مجموعه مقالات چهارمین کنفرانس ملی مهندسی فرآیند، پالایش و پتروشیمی
۷ خرداد ۱۳۹۴، ایران، تهران، مرکز همایش‌های صدا و سیما
مجری: اهم اندیشان انرژی کیمیا ۰۲۱ – ۸۸۶۷۱۶۷۶
www.Processconf.ir

Optimization of gas transportation pipelines for capacity expansion

Mohammad Torkamanzadeh[1], Hossein Amani[2], Hasan Kariminezhad[3]
[1]Department of Chemical Engineering, Babol Noshirvani University of Technology, Babol, Iran
torkamanzadeh.m@gmail.com

Abstract

There is and always has been a need for a single text which explains simple equations and their applications in the natural gas flow. In this work, three types of pipeline arrangements including series, parallel and looped pipelines were reviewed and related equations were presented. Qualitative and quantitative comparison of each method were studied through an example and the results were interpreted. The effects of looped line on the increase of gas flow rate for various pipe diameter ratios were also investigated. It was observed that the benefit of looping increases exponentially with the fraction of looping. A 10-inch pipeline that is 20 miles long is exemplified in the text, and it was found out that the gas capacity expansion for this particular pipeline would be 20.36% for series, 294.83% for parallel and 21.95% for a looped combination, respectively.

Keywords: Pipeline, Optimization, Capacity, Series, Parallel, Looping

---

[1] Senior Chemical Engineering Student

[2] Assistant Professor, PhD, Faculty of Chemical Engineering

[3] Assistant Professor, PhD, Faculty of Basic Sciences

1. Introduction

Process engineering encompasses a vast range of industries, such as chemical and petrochemical industries. Familiarization and understanding of oil and gas production systems are essential to the process engineers. Today's petroleum production engineers work much more efficiently than ever before in their daily activities, including analyzing and optimizing the performance of their existing production systems and designing new production systems. Recently, there has been a steadily growing interest in gas production optimization techniques [1-4].

As illustrated in Figure 1, complete oil or gas production system consists of a reservoir, well, flowline, separators, pumps, and transportation pipelines. Natural gas pipelines are used to transport natural gas from gas wells, to processing plants or directly to distribution systems, depending upon the initial quality of the wellhead product. Once cleaned at the gas processing plants, natural gas is compressed prior to moving into large transmission pipelines consisting of steel pipe. Since larger population requires additional demands, modern commercial models usually dictate that an increase in natural gas pipeline capacity is necessary. So it is likely that the advent of pipeline looping, compression and maximum allowable operating pressure (MAOP) upgrade projects will become a more common theme in the industry[5].

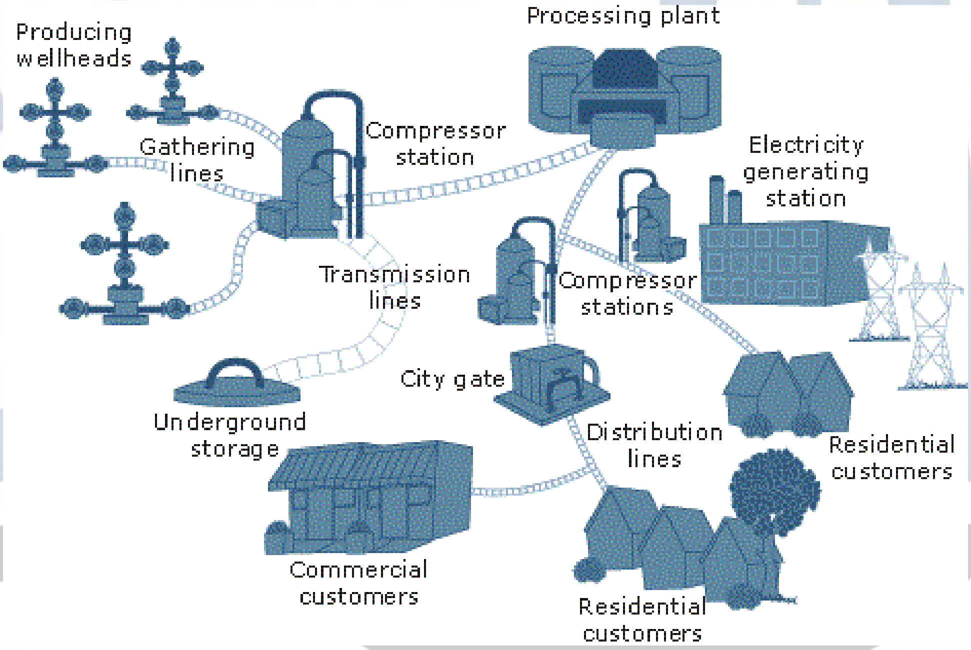

Figure 1. Diagram of the Flow of Natural Gas from Wellhead to End User [6]

To the best of our knowledge, there are many equations being used to date in order to determine gas flow rate in pipelines. Panhandle, Weymouth, AGA, White equations are among the most used equations for steady state flow[7]. The authors realized that there is a need for an article that reflects the simple practice of how flow capacity can be increased. In the present study, an easy-to-use form of Weymouth equation was suggested. The development of the Weymouth equation is commonly found in several books and publications in Fluid Mechanics or connected to industrial gas utilization technologies[8]; therefore, Weymouth mathematical model was readily used when necessary. Based on a real-world example and numerical calculations, this article provides readers with an overview of some basic knowledge about increasing a pipeline's throughput.

2. Theory

Optimization of pipelines requires the knowledge of flow of fluids in the pipe. Here we review Weymouth mathematical model for various gas network pipelines. According to Guo et al.[9], the form of the Weymouth equation commonly used in the natural gas industry is as follows:

$$q_h = \frac{18.062\, T_b}{P_b}\sqrt{\frac{\left(P_1{}^2 - P_2{}^2\right)D^{16/3}}{\gamma_g \overline{T}\,\overline{z} L}} \tag{1}$$

Where

$\gamma_g =$ gas gravity (air = 1)
$\overline{T} =$ average temperature, °R
$\overline{z} =$ gas deviation factor at $\overline{T}$ and $\overline{P} = \frac{P_1 + P_2}{2}$
$L -$ pipe length, ft
$P_1 =$ inlet pressure, psia
$P_2 =$ outlet pressure, psia
$D =$ pipe inner diameter, ft
$T_b =$ base temperature, °R, or boiling point, °R
$P_b =$ base pressure, psia
$q_h =$ gas flow rate (for horizontal flow), scfh

In order to have a better understanding of how capacity can be increased, three types of combinations may be considered:

2.1. Pipelines in Series

Consider a three-segment gas pipeline in a series of total length L depicted in Figure 2a. Applying the Weymouth equation to each of the three segments, adding and rearranging finally gives[9]:

$$\frac{q_t}{q_1} = \sqrt{\frac{\left(\frac{L}{{D_1}^{16/3}}\right)}{\left(\frac{L_1}{{D_1}^{16/3}} + \frac{L_2}{{D_2}^{16/3}} + \frac{L_3}{{D_3}^{16/3}}\right)}} \qquad (2)$$

Where q_1 is the capacity of a single-diameter (D_1) pipeline and q_t is the total capacity of the whole combination.

2.2. Pipelines in Parallel

Consider a three-segment gas pipeline in parallel as depicted in Figure 2b. Applying the Weymouth equation gives[9]:

$$\frac{q_t}{q_1} = \frac{\sqrt{{D_1}^{16/3}} + \sqrt{{D_2}^{16/3}} + \sqrt{{D_3}^{16/3}}}{\sqrt{{D_1}^{16/3}}} \qquad (3)$$

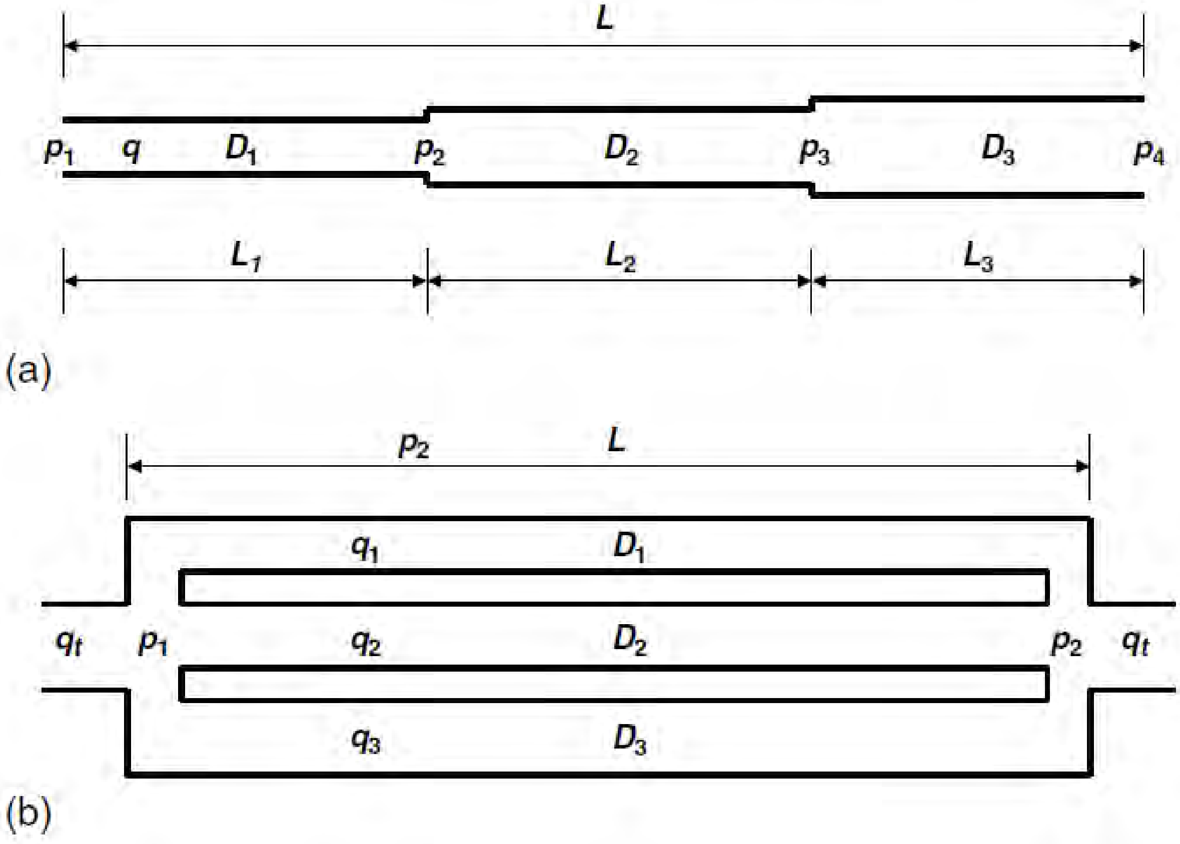

Figure 2. Schematic diagram of (a) a series pipeline and (b) a parallel pipeline.

2.3. Looped Pipelines

Consider a three-segment looped gas pipeline depicted in Figure 3. By applying Weymouth equation to the first two (parallel) segments, and then to the third segment, adding and rearranging[9]:

$$\frac{q_t}{q_3} = \sqrt{\frac{\left(\frac{L}{D_1^{16/3}}\right)}{\left(\frac{L_1}{\sqrt{D_1^{16/3}} + \sqrt{D_2^{16/3}}} + \frac{L_3}{D_3^{16/3}}\right)}} \quad (4)$$

Where q_3 is the capacity of a single-diameter (D_3) pipeline.

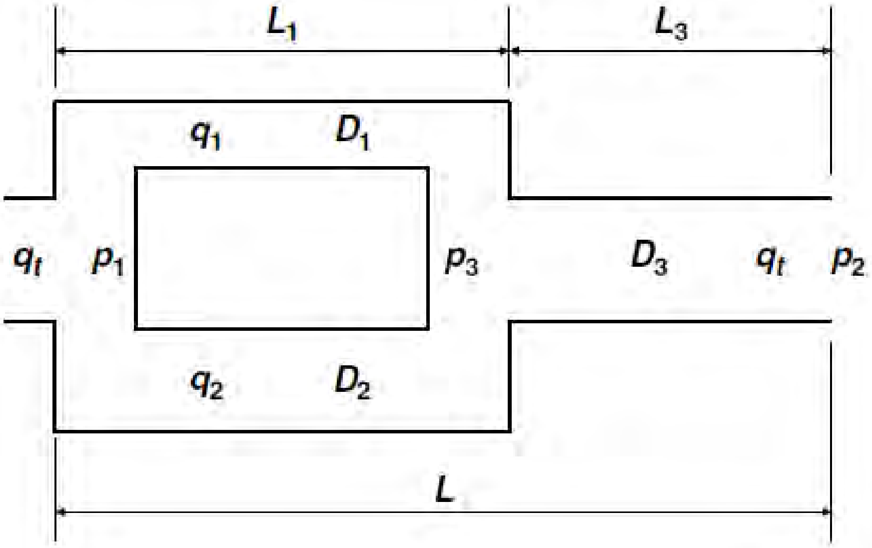

Figure 3. Schematic diagram of a looped pipeline.

3. A Real-world Example

To better understand the application of the above-mentioned equations, consider a 10-in pipeline that is 20 miles long. Assuming that the compression and delivery pressures will maintain unchanged, we aim to calculate gas capacity increases by using the following measures of improvement:
(a) if we replace 7 mi of the 10-in pipeline by a 15-in pipeline segment, then:

$L=20$ mi, $L_1=13$ mi, $L_2=7$ mi, $D_1=10$ in, $D_2=15$ in
by substituting these values into equation (2):

$$\frac{q_t}{q_1}=\sqrt{\frac{\left(\frac{20}{10^{16/3}}\right)}{\left(\frac{13}{10^{16/3}}+\frac{7}{15^{16/3}}\right)}}$$

= 1.2036, or 20.36% increase in flow capacity.

(b) if we place a 15-in. parallel pipeline to share gas transmission, then:

$D_1=10$ in, $D_2=15$ in
using equation (3):

$$\frac{q_t}{q_1}=\frac{\sqrt{10^{16/3}}+\sqrt{15^{16/3}}}{\sqrt{10^{16/3}}}$$

= 3.9483, or 294.83% increase in flow capacity.

(c) if we loop 7 mi of the 10-in pipeline with a 15-in pipeline segment, then:

L=20 mi, L_1=7 mi, L_3=13 mi, D_1=10 in, D_2=15 in, D_3=10 in
and by substituting these values into equation (4) :

$$\frac{q_t}{q_3} = \sqrt{\frac{\left(\frac{20}{10^{16/3}}\right)}{\left(\frac{7}{\sqrt{10^{16/3}}+\sqrt{15^{16/3}}}+\frac{13}{10^{16/3}}\right)}}$$

= 1.2195, or 21.95% increase in flow capacity.
The above calculations are summarized in Table 1.

4. Results and Discussion

4.1. Effect of Looping

As observed in section 3, all three combinations led to increase in pipeline capacity. To discuss the looping combination further, let Y be the fraction of looped pipeline and X be the increase in gas capacity, that is,

$$Y = \frac{L_1}{L}, \quad X = \frac{q_t - q_3}{q_3}$$

If, $D_1 = D_3$, Eq. (4) can be rearranged to solve for X:

$$X = \frac{1}{\sqrt{1 - Y\left(1 - \frac{1}{\left(1 + {R_D}^{2.31}\right)^2}\right)}} - 1 \qquad (5)$$

Where R_D is the ratio of the looping pipe diameter to the original pipe diameter, that is, $R_D = D_2/D_3$

The effects of looped line(Y) on the increase of gas flow rate(X) for various pipe diameter ratios(R_D) are shown in Figure 4 and calculations are summarized in Table 2. Figure 4 indicates an interesting behavior of looping: The increase in gas capacity is not directly proportional to the fraction of looped pipeline. For instance, looping 40% of a pipe with a new pipe of 2.5-fold diameter will increase the gas flow capacity only by 30%. It also shows that the benefit of looping increases rapidly with the fraction of looping. For example, looping 80% of the above-mentioned pipeline will increase the gas flow capacity by 120%, not 60%.

Table 1. Calculations of the three different combinations

Input Data:

Original pipe I.D.:				10	in.
Total pipeline length:				20	miles
Series pipe I.D.'s:	10		15	10	in.
Segment lengths:	13		7	0	miles
Parallel pipe I.D.'s:	10		15	0	in.
Looped pipe I.D.'s:	10		15	10	in.
Segment lengths:		7		13	miles

Solution:

Capacity improvement by series pipelines:

$$\frac{q_t}{q_1}=\sqrt{\frac{\left(\frac{L}{D_1^{16/3}}\right)}{\left(\frac{L_1}{D_1^{16/3}}+\frac{L_2}{D_2^{16/3}}+\frac{L_3}{D_3^{16/3}}\right)}} \quad = \quad 1.2036$$

Capacity improvement by parallel pipelines:

$$\frac{q_t}{q_1}=\frac{\sqrt{D_1^{16/3}}+\sqrt{D_2^{16/3}}+\sqrt{D_3^{16/3}}}{\sqrt{D_1^{16/3}}} \quad = \quad 3.9483$$

Capacity improvement by looped pipelines:

$$\frac{q_t}{q_3}=\sqrt{\frac{\left(\frac{L}{D_3^{16/3}}\right)}{\left(\frac{L_1}{\left(\sqrt{D_1^{16/3}}+\sqrt{D_2^{16/3}}\right)^2}+\frac{L_3}{D_3^{16/3}}\right)}} \quad = \quad 1.2195$$

Table 2. Quantitative comparison between the looped portion and capacity expansion

% LOOPED	% Capacity Increase, X

Y (%)	$R_D = 0.5$	$R_D = 1.0$	$R_D = 1.5$	$R_D = 2.0$	$R_D = 2.5$
	0.50	1.00	1.50	2.00	2.50
0	0.00	0.00	0.00	0.00	0.00
5	0.78	1.93	2.38	2.52	2.57
10	1.57	3.98	4.95	5.24	5.34
15	2.39	6.15	7.71	8.20	8.35
20	3.23	8.47	10.71	11.41	11.64
25	4.08	10.94	13.97	14.93	15.25
30	4.96	13.59	17.54	18.81	19.23
35	5.86	16.44	21.47	23.10	23.65
40	6.79	19.52	25.82	27.90	28.60
45	7.73	22.86	30.67	33.31	34.21
50	8.71	26.49	36.12	39.47	40.61
55	9.71	30.47	42.33	46.57	48.03
60	10.74	34.84	49.47	54.87	56.76
65	11.80	39.69	57.80	64.77	67.24
70	12.89	45.10	67.71	76.85	80.16
75	14.01	51.19	79.75	92.04	96.62
80	15.17	58.11	94.82	111.97	118.60
85	16.36	66.09	114.45	139.75	150.13
90	17.60	75.41	141.54	182.42	200.94
95	18.87	86.50	182.43	260.88	304.91
100	20.18	100.00	255.03	495.54	829.55

4.2. Comparison of the three methods

As illustrated in the latter example, gas capacity expansions were 20.36%, 294.83%, and 21.95% for series, parallel and looped pipelines, respectively. It is obvious that every method gives rise to increase in gas capacity, but it is not true that the larger the gas capacity is, the more optimized the system is. For instance, an apparent 294% increase in parallel lines in fact requires double the length of pipes more than that of required for a single line. It is worth noting that in order to accurately evaluate the efficiency of each type, a comprehensive pipeline economics evaluation should be performed to optimize the cost-performance of the whole system. The economic evaluation of pipelines itself may be a topic worth of research suggested by the authors of this paper.

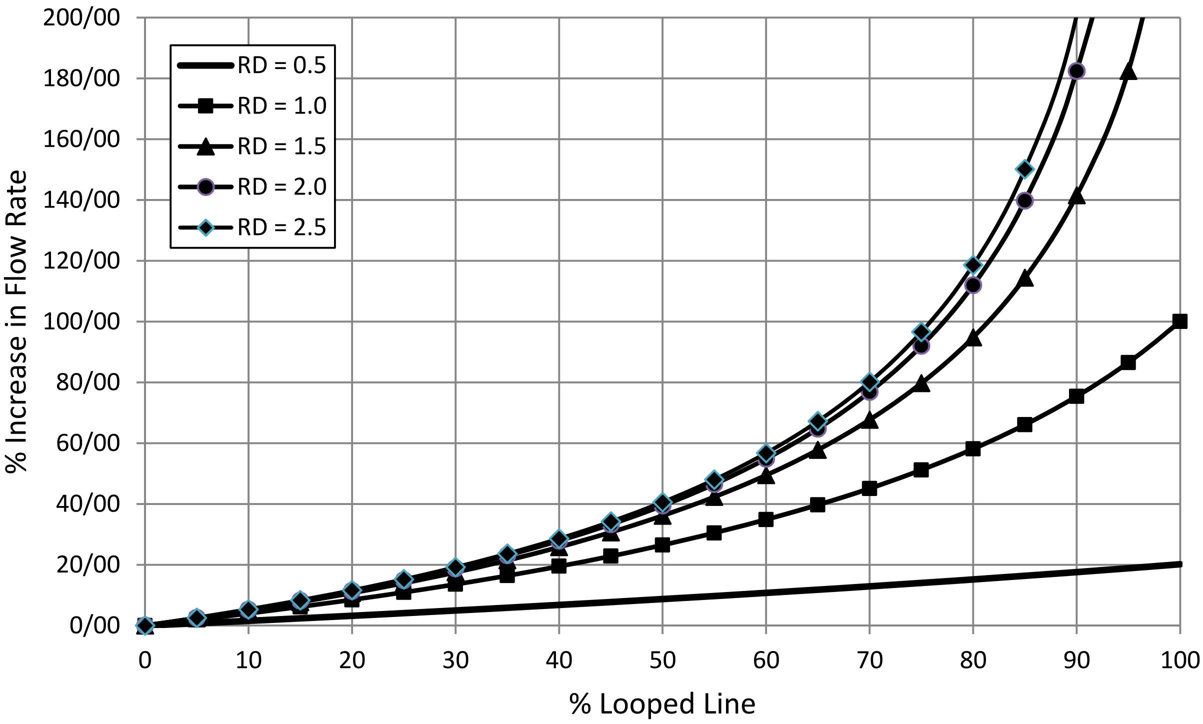

Figure 4. Effects of looped line and pipe diameter ratio on the increase of gas flow rate.

5. Conclusion

The Weymouth equation is a simple and popular equation for calculating the capacity of series, parallel and looped pipelines. In this paper, the Weymouth equation was exploited in a way that it can be used for different combinations of pipelines. The main conclusion of this work is that it is possible, through very simple equations, to correlate various pipe diameter ratios with capacity expansion corresponding to the portion of looped line. It is observed that in the case of using a looped pipeline, increase in gas capacity is not directly proportional to the fraction of looped pipeline. In other words, the benefit of looping increases exponentially with the fraction of looping.

References

[1] Bieker, Hans P., Olav Slupphaug, and Tor A. Johansen. "Real-time production optimization of oil and gas production systems: A technology survey." SPE Production & Operations 22.04 : 382-391, 2007.

[2] Andre, Jean, Frédéric Bonnans, and Laurent Cornibert. "Optimization of capacity expansion planning for gas transportation networks." European Journal of Operational Research 197.3 : 1019-1027, 2009.

[3] Rømo, Frode, et al. "Optimizing the Norwegian natural gas production and transport." Interfaces 39.1 : 46-56, 2009.

[4] Fanaei Shykholeslami, Mohammad Ali, and Mahdi Niknam Shahrak. "Looped Pipeline System for Increasing the Capacity of Natural Gas Transmission."Iranian Journal of Chemical Engineering 7, 2010.

[5] Michael Peoples and David Gratton, “Increasing capacity: relieving pipeline pressure”, Pipeliner 147, 76-77, July 2011.

[6] “Diagram of the Flow of Natural Gas from Wellhead to End User,” Natural Gas in America, Published 16 December 2013, https://naturalgasinamerica.wordpress.com/2013/12/16/diagram-of-the-flow-of-natural-gas-from-wellhead-to-end-user.

[7] Coelho, Paulo M., and Carlos Pinho. "Considerations about equations for steady state flow in natural gas pipelines." Journal of the Brazilian Society of Mechanical Sciences and Engineering 29.3 : 262-273, 2007.

[8] Donald L. Katz, Robert L. Lee. Natural Gas Engineering. McGraw- Hill, New York, N.Y., 1990.

[9] Boyun Guo, William C. Lyons, and Ali Ghalambor, Petroleum Production Engineering: A Computer-assisted Approach. Chemical, Petrochemical & Process, Gulf Professional Pub., 2007.