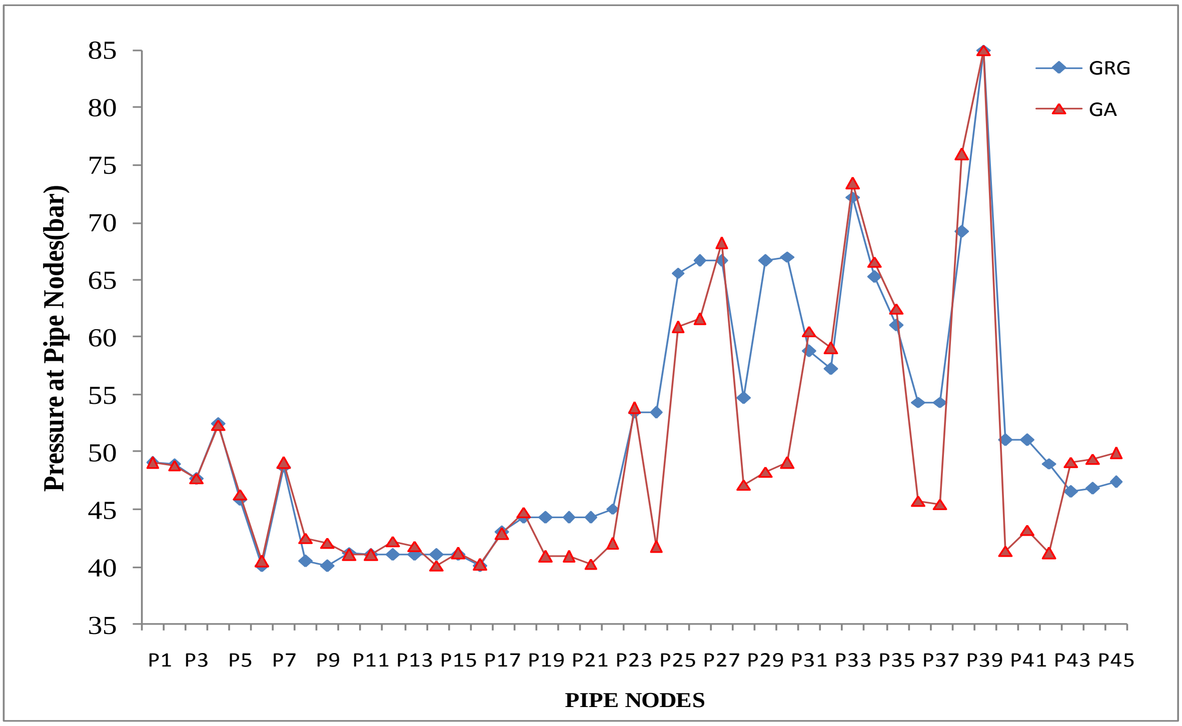

Figure 1: Comparison of Pressure obtained at forty five Pipe Nodes

Comparison of mass flow rate in thirty pipe arc

Figure 2, shows a comparison of natural gas flow rate in pipe arc. It can be seen in most of the pipe arcs the gas flow rate is higher obtained utilizing GA as compared to GRG method. This must be due to the less consumption of gas in compressors.

Gas Supplied from supply station

Figure 3, shows the gas supplied from gas supply station. It can be clearly seen from the figure that gas required as obtained from GA as compared to GRG remains lower. This must be due to the lower gas consumption in compressors and hence lower amount of gas requirement from supply stations.

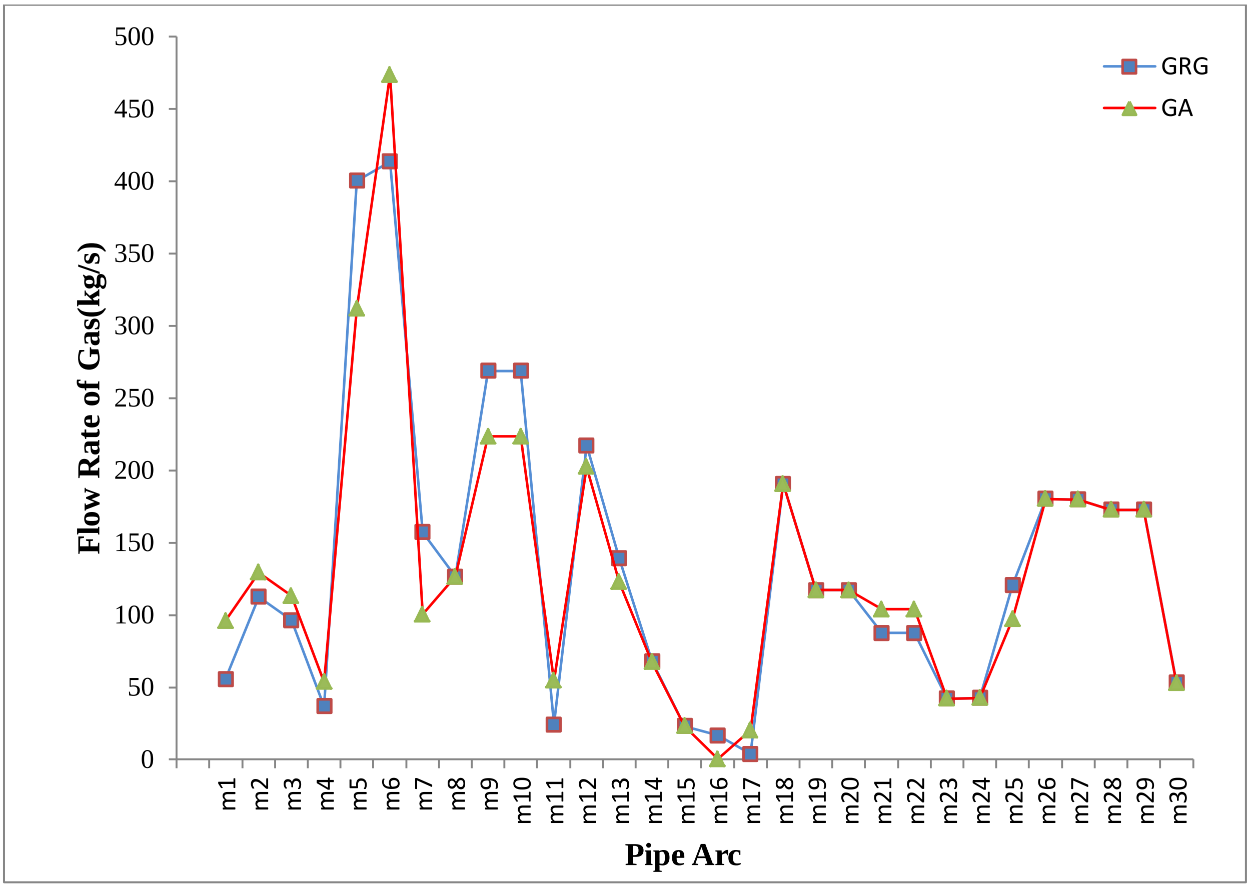

Figure 2:Comparison of mass flow rate in thirty pipe arc

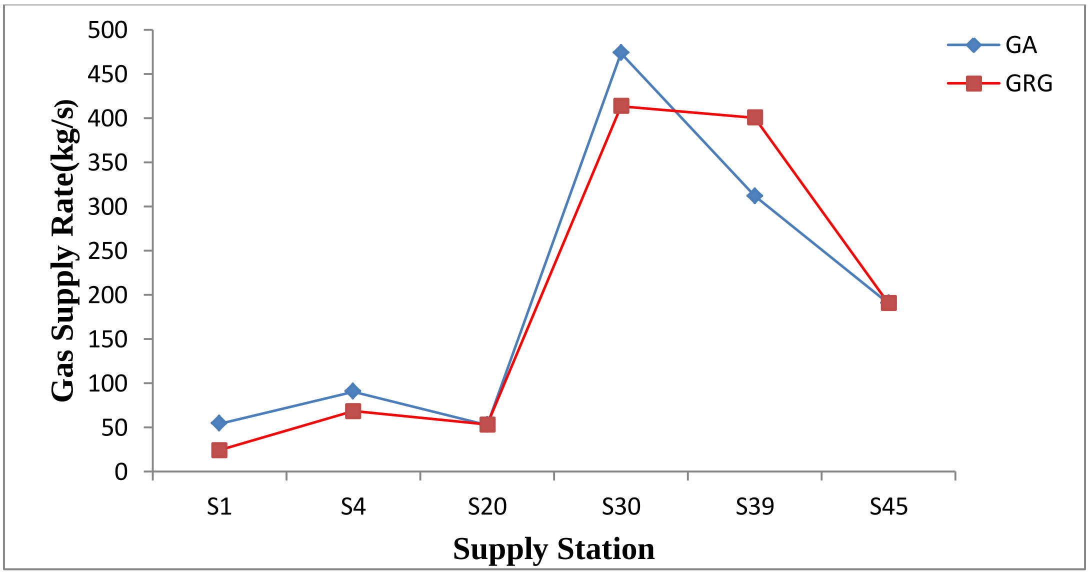

Figure 3: Gas Supplied from supply station

Comparison of Gas flow rate through Valves

Figure 4, compares the flow rate of gas in pipeline valves. It is found that the shape of the curve found through GA as well as GRG remainsalmost similar.

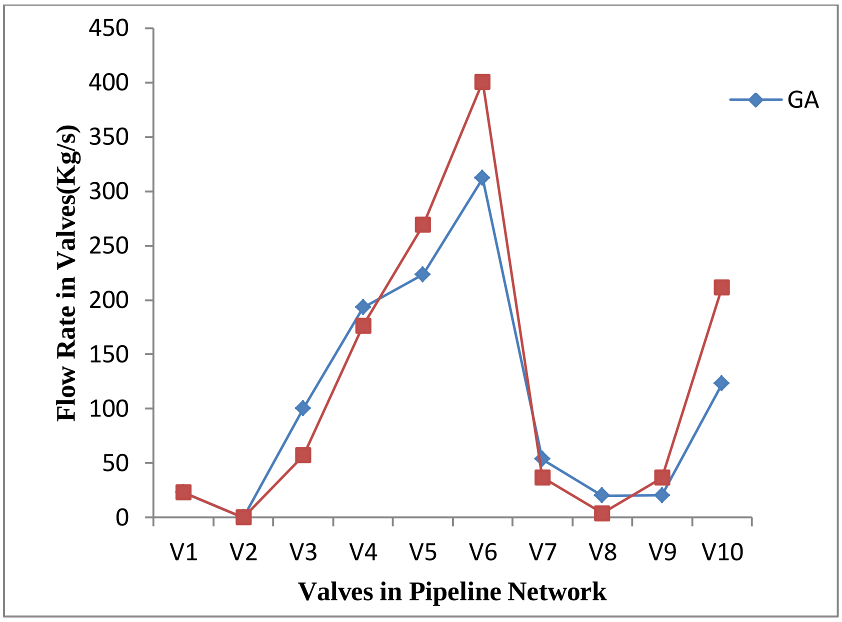

Figure 4: Comparison of Gas flow rate through Valves

Comparison of Fuel consumption in Compressors

In Figure 5, finally comparison of fuel consumed in seven compressors has been presented. It can be clearly seen that in the case of GA the fuel consumed in compressors remains lower than that obtained utilizing GRG method. This has been also presented in Table 1.

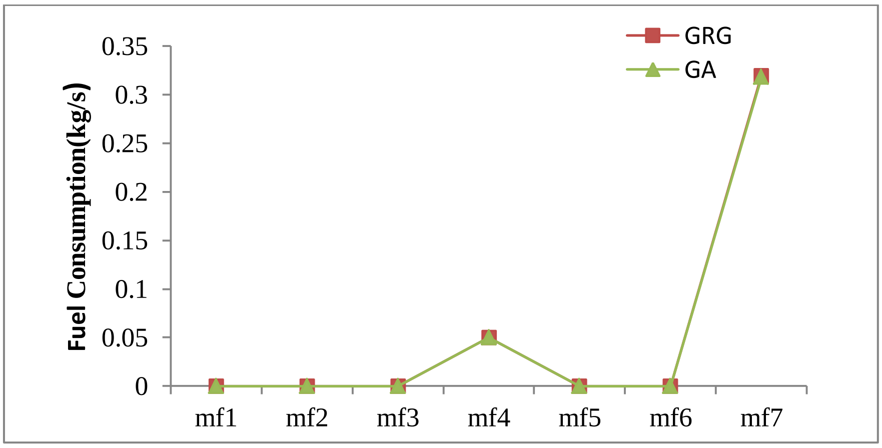

Figure 5: Comparison of fuel consumed in compressors

Economic Impact of Natural Gas saving

From table 1, it can be seen that using Genetic Algorithm a saving of 0.01 kg per sec. is achieved.
The data can be utilized to calculate saving of fuel utilizing GA per year as follows:
Natural Gas saving per year= 0.01*60*60*24*365=3, 15,360
Natural Gas price as available in year 2015= USD 0.74
Hence total saving in Cost USD=3, 15,360*0.74=2, 33,366.
Total savings in INR=2, 33,366*64.15= INR 14,970,428.90(1USD = INR 64.15)
The design life of pipelines is considered as thirty five years.
Hence Saving in Thirty Five years= INR 523, 965,011.5

Now in India there are pipeline like Guwahati- Siliguri pipeline that have been operation from about fifty years. It can be well imagined, the amount of currency saving it would have resulted through optimization utilizing Genetic Algorithms.

Table 1: Fuel Consumption in Compressors obtained using GRG and GA.

Mass Rate	GRG	GA
m_{f1}	0	**0**
m_{f2}	0	0
m_{f3}	0	0
m_{f4}	0.05	0.05
m_{f5}	0	0
m_{f6}	0	0
m_{f7}	0.32	0.31
Total Fuel Consumption(kg/sec)	0.37	0.36

Conclusion

Numerous techniques have come in the past few decades for optimization.Use of these techniques during design and operation phase can result in significant saving. Genetic Algorithm is one of those powerful techniques that can be used for optimizing pipeline operations. In the present work Genetic algorithm was applied to a French Company Pipeline Network 'Gaz De France'. It can be well seen from the results that utilizing Genetic Algorithm has resulted in huge cost savings. Further, other different techniques like Simulated Annealing, Particle Swarm Optimization, and Ant Colony Optimization can be also used and compared for fuel consumption. Different pipeline configuration such as Gun barrel and tree shaped pipeline network can be also tried for optimization.

Nomenclature

Symbol	Meaning	Symbol	Meaning
d_e	Density of gas (kg/m^3)	P_b	Base Pressure (bar)
D	Diameter of Pipeline (m)	P_c	Critical Pressure (bar)
e	Absolute Roughness	P_s, P_d	Suction and discharge Pressure (bar)
f	Friction factor(dimensionless)	P_{sd}	Average Pressure (bar)
h	Isentropic head across compressors (KJ/kg)	q	Volumetric Flow Rate (m^3/sec)
H_m	Heat content of gas mixture (J/kg)	Q_{base}	Volumetric fow rate at std. conditions (m^3/sec)
k	Isentropic Exponent	R	Gas constant (m^3.kPa/ kmol.K)
L	Length of pipe segment (m)	S	Specified Minimum Yield Stress(bar)
M	Mass flow rate of gas in pipe arc(kg/sec)	Tb	Base Temperature(K)
m_f	Mass of fuel consumed in compressors(kg/sec)	t	Thickness of pipeline(m)
m_s	Gas supply rate(kg/sec)	V	Velocity of gas(m/sec)
m_{de}	Gas delivery rate	y	Mole fraction
M_{NG}	Molecular Weight of Natural Gas	z	Compressibiity factor
MAOP	Maximum Allowable Operating pressure	η_{dr}	Driver Efficiency
η_p	Poytropic Exponent	η_{is}	Isentropic Efficiency
η_m	Mechanical Efficiency		

References

1. Menon, E.S. (2005) Gas pipeline hydraulics. Boca Raton: CRC Press.
2. Carter, R.G. (1996). Compressor Station Optimization: Computational Accuracy &Speed. 28th Annual Meeting of Pipeline Simulation Interest Group, 23-25 October, San Francisco.
3. Summing, Wu. Rios-Mercado,R.Z., Boyd, E.A., Scott, &L.R. (2000). Model Relaxation for the Fuel Minimization of Steady State Gas Pipeline Networks.Mathematical & Computer Modelling.197-200.

4. Goldberg, D.E. and Kuo, C.H.: "Genetic Algorithms in Pipeline Optimization", Pipeline Simulation Interest Group, Annual Meeting, Albuquerque, New Mexico, October 24-25, 1985.
5. V. B. Mantri, L. B. Preston, and C. C. Pringle, "Computer program optimizes nature gas pipeline operation," *Pipeline Industry*, vol. 6, no. 6, pp. 39–45, 1986.
6. Z. Renji, S. Selandari, and H. G. Nicolai, "A system for control and optimum operation of a gas transmission network," in *Proceedings of the 19thAnnual Pipeline Simulation Interest Group Meeting (PSIG '87)*, Tulsa, Okla, USA, 1987.
7. M. J. Ryan and P. B. Percell, "Steady state optimization of gas pipeline network operation," in *Proceedings of the 19th Annual Pipeline Simulation Interest Group Meeting (PSIG '87)*, Tulsa, Okla, USA, 1987.
8. T. Williams and G. E. Broadbent, "Optimization in the operation of compressor stations on themoomba to adelaide gas pipeline network," in *Proceedings of the 21th Annual Pipeline Simulation Interest Group Meeting (PSIG'89)*, El Paso,Tex,USA,October 1989.
9. Carter RG. Pipeline optimization: dynamic programming after 30 years. In: Proceedings of the 30th PSIG annual meeting, Denver; October 1998.
10. Mahlke D, Martin A, Moritz S. A simulated annealing algorithm for transient optimization in gas networks. Math Methods Oper. Res 2007;66(1):99–115.
11. Summing, Wu. Rios-Mercado, R.Z., Boyd, E.A., Scott, &L.R. (2000).Model Relaxation for Fuel Minimization of Steady State Gas Pipeline Networks. Mathematical &Computer Modeling.31 (2–3), 197-200.
12. Mora T. and M. Ulieru, 2005, Minimization of energy use in pipeline operations – an application to natural gas transmission systems, Industrial Electronics Society, IECON, 31st annual conference of IEEE, ISBN: 0-7803-9252-3
13. Ríos-Mercado, R.Z., Kim, S., Boyd, E.A., 2006. Efficient operation of natural gas transmission systems: a network-based heuristic for cyclic structures. Comput.Oper.Res. 33, 2323–2351
14. Arya, A.K., and Honwad, S., (2015). Modelling, Simulation and Optimization of a High Pressure Cross- Country Natural Gas Pipeline: Application of Ant Colony Optimization Technique. Journal of Pipeline System Engineering and Practice (ASCE).
15. Tabkhi, F.Optimization of Gas Transmission Networks.PhD Thesis, France, 2007
16. Deb, K. (2003). *Optimization for Engineering Design: Algorithm & Examples.* Prentice-Hall of India Pvt. Limited, NewDelhi, India.

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