NETWORK MODELING AND ANALYSIS: WEST ZONE GAS TRANSMISSION PIPELINE NETWORK OF BANGLADESH

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A Project

By

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RECOMMENDATION OF THE BOARD OF EXAMINERS

The project entitled as "**Network Modeling and Analysis: West Zone Gas Transmission Pipeline Network of Bangladesh**" submitted by S. M. Amir Hossain, Roll No: 1009132005(P), Session: October 2009, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Master of Engineering in Petroleum Engineering** on October 14, 2014**.**

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Declaration

It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

The natural gas transmission pipeline network in the Western Zone of Bangladesh currently comprises of 246 kilometer of pipeline. About 110-120 MMscfd of natural gas, which is 5% of the total production (2350 MMscfd), is supplied through this network. The Government has planned to supply gas to more areas in the north and south western regions of the country. About 177 kilometer of pipeline is already constructed for this purpose, which will be connected to the existing network in near future. Thus natural gas will be available to Kushtia, Jhenidah, Jessore and Khulna districts. Compressor stations are also being erected at Elenga, Tangail and Ashuganj, Brahmanbaria to boost up the pressure and throughput of gas through this network.

Detail study is needed on the west zone gas transmission network regarding pressure drop along the pipeline and availability of gas at various off-takes. Prediction of pressure drop along the pipeline in a network is very important as it indicates the pipeline efficiency, volumes available at various off-takes/outlets, maximum possible distance of transmission for a given upstream pressure, effect of compressors, etc. This kind of study requires numerical simulation with powerful computational resources.

This study presents some results from the simulation study of the west zone gas transmission network. A virtual model is constructed, which includes both the existing and new extensions to the network. The model is first validated by matching with the existing network using known data. Then simulation runs are performed to investigate the issues mentioned above. In addition, sensitivity studies are performed to investigate the effects of supply-demand fluctuations. Commercial software package PIPESIM™ is used for this work. The starting node of the network is at Elenga, Tangail. The existing pressure at this point is 400 psig. The fare most downstream point of the network is Khulna.

The study will improve operational standard consistent with the world gas industry which will be helpful for smooth operation of the network. The study will also be helpful for proper planning and design for augmentation of national gas grid for the uninterrupted transportation of natural gas in safe, reliable and economical way to the demand centers for ultimate distribution of the same.

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1

INTRODUCTION

Natural gas is today considered by many as the fuel of the future. Years ago, when oil companies dilled for oil and found gas, their effort was deemed a failure. The gas, if associated, often had been either re-injected or flared or, if dry, left for another day. When flaring was branded as wasteful by producing countries, companies had to find an alternative use for gas. As oil price rose and production costs fell, gas became more economically feasible. Today companies continue to explore for oil and gas and are delighted for find one or the other or both. Nevertheless, as oil demand grows and the future supply of oil becomes ever more constrained, natural gas is the most viable energy alternative. It is believed that industry will soon be referred to as gas and oil, rather than oil and gas- today's common description [1].

Being riverine delta having porous and permeable hydrocarbon bearing sand structure and unique condition of traps, Bangladesh is always considered a gas prone country. Various national and international companies used to carry out exploration in the potential areas of Bangladesh. The extensive exploration works have so far been discovered 25 (twenty five) nos. gas fields including 1(one) offshore gas field and 1 (one) oil field [2]. Recently another gas field named "Rupganj Gas Field" is discovered in early 2014. With the advent of natural gas and its use as fuel, the necessity arose of transporting natural gas from the gas well to the ultimate consumer. The way of transportation of gas either by pipeline or by cylinder/vessel in the form of CNG or LNG. But the most economical, easiest and safe way of continuous transportation of huge volume of gas is transportation by pipeline. In Bangladesh, National Gas Grid is operated by Gas Transmission Company Limited (GTCL), a state owned company under Petrobangla, dividing the transmission system into two operational regions viz. Transmission East (Dhaka, except greater

Faridpur district, Sylhet and Chittagong divisions) and Transmission West (Rajshai, Khulna and Barisal divisions including greater Faridpur district) [3]. The West Zone comprises geographical area on the west side of the rivers Jamuna and lower Meghna, which means Khulna, Rajshahi, Barisal divisions and greater Faridpur district of Bangladesh [4].

As incidentally all gas fields, except Shabazpur gas field, are situated in the Eastern, North-Eastern and South-Eastern side of the river Jamuna, naturally, most of the principal demand area and major gas consumers in the Transmission East area along with capital Dhaka have been brought under gas transmission and distribution network. For the harmonic scio-economic development of the country, augmentation of transmission pipeline to the West and South-West region to facilitate the gas supply is deserved to be considered. From that point of view, Government took steps to supply and distribute gas to the West and South-West region in Bangladesh in the last decade. The West Zone Gas Transmission Pipeline Project, the first gas supply project for the West Zone, was completed in the year 1997-2000. The first supply of natural gas to the Western region (Sirajgonj & Pabna) began in 1999 [5]. At present, 246 km gas transmission pipelines of various sizes is under operation, supplying 110-120 MMscfd of natural gas to the West Zone of Bangladesh. About 177 km new lines are going to be added to the existing transmission system to include South-West region viz. Kushtia, Jhenaidah, Jessore and Khulna [6, 7]. It can be anticipated that natural gas would boost economic development in these regions [8]. Thus, the gas demand would grow rapidly [9, 10].

A detail study is required to know what quantity of gas at customer's required pressure would be possible to transmit to the West Zone by the present upstream pressure; what should be the upstream pressure to cope with the future demand; the effect of compressors to the network established at Ashuganj, Brahmanbaria, the fare upstream of the West Zone; the effect of compressors to the network established at Elenga, Tangail, the upstream of the West Zone; and the behavior of the network with supply-demand fluctuations.

The project aims to build virtual network models (existing and extended) by using commercial software “PIPESIM” to simulate and to analyze some sensitivity studies on West Zone gas transmission pipeline network from which various scenarios would come up such as pressure drop along the pipeline at different junctions/outlets when gas flow rate varies effectively, maximum gas flow rate at minimum required outlet/downstream pressure and minimum pressure at maximum required flow at demand centers under the network, the effect of compressors to the network after installation at the upstream at Elenga, Tangail and fare upstream at Ashuganj, Brahmanbaria of the network, how long the pipeline can cope up with the forecasted demand or when boost up device(s) would need to be installed etc.

OBJECTIVES OF THE STUDY

The specific objectives are:

(i) To build two virtual network models: one for existing 246 km long West Zone gas transmission pipeline network and another for existing 246 km along with extended/newly constructed 177 km aggregating 423 km long West Zone gas transmission pipeline network to observe the performance as well as pressure drop along the pipeline when gas flow rate varies effectively;

(ii) To calculate maximum gas flow rate at minimum required outlet/downstream pressure and minimum pressure at required flow rate at demand centers under the network;

(iii) To analyze the effect of compressors to the network established at Ashuganj, Brahmanbaria, the fare upstream of the network;

(iv) To analyze the effect of compressors to the network established at Elenga, Tangail, the upstream of the network; and

(v) To perform sensitivity studies to know- how long the pipeline can cope up with the forecasted demand or when boost up device(s) would need to be installed etc.

CHAPTER

2

GAS SECTOR OVERVIEW IN BANGLADESH

2.1 BRIEF HISTORY OF GAS SECTOR

Initial scattered exploration effort for oil and gas was undertaken by private ventures. The search of oil and gas in the area constituting Bangladesh began in the later part of the 19th century through some isolated geological mapping. The first serious attempt to find oil and gas was undertaken in Sitakund in 1908 by the Indian Petroleum Prospecting Company, 18 years after the first oil discovery in Digboi, Assam. During 1923-31 Burmah Oil Company (BOC) drilled two shallow wells in Patharia. The wells were abandoned though there was a reported occurrence of oil. A total of 6 exploratory wells were drilled, there was however no discovery and the Second World War disrupted further activity [11].

The promulgation of Pakistan Petroleum Act in 1948 introduced formal activity and infused interest of international oil companies in oil and gas exploration. The Standard Vacuum Oil Company (STANVAC) of USA, Pakistan Petroleum Ltd. (PPL) - a Burmah Oil Company affiliate and Pakistan Shell Oil Company (PSOC) took up concessions during early fifties and carried out exploration till the end of sixties. These operations saw the drilling of 16 exploration wells including the first offshore well and resulted in the discovery of 7 gas fields.

During this time Oil and Gas Development Corporation (OGDC) was established as the first public sector national organization in 1961 and the root of exploration for oil and gas were firmly set in the country. OGDC started to carry out geological and geophysical survey including gravity, magnetic and seismic, and drilled wells which soon saw success.

After the liberation of Bangladesh, exploration activities gathered pace both by the national and international companies. The part of OGDC that was in operation in Bangladesh was reorganized as Bangladesh Mineral Oil and Gas Corporation (Petrobangla) continued its exploration efforts while the Bangladesh Petroleum Act was enacted in 1974 to facilitate international participation under Production Sharing Contract (PSC). The offshore area of

Bangladesh was divided in to 6 blocks, which were taken up by Ashland, ARCO, BODC (Japex), Union Oil, Canadian Superior Oil and Ina Naftaplin under production sharing contract. This phase of PSC ended with relinquishments by 1978. Since 1972 the operational mandate of Petrobangla has undergone modification several times. In 1974 oil import, refining and marketing was segregated under Bangladesh Petroleum Corporation (BPC), while the mineral operation, which was separate since 1972, was merged with oil and gas operation in 1985. Presently Bangladesh Oil Gas and Minerals Corporation short named Petrobangla operates oil and gas exploration, development, transmission, distribution and conversion together with development and marketing of minerals[11].

2.2 MANAGMENT SYSTEM OF GAS SECTOR IN BANGLADESH

At present seven operating companies including International Oil Companies (IOC's) are producing gas in Bangladesh. Among them Bangladesh Gas Field Company Ltd (BGFCL), Sylhet Gas Field Company Limited (SGFCL), Bangladesh Petroleum Exploration and Production Company Limited (BAPEX) are the state owned companies of Petrobangla. The IOC's are Chevron Bangladesh Blocks 13 & 14, Tullow Bangladesh Limited., Santos, and NIKO Resources. The total daily average gas production of all companies is 2240-2350 MMscf.

Six marketing companies are distributing gas in their franchise areas. The marketing companies are Titas Gas Transmission and Distribution Company Limited (TGTDCL), Bakhrabad Gas System Limited (BGSL), Jalalabad Gas Transmission and Distribution System Limited (JGTDSL), Karnafuli Gas Distibution Company Limited (KGDCL), Paschimanchal Gas Company Limited (PGCL) and Sundarban Gas Company Limited (SGCL). The total daily average distribution volume of these five marketing companies is 2240-2350 MMscf.

Before the formation of Gas Transmission Company Limited (GTCL) in 1993 there were three gas transmission companies in Bangladesh who were also distribution companies i.e. sold gas to end customers. These were Titas Gas Transmission and Distribution Company Limited (TGTDCL), Bakhrabad Gas System Limited (BGSL) and Jalalabad Gas Transmission and Distribution System Limited (JGTDSL). Although after formation of GTCL they are not permitted to expand their transmission facilities. The production, transmission & distribution management system of natural gas is shown in Figure 2.1.

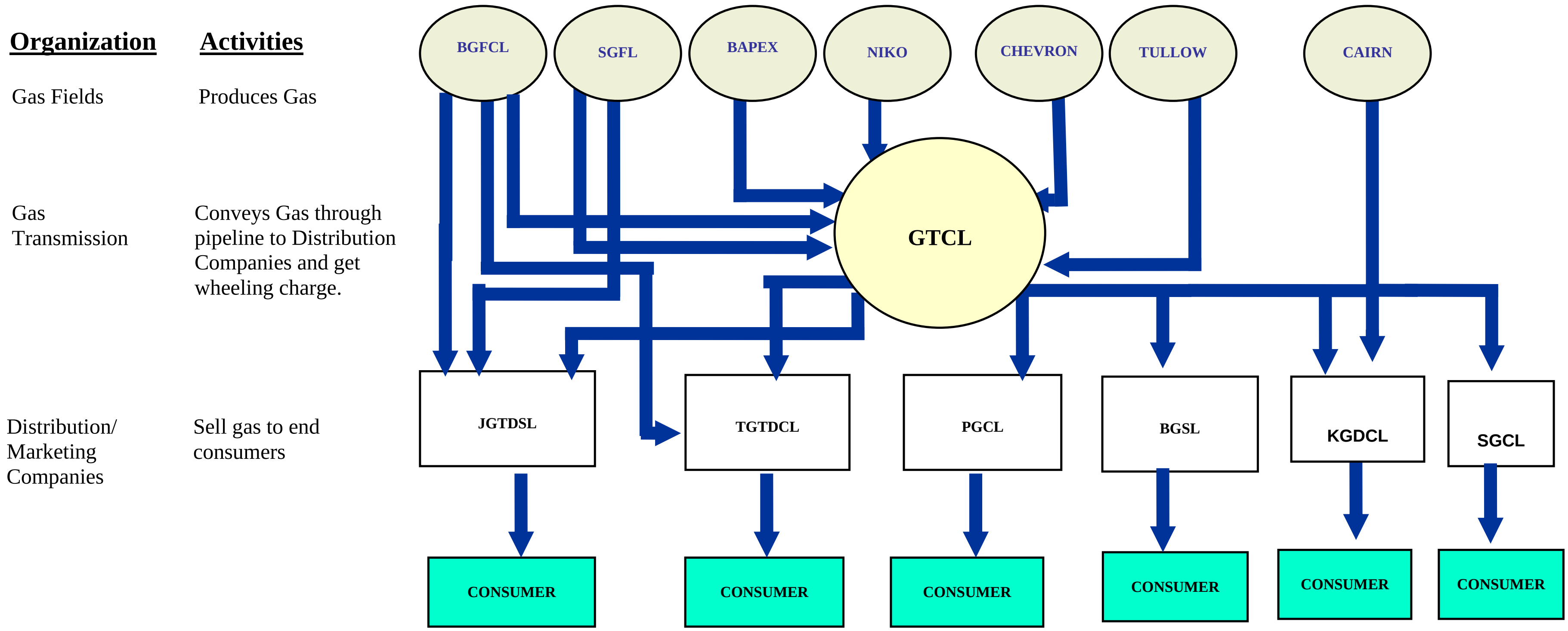


Figure 2.1: Block Diagram of Production, Transmission & Distribution Management Systems of Petrobangla

2.3 PRESENT GAS RESERVE

26 gas fields and an oil field have been discovered in Bangladesh up to June 2014 out of which 19 (nineteen) fields are producing gas at present through 92 producing wells[12-13]. A number of studies were conducted by various agencies/organization in the past. Some of them were for limited number of fields while the others were for countrywide assessment. Present natural gas reserve in Bangladesh is shown in Table 2.1.

Table 2.1: Natural Gas Reserve in Bangladesh [11]

Figure in BCF.

SL No.	Fields	Year of Discovery	Reserve Estimated by		GIIP	Recoverable Reserve Proved + Probable(2P)	Cumulative Production (Dec'2012)	Remaining reserve w.r.t 2P Jan'2013
			Company	Year				
A. Producing								
1.	Titas	1962	RPS Energy	2009	8148.9	6367.0	3537.54	2829.4
2.	Habigonj	1963	RPS Energy	2009	3684.0	2633.0	1930.25	702.75
3.	Bakhrabad	1969	RPS Energy	2009	1701.0	1339.0	735.13	496.39
4.	Kailashtila	1962	RPS Energy	2009	3610.0	2760.0	577.15	2182.85
5.	Rashidpur	1960	RPS Energy	2009	3650.0	2433.0	509.83	1923.17
6.	Haripur	1955	RPS Energy	2009	370.0	318.9	198.87	120.03
7.	Meghna	1990	RPS Energy	2009	122.1	69.9	44.29	25. 61
8.	Narshingdi	1990	RPS Energy	2009	369.0	276.8	138.47	138.33
9.	Beanibazar	1981	RPS Energy	2009	230.7	203.0	73.40	129. 60
10.	Fenchuganj	1988	RPS Energy	2009	553.0	381.0	95.09	285.91
11.	Shaldanadi	1996	RPS Energy	2009	379.9	279.0	53.99	225.01
12.	Shahbazpur	1995	Petrbangla	2011	677.0	390.0	7.05	382.95
13.	Semutang	1969	RPS Energy	2009	653.8	317.7	4.28	313.42
14.	Sundulpur	2011	BAPEX	2012	62.2	35.1	2.4	32.46
15.	Srikail	2012	BAPEX	2012	240.0	161.0	0.00	161.00
16.	Jalalabad	1989	D&M	1999	1491.0	1184.0	721.30	462.70
17.	Moulavibazar	1997	Unocal	2003	1053.0	428.0	211.42	216.58
18.	Bibiyana	1998	D&M	2008	7427.0	5754.0	1267.57	4468.43
19.	Bangura	2004	Tullow	2011	1198.0	522.0	211.30	310.70
Sub-total A:					**35620.6**	**25744.9**	**10319. 62**	**15425.36**
B. Non-producing								
20.	Begumganj	1977	RPS Energy	2009	39.0	21.0	-	21.0
21.	Ktubdia	1977	HCU	2003	65.0	45.50	-	45.50
Sub-total B:					104.0	66.5		66.5
C. Production Suspended								
22.	Chattak	1959	HCU	2000	1039.0	474.0	26.46	447.54
23.	Kamta	1981	NIKO/BAPEX	2000	71.8	50.3	21.1	29.20
24.	Feni	1981	NIKO/BAPEX	2000	185.2	125.0	62.4	62.60
25.	Sangu	1996	Cairn/Shell	2010	899.6	577.8	485.78	91.98
Sub-Total C:					**2195.6**	**1227.1**	**595.78**	**631.28**
Grand Total (A+B+C) in BCF					**37920.2**	**27038.49**	**10915.31**	**16123.18**
Grand Total (A+B+C) in TCF					**37.92**	**27.04**	***10.92**	***16.12**

One of the gas fields named Rupganj Gas Field is discovered by BAPEX in 2014. The production of gas from this gas field is under process.

***Up to June 2014 cumulative production is 12.04 TCF. Hence, remaining reserve stands as 15.00 TCF.**

2.4 GAS SECTOR AT A GLANCE

Though average daily gas production is 2240-2350 MMscf, Bangladesh is currently a gas deficit country due to an average shortfall of 550-650 MMscfd. The overall gas sector scenario is shown in Table 2.2.

Table 2.2: Gas Sector at a Glance [12-13]

*Total Gas Fields	26
Producing Gas Fields	19
Producing Gas Wells	92
Daily Gas Production Capacity	2297 MMscfd
Daily Gas Production (Daily gas production report, Petrobangla, as on 21-22 May 2014)	2350 MMscfd
GIIP (Proven + Probable)	37.7 Tcf
Total Recoverable Gas Reserve (Proven + Probable)	27.04 Tcf
Gas Production since inception as on June 2014	12.04 Tcf
Remaining Reserve (Proven + Probable)	15.00 Tcf
Current Gas Demand	2900 MMscfd
Daily Gas Shortfall	650-550 MMscfd

* Including newly (in 2014) discovered gas field named “Rupganj Gas Field”, Dhaka.

Current gas demand and daily gas shortfall are evaluated by Petrobangla. By the pace of time, the gap between supply and demand will be high unless new supply is added. Petrobangla is trying to reduce this shortfall by drilling new wells in existing gas fields to promote the production capacity. Besides, importation of natural gas in the form of LNG as well as by pipeline is under consideration.

2.5 PRESENT GAS PRODUCTION

Currently average gas production is around 2240-2350 MMscfd. Table 2.3 shows gas production of a particular day (21-22 May 2014) only.

Table 2.3 Daily Gas Production Statistics [12].

Company	Gas Fields	No. of Producing well.	Production capacity (MMscfd)	Gas production (MMscfd)	Production as a % of Total production
1. National Gas Companies (NGCs)					
1.1 BGFCL	Titas	21	518	513	21.82
	Bakgrabad	6	43	38	1.61
	Habigonj	7	225	224	9.52
	Narsigdi	2	30	28	1.19
	Meghna	1	11	11	0.4
	Sub-total	37	827	814	34.62
1.2 SGFL	Sylhet	2	11	9	0.38
	Kailashtila#1	2	15	18	0.76
	Kailashtila#2	4	65	61	2.59
	Rashidpur	4	49	47	1.99
	Beanibazar	2	14	10	0.42
	Sub-Total	14	154	145	6.16
1.3 Bapex	Salda	1	20	14	0.59
	Fenchugonj	3	40	38	1.61
	Shahbazpur	2	30	7	0.29
	Semutung	2	12	10	0.42
	Sundalpur	1	10	5	0.21
	Srikail	2	44	42	1.78
	Sub-Total	11	156	116	4.93
Total (NGCs)		**62**	**1137**	**1075**	**45.72**
2. International Oil Companies (IOCs)					
2.1 Chevron	Jalalabad	4	230	251	10. 67
	Maulavibazar	6	60	75	3.19
	Bibiyana	16	770	839	35.68
	Sub-Total	26	1060	1165	49.55
2.2 Santos	Sangu	-	-	-	-
2.3 NIKO	Feni	-	-	-	-
2.4 Tullow	Bangora	4	100	110	4.72
Total (IOCs)		**30**	**1160**	**1275**	**54.27**
Grand Total (NGCs+IOCs)		**92**	**2297**	**2350**	**100**

From Table 2.3, it is seen that about 45% gas is produced by NGCs and 55% gas is produced by IOCs. Shevron alone is producing near about 50% of total national production. The gas production history [14] from the inception, 1961 to 2014 is shown in Figure 2.2.

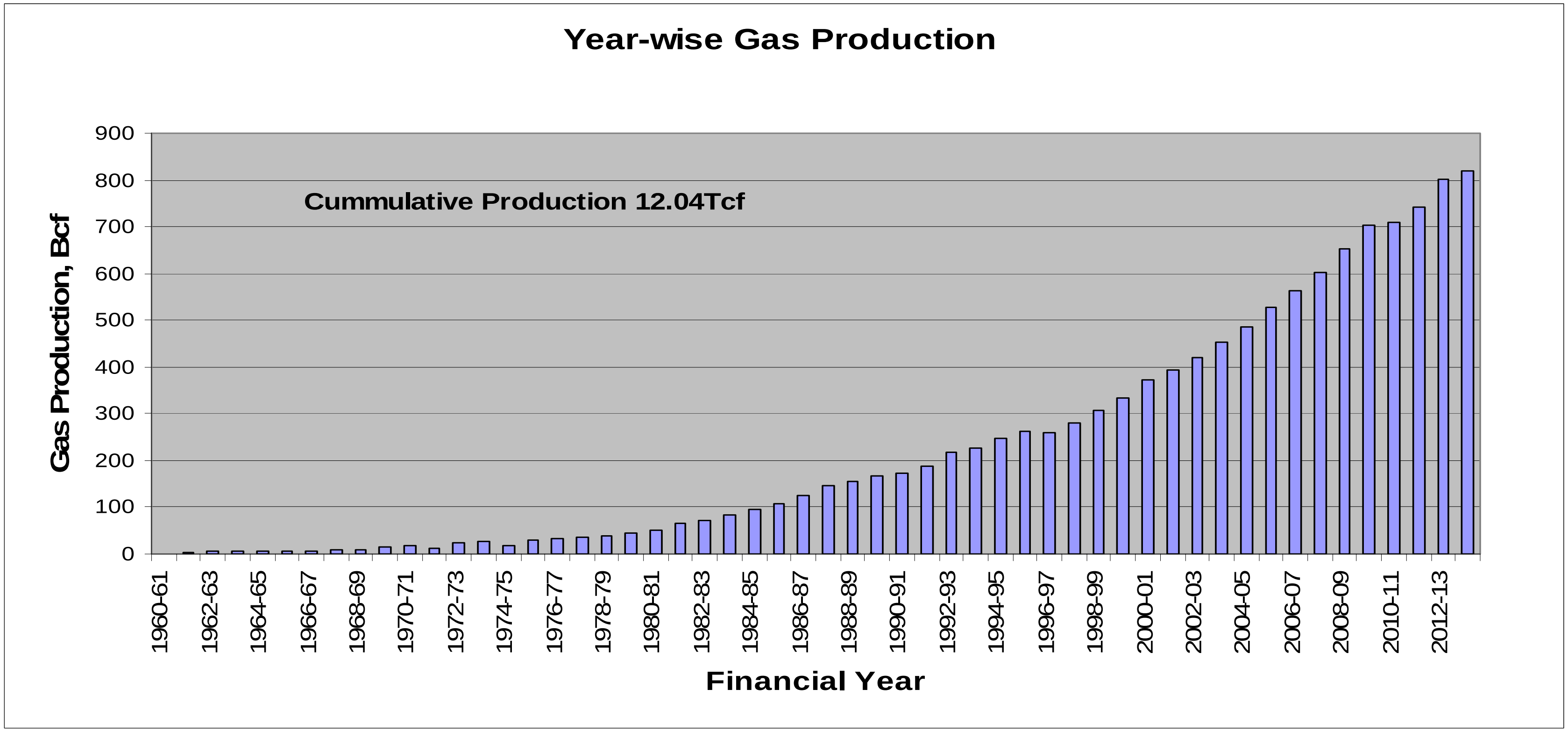


Figure 2.2: Gas Production History of Bangladesh.

In Figure 2.2, it is observed that no significant rise in gas production in sixtieth decade because gas usage was its initial stage at that time. In the seventeenth decade gas production starts to rise gradually. After seventeenth decade, gas production rises significantly due to increase in gas usage in power, fertilizer, industrial and commercial sectors.

2.6 MAJOR GAS TRANSMISSION PIPELINE & FLOW CAPACITY

Before formation of Gas Transmission Company Limited (GTCL), distribution companies were transmitting gas through their transmission pipelines. GTCL is now solely responsible for augmentation, operation and maintenance of national gas grid. The name of the major transmission pipelines are mentioned in Table 2.4.

Table 2.4: Major Gas Transmission Pipeline & Flow Capacity [11]

Sl. No.	Name of pipeline	Length (Km)	OD (inch)	MAOP (psig)	Flow Capacity (MMscfd)	Year of commissioning
Existing Gas Transmission Pipeline Operated by GTCL						
1.	Bakhrabad-Chittagong	175	24	960	350	1982
2.	Bakhrabad-Demra	68	20	1000	150	1985
3.	Ashuganj-Elenga	125	24	1000	270	1992
4.	North-South(KTL-Ashuganj)	175	24	1135	330	1993
5.	Ashuganj-Bakhrabad	59	30	1135	400	1998
6.	Elenga-Baghabari	73	20/24/30	1000	200	1999
7.	Beanibazar-Kailashtila	18	20	1090		2001
8.	Rashidpur-Ashuganj	82	30	1135	425	2002/2004
9.	Nolka-Bogra	6+54	30/20	1000	166	2005
10.	Ashuganj-Monohordi	37	30	1000	400	2006
11.	Dhanua-Aminbazar	60	20	1000	200	2006/7
12.	Monohordi-Dhanua	51	30	1135	300-750	2011
13.	Bonpara-Rajshahi	53	12	1000	45	2012
14.	Titas-AB Pipeline	8	24	1000	-	2012
15.	Hatikumrul-Iswardi	70	30	1000	400	2013
	Sub-total	1114				
Existing Gas Transmission Pipeline Operated by TGTDCL						
16.	Titas-Narshindi-Demra	82	14	1000	175	1968
17.	Habiganj-Ashuganj	58	12	1000	85	1982
18.	Titas-Narshingdi-Joydevpur	84	14/16	1000	260	1986
19.	Narshingdi-Siddirganj	43	20	1000	300	-
20.	Dhanua-Mymensingh	57	12	1000	55	
21.	Elenga-Tarakandi	43	12	1000	80	
	Sub-total					
Existing Gas Transmission Pipeline operated by other companies						
22.	Horipur-NGFF (JGTDSL)	43	-	1000	62	1961
23.	Srimongal-Moulavibazar (JGTDSL)	26	6	1000	11	
24.	Shahaji Bazar-Shamsher Nagar(JGTDSL)	65	6	1000	11	
25.	Kailastila-Kuchai(JGTDSL)	13	8	1000	62	
26.	Meghna-Baghrabad(BGSL)	28	8	1000	20	1998
27.	Salda-Bakhrabad(BGSL)	35	10	1000	35	1999
28.	Jalalbad Field-Kailashtila(Chevron)	15	14	1135		2000
29.	Sangu-Fazdarhat(Satons)	45	20	1000		2001
30.	Chadpur Lateral(BGSL)	42	8	960	35	1985
31.	Maulavibazar-Muchai (Chevron)	22	14	1135		2005
32.	Bibiyana-Muchai(Chevron)	42	30	1135		2007
33.	Semutang-Chittagong(KGDCL)	56	10	960	70	
	Sub-total	432				

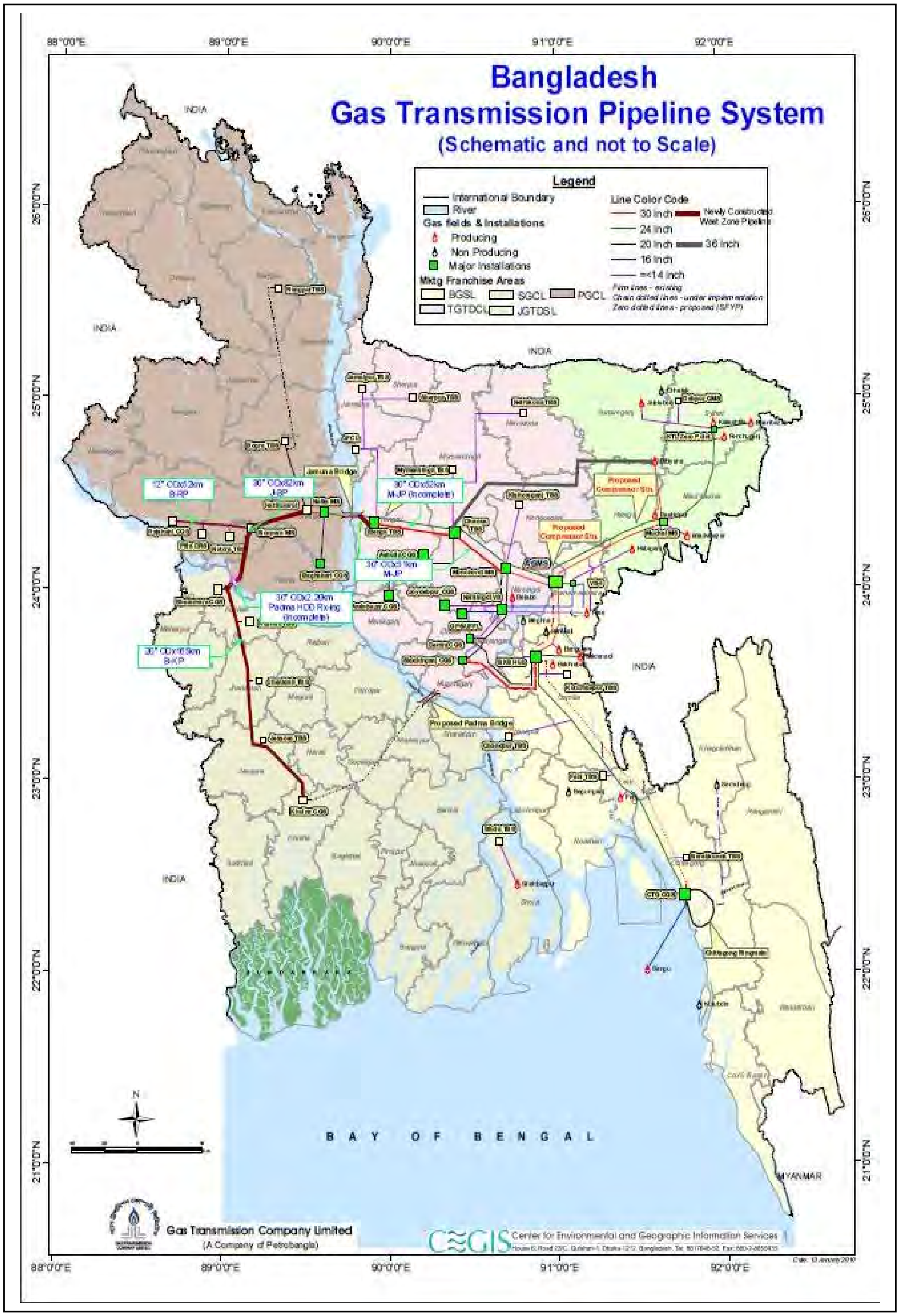


Figure 2.3: Schematic of Gas Transmission System in Bangladesh

CHAPTER

3

LITERATURE REVIEW

3.1 INTRODUCTION

Literature review is very much essential for proper analysis of a gas transmission pipeline networks. For network modeling and simulation, detail literature review about the simulation [15]; geography of the network; pipeline design parameters viz. diameter, wall thickness; pipeline materials and its properties; fluid properties; flow correlations and pressure drop calculation method; sources and demand centers parameters etc. are required to get the best fitted result. In this analysis a simulation network which is only a part of total transmission system of Bangladesh, has designed.

3.2 SIMULATION

It is necessary to simulate whether the existing and planned gas pipeline is adequate to supply the estimated demand at present and future. It is very important to know the characteristics of flow of network for smooth operation of the pipeline. The basis for hydraulic analysis of a gas network is a SIMULATION MODEL. Individual, consultant and many organization simulated present and future supply situation considering existing and planned transmission and production situation by commercial software. In this study pipeline simulation is done by commercial software PIPESIM.

3.2.1 Model

A model is only as good as the data that is used to build it. Analysis based on incorrect values will yield incorrect results. The analysis results should be evaluated and validated with the proper weight. In most gas distribution models, customer usage and load distribution will be the most critical parameter in the analysis.

Benefits of Modeling

- The ability to anticipate operating conditions within the system.
- The ability to identify problem areas and trouble-shoot problems before they become serious.
- The ability to efficiently size new and replacement segments of gas system.
- The ability to estimate the impact on the system of adding new customers.
- And the ability to analyze "What if" scenarios without physical manipulation of the gas system of actual operating settings.

3.2.2 Network

A network is any system of interconnected or interrelated components. In a network, each component to some extent, affects every other component in the network. A gas system can be considered as a network. In a gas system, the components of the network are the pipes, valves, fittings, connectors, and regulators that make up the physical configuration of the system – and the customers attached to the system. An example of how individual components of a gas network might affect the other components in the network, consider the following:

(a) The outlet pressure of a regulator supplying the system is reduced.

(b) To a certain extent, the pressure in the entire system is reduced.

(c) An additional regulator is added to the system, the flow from the other regulators will be changed.

(d) And the flow through the pipes will be redistributed to accommodate the change in flow from the regulators.

(e) A valve in the system is closed. Flow in the system must be redistributed to accommodate the changes caused by the valve closure. The flow and pressure in all the pipes will be changed, to a certain extent. Flow will decrease in the mains to which the valve was attached and increase in mains that might provide flow around the valve. When flows change in the system, so do the pressures in the system.

(f) A large load is connected to the system. The flow in the portions of the system supplying that load will be increased. The increase in flow will affect the pressures in the system and the flow required of the supplying regulators.

3.2.3 Simulation Model

A SIMULATION MODEL consists of Nodes and Pipes. Source, Sink and Storages are all represented by Nodes which are interconnected by Pipes.

Nodes

A node can be:

- Consumer,
- A simple node without consumption
- Producer
- Connection between one or more pipes.

Nodes are characterized by:

- Name
- Geometrical level
- Pressure
- Temperature
- Flow.

A node is placed in the model using one of the following criteria:

- Important change of dimensions;
- Branch;
- A wished position for known pressure of flow;
- Termination of a pipe without continuation;
- A large consumer.

Pipes

Pipes are connections between nodes. A pipe is characterized by-

- An upstream node;
- A downstream node;
- Length;
- Internal diameter;
- Roughness;
- Pressure;
- Pressure drops; and
- The mass flow through the pipe.

Pipes carry gas between nodes. The sum of the pipe flows going into a specific node must equal the sum of the flows leaving the node through the connected pipes plus the flow leaving the system through the node. The sum of the flow coming into the system through a node must equal the sum of the flow leaving the node through the connected pipes. In steady-state modeling, neither nodes nor pipes can store flow.

Source

A source may be producer/supplier, intake point or others that carry in fluid into the network. It is characterized by volume, pressure, temperature etc.

Sink

A sink may be customer, off-take or other load centers that carry out fluid from the network**.** It is characterized by volume, pressure, temperature etc.

Flow

Flow in a pipe moves from the higher pressure end of the pipe to the lower pressure end. That is flow always moves in the direction of the lower pressure node. Like a ball rolling downhill, gas flows from high to low as shown in Figure 3.1

:

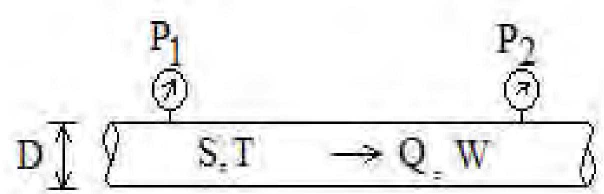


Figure 3.1: Schematic of flow in pipe.

Flow is created by a difference in pressure and consequently flow causes frictional pressure losses. As the flow increases the friction losses also increase, and tend to restrict or limit the flow. The greater the pressure difference, the greater the flow rate and the greater the frictional pressure losses.

Flow Equations

A "flow equation" is required to describe the relationship between the flow in the pipes and pressures at the nodes. Most flow equations require the definition of certain parameters describing the gas in the system, and the physical properties of the pipes. A friction factor may be inherently assumed by the equation, or may be calculated depending on the equation format. There are many equations available for modeling the conditions normally encountered in gas distribution, transmission, and gathering systems. The challenge is selecting the one that best suits for specific application.

The Weymouth, Panhandle A, and Panhandle B equations were developed to simulate compressible gas flow in long pipelines. The Weymouth is the oldest and most common of the three. It was developed in 1912. The Panhandle A was developed in the 1940s and Panhandle B in 1956[16]. The equations were developed from the fundamental energy equation for compressible flow, but each has a special representation of the friction factor to allow the equations to be solved analytically. The Weymouth equation is the most common of the three - probably because it has been around the longest. The equations were developed for turbulent flow in long pipelines. For low flows, low pressures, or short pipes, they may not be applicable.

If the pressure drop in a pipeline is less than 40% of upstream pressure (P_1) then Darcy-Weisbach incompressible flow calculation may be more accurate than the Weymouth or Panhandles for a short pipe or low flow. The Darcy-Weisbach incompressible method is valid for any flow rate, diameter, and pipe length, but does not account for gas compressibility. Crane (1988) states that if the pressure drop is less than 10% of P_1 and it is used an incompressible model, then the gas density should be based on either the upstream or the downstream conditions. If the pressure drop is between 10% and 40%, then the density used in an incompressible flow method should be based on the average of the upstream and downstream conditions. If the pressure drop exceeds 40% of P_1, then use a compressible model, like the Weymouth, Panhandle A, or Panhandle B [17].

The equations for compressible flow are shown below. The Weymouth, Panhandle A, and Panhandle B equations [16-17] are the equation beginning with Q_s=... with the constants c, n, u, x, and y defined below. All of the equations shown below use the English units indicated in the Variables section. Of course, calculation uses a variety of units with all of the unit conversions handled internally by the program.

$$Q_s = cED^n \left[\frac{T_s}{P_s}\right]^u \left[\frac{P_1^2 - P_2^2}{S^x L T Z}\right]^y$$

$$\rho_s = \frac{2.7 P_s S}{T_s}$$

$$W = \rho_s Q_s = \rho_1 Q_1 = \rho_2 Q_2$$

$$\rho_1 = \frac{2.7 P_1 S}{TZ}, \rho_2 = \frac{2.7 P_2 S}{TZ}$$

$$\text{P}r\,essureDrop(\%) = \frac{P_1 - P_2}{P_1 - P_{atm}}(100)$$

Variables:

The units refer to the units that must be used in the equations shown above. However, a variety of units may be used in calculation and shown in Table 3.1.

Table 3.1: Particulars of variables.

Variable	Description	Unit	Value
A	Pipeline cross sectional area	Square inch	
c	Constant	-	Weymouth: c=18.0625, Panhandle A: c=18.16125, Panhandle B: c=30.7083,
D	Pipe inside diameter	Inch	-
E	Efficiency factor	-	Typically 0.85 to 1.0
L	Pipeline length	mile	-
n	Constant		Weymouth: n=2.6667, Panhandle A: n=2.6182, Panhandle B: n=2.53
P	Absolute pressure in pipeline	psia	
Q	Volumetric flow rate	cfh	
S	Specific gravity of gas in pipeline, relative to air	-	
T	Absolute temperature (Rankine)	ºR	
u	Constant		Weymouth: u=1.0, Panhandle A: u=1.07, Panhandle B: u=1.02
V	Velocity of gas = Q/A		
W	Mass flow rate	Ib/hr	
Z	Gas compressibility		Typical value 1.0 at standard condition.
ρ	Density	Ib/ft^3	
X and y	Constant		X=0.96 and y=0.51 for Panhandle B

Subscripts:

1 = Upstream conditions; 2 = Downstream conditions; atm = Atmospheric conditions; and s = Standard conditions (520 ºR, 14.73 psia).

AGA- Turbulent

- Applicable to transmission systems with fully turbulent flow conditions.
- Accounts for relative pipe roughness using rough pipe law.
- Moderately conservative compared to other transmission style equations.

Panhandle – A

- Applicable to transmission systems.
- Yields moderate results.
- Developed in the 1940's.
- The Gas Engineers Handbook reports that the equation is applicable for large diameter transmission piping where the Reynolds number varies between 5 and 20 million. And suggests an average efficiency for steel pipelines of 0.92 for this equation.
- The Gas Process Suppliers Association (GPSA) data book reports that this equation is intended to reflect flow of gas through smooth pipes. When used with an efficiency of 0.90 the equation reasonably approximates the partially turbulent general flow equation.
- The AGA GEOP text reports that this equation is applicable to distribution systems where the Reynolds numbers range between 1,300,000 and 75,000,000 with 2% deviation from the smooth pipe and 16 inch and larger diameter pipe operating between 20 Psig and higher.
- Reynolds number dependent.

Panhandle – B

- Applicable to transmission systems.
- Revised version of Panhandle – A, published in 1956.
- Less conservative transmission equation.
- The Gas Engineers Handbook notes that the equation is applicable for large diameter transmission piping where the Reynolds number varies between 5 and 20 million. And suggests an average efficiency for steel pipelines of 0.9 for this equation.
- Efficiency factors of 0.88 to 0.94 are often used with this equation.
- Reynolds number dependent.

Weymouth

- Applicable to transmission systems, though often for both distribution and transmission.
- Yields conservative results.
- Equation published in 1912.
- The Gas Engineers Handbook reports that this equation provides a reasonable approximation of the general rough pipe equation for diameter equal to ten inch, and effective pipe wall roughness equal 0.002 inches. And suggests an average efficiency for steel pipelines of 1.10 for this equation.
- The GPSA data book reports that for short pipelines and gathering systems this equation agrees closely with metered volumes. However, the degree of error increases with pressure.
- The AGA GEOP text suggests that the equation is not applicable to calculations in distribution systems.
- Not a Reynolds number dependent equation.

Assumptions

For the simplicity of calculation, the following assumptions are often made:

- No external work is done on the system i.e. w = 0;
- The gas flow is at constant temperature;
- The gas behaves as an ideal gas, in other words, $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$
- The compressibility factor Z is taken into account;
- Differences in elevation on long pipelines are disregarded;

3.3 GAS TRANSMISSION PIPELINE

It is very important to know about gas transmission pipeline i.e. pipeline design criteria; codes and standard followed; construction procedures; pipeline materials and its specifications etc for network modeling and simulation.

3.3.1 Pipeline Design

There are several approaches to pipeline design. The American Petroleum Institute (API) and the American Society of Mechanical Engineers (ASME) establish standards for engineering and design to ensure the safe construction and operation of industrial facilities. The standards for natural gas transmission pipeline systems, ASME B31.8, ensures that pipelines engineered, designed and constructed with modern materials and practices can be expected to provide safe and reliable service for many decades when maintained properly. For example, pipelines designed and constructed in the 1930s using steel and coatings that met API and other consensus standards in affect at the time of construction remain in service today. Interstate pipelines utilize integrity management programs designed to ensure that pipelines are maintained and operated in a safe and reliable manner. Pipeline operators use a comprehensive Quality Management System (QMS) to addresses all phases of the engineering, design, material specification and procurement, shipping, construction and commissioning processes. Material and manufacturing quality management programs ensure that pipelines and pipeline appurtenances (materials or accompanying parts of the pipeline) meet the requirements of international consensus standards for manufacturing including API, Specification for Line Pipe, referred to as Specification 5L, API 6D for valves, among others. The objective is to ensure that the pipe has tensile properties, a chemical composition and fracture control properties that conform to International standards.

Pipeline design typically follows these general steps [18]:

(i) A required delivery pressure is determined at the pipeline's destination. This pressure may be set by the customer's facilities or, if the line is branch line, by the pressure required at the junction with the main line to permit fluid to flow into the main line.

(ii) Pressure losses due to friction and the pressure required to overcome changes in elevation are added to the delivery pressure to determine the inlet pressure. In single phase flow, pressure drop in the line that must be overcome by pumps or compressors is essentially the friction loss plus the pressure exerted by a liquid or gas column whose height equals the difference in elevation between the ends of the line. The pressure drop in any segment of the line is calculated in a similar manner. A trial and error procedure may be involved because it is necessary to choose a tentative pipe size in order to calculate pressure losses. If pressure loss is too high, the resulting inlet pressure may exceed the pressure rating of the pipe or an excessive amount of pumping or compression horsepower may be required. In this case, a large pipe is selected and the calculations are repeated. The goal is to select a pipe size that can be operated efficiency at pressure permitted by applicable regulations.

(iii) With the line size and operating pressure determined, the compression horsepower needed to deliver the desired volume of fluid at the specified delivery pressure can be accurately calculated. If a more than one compressor station is required, the location and size of additional stations is set by calculating pressure loss along the line and determining how much compressor horsepower is needed to maintain operating pressure.

(iv) In most cases, it is necessary to perform economic calculations to compare the design with other combinations of line size, operating pressure, and horsepower in order to choose the best system.

This simplified outline represents the basic steps involved in a preliminary design of a single pipeline with no branch connections, no alternative routes and no significant changes in throughput during its life. Few pipeline systems are that simple. Most have several branch lines feeding into a mainline that consists of more than one pipe size. Because of this, most pipelines are designed with sophisticated computer programs. These programs are built on basic flow equations used to design a simple pipeline manually; the computer can perform repeated calculations on a large number of alternative solutions quickly.

To discuss the basics of pipeline design, it is necessary to be familiar with how key physical properties of fluids affect pipeline design. The effect of these parameters varies with the fluid, compressibility does not significantly affect the flow of liquids, for instance, and differences in viscosity among different gases may not greatly affect the flow of natural gas.

Most of the following fluid properties and other variables are considered in designing liquids or natural gas pipeline [18]:

(i) **Pipeline Diameter:** Of course, the larger the inside diameter of the pipeline, the more fluid can be moved through it, assuming other variables are fixed.

(ii) **Pipe Length:** The greater the length of a segment of pipeline, the greater the total pressure drop. Pressure drop can be the same per unit of length for a given size and type of pipe, but total pressure increases with length.

(iii) **Specific gravity and density:** The density of a liquid or gas is its weight per unit volume. The specific gravity of a liquid is the density of the liquid divided by the density of water and the specific gravity of a gas is its density divided by the density of air. The specific gravity of air, therefore, is 1 and the specific gravity of water is also 1.

(iv) **Compressibility:** Because most liquids are only slightly compressible, this term is usually not significant in calculating liquids pipeline capacity at normal operating conditions. In gas pipeline design, however, it is necessary to include a term in many design calculations to account for the fact that gases deviate from describing "ideal gas" behavior when under conditions other than standard, or base, conditions. This term super-compressibility factor is more significant at high pressures and temperatures. Near standard conditions of temperature and pressure [60°F and 1 atm], the deviation from the ideal gas law is small and the effect of the super compressibility factor on design calculations is not significant.

(v) **Temperature:** Temperature affects pipeline capacity both directly and indirectly. In natural gas pipelines, the lower the operating temperature, the greater the capacity, assuming all other variables are fixed. Operating temperature also can affect other terms in equations used to calculate the capacity of both liquids and natural gas pipelines. Viscosity, for example, varies with temperature.

(vi) **Viscosity:** The property of a fluid that resists flow, or relative motion, between adjacent parts of the fluids is viscosity. It is an important term in calculating line size and pump/compressor horsepower requirements when designing liquids pipelines.

(vii) **Reynolds Number:** This dimensionless number is used to describe the type of flow exhibited by a flowing fluid. In streamlined or laminar flow, the molecules move parallel to the axis of flow; in turbulent flow, the molecules move back and forth across the flow axis. Other types of flow are possible, and the Reynolds number can be used to determine which type is likely to occur under specified conditions. In turn, the type of flow exhibited by a fluid affects pressure drop in the pipeline. In general, a Reynolds number below 1,000 describes streamlined flow; at Reynolds number between 1,000 and 2,000, flow is unstable. At Reynolds numbers greater than 2,000, flow is turbulent. Some references recommended, however, that flow be assumed laminar at Reynolds numbers of up to 2,000 and turbulent at values above 4,000. Flow is considered unstable at Reynolds numbers between 2,000 and 4,000.

(viii)**Friction Factor:** A variety of friction factors are used in pipeline design equations. They are determined empirically and are related to the roughness of the inside pipe wall.

Other properties of fluid and pipe may be used in specific calculations, but these are the basic terms used to determine pressure drop and flow capacity. Many system variables are interdependent. For example, operating pressure depends, in part, on pressure drop in the line. Pressure drop, in turn, depends on flow rate, and maximum flow rate is dictated by allowable pressure drop.

3.3.2 Pipeline Materials

Pipeline materials are a key design factor in pipeline design because wall thickness, internal diameter etc. depends on it. Generally, for national gas grid in Bangladesh, transmission pipeline is design for 1135 psig design pressure and 1000 psig operating pressure. International codes and standard viz. API, ASME, ISO, ASTM, BS etc are generally followed in selection of grade of materials used in transmission network.

3.3.2.1 Carrier/Mainline Pipe

API 5LX 60/70 grade pipe is generally used in transmission pipeline of 1135 psig design pressure. The capacity of a pipeline is a relative term and it depends on both internal diameter and differential pressure between upstream and downstream. The description of 423km carrier/mainline pipes from Elenga to Khulna and Rajshahi that built West Zone gas transmission pipeline network, out of which 246 km pipeline is now under operation and another 177 km newly constructed pipeline that will be commissioned soon, are shown in Table 3.2.

Table 3.2: Parameters of carrier/mainline pipes used in West Zone gas transmission network [6].

Segment	Pipeline	Length (km)	OD (inch)	ID (inch)	WT (inch)	Pressure
	Under operation					
1.	Elenga to Jamuna Bridge (JB) East	13.5	24	23.188	0.406	Design pressure: 1135 psig Operating pressure: 1000 psig.
2.	Jamuna Bridge (JB)	9	30	28.874	0.563	
3.	JB(W) to Sadanandapur	10	24	23.188	0.406	
4.	Sadanandapur to Sirajgonj	0.5	8	7	0.5	
5.	Sadanandapur to Nalka	5	24	23.188	0.406	
6.	Nalka to Baghabari	35	20	19.312	0.344	
7.	Nalka to Hatikumrul	6	30	28.874	0.563	
8.	Hatikumrul to Bogra	45	20	19.188	0.406	
9.	Hatikumrul to Bonpara	47	30	28.874	0.563	
10	Bonpara to Rajshahi	53	12	11.5	0.25	
11.	Bonpara to Iswardi	23	30	28.874	0.563	
	Sub-total	**246**				
	Newly constructed and to be commissioned					
12.	Iswardi to Bheramara	12	30	28.874	0.563	
13.	Bheramara to Kushtia	22	20	19.188	0.406	
14.	Kushtia to Jhenaidah	45	20	19.188	0.406	
15.	Jhenaidah to Jessore	45	20	19.188	0.406	
16.	Jessore to khulna	53	20	19.188	0.406	
	Sub -total	**177**				
	Total	**423**				

In Table 3.2, it is observed that Elenga to Hatikumrul segment of the West Zone network comprises various diameters of pipe. Before Jamuna bridge section from Elenga to Jamuna bridge (East) the pipeline is of 24 inch diameter, the bridge section is 30 inch diameter, after downstream of Jamuna bridge upto Nalka there is 24 inch diameter pipeline and far downstream from Nalka to Bheramara it is 30 inch diameter pipeline. Jamuna bridge (West) to Nalka pipeline segment is a bottleneck for the West Zone network that reduces the network supply capacity. Since the pipeline of bridge section is 30 inch diameter and both the downstream and upstream of the bridge section pipeline is 24 inch diameter, ultimately, the efficiency of the pipeline is as 24 inch diameter pipeline rather than 30 inch diameter pipeline.

3.3.2.2 Miscellaneous Fittings

Induction/Field Bends, Elbows, Tees, Reducers/Expanders, Ball Valves, Plug Valves, Insulating Joints and other miscellaneous fittings are used in gas transmission pipeline.

3.3.2.3 Coating Materials

Natural gas pipelines are coated externally to prevent moisture from coming into direct contact with the steel and causing corrosion. Line pipe typically is coated before pipes are delivered to the construction site. Bend/other bare pipes and welding joints (Field joints) are coated at the construction site. Pipeline operators use different types of coatings for field joints, the most common being Fusion Bond Epoxy (FBE)/Heat Shrinkable Sleeve (HSS).

<u>For Mainline Pipe</u>

- Three Layer Polyethylene (3LPE) Coating: The FBE, intermediate layer of copolymer adhesive and outer polyethylene coating.
- Fusion Bonded Epoxy (FBE) Coating: FBE coated pipe shall be used for thrust bored and cased Rail/Road crossing.
- Concrete Weight Coating (CWC): 3LPE Coating envelope by reinforced concrete coating. Concrete coating may be used under streams and in wetlands. Weighting is applied to manage buoyancy in special circumstances, such as river and wetland crossings.

For Bend/Other bare pipe

- **Polyethylene (PE) Plastic Tape (Inner & outer)**:
  Adhesive: Inner layer of BUTYL Rubber
  Backing: Outer layer of Polyethylene (PE) Plastic

- **Primer:** A viscous liquid of petroleum spirit base compatible with the above Inner and Outer Wraps applied directly on pipe.

For Field Joint

Heat Shrinkable Sleeve: The first layer of solvent free 100% solids epoxy primer, a second layer of copolymer adhesive and a third layer of extruded radiation cross-linked heat shrinkable polyethylene.

3.3.3 Pipeline Costing in West Zone

The cost of gas transmission pipeline depends on many factors such as materials grade, cost of materials, cost of acquired land, project period, Horizontal Directional Drilling (HDD) for river crossings, number of valve and regulating and metering stations etc. In West Zone numbers of pipelines had been completed since 1998. Recently, some pipeline projects are under construction. The ongoing 3 (three) gas transmission pipeline projects in West Zone are commenced on 2006-07 and expected to be completed in 2014-15. The revised costs of these projects [19-21] are summarized in Table 3.3.

Table 3.3: Cost of Gas Transmission Pipeline in West Zone.

Taka in million

Component	**Name of Pipeline and Cost**		
	53 km x 12″OD Bonpara-Rajshahi Gas Transmission Pipeline [Number of CGS-1 DRS-2, River Crossing-1 (350m)]	**87 km x 30″OD** Jamuna-Bheramara Gas Transmission Pipeline [Number of CGS-1, River Crossing-5 (3600m)]	**165 km x 20″ OD** Bheramara-Khulna Gas Transmission Pipeline [Number of CGS-1, TBS-3, River Crossing-6 2500m)]
Pay of Officer & Staff	26.38	34.13	55.43
Supply & Services	23.05	41.19	49.58
Land Acquisition	59.96	141.97	637.62
Land requisition and Compensation	25.91	47.31	254.36
Pipeline Materials (All Pipes, Valves and Fittings)	418.14	2500.00	3539.08
Vehicles and equipment	11.04	5.93	8.17
Pipeline Construction	113.70	773.23	983.30
Civil Works	91.88	66.90	171.51
Regulating & Metering Station	489.48	287.88	900.00
River Crossing	16.26	960.80	404.35
SCADA	93.35	441.00	302.25
CD-VAT, IDC and Landing Charge	415.38	1814.70	1697.20
Contingency and Others	50.87	153.47	35.29
Total Cost	**1835.40**	**7268.51**	**9038.14**
Cost per km length/ inch diameter of pipeline	**2.88**	**2.78**	**2.73**

From the Table 3.3, it is seen that cost of per kilometer length and per inch diameter of pipeline of 3 (three) different projects, implementing in West Zone, are almost equal.

3.4 GEOGRAPHY OF THE WEST ZONE OF BANGLADESH

Bangladesh is a riverine delta which has been criss-crossed by several mighty rivers. Major rivers have originated from the Indian hills specially the hills of the Himalayan Range and have flown across Bangladesh to mingle into the Bay of Bengal in the south. The Jamuna-Brahmaputra Rivers have bisected Bangladesh into East and West Zone.

The West Zone comprises geographical area on the west side of the rivers Jamuna and lower Meghna, which means Barisal, Khulna, Rajshahi divisions and greater Faridpur district of Bangladesh [4]. The East Zone has been blessed with the existence of all of the under production natural gas fields. The West Zone has not yet developed as commercial source of natural gas. As such there is a wide difference in the utilization of natural gas between the East and West Zone of Jamuna River and lower Meghna River (hereinafter referred to West Zone) as shown in Figure 3.2. Most of the demand area and major gas consumers at East Zone of the country have been brought under gas transmission and distribution network. The West Zone of Bangladesh deserves to be considered and examined in details for the extensions of the gas network.

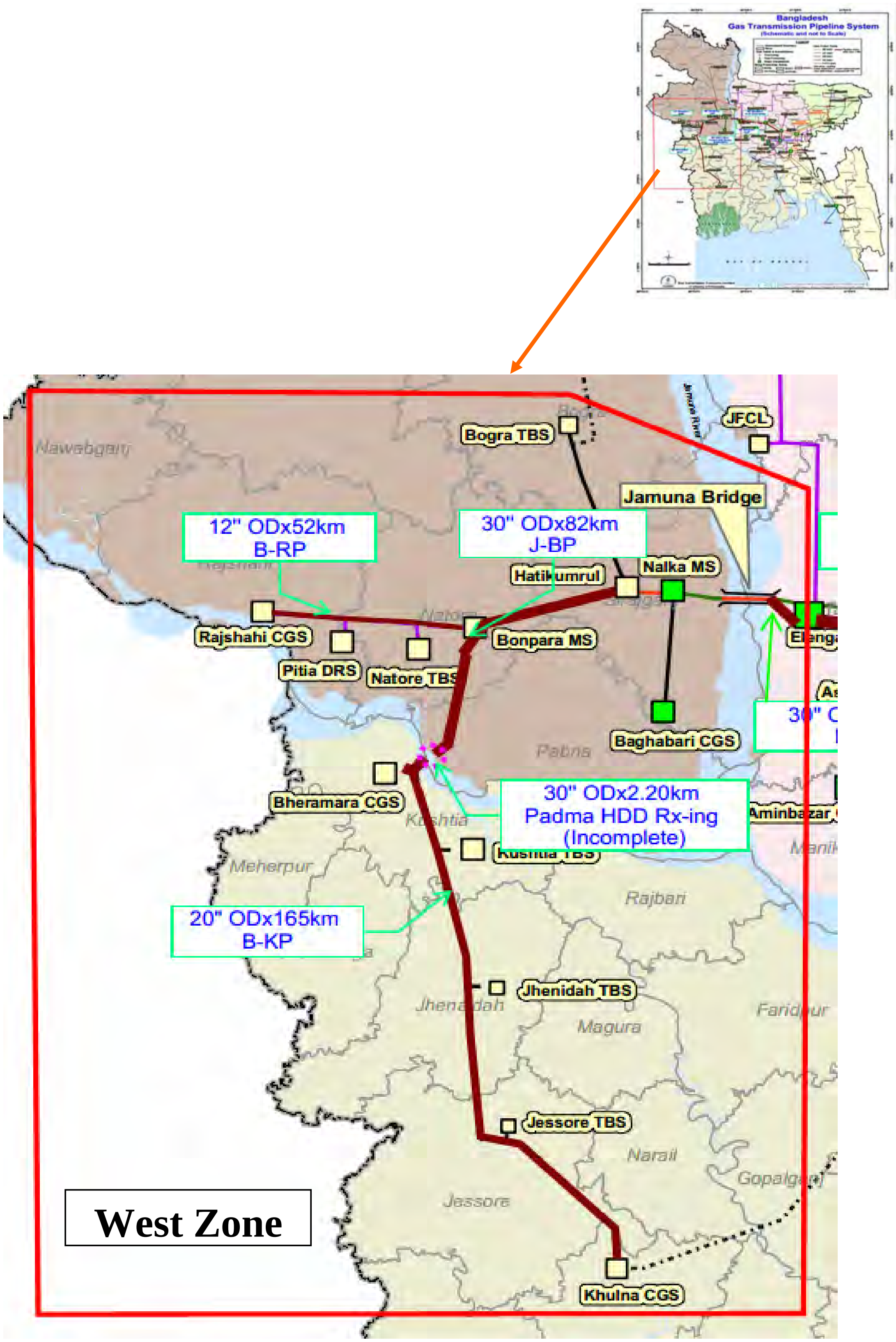


Figure 3.2: Schematic of West Zone Gas Transmission Network

The major impediment for gas transmission to West Zone was overcome after construction of Jamuna multipurpose bridge. The construction of Jamuna bridge and gas pipeline over the bridge, the world's longest suspended pipeline in the world [22], has certainly opened the opportunity for new industrial development projects in this zone.

West Zone comprises of four divisions namely Rangpur, Rajshahi, Khulna and Barisal and part of Dhaka division (greater Faridpur district) of Bangladesh and it can be further divided into three regions:

(i) North-West Region

Joypurhat, Gaibandha, Rangpur, Sayedpur, Kurigram, Nilfamari, Takurgaon, Lalmonirhat, Dinajpur and Panchagar are situated in the North-West region. This region is not so develop compare to other region of West Zone. Some small industries and power plants are situated in the region. Installation of some gas based power plants and Export Processing Zone (EPZ) in this region is under consideration. This region is totally out of gas transmission network. Government has planned to bring Rangpur division under gas transmission and distribution network.

(ii) Central-West Region

Sirajganj, Baghabari, Ishwardi, Pabna, Bogra, Rajshahi, Natore, Nawabgonj, and Naogaon are located in the Central-West region. Natural gas pipeline from the Eastern area is extended to Nalka, Bogra, Baghabari, Sirajganj, Ishwardi, Natore and Rajshahi through Jamuna multi-purpose bridge, further extension up to major cities in the Central-West and North-West regions will contribute to economic development of that regions. Sirajganj is connected with the Eastern area by road, railway, and rivers. It is also connected with riverine system in Bangaladesh. In addition to existing gas based power plants viz. Westmont (70 MW), PDB Baghabari (100+71 MW), Ullapara (11 MW), and North-West Power (150 MW), new power plants viz. Bogra (450 MW), Sirajganj (450 MW) are under consideration for installation in this region. Setting up of fertilizer factory at Sirajganj is also under consideration by Bangladesh Chemical Industries Corporation (BCIC) and also by some private entrepreneurs within and outside the country. The multi-level communication systems make Sirajganj a desirable location to promote industrialization utilizing natural gas. Ishwardi, where an Export

Processing Zone (EPZ) has been installed and natural gas is supplied, 1800MW Nuclear Power Plant is under installation, has become a key location for Central-West region industrialization. At present gas is supplying to power plants, industries, commercial and domestic customers at Sirajganj, Baghabari, Ishwardi and Rajshahi.

(iii) South-West Region

Kushtia, Meherpur, Jhenaidah, Chuadanga, Magura, Jessore, Norail, Khulna, Bagherhat, Satkhira, Rajbari, Faridpur, Madaripur, Sariatpur, Gopalganj, Barisal, Borguna, Patuakhali, Jhalkhati and Bhola a total of 20 districts are situated in this region. Khulna is the most populated city in the South-West region and is located to effectively use Mongla port- nation's second largest sea port. There are five oil-fired power stations (278 MW in total) operated by Bangladesh Power Development Board (BPDB) and a diesel engine power station operated by an IPP (110 MW) in Khulna. 150 MW duel fuel (HSD & Natural gas) power plant is recently installed and is now operated with High Speed Diesel (HSD) by North-West Power Generation Company Limited (NWPGCL), a sister concern of BPDB. This plant will switch its fuel from HSD to natural gas after availability of the later one. Additional 170MW gas based power plants [19] and 750-850 MW LNG based combined cycle power plant, feasibility study is conducting by North-West Power Generation Company, are under consideration at Khulna. Besides, 360 MW gas based power plant is now under installation at Bheramara. Bangladesh- India Power Transmission Center for import of 500 MW power from India through Grid Interconnection between Bangladesh and India is situated at Bheramara, Kushtia. Bangladesh Export Processing Zone Authority is planning to construct an EPZ at Mongla. A LPG bottling plant has been set-up at Mongla. A Fertilizer industry would also be constructed at Mongla. A 1200 MW coal-based power plant is installing at Rampal, Bagherhat. Khulna, Mongla and Bheramara could be the key for the South-West region development. Table 3.4 shows the districts of West Zone [23] and their gas supply status.

Table 3.4: Districts of West Zone.

Region	Division	District under		
		Gas supply	Extended pipeline	Future Provision
North-West	Rangpur	-	-	Rangpur & Gaibandha
Central-West	Rajshahi	Sirajganj, Pabna, Bogra & Rajshahi	Natore	-
South-West	Khulna and Barisal	Bhola	Kushtia, Jhenaidah, Jessore & Khulna	Bagherhat, Barisal & Greater Faridpur

Gas is supplied to Bhola from Shahbajpur gas field which is not connected to main West Zone gas transmission network yet.

3.5 GAS SUPPLY TO WEST ZONE

A total of 73 km high pressure gas transmission pipeline from Elenga, Tangail to Baghabari and 56 km of distribution pipeline in Sirajganj town have been constructed under the Gas Supply to Western Zone Project, the first gas pipeline project in West Zone. Out of the total transmission pipeline, 30″ODx9 km pipeline has been constructed across the River Jamuna (known as Bridge Section) which actually opened up the door for gas supply to West Zone. Later on, Nalka-Bogra pipeline was constructed to supply gas to Bogra and nearby area. After that, the Gas Transmission and Development Project (GTDP) [8] having four components viz. Part A: Gas Transmission Component; Part B: Field Appraisal; Part C: Rajshahi Network Gas Distribution; and Part D: Capacity Building has been taken to augment gas production and transmission capacity as well as expansion of the gas services to the western region of the country in support of the Government's poverty reduction strategy for implementation of policies directed towards expanding the national gas grid to cover less developed regions of the country, and to promote industrialization and accelerate balanced regional development that would help reduce widespread poverty. Under Part A, 30″ODx81km Hatikumrul-Bheramara except 1.8 km Padma River crossing, 20″ODx165 km Bheramara-Khulna and 12″NBx51km Bonpara-Rajshahi gas transmission pipelines have been constructed by 2012. Due to incompleteness of Padma River crossing, Bheramara to Khulna pipeline could not be commissioned yet. Hence, 150MW dual fuel power plant installed by NWPGCL in Khulna is running on high speed diesel (HSD) at high cost. Under Part C, Rajshahi Gas Distribution Network also implemented. Sundarban Gas Company Limited (SGCL), a recently formed state owned company of Petrobangla, is constructing distribution network in South and South-West region viz. Kushtia, Jhenaidah, Jessore and Khulna including Mongla. The following are the upcoming gas transmission pipeline project [3] in West Zone:

(i) Bogra to Rangpur 20˝ dia x 100 km gas transmission pipeline;
(ii) West Bank of Jamuna Bridge to Nalka 30˝ dia x 14 km gas transmission pipeline;
(iii) Mawa to Zajira (including Padma Bridge section) 30˝ dia x 20 km gas transmission pipeline;
(iv) Zajira to Khulna 30˝ dia x 110 km gas transmission pipeline;

The following are the upcoming project for feed back of West Zone transmission network:

(i) Langalband to Mawa 30˝ dia x 40 km gas transmission pipeline;
(ii) Dhanua to Elenga 30˝ dia x 52 km gas transmission pipeline.

3.6 SOURCE, CONSUMPTION, DEMAND AND SUPPLY SITUATION OF WEST ZONE

Source, consumption, demand and supply situation of West Zone is narrated below.

3.6.1 Sources of Gas

The source of gas of West Zone is gas fields that are situated in Eastern side of the country. Gas from the gas fields of Bibiyana, Kailashtila, Moulivibazar, Habiganj, Rashidpur, Jalalabad, Titas is transmitted through pipeline and is gathered in Ashuganj main hub of the National Gas Grid from where it is transported to Titas franchise area, Paschimanchal (West Zone) franchise area through Brahmaputra basin pipeline and Ashuganj-Monohordi-Dhanua pipeline and BGSL and KDGCL franchise area through Ashuganj-Bakhrabad and Bakhrabad-Chittagong pipeline.

3.6.2 Gas Consumption and Demand in West Zone

West Zone of Bangladesh is a potential green field for gas market development. The present gas supply is limited to existing power plants at Baghabari, Sirajganj, Bogra and various kinds of consumers in these area as well as Iswardi and Rajshahi. At present 110-120MMscfd gas is consumed in West Zone. Gas consumption history of West Zone is summarized in Table 3.5.

Table 3.5: Gas Consumption History of West Zone [14]

Financial Year	Natural Gas Consumption (MMscf)	% Increase/Decrease
1999-00	539.55	
2000-01	13406.45	2384.761%
2001-02	16172.99	20.64%
2002-03	17348.42	7.27%
2003-04	19579.65	12.86%
2004-05	21810.88	11.40%
2004-06	17923.96	-17.82%
2006-07	17629.31	-1.64%
2007-08	21621.03	22.64%
2008-09	27424.43	26.84%
2009-10	25594.06	-6.67%
2010-11	30956.00	20.95%
2011-12	26890.88	-13.13%
2012-13	34899.03	29.78%
2013-14	36577.66	4.81%

The year-wise gas consumption is also shown in Figure 3.3.

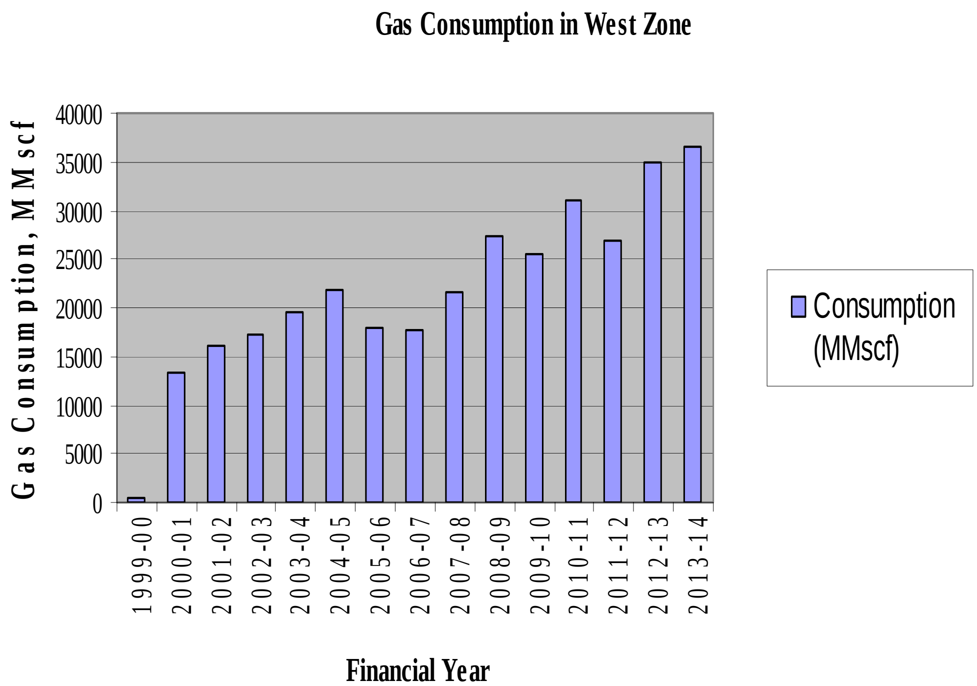


Figure 3.3: Year-wise consumption in West Zone.

From the Table 3.5 and Figure 3.3, it is seen that gas consumption growth rate varies year to year. To get the steady growth rate, consumptions of West Zone of the years 2000-01 to 2013-14 are considered in calculation of compound gas consumption growth rate. The gas consumption growth rate of West Zone is around 8% per year. In future, potential gas demand may rise mainly for power plants, fertilizer factories, Export Processing Zone (EPZ) and other industries. The future demand of West Zone is shown in Table 3.6 at different growth rate considering current demand of 190 MMscfd which comprises additional 70 MMscfd gas required for power plants in Khulna and Bheramara along with present consumption of 120 MMscfd.

Table 3.6: Projected Gas Demand in West Zone at different growth rate.

Year	Projected Gas Demand, MMscfd		
	@ 6%	@ 8%	@ 10%
2015	201	205	209
2016	213	222	230
2017	226	239	253
2018	240	258	278
2019	254	279	306
2020	270	302	337
2021	286	326	370
2022	303	352	407
2023	321	380	448
2024	340	410	493
2025	361	443	542
2026	382	478	596
2027	405	517	656
2028	430	558	722
2029	455	603	794
2030	483	651	873
2031	512	703	960
2032	542	759	1056
2033	575	820	1162
2034	609	886	1278
2035	646	956	1406

CHAPTER

4

METHODOLOGY

The Project involves network modeling and analysis of gas transmission pipeline. The aim of the project is, but not limited to, the analysis of some sensitivity studies i.e. specify the known inlet/outlet pressure and flow rate and calculate the corresponding gas pressure and flow rate at various sets of inputs. This chapter outlines the methodology for the execution of the project.

4.1 OUTLINE OF METHODOLOGY/EXPERIMENTAL DESIGN

The following procedures/outlines are followed within this workflow:

- Building a Physical Model of the network(s);
- Creating a Fluid Model;
- Choosing/Selection of Flow Correlations;
- Validation of the Model with both Field Data and Analytical Value;
- Perform Sensitivity Studies; and
- Analyzing Results.

4.1.1 Building a Physical Model of the Network(s)

Two virtual network models: one for existing West Zone gas transmission pipeline network and another for existing West Zone gas transmission pipeline network along with extended/newly constructed pipelines, are built by using PIPESIM software. A virtual network model comprises two models viz. physical model and fluid model. Among others, pressure drop and volume of flow depend on pipeline length, diameter, wall thickness, efficiency factor etc. which are considered to build the physical model.

4.1.2 Fluid Model

The fluid model is the main prerequisite that should be defined first when builds a simulation network model. To create a fluid model, amount of water and liquefiable hydrocarbons are also defined along with gas composition as pressure drop in pipeline largely depends on these fluid properties. Black Oil Fluid Model is defined in this simulation network. The fluid used in the model is a mixture of natural gas of several gas fields taken from Ashuganj Gas Manifold Station (AGMS) in September 2010 and the defined gas compositions are shown in Table 4.1.

Table 4.1: Used Fluid Model [24]

Element	**% Mole**
Nitrogen	0.331
CO_2	0.101
Methane	96.518
Ethane	2.091
Propane	0.458
i-Butane	0.159
n-Butane	0.086
i-Pentane	0.049
n-Pentane	0.032
Hexane	0.092
Heptane	0.074
Octane	0.011
Total	**100.00**

Specific Gravity: 0.5805 at Base Condition: 60°F & 14.696psia

Ideal Density: 0.0443 lb/ft^3

Real Density: 0.0444 lb/ft^3

Mole Weight: 16.8123 gm/mol

C5+: 0.0951 GPM (gallon per thousand cubic feet)

Effect of temperature gradient is not considered and 60ºF of gas temperature is considered all through the pipeline. The Watercut and Liquid Gas Ratio (LGR) are considered 0% and 0 STB/MMscf respectively to represent the fluid in the model as gas.

4.1.3 Selection of Flow Correlations

There are numbers of equations for long pipelines such as the Weymouth, Panhandle A, and Panhandle B equations to simulate compressible gas flow. These equations were developed from the fundamental energy equation for compressible flow, but each has a special representation of the friction factor. The selection of appropriate flow equation/correlation for a particular pipeline is very important and it requires detailed study on selection criteria such as flow characteristics viz. turbulent/laminar flow, flow rate, operating pressure, percentage of pressure drop etc. and length/diameter of pipeline. In these models Beggs and Brill Revised fluid flow correlation has been used for horizontal flow assuming there is no vertical flow in the network and Panhandle 'B' equation- the most useful and fairly accurate for transmission pipeline is used for analytical calculation. Moreover, this equation is commonly used in gas industry for its simplicity and well defined parameters.

4.1.4 Validation of the Model with both Field Data and Analytical Results;

To validate the network model, pressure drop calculations are performed analytically to compare the result with both field data from the existing outlets and the simulated data obtained from existing West Zone gas transmission pipeline network analysis by PIPESIM. Once the network model is validated, it can be used to perform several sensitivity studies at various sets of input conditions such as upstream/downstream pressure, operating pressure and flow rate at inlet/outlets and analyze and summarize the result to achieve the specific objectives and outcomes.

Assumptions

The following assumptions are taken into consideration in designing a simulation network:

(i) The pipeline network is considered completely horizontal though there have some elevations;

(ii) The temperature gradient could not be measured and hence, the effect of temperature gradient is considered negligible assuming the gas is flowing at constant temperature (60ºF);

(iii) The pipeline network is considered a straight line for the ease of modeling but there are numbers of bends, elbows and other fittings. The effect of such fittings in flow are not considered in this analysis;

(iv) The fluid is considered single phase and 100% dry gas;

(v) The gas behaves as an ideal gas.

CHAPTER

5

NETWORK MODELING AND ANALYSIS

5.1 INTRODUCTION

For transmission system analysis, it is necessary to configure the pipeline model with correct pipeline data. The schematic diagram of the transmission system related to the model for analysis has also been drawn which would be necessary to understand the transmission system under investigation. The transmission model was updated using all pipeline data within the software PIPESIM for steady state analysis of the main transmission grid along with interconnected transmission pipelines in the network.

The transmission system analysis have been carried out on two major premises viz. (a) the transmission network already under operation, and (b) the transmission network already under operation along with the extended segment of the grid downstream of Iswardi (upto Khulna) to see the transmission capacity in meeting the demand at different load centers/withdrawal points in the western region which are planned for supplying gas under Gas Transmission and Development Project (GTDP). Elenga has been considered as the inlet point to the western hub of the grid since mainline compressor at Elenga would facilitate pushing gas at the designed maximum operating pressure of the transmission pipelines covering areas under Paschimanchal Gas Company Limited (PGCL) and areas under South and South-West (S&SW) region under Sundarban Gas Company Limited (SGCL). This will also facilitate to understand the availability of gas, after meeting the demand at different load centers under PGCL, and pressure at Hatikumrul since Hatikumrul is the source for Rajshahi, Bheramara and Khulna. Khulna, an industrial city, has been considered important for which few major power plants have been planned although non-bulk demand may not rise sharply immediately after availability of gas.

5.2 CASE STUDIES

The West Zone gas transmission network (existing and extended) are modeled, run and sensitivities are studied and finally analyzed. The following sensitivity studies are made and analyzed in this work:

(i) Present Situation: Volumetric flow rate and pressure drop scenario of the existing network.

(ii) Case-I: Minimum pressure in Khulna at present demand and upstream pressure (400 psig) at Elenga, Tangail.

(iii) Case-II: Maximum possible volumetric flow rate in the network at present pressure at Elenga, Tangail.

(iv) Case-III: Maximum possible volumetric flow rate in the network when upstream pressure is raised to 650 psig at Elenga with the help of compressors established at Ashuganj, Brahmanbaria.

(v) Case-IV: Maximum possible volumetric flow rate in the network when upstream pressure is raised to 1000 psig at Elenga with the help of compressors established at Elenga.

5.2.1 Present Situation: Volumetric Flow Rate and Pressure Drop Scenario of the Existing Network.

The physical model of the existing network is shown in Figure 5-1. The existing network comprises of 246 Km gas transmission pipelines of various sizes from Elenga to Rajshahi via. Baghabari, Bogra and Iswardi. At present about 110-120 MMscfd gas is supplied in West Zone through the network with upstream pressure 390 psig at Elenga. The supplied volume is very low compare to the network supply capacity. The pressure at different junctions and sinks, obtained from the network simulation at present demand situation, are tabulated in Table 5.2.

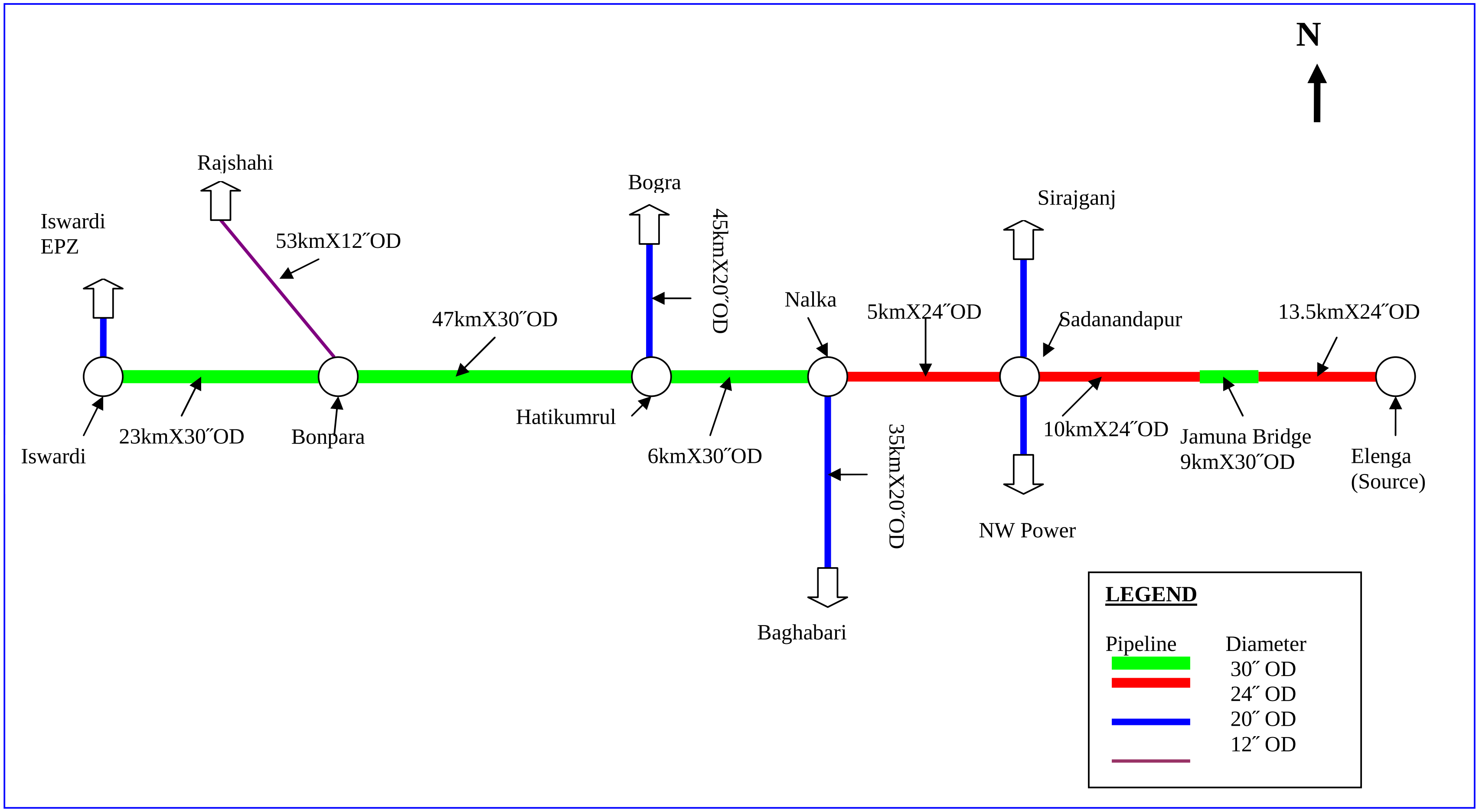


Figure 5-1: Existing Physical Network Model.

Inputs: The input of the system is tabulated in Table- 5.1.

Table-5.1: Input parameters (Actual Value) [12]

Upstream pressure at Elenga	390 psig
Consumption, MMscfd	
Sirajganj	9
NorthWest Power	35
Baghabari	48
Bogra	19
Iswardi	3
Rajshahi	2
Total	**116 MMscfd**

Output: The output pressure at different Junctions and Sinks are tabulated in the Table-5.2

Table- 5.2: Out put Pressure at different Junctions and Sinks.

Name of Junction/Sink	Type	Distance from Source (km)	Pressure (Psig)	Gas Flow (MMscfd)	Remarks
Elenga	Source	0	390	116	Elenga is considered as a source of the West Zone Network.
J-1: Jamuna Bridge(JB) East	Junction	13.5	383.77	116	
J-2: JB West	Junction	22.5	382.32	116	
J-3: Sadanandapur	Junction	32.5	377.75	116	
Sink-1: **Sirajgonj**	Sink	33	377.74	9	
Sink-1-a: NW Power	Sink	33.5	377.51	35	
J-4: Nalka	Junction	37.5	376.86	72	
Sink-2: **Baghabari**	Sink	72.5	369	48	
J-5: Hatikumrul	Junction	43.5	376.79	24	
Sink-3: **Bogra**	Sink	88.5	375	19	
J-6: Bonpara	Junction	90.5	376.77	5	
Sink-4: **Rajshahi**	Sink	143.5	376.48	2	
Sink-5: **Iswardi**	Sink	114	376.77	3	

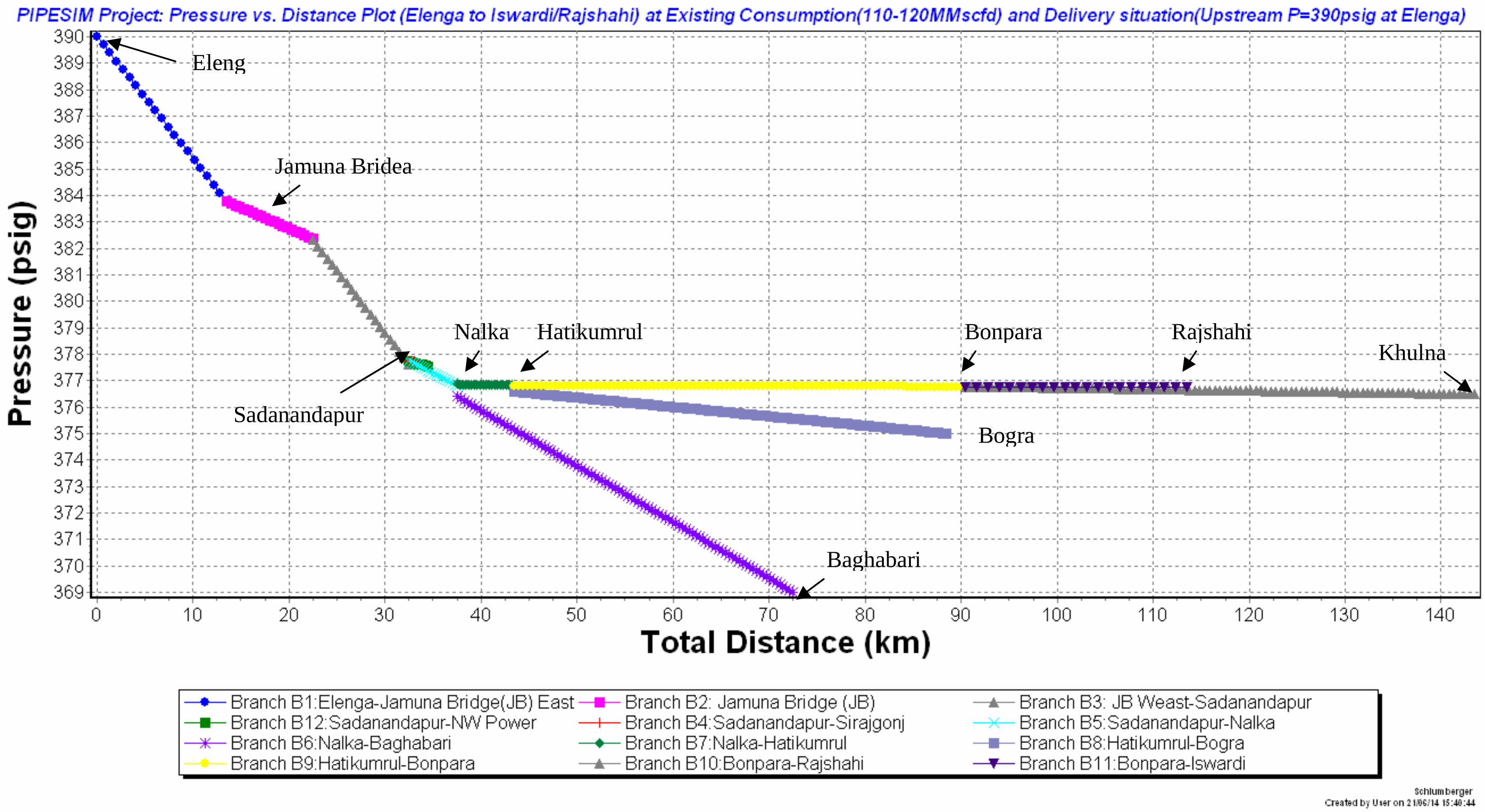


Figure 5-2: Pressure Drop Profile at present flow condition in West Zone.

Analytical Data

To validate the simulation model, pressure at different off-take/outlet points are calculated analytically using following modified Panhandle 'B' equation.

$$Q_{mmscfd} = 0.00128084\left[\frac{P_1^2 - P_2^2}{L_{miles}}\right]^{0.51} d^{2.53}$$

Where,

Q= Flow in MMscfd

P_1= Upstream Pressure, psia

P_2= Downstream Pressure, psia

d= Inside pipe diameter, inch

L= Length of pipeline in Miles

Simulated, analytical and real field data of some off-take/outlet points are tabulated in Table 5.3.

Table 5.3: Simulated, Real and Analytical Pressure at different off-take/outlet.

Name of Off-Take/ Outlet Point	Pressure, psig		
	Simulated	Real	Analytical
Sirajganj	377.74	378	372
Baghabari	369	369-354	360
Bogra	375	375-260	368
Rajshahi	376.48	375	370

The simulated and analytical data are obtained against a particular input data at a particular moment, where as the real value, large range is observed, is recorded over the full day range. The simulated, analytical and real pressures are plotted in the graph shown in Figure 5-3 to compare with each other at particular off-take/outlet.

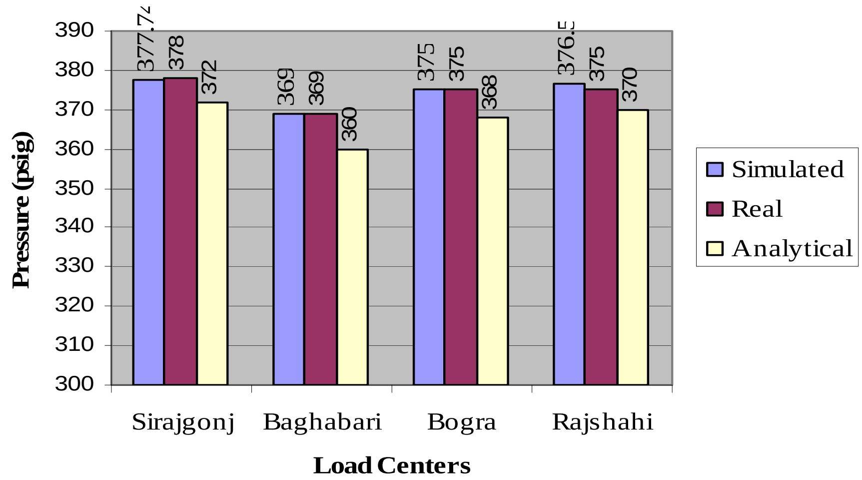


Figure 5-3: Pressure at different load centers.

Analysis of Present Situation

The simulated result is compared with both the real field data and the analytical value. Simulated value is quite equal to real value, though few variation (maximum 8 psig i.e. 0.025% only) is observed incase of analytical value as shown in Figure 5-3. This variation may be occurred due to the variation of the value of the some factors viz. average temperature, specific gravity, compressibility factor etc. in consideration. Besides, there may have some error with field data as, sometimes, calibration and human error being associated with it. The overall value is seemed to be very close. So, simulation network model can be considered as valid.

It is observed that maximum 21 psig pressure drop which is 5% of upstream pressure occurs at Baghabari at present flow situation in the network. This low pressure drop is due to low gas flow compared to the network capacity. It is also observed from the pressure drop profile in Figure 5-2 that at higher flow (Elenga to Sadanandapur) the pressure drop profile declined very sharply which indicates high pressure drop. On the other hand, the pressure drops profile of Nalka to Bogra and Nalka via. Bonpara to Iswardi/Rajshahi are very horizontal i.e. pressure drop is very low in these sections because of low flow. Hence, the overall flow in the network can be termed as “low flow, medium pressure”.

5.2.2 Case-I: Minimum Pressure in Khulna at Present Demand and Upstream Pressure (400 psig) at Elenga, Tangail.

This case study is made for the network of 423 km pipeline (existing along with extension) from Elenga to Khulna. It is to be mentioned here that 177 km pipeline from Iswardi to Khulna has already been constructed except Padma River Crossing. After successful completion of HDD Padma River crossing, this pipeline section will be hooked-up with the existing network and will be brought under operation to supply gas to Bheramara power plant and Kushtia, Jhenaidah, Jessore and Khulna region. The physical model of the existing network is shown in Figure 5-4.

At Khulna 150 MW combined cycle power plant has already been installed. The plant is producing power by high speed diesel as gas is not available there at this moment. About 30 MMscfd gas would be required to run this plant for power generation. Taking into account other industrial, commercial demand at this moment, it is anticipated that about 35 MMscfd gas might have required for Khulna at present. A lump sum 30 MMscfd gas is considered for Bheramara as a gas based power plant (360 MW) is under installation there. Though, this plant will need at least 90 MMscfd gas for its full capacity production, only 30 MMscfd is considered, at this stage, considering its first phase of production. For Kushtia, Jhenaidah and Jessore 1 MMscfd are set for each as there is no bulk consumer at this moment in these areas. Considering existing demand in Serajganj, Bogra, Bheramara and Rajshahi, it can be assumed that around 190 MMscfd gas would be needed to cop up the demand in West Zone right now.

This case study analyzes the pressure drop profile and predicts the minimum pressure at Khulna, the far most downstream of the network, against the present demand and upstream pressure (400 psig) in the network.

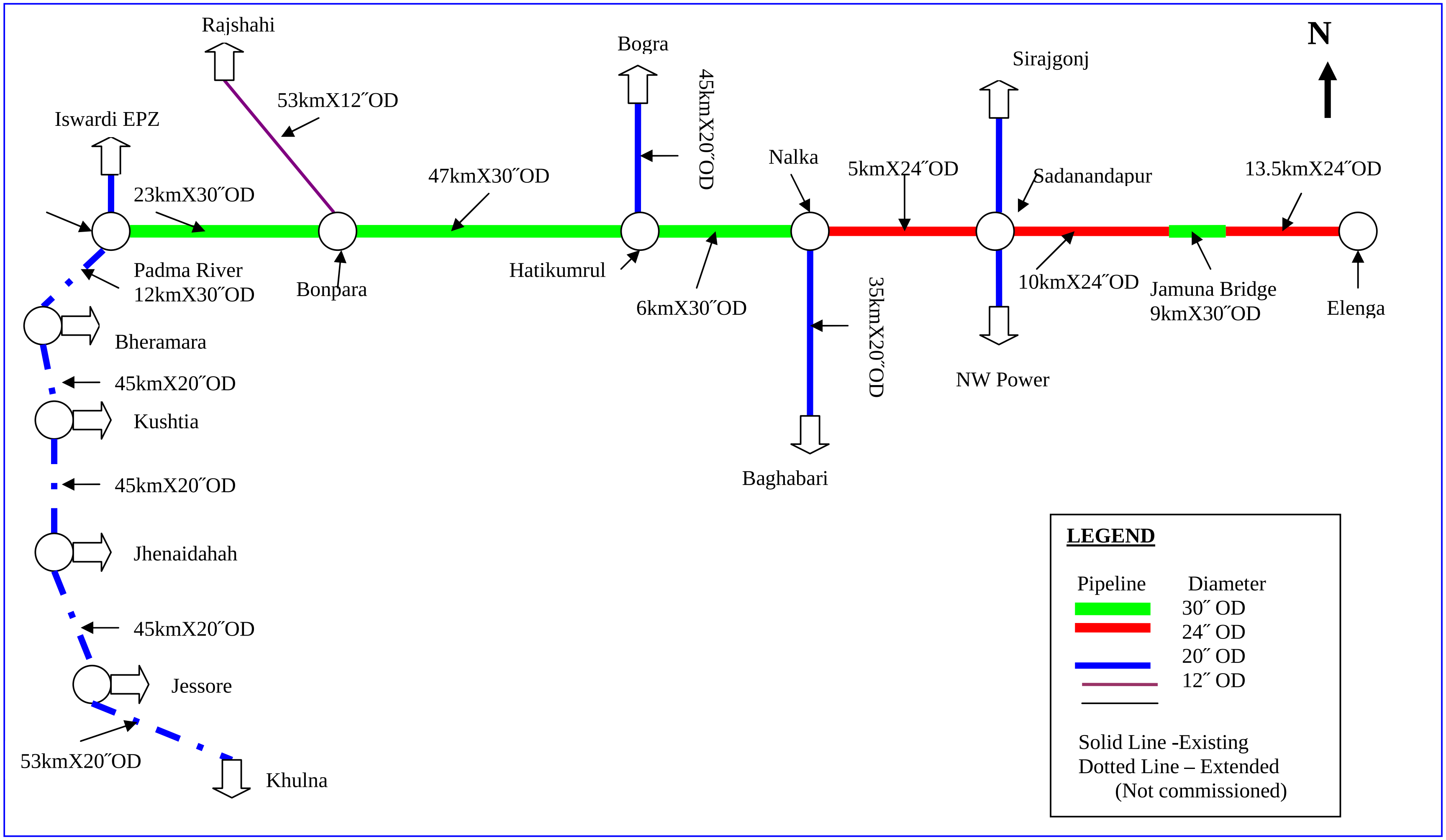


Figure 5-4: Extended Physical Network Model.

Inputs: The input of the network model is tabulated in Table- 5.4.

Table-5.4: Input parameters.

Upstream pressure at Elenga	400 psig	Remarks
Consumption/Demand, MMscfd		
Sirajgonj	10	Present consumption
NorthWest Power	35	
Baghabari	50	
Bogra	20	
Iswardi	5	
Rajshahi	2	
Khulna	35	Anticipated present demand
Bheramara Power Plant	30	
Others (Kustia, Jhenaidah & Jessore)	3	
Total	**190 MMscfd**	

Output: The output of this case study is summarized in Table 5.5.

Table- 5.5: Simulated result of minimum pressure and volume of flow.

Name of Junction/Sink	Type	Distance from Source (km)	Pressure (psig)	Gas Flow (MMscfd)
Elenga	Source	0	400	190
J-1: Jamuna Bridge(JB) East	Junction	13.5	382.70	190
J-2: JB West	Junction	22.5	378.86	190
J-3: Sadanandapur	Junction	32.5	366.06	190
Sink-1: **Sirajgonj**	Sink	33	366.06	10
Sink-1-a: **NW Power**	Sink	33.5	365.97	35
J-4: Nalka	Junction	37.5	362.28	145
Sink-2: **Baghabari**	Sink	72.5	353.82	50
J-5: Hatikumrul	Junction	43.5	361.59	95
Sink-3: **Bogra**	Sink	88.5	359.74	20
J-6: Bonpara	Junction	90.5	357.71	75
Sink-4: **Rajshahi**	Sink	143.5	357.79	2
J-7: Iswardi	Junction	114	356.46	73
Sink-5: **Iswardi EPZ**	Sink	115	354.42	5
J-8: Bheramara	Junction	126	355.72	68
Sink-6: **Bheramara**	Sink	126	355.71	30
J-9: Kushtia	Junction	148	352.03	38
Sink-7: **Kushtia**	Sink	148	352.03	1
J-10: Jhenaidah	Junction	193	344.79	37
Sink-8: **Jhenaidah**	Sink	193	344.79	1
J-11: Jessore	Junction	238	337.85	36
Sink-9: **Jessore**	Sink	238	337.85	1
Sink-10: **Khulna**	Sink	291	328. 66	35

The pressure drop profile is shown in Figure 5-5.

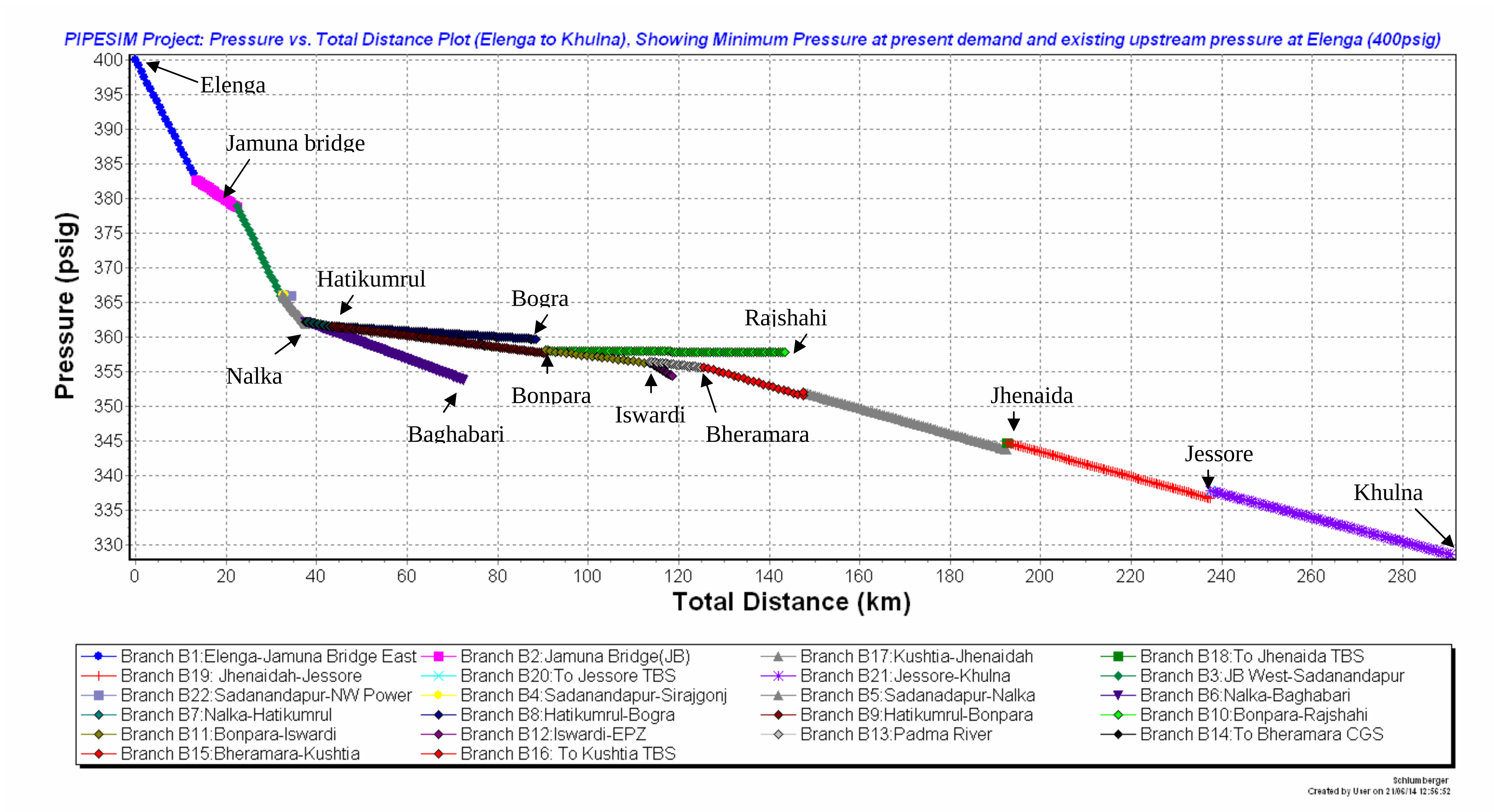


Figure 5-5: Pressure drop profile at present demand condition.

Analysis of Case-I

This case study is made for the network of 423 kilometer pipeline (existing along with extension) from Elenga, Tangail to Khulna. By this case study, the pressure drop situation against the present demand is predicted.

From the simulated result it is observed that the minimum pressure of the network remains 328 psig in Khulna, the fare most downstream of the network, against the present demand of 190 MMscfd with the present upstream pressure of 400 psig at Elenga, Tangail. This minimum pressure (328 psig) of the network in Khulna, in this situation, is quite enough to meet the requirement of Distribution Company's required pressure (300 psig) at the inlet of their network.

So, West Zone network is not only capable of meet the present demand but also can handle more gas than present demand with the present upstream pressure of 400 psig at Elenga, Tangail, the upstream of the West Zone network.

5.2.3 Case-II: Maximum Possible Volumetric Flow Rate in the Network at Present Upstream Pressure at Elenga, Tangail.

In case study-I, it is seen that the network would handle more gas than present demand. By this case study, the volumetric flow rate to Khulna and the maximum volumetric flow rate of the network against present network upstream pressure 400 psig at Elenga, is predicted maintaining minimum required downstream terminal pressure (300 psig).

Inputs: The input of the network model is tabulated in Table- 5.6.

Table-5.6: Input parameters

Upstream pressure at Elenga	400 psig
Downstream pressure at Khulna	300 psig
Present consumption/Demand, MMscfd	
Sirajgonj	10
NorthWest Power	35
Baghabari	50
Bogra	20
Iswardi	5
Rajshahi	2
Anticipated demand, MMscfd	
Bheramara Power Plant	30
Others (Kustia, Jhenaidah & Jessore)	3

The flow volumetric flow rate for Khulna is not inputted here to predict the maximum rate of the network.

Output: The pressure and volume of flow at different Junctions and Sinks are tabulated in Table-5.7

Table- 5.7: Simulated result of pressure and volume of flow.

Name of Junction/Sink	Type	Distance from Source (km)	Pressure (psig)	Gas Flow (MMscfd)	Remarks
Elenga	Source	0	400	205	Source pressure at Elenga and downstream pressure at Khulna are inputted and others pressures are system output.
J-1: Jamuna Bridge(JB) East	Junction	13.5	380.75	205	
J-2: JB West	Junction	22.5	376.47	205	
J-3: Sadanandapur	Junction	32.5	361.94	205	
Sink-1: **Sirajgonj**	Sink	33	361.94	10	
Sink-1-a: **NW Power**	Sink	33.5	361.85	35	
J-4: Nalka	Junction	37.5	357.54	160	
Sink-2: **Baghabari**	Sink	72.5	348.96	50	
J-5: Hatikumrul	Junction	43.5	356.54	110	
Sink-3: **Bogra**	Sink	88.5	354.67	20	
J-6: Bonpara	Junction	90.5	351.59	90	
Sink-4: **Rajshahi**	Sink	143.5	351.41	2	
J-7: Iswardi	Junction	114	349.45	88	
Sink-5: **Iswardi EPZ**	Sink	115	347.36	5	
J-8: Bheramara	Junction	126	348.40	83	
Sink-6: **Bheramara**	Sink	126	348.39	30	
J-9: Kushtia	Junction	148	342.16	53	
Sink-7: **Kushtia**	Sink	148	342.16	1	
J-10: Jhenaidah	Junction	193	329.42	52	
Sink-8: **Jhenaidah**	Sink	193	329.42	1	
J-11: Jessore	Junction	238	315.36	51	
Sink-9: **Jessore**	Sink	238	315.36	1	
Sink-10: **Khulna**	Sink	291	300.00	50	

The pressure drop profile is shown in Figure 5-6.

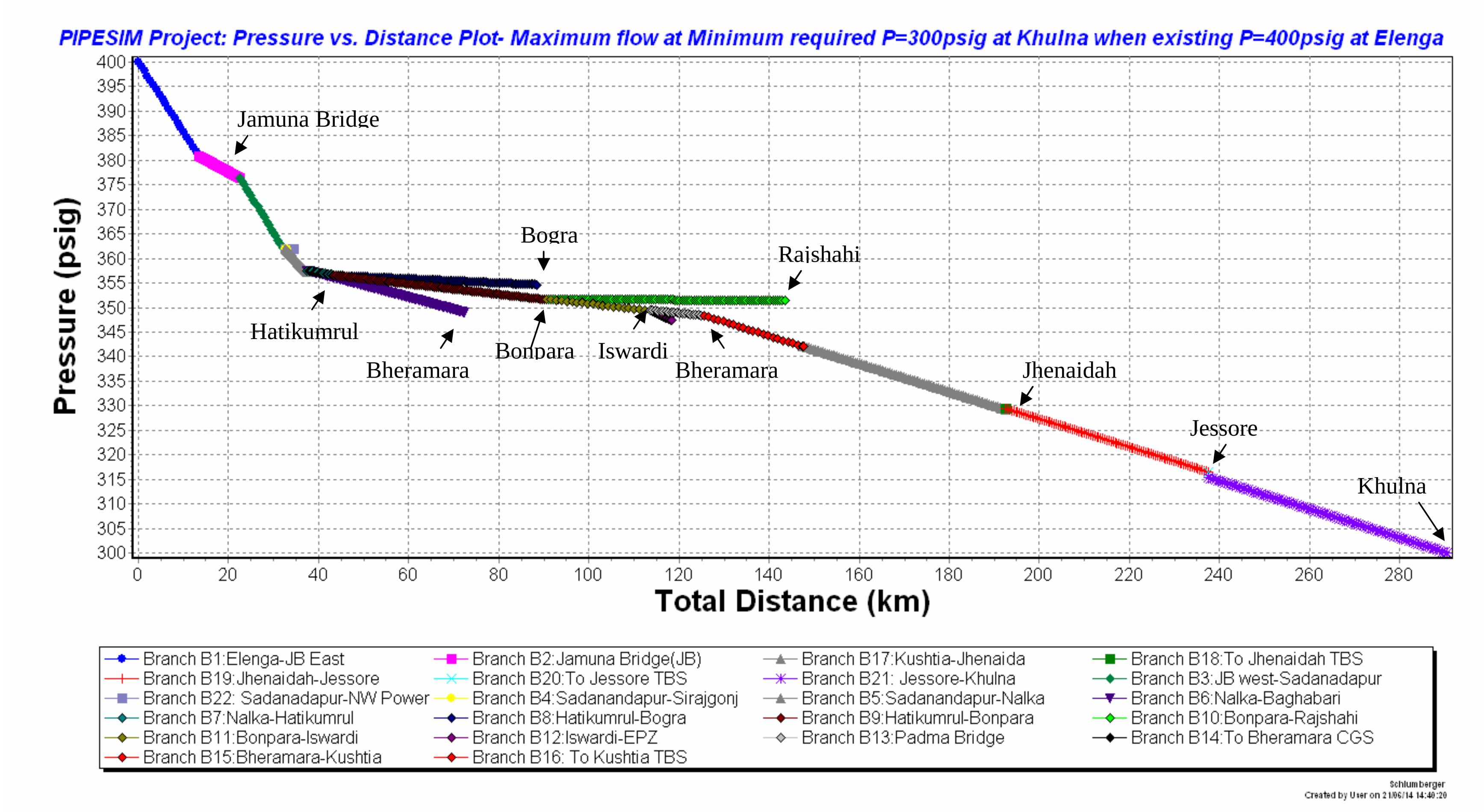


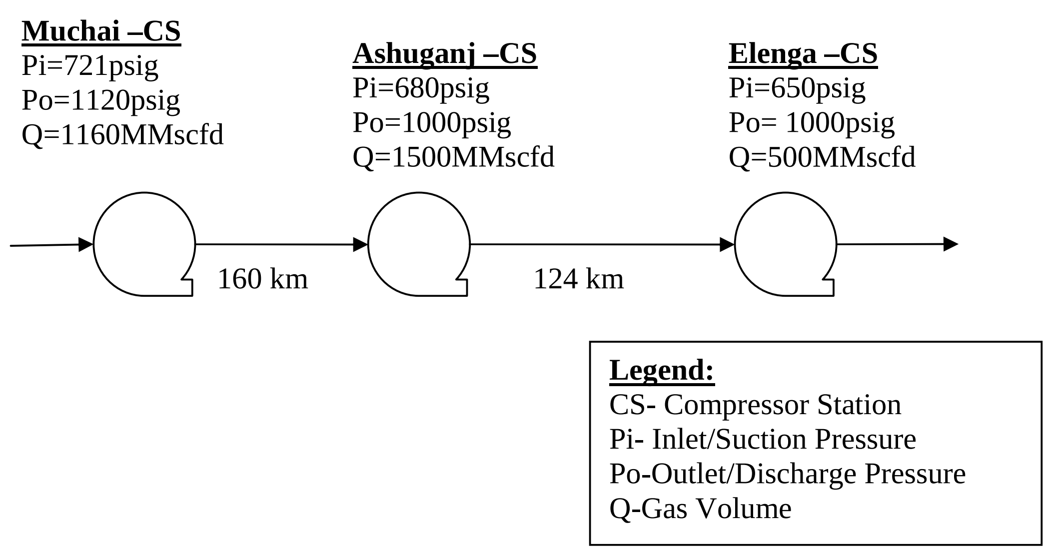
Figure 5-6: Pressure Drop Profile at maximum flow at minimum required pressure at the end of network.

ANALYSIS OF CASE-II

By this case study, it is seen that maintaining minimum required pressure (300 psig) distribution company's at end points of the network about 205 MMscfd gas including 50 MMscfd for Khulna would be possible to transmit through the network with present upstream pressure (400 psig) at Elenga. It is observed that about 90 MMscfd more gas would be possible to supply through the network, in addition to the present consumption of 110-120 MMscfd. So, it is possible to transmit 50 MMscfd gas to Khulna with present upstream pressure.

5.2.4 Case-III: Maximum Possible Volumetric Flow Rate in the Network When Upstream Pressure is Raised to 650 psig at Elenga with the Help Compressors Established at Ashuganj, Brahmanbaria.

At present the overall national gas grid pressure is not well enough to maintain the distribution companies minimum required pressure. Distribution companies specially Titas Gas Transmission and Distribution Company Limited (TGTDCL) in Greater Dhaka region and Karnafuly Gas Distribution Company Limited (KGTCL) in Chittagong region are continuously facing low pressure problem i.e. they can not supply gas to their customers at required pressure as they received gas from the grid at pressure lower than that of required at upstream of their distribution network. To boost up the national gas grid pressure, a compressor station has been installed by Chevron at Muchai, Habiganj and another one at Ashuganj, Brahmanbaria by GTCL. Installation of 3rd compressor station by GTCL at Elenga, Tangail is in progress [25-26]. These three compressor stations are synchronized and suppose to maintain the grid pressure as follows:



The compressor station established at Muchai, Habiganj will feed gas to Ashuganj hub at pressure not less than the minimum required pressure of 680 psig at the inlet of Ashuganj compressor that will boost up pressure to 1000 psig at its outlet to feed gas to Chittagong and greater Dhaka franchise area along with West Zone. Ashuganj compressor is designed in such a way that it will feed gas to Elenga at pressure not less than minimum required pressure of 650 psig at the inlet of Elenga compressor that will boost up pressure to 1000 psig to feed gas to the West Zone.

This case study will show the pressure drop scenario and help to predict the maximum volumetric flow rate in the West Zone network when upstream pressure of the network rises to 650 psig at Elenga with the help of compressor at Ashuganj. In other words, this study analyzes the effect of compressor, established at Ashuganj, to the West Zone network.

Inputs

In this case study network inlet pressure at Elenga and fare most downstream pressure at Khulna are set as well as some volumetric flow rate which are shown in Table- 5.8.

Table-5.8: Input parameters.

Upstream pressure at Elenga (Ashuganj compressor will maintain this pressure at Elenga)	650 psig
Downstream pressure at Khulna	350 psig (350 psig pressure at inlet of CGS and TBS is well enough for smooth operation).
Probable Future Demand (MMscfd)	
Sirajganj	80
North-West Power	35
Baghabari	50
Bogra	80
Iswardi	5
Rajshahi	5
Bheramara Power Plant	80
Kustia & Jhenaidah	2
Jessore	3

The probable demands are set considering bulk customers basically power plant and industrial infrastructure of the respected sink which are already mentioned before.

Output/Results

The output of this case study is summarized in the Table 5.9.

Table- 5.9: Simulated result of volumetric flow rate and corresponding pressure.

Name of Junction/Sink	Type	Distance from Source (km)	Pressure (psig)	Gas Flow (MMscfd)	Remarks
Elenga	Source	0	650	380	The gas flow, except Elenga (Source) and Khulna, are set considering probable demand of the respected Sink area.
J-1: Jamuna Bridge(JB) East	Junction	13.5	553.53	380	
J-2: JB West	Junction	22.5	534.25	380	
J-3: Sadanandapur	Junction	32.5	433.85	380	
Sink-1: **Sirajgonj**	Sink	33	433.40	80	
Sink-1-a: **NW Power**	Sink	33.5	433.71	35	
J-4: Nalka	Junction	37.5	408.44	265	
Sink-2: **Baghabari**	Sink	72.5	400.50	50	
J-5: Hatikumrul	Junction	43.5	403.68	215	
Sink-3: **Bogra**	Sink	88.5	377.10	80	
J-6: Bonpara	Junction	90.5	393.41	135	
Sink-4: **Rajshahi**	Sink	143.5	407.41	5	
J-7: Iswardi	Junction	114	390.29	130	
Sink-5: **Iswardi EPZ**	Sink	115	388.43	5	
J-8: Bheramara	Junction	126	388.1	125	
Sink-6: **Bheramara**	Sink	126	388.10	80	
J-9: Kushtia	Junction	148	381.87	45	
Sink-7: **Kushtia**	Sink	148	381.87	1	
J-10: Jhenaidah	Junction	193	370.54	44	
Sink-8: **Jhenaidah**	Sink	193	370.54	1	
J-11: Jessore	Junction	238	358.9	43	
Sink-9: **Jessore**	Sink	238	357.33	3	
Sink-10: **Khulna**	Sink	291	350	40	

The pressure drop profile is shown in Figure 5-7.

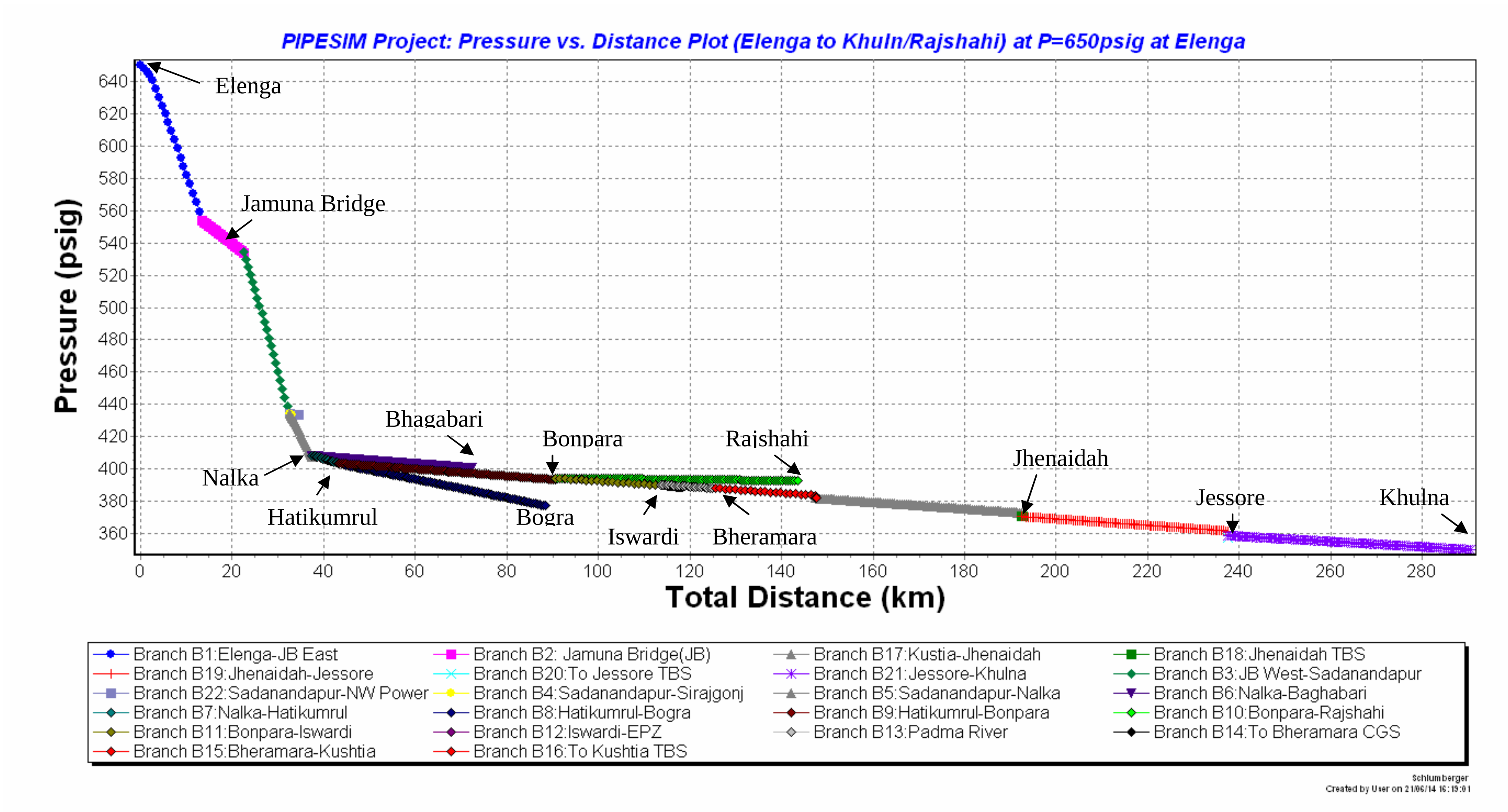


Figure 5-7: Pressures drop profile at maximum volumetric flow rate when network upstream pressure at Elenga rises to 650 psig with help of compressor established at Ashuganj, Brahmanbaria.

Analysis of Case-III

This case study shows that maximum 380 MMscfd gas would be possible to transmit through network maintaining minimum downstream pressure 350 psig at Khulna. The study predicts that 40 MMscfd gas would be possible to transmit to Khulna fulfilling the near future demand of other demand centers in the network. It is to be mentioned here that 110-120 MMscfd gas is supplied in West Zone at present. But the West Zone network can consume more gas than present supply at this moment, because gas based 150 MW power plant in Khulna and first phase of 360 MW power plant at Bheramara are ready to consume around 70 MMCFD gas. So, present demand can be considered 190 MMCFD.

Analysis also shows that it would take at least 9 (nine) years i.e. upto 2024 to reach the demand of West Zone from 190 MMscfd to 380 MMscfd with 8% growth rate. So, if Elenga compressor is installed now, it will be sitting idle for next 9 years. Moreover, if it is failed to maintain minimum required pressure of 650 psig at the inlet of Elenga compressor due to failure of Ashuganj compressor or supply constrained in the upstream, it will not be possible to run it. The compressor stations at Muchai, Habiganj and Ashuganj, Brahmanbaria will, definitely, play important rule to boost up pressure and to increase throughput to national grid that will, ultimately, overcome the pressure deficit in greater Dhaka and Chittagong franchise area at this moment.

5.2.5 Case-IV: Maximum Possible Volumetric Flow Rate in the Network When Upstream Pressure is Raised to 1000 psig at Elenga with the Help Compressors Established at Elenga.

As mention before in previous case study, a compressor station is under installation at Elenga, the upstream point of the West Zone network to boost up the network pressure to 1000 psig. By this case study, it is analyzed the effect of compressor to the West Zone network, the pressure drop profile, maximum volume of flow in the network, volume of flow at Khulna etc. In addition to this, another experiment was made under this case study to predict the effect bottleneck in the West Zone network.

Inputs: The input of the network model is tabulated in Table- 5.10.

Table-5.10: Input Parameters.

Upstream pressure at Elenga (Elenga compressor's outlet/discharge pressure)	1000 psig
Minimum required pressure at Khulna	350 psig
Consumption/Probable Demand	MMscfd
Sirajgonj	110
NW Power	35
Baghabari	60
Bogra	120
Rajshahi	30
Iswardi EPZ	10
Bheramara	100
Kushtia	20
Jhenaidah	30
Jessore	20

The gas flow, except Elenga (Source) and Khulna, are set considering probable long term demand of the respected sink area.

Output/Results: The output of this case study is summarized in the following Table 5.11.

Table- 5.11: Simulated result of volumetric flow rate and corresponding pressure.

Name of Junction/Sink	Type	Distance from Source (km)	Pressure (psig)	Gas Flow (MMscfd)
Elenga	Source	0	1000	620
J-1: Jamuna Bridge(JB) East	Junction	13.5	866.11	620
J-2: JB West	Junction	22.5	835. 68	620
J-3: Sadanandapur	Junction	32.5	684.19	620
Sink-1: **Sirajgonj**	Sink	33	683.70	110
Sink-1-a: **NW Power**	Sink	33.5	684.10	35
J-4: Nalka	Junction	37.5	644.05	475
Sink-2: **Baghabari**	Sink	72.5	636.51	60
J-5: Hatikumrul	Junction	43.5	631.54	415
Sink-3: **Bogra**	Sink	88.5	587.12	120
J-6: Bonpara	Junction	90.5	595.94	295
Sink-4: **Rajshahi**	Sink	143.5	559.18	30
J-7: Iswardi	Junction	114	584.78	265
Sink-5: **Iswardi EPZ**	Sink	115	580.04	10
J-8: Bheramara	Junction	126	579.12	255
Sink-6: **Bheramara**	Sink	126	579.06	100
J-9: Kushtia	Junction	148	528.39	155
Sink-7: **Kushtia**	Sink	148	528.38	20
J-10: Jhenaidah	Junction	193	428.43	135
Sink-8: **Jhenaidah**	Sink	193	428.42	30
J-11: Jessore	Junction	238	384. 60	105
Sink-9: **Jessore**	Sink	238	385.51	20
Sink-10: **Khulna**	Sink	291	350.00	85

The pressure drop profile is shown in Figure 5-8.

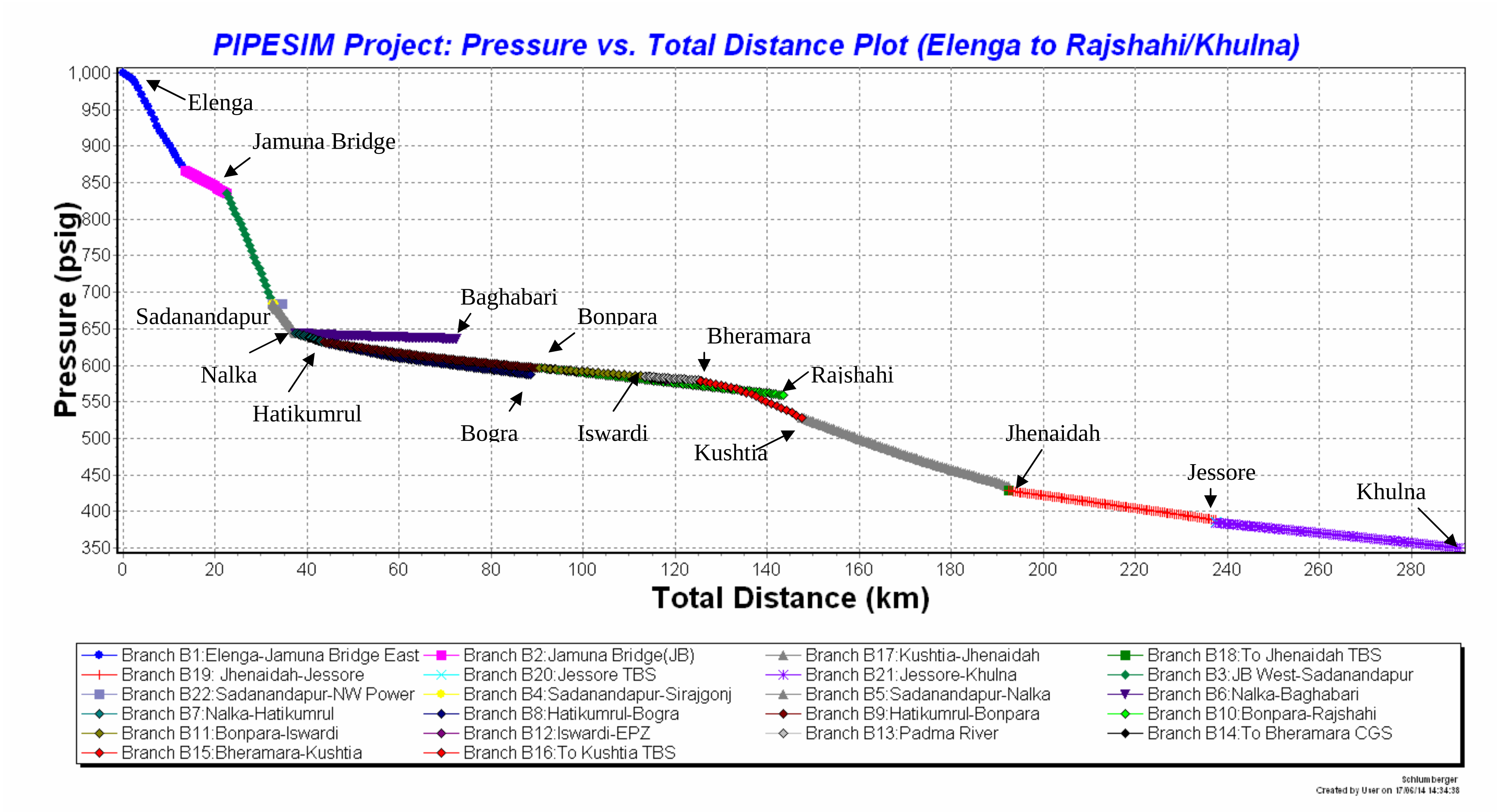


Figure 5-8: Pressures drop profile at maximum volumetric flow rate when network upstream pressure at Elenga rises to 1000 psig with help of compressor established at Elenga, Tangail.

Analysis of Case-IV

This case study shows that maximum 620 MMscfd gas would be possible to transmit through network maintaining minimum downstream pressure 350 psig at Khulna if upstream pressure of the network raises to1000 psig with help of compressor established at Elenga. The study also shows that 85 MMscfd gas would be possible to transmit to Khulna fulfilling the probable long term future demand of other demand centers in the network.

Analysis also shows that it would take at least 15 years i.e. upto 2029 to reach the demand of West Zone from 190 MMscfd to 620 MMscfd with 8% growth rate.

Another experiment under this case study shows that if Elenga to Jamuna Bridge (East) and Jamuna Bridge (West) to Nalka segments of pipeline is considered 30 inch dia rather than 24 inch dia., then network supply capacity would be 680 MMscfd i.e. it would possible to supply additional 60 MMscfd gas through West Zone network.

5.2.6 Summery of Analysis

The summery of analysis of the previous cases are summarized in Table 5.12.

Table 5.12: Summery of Case Studies.

Parameter	Existing Network: 246km	Extended network upto Khulna: 423km			
	Present Situation : P_{us}=390 psig	Case-I: P_{us}=400 psig, Q=190 MMscfd Present demand of the network.	Case-II: P_{us} =400 psig, P_d=300 psig	Case-III: P_{us} =650psig, Effect of compressor at Ashuganj. P_d=350 psig	Case-IV: P_{us} =1000psig, Effect of compressor at Elenga, P_d=350 psig
Flow rate (MMscfd)	115	190	205	382	620
Minimum Down stream Pressure (psig)	369	328	300	350	350
Remarks	Shows the present scenario.	Minimum down stream pressure is predicted at present demand and present source pressure.	Max. Volume of flow is predicted at minimum required down stream pressure and present source pressure.	Max. Volume of flow is predicted at minimum required down stream pressure when source pressure rises to 650 psig due to the effect of compressor at Ashuganj, Brahmanbari, the fare upstream of the network.	Max. Volume of flow is predicted at minimum required down stream pressure when source pressure rises to 1000 psig due to the effect of compressor at Elenga, Tangail, the upstream of the network.

P_{us}: Upstream Source Pressure, P_d: Downstream Pressure.

5.2.7 Maximum Flow Rate at Different Upstream Pressure

Maximum volumes of flow at different upstream pressure at Elenga are found out in Case-II, Case-III and Case-IV which are tabulated in Table 5.13 and also shown in Figure 5-9.

Table-5.13: Maximum volume of flow at different upstream pressure.

Case	Upstream pressure, (Psig)	Flow (MMscfd)
Case-II	400	205
Case-III	650	382
Case-IV	1000	620

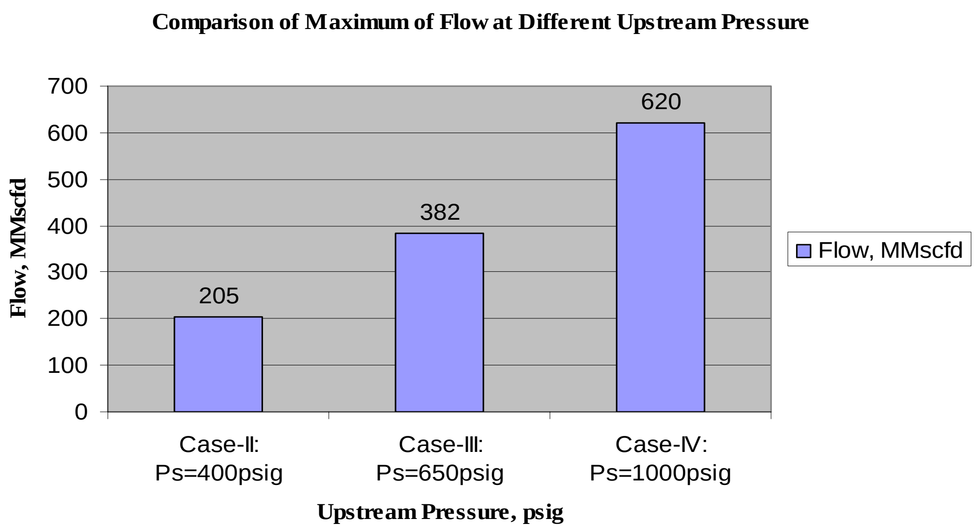


Figure-5.9: Maximum Flow vs. Upstream Pressure Chart

The case-II refers to maximum possible volumetric flow rate at present flow condition. Case-III indicates maximum possible volumetric flow rate when upstream pressure rises from 400 psig to 650 psig with the help of compressor established at Ashuganj. In this case, flow is almost double of volumetric flow at present flow condition. In case of case-IV, network can handle more gas, almost 3 times of volumetric flow at present flow condition when upstream pressure will be raised to 1000 psig with the help of compressor established at Elenga, the network upstream point.

5.2.8 Effect of Compressors

It is measured from the cases study that around 380 MMscfd and 620 MMscfd gas can be supplied through the network, maintaining downstream pressure not less than 350 psig at any demand center, with the help of compressors established at Ashuganj, Brahmanbaria and Elenga, Tangail respectively. Table 5.14 shows the number of years required from 2015 to reach the demand of West Zone to 380 MMscfd and 620 MMscfd considering present demand of 190 MMscfd.

Table 5.14: Number of years required to reach the demand of West Zone to 380 MMscfd and 620 MMscfd at different gas consumption growth rate.

Demand	No. of year required.		
	@ 6%	@ 8%	@ 10%
380 MMscfd	12	9	7
620 MMscfd	20	15	12

CHAPTER

6

CONCLUSION

6.1 CONCLUSION

The West Zone Gas Transmission Pipeline Network from Elenga, Tangail to Rajshahi via. Sirajganj, Baghabari, Bogra, Iswardi along with newly constructed pipeline from Iswardi to Khulna via. Bheramara, Kushtia, Jhenaidah and Jessore is analyzed. In this study, along with present situation, number of cases study mainly for effect of compressors are done to predict the pressure drop and volumetric flow of the network at various flow conditions. Besides, experimental results are analyzed and numbers of analytical calculations are done to predict consumption growth rate, future demand at different growth rate and how long the pipeline and boost up devices can cope up with the forecasted future demand.

The study shows that at present situation with consumption of 120 MMscfd at an upstream pressure of 390 psig at Elenga, Tangail, there is no pressure deficit in West Zone gas transmission network. Pressure drop in West Zone network at present situation is very low as gas flow is low compared to maximum network supply capacity of 620 MMscfd at an upstream pressure of 1000 psig, the design operating pressure of the pipeline. Maximum 21 psig pressure drop which is 5% of upstream pressure occurs at Baghabari at present situation in West Zone. With the present upstream pressure, maximum 205 MMscfd gas can be supplied through the network including 50 MMscfd for Khulna. So, present demand of 35 MMscfd for Khulna could easily be met with present upstream pressure.

This study also shows that around 380 MMscfd gas can be supplied through the West Zone network, maintaining downstream pressure not less than 350 psig at any demand center, with the help of compressors established at Ashuganj, Brahmanbaria. It will take at least 9 years to reach the demand of West Zone to 380 MMscfd with 8% growth rate. So, if Elenga compressor is installed now, it will be sitting idle for next 9 years. Moreover, if it is failed to maintain minimum required pressure of 650 psig at the inlet of Elenga compressor due to failure of Ashuganj compressor or supply constrained in the upstream, it will not be possible to run it. The other two compressor stations at Muchai, Habiganj and Ashuganj, Brahmanbaria will, definitely, play important rule to boost up pressure and to increase throughput to national grid that will, ultimately, overcome the pressure deficit in greater Dhaka and Chittagong franchise area at this moment. However, if Elenga compressor is installed, it will possible to supply 620 MMscfd gas to the West Zone. It will take at least 15 years to reach the demand of West Zone to 620 MMscfd with 8% growth rate. Network supply capacity can be increased by 60 MMscfd, if bottleneck is removed from Elenga to Jamuna Bridge (East) and Jamuna Bridge (West) to Nalka section of the West Zone network.

The study will, definitely, help to make proper planning and design for further augmentation of West Zone gas transmission network for the uninterrupted transportation of natural gas in safe, reliable and economical way to the demand centers for ultimate distribution of the same. By this model, it can easily be validated the performance of the network that will be helpful for smooth operation of the network. The study will, ultimately, improve the operational standard of the West Zone gas transmission network consistent with the national gas grid as well as world gas industry.

6.2 RECOMMENDATION

There are some recommendations as follow:

(i) The study is made in West Zone, a part of total transmission network of Bangladesh. For better analysis entire transmission network of Bangladesh along with West Zone can be modeled and analyzed.

(ii) An extensive survey/feasibility study should be conducted in West Zone to identify the potential consumers and gas demand that will help to analyze the network more accurately.

(iii) The proposed parallel pipeline from Elenga to Jamuna Bridge (East) and Jamuna Bridge (West) to Nalka may be installed to overcome the bottleneck of the West Zone network after couple of years when existing pipeline will get saturated.

(iv) Installation of compressor station at Elenga, Tangail, the upstream of West Zone network, can be introduced after couple of years when the demand of West Zone will reach beyond the maximum possible supply volume to West Zone by Ashuganj compressor station.

(v) Moreover, the lessons learned from the past in design, construction and operation of pipeline can be taken as a guideline for augmentation of pipeline in West Zone to avoid bottleneck in pipeline network for better performance of the same.

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APPENDIX

ABBREBIATIONS AND ACRONYMS

AGA	American Gas Association.
AGMS	Ashuganj Gas Manifold Station.
API	American Petroleum Institute.
BCF	Billion Cubic feet.
BGFCL	Bangladesh Gas Field Company Limited.
BGSL	Bakhrabad Gas System Limited.
BOC	Burmah Oil Company.
BPDB	Bangladesh Power Development Board.
CEGIS	Center for Environment and Geographical Information Services.
CFH	Cubic Foot per Hour
CGS	City Gate Station
CNG	Compressed Natural Gas.
CS	Compressor Station.
CWC	Concrete Weight Coating.
DPP	Development Project Proforma/Proposal.
DRS	District Regulating Station
EPZ	Export Processing Zone.
FBE	Fusion Bond Epoxy.
GIIP	Initial Gas in Place.
GPSA	Gas Processors Suppliers Association.
GPM	Gallon Per Thousand Cubic Feet.
GEOP	Geosciences Education Outreach Program.
GTDP	Gas Transmission and Development Project.
GTCL	Gas Transmission Company Limited.
HDD	Horizontal Directional Drilling.
HSD	High Speed Diesel.
HSS	Heat Shrinkable Sleeve.
ID	Internal Diameter
IOC	International Oil Company.
JGTDSL	Jalalabad Gas Transmission and Distribution System Limited.

KGDCL	Karnafuli Gas Distibution Company Limited.
KTL	Kailastila.
LGR	Liquid Gas Ratio.
LNG	Liquid Natural Gas.
MMscfd	Million cubic feet per day at standard condition.
NGC	National Gas Company.
NWPGCL	North-West Power Generation Company Limited.
OD	Outer Diameter.
OGDC	Oil and Gas Development Corporation.
Petrobangla	Bangladesh Oil, Gas & Mineral Corporation.
PE	Polyethylene.
PGCL	Paschimanchal Gas Company Limited.
PPL	Pakistan Petroleum Ltd.
PSOC	Pakistan Shell Oil Company.
QMS	Quality Management System.
RDDP	Revised Development Project Proforma/Proposal
SCADA	Supervisory Control and Data Acquisition
SGCL	Sundarban Gas Company Limited.
SGFCL	Sylhet Gas Field Company Limited.
STANVAC	Standard Vacuum Oil Company.
STB	Standard Stock Tank Barrel.
STP	Standard Temperature and Pressure.
TBS	Town Border Station.
TGTDCL	Titas Gas Transmission and Distribution Company Limited.
WT	Wall Thickness.
3LPE	Three Layer Polyethylenes.

STANDARD VALUE

1 MMcm = 35.31 MMcf.

1 MMscfd = 10^6 cubic feet at standard condition per day.

1MW = 10^6 Watt.

1 Tcf = 10^{12} cubic feet.

STP = 273º K and 1 atmospheric pressure (14.69 psig).

SAMPLE CALCULATION

1. Calculation of Gas Demand Growth Rate

$C = P(1+r)^n$ --------------------(i)

C = Consumption of n-th year

P= Initial gas consumption

r= % of gas consumption growth rate (compound rate)

n= No. of years.

Calculation:

Initial gas consumption in the financial year 2000-01, P = 13406.45 MMscf

Gas consumption in the financial year 2013-14, C = 36577.66 MMscf

No. of years, n = 13.

Growth rate, r = ?

From Equation (i),

$36577.66=13406.45\ (1+r)^{13}$

Or, $(1+r)^{13}=2.72836$

Or, 13ln(1+r)=ln(2.72836)

Or, ln(1+r) = 0.077207

Or, 1+r = $e^{0.077207}$

Or, r = 0.08026 ≈ 8%

For consumption of 382 MMscfd:

C_1 = 382 MMscf per day x 365 days=139430 MMscf in n_1-th year.

P_1 = 190MMscfd x 365 days = 69350 MMscf, Considering present demand including extended network at the end of 2014.

r = 8%

No. of year, n_1 = ?

From equation (i),

$139430 = 69350 \ (1+8\%)^n$

Or, $(1.08)^n = 2.01$

Or, n_1 = 9 years

Similarly, for consumption of 620 MMscfd, n_2 = 15 years

2. Calculation of Pressure

The modified Panhandle – B equation (ii) is used in analytical calculation-

$$Q_{mmscfd} = 0.00128084 \left[\frac{P_1^2 - P_2^2}{L_{miles}} \right]^{0.51} d^{2.53} \text{ ------------------------(ii)}$$

Hatikumrul-Bogra pipeline:

Pressure at Hatikumrul, P_1= (370.3+14.7) =385 psia

Flow, Q= 19 MMscfd

Inside pipe diameter, d =19.188 inch.

Length of pipeline, L =45km=27.962 miles

Downstream pressure at Bogra, P_2 = ?

From equation (ii),

$$19 = 0.00128084 \left[\frac{(385)^2 - P_2^2}{27.96} \right]^{0.51} (19.188)^{2.53}$$

Or, $46.017 = \left[148225 - P_2^2 \right]^{0.51}$

Or, $1822.3156 = 148225 - P_2^2$

Or, $P_2^2 = 146402.6844$

Or, P_2 = 382.62 psia = (382.62-14.7) psig =368 psig.