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A
Report
On

CITY GAS DISTRIBUTION FOR HARIDWAR CITY

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in
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Under the guidance of

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CERTIFICATE

This is to certify that the thesis titled **"City Gas Distribution for Haridwar City"** submitted by **Nishshesh Singh (R900211021)**, **Vivek Saini (R900211031)** and **Pranshu Gupta (R900211052)** to the University of Petroleum & Energy Studies, for the award of the degree of **BACHELOR OF TECHNOLOGY** in Chemical Engineering with specialization in Refining & Petrochemicals is a bonafide record of project work carried out by them under my supervision.

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Date:_______________

NOMENCLATURE

$P_{standard}$	=	Standard pressure in bar
$Q_{standard}$	=	Standard flow rate m^3/hr
P_{actual}	=	Actual pressure in bar
Q_{actual}	=	Actual flow rate in m^3/hr
T_{actual}	=	Actual temperature ^oC
$T_{standard}$	=	Standard temperature ^oC
T_{pc}	=	Pseudo Critical Temperature ^oR
P_{pc}	=	Pseudo Critical Pressure psi
T_{pr}	=	Pseudo Reduced Temperature ^oR
P_{pr}	=	Pseudo Reduced Pressure psi
Z	=	Compressibility Factor
E	=	Weld joint factor
S	=	Allowable stress
A	=	Area of pipe in m^3
u	=	Velocity of gas m/s
d	=	Diameter of pipe in inch
e	=	Pipe roughness value
ΛP	=	Pressure loss in pipeline Pa
t	=	Wall thickness, inch
T	=	Temperature deration factor
K	=	Loss coefficient
F	=	Design factor
E	=	Longitudinal joint factor
d_o	=	Nominal outside diameter of pipe
e_o	=	Nominal wall thickness of pipe
K_k	=	Pipe constant
J_k	=	Jacobian matrix

P	=	Final Value of Population
P_o	=	Initial Value of Population
r	=	Growth Rate
t	=	Time Period
L	=	Vector of loads at the load nodes
A_1	=	Reduced branch-nodal incidence matrix
B	=	Branch-loop incidence matrix
CGD	=	City Gas Distribution
LNG	=	Liquefied Natural Gas
CGS	=	City Gate Station
SR	=	Service Regulator
CNG	=	Compressed Natural Gas
DRS	=	District Regulatory station.
GI	=	Galvanized Iron.
PE	=	Polyethylene
BCM	=	Billion cubic meter.
HDPE	=	High Density Polyethylene.
LPG	=	Liquefied Petroleum Gas
MDPE	=	Medium Density Polyethylene
MMSCMD	=	Million Metric Standard Cubic Meter per day
MRS	=	Meter regulating station
MAOP	=	Maximum Allowable Operating Pressure.
NG	=	Natural Gas
PNG	=	Piped Natural Gas
PNGRB	=	Petroleum and Natural Gas Regulatory Board
SCMD	=	Standard Cubic meter per day
SCMH	=	Standard Cubic Meter per Hour.
SDR	=	Standard Dimension Ratio
MRS	=	Minimum Required Strength

ABSTRACT

There has been a growing concern in today's world for the availability of primary commercial energy sources to meet any country's growth imperatives. The continuous increase in costs and pollution by petroleum products have forced customers to find a replacement for existing fuels. These consequences have been found to be overcome by Natural Gas. In India, various cities in different states have already implemented City Gas Distribution system and it is found to catch a great pace in other states of the country in upcoming years. Various segments such as Domestic, Commercial Transport and Industrial are being supplied Piped Natural Gas (PNG) and Compressed Natural Gas (CNG) respectively as a clean fuel. This project is concerned with the infrastructure of City Gas Distribution in order to determine the Gas Flow and carry out the required Pressure Calculation in a particular gas network. It focuses on the fundamentals of pipe selection codes and standards and also the methods used for selecting and solving the gas networks. The project includes design calculations for a Natural Gas Cross Country pipeline along with the materials specifications for City Gas Distribution network and Virtual Simulation Calculations for CGD network in Haridwar.

Natural Gas demand analysis for Haridwar City is performed along with Network Analysis for Low Pressure pipeline for balancing the withdrawal (distribution) flow and pressures.

Keywords: City Gas Distribution, Natural Gas, PNG, CNG, Virtual Simulation, Network Analysis

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER -1 INTRODUCTION

1.1 INTRODUCTION

Our economy is growing at a brisk rate of around 9% and is projected to become the second largest economy of the world by 2050 as per a report by **Goldman Sachs**. Such growth requires a corresponding increase in sources of energy as well as in supply infrastructure. Until the recent past, the focus had been primarily on exploiting oil reserves. The quest for oil and lack of transmission and distribution infrastructure for transportation of Natural Gas the immense scope offered by it has been largely marginalized. Gas utilization was limited to few sectors only i.e. power and fertilizer respectively. The increasing crude prices and simultaneously depleting oil reserves have diverted attention towards gas globally. [3]

In India, the use of Natural Gas has lagged behind comparatively to other countries and this is only due to government monopoly over Natural Gas distribution through GAIL. Due to this monopoly, gas fields in India are underdeveloped and Natural Gas is under used in all segments of economic activity. But with the growing concern about environmental aspect Government of India started CNG rollouts in cities suffering from increasing pollution. The CNG demand got a boost with the Supreme Court directive on pollution reduction in 12 major cities in India and hence provided a platform to a highly ambitious sector of City Gas Distribution in cities like Delhi. Mumbai, Surat, Lucknow etc. Various organizations like GAIL, IOCL, BPCL, and GGCL entered into this sector by forming JVs with other players and provided the sector the necessary thrust it deserves. The CGD network caters to the supply of Piped Natural Gas (PNG) to domestic Households (HH) & small commercial/industrial establishments & CNG to automobile sector. Considering CGD as the last milestone of Indian gas chain lot of efforts has been done by various players and GOI to ensure last mile connectivity of gas which has been substantial in the current decade. [14]

With the introduction of PSUs in all of the sectors of the Indian gas chain the gas chain has become more structured and organized. Currently major oil PSUs like Indian Oil Corporation Ltd, Bharat Petroleum Corp. Ltd and Hindustan Petroleum Corp. Ltd are providing substantial support in all parts of the gas chain with the formation of JVS like Green Gas Ltd (GGL) in Lucknow & Agra, Indraprastha Gas Ltd (IGL) in Delhi-NCR etc. With a vision to empower most of the cities and the citizens by providing access to natural gas oil PSUs are coming up with more plans on CGD network development.

The demand pattern (Gas) zeroed by the Ministry of Petroleum and Natural Gas in its Draft Paper on Utilization of Natural Gas-2007 for CGD network classifies the consumers of Natural Gas via CGD network into different categories based on their capacity and end use [17]. They are broadly classified as:

Types of Consumer Description

1. **Domestic consumers:** Consumers demanding NG for cooking as well as for heating water etc.

2. **Transport Sector**: Transport Sector need NG for the transportation purpose and catered through the development of Compressed Natural Gas stations network.

3. **Commercial consumers:** While Hotels, Restaurants, Sweetshops, Hospitals, Offices etc. would primarily require gas for the Cooking and Hot Water requirement, there are large number of applications within such segments that can use gas.

4. **Industrial consumers**: Industrial Consumers are classified in two primary categories, the Large Scale Industries (LSI) & Medium & Small Scale Industries

1.2 OBJECTIVES

The main objectives of this project is to develop a City Gas Distribution network for Haridwar City using the following steps stated below:-

1. Gas demand Calculation for upcoming 35 years.
2. Piping route in Haridwar
3. Design of Steel and MDPE pipeline
4. Pressure and flow rates calculation at nodes of pipeline using steady state and low pressure compressible fluid equation.
5. Network Analysis with Newton Nodal Method, Newton Loop Method and Newton Loop-Node Method

1.3 PNGRB ACT [18]

PETROLEUM AND NATURAL GAS REGULATORY BOARD

It is an act used to regulate the processing, storage, transportation, refining, distribution, marketing and sale of petroleum, petroleum products and natural gas excluding production of crude oil and natural gas so as to protect the interests of entities engaged in specified activities relating to petroleum, petroleum products and natural gas to ensure uninterrupted and adequate supply in all parts of the country and to promote competitive markets.

Functions of PNGRB:-

1. Register all entities for marketing natural gas by establishing and operating Liquefied Natural Gas (LNG) terminals, establishing storage terminals, permitting entities to lay, build, operate, or expand a common or contract carrier, and city or local distribution networks.

2. Declare pipelines as common or contract carriers and regulate access to such carriers, thereby ensuring fair trade and competition among various entities.

3. Enforce retail and marketing service obligations and problems.

4. Monitor price of petroleum products along with natural gas and ensure enough availability and equal distribution.

5. Prevent restrictive trade practice, maintains a data base of information and lay down technical specifications including safety standard.

6. The PNGRB act provides for first right by use of entity laying, building, operating or expanding pipeline for transportation, provided such an entity is not engaged in the marketing of natural gas.

7. Entities which are engaged in marketing of natural gas, and the laying, building, operating or expanding a pipeline for transportation of natural gas, needs to compensate with an affiliate code of conduct.

8. All disputes between various entities and persons involved with any of the downstream activity is defined by the PNGRB act will be settled by PNGRB.

9. The government has retained the power to issue direction and intervene in matter relating to issue that might adversely affect public interest or those related to the nation sovereignty or its foreign relation.

1.4 NATURAL GAS [2]

Natural Gas is very important component of the world's supply of energy. It is one of the cleanest, safest and most useful of all energy sources. The information mentioned below explains about natural gas, what exactly it is, how it is formed and how it is found in nature. Natural Gas is gaseous fossil fuel which consists primarily of Methane an also some other heavier gaseous hydrocarbon namely, Ethane, Propane, Butane etc. Sometime Nitrogen, Helium, Carbon Dioxide, traces of Hydrogen Sulfide and water is also present in the same. Mercury is also present in small field. The exact composition of Natural Gas varies between gas fields.

Table 1.1: Composition of Natural Gas [2]

S.NO.	NAME OF CONSTITUENT	CHEMICAL FORMULA	PERCENTAGE
1	Methane	CH4	70- 90
2	Ethane	C2H6	0-20
3	Propane	C3H8	0-20
4	Butane	C4H10	0-20
5	Carbon Dioxide	CO2	0-8
6	Oxygen	O2	0-2
7	Nitrogen	N2	0-5
8	Hydrogen Sulphide	H2S	0-5
9	Rare Gases	A, He, Ne, Xe	TRACES

Properties of Natural Gas:-

The properties of natural gas are as follows:

1. Natural Gas is colourless, odourless and is clean gas.
2. It is lighter than air so tends to dissipate.
3. Property of natural gas vary with the composition of gas.
4. Explosive concern of CNG are almost non-existent.
5. Processed natural gas is harmless to human body.

Physical Properties

Table 1.2:- Physical Properties of Natural Gas [2]

S.NO.	PROPERTIES	DESCRIPTION
1	Appearances	Clear gas, burns with blue flame
2	Density and Phase	0.717 kg/m^3 ; Gaseous state
3	Boiling Point	-161.6 degree Celsius
4	Flash Point	-188 degree Celsius
5	Explosive limit	5-15% in air
6	Flash Temperature	2148 degree Celsius
7	Auto ignition Temperature	1100 degree F

Sources- Natural Gas:

Basically there are two types of sources of natural gas:

1. Conventional Sources
2. Unconventional Sources

Conventional Sources: - There are two types of sources in this category-

Non-Associated Gas: - Non associated gas are sometimes also called as “Gas well gas” which is produced from geological formation that typically do not contain much higher hydrocarbon than Methane. Non associated gas can contain hydrocarbon gas such as carbon dioxide, hydrogen sulphide etc. The reservoir of Non-Associated Gas that contains only gas but no oil. It may be dry and wet.

Associated Natural Gas: -Natural gas is mostly found dissolved in oil at the high pressure existing in a reservoir and it may be present as a Gas Cap above the oil. Natural Gas available from such source is known as Associated Gas. An associated gas may contain heavier fraction (Ethane& Higher Hydrocarbons) with respect to non-associated gas.

Unconventional Sources:-

1. **Deep Natural Gas: -** Deep natural gas is exactly what it name like – natural gas that exist in deposits very far underground, beyond conventional drilling depths. This gas is typically 15,000 feet or deeper underground, quite a bit deeper than conventional gas deposits which are traditionally only a few thousand feet deep. Deep gas is still more expensive to produce than conventional natural gas, and as for such reason, economic conditions have to be such that it is profitable for the industry to extract from these sources.

2. **Tight Natural Gas: -**Yet another form of unconventional natural gas is referred to as tight gas .This gas is stuck in a very tight formation underground, trapped in unusually impermeable, hard rock, or in a sandstone or limestone formation that is unusually impermeable and non-porous (tight sand).

3. **Shale Gas: -**Shale is typically a very fine- grained sedimentary rock, which is easily breakable into thin, parallel layers. It is a very soft rock, but does not disintegrate when it becomes wet. Shale formations act as both a source of gas and as its reservoir.

   Natural Gas is stored in a shale in three forms: free gas in rock pores, free gas in natural fractures and adsorbed gas on organic matters and mineral surfaces. These different storage mechanisms affect the speed and efficiency of gas production.

4. **Coal Bed Methane: -** Coal is another fossil fuel which is formed underground under similar geologic conditions as natural gas and oil. Many coal seams also contain natural gas, either within the seam itself or the surrounding rock. Coal bed methane has always been considered a nuisance in the coal mining industry. Once a mine built and coal is extracted, the methane contained usually leaks out into the coal mine itself.

   This possesses a safety threat, as if here is too high concentration of methane in the well create dangerous conditions for coal miners. However coal bed methane has become a popular unconventional form of natural gas. This methane is extracted and injected into natural gas pipelines for resale, used as an industrial feedstock or used for heating and electricity generation.

5. **Geo Pressurized Zones: -** Geo Pressurized zones are natural underground formations that are under unusually high pressure for their depth. These areas are formed by layers of clay that are deposited and compacted very quickly on top of more porous, absorbent material such as sand or silt. This natural gas, due to the compression of the clay, it is deposited in this sand or silt under very high pressure (hence the term 'geopressure').

   Geo Pressurized zones are typically located at great depth, usually 10,000-25,000 feet below the surface of the earth. The combination of all of these factors which are mentioned makes the extraction of natural gas in geo pressurized zones are estimated to hold the greatest amount of gas.

6 Methane Hydrates: - Methane hydrates are the most recent form of unconventional natural gas to be discovered and researched. These interesting formations are made up of a lattice of frozen water, which forms a sort of 'cage 'around molecules of methane.

These hydrates look like melting snow and were first discovered in permafrost regions of the Arctic. However, research into methane hydrates has revealed that they may be much more plentiful than first expected. However, research into methane hydrates is still in its infancy. It is not known what kind of effects the extraction of methane hydrates may have on the natural carbon cycle.

Natural Gas is considered dry when it contains almost pure Methane and it is wet when other impurities are present. Natural Gas is sweet when sulphur content is very low and it the sulphur content is high then it is called sour.

CHAPTER: -2 LITERATURE REVIEW

2.1 LITERATURE REVIEW

Supply Scenario

Supply of gas has always been a constraint for the development of CGD business. This sector has always been neglected as the distribution of gas has been prioritized. At the end of 2007 the total proven reserves of natural gas was about 1645 billion cubic meters (bcm) which is about 0.6% of the total reserve worldwide. According to an estimation with the current production level, India's reserve are likely to last for around 30 years, but at the same time the world reserve would last for 67 years. ONGC accounts for 60% of these reserves with 990 bcm gas, while Oil India Limited (OIL) accounts for another 10% with 170 bcm and other private players and joint ventures accounts for 30% with about 483 bcm. Of the total supply of gas, offshore fields contribute 72% and onshore fields contribute 28%. In the last five years the supply of gas has risen by 35% that is form 84 MMSCMD per day during 2003-04 to 114 MMSCMD during 2007-08.[3]

Domestic Production

In India there was a boom during the period between 1980 to 1996, during this period the gas production grew to ten times that is from 2.36 bcm to 22.64 bcm and this was because of the flaring of gas during that period was reduced to 68.5% at one go. During the period of 1997- 2007 the overall annual growth rate remained stagnant because the flaring was almost constant. The utilization rate has increased from 93.7% in 1995-96 to about 97.2% in 2005-06. Due to the emphasis being laid on a cleaner environment and lower pollution levels in cities, CGD is expected to get a push in the coming years. Thus, apart from GAIL, a few players have drawn up ambitious plans to roll out city gas infrastructure across a number of cities in the country. States which are likely to see further activity include Uttar Pradesh, Maharashtra, Andhra Pradesh, Rajasthan, Karnataka, Kerala, Madhya Pradesh and West Bengal. The main driver for the development of gas transmission and CGD shall be the availability of requisite volumes of gas. The development of RIL's KG Basin and other fields has provided some opportunities but the challenge is whether the CGD license-holders can obtain gas supplies and develop gas distribution infrastructure. [4]

Table 2.1: Chronological movement of CGD market in India [3]

Year	City	Company
1880	Calcutta	Calcutta Gas company
1900	Mumbai	Bombay Gas Company
1972	Vadodara	Vadodara Municipal
1980	Delhi	Delhi Municipal Corporation
1982	ONGC colony – Mehsana ,	ONGC
1985	Duliajan	Assam gas company
1986	Sibasagar	Assam gas company
1989	Surat, Ankleshwar, Bharauch	Gujarat Gas Company Ltd.
1994	Mumbai	Mahanagar Gas ltd.
1995	Delhi	Indraprastha Gas
2004	Vadodara, Ahmedabad	Adani
2005	Hyderabad	Bhagayanagar gas
2006	Kanpur, Lucknow	CUGL & GGL
2006	Gandhinagar , Kadi, Mehasana, Rajkot,	GSPC/ SGL

Few years ago CGD was limited to only Mumbai and Delhi, but today we have 25 cities where the infrastructure for CGD has been developed. Some of the major cities are Delhi, Mumbai, Ankleshwar, Baruch and Surat, Vadodara, Agartala, Vijaywada, etc. For the year 2007-08 CGD contributed 7% of the total gas demand in India.

The demand was 12.08 MMSCMD. Gujarat as a state is the largest consumer of CGD with a consumption of 5.57 MMSCMD which is about 55% of the total consumption of CGD. Delhi and Mumbai are the next two largest consumers with 2.3 MMSCMD and 2 MMSCMD respectively. The total consumption was consumed by 509000 vehicles through over 375 CNG station, about 645000 domestic consumers, 1300 industrial and 4000 commercial customer. The penetration of CGD has been limited as currently CNG is distributed through only 1% of the total 35000 retail outlets of other transport fuels. [4]

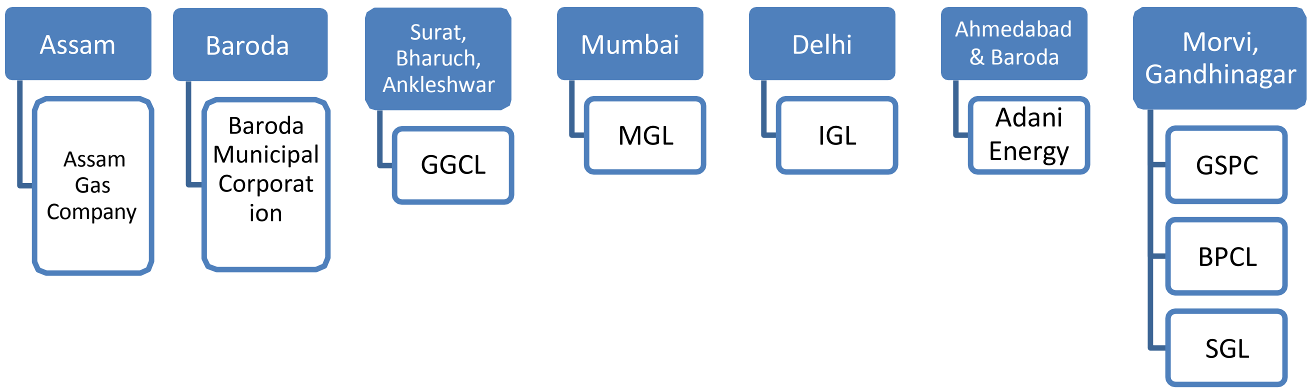


Figure 2.1: CGD's in India [3]

Table 2.2:- Consumption pattern of CNG in different sectors for different cities [3]

Location	Company	MMSCMD	CNG Vehicles	Domestic	Industrial	Commercial
Delhi	IGL	2.3	134608	107487	-	400
Vadodara	GAIL	0.021	3222	-	-	-
Vadodara	GAEL	0.075	75000	-	70	-
Ahmedabad	GAEL	0.45	43500	20000	220	200
Surat, Ankleshwa	GGCL	4	50000	200000	800	2500
Gujarat	GSPC Gas	1.025	-	20813	230	55
Mumbai	MGL	2	179720	297163	40	882
Lucknow	CUGL	0.056	8290	-	-	-
Kanpur	CUGL	0.01	7400	400	-	-
Agra	GGL	0.0249	4048	-	-	-
Agartala	TNGCL	0.0001	41	-	-	-
Vijayawada	BGL	0.012	2000	-	-	-
Hyderabad	BGL	0.0076	1700	-	-	-
Total		**9.9816**	**509529**	**645863**	**1360**	**4037**

Source: India Infrastructure Report

In order to find the most suitable way to analyze the gas piping network in a systematic manner the concept of steady state compressible flow and method of loop type network analysis is done. The compressibility of a fluid is basically a measure of change in density that will be produced in the fluid by a specified change in pressure. Gases are more compressible than liquids and in a fluid flow there are changes in pressure associated as in case of velocity changes in the flow. These pressure changes will induce density changes which will have influence on the flow i.e. the compressibility of the fluid involved will be having influence on the flow. Flow equations are required to calculate the pressure drop in the gas network. There are number of flow equations that can be used in gas industry but they are capable to a limited range of flow and pipe surface conditions. [1]

Table 2.3: Guidelines for the selection of flow equations [1]

Pressure Range (bar gauge)	Type of Flow	Equation
High pressure (main supply) > 7.0	Partially turbulent	Panhandle A $$Q = 7.57 \times 10^{-4} \frac{T_n}{P_n} \sqrt{\frac{(p_1^2 - p_2^2)D^5}{fSLTZ}}$$
High pressure (main supply) > 7.0	Fully turbulent	Weymouth $$Q = 11854124.6 \frac{T_n}{P_n} D^{8/3} \sqrt{\frac{(p_1^2 - p_2^2)}{SLT}}$$
Medium and high pressure (distribution) > 7.0	Partially turbulent	Panhandle A $$Q = 7.57 \times 10^{-4} \frac{T_n}{P_n} \sqrt{\frac{(p_1^2 - p_2^2)D^5}{fSLTZ}}$$

Medium and high pressure (distribution) > 7.0	Partially turbulent	Weymouth $$Q = 11854124.6 \frac{T_n}{P_n} D^{8/3} \sqrt{\frac{(p_1^2 - p_2^2)}{SLT}}$$
Medium and high pressure (distribution) 0.75 – 7.0	Partially turbulent	Cox's $$Q = 1.69 \times 10^{-3} \sqrt{\frac{(p_1^2 - p_2^2)D^5}{SL}}$$
Low pressure (distribution) 0 – 0.075	Partially turbulent	Lacey's $$Q = 7.1 \times 10^{-3} \sqrt{\frac{(p_1 - p_2)D^5}{SL}}$$

Table 2.4: K Value Calculation [1]

Equation	K value calculation
Lacey's	$K = 11.7 \times 10^3 \frac{L}{D^5}$
Cox's	$K = 206.22527 \times 10^3 \frac{L}{D^5}$
Panhandle A	$K = 18.43 \frac{L}{E^2 D^{4.854}}$
Weymouth	$K = 2590000 \frac{L}{D^{16/3}}$

Note:-There is no friction factor for Weymouth, Cox's and Lacey's equation. The specific gravity of gas is assumed to be 0.589. This specific gravity value is subjected to change depending on the properties of natural gas. The temperature and pressure is assumed as standard pressure, normally used by international gas users in doing network analysis

CHAPTER 3: - CITY GAS DISTRIBUTION

3.1 INTRODUCTION

In a City Gas Distribution system distribution of CNG & PNG is being sold to various segments by interconnecting gas pipeline & related equipment. In a CGD system, high pressure steel pipeline is being laid across various areas of city. City Gas Distribution (CGD) project present a huge amount of investment opportunity to prospective investors with expected increase in gas supply, changing regulatory scenario and growing concern over pollution in cities due to traditional fossil fuels. The two major factors that will enhance this growth are increase in domestic gas production and the development of infrastructure respectively, both at local and cross-country level. The growth in city gas distribution will be further pushed by market factors and also by environmental activism. However, to capture this opportunity developers need to analyze several critical aspects of the project in terms of supply, demand, cost, project, market, price scenario and risk factors. In city gas distribution networks there is a requirement for local involvement of state/local government and citizens in order for the successful completion of project. In order to encourage supply of CNG for transport sector and PNG for household sector the **Ministry of Petroleum & Natural Gas** (MoP&NG) has finalized '**Vision-2015**'of the oil sector for 'Consumer Satisfaction and Beyond' ,wherein 20 cities are to be provided CNG within the year 2015. The city gas distribution accounts for **4** to **6 MMSCMD** in the country. It is assumed to increase up to an amazing **20** MMSCMD in the next three years. CGD is increasing at a fast rate in India for the usage of PNG for the domestic, commercial, industrial and CNG for transportation. In order to drive this growth two factors need to be implemented which are increase in gas production and the development of the infrastructure. [5]

3.2 CNG & PNG

3.2.1 Compressed Natural Gas (CNG)

CNG mainly contains methane which is compressed up to **250 bar** for using it as a vehicular fuel in vehicles running on CNG kits. It has a Research Octane Number in excess of 120. The excellent knock resisting property of CNG allows for use of a higher compression ratio resulting in an increased power output and greater fuel economy when compared to petrol. CNG can be used in engine with a compression ratio as high as **12:1** compared to normal gasoline (**7.5:1** to **10:1).** At this high compression ratio, natural gas-fueled engines have higher thermal efficiencies than those fuelled by gasoline .The fuel efficiency of CNG driven engines is about **10-20%** better than diesel engines

Benefits of using CNG:

1. **Green Fuel: -** Commonly referred to as the green fuel because of its lead and sulphur free character, CNG reduces harmful emissions. Being non-corrosive, it enhances the longevity of spark plugs. Due to the absence of any lead or benzene content in CNG, the lead fouling of spark plugs and lead or benzene pollution are eliminated.

2. **Increased Life of Fuel: -** Another practical advantage observed is the increased life of lubricating oils, as CNG does not contaminate and dilute the crankcase oil.

3. **Mixes Evenly in Air: -** Being a gaseous fuel CNG mixes in the air easily and evenly.

4. **Safety: -** CNG is less likely to auto-ignite on hot surfaces, since it has a high auto-ignition temperature (540^0C) and a narrow range (5%-15%) of inflammability. It means that if CNG concentration in the air is below 5% or above 15% it will not burn. This high ignition temperature and limited flammability range makes accidental ignition or combustion very unlikely.

5. **Low Operational Cost: -**The operational cost of vehicles running on CNG, as compared to those running on other fuels, is significantly low. At the prevailing price of fuel in Gujarat, operational cost of CNG vehicles is **68%** lower than petrol and **36%** lower than diesel.

Advantages of CNG over other fuels

- No impurities, no sulphur (S), no lead (Pb).
- Very low levels of polluting gaseous emissions without smell and dust.
- Molecular structure compactness prevents the reactive processes which lead to the formation of Ozone (O_3) in the troposphere.

Safety Point of View

- It is lighter than air-in case of leak no dangerous puddles.
- Unlikely to ignite due to:
  - High ignition temperature
  - Narrow range of ignition
- Due to it lower injury and death rate per vehicle mile
- All CNG cylinders are structurally sounder and have passed every severe tests.

Technical aspects of CNG

- Very high antiknock power (more than 120 ON) allows greater performance compared to petrol.
- It does not require refining plant or additive adding and be used immediately after its extraction.
- It has no evaporation leaks and spills of fuel, both during refueling and feeding of the car.

Its combustion produces a very low quantity of carbon deposits (permits a longer life of lubricant oil, spark plug, and piston drum, valves & other component)

3.2.2 Piped Natural Gas (PNG)

When natural gas is supplied through the **GI/Cu** pipes for domestic and commercial users then we call it Piped Natural Gas (PNG). PNG is supplied through MDPE pipeline from District Regulating Station (DRS) with pressure range **1-4** bar (g).

PNG is a reliable and convenient fuel due to following reasons

- Continuous supply of gas.
- There is negligible delivery problem.
- The payment is done after generation of bill at the end of each scheduled time period.
- Because it contains 94% combustible material it doesn't leave any residue.
- It does not make vessel dark.
- It contribute to a cleaner society.

Applications of PNG

- Used for cooking purpose.
- Used for heating/furnace purpose.
- Used in hotels, restaurants, for cooking purpose.
- Used in industries.

3.3 MAJOR COMPONENTS OF CITY GAS DISTRIBUTION

Setting up of a CGD network is a big task in itself in terms of management of public private interest. It is not only a matter of distribution and marketing of the product it is also about creating a feeling of security in the mind of prospective customers. PNGRB board has provided the guidelines in the form of its "*Draft Paper on Access Codes*" which has clearly mentioned the responsibilities associated with the transporter and shipper making things more clearly too both parties.

The essential elements of a CGD network are:

1. City Gate Station (CGS)
2. Odourization Unit
3. District Regulating Station (DRS)
4. Service Regulator (SR)
5. Gas metering system
6. Pipe Line System and CNG system.

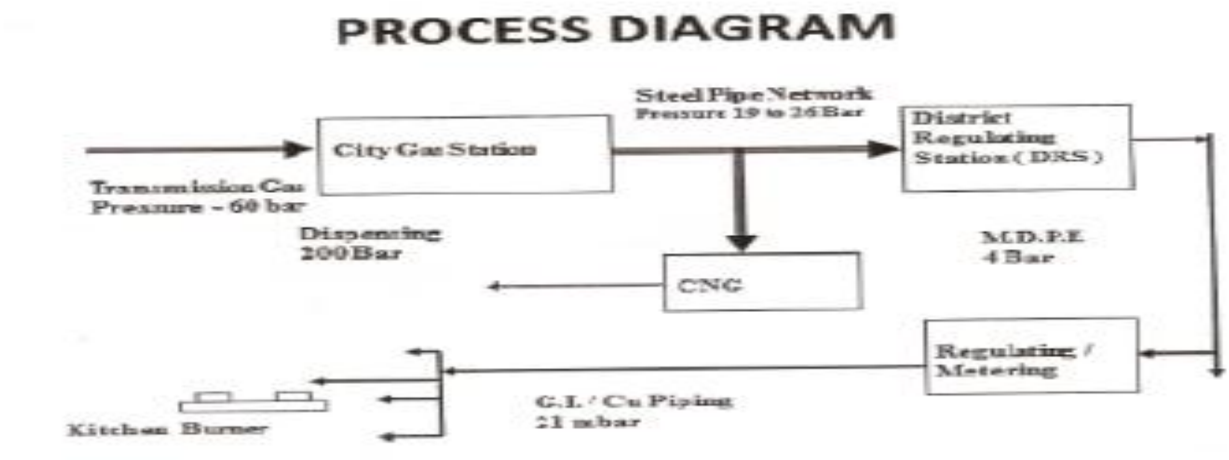


Figure 3.1: CGD Distribution Network [3]

All of the above mentioned facilities are directly related to each other and thus have a deep impact on the functioning of the whole CGD network. As far as the cost is concerned the establishment of these fundamental facilities bring major cash outflow to the distribution company. The networking is defined as:

1. **City Gate Station (CGS):**

   A city gate station is a place, mainly established at a tap-off point of high pressure transmission pipeline; from where we get gas inside the city via pipelines. The gas delivered at this point is at higher pressure i.e. greater than **40** bar. Once gas enters to CGS unit its pressure is reduced to around **25-30** bar. City Gate Stations are composed of a complex array of valves, pipes, and pressure reduction devices designed to meter the gas and reduce its pressure so that it can be delivered safely to customers through distribution. A city gate station consists of various skids for different purposes such as: -

   Filtration Skid: - Gas enters in the knock out drum which is in shape of a vertical cylinder all the dust particle and liquid coming with the gas stream are separated by high efficient filters. Gas is maintained at same pressure from the inlet to the filtration skid. After the filtration two streams are divided from the main line using a header. Line which is in function is known as active line where another one is called passive line.

   Pressure Reduction Unit: - A pressure reduction valve is installed for the reduction of the gas stream pressure from 40- 45 bars to 25-30 bars. Creep relief valve and Slam Shut off valve is being installed in this skid for the safety purpose.

   Metering Skid: -Metering skid is installed for the gas flow measurement. Orifice meter is used in this metering skid; because of the large pressure drop requirement. The various parameters such as temperature in the various sections of the line pressure at the inlet and outlet joints, flow inlet & outlet are monitored by the SCADA systems in the control room.

2. **Odourization Unit: -**As the natural gas is odourless, Ethyl Mercaptan is being added in natural gas. An odourization unit is installed for addition of ethyl mercaptan in the gas stream. The dozing unit of the ethyl mercaptan should be of 9 mg/m^3 .This unit consists of mainly two cylinders of capacity of 160 kg, pneumatic panel, level indicator and a filter. This unit is directly connected to metering.

3. **District Regulating Station (DRS):** "Distribution Pressure Regulating Station or District Regulating Station (DPRS)" means a station located within authorized area for CGD network having isolation, metering, pressure regulating and overpressure protection devices.

4. **Service Regulator (SR):** It reduces the gas pressure from 4 BAR to 100 mbar and ensures the flow of gas at constant pressure at all time. It is being installed before tertiary PE lines, generally located at customer premises for maintaining supply pressure and designed to maintain safe condition even in the event of rupture in the regulating downstream section. It reduces the pressure from **4** bar to **100** mbar to the service device. These regulators' maintain the required maximum and minimum pressure with the shut off device. The types of regulators that are used generally depend upon the number of connection, Various types of service regulators available are listed below:

Table 3.1:- Types of Service Regulators [3]

S.N	Type	Flow Rate	Maximum Capacity
1	B-6	6 m^3/ hr	1-8 domestic connections
2	B-10 & FE-10	10 m^3/ hr	1-20 domestic connections
3	B-25 & FE-25	25 m^3/ hr	1-30 domestic connections
4	B-50 & FE-50	50 m^3/ hr	1-75 domestic connections

5. **Metering Skid: -** Installed before the meter, the meter regulator reduces the gas pressure from **100** mbar to **21** mbar. Meters are the important part of City Gas Distribution. It gives the database about the amount of gas sold to the customer. Billing of gas is usually done based on the standard conditions i.e. SCM. Meters are used based on type of the customer and his requirements. Meter used for the domestic customer is usually diaphragm meter, which is having a flow range of 0.017 to 2.6 m^3/hr having a maximum operating pressure of 0.1 bar. Mainly PD/RPD/Turbine meter is being used for commercial & industrial customers.

Selection of Meters:

Following criteria shall be considered for the selection of meters:

- Rangeabiltiy or Turndown ratio.
- Accuracy required.
- Suitability of meter or quality of gas available.
- Pressure requirement.
- Calibration and maintenance requirement.
- Size and weight.
- Installation and maintenance constraint.
- Operability
- Cost

Turn down Ratio: - It is a flow measurement term which indicates the range of a specific flow meter that is able to measure with acceptable accuracy. It is also called Rangeabiltiy. It is significant when choosing flow meter machinery for a specification.

Table 3.2: - Types of Meters [3]

S. N	Type of Meter	Working Pressure(l	Flow Range (m^3/hr)	Turn Down Ratio	Type of Customer	Limitations
1	Diaphragm Meter	0-0.2	0.016-30	80:1	Domestic Commercial and Small scale industry	▪ Bigger Sized ▪ Expensive for high flow. ▪ No pressure & temperature compensation
2	Rotary Positive Displacement	0-16	30-1000	10:1-80:1	Commercial and Industrial only	Requires ▪ 50 micron filtration gas quality ▪ Lubrication maintenance
3	Orifice Meter with Single transmitter	1.5	200	3:1	Large industrial Customers	▪ Inaccuracies ▪ Regular Calibration. ▪ Long strait Length of pipe
4	Orifice meter with Double transmitter	1.5	200	3:1	Bulk Customers and Transportation	▪ Inaccuracies ▪ Regular Calibration. ▪ Long strait length of pipe
5	Turbine meters	2	500	10:1	Large industrial customers	▪ High cost gas Quality
6	Ultrasonic meters	7	1500	50:1	Bulk Customers and Transportation	

Table 3.3: - Standard recommended for Pipelines [3]

S.N	STANDARD CODE	STANDARD SPECIFICATION
1	IGE/CL/1	Planning of gas distribution system of MAOP not exceeding 16 bar
2	IGE/TD/3	Steel & PE pipelines for gas distribution
3	IGE/TD/4	Gas Services
4	IGE/TD/12	Pipework stress analysis for gas industry plant
5	IGE/TD/13	Pressure regulating installations for transmission and distribution system
6	IGE/TD/18	Safe working practice to ensure the integrity of gas pipelines & associated installations
7	IGE/TD/22	Purging operations for fuel gases in Transmission, Distribution of storage
8	IGE/TD/23	Venting of Natural Gas
9	IGE/TD/25	Hazardous area classification of Natural Gas Installation
10	ASME B31.8	Gas supply MoP over 16 bar
11	API 5L	Specification of line pipe

3.4 CNG DISTRIBUTION SYSTEM

CNG STATION:

A CNG station in an establishment where CNG filling is done in vehicles running on CNG kits.

Main components of a CNG station are:

- Compressor- To compress the gas up to a certain pressure.
- Cascade- For storage of the compressed gas.
- Dispenser- For dispensing the compressed gas.

Types of CNG stations: -

- **Mother Station: -** A CNG station provided with whole set up (compressors, dispensers, cascade etc.) along with a LCV filling point is known as a mother CNG station.
- **Online Station: -**This CNG station has same set up as a mother station but LCV connection is not provided for filling.
- **Daughter Booster Station: -**It is provided with the compressors (known as boosters) to compress the gas we are getting from the mother station known as daughter booster station.
- **Daughter Station: -** It is established in those areas where laying a pipeline is not possible .In that case gas is delivered from mother station to daughter station; via mobile cascade van. The gas from mother station is filled in mobile e cascade by a LCV filling point.

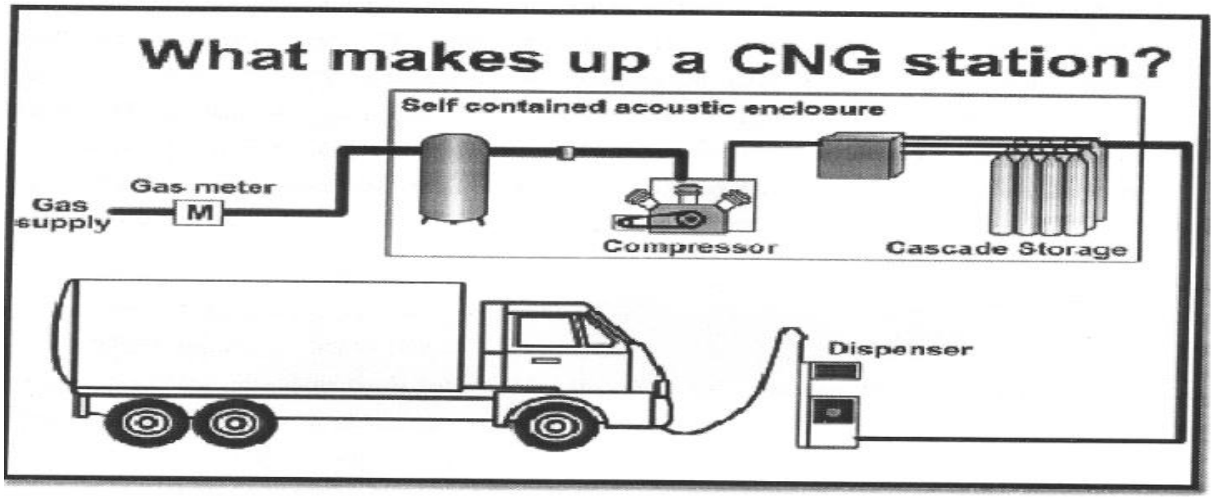


Figure 3.2:- A typical CNG station [3]

3.5 PNG DISTRIBUTION SYSTEM

Mainly there are 4 types of piping systems other than supply mains:-

1. **Feeder mains: -** Transport gas from the pressure regulator or supply main to the distribution mains. Feeder mains might also have some lines connected to large industrial users.
2. **Distribution mains: -** Supply gas primarily to residential, commercial, and smaller industrial consumers.
3. **Service lines: -** Deliver gas from the distribution main in the street to the consumer's meter. Service lines are usually the property and responsibility of the utility. However, some utilities own only the portion of the service lines in the public domain.
4. **Fuel lines**: -Customer piping beyond the meter to various appliances. These lines are the property and responsibility of the building owner.

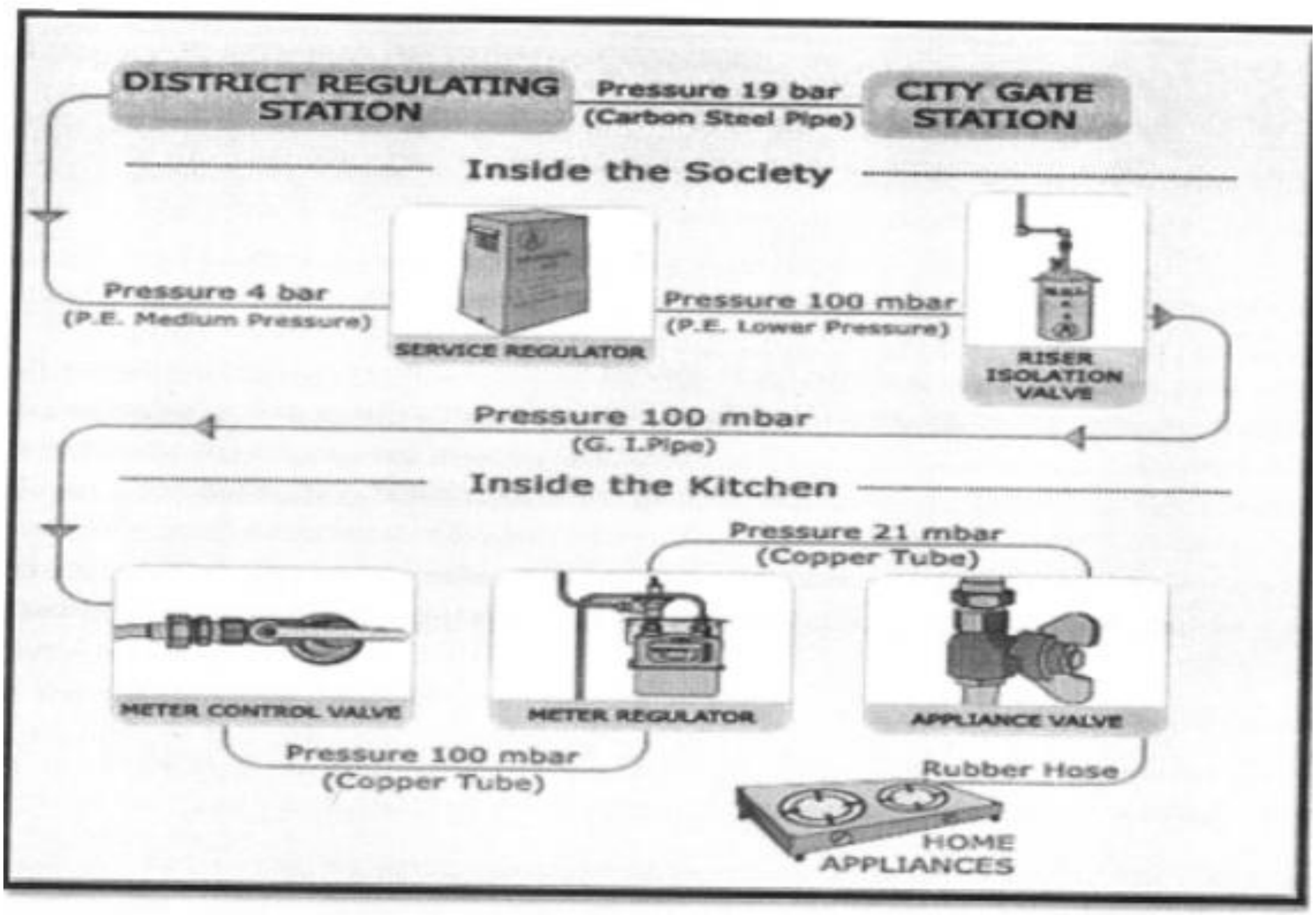


Figure 3.3: -PNG Distribution System [3]

CHAPTER 4:-

STRUCTURE OF CGD NETWORK

4.1 EXECUTIVE SUMMARY FOR HARIDWAR CGD

The project City Gas Distribution for Haridwar city covers all system requirements for the distribution system in Haridwar

Haridwar is an important pilgrimage city and municipality in the Haridwar district of Uttarakhand, India. The River Ganges, after flowing for 253 kilometers (157 mi) from its source at Gaumukh at the edge of the Gangotri Glacier, enters the Indo-Gangetic Plains of North India for the first time at Haridwar, which gave the city its ancient name, Gangadwára. Haridwar is regarded as one of the seven holiest places to Hindus. According to the Samudra Manthan Haridwar along with Ujjain, Nasik and Allahabad is one of four sites where drops of Amrit , the elixir of immortality, accidentally spilled over from the pitcher while being carried by the celestial bird Garuda. This is manifested in the Kumbha Mela being celebrated every 3 years in one of the 4 places, and thus every 12 years in Haridwar. Amidst the Kumbha Mela, millions of pilgrims, devotees, and tourists congregate in Haridwar to perform ritualistic bathing on the banks of the river Ganges to wash away their sins to attain Moksha *Brahma Kund*, the spot where the Amrit fell, is located at Har ki Pauri (literally, "footsteps of the Lord") and is considered to be the most sacred ghat of Haridwar. [5]

Haridwar is the headquarters and the largest city of the district. Today, the city is developing beyond its religious importance, with the fast developing industrial estate of State Infrastructure and Industrial Development Corporation (SIDCUL), and the close by township of Bharat Heavy Electricals Limited in Ranipur, Uttarakhand as well as its affiliated ancillaries.

Brief Description about HARIDWAR GA

- Population 175,010 (2001)
- Density 14,228 /km^2 (36,850 /sq. mi)
- Sex ratio 1.18
- Time zone IST (UTC+5:30)
- Area 12.3 square kilometers (4.7 sq. mi)
- Elevation 314 meters (1,030 ft.)

DEMOGRAPHIC:

As of 2011 India census, Haridwar district had a population of 295,213. Males constitute 54% of the population and females, 46%. Hardwar has an average literacy rate of 70%, higher than the national average of 59.5%: male literacy is 75%, and female literacy is 64%. In Hardwar, 12% of the population is under six years of age.

ECONOMY*:*

Haridwar is rapidly developing as an important industrial township of Uttarakhand since the state government agency, SIDCUL (State Infrastructure & Industrial Development Corporation of Uttrakhand Ltd.) set up the Integrated Industrial Estate in a district attracting many important industrial houses which are setting up manufacturing facilities in the area. Haridwar has a thriving industrial area situated at the bypass road, comprising mainly ancillary units to PSU, BHEL, which was established here in 1964 and currently employs over 8000 people.

Agriculture is the mainstay of this well irrigated district. Industrialization had commenced with the establishment of Central Government owned Public Sector plants (PSUs) of Hindustan Antibiotics Limited and Bharat Heavy Electricals Limited, in pre-Uttarakhand 1960s period. The State Infrastructure & Industrial Development Corporation Limited of Uttarakhand Government (SIDCUL) has now established one new ‘industrial development zone’ in the district, near Haridwar, to encourage industrialization; with industrial giants like Hindustan Lever, Dabur, Mahendra & Mahendra and Havells having moved in, it is making the desired progress. Not insignificant to the district’s economy is the contribution of Hindu pilgrims who visit the holy places and attend the religious fairs in large numbers.

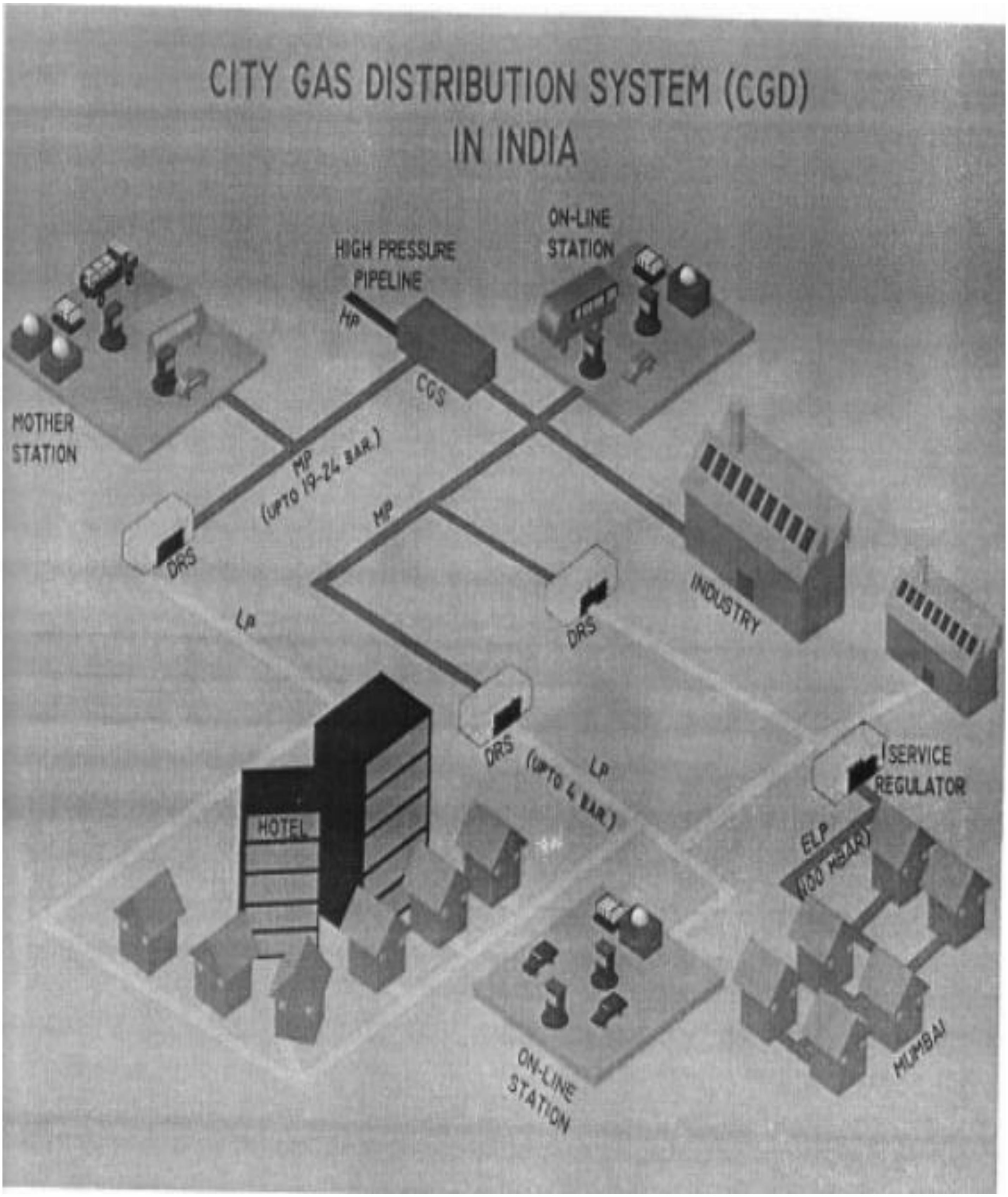


Figure 4.1: - City Gas Distribution System (CGD) in India [3]

4.2 NETWORK LAYOUT

CGD network consist primarily of three kinds of network which are as follow:

- Primary Network
- Secondary Network
- Tertiary Network

Primary Network

In primary network system all the DRS, IPRS and CNG stations are connected with city gate station through steel pipelines with the following specifications.

- Design Pressure 30- 49 kg/cm^2.
- Operating Pressure 19- 26 kg/cm^2.
- Wherever it goes outside the ground level the proper 3-LPE coating is provided over it.

The maximum velocity in this pipeline network is 30 m/s immediately after pressure regulating instrument.

Secondary Network

In secondary network system all the service regulators at commercial, industrial and domestic consumers are connected with DRS through Medium Density Polyethylene Pipeline (MDPE) with pressure range of 4 bar.

Tertiary Network

In tertiary network system the service regulators at commercial and domestic consumers are connected with Kitchen burner hose pipe through GI/Cu pipeline with pressure range 21-75 mbar.

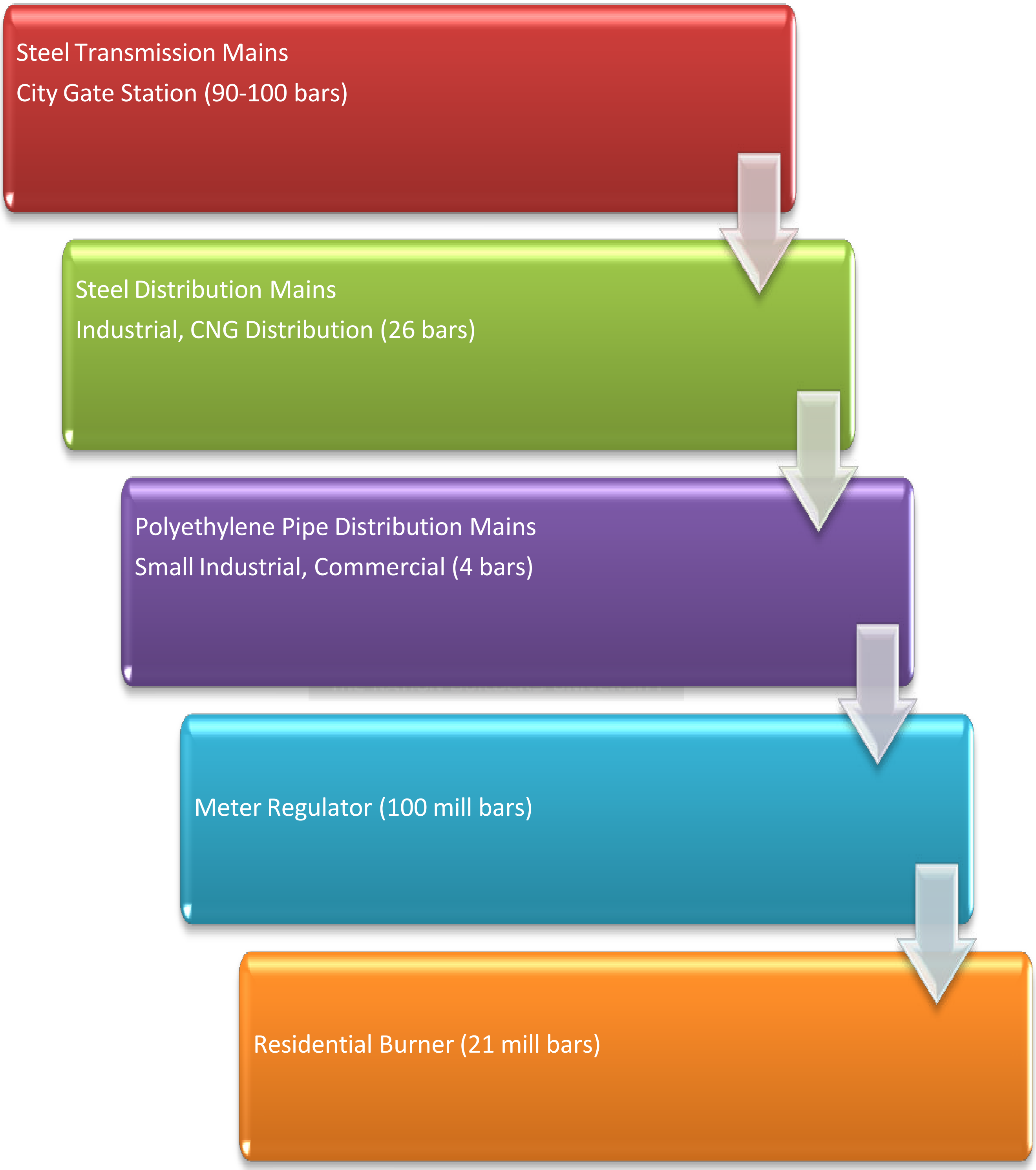


Figure 4.2: -Depicting the Pressure Regime in CGD [3]

4.3 BASIC DESIGN OF CGD NETWORK

For **HARIDWAR GA**, natural gas is considered to be tapped-off from Spur line of **Dadri-Bhavana Nagal Pipeline** near Haridwar. A steel pipe of 16inch Dia shall be laid from the City Gate Station (CGS) to main HARIDWAR city. The pressure at inlet to CGS has been considered at **49**kg/cm^{2}g with a gas flow rate of 0.48 MMSCMD, which is the peak demand flow on realistic scenario in 35th year.

DESIGN CAPACITY

The design is based on a daily peak demand requiring gas for various sectors. The city gas distribution system has been designed considering demand load, supply pressure and future requirements for all the consuming sectors and the available pressure at tap-off points. The details are as follows:

Gas Analysis

Density of gas	:	0.719
Design Temperature	:	
- Buried	:	45^{o}C
- Above ground	:	65^{o}C

City Gate Station

Inlet pressure	:	49.5 kg/cm^{2}g
Outlet pressure	:	49.0 kg/cm^{2}g
Capacity	:	1.12795m^3/s

Main Grid Line

Joint factor	:	1
Temperature factor	:	1
Population density factor	:	Class-IV

Industrial Sector

In HARIDWAR GA, industries are mainly located at Sidqul Industrial Area. Gas shall be transported from DRS through MDPE grid. Supply pressure at consumer end shall generally be kept as 4-2 kg/cm^2g. However it shall be as per consumer requirement.

CNG Station

The design parameters of CNG Stations are as follows:

<table>
<tr><td>Inlet pressure</td><td>:</td><td>19-49 kg/cm²g</td><td rowspan="2"></td><td rowspan="2">For Mother /Online Stations</td></tr>
<tr><td>Outlet pressure</td><td>:</td><td>255 kg/cm²g</td></tr>
<tr><td>Cascade capacity</td><td></td><td colspan="3"></td></tr>
<tr><td>- Mother station</td><td>:</td><td colspan="3">3000 litres of water/cascade</td></tr>
<tr><td>- Daughter station</td><td>:</td><td colspan="3">3000 litres of water/cascade</td></tr>
<tr><td>- LCV Mounted (Mobile)</td><td>:</td><td colspan="3">3000 litres of water/cascade</td></tr>
<tr><td>- Average Filling capacity</td><td></td><td colspan="3"></td></tr>
<tr><td>○ Bus</td><td>:</td><td colspan="3">80-100 kg</td></tr>
<tr><td>○ Car/LCV</td><td>:</td><td colspan="3">8-10 kg</td></tr>
<tr><td>○ Auto</td><td>:</td><td colspan="3">3.5-5 kg</td></tr>
</table>

PEAK HOUR DEMAND

Domestic

Peak hours per day	:	4

Commercial

Peak hours per day	:	12

Industrial

Peak hours per day	:	16

Automobile (CNG)

Compressor Capacity	:	1200 SCMH each
Peak hours per day	:	18

PIPELINE NETWORK

From CGS, the pipeline network for HARIDWARGA has been designed in two parts.

STEEL GRID

Natural gas from CGS has been considered at a minimum pressure of 49 kg/cm^{2}g and temperature 35^{0}C. The steel grid has been designed covering the entire geographical area to maintain required pressure at all points in the grid so that sizes can be optimized. Steel grid of 16", 12”, 8" & 4" has been considered to cater the demand of CNG stations and to supply gas to DRS for domestic, commercial and industrial sectors. The design is based on 35th year demand projected under realistic scenario.

MDPE NETWORK

For supplying gas to domestic, commercial and industrial sectors, the pressure of piped gas shall be reduced to distribution pressure in the District Regulating Station (DRS), which shall feed gas to MDPE distribution network. The domestic consumers shall be fed from the MDPE distribution network through service lines up to the domestic premises where regulating and metering facilities shall be provided. Industrial and commercial consumers shall also be supplied gas from distribution network through service lines up to the industrial and commercial consumer's premises from where regulating and metering facilities shall be arranged.

In the present study, the routing of pipeline of different diameter i.e. 180mm, 125 mm, 90mm, 63 mm, 32 mm of MDPE and 20mm of MDPE & GI have been considered.

The MDPE Network has been made to cater to the need of gas at 4 kg/cm^2g and lower pressure after DRS.

CNG NETWORK

The CNG station design is based on the following:

The actual sizing and numbers of the compressors for the CNG stations is a function of the following:

- The actual gas filling time for the vehicle.
- The dwell time between vehicle or turn-around time for the vehicle.
- The storage capacity provided in the cascades for the system.
- The actual gas filling time is primarily dependent on the following:
    - The cylinder capacity provided for the various types of vehicles that are to be serviced at the CNG station e.g. auto-rickshaws (autos), Rural Transport Vehicles (RTV), cars, taxis and buses.
    - The cylinder capacities vary for the vehicles depending upon whether the vehicles have been retrofitted with gas cylinders for operation on CNG or are factory installed. Especially the total cylinder capacities for the buses vary widely between 80 to 100 kg affecting the actual filling time required for the vehicles.

- The gas pressure in the cylinder at the time of gas filling. This has been observed to vary between 10 and 50 bar (g).

The turnaround time of the vehicles considered is furnished as below:

Table 4.1: - Vehicles Turn-around Time [3]

Vehicle	Fuel cylinder capacity	Actual gas filling time (minutes)	Turnaround time (minutes)
• Buses	80 - 100 kg	4-5 minutes	10
• Car	8-10 kg	3-4 minutes	5
• Taxi	10 kg	3-4 minutes	5
• Auto-rickshaw	3.5 - 5 kg	1.5-2 minutes	3

The turnaround time indicated above accounts for the time required for the vehicle to be positioned, the filling nozzles to be connected, the gas filling and finally the payment transaction before the vehicle makes way for the next vehicle. The gas compressor operates continuously and the compression achieved during the difference between the dwell time and the actual filling time between vehicle fillings is diverted to the cascades.

Filling cut-off pressure for the cylinder is 250 bar (g). The actual gas filled therefore shall vary between about 90% and 95% of the available cylinder capacity. Considering the actual average filling requirements for the vehicles to be about 90 % of the cylinder capacities. i.e. the corresponding average gas dispensing rates would be about 15.5 kg/min for buses, 2.3 kg/min cars and taxis and about 2 kg/min for autos.

Dispensers provided are of the following types:

- Single hose fast fill free standing type for bus filling.

- Double hose fast fill free standing type for auto / car filling.

CRITERIA FOR ROUTING OF GAS PIPELINES

The gas pipeline route shall be selected considering the following criteria:

- Shortest length of grid pipeline
- Minimize rail, major road, drain and river / major canal crossings
- Availability of space
- Least stretch through slushy, rocky and cultivable terrain.
- Avoiding HT transmission lines.
- Minimum number of turning points.
- Easy access to the route during construction phase.
- Availability of any existing pipeline corridor.
- Close proximity to unstable structures or where construction could lead to damage to pipeline.
- Areas of known or suspected aggressive soil conditions.

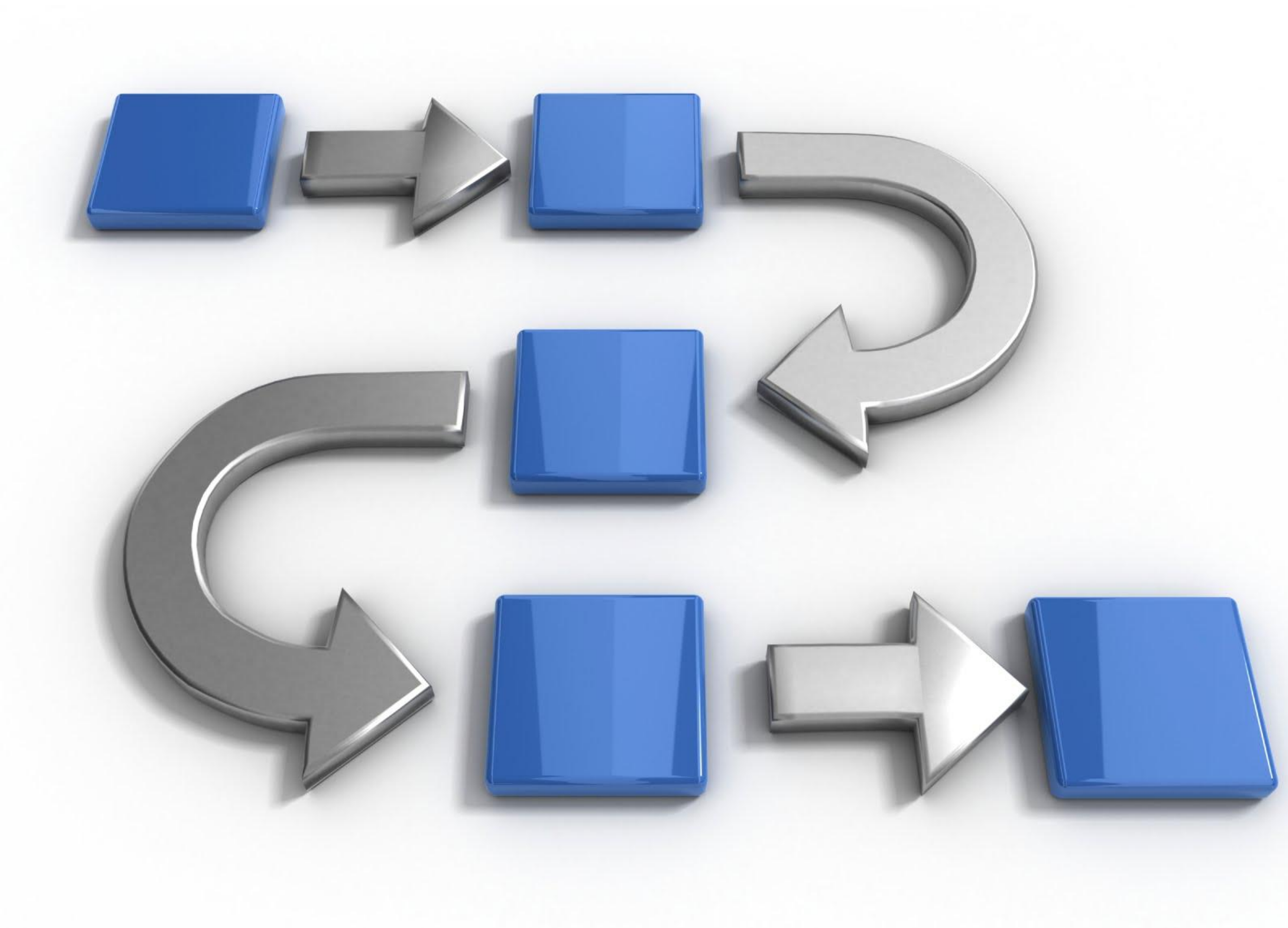
Pipeline crossings of major obstructions like waterways, railways and highways are envisaged using Horizontal Directional Drilling (HDD). However, the crossings of minor obstructions wherever necessary shall be done by "boring" methods.

4.4 CODES & STANDARDS

The principal international standards proposed for distribution network is ANSI/ASME B 31.8, 'Gas Transmission and Distribution Piping System'. Since ASME B31.8 does not adequately cover plastic pipes, for this ISO : 4431 'Buried Polyethylene (PE) pipes for the supply of gaseous fuels- Metric Services specifications' shall be followed.

Steel Pipes	**MDPE Pipelines for U/G Gas Services**	**CNG System**
ANSI / ASME B31.8	*ANSI / ASME B31.8*	OISD: 110, 132, 137 & 179
ANSI B31.3	IS: 14885	NZS – 5425
API 5L	OISD: 220	NFPA – 37, 52, 70
OISD: 226		ANSI B 31.3 & B 31.8
		IS – 2148

CHAPTER 5:- METHODOLOGY



5.1 METHODOLOGY

1. To assess the current demand of gas for different consumers which includes:

- Industrial Consumers
- Transport Consumers
- Households Consumers

2. Depending on the current demand of gas, the gas usage for the upcoming 35 years will be assessed.

3. The City Gas Distribution system layout will be done based on the following analysis:

- Design Analysis
- Network Analysis

Table 5.1: -HARIDWAR CGD Pressure Regime [3]

Equipment / Facility	Pressure up-stream – bar(g)	Pressure down-stream – bar(g)	Peak hr. per day
City Gate Station	49 bars (g)	49 (max)	-
District Regulating Station	49 (max)	4 (max)	-
Domestic	0.1 (max)	21mbar(g)	4
Commercial	1 (max)	-	12
Industries (total)	49 (max)	-	16
CNG 1200 SCMH compressor	49	200-250	18

4. Implementation Strategy

Geographical Area (GA) of HARIDWAR has been divided in to 7 Charge areas (CA). While CA 06 has the maximum industrial demand as well as domestic and commercial demand. Mostly, the CNG stations are envisaged along the NH/ SH in addition to the CNG demand of CA.

Network building would target CA-01, CA-02, C A-03, CA-04, CA-05, CA-06 and CA-07 to cater to maximum demand for domestic, commercial and industrial sectors.

Fig 5.1: - Haridwar Map

5. Operation and Maintenance Control Philosophy

Philosophy for O&M will essentially have the following features

- Uninterrupted supply of natural gas for Customers satisfaction
- Technology development / absorption for safety, service reliability and cost effectiveness
- Outsourcing bulk of the activities
- Most equipment maintenance through maintenance contracts, preferably on Original Equipment Manufacturers (OEMs)
- Maximum leveraging of technology to minimize man-power and maximize efficiency.
- Compliance with regulatory stipulations, standards and codes of practices
- Liaison with external agencies
- Development and implementation of sound procedures on:
    - Materials Management
    - Contract Administration
    - Communications
    - Decision making
    - Human resource development
    - Revenue collection

6. Disaster Management Plan

This Plan provides a guide for assuring safety for the public and maintaining facilities in satisfactory condition, during emergency conditions. The management or a responsible person of CGD project should have procedures for emergency situation that must be employed to protect the public safety or property from existing or potential hazard.

CHAPTER 6: -

HARIDWAR GAS DEMAND CALCULATION

6.1 CITY GAS DEMAND CALCULATION

For Calculating gas Pipeline diameter we have to first calculate the City Gas Distribution demand for the city considering each sector:-

Customer in a city:-

1. Domestic Consumer

2. Transportation
    - Bus
    - Three wheelers
    - Four wheelers

3. Industrial and commercial requirement

The total gas required by the city is being calculated sector wise:-

Domestic Consumer

- Current population of Haridwar city=1890422(2011 census)[6]
- No. of Households in the city= 315070(assuming 6-member family)
- Each House LPG cylinder usage=1.5
- Standard Weight of an LPG in cylinder=14.2 kg
- Calorific Value of LPG=11920 Kcal/Kg[5]
- Calorific Value of NG=12000Kcal/Kg[5]

Amount of LPG consumed in each house = (14.7*1.5)/30 =0.71 Kg/day

Equivalent amount of NG = (0.71)*[(11920)/12000)] = 0.7058 Kg/day of NG

Volumetric Flow Rate=0.7058/0.862=0.8178 m^3/day

Total Domestic Demand, 'X'= 315070*0.8178*10^{-6} =0.2576 MMSCMD

Now assuming growth rate of 1.5 % the increase in population will be estimated for the next 35 years using the equation-

$$P=P_0e^{rt}$$ [8]

Where, P=Current value of population

P_0=Initial Value of population

r=growth rate

t=time period

Based on the population estimate the no of households and gas demand increase will be calculated for the next 35 years as shown in the table below-

Table 6.1: - Domestic PNG demand Projection

Year	Population	No. of Households	Gas Demand(MMSCMD)
2011	1890422	315070	0.2576
2016	2037656	339609	0.2777
2021	2196357	366060	0.2993
2026	2367418	394570	0.3226
2031	2551802	425300	0.3478
2036	2750547	458424	0.3748
2041	2964770	494128	0.4040
2046	3196678	532780	0.4357

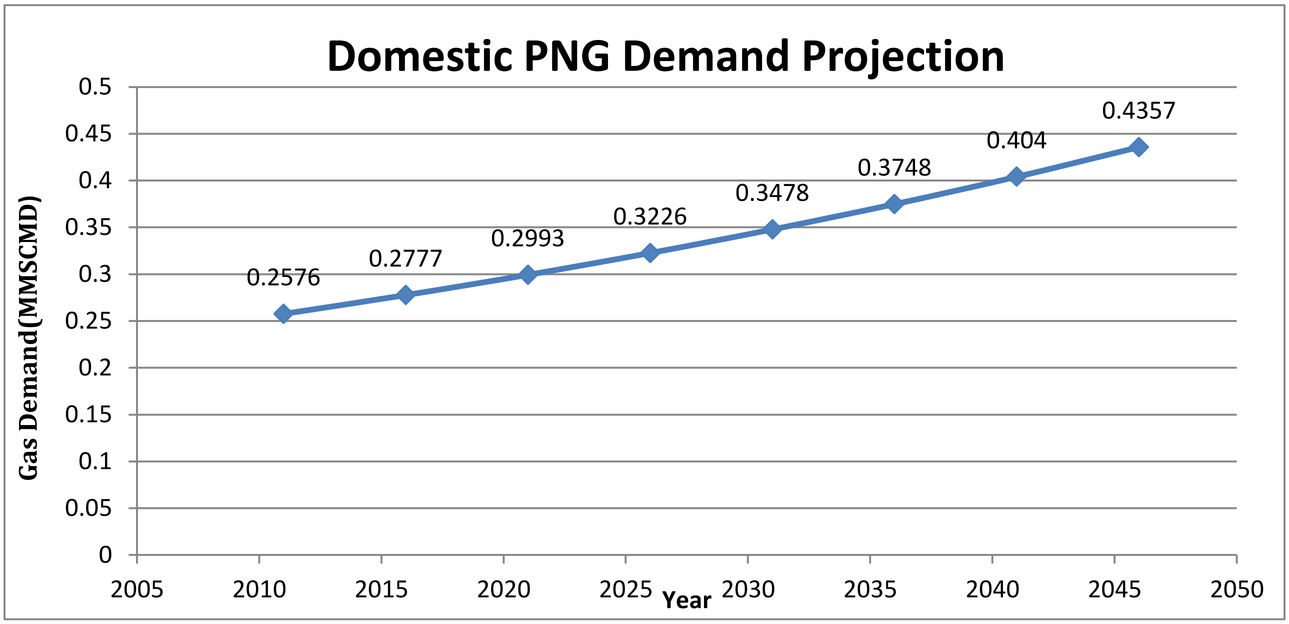


Figure 6.1:

Hence, the projected domestic PNG demand will be=0.4357 MMSCMD

Transportation Sector

A transportation sector covers all kinds of vehicles as:-

- Buses
- Bajaj Auto(Three wheeler)
- Cars(Four wheelers)

Nowadays Petrol and Diesel both are costly so both type of consumers want to have options at their hands to opt for **CNG** engines and if we use **CNG** engines it is beneficiary for both consumer and environment because it reduces the release of environmental pollutants.

Vehicle Type: -Based on 2011 census [7, 4]

1 Bus

- No. of buses in Haridwar =20
- Fuel Type Used=Diesel
- Average distance covered by each bus=250 km/day
- Fuel Average=8 km/liters
- Total Diesel Consumed=20*(250/8)=625 liters/day
- Diesel Calorific Value=10000 Kcal/Kg[5]
- CNG Calorific Value= 10270 Kcal/Kg[5]

Equivalent amount of CNG= (625)*[(10000)/10270)] =520.83 kg/day

CNG Total Demand for Buses (MMSCMD)=520.83*10^-6/0.862=0.000604 MMSCMD

2 Auto

- No. of autos in Haridwar =1900
- Fuel Type Used=Petrol
- Average distance covered by each Auto=200 km/day
- Fuel Average=30 km/liters
- Total Petrol Consumed=1900*(200/30)=12666 liters/day
- Petrol Calorific Value=11300 Kcal/Kg
- CNG Calorific Value=10270 Kcal/Kg

Equivalent amount of CNG= (12666)*[(11300)/10270)] =13936 kg/day

CNG Total Demand for Auto (MMSCMD)=13936*10^-6/0.862=0.01616 MMSCMD

3 Vikram

- No. of Vikram in Haridwar =1000
- Fuel Type Used=Diesel
- Average distance covered by each Vikram=175 km/day
- Fuel Average=25 km/liters
- Total Diesel Consumed=1000*(175/25)=7000 liters/day
- Petrol Calorific Value=10000 Kcal/Kg
- CNG Calorific Value=10270 Kcal/Kg

Equivalent amount of CNG= (7000)*[(10000)/10270)] =6815.96 kg/day

CNG Total Demand for Vikram (MMSCMD)=6815.96*10^-6/0.862=0.007907 MMSCMD

4 Taxi

- No. of Taxis in Haridwar =2000
- Fuel Type Used=Petrol
- Average distance covered by each taxi=116 km/day
- Fuel Average=20 km/liters
- Total Petrol Consumed=2000*(116/20)=11600 liters/day
- Petrol Calorific Value=10000 Kcal/Kg
- CNG Calorific Value=10270 Kcal/Kg

Equivalent amount of CNG= (11600)*[(10000)/10270)] =12763.3 kg/day

CNG Total Demand for Taxi (MMSCMD)=12763.3*10^-6/0.862=0.0148 MMSCMD

Total CNG demand for vehicles in Haridwar = (Buses + Auto + Vikram +Taxis) MMSCMD

= (0.000604+0.01616+0.007907+0.0148)

= 0.039471 MMSCMD

Now let us assume the growth rate in automobile industry to be 10.11% then based on this we will calculate the gas demand for the next 35 years using the equation-

$$G.D. = (G.D.)_o [1+(r/100)]^n$$

Where, G.D. = Current Gas Demand

$(G.D)_o$. = Initial Gas Demand

r= growth rate

n=time period

Table 6.2: - CNG demand projection

Year	**Gas Demand (MMSCMD)**
2011	0.039471
2016	0.06388
2021	0.10339
2026	0.167346
2031	0.2708
2036	0.4383
2041	0.709
2046	1.148

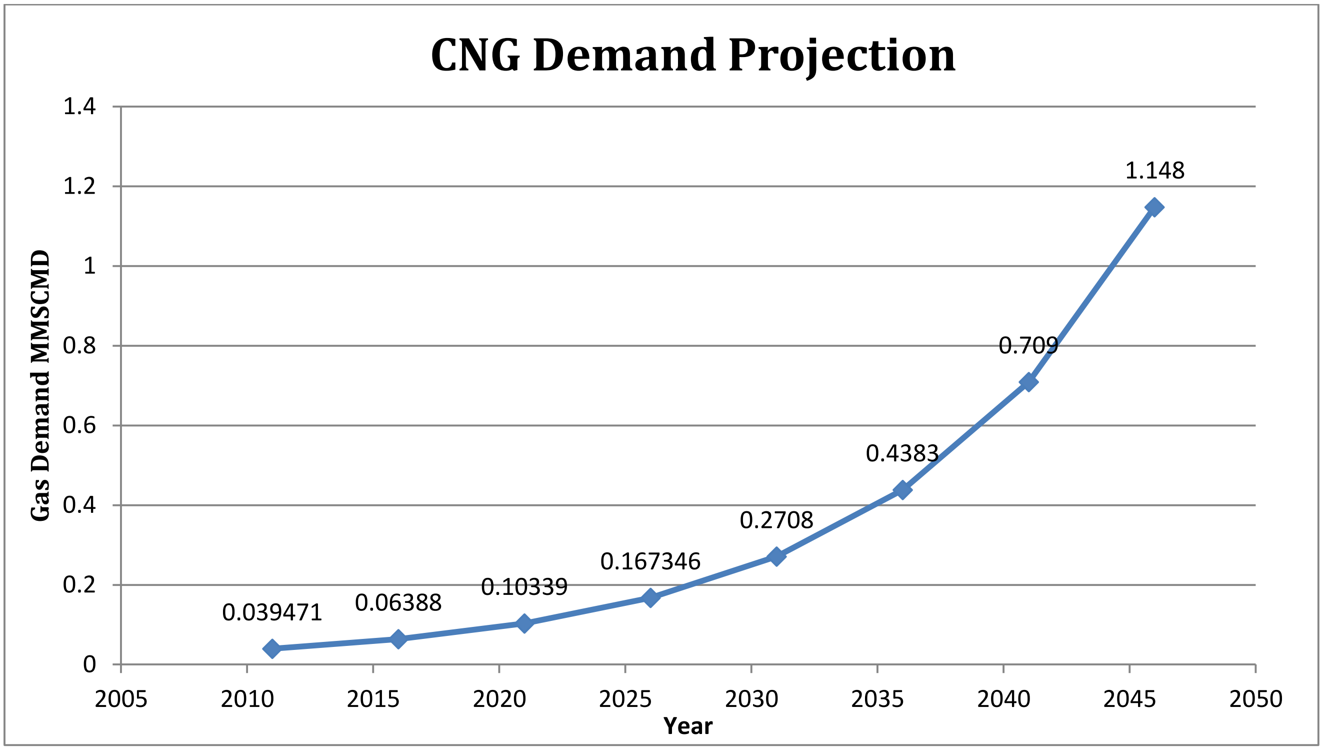


Figure 6.2:

Hence the estimated CNG demand will be= 1.148 MMSCMD

Commercial and Industrial Sector

It is very difficult to calculate exact demand for commercial and industrial sector without their cooperation. As a result for this project we can assume the demand in this sector.

Let the industrial demand be 0.3 MMSCMD.

Total Demand of Gas MMSCMD, $Q_{standard}$ = (Domestic PNG + CNG + Industrial)

=0.4357+1.148+0.3 MMSCMD

=1.8837 MMSCMD

6.2 ACTUAL DEMAND CALCULATION

Now in order to calculate Q_{actual} we use the following equation:-

$$(P_{stan}*Q_{stan})/T_{stan}= (P_{act}*Q_{act})/ (T_{act}*Z)$$

Where,

P_{stan}=1 bar

T_{stan}=15^{o}C

P_{act}=19 bar

T_{act}=25^{o}C

Z=compressibility Factor

Calculation of Compressibility Factor Z

$$\Sigma y_i P_{ci}=664.739=P_{pr}$$

$$\Sigma y_i T_{ci}=350.665=T_{pr}$$

T_{pr}=Pseudo reduced Temperature in ^{o}R

P_{pr}=Pseudo reduced pressure in psi

T_{pc}=Pseudo critical temperature in ^{o}R

P_{pc}=Pseudo critical temperature in psi

$T_{pr}=T/T_{pc}=537/350.665=1.531$

$P_{pr}=P/P_{pc}=275.647/664.739=0.414$

Natural Gas Composition

Table 6.3: - Natural Gas Composition [2]

Component	**Y_i**	**Critical Pressure Pc(psi)**	**Critical Temperature T_c(°R)**
Methane	0.95	667.8	343.1
Ethane	0.032	707.8	549.8
Propane	0.002	616.3	665.7
n-butane	0.0003	529.1	734.7
Iso-butane	0.0003	550.7	765.4
n-pentane	0.0001	490.4	828.8
Iso-pentane	0.0001	488.6	845.4
Hexane +	0.0001	304.6	1111.8
N_2	0.01	493.8	227.3
$C0_2$	0.005	1070.9	547.6
0_2	0.0002	737.1	278.6

Calculation of **Z** is done using standard correlation available in literature:-

In this project we will be using **Standing and Katz,** 1942 compressibility factor for natural gas charts:-

From the Katz chart we obtain the value of **Z=0.95**

So, $(P_{stan}*Q_{stan})/T_{stan} = (P_{act}*Q_{act})/ (T_{act}*Z)$

$(1*1.8837*10^6)/288 = (19*Qact)/ (298*0.95)$

$Qact=97455.3125\ m^3/day=1.12795 m^3/s$

Hence, the total gas demand comes out to be = **$1.12795\ m^3/s$**

FIG. 23-4
Compressibility Factors for Natural Gas[1]

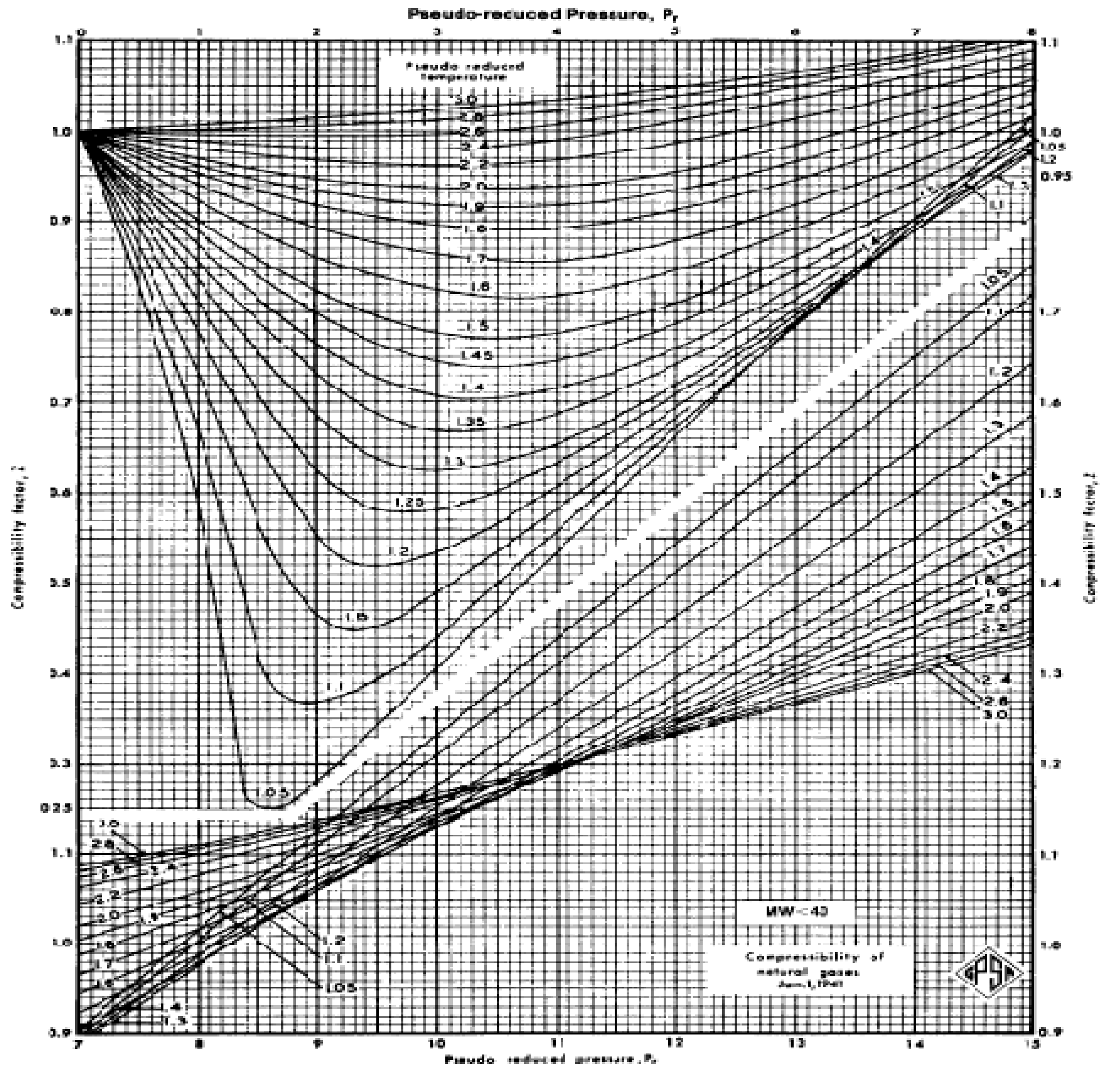


Figure 6.3: - Compressibility factor for natural gases as a function of reduced pressure and temperature (After **Standing and Katz**, 1942; courtesy of **SPE** of **AIME**) [2]

CHAPTER 7: - CGD NETWORK DESIGN

7.1 DESIGN CALCULATION

As we go for City Gas Distribution designing phase we have to design three different kind of pipeline:-

- Design of steel pipe for CGD(High Pressure Network)
- Design of MDPE pipe for CGD(Medium Pressure Network)
- Design of Cu/GI pipe(Low Pressure Network)

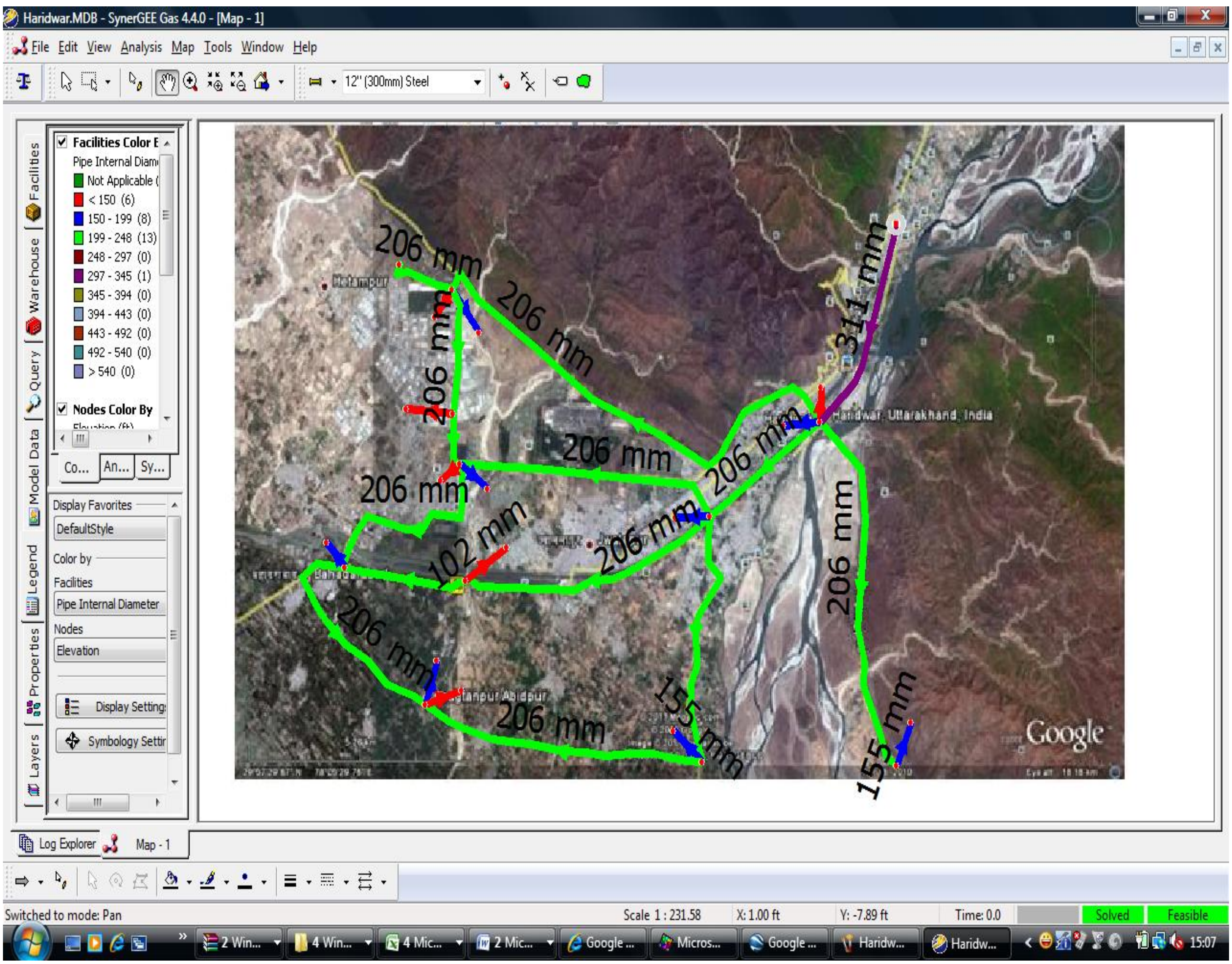


Figure 7.1: - GA MAP SHOWING PROPOSED PIPELINE ROUTE

7.2 DESIGN OF STEEL PIPELINE

Before designing the High Pressure pipeline we have a select a desired ROW over the entire Haridwar city for the high pressure pipeline and further calculate the pressure drop over all the modes of the high pressure network and find out the operating pressure value that would be required at the outlet of City Gate Station (CGS) of the high pressure network.

Selection of Diameter for High Pressure Steel Pipeline:-

The actual value of 'Q' as calculated previously is below mentioned

Q_{actual} =**97433.571** m^3/day =**1.12795** m^3/s

Now as we know that- **Q= A X V** [1]

Where, V=Velocity of Gas =10 m/s (assumed)

A=Area of the pipe conduit

So, 1.12795=A*10

Where, A= (π/4*D^2)

$$D = \sqrt{\frac{4*Q}{V*\pi}}$$

$$= \sqrt{\frac{4*1.12795}{10*\pi}} = 0.378811806 \text{ m}$$

= **14.91 inch**

With according to **API 5L** the Grade and Diameter of steel pipeline is to be selected from the below mentioned table

Table 7.1: -API- 5L Grade and Diameter[2]

Table 6.5 Pipeline Internal Design Pressures and Test Pressures

Pipe Material API 5L X42		SMYS	42000 psig						
Diameter	Wall Thickness	Weight	Internal Design Pressure, psig				Hydrostatic Test Pressure, psig		
in.	in.	lb/ft	Class 1	Class 2	Class 3	Class 4	90% SMYS	95% SMYS	100% SMYS
4.5	0.237	10.79	3185	2654	2212	1770	3982	4203	4424
	0.337	14.98	4529	3774	3145	2516	5662	5976	6291
	0.437	18.96	5873	4894	4079	3263	7342	7749	8157
	0.531	22.51	7137	5947	4956	3965	8921	9416	9912
6.625	0.250	17.02	2282	1902	1585	1268	2853	3011	3170
	0.280	18.97	2556	2130	1775	1420	3195	3373	3550
	0.432	28.57	3944	3286	2739	2191	4930	5204	5477
	0.562	36.39	5131	4275	3563	2850	6413	6769	7126
8.625	0.250	22.36	1753	1461	1217	974	2191	2313	2435
	0.277	24.70	1942	1619	1349	1079	2428	2563	2698
	0.322	28.55	2258	1882	1568	1254	2822	2979	3136
	0.406	35.64	2847	2372	1977	1582	3559	3756	3954
10.75	0.250	28.04	1407	1172	977	781	1758	1856	1953
	0.307	34.24	1727	1439	1199	960	2159	2279	2399
	0.365	40.48	2054	1711	1426	1141	2567	2709	2852
	0.500	54.74	2813	2344	1953	1563	3516	3712	3907
12.75	0.250	33.38	1186	988	824	659	1482	1565	1647
	0.330	43.77	1565	1304	1087	870	1957	2065	2174
	0.375	49.56	1779	1482	1235	988	2224	2347	2471
	0.406	53.52	1926	1605	1337	1070	2407	2541	2675
	0.500	65.42	2372	1976	1647	1318	2965	3129	3294
14.00	0.250	36.71	1080	900	750	600	1350	1425	1500
	0.312	45.61	1348	1123	936	749	1685	1778	1872
	0.375	54.57	1620	1350	1125	900	2025	2138	2250
	0.437	63.30	1888	1573	1311	1049	2360	2491	2622
	0.500	72.09	2160	1800	1500	1200	2700	2850	3000

(continued)

Table 6.5 Pipeline Internal Design Pressures and Test Pressures (Continued)

Pipe Material API 5L X42		SMYS	42000 psig						
Diameter	Wall Thickness	Weight	Internal Design Pressure, psig				Hydrostatic Test Pressure, psig		
in.	in.	lb/ft	Class 1	Class 2	Class 3	Class 4	90% SMYS	95% SMYS	100% SMYS
16.00	0.250	42.05	945	788	656	525	1181	1247	1313
	0.312	52.27	1179	983	819	655	1474	1556	1638
	0.375	62.58	1418	1181	984	788	1772	1870	1969
	0.437	72.64	1652	1377	1147	918	2065	2180	2294
	0.500	82.77	1890	1575	1313	1050	2363	2494	2625
18.00	0.250	47.39	840	700	583	467	1050	1108	1167
	0.312	58.94	1048	874	728	582	1310	1383	1456
	0.375	70.59	1260	1050	875	700	1575	1663	1750
	0.437	81.97	1468	1224	1020	816	1835	1937	2039
	0.500	93.45	1680	1400	1167	933	2100	2217	2333
20.00	0.312	65.60	943	786	655	524	1179	1245	1310
	0.375	78.60	1134	945	788	630	1418	1496	1575
	0.437	91.30	1321	1101	918	734	1652	1744	1835
	0.500	104.13	1512	1260	1050	840	1890	1995	2100
	0.562	116.67	1699	1416	1180	944	2124	2242	2360
22.00	0.375	86.61	1031	859	716	573	1289	1360	1432
	0.500	114.81	1375	1145	955	764	1718	1814	1909
	0.625	142.68	1718	1432	1193	955	2148	2267	2386
	0.750	170.21	2062	1718	1432	1145	2577	2720	2864
24.00	0.375	94.62	945	788	656	525	1181	1247	1313
	0.437	109.97	1101	918	765	612	1377	1453	1530
	0.500	125.49	1260	1050	875	700	1575	1663	1750
	0.562	140.68	1416	1180	984	787	1770	1869	1967
	0.625	156.03	1575	1313	1094	875	1969	2078	2188
	0.750	186.23	1890	1575	1313	1050	2363	2494	2625
26.00	0.375	102.63	872	727	606	485	1090	1151	1212
	0.500	136.17	1163	969	808	646	1454	1535	1615
	0.625	169.38	1454	1212	1010	808	1817	1918	2019
	0.750	202.25	1745	1454	1212	969	2181	2302	2423

28.00	0.375	110.64	810	675	563	450	1013	1069	1125
	0.500	146.85	1080	900	750	600	1350	1425	1500
	0.625	182.73	1350	1125	938	750	1688	1781	1875
	0.750	218.27	1620	1350	1125	900	2025	2138	2250
30.00	0.375	118.65	756	630	525	420	945	998	1050
	0.500	157.53	1008	840	700	560	1260	1330	1400
	0.625	196.08	1260	1050	875	700	1575	1663	1750
	0.750	234.29	1512	1260	1050	840	1890	1995	2100
32.00	0.375	126.66	709	591	492	394	886	935	984
	0.500	168.21	945	788	656	525	1181	1247	1313
	0.625	209.43	1181	984	820	656	1477	1559	1641
	0.750	250.31	1418	1181	984	788	1772	1870	1969
34.00	0.375	134.67	667	556	463	371	834	880	926
	0.500	178.89	889	741	618	494	1112	1174	1235
	0.625	222.78	1112	926	772	618	1390	1467	1544
	0.750	266.33	1334	1112	926	741	1668	1760	1853
36.00	0.375	142.68	630	525	438	350	788	831	875
	0.500	189.57	840	700	583	467	1050	1108	1167
	0.625	236.13	1050	875	729	583	1313	1385	1458
	0.750	282.35	1260	1050	875	700	1575	1663	1750
42.00	0.375	166.71	540	450	375	300	675	713	750
	0.500	221.61	720	600	500	400	900	950	1000
	0.625	276.18	900	750	625	500	1125	1188	1250
	0.750	330.41	1080	900	750	600	1350	1425	1500
	1.000	437.88	1440	1200	1000	800	1800	1900	2000

Hence from the above table we can select the desired Diameter of pipeline with specific grade.

Selected Grade=API X 42

Selected Diameter=16 inch

Now we have to decide the thickness of the pipeline and it should be calculated from the below mentioned formula-

$$t=\frac{P*D}{2*T*s*E*F}$$ [1]

Where,

P=Design Pressure psi =19 to 49 bar=279 to 725 psi

S=Specified Minimum Yield Strength=42000psi

D=Outside Diameter of the pipeline=16 inch

t=Wall thichness in inch

T=Temperature Duration Factor=1

F=Location Design Factor=0.4

E=Longitudinal Joint Factor=1

Hence for calculation of wall thickness of pipeline first we have to calculate the operating pressure of pipeline.

Operating Pressure is the pressure of the gas at the outlet of the City Gate Station(CGS).

Procedure to Calculate the pressure at each node of High Pressure Pipeline Network:-

Practical flow equation used for pressure above 7 bar (assuming partial turbulent)

Panhandle A Equation ⟶

$$Q_n= 7.57*10^{-4} (T_n/P_n) \sqrt{[(P_1^2- P_2^2)/ (fsLt)]}$$ [1]

Where , P is in bar

Q_n is in m^3/hr

$$\sqrt{\frac{1}{f}} = 6.872\ Re^{0.073}$$

The main equations used for High Pressure Pipeline are mentioned below:-

$$(P_1^2- P_2^2)=KQ_n^{1.854}$$ [1]

$$K=18.43*L/ (E^2*D^{4.854})$$

Where, E=0.8

The schematic diagram of the steel pipeline network laid across the whole haridwar city is shown in the diagram below:-

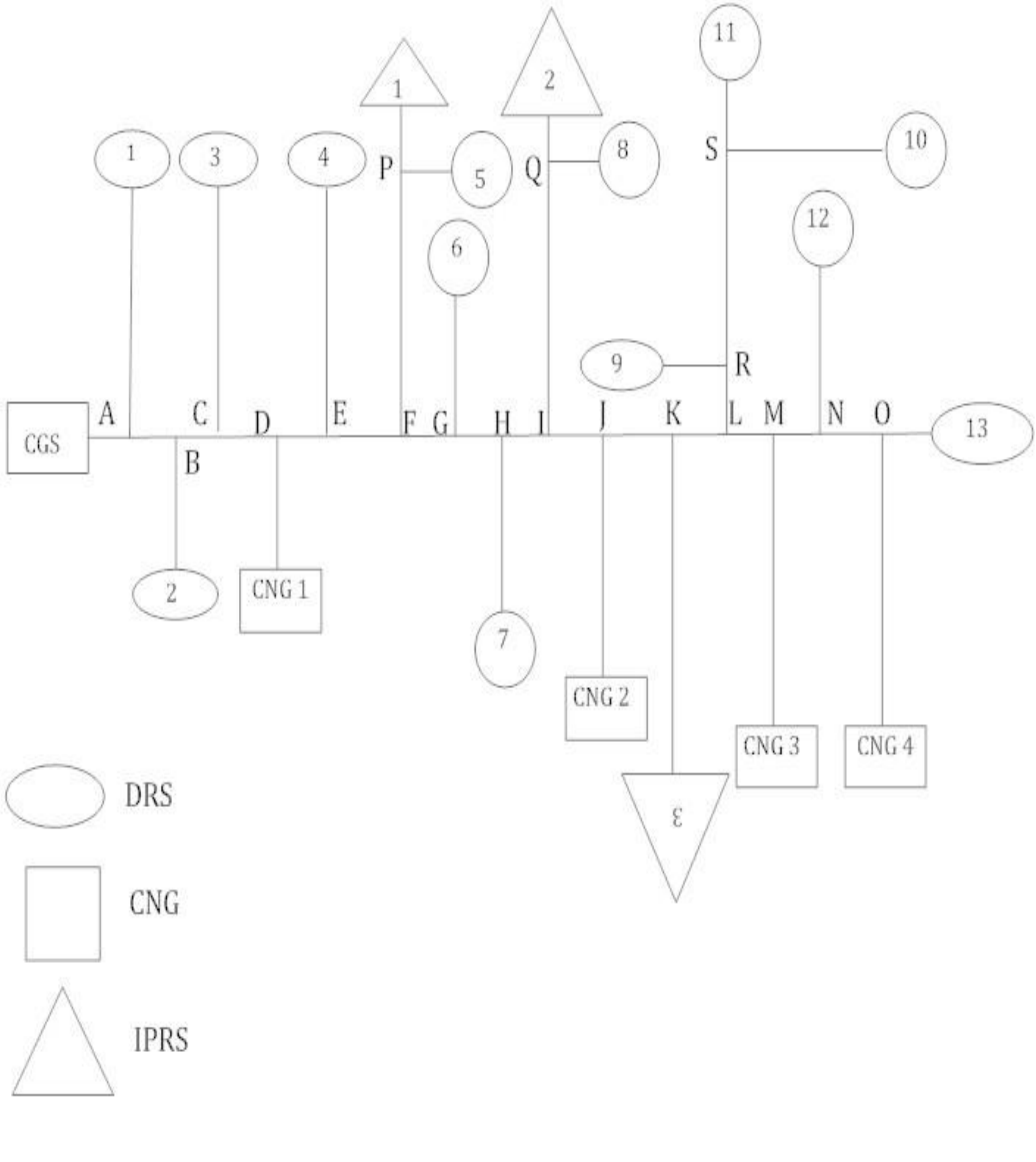


Figure 7.2: STEEL PIPELINE SCHEMATIC DIAGRAM

For Steel Pipeline as shown in schematic diagram:

LENGTH:

CGS TO A =825 M	A TO B =1875 M	B TO C=675 M	C TO D=375 M
D TO E =1125 M	E TO F =5750 M	F TO G =1125 M	G TO H =250 M
H TO I =750 M	I TO J =125 M	J TO K =2375 M	K TO L =1625 M
L TO M=375 M	M TO N=1250 M	N TO O =500 M	0 TO DRS 13 =1200M
B TO DRS 2 =625 M	D TO CNG 1= 225 M	H TO DRS 7 =975 M	J TO CNG 2=250 M
K TO IPRS 3=325 M	M TO CNG 3=250 M	O TO CNG 4=250 M	N TO DRS 12=625 M
L TO R =750 M	R TO DRS 9 =250 M	R TO S =1000 M	S TO DRS 10 =350 M
S TO DRS 11 =1875 M	I TO Q =2000 M	Q TO DRS 8 =250 M	Q TO IPRS 2=7500 M
G TO DRS 6= 1625 M	F TO P= 4000 M	P TO DRS 5 =1250 M	P TO IPRS 1=1125 M
E TO DRS 4= 1000 M	C TO DRS 3=1450 M	A TO DRS 1=1450 M	

Length from CGS(Start) to DRS 13(End) =

825+675+1125+5750+1125+250+750+125+2375+1625+375+1250+500+1200

=18325 m =**18.325 Km**

DEMAND:

Q=1.883279762 MMSCMD = **1883279.762 SCMD**

Joint Node

A=0.07689 MMSCMD= 76890 SCMD

B=0.02554 MMSCMD= 25540 SCMD

C=0.05492 MMSCMD= 54920 SCMD

D=0.03452 MMSCMD =34520 SCMD

E=0.05492 MMSCMD = 54920 SCMD

DRS 5 P=0.03295 MMSCMD =32950 SCMD

IPRS 1=0.2746 MMSCMD =274600 SCMD

G=0.10435 MMSCMD = 104350 SCMD

H=0.2746 MMSCMD =274600 SCMD

DRS 8 Q=0.10984 MMSCMD = 109840 SCMD

IPRS 2 Q=0.52173 MMSCMD =521730 SCMD

J=0.02804 MMSCMD = 28040 SCMD

IPRS 3 K=0.02746 MMSCMD =27460SCMD

DRS 9 R=0.08238 MMSCMD = 82380 SCMD

DRS 10 S=0.10984 MMSCMD =109840 SCMD

DRS 11 S=0.10984 MMSCMD =109840 SCMD

CNG 3 M=0.02322 MMSCMD = 23220 SCMD

N=0.1373 MMSCMD =137300 SCMD

O=0.02003 MMSCMD =20030 SCMD

DRS 13=0.02746 MMSCMD =27460SCMD

FLOW RATE:DEMAND AT EACH NODE

FORMULA USED

$$(P_{stan}*Q_{stan})/T_{stan} = (P_{act}*Q_{act})/ (T_{act}*Z)$$ [1]

Where,

P_{stan}=1 bar

T_{stan}=15ºC=273+15=288 K

P_{act}=19 bar

T_{act}=25ºC=273+25=298 K

Z=0.95

Q_{act}=?

For Joint Node A-DRS 1

$(1*76890)/288 = (19*Q_{act})/298*0.95$

$=3977.989583\ m^3/day$

$=165.749566m^3/hr$

$Q_{act} = 0.046041546m^3/s$

For Joint Node B-DRS 2

$(1*25540)/288 = (19*Q_{act})/298*0.95$

$=1321.0340278\ m^3/day$

$=55.05584492m^3/hr$

$Q_{act} = 0.01529329m^3/s$

For Joint Node C-DRS 3

$(1*54920)/288 = (19*Q_{act})/298*0.95$

$=2841.347222\ m^3/day$

$=118.3478009m^3/hr$

$Q_{act} = 0.032885963m^3/s$

For Joint Node D-CNG 1

$(1*34520)/288 = (19*Q_{act})/298*0.95$

$=1785.930556 m^3/day$

$=74.41377317 m^3/hr$

$\mathbf{Q_{act} = 0.020670492 m^3/s}$

For Joint Node E-DRS 4

$(1*54920)/288 = (19*Q_{act})/298*0.95$

$=2841.347222\ m^3/day$

$=118.3894676 m^3/hr$

$\mathbf{Q_{act} = 0.032885963^3/s}$

For DRS 5

$(1*32950)/288 = (19*Q_{act})/298*0.95$

$=1704.704861\ m^3/day$

$=71.02936921 m^3/hr$

$\mathbf{Q_{act} = 0.01973038 m^3/s}$

For Joint IPRS 1

$(1*274600)/288 = (19*Q_{act})/298*0.95$

$=14206.73611\ m^3/day$

$=591.9473379 m^3/hr$

$\mathbf{Q_{act} = 0.164429816 m^3/s}$

For Joint Node G-DRS 6

$(1*104350)/288 = (19*Q_{act})/298*0.95$

$=5398.663194\ m^3/day$

$=224.9442998 m^3/hr$

$\mathbf{Q_{act} = 0.062484527 m^3/s}$

For Joint Node H-DRS 7

$(1*27460)/288 = (19*Q_{act})/298*0.95$

$=1420.6737611\ m^3/day$

$=59.19474005 m^3/hr$

$Q_{act} = 0.016442981 m^3/s$

For DRS 8

$(1*109840)/288 = (19*Q_{act})/298*0.95$

$=5682.694444\ m^3/day$

$=236.7789352 m^3/hr$

$Q_{act} = 0.065771926 m^3/s$

For IPRS 2

$(1*521730)/288 = (19*Q_{act})/298*0.95$

$=26992.28125\ m^3/day$

$=1124.678385 m^3/hr$

$Q_{act} = 0.312410662 m^3/s$

For J-CNG 2

$(1*28040)/288 = (19*Q_{act})/298*0.95$

$=1450.680556\ m^3/day$

$=60.044502317 m^3/hr$

$Q_{act} = 0.016790284 m^3/s$

For K-IPRS 3

$(1*27460)/288 = (19*Q_{act})/298*0.95$

$=1420.673611\ m^3/day$

$=59.19473379 m^3/hr$

$Q_{act} = 0.016442981 m^3/s$

For Joint R-DRS 9

$(1*82380)/288 = (19*Q_{act})/298*0.95$

$=4262.020833\ m^3/day$

$=177.5842014m^3/hr$

$Q_{act} = 0.049328944m^3/s$

For DRS 10-JOINT S

$(1*109840)/288 = (19*Q_{act})/298*0.95$

$=5682.694444\ m^3/day$

$=236.7789352m^3/hr$

$Q_{act} = 0.065771926m^3/s$

For DRS 11-JOINT S

$(1*109840)/288 = (19*Q_{act})/298*0.95$

$=5682.694444\ m^3/day$

$=236.7789352m^3/hr$

$Q_{act} = 0.065771926m^3/s$

For M-CNG 3

$(1*23220)/288 = (19*Q_{act})/298*0.95$

$=1201.3125\ m^3/day$

$=50.0546875m^3/hr$

$Q_{act} = 0.013904079m^3/s$

For N-DRS 12

$(1*137300)/288 = (19*Q_{act})/298*0.95$

$=7103.368056\ m^3/day$

$=295.973669\ m^3/hr$

$Q_{act} = 0.082214908m^3/s$

For O-CNG 4

(1*20030)/288 = (19*Q_{act})/298*0.95

=1036.274306m^3/day

=43.17809608m^3/hr

Q_{act} =0.011993915m^3/s

For DRS 13

(1*27460)/288 = (19*Q_{act})/298*0.95

=1420.673611 m^3/day

=59.19473379m^3/hr

Q_{act} =0.016442981m^3/s

CGS TO DRS 13(MAINLINE)

DRS 13 TO O

Q_{act} =1420.673611 m^3/day

= 59.19473379m^3/hr

= 0.016442981m^3/s

O TO N

Q_{act} =1420.673611+1036.274306

= 2456.647917m^3/day

= 102.3728299m^3/hr

= 0.028436897m^3/s

N TO M

Q_{act} $=2456.647917+7103.368056$

$= 9560.315973 m^3/day$

$= 398.3464989 m^3/hr$

$= 0.110651805 m^3/s$

M TO L

Q_{act} $=9560.315973+1201.3125$

$= 10761.62847 m^3/day$

$= 448.4011863 m^3/hr$

$= 0.124555885 m^3/s$

LTO K

Q_{act} $=10761.62847+5682.694444+4262.020833+5682.694444$

$= 26389.03819 m^3/day$

$= 1099.543258 m^3/hr$

$= 0.305428682 m^3/s$

K TO J

Q_{act} $=26389.03819+1420.673611$

$= 27809.7118 m^3/day$

$= 1158.737992 m^3/hr$

$= 0.321871664 m^3/s$

J TO I

Q_{act} =27809.7118+1450.680556

= 29260.39236m^3/day

= 1219.183015m^3/hr

= 0.338661948m^3/s

I TO H

Q_{act} =29260.39236+26992.28125+5682.694444

= 61935.36805m^3/day

= 2580.640335m^3/hr

= 0.716844537m^3/s

H TO G

Q_{act} =61935.36805+1420.6737611

= 63356.04181m^3/day

= 2639.835075m^3/hr

= 0.733287521m^3/s

G TO F

Q_{act} =63356.04181+5398.663194

= 68754.705m^3/day

= 2864.779375m^3/hr

= 0.795772048m^3/s

F TO E

Q_{act} =68754.705+14206.73611+1704.704861

= 84666.14597m^3/day

= 3527.756082m^3/hr

= 0.979932245m^3/s

E TO D

Q_{act} =84666.14597+2841.347222

= 87507.493m^3/day

= 3646.14555m^3/hr

= 1.012818208m^3/s

D TO C

Q_{act} =87507.493+1785.930556

= 89293.42375m^3/day

= 3720.559323m^3/hr

= 1.033488701m^3/s

C TO B

Q_{act} =89293.42375+2841.347222

= 92134.77097m^3/day

= 3838.94879m^3/hr

= 1.066374664m^3/s

B TO A

Q_{act} $=92134.77097+1321.340278$

$= 93456.11125 m^3/day$

$= 3894.009635 m^3/hr$

$= 1.081667954 m^3/s$

A TO CGS

Q_{act} $=93456.11125+3977.989583$

$= 97434.10083 m^3/day$

$= 4059.754201 m^3/hr$

$= 1.1277095 m^3/s$

TEE JOINTS

P TO F

Q_{act} $=1704.704861+14206.73611$

$= 15911.44097 m^3/day$

$= 662.9767071 m^3/hr$

$= 0.184160196 m^3/s$

At JOINT Q

Q_{act} $= 5682.694444+26992.28125$

$= 32674.97569 m^3/day$

$= 1361.45732 m^3/hr$

$= 0.378182589 m^3/s$

At JOINT S

$\mathbf{Q_{act}}$ =5682.694444+5682.694444

= 11365.38889m^3/day

= 473.5578704m^3/hr

= 0.131543852m^3/s

At JOINT R

$\mathbf{Q_{act}}$ =5682.694444+5682.694444+4260.020833

= 15627.40972m^3/day

= 651.1420717m^3/hr

= 0.180872797m^3/s

PRESSURE CALCULATIONS

CGS TO DRS 13(MAINLINE)

D=16''=406.4 mm

d=D-2t

Let us assume a wall thickness of t=0.375mm

So, d=406.4-2*0.375

d=**387.35 mm**

FOR JOINT O

K= $(18.43*L)/ [(E^2)*(D^{1.854})]$
$= (18.43*1200)/ [(0.8^2)*(387.35^{1.854})]$

K=$8.741655429 * 10^{-9}$

Q=59.19473379 m^3/hr

$P_2^2 – P_1^2 = K Q^{1.854}$

$P_2^2 = (20)^2 + [(8.741655429*10^{-9})*(59.19473379^{1.854})]$

P_2 =20.00000042 bar

FOR JOINT N → OTO N

K= $(18.43*500) / [(0.8^2)*(387.35^{1.854})]$

K=$3.642356429 * 10^{-9}$

Q=102.3728299 m^3/hr

$P_2^2 = (20)^2 + [(3.642356429*10^{-9})*(102.3728299^{1.854})]$

P_2 =20.00000049 bar

FOR JOINT M → N TO M

K= $(18.43*1250)/ [(0.8^2)*(387.35^{1.854})]$

K=$9.105891071 * 10^{-9}$

Q=398.3464989 m^3/hr

$P_2^2 = (20)^2 + [(9.105891071*10^{-9})*(398.3464989^{1.854})]$

P_2 =20.00001507 bar

FOR JOINT L → M TO L

K= $(18.43*375)/ [(0.8^2)*(387.35^{1.854})]$

K=$2.731767321 * 10^{-9}$

Q=448.4011863 m^3/hr

$P_2^2 = (20)^2 + [(2.731767321*10^{-9})*(448.4011863^{1.854})]$

P_2 =20.00000563 bar

FOR JOINT K → L TO K

K= $(18.43*1625)/ [(0.8^2)*(387.35^{1.854})]$

K=$1.183765839 * 10^{-8}$

Q=1099.543258 m^3/hr

$P_2^2 = (20)^2 + [(1.183765839*10^{-8})*(1099.543258^{1.854})]$

P_2 =20.00012871 bar

FOR JOINT J → K TO J

K= $(18.43*2375)/ [(0.8^2)*(387.35^{1.854})]$

K=$1.730119304 * 10^{-8}$

Q=1188.737992 m^3/hr

$P_2^2 = (20)^2 + [(1.730119304*10^{-8})*(1188.737992^{1.854})]$

P_2 =20.00020732 bar

FOR JOINT I → J TO I

K= $(18.43*125)/ [(0.8^2)*(387.35^{1.854})]$

K=$9.105891071 * 10^{-10}$

Q=1219.183015 m^3/hr

$P_2^2 = (20)^2 + [(9.105891071*10^{-10})*(1219.183015^{1.854})]$

P_2 =20.00001199 bar

FOR JOINT H → I TO H

K= $(18.43*750)/ [(0.8^2)*(387.35^{1.854})]$

K=$5.463534643 * 10^{-9}$

Q=2580.640335 m^3/hr

$P_2^2 = (20)^2 + [(5.463534643*10^{-9})*(2580.640335^{1.854})]$

P_2 =20.0002889 bar

FOR JOINT G → H TO G

K= $(18.43*250)/ [(0.8^2)*(387.35^{1.854})]$

K=31.821178214 * 10^{-9}

Q=2639.835075m^3/hr

$P_2^2 = (20)^2 + [(1.821178214*10^{-9})*(2639.835075^{1.854})]$

P_2 =20.00010044 bar

FOR JOINT F → G TO F

K= $(18.43*1125)/ [(0.8^2)*(387.35^{1.854})]$

K=8.195301964 * 10^{-9}

Q=2864.779375 m^3/hr

$P_2^2 = (20)^2 + [(8.195301964*10^{-9})*(2864.779375^{1.854})]$

P_2 =20.00052595 bar

FOR JOINT E → F TO E

K= $(18.43*5750)/ [(0.8^2)*(387.35^{1.854})]$

K=$4.188709893 * 10^{-8}$

Q=3527.756082 m^3/hr

$P_2^2 = (20)^2 + [(4.188709893*10^{-8})*(3527.756082^{1.854})]$

P_2 =20.00395403 bar

FOR JOINT D → E TO D

K= $(18.43*1125)/ [(0.8^2)*(387.35^{1.854})]$

K=$8.195301964 * 10^{-9}$

Q=3646.14555 m^3/hr

$P_2^2 = (20)^2 + [(8.195301964*10^{-9})*(3646.14555^{1.854})]$

P_2 =20.0008225 bar

FOR JOINT C → D TO C

K= $(18.43*375)/ [(0.8^2)*(387.35^{1.854})]$

K=$2.731767321 * 10^{-9}$

Q=3720.559323 m^3/hr

$P_2^2 = (20)^2 + [(2.731767321*10^{-9})*(3720.559323^{1.854})]$

P_2 =20.00028463 bar

FOR JOINT *B* → C TO B

K= $(18.43*675)/ [(0.8^2)*(387.35^{1.854})]$

K=$4.917181179 * 10^{-9}$

Q=3838.94879 m^3/hr

$P_2^2 = (20)^2 + [(4.91781179*10^{-9})*(3838.94879^{1.854})]$

P_2 =20.0054298 bar

FOR JOINT A → B TO A

K= $(18.43*1875)/ [(0.8^2)*(387.35^{1.854})]$

K=$1.365883661 * 10^{-8}$

Q=3894.004635 m^3/hr

$P_2^2 = (20)^2 + [(1.365883661*10^{-8})*(3894.004635^{1.854})]$

P_2 =20.00154857 bar

At CGS → A TO CGS

K= (18.43*825)/ [(0.8^2)*$(387.35^{1.854})$]

K=6.009888107 * 10^{-9}

Q=4059.754201 m^3/hr

$P_2^2 = (20)^2 + [(6.009888107*10^{-9})*(4059.754201^{1.854})]$

P_2 =20.00073615 bar

<u>Hence Mainline Calculations</u>

A = 20.00154857 bar

B = 20.0054298 bar

C = 20.00028463 bar

D = 20.0008225 bar

E = 20.00395403 bar

F = 20.00052595 bar

G = 20.00010044 bar

H = 20.0002889 bar

I = 20.00001199 bar

J = 20.00020732 bar

K = 20.00012871 bar

L = 20.00000563 bar

M = 20.00001507 bar

N = 20.00000049bar

O = 20.00000042 bar

Mainline Joint Nodes to Single Step DRS/CNG/IPRS Inlet Pressure Calculation

At DRS 1

K= $(18.43*1450)/ [(0.8^2)*(387.35^{1.854})]$

K= $1.056283364 * 10^{-8}$

Q= $165.749566\ m^3/hr$

$P_2^2 = (20.00154857)^2 + [(1.056283364*10^{-8})*(165.749566^{1.854})]$

P_2 =20.00155201 bar

At DRS 2

K= $(18.43*625)/ [(0.8^2)*(387.35^{1.854})]$

K=$4.552945536 * 10^{-9}$

Q=55.05584492 m^3/hr

$P_2^2 = (20.0054298)^2 + [(4.552945536*10^{-9})*(55.05584492^{1.854})]$

P_2 =20.00542999 bar

At DRS 3

K= $(18.43*480)/ [(0.8^2)*(387.35^{1.854})]$

K=$3.455684951 * 10^{-9}$

Q=118.3894676 m^3/hr

$P_2^2 = (20.00028463)^2 + [(3.455684951*10^{-9})*(118.3894676^{1.854})]$

P_2 =20.00028523 bar

At CNG 1

K= $(18.43*225)/ [(0.8^2)*(387.35^{1.854})]$

K=$1.639060393 * 10^{-9}$

Q=74.41377317 m^3/hr

$P_2^2 = (20.0008225)^2 + [(1.639060393*10^{-9})*(74.41377317^{1.854})]$

P_2 =20.00082262 bar

At DRS 4

K= (18.43*10000)/ [(0.8^2)*(387.35$^{1.854}$)]

K=7.284712857* 10^{-8}

Q=118.3894676 m^3/hr

$P_2^2 = (20.00395403)^2 + [(7.284712857*10^{-8})*(118.2894676^{1.854})]$

P_2 =20.00396674 bar

At DRS 6

K= (18.43*1625)/ [(0.8^2)*(387.35$^{1.854}$)]

K=1.183765839 * 10^{-9}

Q=224.9442998m^3/hr

$P_2^2 = (20.00010044)^2 + [(1.183765839*10^{-9})*(224.9442998^{1.854})]$

P_2 =20.00010112 bar

At DRS 7

K= (18.43*975)/ [(0.8^2)*(387.35$^{1.854}$)]

K=7.102595036 * 10^{-9}

Q=59.19474005m^3/hr

P_2^2 = (20.0002889)^2 + [(7.102595036*10^{-9})*(59.19474005$^{1.854}$)]

P_2 =20.00028924 bar

At CNG 2

K= (18.43*250)/ [(0.8^2)*(387.35$^{1.854}$)]

K=1.821178214 * 10^{-9}

Q=60.44502317 m^3/hr

P_2^2 = (20.00020732)^2 + [(1.821178214*10^{-9})*(60.44502317$^{1.854}$)]

P_2 =20.00020741 bar

At IPRS 3

K= (18.43*325)/ [(0.8^2)*(387.35$^{1.854}$)]

K=2.367531679 * 10^{-9}

Q=59.19473379m^3/hr

$P_2^2 = (20.00012871)^2 + [(2.367531679*10^{-9})*(59.19473379^{1.854})]$

P_2 =20.00012882 bar

At CNG 3

K= $(18.43*250)/ [(0.8^2)*(387.35^{1.854})]$

K=$1.821178214 * 10^{-9}$

Q=50.0546875 m^3/hr

$P_2^2 = (20.00001507)^2 + [(1.821178214*10^{-9})*(50.0546875^{1.854})]$

P_2 =20.00001513 bar

At DRS 12

K= $(18.43*625)/ [(0.8^2)*(387.35^{1.854})]$

K=$4.552945536 * 10^{-9}$

Q=295.973669 m^3/hr

$P_2^2 = (20.00000049)^2 + [(4.552945536*10^{-9})*(295.973669^{1.854})]$

P_2 =20.00000483 bar

At CNG 4

$\mathbf{K}$= (18.43*625)/ [(0.8^2)*(387.35$^{1.854}$)]

$\mathbf{K}$=4.552945536 * 10^{-9}

$\mathbf{Q}$=43.17809608 m^3/hr

P_2^2 = (20.00000042)^2 + [(4.552945536*10^{-9})*(43.17809608$^{1.854}$)]

P_2 =20.00000054 bar

F to IPRS 1 and DRS 5

For Joint P

P_1 =20.00052595 bar

F to P

$\mathbf{K}$= (18.43*4000)/ [(0.8^2)*(387.35$^{1.854}$)]

$\mathbf{K}$=2.913885143 * 10^{-8}

$\mathbf{Q}$=662.9767071 m^3/hr

P_2^2 = (20.00052595)^2 + [(2.913885143*10^{-8})*(662.9767071$^{1.854}$)]

P_2 =20.00064996 bar

For IPRS 1

K= $(18.43*1125)/ [(0.8^2)*(387.35^{1.854})]$

K= $8.195301964 * 10^{-9}$

Q= $591.9473379 m^3/hr$

$P_2^2 = (20.00064996)^2 + [(8.195301964*10^{-9})*(591.9473379^{1.854})]$

P_2 =20.00067823 bar

For DRS 5

K= $(18.43*1250)/ [(0.8^2)*(387.35^{1.854})]$

K= $9.105891071 * 10^{-9}$

Q= $71.02936921 m^3/hr$

$P_2^2 = (20.00064996)^2 + [(9.105891071*10^{-9})*(71.02936921^{1.854})]$

P_2 =20.00065058 bar

I to IPRS 2 and DRS 8

For Joint Node Q

P_1 =20.00001199 bar

I to Q

K= $(18.43*2000)/ [(0.8^2)*(387.35^{1.854})]$

K=$1.456942571 * 10^{-8}$

Q=1361.45732 m^3/hr

$P_2^2 = (20.00001199)^2 + [(1.456942571*10^{-8})*(1361.45732^{1.854})]$

P_2 =20.0002474 bar

For IPRS 2

K= $(18.43*7500)/ [(0.8^2)*(387.35^{1.854})]$

K=$5.463534643 * 10^{-8}$

Q=1124.678385 m^3/hr

$P_2^2 = (20.0002474)^2 + [(5.463534643*10^{-8})*(1124.678385^{1.854})]$

P_2 =20.00086685 bar

For DRS 8

K= (18.43*250)/ [(0.8^2)*(387.35$^{1.854}$)]

K=1.821178214 * 10^{-9}

Q=236.7789352m^3/hr

P_2^2 = (20.0002474)^2 + [(1.821178214*10^{-9})*(236.7789352$^{1.854}$)]

P_2 =20.00024855 bar

L to DRS 9, DRS 10 and DRS 11

For Joint Node Q

P_1 =20.00000563 bar

L to R

K= (18.43*750)/ [(0.8^2)*(387.35$^{1.854}$)]

K=5.463534643 * 10^{-9}

Q=651.1420717m^3/hr

P_2^2 = (20.00000563)^2 + [(5.463534643*10^{-9})*(651.1420717$^{1.854}$)]

P_2 =20.00002812 bar

For DRS 9

P_1 =20.00002812 bar

K= (18.43*250)/ [(0.8^2)*(387.35$^{1.854}$)]

K=1.821178214 * 10^{-9}

Q=177.5842014m^3/hr

P_2^2 = (20.00002812)^2 + [(1.821178214*10^{-9})*(177.5842014$^{1.854}$)]

P_2 =20.00002879 bar

For Node S

R to S

K= (18.43*1000)/ [(0.8^2)*(387.35$^{1.854}$)]

K=7.284712857* 10^{-9}

Q=473.5578704m^3/hr

P_2^2 = (20.00002812)^2 + [(7.284712857*10^{-9})*(473.5578704$^{1.854}$)]

P_2 =20.00004473 bar

For DRS 10

$\mathbf{K}$= (18.43*350)/ [(0.8^2)*(387.35$^{1.854}$)]

$\mathbf{K}$=2.5496495 * 10^{-9}

$\mathbf{Q}$=236.7789352m^3/hr

P_2^2 = (20.00004473)^2 + [(2.5496495*10^{-9})*(236.7789352$^{1.854}$)]

P_2 =20.00004634 bar

For DRS 11

$\mathbf{K}$= (18.43*1875)/ [(0.8^2)*(387.35$^{1.854}$)]

$\mathbf{K}$=1.365883661 * 10^{-8}

$\mathbf{Q}$=236.7789352 m^3/hr

P_2^2 = (20.00004473)^2 + [(1.365883661*10^{-8})*(236.7789352$^{1.854}$)]

P_2 =20.00005335 bar

Hence the pressure at the outlet of CGS is =**20.00078082bar**

= **290.0868008psi**

Design Factors for Steel Pipe

The following Safety factors are considered for designing of Steel pipeline:-

1 Location Factor

The description of various class of locations described and the recommended safety factors for each class is given in the table below:

Table 7.2 : - Loacation Factor[2]

Class Location	Design Factor, F
1	0.72
2	0.60
3	0.50
4	0.40

- **Class 1:-**Offshore gas pipelines are class 1 locations. For onshore pipelines, any class location unit that has 10 otherwise fewer buildings intended for human occupancy is termed as Class 1.

- **Class 2:-**The class location unit has more than 10 but lesser than 46 buildings intended to human occupancy.

- **Class 3:-**The Class location unit which has 46 or more buildings intended for human living or area where the pipeline is within 100 yards of a building or a playground, outdoor theatre, or any place of public assembly which is taken up by 20 or more people at least 5 days a week for 10 weeks in any 12 month time. The days and weeks needn't to be in regular interval.

- **Class 4:-** The Class location unit that has buildings with four or more stories existing above the ground level.

2 Pipe Seam Joint Factor

Steel pipes are manufactured using variable types of welding processes and for each different type of welding process we have to use proper pipe seam joint factor for our calculation. The complete detail about these factors is given below:

Table 7.3: - Pipe Seam Joint Factor [2]

Table 4.4 Pipe Seam Joint Factor

Specification	Pipe Class	Seam Joint Factor, *E*
ASTM A53	Seamless	1
	Electric resistance welded	1
	Furnace lap welded	0.8
	Furnace butt welded	0.6
ASTM A106	Seamless	1
ASTM A134	Electric fusion arc welded	0.8
ASTM A135	Electric resistance welded	1
ASTM A139	Electric fusion welded	0.8
ASTM A211	Spiral welded pipe	0.8
ASTM A333	Seamless	1
ASTM A333	Welded	1
ASTM A381	Double submerged	
	Arc welded	1
ASTM A671	Electric fusion welded	1
ASTM A672	Electric fusion welded	1
ASTM A691	Electric fusion welded	1
API 5L	Seamless	1
	Electric resistance welded	1
	Electric flash welded	1
	Submerged arc welded	1
	Furnace lap welded	0.8
	Furnace butt welded	0.6
API 5LX	Seamless	1
	Electric resistance welded	1
	Electric flash welded	1
	Submerged arc welded	1
API 5LS	Electric resistance welded	1
	Submerged arc welded	1

3 Temperature Deration Factor

The temperature deration factor purely depends upon the temperature of gas flow inside the pipeline and its values are mentioned below:

Table 7.4: - Deration Factor [2]

Temperature		Derating Factor T
°F	°C	
250 or less	121 or less	1.000
300	149	0.967
350	177	0.033
400	204	0.900
450	232	0.867

Thickness of the pipeline diameter: - $t = \frac{P*D}{2*T*s*E*F}$ [1]

$$t = \frac{290.0868008*16}{2*42000*0.4*1*1}$$

= **0.138 inches**

So, according to **API 5L** under **X 42** grade we choose **0.375 inch** thickness for the steel pipe.

To Calcalulate Maximum Allowable Operating Pressure(MAOP) of the pipeline:-

$$P=\frac{2*T*s*E*F}{D}$$ [1]

P = (0.375*2*42000*0.4*1*1/16)

= 787.5 psi

MAOP = 54.296 bar

Hence the selected diameter and thickness is totally correct because in city gas distribution system of high pressure network the operating pressure range is **19 to 49 bar** and our designed pipeline **MAOP** is **54.296 bar**. So, our pipeline is under safe limit.

7.3 MEDIUM PRESSURE PIPELINE NETWORK (MDPE)

The medium density polyethylene pipeline has got different grades. The grades which are used generally for city gas distribution are **PE 80** and **PE 100** and most of the time **PE 100** with **MRS 10**(Minimum Required Strength) is used for standard piping because of characteristics of regaining its shape just after squeezing.

The distribution pipe is selected based on **Standard Dimension Ratio** (**SDR 9**) for **20** mm, (**SDR**) **11** from **32** mm up to **63** mm & (**SDR**) 17.6 for above **63** mm. The term **SDR** is defined as the normal outside diameter (**DN**) divided by the minimum wall thickness. It is standard practice in India to have a minimum **1.0** meter cover. This additional depth in a densely populated area would be recommended. All MDPE pipe back filled with sand around it to protect the plastic material.

The key features of Medium Pressure Network are:

- **Tech Spec**: IS 14885:2001 & ISO 4437.
- **Material Grade & Color**: Internationally approved resins of PE 100 grade of Orange color.
- **Minimum Required Strength** (MRS) of PE 100 grade pipe: 10 MPa.
- **Pressure Class**: SDR 9 (dia 20 mm), SDR 11 (dia 32 & 63 mm) and SDR 17.6 (dia 90, 110, 125 and 160 mm).
- **Operating pressure**: 4 bar (g).
- **Operating temperature range**: - 10 ^{0}C to + 40 ^{0}C.
- MDPE network originates from district regulating station which is connected to the high grid pressure.
- Method of joining used is electro fusion.
- Isolation valves are provided at strategic locations.

MDPE Fittings

- Tech Spec: ISO 8085-3 or EN 1555-3
- Material Grade: PE 100
- Terminal pin size: 4 or 4.7 mm
- Voltage: 39 – 40 Volts.
- Color: Black

Design for MDPE Pipeline

In designing of MDPE pipeline we have to design given parameters:-

- MDPE pipe diameter.
- Pipe MAOP.
- Wall thickness of the Pipe.

In order to calculate the above things we have to calculate the **Standard Dimension Ratio (SDR).** Once we calculate the SDR we can easily calculate the MAOP with MAOP and SDR given relation:

Standard Dimension Ratio: - It is the ratio of nominal outside diameter of pipe to nominal thickness of the pipe.

$$\mathbf{SDR = D_n / E_n}$$ [2]

Where, d_n =Nominal outside Diameter of the pipe

e_n =Nominal wall thickness of the pipe (minimum)

SDR used in MDPE network for City Gas distribution are **SDR 9**, **SDR 11** & **SDR 17.6.**

MRS (Minimum Required Strength)

The MRS value represents the long-term circumferential stress in the pipe under which the break may occur after 50 years at the earliest.

Stress, S = MRS / C [2], where **C** is overall service coefficient, **MRS =10**

The value of C for the material to be used for Gas application is 2-3=**2.85**

MAOP (Max. allowable Operating Pressure)

$$\textbf{MAOP} = (20 * \textbf{MRS}) / [C * (\textbf{SDR}-1)].$$ [2]

Table 7.5: - Standard Dimensional Ratio [2]

PE 63 Nominal working Pressure HDS 5MPa								(Class) PN 3.2				(Class) PN 4			
PE 80 Nominal working Pressure HDS 6.3MPa				(Class) PN 3.2				(Class) PN 4							
PE 100 Nominal working Pressure HDS 8MPa				(Class) PN 4								(Class 6) PN 6.3			
Standard diameter ratio				SDR 41				SDR 33				SDR 26			
Nominal size mm	Mean outside diameter		Maximum out of roundness	Wall thickness t		Pipe ID and mass		Wall thickness t		Pipe ID and mass		Wall thickness t		Pipe ID and mass	
	Min	Max	Ovality	Min	Max	ID	Kg/m	Min	Max	ID	Kg/m	Min	Max	ID	Kg/m
16	16	16.3	1.20												
20	20	20.3	1.20												
25	25	25.3	1.20												
32	32	32.3	1.30									1.6	1.9	29	0.16
40	40	40.4	1.40									1.6	1.9	37	0.20
50	50	50.5	1.40	1.6	1.9	47	0.25	1.6	1.9	47	0.25	1.9	2.3	46	0.30
63	63	63.6	1.50	1.6	1.9	60	0.32	1.9	2.2	59	0.38	2.4	2.8	58	0.48
75	75	75.7	1.60	1.8	2.1	71	0.43	2.3	2.6	70	0.53	2.9	3.3	69	0.67
90	90	90.9	1.80	2.2	2.5	86	0.62	2.7	3.1	85	0.77	3.5	4.0	83	0.97
110	110	111.0	2.20	2.7	3.1	105	0.93	3.3	3.8	103	1.15	4.2	4.9	101	1.45
125	125	126.2	2.50	3.0	3.5	119	1.20	3.8	4.4	117	1.48	4.8	5.5	115	1.87
140	140	141.3	2.80	3.4	3.9	133	1.51	4.2	4.9	132	1.86	5.4	6.2	129	2.34
160	160	161.5	3.20	3.9	4.4	152	1.94	4.8	5.4	150	2.40	6.2	6.9	148	3.02
180	180	181.7	3.60	4.4	4.9	172	2.46	5.5	6.1	169	3.04	6.9	7.8	166	3.82
200	200	201.8	4.00	4.9	5.5	191	3.03	6.1	6.8	188	3.75	7.7	8.6	185	4.71
225	225	227.1	4.50	5.5	6.1	214	3.83	6.8	7.6	212	4.73	8.7	9.6	208	5.95
250	250	252.3	5.00	6.1	6.8	238	4.73	7.6	8.4	235	5.84	9.6	10.7	231	7.35
280	280	282.6	9.80	6.8	7.6	267	5.94	8.5	9.5	263	7.33	10.8	12.0	259	9.22
315	315	317.9	11.10	7.7	8.6	300	7.51	9.5	10.6	296	9.27	12.1	13.5	291	11.67
355	355	358.2	12.50	8.7	9.7	338	9.54	10.8	12.0	334	11.78	13.7	15.2	328	14.82
400	400	403.6	14.00	9.8	10.9	381	12.11	12.1	13.5	376	14.95	15.4	17.2	369	18.81
450	450	454.1	15.60	11.0	12.2	429	15.29	13.6	15.1	423	18.88	17.3	19.2	416	23.75
500	500	504.5	17.50	12.2	13.5	477	18.88	15.2	16.8	470	23.31	19.2	21.3	462	29.32
560	560	565.0	19.60	13.7	15.2	534	23.68	17.0	18.8	527	29.24	21.5	23.9	517	36.78
630	630	635.7	22.10	15.4	17.1	600	29.98	19.1	21.2	593	37.01	24.2	26.9	582	46.56

PE 63 Nominal working Pressure HDS			5MPa					(Class 6) PN 6.3				(Class) PN 8			
PE 80 Nominal working Pressure HDS			6.3MPa	(Class 6) PN 6.3				(Class) PN 8				(Class) PN 10			
PE 100 Nominal working Pressure HDS			8MPa	(Class) PN 8				(Class) PN 10				(Class) PN 12.5			
Standard diameter ratio				SDR 21				SDR 17				SDR 13.6			
Nominal size mm	Mean outside diameter		Maximum out of roundness	Wall thickness t		Pipe ID and mass		Wall thickness t		Pipe ID and mass		Wall thickness t		Pipe ID and mass	
	Min	Max	Ovality	Min	Max	ID	Kg/m	Min	Max	ID	Kg/m	Min	Max	ID	Kg/m
16	16	16.3	1.20												
20	20	20.3	1.20									1.6	1.9	17	0.10
25	25	25.3	1.20					1.6	1.9	22	0.12	1.8	2.2	21	0.14
32	32	32.3	1.30	1.6	1.9	29	0.16	1.9	2.2	28	0.18	2.4	2.8	27	0.23
40	40	40.4	1.40	1.9	2.2	36	0.24	2.4	2.8	35	0.29	2.9	3.4	34	0.35
50	50	50.5	1.40	2.4	2.8	45	0.37	2.9	3.4	44	0.45	3.7	4.3	42	0.55
63	63	63.6	1.50	3.0	3.5	57	0.59	3.7	4.3	55	0.72	4.6	5.4	53	0.88
75	75	75.7	1.60	3.6	4.1	68	0.82	4.4	5.1	66	1.00	5.5	6.3	63	1.23
90	90	90.9	1.80	4.3	4.9	81	1.19	5.3	6.1	79	1.45	6.6	7.6	76	1.78
110	110	111.0	2.20	5.2	6.0	99	1.77	6.5	7.4	97	2.16	8.1	9.3	93	2.66
125	125	126.2	2.50	6.0	6.8	113	2.29	7.4	8.5	110	2.79	9.2	10.6	106	3.43
140	140	141.3	2.80	6.7	7.7	126	2.87	8.2	9.5	123	3.50	10.3	11.8	119	4.30
160	160	161.5	3.20	7.6	8.5	145	3.70	9.4	10.5	141	4.51	11.8	13.2	136	5.55
180	180	181.7	3.60	8.6	9.6	163	4.68	10.6	11.9	158	5.71	13.2	14.8	153	7.02
200	200	201.8	4.00	9.5	10.7	181	5.78	11.8	13.2	176	7.05	14.7	16.5	170	8.66
225	225	227.1	4.50	10.7	11.9	203	7.30	13.2	14.8	198	8.90	16.5	18.4	191	10.95
250	250	252.3	5.00	11.9	13.3	226	9.01	14.7	16.4	220	10.99	18.4	20.5	212	13.51
280	280	282.6	9.80	13.3	14.9	253	11.30	16.5	18.4	246	13.79	20.6	23.0	238	16.95
315	315	317.9	11.10	15.0	16.7	285	14.30	18.5	20.7	277	17.45	23.2	25.8	267	21.45
355	355	358.2	12.50	16.9	18.8	321	18.16	20.9	23.3	312	22.16	26.1	29.1	301	27.24
400	400	403.6	14.00	19.0	21.2	352	23.06	23.5	26.2	352	28.13	29.4	32.8	340	34.58
450	450	454.1	15.60	21.4	23.8	407	29.12	26.5	29.4	396	35.52	33.1	33.7	382	43.68
500	500	504.5	17.50	23.8	26.4	452	35.94	29.4	32.6	440	43.85	36.8	40.8	425	53.92
560	560	565.0	19.60	26.7	29.6	506	45.08	32.9	36.6	493	55.00	41.2	45.7	476	67.63
630	630	635.7	22.10	30.0	33.3	570	57.07	37.1	41.1	555	69.62	46.3	51.4	535	85.60

PE 63 Nominal working Pressure HDS			5MPa	(Class) PN 10				(Class) PN 12.5				(Class) PN 16			
PE 80 Nominal working Pressure HDS			6.3MPa	(Class) PN 12.5				(Class) PN 16				(Class) PN 20			
PE 100 Nominal working Pressure HDS			8MPa	(Class) PN 16				(Class) PN 20				(Class) PN 25			
Standard diameter ratio				SDR 11				SDR 9				SDR 7.4			
Nominal size mm	Mean outside diameter		Maximum out of roundness	Wall thickness t		Pipe ID and mass		Wall thickness t		Pipe ID and mass		Wall thickness t		Pipe ID and mass	
	Min	Max	Ovality	Min	Max	ID	Kg/m	Min	Max	ID	Kg/m	Min	Max	ID	Kg/m
16	16	16.3	1.20	1.6	1.9	13	0.08	1.8	2.1	12	0.08	2.2	2.5	11	0.10
20	20	20.3	1.20	1.8	2.1	16	0.11	2.2	2.6	15	0.13	2.7	3.2	14	0.15
25	25	25.3	1.20	2.3	2.7	20	0.17	2.8	3.3	19	0.20	3.4	4.0	18	0.24
32	32	32.3	1.30	2.9	3.4	26	0.27	3.6	4.2	24	0.33	4.3	5.1	23	0.39
40	40	40.4	1.40	3.6	4.3	32	0.43	4.4	5.2	31	0.51	5.4	6.3	28	0.60
50	50	50.5	1.40	4.5	5.3	40	0.67	5.6	6.5	38	0.80	6.8	7.9	36	0.94
63	63	63.6	1.50	5.7	6.7	51	1.06	7.0	8.2	48	1.27	8.5	10.0	45	1.50
75	75	75.7	1.60	6.8	7.8	61	1.50	8.3	9.6	57	1.78	10.1	11.7	54	2.11
90	90	90.9	1.80	8.2	9.4	73	2.16	10.0	11.5	69	2.57	12.2	14.0	64	3.04
110	110	111.0	2.20	10.0	11.5	89	3.22	12.2	14.1	84	3.84	14.9	17.1	79	4.53
125	125	126.2	2.50	11.4	13.1	101	4.16	13.9	16.0	96	4.96	16.9	19.4	89	5.86
140	140	141.3	2.80	12.7	14.6	113	5.21	15.6	17.9	107	6.22	18.9	21.8	100	7.34
160	160	161.5	3.20	14.5	16.3	130	6.72	17.8	19.9	123	8.02	21.6	24.2	115	9.48
180	180	181.7	3.60	16.4	18.3	146	8.51	20.0	22.4	138	10.16	24.3	27.2	129	12.00
200	200	201.8	4.00	18.2	20.4	162	10.50	22.2	24.9	154	12.53	27.0	30.3	144	14.81
225	225	227.1	4.50	20.5	22.8	183	13.27	25.0	27.9	173	15.83	30.4	33.9	162	18.71
250	250	252.3	5.00	22.7	25.3	203	16.38	27.8	31.0	192	19.55	33.8	37.7	180	23.10
280	280	282.6	9.80	25.5	28.4	227	20.54	31.1	34.7	216	24.52	37.8	42.2	201	28.97
315	315	317.9	11.10	28.6	31.9	256	26.00	35.0	39.0	242	31.03	42.6	47.5	226	36.67
355	355	358.2	12.50	32.3	36.0	288	33.01	39.4	44.0	273	39.41	48.0	53.5	255	46.56
400	400	403.6	14.00	36.4	40.5	325	41.91	44.4	49.6	308	50.03	54.1	60.3	287	59.11
450	450	454.1	15.60	40.9	45.4	366	52.94	50.0	55.5	347	63.19	60.8	67.5	324	74.67
500	500	504.5	17.50	45.5	50.5	406	65.36	55.6	61.7	385	78.01				
560	560	565.0	19.60	50.9	56.5	455	81.97								
630	630	635.7	22.10	57.3	63.6	512	103.75								

Base resin

The PE resins of "Third Generation" (**PE 100** or MRS 10) in full compliance with detailed specification are being used. First Generation is PE **63;** second PE **80** & Third generation is **PE 100**.

Wall thickness

The MDPE network designed and qualified for a MOP of 4 bars.

The "Network analysis" and resulting structure and behaviors are based on such design. PE line pipes wall thickness is in accordance with the following SDR:

- Gas mains (ND ≥ 90 mm): **SDR 17.6**
- Gas mains and Service lines (ND ≤ 90 mm): **SDR 11**.
- Service lines (ND = 20 mm): **SDR 9**

Now using the different values:

SDR 9

MAOP = (MRS*20)/ [(C (SDR-1)]

=20*10[(2.85(9-1)]

MAOP = 8.7719 bar

SDR 11

MAOP = (MRS*20)/ [(C (SDR-1)]

=20*10[(2.85(11-1)]

MAOP = 7.0175 bar

SDR 17.6

MAOP = (MRS*20)/ [(C (SDR-1)]

=20*10[(2.85(17.6-1)]

MAOP = 4.2274 bar

Hence the Maximum Operating Pressures of PE 100 of different **SDR**s are:-

- **SDR 9 =** 8.7719 bar
- **SDR 11** = 7.0175 bar
- **SDR 17.6** = 4.2274 bar

All the MAOP values are well above the maximum operating pressure rating which is **4 bars.** So we can choose anyone of the above pipe type.

Hence the best possible type will be **PE 100 SDR 11** size with an **MAOP** of **7.0175 bars.**

7.4 LOW PRESSURE PIPELINE (GI/CU PIPELINE)

The key features of low pressure network are mentioned below:

- The pressure range for GI/Cu pipes is 21 to 75 mbar.
- GI pipes are used as per the standard of **IS-1239** and **IS-1879.**
- The Cu pipes used as per standard of **BS EN 1057.**
- The standard GI/Cu pipes used are
- GI:- $\frac{1}{2}$" & $\frac{3}{4}$"
- Cu:-12mm
- GI pipes are installed on the walls of the buildings and is connected to medium pressure grid of PE network by transition fitting.
- Main risers are of higher size and then the pipe is reduced inside the kitchen and option of copper pipe installation is also available.
- GI pipes are routed considering safety and economics so as to cater all the customers.

GI ERW Pipes

- Tech Spec: IS 1239 (Part 1)
- Types used: Medium Class and Heavy Class
- Material: IS 1387
- Pipes shall be screwed with Taper threads
- Threads: Tapered and conforming to BS 21
- Galvanizing: IS 4736
- Coating requirements: Mass of coating is 400 gms / m^2
- Test Pressure: 5 MPa
- Powder Coating:
  - Powder Material: Pure Polyester
  - Application: Electrostatic spraying (40 – 90 KV, Manual / Automatic)

Route Selection for GI / Copper Pipe Installation

Route selection for GI pipe installation shall be carried out as per the guideline given below:

- Pipe shall not be installed on un-plastered wall or in the house under construction.
- Pipe shall not be installed in an unventilated void space.
- Route shall be selected that maximum length of the pipeline shall be installed outside.
- Route of the pipeline shall be planned for the shortest possible length.
- The gas pipeline shall be away (minimum distance of 200mm) from the electrical line.
- There shall be minimum change of directions and minimum no of threaded joints.
- Maximum two Point in the kitchen for gas stove only.
- Compound gate or doors and windows inside the house shall not hit the Gas pipeline.
- Copper installation should be a minimum 300mm away from heat source and Electrical installations. If it is not possible for copper installation then suitable protection should be given.
- If the copper pipe installation is carried out inside cupboards, there should be a provision for adequate ventilation like louvers/holes in cupboard doors.

Positioning of Valves, Regulator & Meter

Riser Isolation Valve:

- For apartments, one riser isolation valve shall be provided at a height of 2 meter
- From the ground and individual meter control valve shall be installed for each connection.
- The riser isolation valve shall be installed at a convenient height so that it is easy to operate the valve in emergency.

Meter Regulator:

- Regulator shall be installed in such a way that it reduces the length of H.P. Line (Max. pressure 0.1 Bar) to minimum possible.
- The Meter Regulator shall always be installed outside the residence and at a convenient height.

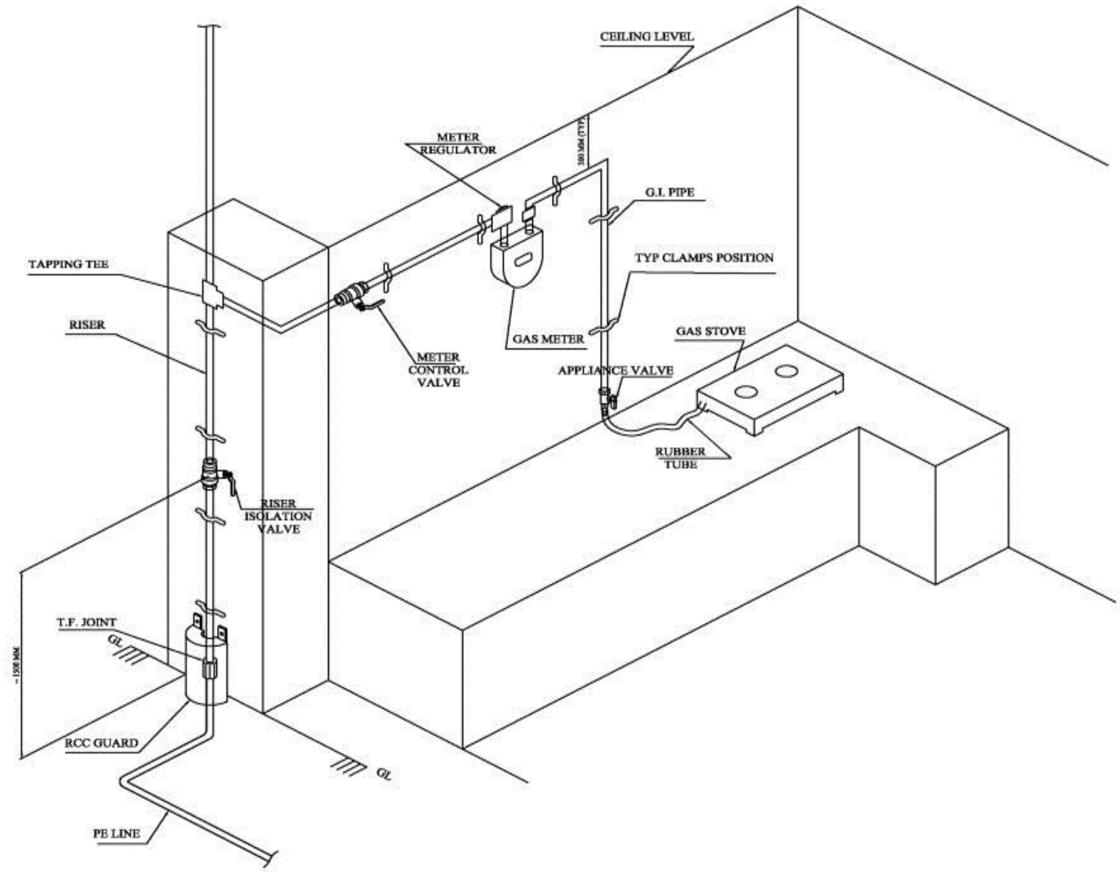


Figure 7.3: - Low pressure distribution system

<u>Note</u>: - In low pressure network from a single regulator we have 1 to 75 domestic user connection .So, it is very simulate such a huge network by manual calculation. Hence, in the next chapter a small network has been shown to understand how these networks are simulated.

CHAPTER 8: - NETWORK ANALYSIS

8.1 ANALYSIS OF LOW PRESSURE NETWORK (UNDERSTANDING PURPOSE)

Computer simulation allows us to study the properties of gas networks by means of mathematical models of gas flows in pipes. If we assume that the mathematical models are adequate, simulation allows us to get a detailed knowledge of the real properties of the properties of the networks. We distinguish simulation of networks in steady and unsteady states. A network is in steady state when the values of the quantities characterizing the flow of gas in the system are independent of time and the system is described by a set of non-linear algebraic equations. The problem of simulation of gas networks in steady state is usually that of computing the values of node pressures and the values of flows in the individual pipes for known values of source pressures and of gas consumption in the nodes. The aim of static simulation is to estimate the values of pressures at the nodes and of flow rates in the pipes. The pressures at the nodes and the flow rates in the pipes must satisfy the flow equation and together with the values of loads and values of sources must fulfill the first and second **Kirchhoff's Laws** [1].

KIRCHHOFF'S FIRST LAW: - It states that the algebraic sum of all the flows at any node is zero. This means that the load at any node is equal to the sum of the branch flows into and out of the node:-

$$\sum Q=0$$

Consider the network given below:-

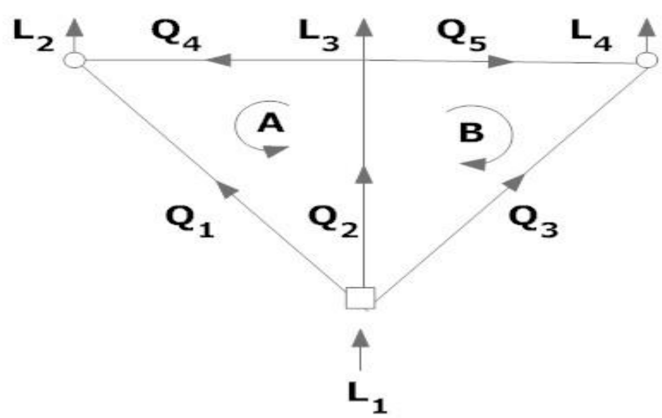


Figure 8.1: - Network Diagram

From Kirchhoff's first law, the nodal equations of this network are:-

$$\begin{array}{rrrrrcl} -Q_1 & -Q_2 & -Q_3 & & & = & -L_1 \\ Q_1 & & & +Q_4 & & = & L_2 \\ & Q_2 & & -Q_4 & -Q_5 & = & L_3 \\ & & Q_3 & & +Q_5 & = & L_4 \end{array} \qquad (11.1)$$

Node 1 is the reference node and its pressure is independent of the load at the node. Since Node 1 is the source node, the load $\mathbf{L_1}$ is the inflow to the network and is equal to the sum of loads on the network i.e. ($\mathbf{L_1=L_2+L_3+L_4}$). In the first equation of the set $\mathbf{L_1}$ is given a negative sign since the positive sign convention for a load is a flow out of the node (i.e. a demand).

General form of nodal equation:-

$$\mathbf{L} = \sum_{j=1}^{m} aijQj \quad i = 1 \ldots\ldots\ldots n_1 \qquad (11.2)$$

Matrix form: -

$$\mathbf{L=A_1Q} \qquad (11.3)$$

Where: **L**=vector of loads at the load nodes, of dimension n.

Q=vector of flows in the branches, of dimension m

$\mathbf{A_1}$=reduced branch-nodal incidence matrix

The pressure drops in the branches can be related to the nodal pressures.

$$\begin{aligned} \Delta P_1 &= P_1 - P_2 \\ \Delta P_2 &= P_1 - P_3 \\ \Delta P_3 &= P_1 - P_4 \\ \Delta P_4 &= -P_2 + P_3 \\ \Delta P_5 &= P_3 - P_4 \end{aligned} \qquad (11.4)$$

General form: -

$$\Delta P_J = \sum_{j=1}^{m} -aijPj \quad j = 1 \ldots\ldots\ldots m \qquad (11.5)$$

Matrix form: -

$$\Delta P = -A^T P \qquad (11.6)$$

Where: **ΔP**=vector of pressure drops in the branches, of dimension m.

Q=vector of nodal pressures, of dimension n.

A_1=transpose of branch-nodal incidence matrix

But, **$Q=\phi' (\Delta P)$** So, **$Q=\phi' (-A^T P)$**

Hence

$$L = A_1 [\phi' (-A^T P)] \qquad (11.7)$$

KIRCHHOFF'S SECOND LAW: - This law states that the pressure drop around any closed loop is zero. A closed loop starts and finishes at the same node so there can be no pressure drop around the loop.

$$\sum \Delta P = 0$$

For the network shown previously, the loop equations are:-

$$\begin{aligned} &\textbf{Loop A: -} \quad -\Delta P_1 + \Delta P_2 \qquad + \Delta P_4 \qquad = 0 \\ &\textbf{Loop B: -} \qquad\qquad + \Delta P_2 - \Delta P_3 \qquad + \Delta P_5 = 0 \end{aligned} \qquad \textbf{(11.8)}$$

The sign convention is that ΔP is positive if the branch flow is in the same direction as the loop flow, and ΔP is negative if the branch flow is in the opposite direction to the loop flow.

General form: -

$$\sum_{j=1}^{m} bij\Delta Pj = 0 \quad i = 1.........k \qquad \textbf{(11.9)}$$

Matrix form: -

$$\mathbf{B\Delta P = 0} \qquad \textbf{(11.10)}$$

Where: **ΔP**=vector of pressure drops in the branches, of dimension m.

0=zero vector, of dimension k.

B=branch-loop incidence matrix

But **ΔP =ϕ (Q)** where**, ϕ' (Q)** = vector of flow functions, of dimension m

Hence

$$\mathbf{B\,[\phi\,(Q)] = 0} \qquad \textbf{(11.11)}$$

So, the network is not balanced unless both laws are satisfied .There is no analytical solution for looped network. So, it is necessary to guess a solution and then iterate it until the network is balanced. The first guess is obtained by using the Kirchhoff's law to allocate flow to each of the pipes in a spanning tree. Since, the flows are allocated only to pipes in spanning tree the flow in any loop defining pipe is zero. Using these initial flows the pressure drop in each pipe is calculated .Kirchhoff's Second Law is applied to test if flows are correct-if not, a correction is applied to all the flows including the loop defining pipes and pressure drop recalculated. The iterations are repeated until Kirchhoff's Second Law indicates that the network is balanced.

Three method are used in this study to simulate the given gas networks:-

1. Newton-Nodal Method (Multi-Dimensional Case)
2. Newton-Loop Method (Multi-Dimensional Case)
3. Newton Loop-Node Method (Multi-Dimensional Case)

8.2 Newton Nodal Method

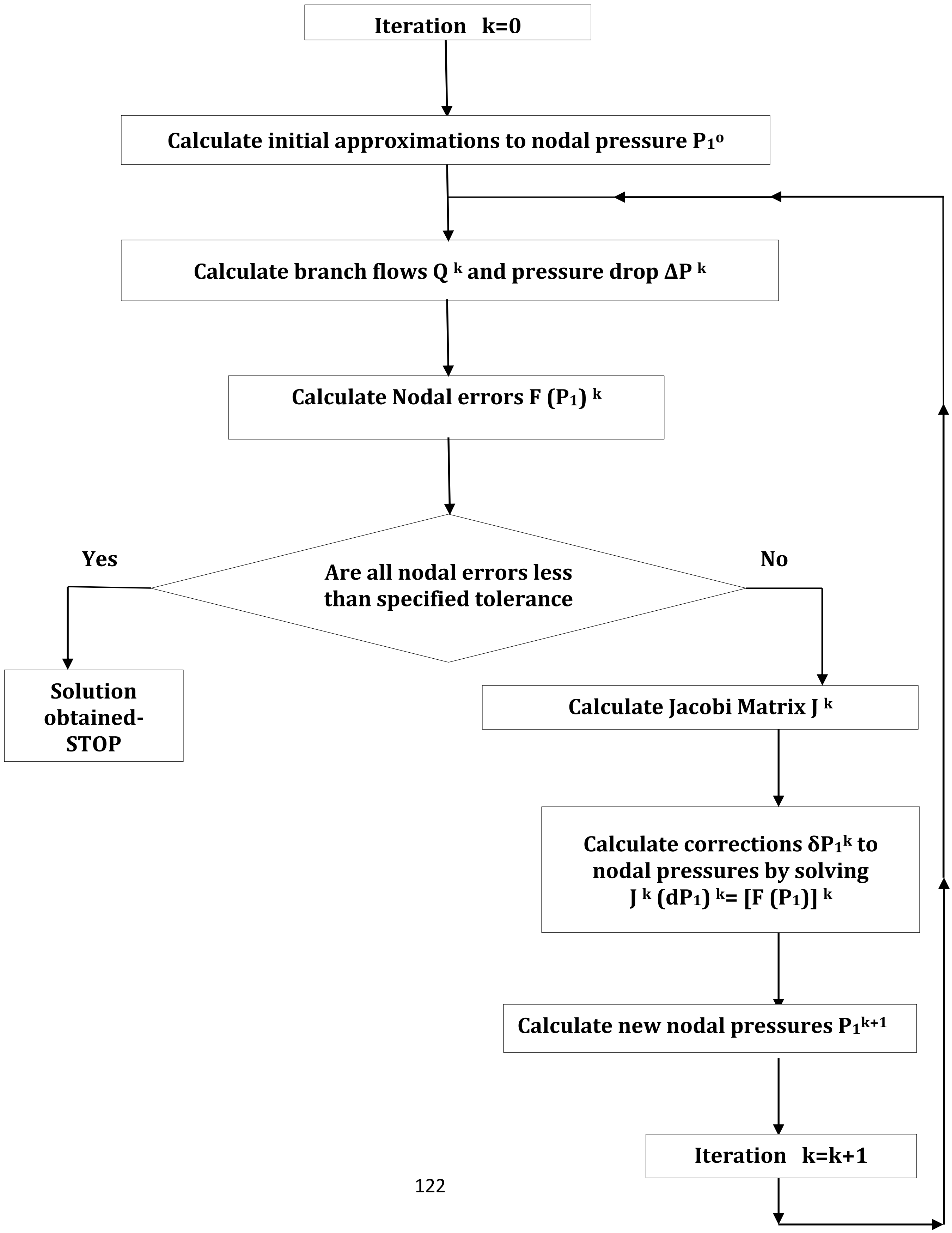
The set of nodal equations used to describe a gas network in matrix form is:-

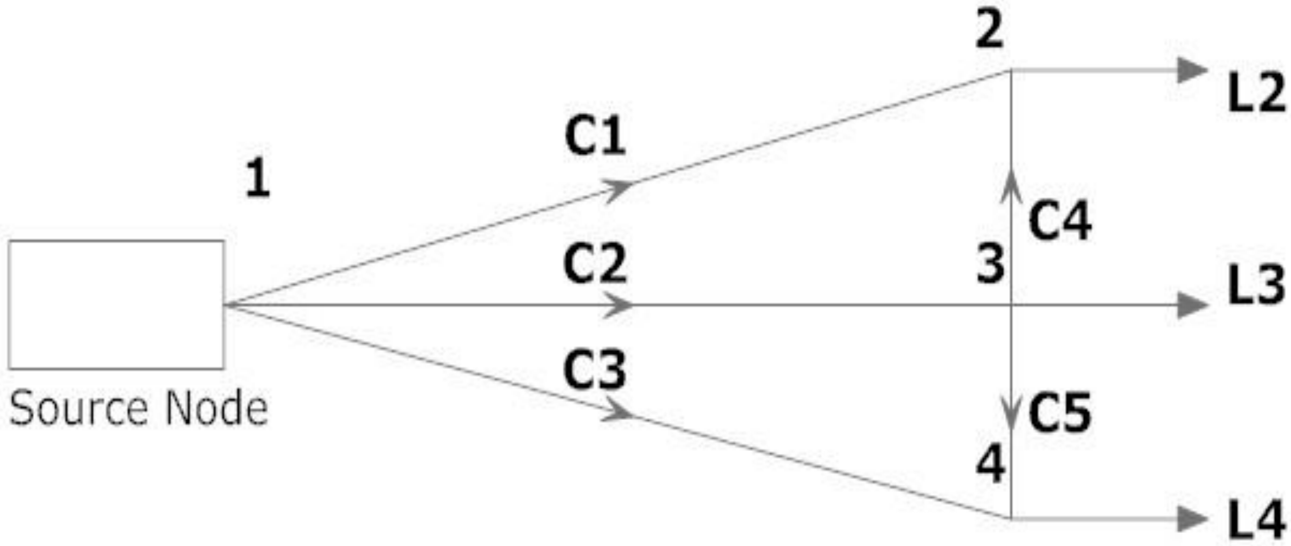
$$\mathbf{L = A_1 [\phi' (-A^T P)]} \text{ (from equ. 11.7)}$$

This equation is rearranged to give: $\mathbf{A_1 [\phi' (-A^T P)] - L = 0}$

Hence, the above equation is simply a mathematical representation of Kirchhoff's first law. So, in Newton-Nodal method an initial approximation is made to the nodal pressures .This approximation is then successively corrected until the final solution is reached. At each iteration the left-hand side of above equation is not equal to zero. The pressures are only approximations of their true values and the flows calculated from these pressures are not balanced at each node. The imbalance at a node is the nodal error which is a function of all the nodal pressures (except the reference node pressures which are fixed) and is denoted as $\mathbf{f (P_1)}$.

Flowchart for the Newton (multi-dimensional case) nodal method





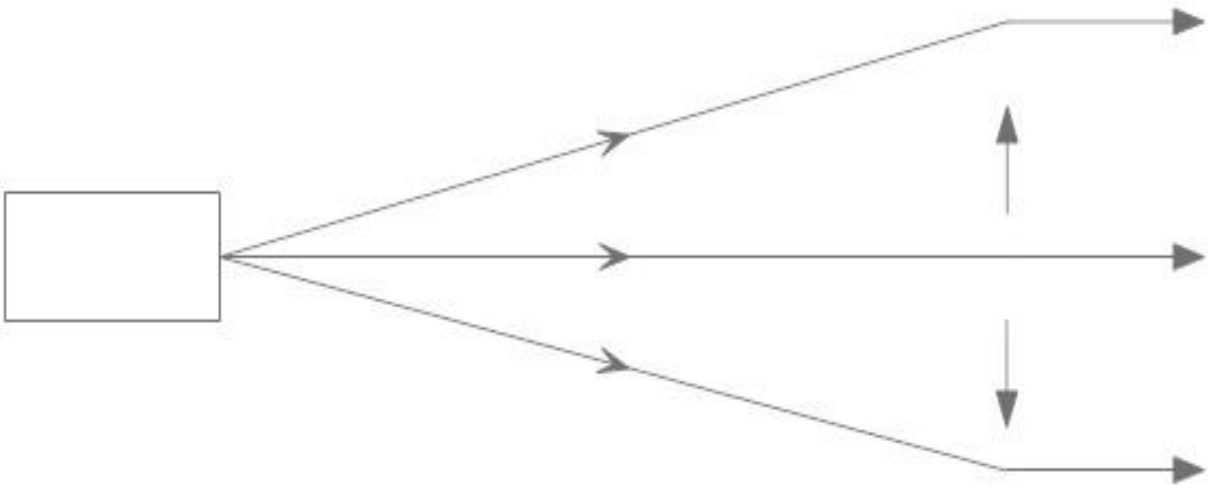


Figure 8.2: -A Simple Network with Load Nodes and corresponding Pipe Flows

Node Data

Node	Load (m^3/hr)	Pressure(m bar gauge)
1	-	30
2	250	-
3	100	-
4	180	-

Assumptions:-

1. Flow in chords 4 and 5 are zero.
2. Node 1 is the outlet of DRS and is at a fixed pressure of 30 m bar (g).

Pipe Data

Pipe	Sending Node	Receiving Node	D(mm)	L(m)
1	1	2	150	680
2	1	3	100	500
3	1	4	150	420
4	3	2	100	600
5	3	4	100	340

Flow in Tree Branch

Branch	Flow(m^3/hr)
1	250
2	100
3	180

From these flows the pressure drop along each tree branch can be calculated from the **Lacey's low pressure equation.** Using Lacey's equation we get-

$$\Delta P_k = K_k Q^2_k \quad (11.12)$$

Where, $K_k = 11.7 * 10^3 * (L_k / D^5_k)$

Hence, the value pipe constant '**K**' for each leg is given below:

PIPE	K
1	0.000104782
2	0.000585065
3	0.000064718
4	0.000702078
5	0.000397844

The source node pressure **P1** is fixed at 30 mbar (g). Therefore, the pressure at nodes 2, 3 and 4 can be calculated as:-

Local Node Pressure= Source Node Pressure- ΔP $_k$ (pressure drop in the connecting pipe leg)

Pipe	D(mm)	L(mm)	K	Q	KQ^2
1	150	680	0.0001047	250	6.548148
2	100	500	0.000585	100	5.85
3	150	420	$6.47*10^{-7}$	180	2.09664

The initial approximations to the nodal pressures are therefore:-

P2 = 30-0.0001047*(250^2)

= 23.45185185

P3 = 30-0.000585*(1000^2)

= 24.15

P4 = 30-$6.47*10^{-7}$*(180^2)

= 27.90336

The initial approximation to the nodal pressures are therefore:-

Node	Pressure
2	23.45185185
3	24.15
4	27.90336

Nodal Errors [F (*p1*)]

The flows in the tree branches 1, 2 and 3 have already been assigned .The differences in pressure between nodes 2, 3 and 4 mea that there are flows in the chords 4 and 5 also. These flows are calculated using the equation:

$$\mathbf{Q_k = S_{ij} \left[S_{ij} \frac{(pi - pj)}{Kk}\right]^{1/2}} \quad \mathbf{(11.13)}$$

Where, $S_{ij}=1$ if $P_i > P_j$

$S_{ij}=-1$ if $P_i < P_j$

Pi= absolute pressure at node i

Pj=absolute pressure at node j

I= sending node of pipe k

J=receiving node of pipe k

Leg No	Pressure Drop ΔP	K_k	Q
4	0.698148148	0.000702	31.53590068
5	-3.75336	0.0003978	-97.13544213

The negative sign shows that the initially selected flow direction is just opposite to the real flow direction but it doesn't affect the calculation. Now we have to calculate the nodal error at each node by simply taking the summation of incoming and out-going flow at that particular node.

At Node 2:-

F2 = $Q_1 - L_2 - Q_4$

= 250-250+31.53

= 31.5353

At Node 3:-

F3 = $Q_1 - Q_4 - Q_5 - L_3$

= 100-31.53-(-97.13)-100

= 65.605

At Node 4:-

F4 = $Q_3+Q_5-L_4$

= 180-97.135+180

= -97.1358

Hence Nodal Error: **- F (p_1)^0 =** $\begin{bmatrix} \mathbf{31.5353} \\ \mathbf{65.6005} \\ \mathbf{-97.1358} \end{bmatrix}$

Nodal Jacobi Matrix J

Branch	1	2	3	4	5
Q	250	100	180	31.5353	-97.1358
Δ P	6.5489	5.8507	2.0969	0.6982	-3.7538
Q/ΔP	38.17434989	17.0919719	85.84100339	45.1666	25.8767

For generating Jacobian matrix we have to calculate Q/ΔP

Using equation:-

$$J=\frac{-1}{m1}\begin{bmatrix} (\frac{Q1}{\Delta P1}+\frac{Q4}{\Delta P4}) & -\frac{Q4}{\Delta P4} & 0 \\ -\frac{Q4}{\Delta P4} & (\frac{Q2}{\Delta P2}+\frac{Q4}{\Delta P4}+\frac{Q5}{\Delta P5}) & -\frac{Q5}{\Delta P5} \\ 0 & -\frac{Q5}{\Delta P5} & (\frac{Q3}{\Delta P3}+\frac{Q5}{\Delta P5}) \end{bmatrix} \quad \textbf{(11.14)}$$

$$J=\frac{-1}{2}\begin{bmatrix} 1+4 & -4 & 0 \\ -4 & 2+4+5 & -5 \\ 0 & -5 & 3+5 \end{bmatrix}$$

$$J^0=\frac{-1}{2}\begin{bmatrix} 83.3409 & -45.1666 & 0 \\ -45.1666 & 88.1353 & -25.8767 \\ 0 & -25.8767 & 111.7177 \end{bmatrix}$$

Corrections δp_1^0

The corrections to the nodal pressures are calculated using the equation

$$J^k(\delta P_1)^k = -[F(P_1)]^k \quad (11.15)$$

$$\delta P_1^0 = \begin{bmatrix} 1.8882 \\ 2.0877 \\ -1.2554 \end{bmatrix} \text{ (mbar) gauge}$$

Therefore, the new values of nodal pressures are

$$P_1^1 = P_1^0 + \delta P_1^0 = \begin{bmatrix} 25.3393 \\ 26.2370 \\ 26.6477 \end{bmatrix} \text{ (mbar) gauge}$$

This is the end of the first iteration

Now the nodal pressure $\mathbf{P_1^1}$ are the better approximation to the true pressure than $\mathbf{P_1^0}$ after this a second iteration is now performed to obtain an even better approximation to the nodal pressure.

Second Iteration

Branch Flows

Branch	1	2	3	4	5
Q(m³/hr)	210.9027	80.1983	227.5930	35.7580	-32.1296

Hence Nodal Error: - **F (*p*$_1$)^1 =** $\begin{bmatrix} \mathbf{-3.3393} \\ \mathbf{-23.4301} \\ \mathbf{15.4634} \end{bmatrix}$

Nodal Jacobi Matrix J

For generating Jacobian matrix we have to calculate Q/ΔP

Branch	1	2	3	4	5
Q(m³/hr)	210.9027	80.1983	227.5930	35.7580	-32.1296
Δ P	4.6607	3.7630	3.3523	0.8977	0.4107
Q/ΔP	45.2513	21.3123	67.8916	39.8329	78.2313

Using equation:-

$$J^1 = \frac{-1}{2}\begin{bmatrix} 85.0842 & -39.8329 & 0 \\ -39.8329 & 139.3765 & -78.2313 \\ 0 & -78.2313 & 146.1229 \end{bmatrix}$$

Corrections δp_1^1

$$\boldsymbol{\delta P_1^1} = \begin{bmatrix} \mathbf{-0.2770} \\ \mathbf{-0.4240} \\ \mathbf{-0.0153} \end{bmatrix} \text{ (mbar) gauge}$$

Therefore, the new values of nodal pressures are

$$\boldsymbol{P_1^2 = P_1^1 + \delta P_1^1} = \begin{bmatrix} \mathbf{25.0623} \\ \mathbf{25.8130} \\ \mathbf{26.6324} \end{bmatrix} \text{ (mbar) gauge}$$

Third Iteration

Branch Flows

Branch	1	2	3	4	5
Q(m³/hr)	217.0795	84.5959	228.1117	32.6994	-45.382

Hence Nodal Error: - **F (*p₁*)²** = $\begin{bmatrix} \mathbf{-0.2211} \\ \mathbf{-2.7215} \\ \mathbf{2.7297} \end{bmatrix}$

Nodal Jacobi Matrix J

For generating Jacobian matrix we have to calculate Q/ΔP

Branch	1	2	3	4	5
Q(m³/hr)	217.0795	84.5959	228.1117	32.6994	-45.382
Δ P	4.9377	4.187	3.3676	0.7507	-0.8194
Q/ΔP	43.9636	20.2044	67.7371	43.5585	55.3844

Using equation:-

$$J^2 = \frac{-1}{2}\begin{bmatrix} 87.5221 & -43.5585 & 0 \\ -43.5585 & 119.1473 & -55.3844 \\ 0 & -55.3844 & 123.1215 \end{bmatrix}$$

Corrections δp_1^2

$$\boldsymbol{\delta P_1^2} = \begin{bmatrix} \mathbf{-0.02705} \\ \mathbf{-0.044204} \\ \mathbf{-0.02445} \end{bmatrix} \text{ (mbar) gauge}$$

Therefore, the new values of nodal pressures are

$$\mathbf{P_1^3 = P_1^2 + \delta P_1^2} = \begin{bmatrix} \mathbf{25.0352} \\ \mathbf{25.7687} \\ \mathbf{26.6079} \end{bmatrix} \text{ (mbar) gauge}$$

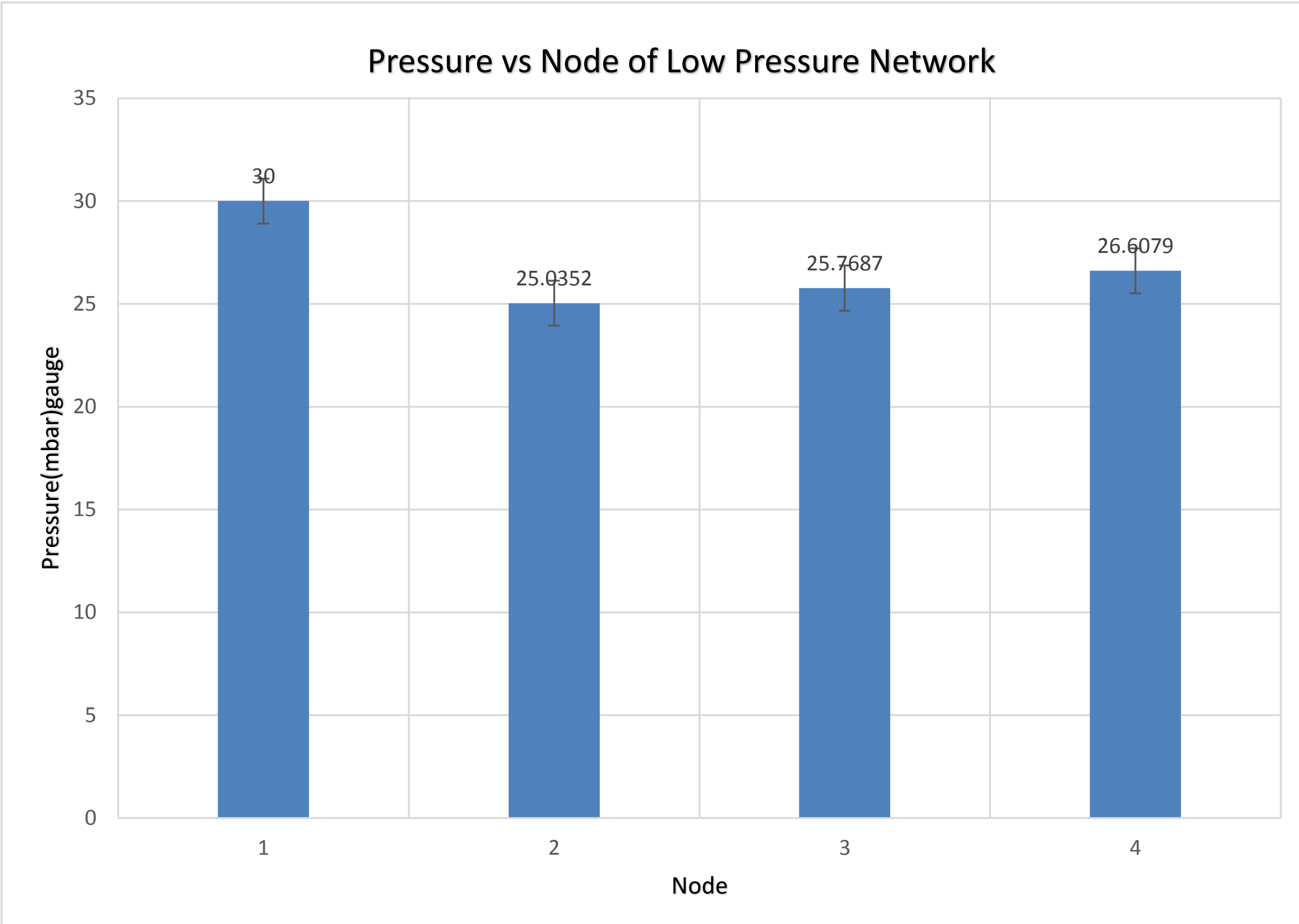


Figure 8.3: - Pressure vs. Node of Low Pressure Network

8.3 Newton Loop Method

The set of loop equations used to describe a gas network in matrix form is:-

$$\mathbf{B\,[\phi\,(Q)]=0} \text{ (from equ. 11.11)}$$

Hence, the above equation is simply a mathematical representation of Kirchhoff's second law which states that the sum of pressure drops around any loop is zero. This method requires that a set of loops in the network be defined. An initial approximation made to the branch flow ensures that a flow balance exists at each node .Since, the branch flows are approximations to their true values, and a loop flow is introduced. The loop flow is the flow correction to be added to the branch flow approximations to yield the true values. Considering the single loop of the network defined previously.

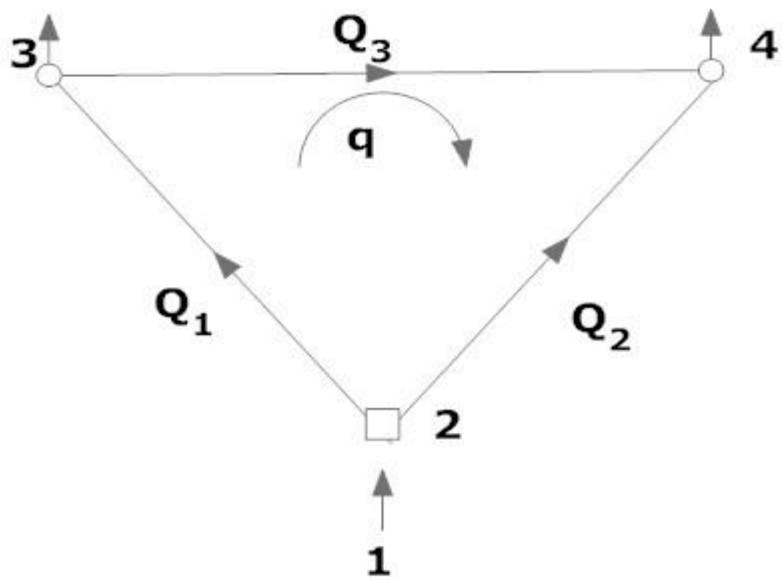
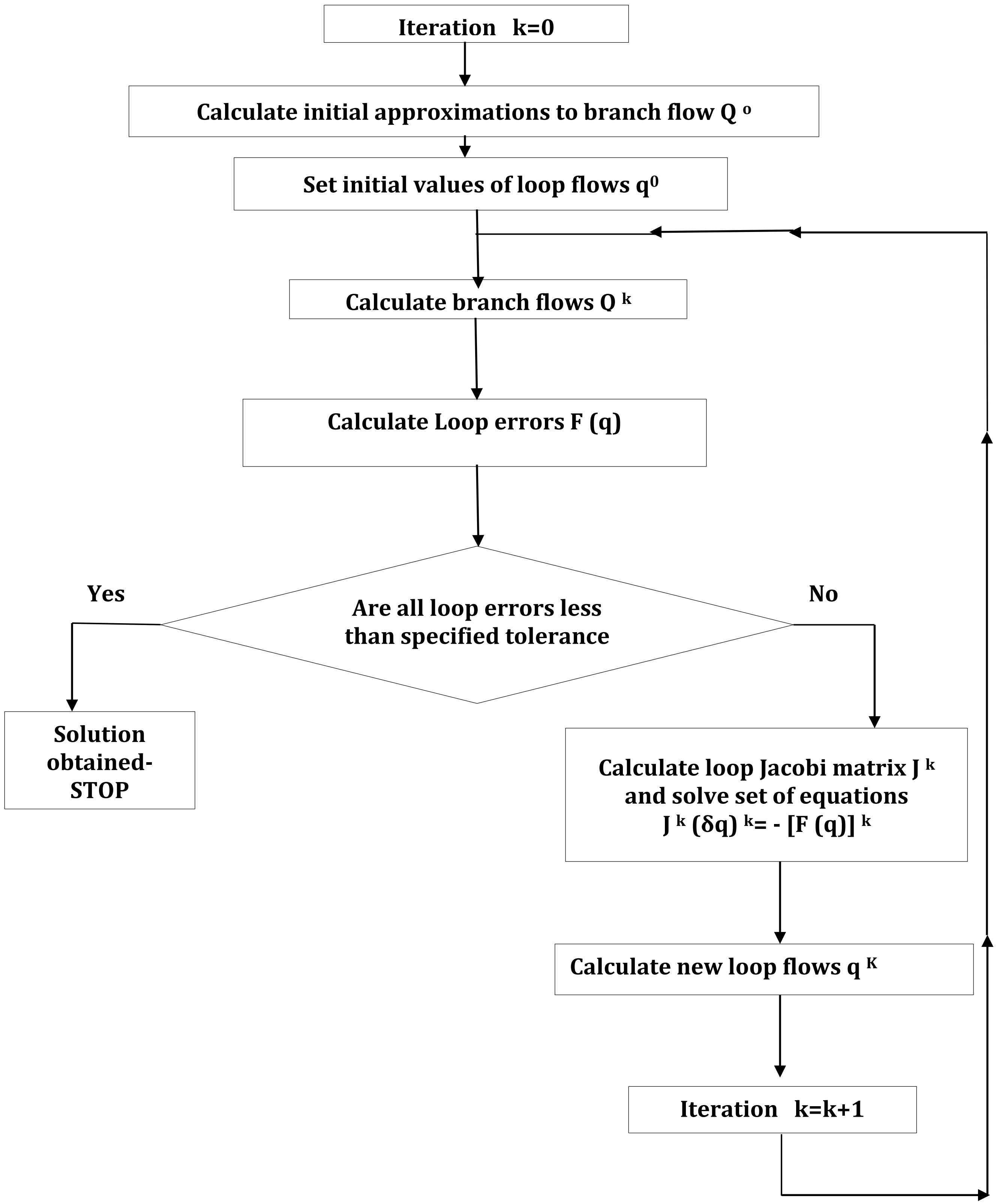


Figure 8.4: - Network Loop Diagram

The loop of branches containing nodes 2, 3 and 4 is the part of a network connected by a set of other branches to a source node 1. L_3 and L_4 are the loads at nodes 3 and 4and Q_1, Q_2 and Q_3 are the branch flows.

If the initial approximation consists of putting Q_3 equal to zero then the initial branch flow approximations will be: $\mathbf{Q_1^0=L_3 \quad , Q_2^0=L_4 \quad , Q_3^0=0}$

Flowchart for the Newton (multi-dimensional case) loop method



Assumptions:-

1. Flow in branch 4 and 5 are zero.
2. The initial loop flow value is assumed to be zero i.e. $\mathbf{q_a^0=0}$, $\mathbf{q_b^0=0}$

Flow in Tree Branch

Branch	Flow(m^3/hr)
1	250
2	100
3	180

From these flows the pressure drop along each tree branch can be calculated from the **Lacey's low pressure equation.** Using Lacey's equation we get-

$$\Delta P_k = K_k Q^2_k \quad (11.12)$$

Where, $\mathbf{K_k=11.7*10^3*(L_k/D^5_k)}$

The initial approximations to the pressures drops are therefore:-

Δ P2 = 0.000104782*(250^2)

= 6.5489

Δ P3 = 0.000585065*(100^2)

= 5.8507

Δ P4 = 0.000064718*(180^2)

= 2.0969

Loop Errors [F (*q*)]

Loop A: - $-\Delta P_1 + \Delta P_2 + \Delta P_4$ =-6.5489+5.8507+0 = -0.6982

Loop B: - $\Delta P_2 - \Delta P_3 + \Delta P_5$ = 5.8507-2.0969+0 =3.7538

Hence Loop Error: - **F (*q*) ^{0} =** $\begin{bmatrix} \mathbf{-0.6982} \\ \mathbf{3.7538} \end{bmatrix}$

Loop Jacobi Matrix J

For generating Jacobian matrix we have to calculate **K|Q|**

Branch	1	2	3	4	5
Q	250	100	180	0	0
Δ P	6.5489	5.8507	2.0969	0	0
K|Q|	0.0262	0.0585	0.0117	0	0

Using equation:-

$$J^0 = 2\begin{bmatrix} 0.0847 & 0.0585 \\ 0.0585 & 0.0702 \end{bmatrix}$$

Corrections δq^0

The corrections to the loop flows are calculated using the equation

$$\boxed{J^k (\delta q)^k = -[F(q)]^k} \qquad \textbf{(11.16)}$$

$$\delta q^0 = \begin{bmatrix} 53.3089 \\ -71.2104 \end{bmatrix}$$

Therefore, the new values of loop flows are

$$\mathbf{q^1 = q^0 + \delta q^0} = \begin{bmatrix} \mathbf{53.3089} \\ \mathbf{-71.2104} \end{bmatrix}$$

This is the end of the first iteration

Now the loop flows $\mathbf{q^1}$ are the better approximation to the true values than $\mathbf{q^0}$ after this a second iteration is now performed to obtain an even better approximation to the loop flow.

Second Iteration

Branch	1	2	3	4	5
Q	196.6911	82.0985	251.2104	53.3089	-71.2104
Δ P	4.0537	3.9434	4.0841	1.9952	-2.0174
K|Q|	0.0206	0.0480	0.0163	0.0374	0.0283

The branch flows and pressure- drops and **K|Q|** are

Hence Loop Error: - $\mathbf{F}\,(q)^{1} = \begin{bmatrix} \mathbf{1.8849} \\ \mathbf{-2.1581} \end{bmatrix}$

Loop Jacobi Matrix J

For generating Jacobian matrix we have to calculate **K|Q|**

Using equation:-

$$J^1 = 2\begin{bmatrix} 0.1060 & 0.0480 \\ 0.0480 & 0.0926 \end{bmatrix}$$

Corrections δq^1

The corrections to the loop flows are calculated using the equation

$$\mathbf{J^{k}\,(\delta q)^{k} = -[F\,(q)]^{k}} \qquad \mathbf{(11.16)}$$

$$\delta q^1 = \begin{bmatrix} -18.5072 \\ +21.2480 \end{bmatrix}$$

Therefore, the new values of loop flows are

$$q^2 = q^1 + \delta q^1 = \begin{bmatrix} 34.8017 \\ -49.9624 \end{bmatrix}$$

Third Iteration

The branch flows and pressure- drops and **K|Q|** are

Branch	1	2	3	4	5
Q	215.1983	84.8393	229.9624	34.8017	-49.9624
Δ P	4.8524	4.2111	3.4224	0.8503	-0.9931
K|Q|	0.0225	0.0496	0.0148	0.0244	0.0198

Hence Loop Error: - **F** (***q***) ^{2} = $\begin{bmatrix} \mathbf{0.209} \\ \mathbf{-0.2044} \end{bmatrix}$

Loop Jacobi Matrix J

For generating Jacobian matrix we have to calculate **K|Q|**

Using equation:-

$$J^2 = 2\begin{bmatrix} 0.0966 & 0.0496 \\ 0.0496 & 0.0843 \end{bmatrix}$$

Corrections δq^2

The corrections to the loop flows are calculated using the equation

$$\boxed{J^k (\delta q)^k = -[F(q)]^k} \qquad \textbf{(11.16)}$$

$$\delta q^2 = \begin{bmatrix} -2.442 \\ +2.649 \end{bmatrix}$$

Therefore, the new values of loop flows are

$$q^3 = q^2 + \delta q^2 = \begin{bmatrix} 32.3597 \\ -47.3134 \end{bmatrix}$$

This is the end of the third iteration

Now the loop flows $\mathbf{q^3}$ are the better approximation to the true values than $\mathbf{q^2}$ and this way further iterations are performed until the loop errors are less than a specified tolerance.

8.4 Newton Loop -Node Method

The Newton loop-node method solves the set of loop equations used to describe a gas network in matrix form is:-

$$\mathbf{F}\ (q) = \mathbf{B}\, [\phi\ (\mathbf{Q})\quad (11.17)$$

Hence, the above equation is simply a mathematical representation of Kirchhoff's first and second law. In this method if each loop in a network is made identical to a particular chord flow, then from the above equation the flow in chords can be determined.

The process of making a loop flow synonymous to a chord flow consists of defining a set of loops for the network which may be complex and can be seen in the below diagram:-

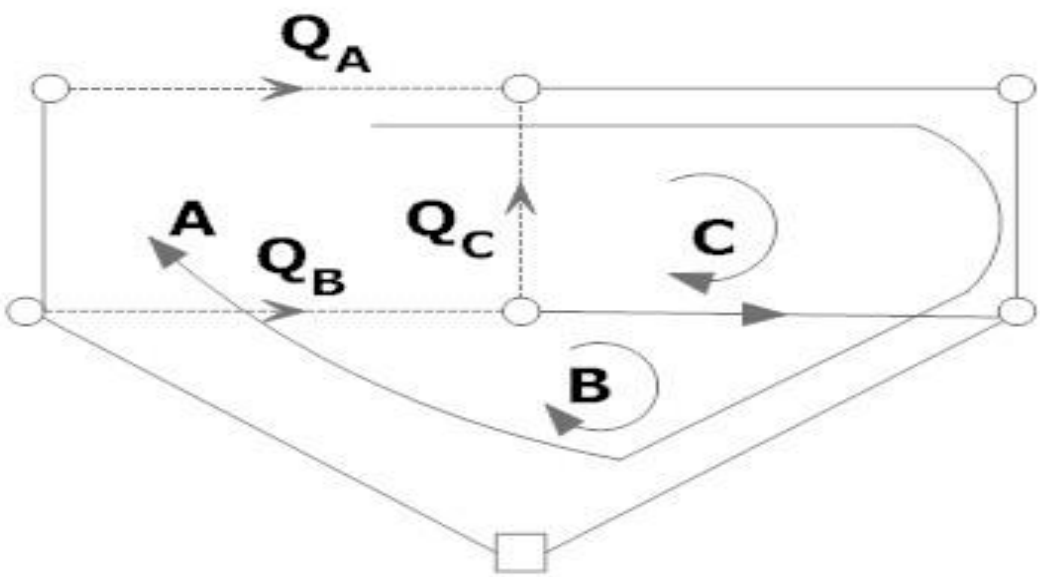


Figure 8.5 : -Gas Network (Chord flow Q_A is identical to the flow in loop A, Chord flow Q_B is identical to the flow in loop B, Chord flow Q_C is identical to flow in loop C-tree branch…chord)

The solution of the loop equations will give the loop flows which in this case are the chord flows .The flows in the tree branches can be obtained from the chord flows without knowing which branches are associated with the particular loop.

Equation 11.17 can be partitioned into its dendrite and co-tree elements:-

$$\mathbf{L= [A_{1t}]\ [A_{1c}]\ [\frac{Q_t}{Q_c}]} \qquad \textbf{(11.18)}$$

Where, $\mathbf{Q_t}$=the vector flow in the tree branches, and

$\mathbf{Q_c}$ = the vector of flow in the chords

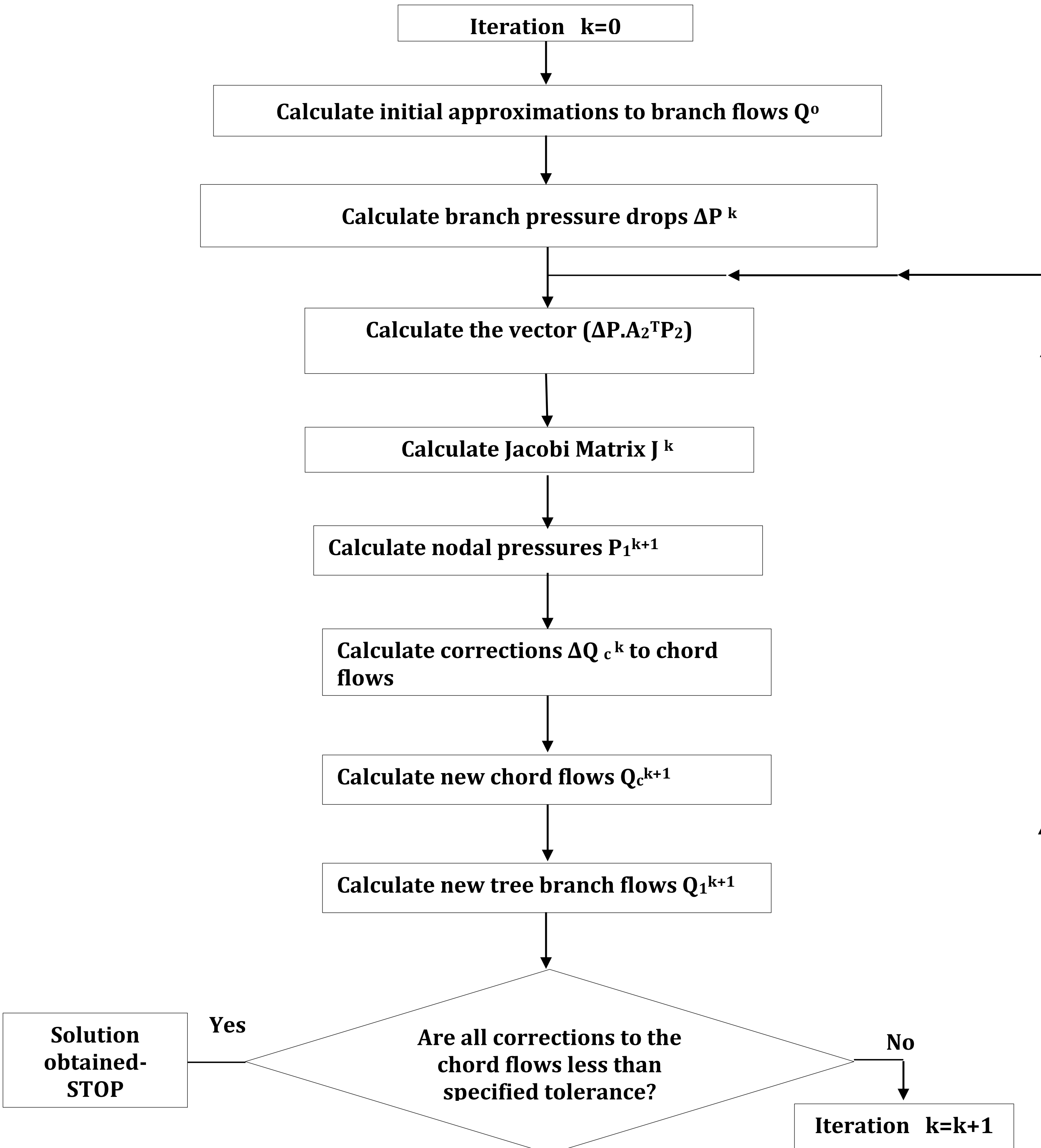
Hence,

$$\mathbf{L=A_{1t}Q_1 + A_{1c}Q_c}$$

Finally ,

$$\mathbf{Q_t= A_{1t}^{-1}\ [L-A_{1c}Q_c]} \qquad \textbf{(11.19)}$$

Flowchart for the Newton Loop-Node (multi-dimensional case) method



Assumptions:-

1. The flow is a loop is synonymous with a chord flow.

2. The initial chord flow are assumed to be 0.5 m^3/hr.

Flow in Tree Branch

Branch	Flow(m^3/hr)
1	249.5
2	101.0
3	179.5
4	0.5
5	0.5

From these flows the pressure drop along each tree branch can be calculated from the **Lacey's low pressure equation.** Using Lacey's equation we get-

$$\Delta P_k = K_k Q^2_k \quad (11.12)$$

Where, $K_k = 11.7 * 10^3 * (L_k / D^5_k)$

The initial approximations to the pressures drops are therefore:-

Δ P1 = 0.000104782*(249.5^2)

= 6.5227

Δ P2 = 0.000585065*(101.0^2)

= 5.9682

Δ P3 = 0.000064718*(179.5^2)

= 2.0852

Δ P 4= 0.000702078*(0.5^2)

= 0.0002

Δ P5 = 0.000397844*(0.5^2)

= 0.0001

Branch Quantities

Branch	1	2	3	4	5
Δ P	6.5227	5.9682	2.0852	0.0002	0.0001
R- =2K|Q|	0.0523	0.1182	0.0232	0.0007	0.0004
R^{-1}	19.1255	8.4614	43.0406	1424.3432	2513.5468

Corrections V^0

$$V=A_1R^{-1}[\Delta P+A_2^TP_2] \quad (11.20)$$

Node 2: $V_2^0= R_{11}^{-1}(\Delta p_1-p_1) +R_{44}^{-1}\,\Delta p_4= -448.7649$

Node 3: $V_3^0= R_{22}^{-1}(\Delta p_2-p_1) -R_{44}^{-1}\,\Delta p_4 - R_{55}^{-1}\,\Delta p_5= -203.8433$

Node 4: $V_4^0= R_{33}^{-1}(\Delta p_3-p_1) +R_{55}^{-1}\,\Delta p_5= -1201.2184$

Jacobi Matrix

The elements of the Jacobi matrix are obtained as follows:

$$J^0 = \begin{bmatrix} 1443.4687 & -1424.3432 & 0 \\ -1424.3432 & 3946.3514 & -2513.5468 \\ 0 & -2513.5468 & 2556.5874 \end{bmatrix}$$

Nodal Pressure p_1

The nodal pressures are obtained from equation:

$$J_k\, p_1^{k+1} = V^k \qquad \textbf{(11.21)}$$

We get:

$$P_1^{\,1} = \begin{bmatrix} 26.2040 \\ 26.2408 \\ 26.2689 \end{bmatrix}$$

Corrections ΔQ_c

The corrections to the chord flows are obtained from equ. 11.20

$\mathbf{\Delta Q_4^0 =}$ R_{44}^{-1} $[(p_3 - p_2) - \Delta p_4]$ =52.1310

$\mathbf{\Delta Q_5^0 =}$ R_{55}^{-1} $[(p_3 - p_4) - \Delta p_5]$ =-70.8820

New Chord Flows

The new chord flows are obtained as:-

$\mathbf{Q_4^1 =}$ $Q_4^0 + \Delta Q_4^0 = 0.5 + 52.1310 = 52.6310$

$\mathbf{Q_5^1 =}$ $Q_5^0 + \Delta Q_5^0 = 0.5 - 70.8820 = -70.3820$

The new branch flows are:

Branch	1	2	3	4	5
Q	197.3690	82.2490	250.3820	52.6310	-70.3820

Hence, in this way the iterations are further carried out until we reach the desired tolerance limit.

CHAPTER 9: -RESULTS & DISCUSSIONS

9.1 Results and Discussions

Design of a city gas distribution for Haridwar city is made. Design of main steel pipeline, MDPE pipeline, GI /CU pipe and network analysis is carried out.

1. The total amount of natural gas required for Haridwar city is estimated to be **1.12795 m^3/s.**

2. The steel pipeline which is connected from city gas station (CGS) to district regulating stations (DRS) has the following specifications _the diameter of the pipeline is calculated as **16** inch, thickness comes out to be **0.375** inch with **X42** grade pipeline.

3. Network analysis for the steel pipeline connected from CGS station to DRS is carried out with the help of high pressure flow equation giving a **MAOP** of **54.296** bar

4. The polyethylene piping connecting DRS and meter regulating station is designed and it is found out that the required **SDR** is **11** and the corresponding **MAOP** is **7.018 bar**.

5. The network analysis of low pressure network is done by **Newton nodal method, Newton Loop method** and **Newton Loop Node Method.**

CHAPTER 10: -CONCLUSIONS

10.1CONCLUSIONS

The designing of a City Gas Distribution for Haridwar city is made using main steel pipeline, MDPE pipeline, GI /CU pipe and network analysis is carried on each of the following . The total amount of natural gas required in Haridwar city for different consumers including **Domestic, Transportation** and **Industrial** was estimated and the actual demand then calculated unique compressibility factor **Z** charts. The proposed pipeline route was also shown using **SYNERGEE** mapping software.

The steel pipeline which is connected from city gas station (CGS) to district regulating stations (DRS) was also designed with the following specifications of ;diameter of the pipeline-**16** inch, thickness-**0.375** inch with **X42** grade pipeline. The proposed steel pipeline schematic diagram was also drawn to show various distribution points. Network analysis for the steel pipeline connected from CGS station to DRS is carried out with the help of high pressure flow equation giving a **MAOP** of **54.296** bar which is well above the design pressure of **49** bar hence our pipeline is under safe limits. The polyethylene piping connecting DRS and meter regulating station is designed and it is found out that the required **SDR** is **11** and the corresponding **MAOP** is **7.018 bar**.

Finally the network analysis of low pressure network is done by **Newton nodal method, Newton Loop method** and **Newton Loop Node Method** for understanding purpose to give a small insight to the readers on how these networks are simulated and the pressure and flow rates calculated in case of a big network.

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