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Tackling the Supply Disruption of Natural Gas Pipeline Networks A Case Study on Upper Egypt Network

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Abstract

Natural gas plays a vital and effective role in the world energy market. Transportation is an important and sophisticated sector in the natural gas industry. Pipelines have been recognized as the most economic, effective and safest way of transporting natural gas. All-natural gas transportation networks face the challenge of unplanned disruption of gas supply due to different reasons. A unique feature of gas transportation networks is to make good use of line pack to secure its operation especially in the emergency cases and need to repair pipeline. This paper dealt with a case study of a single-supply gas transportation network in Upper Egypt and having a tree structure. It assumed all possible single failure scenarios at network segments and the consequences of these failure scenarios on the network operation. Two methods including line pack, and looping were proposed and checked to tackle or mitigate the challenge of gas supply disruption taking into consideration the service criticality of each consumer. The application of only line pack improved the operational reliability of the concerned network by providing reasonable time to take necessary action without any additional structures. Applying pipeline looping in addition to using line pack largely improved the situation, but additional cost is needed. Moreover, looping construction while the pipeline is in operation will face technical difficulties.

Keywords: *Natural gas; Pipeline network; Supply disruption; Line-pack; Pipe looping.*

1. Introduction

Natural gas is a fossil fuel like crude oil and coal. It is a vital component of the world's supply of energy as it is one of the cleanest, safest, and most useful of all energy sources. It offers important energy saving benefits when it is used instead of oil or coal. Although the primary use of natural gas is as a fuel, it is also a source of petrochemical feedstock and a major source of elemental sulfur. Its popularity as an energy source is expected to grow substantially in the future because natural gas can help achieve two important energy goals for the twenty-first century providing the sustainable energy supplies and services needed for social and economic development and reducing adverse impacts on global climate and the environment in general [1]. Usually, the location of natural gas resources and the place where the gas is needed are far from each other [2]. Several types of transportation means might be applied to transport gas, yet it is well known that pipelines represent the most economical means to transport large quantities of natural gas. In addition, the advent of metallurgical improvements and welding techniques, coupled with the exponential increase of pipeline networks during the last decades all over the world, have made the gas transportation via pipelines more economically attractive [3].

2. Methods

Line-packing, looping, and reverse supply are methods used to enhance the reliability and flexibility of a natural gas transmission network. In general, gas supply is almost constant while the consumption has variable values.

2.1. Line-packing

For the purpose of maintaining a safe and effective operating pressure range, pipeline systems frequently utilize line pack [4]. Due to the compressible nature of dry gas, large reserves can be stored on a short-term basis inside the pipeline through a process called line-packing. This is accomplished by injecting more gas into the pipelines during off-peak times by increasing the gas pressure, and by withdrawing larger amounts of gas during periods of high demand when flow capacities elsewhere in the system break down. Hence, the problem of keeping a sufficient level of line-pack during a given planning horizon becomes critical to the gas transporter [5].

Natural gas transportation networks depend on line-pack techniques to make balance between supply and demand for short-term operation. In addition, a line-pack is also useful in case of unplanned outage of a supply source or consumption center. Line-pack storage can provide reasonable time to feed important consumers during the time required for repair or modification [2].

Line-packing method requires a careful assessment of the pipeline's integrity to ensure it can handle the applied higher pressure without rupturing. It is a relatively cost-effective method for tackling unplanned gas supply disruption compared to looping as there is no need for additional piping components. It has the disadvantage of limited time and temporary gas supply in contrast to line looping.

2.2. Pipeline looping

Pipeline looping involves constructing a new pipeline of equal or non-equal diameter that run parallel to existing pipeline, creating a loop. The length of the added loop may be equal or less than the existing pipe. Both already existing and added pipelines are connected to each other at the start and end points of the loop and may be also connected at additional points according to operation requirements. This increases pipeline capacity if they are working in synchronous mode. It also increases redundancy in the system. If one pipeline goes down, gas can still have flow through the loop, enhancing pipeline reliability. A significant drawback of looping is the high cost associated with building new pipelines [6-8].

We generally use line looping in a pipeline network for three reasons:

1- As a main alternative to some important main lines in case of emergency in these lines, which feed important customers.

2 – To act as line pack for the main lines in the event of an emergency cases and a decrease in the pressures of the national gas network or the main source feeding the network.

3- To increase the transportation capacity of a connection in the pipeline network to meet the requirements of a new consumer or increased consumption of an existing consumer.

2.3. Reverse gas supply

Reverse gas supply utilizes existing pipelines that are designed for bi-directional flow. In this strategy, the flow direction is reversed to deliver gas from a different source. It may require adjustments to pipeline infrastructure and operational procedures to accommodate the reversed flow. It can be a temporary or permanent solution depending on the network's needs and the location of the damaged pipeline. Herein after I, find a brief comparison among the above-mentioned methods as shown in Table 1.

The choice of the appropriate method to enhance the operation of a natural gas transmission network depends on various factors, including the required capacity increase, budget constraints, and existing infrastructure capabilities [9].

Table 1. Comparison among the methods to tackle gas supply disruption.

Method	Description	Advantages	Disadvantages
Looping	Constructing new pipelines to create a loop around existing ones	Increased redundancy, bi-directional flow, enhanced reliability and flexibility	High cost due to new pipeline construction
Line-packing	Increasing pressure within existing pipelines	Relatively cost-effective capacity increase	Requires careful evaluation of pipeline integrity for safety reasons
Reverse supply	Utilizing existing bi-directional pipelines in the opposite direction	Can be a quick solution, potentially lower cost	May require infrastructure adjustments, might be a temporary solution

2.4. Description of the case-study gas pipeline network

The Egyptian Natural Gas Transmission Network (ENGTN) is considered as one of the largest and longest gas transmission pipeline networks in Africa and in the Middle East, so it has a significant impact on the Egyptian economy. Like all gas transportation pipeline networks, ENGTN faces many challenges including unplanned disruption of gas supply [10].

The objective of this paper is to study the operation of a tree-branched gas pipeline network at Upper Egypt. This research proposed appropriate methods to tackle or mitigate the problem of unplanned disruption of gas supply to ensure service continuity and reliability of the concerned network.

The natural gas pipeline network under study is located at Upper Egypt and prepared for residential and commercial service pipelines. It consists of a set of pipes and further installations which, receiving gas from key delivery point, allow its distribution and delivery to final consumers. The concerned network has about 72 kilometers of total length serving about 40 customers. Figure 1 illustrates a schematic diagram of the natural gas pipeline network under study with relevant diameters and lengths.

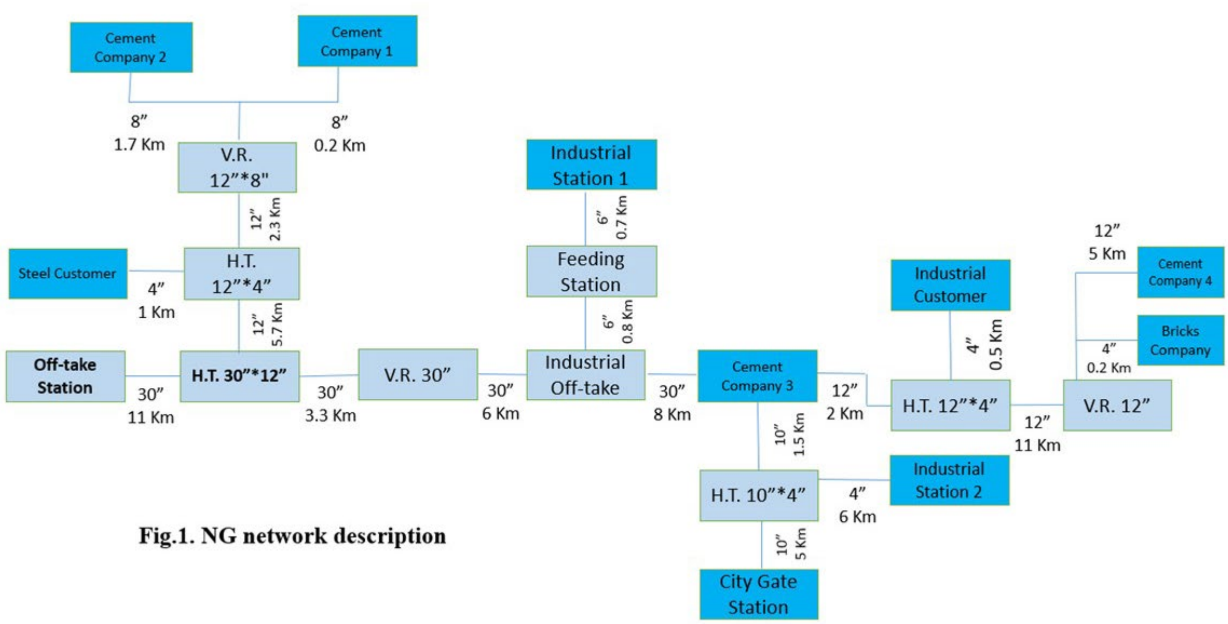

Figure 1. Natural gas network description.

To simplify the presentation and handling the case study in question later, all the consumers in the gas network will be denoted according to the following Table 2.

Table 2. List of network consumers and their denotation.

Denotation	A	B	C	D	E
Consumer	Steel Company	Cement Company 1	Cement Company 2	Industrial station 1	Cement Company 3

Denotation	F	G	H	J	K
Consumer	Industrial station 2	City Gate Station	Industrial customer	Cement Company 4	Bricks company

2.5. Network failure modeling

In this section, the information required to accomplish this study was collected and processed. The main information includes the line data (pipeline network), consumer information, emergency cases, forming matrix and set priority order and Software equations and calculations. Pipeline Data means, the main lines in the network were described, where the inside and outside diameter of the line, thickness, maximum operating pressure of the line, the actual pressure, as well as the length of each line. Consumers information**,** here is to collect the data pertaining to the gas consumers in the pipeline network under study. Furthermore, the consumers were categorized according to their service criticality and consequent priority to receive gas in case of emergency.

Cases of emergency were prepared on how to deal with the various emergency cases expected to occur to the network lines.

- Ten emergency cases were identified and assumed in the network as shown in Table 3.
- For each case of the main ten cased, the possible scenarios of supplying gas to the different consumers were identified.
- In each assumed failure location, the location of the damage, the diameter and length of the affected line and the affected stations, and the priority of gas delivery were identified and described.

Table 3 shows the possible failure scenarios and the affected consumers. Figure (2) shows the locations of the assumed failure cases.

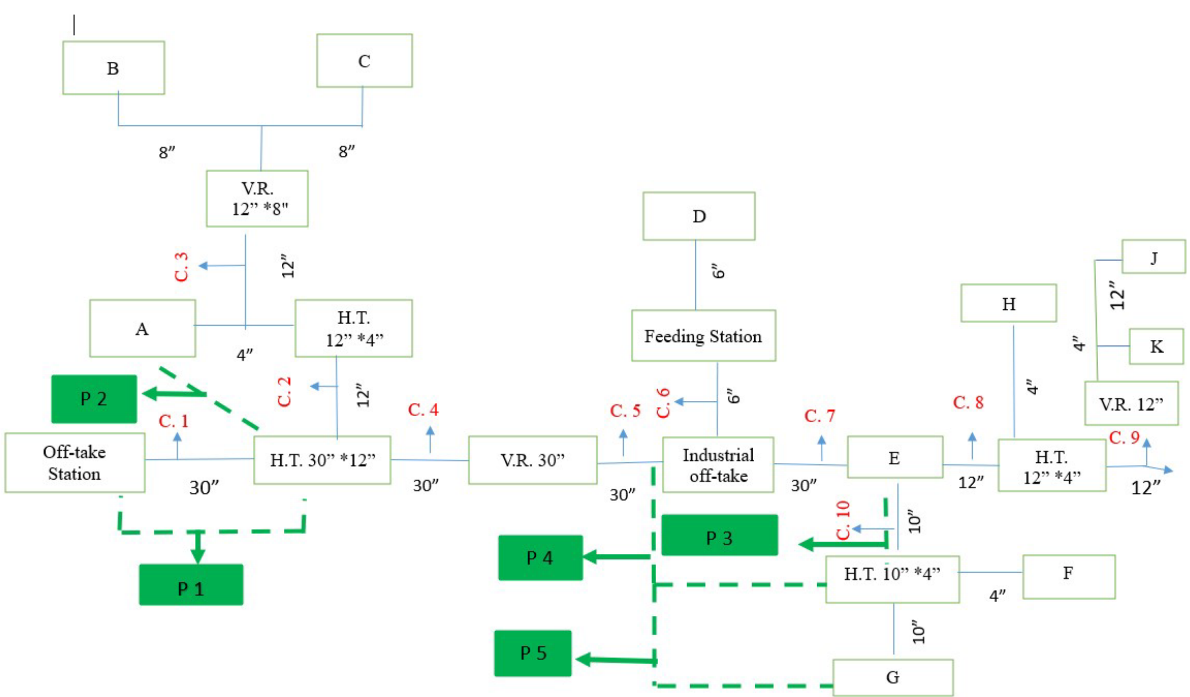

Figure 2. Locations of the assumed failure cases (C_n) and proposed loops (P_n).

Table 3. Network possible failure scenarios.

Case No.	Line diameter [in]	Line length [km]	Possible scenario no.	Consumers affected
C1	30	11	1-1	G
				A
			1-2	G
				A
				E
				J
			1-3	G
				A
				E
			1-4	G
				A
				J
C2	12	5.700	2-1	A
C3	12	2.300	3-1	C
				B
			3-2	C
			3-3	B
C4	30	3.300	4-1	G
			4-2	E
				G
			4-3	J
				G
C5	30	6	5-1	G
			5-2	G
				E
			5-3	G
				J
C6	6	1.500	6-1	D
C7	30	8	7-1	G
			7-2	E
				G
			7-3	J
				G
C8	12	2	8-1	H
			8-2	J
C9	12	11	9-1	J
C10	10	5	10-1	G
	4	6		G

2.6. Priority order table

A simplified table was formed where the most important consumers of gas were arranged according to the priority of delivering gas to them in emergency cases, and each consumer was given a priority index from (1:10) as each number indicates the degree of the consumer's priority concerning delivering gas (Table 4). It is worth mentioning that the given priority index was estimated based on the accumulated experience of the network operation.

Priority Index was ranged from 0-10, where: 1-Low emergency, very low priority index; 10-High emergency, top priority index.

Table 4. Priority index of network consumers.

Consumer	A	B	C	D	E	F	G	H	J	K
Priority index	8	5	5	3	5	5	10	3	5	1

2.7. Software equation and calculation

Individual pipe case: For the study calculations, The line pack (LP) equation was applied. Therefore, an excel sheet was developed to calculate LP for each consumer [5,7].

$P_{avg} = {}^{2}/_{3} * (P_1+P_2 - P_1*P_2/P_1+P_2)$ (1)

$V_b = 0.0007855 * (T_b/P_b) * (P_{avg} / Z_{avg} * T_{avg}) * (ID^2 * L)$ (2)

Series and parallel pipe's equation case: The following equations provide the equivalent length or diameter when the lines are connected in series or parallel to each other, and the effect of that on the quantity of the line pack and informing customers in the event of an emergency [11].

In series pipe

$*Le= L_1 + L_2 * (D_1/D_2)^{5} + L_3 * (D_1/D_3)^5$ (3)

In parallel pipe

$*(Q_1/Q_2) = (L_2/L_1)\ 0.5 * (D_1/D_2)\ 2.5$ (4)

Equivalent diameter

$*D_e= D_1 \{(1+Con./Cons.)\ 2\}\ 0.2$ (5)

3. Results and discussion

3.1. The line pack results

For this stage, reference is directed to Tables (3-5), including the possible single failure and the relevant gas supply according to operation priority index. The obtained results for every emergency case (10 Emergency cases) were shown including the time that the affected consumers could be operated depending only on line-pack storage of gas, refer to Tables (6-15).

3.2. The pipe looping results

Sometimes, the operation time provided by the line pack storage is not enough to repair the damaged pipes and restore the normal operation of the gas network especially when the occurring damage is pertaining to the main gas pipelines. Therefore, it was necessary to seek another method to raise the reliability of the gas network. Taking into consideration the possible emergency cases and service criticality of the network consumers, the method of pipe looping was proposed. It was proposed to have line looping at only five locations in the gas network under study due to its high cost. The five proposed loops are illustrated in Figure 2.

3.2.1. Pipe looping as an alternative to the existing important pipes

Illustrate the impact of each proposal on the previously imposed cases of emergency, the clients affected by this state of emergency, and the beneficiaries of this proposal Table 16.

3.2.2. Pipe looping as line pack

The following tables illustrate the difference in the quantity of Line-Pack (Vb.) for the pipeline in each scenario between the existing network and the proposed new loops for these lines. A comparison between V_b before and after modification of the pipeline network are given in Tables (17-22).

Table 5. The emergency operation matrix of the gas network.

	1				2	3			4	
Scenario/ Consum.	1a	1b	1c	1d	2a	3a	3b	3c	4a	4b
A	L	L	L	L	L	N	N	N	N	N
B	O	O	O	O	O	L	L	O	N	N
C	O	O	O	O	O	L	O	L	N	N
D	O	O	O	O	N	N	N	N	O	O
E	O	L	L	O	N	N	N	N	O	L
F	O	O	O	O	N	N	N	N	O	O
G	L	L	L	L	N	N	N	N	L	L
H	O	O	O	O	N	N	N	N	O	O
J	O	L	O	L	N	N	N	N	O	O
K	O	O	O	O	N	N	N	N	O	O

	5			6	7			8	9	10
Scenario/ Consum.	5a	5b	5c	6a	7a	7b	7c	8a	9a	10a
A	N	N	N	N	N	N	N	N	N	N
B	N	N	N	N	N	N	N	N	N	N
C	N	N	N	N	N	N	N	N	N	N
D	O	O	O	L	N	N	N	N	N	N
E	O	L	O	N	L	O	O	N	N	N
F	O	O	O	N	O	O	O	N	N	O
G	L	L	L	N	L	L	L	N	N	L
H	O	O	O	N	O	O	O	L	N	N
J	O	O	L	N	O	O	L	L	L	N
K	O	O	O	N	O	O	O	O	O	N

Operation symbols: L = operated by line-pack; N = Normal operation; O = out of service

It is noted that consumers F and K were excluded from the line-pack plan. Consumer F was excluded as it has a common feed line with a consumer of top priority index which is the city gate station. Consumer K was excluded as it has a very low priority index.

Table 6. Line pack results of emergency case no. 1.

	Operation time with Line-pack, [hr]			
Scenario	11	12	13	14
Consumer				
G	46.62	39.95	39.95	39.95
A	13.2	13.2	13.2	13.2
E	O	0.76	6.66	O
J	O	5.9	O	6.66

Table 7. Line pack results of emergency case no. 2.

	Operation time with Line-pack, [hr]
Scenario	21
Consumer	
A	4.80
E	O
J	O

Table 8. Line pack results of emergency case no. 3.

	Operation time with Line-pack, [hr]		
Scenario	31	32	33
Consumer			
C	0.033	0.310	O
B	0.278	O	0.310

Table 9. Line pack results of emergency case no. 4.

	Operation time with Line-pack, [hr]		
Scenario	41	42	43
Consumer			
G	39.39	32.73	32.73
E	O	6.66	O
J	O	O	6.66

Table 10. Line pack results of emergency case no. 5.

	Operation time with Line-pack, [hr]		
Scenario	51	52	53
Consumer			
G	25.25	19.59	19.59
E	O	6.66	O
J	O	O	6.66

Table 11. Line pack results of emergency case no. 6.

	Operation time with Line-pack, [hr.]
Scenario	61
Consumer	
G	0.26

Table 12. Line pack results of emergency case no. 7.

	Operation time with Line-pack, [hr]		
Scenario	71	72	73
Consumer			
G	1.92	8.59	1.92
E	6.66	O	O

Table 13. Line pack results of emergency case no. 8.

	Operation time with Line-pack, [hr]	
Scenario	81	82
Consumer		
H	0.11	O
J	O	5.91

Table 14. Line pack results of emergency case no. 9.

	Operation time with Line-pack, [hr]
Scenario	91
Consumer	
G	1.85

Table 15. Line pack results of emergency case no. 10.

	Operation time with Line-pack, [hr]
Scenario	101
Consumer	
G	1.54

Table 16. Pipe looping as an alternative to the existing important pipes.

Loop No.	Emergency case to overcome	Customers to benefit from loop
Proposal no. 1 (P1)	C1	All
Proposal no. 2 (P2)	C2	A
Proposal no. 3 (P3)	C10	F, G
Proposal no. 4 (P4)	C7, C10	F, G
Proposal no. 5 (P5)	C7, C10	F, G

Table 17. Proposal 1 for consumer G

Case No.	Scenario No.	1	Sc. Location	Offtake station
LP volume/no. of hrs		without loop	with loop	increase %
Vb., m^3	SC.1	372940	565672	52%
No. hr.		46.62	70.71	52%
Vb., m^3	SC.2	319630	512362	60%
No. hr.		39.95	64.05	60%
Vb., m^3	SC.3	319630	512362	60%
No. hr.		39.95	64.05	60%
Vb., m^3	SC.4	319630	512362	60%
No. hr.		39.95	64.05	60%

Table 18. Proposal 2 for consumer A

Case No.	2	Sc. Location	From (30” *12”) Hot tap’ room to (12” *4”) Hot tap’ room	
LP volume/no. of hrs	Scenario No.	without loop	with loop	increase %
Vb., m^3	SC.1	9590	11719.52	22%
No. hr.		4.80	5.87	22%

Table 19. Proposal 3.1 for emergency case no.7. for consumer G.

Case No.	7	Sc. Location	From industrial off-take H.T. room to cement company 3	
LP volume/no. of hrs	Scenario No.	without loop	with loop	increase %
Vb., m^3	SC.1	15384	18486	20%
No. hr.		1.92	2.31	20%
Vb., m^3	Sc.2	68693	71777	4%
No. hr.		8.59	8.97	4%
Vb., m^3	SC.3	15384	18486	20%
No. hr.		1.92	2.31	20%

Table 20. Proposal 3.2 for emergency case no.10. for consumer G.

Case No.	10	Sc. Location	From cement company 3 to CG. Station	
L.P. volume no. of Hr.	Scenario No.	without loop	with loop	increase %
Vb., m^3	SC.1	12287	15371	25%
No. hr.		1.54	1.92	25%

Table 21. Proposal 4 for consumer G.

Case No.	5	Sc. Location	From (30”) Valve room to industrial off-take H.T. room	
LP volume/no. of hrs	Scenario No.	without loop	with loop	increase %
Vb., m^3	SC.1	209993	297599	41.72%
No. hr.		26.25	37.21	41.72%
Vb., m^3	SC.2	156683	244289	55.91%
No. hr.		19.59	30.54	55.91%
Vb., m^3	SC.3	156683	244289	55.91%
No. hr.		19.59	30.54	55.91%

Table 22. Proposal 5 for consumer G.

Case No.	5	Sc. Location	From (30”) Valve room to industrial off-take H.T. room	
LP volume/no. of hrs	Scenario No.	without loop	with loop	increase %
Vb., m^3	SC.1	209993	367683	75.09%
No. hr.		26.25	45.96	75.09%
Vb., m^3	SC.2	156683	314373	100.64%
No. hr.		19.59	39.31	100.64%
Vb., m^3	SC.3	156683	314373	100.64%
No. hr.		19.59	39.31	100.64%

4. Conclusions

Studying the use of line pack in the concerned network revealed that it can provide reasonable time to operate one or more of the network consumers according to the service criticality evaluated by network operators. Not in all cases, the operation time provided by line-pack gas is enough to tackle the problem of gas supply disruption. So, it was needed to seek another method to minimize or eliminate the downtime of gas supply disruption during emergency cases. The pipeline looping was proposed to work as an alternative to transport lines in the event of emergency cases and to enhance the line pack capacity of the concerned network. The use of pipeline looping was proved to improve the network availability and reliability compared with the case of using only line pack.

Recommendations

It is generally recommended to the dispatchers of the gas transportation networks to make good use of the pipeline gas line pack and prepare operation emergency plans according to service criticality of the network consumers. Due to the involved technical difficulties and costly implementation of loops while the pipeline is in operation, it is recommended to consider the problem of gas supply disruption during the phase of pipeline design and construct the necessary looping before putting it in operation.

Nomenclature

ENGTN	*Egyptian Natural Gas Transmission Network*
NG	*Natural gas.*
LP	*Line-pack.*
P_{avg}	*Average gas pressure in pipe segment, (kPas).*
P_1	*Upstream pressure, (kPas).*
P_2	*Downstream pressure, (Kpas.).*
P_b	*Base pressure, Constant value, (kPas).*
P_{max}	*Actual upstream Press., (bar).*
P_{min}	*Actual downstream pressure, (bar).*
T_b	*Base temperature constant value, (°K).*
T_{avg}	*Average gas temperature in pipe segment, (°K).*
Z_{avg}	*Average gas compressibility in pipe segment.*
ID	*Pipe inside diameter, (mm).*

L	*Pipe segment length, (km).*
V_b	*Line pack in pipe segment, standard cubic meter (m^3).*
L_1	*Length of the first pipe segment, km.*
L_2	*Length of the second Pipe segment, km.*
L_3	*Length of the third pipe segment, km.*
D_1	*Diameter of the first pipe segment, in.*
D_2	*Diameter of the second pipe segment, in.*
D_3	*Diameter of the third pipe segment, in.*
L_e	*Equivalent length of pipe, km.*
D_e	*Equivalent diameter of pipe, in*
Q_1	*Flow rate in the first pipe segment, m^3/hr.*
Q_2	*Flow rate in the second pipe segment, m^3/hr.*

Declarations

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Authors' contributions: *HH: Conducting studies on the natural gas network in question, assuming emergency scenarios and developing proposals to optimize the network in emergencies, manuscript draft writing.NZ: Supervising search steps, results and conclusions, editing manuscript .NE, AS: General Supervision. All authors read and approved the final manuscript.*

References

[1] Mokhatab S, Poe WA., Mak JY. Handbook of Natural Gas Transmission and Processing Principles and Practices, Fourth Edition ,Gulf Professional Publishing ,2019.
[2] Debebe A., Woldeyohannes, Abd Majid M. Simulation model for natural gas transmission pipeline network system, Malaysia, 2010.
[3] Roger Z. Optimization Problems in Natural Gas Transportation Sys-tems: A State-of-the-Art Review. San Nicolas, NL 66450, Mexico, 2014.
[4] Rawash YY, Aly SM, Samad HAA, Hussein MH. Systematic Method for Multi Objective Design Optimization of Natural Gas Transmission. Petroleum and Coal, 2024; 66(6): 773.
[5] Tran TH. Line-pack Planning Models for Gas Transmission Network under Uncertainty. European Journal of Operational Research, 2018; 268(2): 688-702.
[6] Fanaei MA and Niknam M. Looped Pipeline System for Increasing the Capacity of Natural Gas Transmission. Iranian Journal of Chemical Engineering, 2010; 7(1): 76-86.
[7] Pipeline Briefing Paper #2,Pipeline Basics and Specifics About Natural Gas Pipelines, Pipeline Safety Trust magazine,2015.
[8] Lenz R, Schwarz R. Optimal Looping of Pipelines in Gas Networks. Zuse Institute Berlin,2016.
[9] Omobolanle OC. Analysis of Flowrate in Loop Gas Pipe-line Networks Using Pipe 2016 and Hardy Cross Method. Saudi Journal of Engineering and Technology, 2020; 5(2): 49-62.
[10] Nafey S, Zoghaib N, Omar M. Optimization of the Egyptian Natural Gas Transmission Networks, International Journal of Engineering Research and Technology, 2020, 13(9): 2347.
[11] Menon E S. Gas Pipeline Hydraulics, CRC Press Taylor and Francis Group, 2005.
[12] Huang Z, Seireg A. Optimization in Oil and Gas Pipeline Engineering, Madison, Wise. 53706.
[13] Edgar TF, Himmelblau DM, Bickel TC. Optimal Design of Gas Transmission Networks, Society of Petroleum Engineers Journal, 1978; 18(02): 96-104.
[14] Bahadori A. Natural Gas Processing Technology and Engineering Design. Gulf Professional Publishing, 225 Wyman Street, Waltham, MA 02451, USA,2014.
[15] Chebouba A. Multi objective optimization of line pack management of gas pipeline system. J. Phys.: Conf. Ser., 2016; 574: 012114.
[16] Ikoku CU. Natural Gas Production Engineering, Krieger Publish-Ing Company, Malabar, Florida 32950, 1984.
[17] EIA, U.S.,The Basics of Underground Natural Gas Storage, 2015.
[18] Tabkhi F. Optimization of gas transmission networks. PhD Thesis, Persian Gulf University 2007.

[19] Wilson I. Transmission Pipeline Balancing Issues. 2008, https://www.gasindustry.co.nz/assets/WorkProgrammeDocuments/3542Issues-Paper-Transmission-Pipeline-Balancing-164547.pdf .
[20] Speight JG. Natural Gas: A Basic Handbook. Gulf Publishing Company, Houston, Texas,2007.
[21] Sanaye S, and Mahmoudimehr J. Optimal design of a natural gas transmission network layout. Chemical Engineering Research and Design, 2013; 91(12): 2465-2476.
[22] Guo B, and Ghalambor A. Natural Gas Engineering Handbook. 2nd Edition, Gulf Publishing Company, Houston, Texas, 2005.

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