DESIGN OF A TRUNK GAS PIPELINE USING GEOGRAPHIC INFORMATION SYSTEM (GIS)

BY

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DECLARATION

I declare that the work in this thesis entitled Design of a trunk gas pipeline using geographic information system (GIS), has been performed by me in the Department of Chemical Engineering under the supervision of Dr I. A. Mohammed and Dr. I. M. Bugaje.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this project report was previously presented for another degree or diploma at any university.

_____ _____

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CERTIFICATION

This thesis entitled "DESIGN OF TRUNK GAS PIPELINE USING GIS (GEOGRAPHIC INFORMATION SYSTEM)) by Umar, Hamisu Farouk meets the regulations governing the award of the degree of Masters in Chemical Engineering of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

Electrical energy supply has been a problem for a long time in Nigeria, especially in the Northern States where alternatives like natural gas are not available. A complete analysis on the capacity under utilization of the industries in Kano and Kaduna was carried out and found that only 41.24% of the required power is supplied to these locations as at September 2005. The remaining 58.76% will have to be provided by other sources of power generation mostly by the use of generators. While this energy crisis is taking place, a large volume of natural gas is flared in the Nigerian Niger delta area with around 2.5 billion scf, being flared daily representing an annual economic loss to the country of about $2.5billion. This work reports on the design of gas pipeline extension from Ajaokuta-Kaduna-Kano. Trunk Gas Pipeline cost and some aspects of Engineering Design were carried out in using Geographic Information System (GIS). The important design parameters obtained are the volume of gas flow rate per day Q as 2.1573 $*10^7$ ft^3 /day, total pipe length was 552.024 km while the pipe internal diameter was found to be 16.4inches. The nominal wall thickness and stresses inside the pipeline was found to be 0.36 inches and 27963.1336 psia respectively, while the design pressure was 740 psia. The total cost of laying the pipeline was found to be N20.08 Billion representing N16.73 Billion as plant facilities and N3.35 Billion as working Capital. The rate of return on investment was found to be 30% per year.

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ABBREVIATIONS AND SYMBOLS

SYMBOLS

a and b = constants characteristic of the actual value of relative roughness

ata = atmospheres absolute

D = nominal outside diameter of pipe, mm

d = Internal diameter of pipe, in

E = longitudinal joint factor

F = design factor

f = "draught factor"

G = Specific gravity of gas

h_1 = elevation at origin of line, ft

h_2 = elevation at terminus of line, ft

I = The moment of inertial of the metal cross section

l = Length

L = Length of pipeline, Miles

m_G = Mass flow rates of gas

m_L = Mass flow rates of liquid

N_{Re} = Reynolds Number

p = design Pressure, barg

P_o = Absolute Pressure base, psia

P_1 = Inlet (initial) pressure, psia

P_2 = Outlet (terminal) pressure, psia

Ps = Press. Drop from friction, N/m^2

Q = Flow rate, scf/d

S = specified minimum yield strength, N/mm^2

S_{Ra}/R_a = Roughness profile

t = nominal wall thickness, mm

T = Temperature

T_o = Absolute Temperature base, ^oR

T_{af} = Average Flowing temperature, ^oR

T_d = temperature derating factor

T_{avg} = Average temperature

V = volume m^3

Y = Flow velocity, m/s

W_p = The weight of steel pipe per foot

W_w = The weight of water per foot is

Z = Compressibility factor

Z_{avg} = Average Compressibility factor

$\in_L$ = Liquid hold-up

λ = Pipe friction factor

λ_{sm} = Friction factor of smooth pipe

λ_{avg} = Average Pipe friction factor

P = Density, kg/m^3

σ_H = hoop stress, psi

σ_L = Longitudinal Stress

τ_w = Mean wall shear stress

ABBREVIATIONS

AGUFI	Associated Gas Utilization Fiscal Incentives
ALSCON	Aluminium Smelter Company
ANSI	American National Standards Institute
AOI	Area Of Interest
ASME	American Society of Mechanical Engineers
DEM	Digital Elevation Model
DPR	Department of Petroleum Resources
GERD	Group European de Recherches Gazieres
IGT	Institute of gas Technology
HIS	Information Handling Services
IPP	Independent Power Plant
MAN	Manufacturers Association of Nigeria
MOP	Maximum Operating Pressure
NAG	Non-Associated Gas
NAPIMS	National Petroleum Investment Management Services
NAFCON	National Fertilizer Company
NGC	Nigeria Gas Company
NPS	Nominal Pipe Size
PHCN	Power Holding Company of Nigeria
PPT	Petroleum Profit Tax
PSC	Production Sharing Contract
VAT	value Added Tax

SPDC	Shell Petroleum Development Company
SMYS	Specified Minimum Yield Strength
SCF	Standard Cubic Feet
SCFCD	Standard Cubic Feet per Calendar Day
SCFOD	Standard Cubic Feet per Operating Day
WAPCO	West African Portland Cement Company

CHAPTER ONE

1.0 INRODUCTION

1.1 Energy and Economic Development

As the world enters the new millennium, it has become something of a self imposed obligation among nations to preserve and utilize efficiently nature's valuable reserves. Nations are developing new strategies and solutions in the way they go about utilizing natural resources. A typical example is the Nigerian Government commitment to eliminate gas flaring by the year 2010.

Flaring is the controlled burning of natural gas that cannot easily be processed or sold. It is often viewed as a safe and economical means of disposing of excess flammable, toxic or corrosive vapors to less objectible compounds by combustion.

It is estimated that more than 100billion cubic meters of gas is vented worldwide annually. That is enough fuel to cover the combined annual gas consumption of Germany and France.

It was estimated that by 2002 flaring in Nigeria had contributed to more green house gases to the Earth's Atmosphere than all other sources in Sub Saharan Africa combined–and yet this gas is not being used as fuel.

It is estimated that over 3.5billion standard cubic feet (scf) of associated gas was produced in 2000 of which more than 70% was burnt off i.e. flared. As oil production has increased Nigeria has become the World's biggest gas flarer, both proportionally and absolutely, with around 2.5 billion scf, a day being flared. The biggest flarer in Nigeria is Shell Petroleum Development Company (SPDC). A recent report estimates flaring representing an annual economic loss to the country of about $2.5billion.

Despite all efforts by countries and companies to capture more of this gas for utilization, global flaring and venting levels have remained fairly constant over the past 20years, World Bank statistics show. Increased oil production and the corresponding rise in associated gas production as well as lack of stakeholder collaboration among industries, Governments and consumers have affected the reductions (Christen, 2006).

Natural gas is the cleanest-burning fossil fuel available. It helps improve air and water quality especially when used in place of more polluting energy sources. When natural gas burns, virtually no harmful pollutants are produced. Natural gas can be used to produce carbon dioxide in a cheaper and more efficient way.

One can easily achieve between 24 – 43% savings over alternative fuels. The difference could be as high as N180m in a N2bn turnover company; it can also be in multiples. Gas offers a cheaper, cleaner and safer alternative.

Nigeria is rich in natural gas, it ranks among the world's top 10 countries in Natural gas reserves.

Natural gas is a naturally occurring fuel that is gaining popularity in meeting our increasing energy demand because of its unique qualities, in terms of Safety, reliability, competitive pricing and environmental friendliness. Gas is today the most efficient energy source and therefore the future (Gaslink, 2006).

1.2 Design of Gas transport pipelines

The design work is mainly concerned with the basic aspects of gas pipeline design that will allow for a fair economic analysis.

Before embarking on any preliminary pipeline design, four basic steps are the most crucial and they are as follows:

1. Legal aspects, codes and incentives offered by the Government should be studied extensively.
2. Hydraulics will cover basic pressure drop calculations, special hydraulic conditions and Hydraulic Profiles
3. Determining the customer peak gas demand. This is the volume of gas of various customers on the network both the industrial demand and others. This factor determines how much natural gas volume is to be transported. This information is used in sizing of the pipeline.
4. Pipeline route selection (this is the most important aspect because it determines the cost implications of the project). Application of all the steps above depends entirely on the Route the pipeline will follow. Therefore, careful placement of the pipeline route is the most important aspect of pipeline construction because a slight undesirable change in the direction of the pipeline will result in additional undesirable cost. Reduction of cost of up to 29% have been recorded in Delavar and Naghibi (2002).

   One of the modern ways of creating an optimum pipeline route is by using Geographic Information System (GIS), which can be defined as:

"computer system for capturing, managing, integrating, manipulating, analyzing and displaying data which is spatially referenced to the Earth" (McDonnell and Kemp,1995).

The ability of a GIS to capture, store and process geographical data in an integrated environment makes it an ideal tool for practitioners, in a wide range of fields, seeking to address complex issues, questions and problems found in the environment. The range of problems to which GIS is presently deployed demonstrates the significance of this technology in contemporary society.

GIS is now routinely used by government departments, local authorities, commercial organizations and environmental groups for an enormous range of tasks. These include land-use planning, market analysis, industrial development, and management of emergency services, transport planning, environmental impact assessment and wildlife conservation. Whether the concern is the siting of a new out of town supermarket, the routing of a controversial rail link, examining the social and economic characteristics of the population within an hours drive of a new theme park or identifying clusters of disease incidents. GIS now provides the ability to integrate information, solve problems, develop effective solutions and visualize scenarios in a way that was simply not possible even a decade ago (Montemurro and Gale, 1996).

GIS use in pipeline design is now in the fore front globally due to its flexibility of being a software program which when combined with other software can be used to modify the GIS software capabilities as required.

1.3 Statement of Research problem.

According to MAN, no fewer than 350 industries have folded up in Kano, (Sharada/Chalawa industrial layout) following incessant power outages (as at September, 2005). As a result of the closure, only 150 of the 500 industries in the area were functioning. The companies have incurred huge loses due to power outages they suffered over the years. Kano township is the most affected by the power outages, making the industries to operate three times more than their production costs Madugu (2005).

This similar trend is also experienced in Kaduna, a neighboring state, thus bringing industrial activity in this region to a stand still.

Massive unemployment always follows these closures, with resultant loss of revenue and productivity.

Energy remains a major part of an organization's value creation process, where most companies spend between 15 - 35% of their turnover. The desire to find or recommend a lasting solution for the energy crisis facing this region is borne out of necessity due to the persistence of this problem over the years.

There is hope that natural gas will also find other uses as soon as it is delivered to those locations, such uses include a raw material for fertilizer industries, since agriculture is the chief occupation of majority of people from those areas.

1.4 Research Objective

The research project was set to achieve the following objectives:

- To carryout design of some aspects of a trunk gas pipeline system from Ajaokuta to Kano via Kaduna with the aim of improving the management of natural gas reserves.
- To obtain the best pipeline route using GIS as a tool.
- To carry out economic evaluation of the proposed gas pipeline system.

1.5 Research Justification

- Inability of PHCN to supply the required energy targets to industries.
- There is abundance of natural gas in Nigeria that can be distributed to various parts of the country.
- Natural gas flaring is an economic wastage of valuable raw material.
- Helping in achieving the objective of national energy policy of eliminating gas flaring by 2008.

1.6 Scope of Research

The work is limited to specifications of length of pipeline from Ajaokuta to Kano via Kaduna, pressure heads, pipe diameter, internal pressure, stresses inside the pipe, pipe thickness required for the evaluated end-user targets/requirements and economic analysis of the project

1.7 Research Limitations

i. The inability to obtain gas pipes manufactured and priced in Nigeria at the time of carrying out the economic analysis of this project. This may add extra cost to

the total cost of the project due to importation taxes and other miscellaneous expenses.

ii. Not many sophisticated software programs will be used in this thesis, this is deliberate in order to demonstrate the simplistic ways of preliminary gas pipeline design, even though when the final cost estimate of the project is to be carried out, complex and sophisticated programs will have to be used from various fields to ensure increased accuracy.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Gaseous Hydrocarbons

These are C_1-C_4 hydrocarbons namely methane, ethane, propane butane, isobutene and 2,2-dimethyl propane which exist in the gaseous state under standard conditions. All of them are contained in natural and petroleum casing-head gases/associated gases (Erikh *et al*,1988).

Natural gas is a mixture of hydrocarbons in which methane predominates; the mixture varies considerably according to where and how the gas is found and particularly according to whether it is 'associated' with a crude oil reservoir-or 'unassociated'

Associated gas is richer because it contains a higher percentage of ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}). All of which have a higher calorific value than methane (CH_4) (Fooks, 1979).

Natural gas may contain a small percentage of Nitrogen and is usually accompanied by noble gases such as Helium and Argon. Because of the great predomination of methane and the small amount of C_4/C_5 hydrocarbons, most natural gases belong to the dry gases (methane = 93-98.8%). They are usually found in the natural gas well (unassociated).

Mixtures of methane and ethane only are called dry gases, while mixtures ranging from methane to propane, sometimes associated with a substantial naphtha fraction are called the wet gases. In both cases some carbon dioxide and invert gases, including helium, are present together with hydrogen sulphide and a small quantity of organic sulphur.

The other natural gases usually found in petroleum fields dissolve in the petroleum and separate from it at the surface, (associated) they contain a considerable amount of ethane, propane, butane and higher hydrocarbons of total of up to 50%. This is why they have been named rich gases. These gases are the source of the highest gas gasoline, which is added to commercial gasoline, and also of compressed liquid gases used as fuel (Erikh *et al,* 1988).

2.2 Disposal of evolved gases

Gases released from the oil wells during drilling of oil wells are called the evolved gases. Oil and gas produced in oil fields are separated, purified, metered, gathered and shipped to refiners and point of utilization. Different oil fields (depending on local conditions), common basic requirement demand that they should ensure the greatest possible separation of gas from the oil, with subsequent use of gas, without permitting losses of light petroleum fractions by evaporation, hence the need for closed oil gathering systems.

2.3 Methods of 'evolved' gas disposal

The three basic methods of disposing evolved gas are by flaring, re-injection and liquefaction.

2.3.1 Flaring

Flaring is the controlled burning of natural gas that cannot be easily processed or sold. Flaring is often viewed as soft and economical means of disposing of excess flammable, toxic or corrosive vapors to less objectible compounds by combustion.

Gas is flared at both the upstream and downstream sector of petroleum industry (Christen, 2006).

2.3.1.1 Sources of flared gases

There are two major sources of flared gases: from oil drilling and from refineries and gas plants.

From oil drilling: During drilling of oil wells, the crude is almost always accompanied by an appreciable amount of associated gases mainly methane, ethane, propane and butane. More often than not, these gases are flared. Especially in fields where there is no adequate provision for gathering-transporting-consumer ladder, flaring becomes the most economic option. Also as part of the completion and testing of natural gas wells, well test flaring occur in order to asses a well's capacity and determine the appropriate gathering and processing systems needed to handle the well's production. When oil wells produce very small amounts of solution gas, it is often uneconomical to construct pipelines or gas compression facility to gather the solution gas; instead the gas is flared (Crawford, 1989).

From refineries and gas plants: Separation processes in the refineries are the main sources of flue gas e.g. Naphtha hydrotreating/catalytic reforming unit and stabilizer

gas mostly made up of H_2S, $C_{1,}$ C_2 and C_3 as well as fuel gas C_1 and C_2 are removed for firing heaters, excess are sent to flares.

From gas plants, this may occur during routine maintenance at gas processing facilities. Flaring is used as a means to safely dispose of gas from the depressurized equipment (this occurs during operational upsets e.g. equipment failures, power outages, pipeline problems etc).

In situations where to flare the gas could itself lead to possible hazard of operation, the incineration method is used. In this method, thermal incinerator unit is used as another method of gas disposal. The incineration method is often applied to steam-raising boilers for operating domestic or process systems on offshore installation, and is possibly the cheapest and most effective way to burn the gas in an adjacent furnace of a process unit or boiler. This arrangement, however, is limited and a relatively small quantity of the gas is disposed of in this manner (Crawford, 1989).

2.3.1.2 Flare systems

In most oil fields, a significant proportion of the hydrocarbon content is present as gas and, where this cannot be converted into useful energy, arrangements have to be made for its safe disposal in both routines and emergency operations with due regard to anti-pollution requirements. Where production is from deep water locations, this adds new dimensions to the problem particularly that of safety. Flaring from the end of an open pipe is not necessarily adequate for today's stringent safety and environmental requirements, and this has led to a growing demand for systems

incorporating high-technology flares that can be integrated into gas-processing systems.

The primary function of a flare is to convert flammable, toxic, or corrosive vapors to less objectionable compounds by combustion. This can be accomplished successfully with either a ground or elevated flare. Selection of the type of flare and special design features required, will be influenced by several factors which include, availability of space, characteristics of the flare gas i.e. composition, quantity, and pressure level and lastly economics, including both initial investment and operating costs and public relations. Public relations are likely to be of prime importance if the flares can be readily observed from residential areas. In some locations, producing relatively high noise levels will also pose another disadvantage for the flares Crawford (1989).

2.3.1.3 Types of flaring

Flaring can be for a few days, months, years or permanently (as long as it takes).

There are two main types of flaring: continuous and intermittent flaring.

Continuous flaring: This is the type of flaring that continues over a long period of time, it can be years or permanently. Example is during oil drilling and from refineries during separation processes.

Intermittent flaring: This type of flaring takes place during routine maintenance of plants or as part of the completion and testing of natural gas wells it is never permanently.

2.3.1.4 Effects of Natural gas flaring

Disposal of associated gas has been a major problem for the Nigerian oil and gas industry. The resultant effect of gas flaring includes acid rain formation, global warming, noise pollution, economic wastage and heat effects (radiation) on humans.

The combustion of gaseous hydrocarbons contained in the natural gas is an exothermic process which results in the evolution of heat to the atmosphere. This endangers both the animal and plant life around the vicinity of gas flaring.

Typical gas flares in Nigerian oil fields are located at ground level and are surrounded by thick vegetation, farmlands and village huts 20-30 meters from the flare.

The heat radiation from the flares is a function of the flame temperature, gas flow rate and the geometric design of the flame stack. In some cases, the surrounding soil is scorched, vegetation and farmlands are perched and villagers complain of “internal heat” due to the cumulative effect of long exposure to radiant heat.

There is great environmental impact on crops planted in the vicinity of flares. There are about 100% losses in the yield of crops cultivated 200 meters away from the flame, 45% loss in yield of crops 600 meters away and 10% yield for crops planted 1000 meters away. The high temperature and radiation intensity characteristic of the farms closest to the flame accounted for the loss in yield of the crops (Oyekunle,1999).

2.3.1.5 Natural gas flaring in Nigeria

The flaring of natural gas has been an integral part of the operations associated with the exploitation of crude oil and natural gas resources in Nigeria since inception. Currently more than 75% of associated gas produced in the country is flared- an amount totaling more than two billion standard cubic feet per day (scf/d), which is estimated to be about a quarter of the gas the world flares and vents. About half the gas flared in Nigeria is produced by the Shell Petroleum Development Company of Nigeria Limited (SPDC) in the course of producing almost half the country's oil exports. The company has more than 90 oil and gas fields spread over some 30,000 square kilometers of oil mining leases in Niger Delta. It is a massive operation; flow-stations and 4 Non Associated Gas (NAG) plants, invariably contributing to the company's flaring level of about 40% (Ageh *et al* 1999).

2.3.1.6 Why gas is flared in Nigeria (flared gas management: SPDC approach)

Most of Nigeria's oil facilities were built in the 1960s and 1970s. In those days, gas was not a popular energy source as it was more difficult to produce and transport than crude oil, on which many of the world's economies were based. There were few markets for gas in Nigeria then, and at the same time there was little environmental awareness of the consequences of gas flaring.

Little was done to find or develop gas reserves and no facilities built to collect the associated gas, which was, and remains, one of the most difficult and expensive gas sources to harness. It is produced at low pressure and has to be compressed and treated in purpose-built facilities before it can be used. In addition, individual oil

fields do not produce enough associated gas to be economic on their own, so an expensive network of compression facilities and pipelines is needed to link these scattered fields to collect enough gas for a typical industry.

Therefore, it is not surprising that when the first small volumes of gas started flowing to Nigeria industry in the 1960s they were from gas reservoirs, a cheaper and more reliable source because they are produced at high pressure and do not depend on oil production.

However, simply substituting gas from the flares for these small commercial volumes of non-association gas cannot solve Nigeria's flaring problem. Today's commercial demand for gas in Nigeria is estimated to be about 330 million scf/d, many times smaller than the large volumes of associated gas being flared (at 75% of current flaring level) (Ageh *et al* 1999).

Until now the best option to conserve and/or harness this flared gas have been re-injection into oil reservoirs underground, or export. Shell Petroleum and Development Company was the first company to re-inject gas (at Ogun in 1978) but most reservoirs are unsuitable for large-scale re-injection.

In view of the limited domestic market for gas, and the high cost associated with gas companies operating in the country, there was no compelling reason to embark on gas utilization and development programs. A review of the 1979 Associated Gas Re-Injection Decree became necessary. This came in form of the Associated Gas Re-Injection (Continued Flaring of Gas Regulations 1984), which sets out the conditions for the issuance of Certificate by the Minister under section 3(2) of the previous Decree of 1979, permitting the continued flaring of gas. The Associated Gas re-

injection (Amendment) Decree Number 7 of 1985 permitted a company to continue to flare gas in a particular field or fields. The Minister issues a certificate to that effect, and has to be satisfied after January 1, 1984, that gas utilization or re-injection of the produced gas is not appropriate or feasible in that particular field or fields. The certificate enabled the company to continue to vent and flare gas if the company paid such sum as the Minister prescribed from time to time for every 28,317 standard cubic meter (1000Mscf) of gas flared, payable in hard currency. The 1997 review of the national gas policy increased the penalty for gas flaring to 10 Naira for every 1,000 cubic feet of gas flared, as against 50 Kobo for the same quantity, under the previous policy. The current policy states clearly that gas flaring shall stop in the year 2005, prior to which time; there would be a gradual termination of flaring.

The growing concern about the utilization of natural gas has made the government to introduce associated gas utilization clauses in recent Production Sharing Contracts (PSCs) signed with oil companies. This is in line with current practice in major oil producing countries and in compliance with international standards. The main thrust of the gas policy (for the gas production phase) is to eliminate gas flaring and encourage producers to make capital investment in the production phase. To facilitate the realization of these objectives, gas producers are to carry out gas field development optimization study on their respective concessions while National Petroleum Investment Management Services (NAPIMS) would be solely responsible for overall optimization planning of gas field development irrespective of concession holder. These are spelt out in the Associated Gas Utilization Fiscal Incentives

(AGUFI) to make attractive the additional investment a gas producer would make to deliver flared gas to any interested user at the producer's battery limit.

The objective of the gas policy transmission phase is to facilitate construction, operation and maintenance of an integrated national supply system that would guarantee regular supply to end user through the development of a national grid system. Currently there is no national gas grid system, which is essential in the development of a mature gas market.

The national gas policy makes the transmission system a fully commercial operation in the hands of the private sector investors (both foreign and local) who take gas from the transmission companies at designated city gates in the urban locations.

Overall, the Government has given clear indications that it seeks to diversify revenue base from oil through efficient and effective management of natural gas resources and promote commercial utilization. The continuing strategies have included initiating new and reviewing existing gas policies, fiscal incentives and pricing policies to attract investments to the gas sector. Effective and efficient marketing of gas produced, and the promotion of gas utilization through re-injection, natural gas liquids (NGL) production, and petrochemical feed stocks are also some of the strategies (Ageh *et al* 1999).

2.3.2 Re-injection

Gas re-injection involves re-injection of natural gas into an underground reservoir, typically one already containing both natural gas and crude oil, in order to increase the pressure within the reservoir and thus induce the flow of crude oil. After the crude

has been pumped out, the natural gas is once again recovered. Since many of the wells found around the world contain heavy crude, this process increases their productivity. The basic difference between light crude and heavy crude is its viscosity and pumpability - the lighter the crude the easier it is to pump. Recovery of hydrocarbons in a well is generally limited to 50% (heavy crudes) and 75-80% (light crudes). Recycling of natural gas or other inert gases causes the pressure to rise in the well, thus causing more gas molecules to dissolve in the oil lowering its viscosity and thereby increasing the well's output. Air is not suitable for re-pressuring wells because it tends to cause deterioration of the oil, thus carbon dioxide or natural gas is used to re-pressure the well.

The term 'gas-reinjection' is also sometimes referred to as re-pressuring, the term being used only to imply that the pressure inside the well is being increased to aid recovery. Injection or reinjection of carbon dioxide also takes place in order to reduce the emission of CO_2 into the atmosphere. This has been mooted as a major weapon in the future fight against climate change, allowing mass storage of CO_2 over a geological timescale. Reinjection of carbon dioxide in the Norwegian Sleipner gas field saves the operators 1 million Norwegian Kroners per day in national carbon taxes (Wikipedia, 2006).

2.3.3 Liquefaction

Liquefied natural gas or LNG is natural gas that has been processed to remove either valuable components e.g. helium, or those impurities that could cause difficulty downstream, e.g. water, and heavy hydrocarbons and then condensed into a liquid at

almost atmospheric pressure (maximum transport pressure set around 25 kPa) by cooling it to approximately minus163 ^{o}C (-163 ^{o}C). LNG is transported by specially designed cryogenic sea vessels and cryogenic road tankers and stored in specially designed tanks. LNG is about 1/614th the volume of natural gas at standard temperature and pressure (STP), making it much more cost-efficient to transport over long distances where pipelines do not exist. Where moving natural gas by pipelines is not possible or economical, it can be transported by LNG vessels, where the most common tank types are membrane (prismatic), Moss Rosenberg (spheres) or Self-Supporting Prismatic Type.

The natural gas fed into the LNG plant will be treated to remove water, hydrogen sulfide, carbon dioxide and other components that will freeze (e.g., benzene) under the low temperatures needed for storage or be destructive to the liquefaction facility. Purified LNG typically contains more than 90% methane. It also contains small amounts of ethane, propane, butane and some heavier alkanes. The purification process can be designed to give almost100% methane.

Conditions required to condense natural gas depend on its precise composition, the market that it will be sold to and the process being used, but typically involve temperatures between −120 and −170 degrees Celsius (pure methane liquefies at −161.6 °C) and pressures of between 101 and 6000 kPa (14.7 and 870 lbf/in²). High pressure natural gas that is condensed is then reduced in pressure for storage and shipping. The density of LNG is roughly 0.41 to 0.5 kg/L, depending on temperature, pressure and composition. In comparison, water has a density of 1.0 kg/l.

LNG does not have a specific heat value as it is made from natural gas, which is a mixture of different gases. The heat value depends on the source of gas that is used and the process that is used to liquefy the gas. The higher heating value of LNG is estimated to be 24 MJ/l at −164 degrees Celsius. This corresponds to a lower heating value of 21 MJ/l.

LNG offers an energy density comparable to petrol and diesel fuels and produces less pollution, but its relatively high cost of production and the need to store it in expensive cryogenic tanks have prevented its widespread use in commercial applications (Wikipedia, 2006).

2.4 Oil and gas gathering systems

Oil and gas produced in oil fields are separated, purified, metered, gathered and shipped to refiners and to point of utilization. Different system of oil and gas gathering are used in different oil fields, depending on local conditions. The common basic requirement is that they should ensure the greatest possible separation of gas from the oil, with subsequent use of gas, without permitting losses of light petroleum fractions by evaporation, hence the need for closed oil gathering systems.

Existing oil and gas gathering system may be classified based on:

i. the number of wells served by the primary oil gathering facilities into individual or central
ii. the degree of seal into: fully closed sealed or partially close:
iii. the nature of the flow in the flow lines into gravity or pressure systems, in which the well fluids may move either together or separately;

iv. the nature of the gathering technology: into single or multistage separation, with dehydration, drying; desulphurization, extraction of natural gasoline, utilization of gas in gas life operations, heating and desalting or without these processes.

2.5 Separation of gas from oil

As the multiphase well fluid moves from the formation to the gathering point, pressure steadily declines with attendant evolution of gas and vapors, which interfere with the motion of the fluid, at this point gases and vapors are lost into the atmosphere. To avoid operational problems and loss of gas, it is separated from the oil in gas separators (traps) of various designs separation is aided by reduction of pressure, by breaking up the fluid flow into jets, by changing the direction of the flow, and by other methods. The operation of the gas separation consists in separating the gas dissolved and occluded in the oil, trapping the oil droplets entrained by the gas, retaining the essential constituents of the gas and oil, breaking up from and preventing its formation. Gas separators may be conveniently classified by:

i. the type of well served: flowing, gas-lift, pumping, combined
ii. shape and position: cylindrical vertical, inclined horizontal
iii. the nature of the main operative force: gravity, centrifugal or combined
iv. the working pressure: vacuum, Low-pres and medium – pressure
v. the number of wells served; individual or central
vi. stage of separation: first stage, second stage and so on
vii. function: Separating or measuring

viii. the method of manufacture: Welded, riveted or tubular

Vertical gas separators have found the widest use in field practice. These are cylindrical vessels 0.4 to 2.6m in diameter and 4 to 10 times as high as they are wide. Production is admitted into the separators nears their middle part either radially or tangentially. The latter construction imparts a swirling motion to the fluid and sets up centrifugal forces which aid gas separation. The gas separated from oils rises up the central part of the separator where baffles are provided to catch the entrained oil droplets. The rate of rise should not exceed 0.8, 0.6, 0.5, 0.4, 0.35 and 0.3m/sec for gas-separation pressures of 1.5, 10, 20, 35, and 50 ata respectively. The rate of rise and the volume of gas evolved are determined by the cross section of gas flow and therefore by the cross-sectional area of the separator.

Separators are provided with sleeves for the connection of pipelines, with manholes, maintenance platforms and ladders, and also with regulating control and safety equipment. The oil is drained from the lower part of the separator, care being taken to prevent the formation of dead zones. The gas is drawn off from the highest point to prevent oil from entering the gas line. The required oil level in the separator is maintained by means of a float mechanism, mechanically or pneumatically connected to the actuating mechanism.

Flow meters are installed on the gas line on the downstream side of the separator to measure the gas, and a pressure regulator is installed which automatically maintains the pressure required to ensure normal separation of gas from oil and to move them through the pipelines. Tests have shown that gas separation is most efficient if use is

made of centrifugal forces set up when the fluids are introduced into the separator tangentially.

2.6 Separation of water and solids from oil

In addition to gas, the well fluids contain water, solid impurities and dissolved salts. To avoid problem in transporting and refining the oil, all these impurities must be removed in the field.

2.7 Field pipelines

The system of field pipelines is the principal component of the oil, gas and water gathering and transmission systems. Considerable investment is required to lay and operate the pipelines. Oil-field pipelines may be classified based on the:

i. destination-oil, gas, water, steam, sewerage or mixed well fluids.

ii. material steel or non-metallic (as best cement, wood plastic etc).

iii. the nature of the flow – Pressure or gravity.

iv. working pressure high medium or low pressure and vacuum.

v. function laterals, gathering, transmission and mainlines.

vi. method of laying – buried, surface or elevated.

2.8 Transport of natural gas

There are basically two ways in which natural gas can be shipped from a gas or oilfield to its consumer. Either it can be moved by compressors along a pipelines or it can be liquefied and the liquid carried by specially designed tankers to its market.

Detailed design development for a high-pressure (ANSI 600# or higher) gas transmission system includes hydraulic analysis of transient pressure and temperature conditions in the pipeline, and of two-phase flow resulting from pressuring of the line from a high-pressure source and de-pressuring, whether intentional or resulting from line rupture. Low temperatures caused by auto refrigeration during de-pressuring can significantly affect fluid properties (and influence material selection).

Effects of normal flow variation that stem from the delay in system response at other locations must also be considered. Unless seasonal ambient ground temperature variations are extreme, the annual mean ambient air temperature adequately approximates the average flow temperature for long buried lines. For short lines, gas temperatures of the compressor station or wells may be considerably higher than ambient, and should be taken into account.

The design of annual throughput of gas lines is usually expressed in standard cubic feet per calendar day (SCFCD). Seasonal throughput for gas lines can vary significantly because of demand fluctuations and should be considered in setting the load factor that determines design flow rate, expressed in standard cubic feet per operating day (SCFOD).

Pipeline transportation will generally be preferred where shipment is across land rather than sea, where there is little or no likelihood of interference with permanent installation by political or ideological opponents and where there are no serious physical obstacles to pipelines construction. Gas liquefaction on the other hand, although generally more expensive, is the only possible means of conveyance by ship across deep open seas and may also be preferred for reasons of politics and strategy.

Transport by pipeline requires gas compression; since throughput of a line is a function of pipe diameter and pressure drop. Apart from physical properties of the gas, economic optimization requires careful calculation of pressures, and hence pipe strength, along the line. Compressor stations along the line must be planned in such a way that their extra cost is more than compensated by the additional carrying capacity. Since, inevitably, some pressure drop occurs, careful calculation of so-called retrograde condensation phenomena is required. Condensate formed in the line must be trapped and separated before the gas is re-compressed to prevent damage to compression plant.

Other gas properties that affect behavior during pipeline transmittal are moisture content, corrosivity caused by impurities in the gas, gas compressibility and viscosity.

If natural gas is to be as LNG, depending on the available pressure, it may have to be recompressed. This involves complex liquefaction cycles in which energy consumption is minimized by careful pre-cooling or by a combination of the two refrigeration mechanisms.

Gas properties of significance in LNG shipment are again gas make-up, moisture content, impurities and constancy of compose, will clearly affect the operation of a carefully optimized liquefaction plant changes in liquid density have also been shown to result in dangerous conditions of instability, and accidents due to roll-over, the sudden readjustment of layers of different density, can occur if LNG composition undergoes a sudden change (Lom and Williams, 1976).

2.9 Design of oil and gas pipelines

Major factors influencing pipeline system design include the following;

Fluid properties, Codes and standards, Design conditions, Supply and demand magnitude/location, Route-topography and access, Environmental impact, Economics, Hydrological impact, Seismic and Volcanic impacts, Material, Construction, Operation, Project, Long – term integrity (Mohitpour *et al*, 2003).

The major steps considered during pipeline design include the following

i. Regulations and Codes to be followed this include:

Regulatory Jurisdictions and Codes

ii. Hydraulics includes:

Basic Pressure Drop Calculations, Special Hydraulic Conditions and Hydraulic Profiles

iii. Line Sizing include:

Elements to Determine an Economic System, Preliminary Pipe Selection and Line Operating Pressure, Hydraulic Profiles and Pump Station Locations, Order-of-Magnitude Estimates for Investment Costs, Order-of-Magnitude Estimates for Operating Costs, Economic Analysis for Line Sizing, Improving Cost Estimates and Sizing of Short Lines details in Appendix B.

iv. Line Design

Pipe and Coating Selection, Pipe Stress and Wall Thickness Calculations for Liquid Pipelines per, ANSI/ASME Code B31.4, Pipe Stress and Wall Thickness Calculations for Gas Transmission Pipelines, per ANSI/ASME Code B31.8, Coating Selection,

Burial—Restrained Lines and Provision for Expansion, Seismic Considerations, Crossings and Special Considerations. Refer to appendix B.

v. Pipeline Appurtenances

Line valves, Scraper traps, Electronic inspection pigs, Line pressure control and Relief, Slug catchers, Vents and Drains, Electrical area classification and Line markers.

vi. Corrosion Prevention Facilities

General, Impressed Current System for Cathodic Protection, Galvanic Sacrificial Anodes for Cathodic Protection, Insulating Flanges and Joint Assemblies and Cathodic Protection Test Stations and Line Bonding Connections

2.10 Trunk gas pipeline design

Trunk gas pipelines are used for the transmission of gas from the point of production to the point of utilization. These lines differ from field, factory, and municipal pipelines in the great length, high pressure and large diameter they posses.

In designing a trunk gas pipeline, the same steps are followed as in design of oil and gas pipelines with slight modifications.

To obtain optimum results for a pipeline transmission system, complex economic and engineering studies are necessary to decide on the pipeline diameter, material, compressed pumping power requirements, and location of the pipeline route.

2.10.1 Codes and Standards (ANSI/ASME Code B31.8)

Incorporated by reference in 49 CFR 192 for natural and other gases, ANSI/ASME Code B31.8, gas transmission and distribution piping systems, applies to field gathering, transmission and distribution pipelines for natural gas. It covers the design, fabrication, installation, inspection, testing, and safety aspects of gas transmission and distribution system operation and maintenance. Other range of facilities covered by the code, include gas compressor stations, gas metering and regulation stations, and closed-pipe gas storage equipment.

Code B31.8 does not apply to piping with metal temperatures above 450°F (232.2^{o}C) or below -20°F (-6.7^{o}C), vent piping operating at substantially atmospheric pressures, wellhead assemblies, or control valves and flow lines between wellhead and trap or separator (Chevron, 1999).

2.10.2 Hydraulics

Fluid Rheology

Liquids that have a constant shear rate with respect to shear stress at any given temperature are termed Newtonian fluids (e.g. water crude oil). Their viscosity is a function of temperature only increasing with decreasing temperature. Non-newtonian fluids, such as bitumen have viscosities that are not only a function of temperature, but also of shear rate and in some cases time (shrinkage).

There are a number of fluids that can exhibit non-newtonian behavior. These include dilutants (e.g. starch, water, quicksand) pseudo-plastic fluids (e.g. lime solution) and Bingham plastics (Mohitpour *et al* 2003).

Flow of Non-newtonian fluids in pipes; classification of fluids in rheology

Fluids fall by their rheological properties into the following groups:

i. Purely viscous or time independent fluids

The viscosity of these fluids is independent of the duration of shear (e.g. force applied to cause flow). The group includes Newtonian fluids, whose viscosity is constant at a given pressure and temperature, as well as non-Newtonian fluids in the strict sense, whose apparent viscosity is a function of shear stress.

ii. Time dependent fluids

The apparent viscosity depends in addition to the shear stress also on the duration of the shear.

iii. Visco-elastic liquid

The apparent viscosity is a function of both the shear stress and the extent of deformation.

iv. Complex rheological bodies

These fluids exhibit several of the properties of groups i, ii and iii described above.

The oil industry most often has to deal with fluids of groups i and ii described above.

Flow properties are characterized by flow curves or sets of such. Flow curves illustrate the variation of shear stress versus deformation rate.

The fundamental equation

In natural gas pipeline industry there is a need for workable equations to relate the flow of gas through a pipe to the properties of both the pipe and the gas and to the operating conditions such as pressure and temperature.

The reason for this is that systems must be designed and operated with full knowledge of what pressures will result from required flow rates.

In fluid mechanics there are so many derivations of fundamental equations governing one dimensional, compressible fluid flow, but essentially one begins with the partial differential equations of motion along with the equation of state and then starts assuming and integrating. The resulting equation for a flow in a horizontal pipe is the following: (Schroeder, 2001).

$$Q = \frac{CT_b D^{2.5} e}{P_b}\left(\frac{P_1^2 - P_2^2}{LGT_a Z_a f}\right)^{0.5} \quad - \quad - \quad - \quad - \quad -2.1$$

Where:

C = Constant, 77.54 (English units)

D = Pipe diameter (inches)

e = Pipe efficiency (dimensionless)

f = Darcy-Weisbach friction factor (dimensionless)

G = Gas specific gravity (dimensionless)

L = Pipe length (miles)

P_b = Pressure base (psia)

P_1 = Inlet pressure (psia)

P_2 = Outlet pressure (psia)

Q = Flow rate (standard cubic feet/day)

T_a = Average temperature (^{o}R)

T_b = Temperature base (^{o}R)

Z_a = compressibility factor (dimensionless)

Examining the components of the equation, note first that the equation expresses flow rate in terms of standard cubic feet per day. Although it looks like one, this is not a measure of volume per time; it is rather a measure of mass per time. It is in fact the mass contained in one cubic foot of the stated gravity of gas at the standard conditions defined by P_b and T_b, the base pressure and temperatures, they are standard conditions usually defined by gas sales contracts and not the scientific community.

The equation shows clearly how flow varies with the pertinent parameters.

Z_a the average compressibility factor is a function of pressure and temperature it must be evaluated at average conditions for the pipe.

For temperature, an arithmetic average flowing temperature is usually used while the following equation, which accounts for the non-linearity of pressure drop with distance, is generally accepted for determining the average pressure:

$$P_{av} = \frac{2}{3}\left(P_1 + P_2 - \left(\frac{P_1 P_2}{P_1 + P_2} \right) \right) \qquad - \quad - \quad - \quad - \quad -2.2$$

Using the value of average temperature and the value of average pressure calculated from equation 2.2, the average compressibility factor Z_a can be obtained from a compressibility chart for natural gas in (McAllister, 1993).

Equation 2.2 can also be used for line-pack determinations, which represents the amount of gas in the pipe.

Pipes are not always horizontal, so long as the slope is not too great, a correction for the static head of fluid may be incorporated and determined as follows:

$$Q = C \frac{T_b}{P_b} D^{2.5} e \left(\frac{P_1^2 - P_2^2 - H_c}{LGT_a Z_a f} \right)^{0.5} \qquad - \quad - \quad - \quad - \quad -2.3$$

Where:

$$H_c = \frac{0.0375(H_2 - H_1)P_a^2}{ZT_a} \quad - \quad - \quad - \quad - \quad - \quad -2.4$$

Note also that the flow equation includes an efficiency term for calibration purposes. Many correction factors have been used to account for many theoretical assumptions that do not necessarily apply in reality, it therefore becomes necessary to say that pipe roughness, which is related to friction factor *f* alone is not adequate compensator for friction effects in a pipe. Other effects can be from condensate accumulations, rust and sediment that behave more like diameter reductions.

The friction factor

This brings us to the most interesting and complex part of the equation, the friction factor. The first complication that arises is that there are two common friction factor definitions in standard usage:

1. Fanning
2. Darcy-Weisbach

Darcy-Weisbach is four times the fanning factor (use of any is a matter of personal choice).

Fundamental equation for calculating flow requires the numerical evaluation of *f*, the friction factor. In general, the friction factor itself is in turn a function of flow rate, thus making the whole flow equation an explicit one. For the purposes of determining friction factor, it has been found that fluid flow may be characterized by a dimensionless grouping of variables known as the Reynolds' Number, which is defined as:

$$N_{\mathrm{Re}} = \frac{Dv\rho}{\mu} \quad - \quad - \quad - \quad - \quad - \quad - \quad -2.6$$

where:

N_{Re} = Reynolds' number (dimensionless)

D = pipe diameter (feet)

v = fluid velocity (feet/second)

ρ = fluid density ($Ib_m/foot^3$)

μ = fluid viscosity (Ib_m/second-foot)

Note that in this context the units are not the same for they must cancel to produce a dimensionless group. For a compressible fluid, we can determine density from the equation of state to substitute for ρ, and determine velocity as flow rate/ area corrected to actual conditions to substitute for v, conveniently, much of the equation of state cancels-out and we are left with the following expression:

$$N_{\mathrm{Re}} = \frac{0.015379 Q g P_b}{\mu D T_b} \qquad \text{- - - - - -2.7}$$

where:

N_{Re} = Reynolds' number (dimensionless)

D = pipe diameter (inches)

g = Gas specific gravity (dimensionless)

P_b = Base Pressure (psia)

Q = Gas flow rate (standard ft^3/day)

T_b = Base Temperature (^oR)

μ = fluid viscosity ($Ib_f sec/ft^2$)

This is a better way to view the Reynolds' number in a gas industry constant since it points out that the Reynolds' number is essentially proportional to the flow rate.

The other parameter in the friction factor correlation is pipe roughness.

Friction factor *f* may be correlated as a function of:

1. Flow rate, and flow rate is a function of Reynolds number:
2. Pipe roughness

Therefore friction factor can be correlated as a function of Reynolds number and relative pipe roughness

Moody Diagram

Friction factor and Reynolds number Vs Friction factor relative to pipe roughness gives what is known as Moody diagram, figure 2.1.

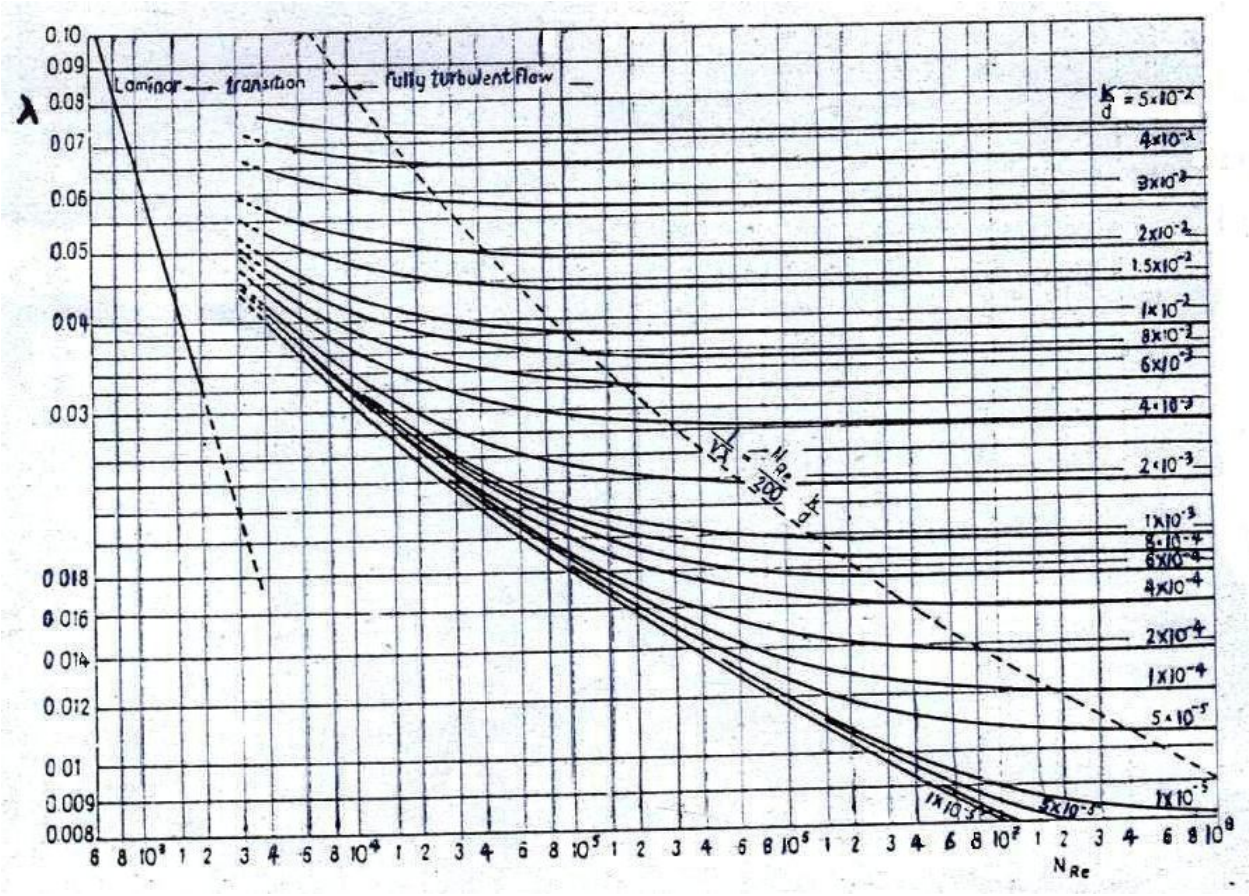


Figure 2.1: Friction Factor in Pipes, according to Moody (Schroeder, 2001).

The moody diagram can be broken down into four zones: Laminar, Transition, Partially turbulent and Fully turbulent

Characteristics of the zones in Moody diagram

Laminar zone (Hagen-Poiseuille equation) extreme left of Moody diagram.

In this zone of extremely low flow rate the fluid flows strictly in one direction and the friction factor shows a sharp dependency on flow rate as defined by the Hagen-Poiseuille equation:

$$f = \frac{64}{N_{\mathrm{Re}}} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad \text{-2.9}$$

Fully turbulent (Nikuradse equation) extreme right.

The fully turbulent zone is the part on the extreme right where the lines flatten-out. In this zone of extremely high flow rate the fluid flows laterally within the pipe in complete turbulence as well as in the primary direction and the friction factor shows no dependency on flow rate. Note: the ultimate friction factor is only a function of roughness and an ideally smooth pipe never makes it to this zone. Here the friction factor is given by the rough pipe law of Nikuradse:

$$\frac{1}{\sqrt{f}} = 2\log\frac{D}{\varepsilon} + 1.14 \quad - \quad - \quad - \quad - \quad - \quad - \quad \text{-2.10}$$

The Partially Turbulent zone is the part in the middle where the curves exist.

In this zone of moderately high flow rate the fluid flows laterally within the pipe as in the primary direction although some laminar boundary layer outside the zone of roughness still exists. Starting in the left side of this region, flow is governed by the smooth pipe law of von Karman and Prandtl equation:

$$\frac{1}{\sqrt{f}} = 2\log\left(N_{\mathrm{Re}}\sqrt{f}\right) - 0.8 \quad - \quad - \quad - \quad - \quad -2.10$$

How the friction factor varies across this region from the smooth pipe law to the rough pipe law should be extended to the smooth pipe law forming a corner at the intersection. Others feel that the corner should not be there and that Colebrook-White equation, which is a combination of the two, is the proper method shown in figure 2.2

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{N_{\mathrm{Re}}\sqrt{f}}\right) - \quad - \quad - \quad - \quad - \quad -2.12$$

It should be noted that the use of fundamental equation for calculating flow requires the numerical evaluation of the friction factor, *f*.

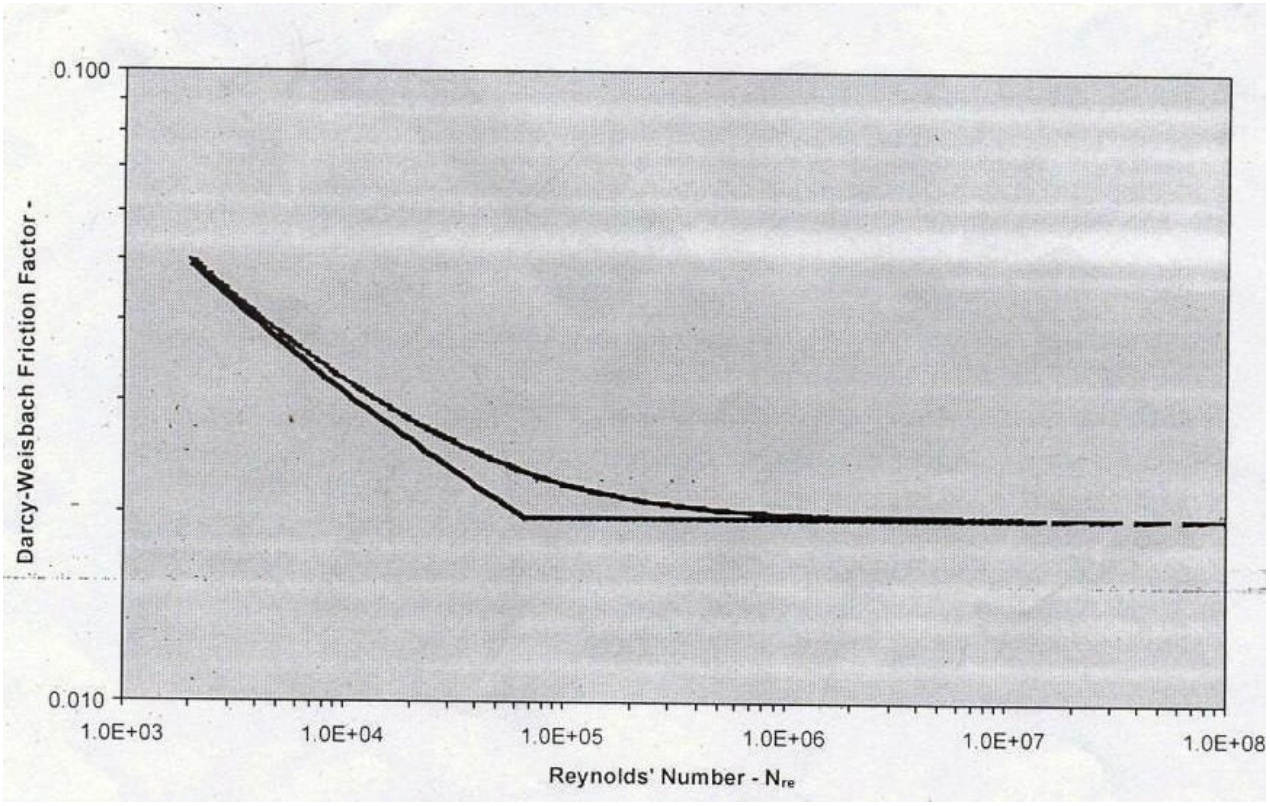


Figure 2.2: Moody Diagram – Colebrook-White

Unfortunately the published data are inconclusive so that either method may be considered valid. Recent work by Groupe European de Recherches gazieres (GERG) has proposed a new flow equation (Gersten *et. al*, 2000) that includes an additional parameter "n". The term "n" is essentially a shape factor that places the friction factor between these two limits (n=1 approximates Colebrook-White while n=10 approximates the sharp intersection). Several observations are important:

1. The Colebrook-white equation always predicts a higher friction factor: hence it is the more conservative.
2. The maximum difference in friction factor (The difference between the two limits n=1 and n=10) is about 17% which translates to a 8.5% difference in flow.
3. This maximum difference occurs at fairly low Reynold's numbers associated with low pressure drop and lessens with increasing pressure drop where it is more important.
4. There is significant scatter to the data.

While this work is exciting, it is unclear how adding one more factor that is even more physically remote than the roughness term will help clarify the very murky world of system calibration.

These equations point out the other reason for stating earlier that roughness alone is not a sufficient calibration parameter: roughness only affects half of the equation. Note that the smooth pipe law does not include an effect for roughness. This means that as flow rate decreases, roughness enters in less and less, and not at all if using the sharp intersection technique.

The critical zone is where there are no lines, hence no function. In this zone of relatively low flow between the laminar and Partially Turbulent zones no one knows what is happening. This is not due to lack of effort in trying to explain it. The fact is that the upper end of laminar flow is unstable and in this region multiple behaviors are observed.

The connection of these zones works pretty much as follows. As fluid starts flowing from rest, the friction factor decreases at a fairly fast rate. During this time the fluid is in the laminar flow regime in which there is no motion at the wall, the velocity follows a parabolic distribution to the center of the pipe, and there is no non-axial flow. At some point, usually assumed to be at an N_{Re} greater than 2000, the laminar flow begins to break up in the center of the pipe and the friction factor sharply and discontinuously increases. Precisely where this happens cannot be determined. Nothing fully predictable happens until an N_{Re} of at least 3250 is reached, at which point a partially turbulent regime may be assumed to be established and the friction factor is again decreasing with flow rate in a regular manner according to the smooth pipe law. As flow further increases, the turbulent core increases in diameter at the expense of the annular laminar outer layer. At some point the inherent roughness of the pipe limits further drop in friction factor. As stated previously, how the friction factor approaches its limit is not completely clear.

The mathematical representation of the above has presented serious problems to modelers from the beginning. The most common approach has been to use either the familiar Colebrook-White equation or a combination of the smooth pipe and rough pipe laws which accurately represent the partial and fully turbulent regions, use the

Hagen- Poiseuille relationship for laminar flow, and connect the end of laminar flow, assumed at an N_{Re} of 2000, and the beginning of the smooth pipe law, assumed at an N_{Re} of 3250 with a straight line. This is without question the best that can be done. Its only questionable area is that it has reduced the ambiguity of the Critical zone to a representative equation, but that operation is essential for modeling.

When performance issue does arise however, the fact that neither the Colebrook-White equation nor the smooth pipe law are explicit in the partially turbulent zone (*f* appears on both sides of the equation) requires an iterative method for computation. Since the function is very well behaved and predictor-corrector techniques work very well, this only means that the computing requirements increase slightly. Alternative methods have been developed to provide an explicit, hence faster performance, method. An excellent comprehensive discussion of the available equations may be found in (Gregory and Fogarasi, 1985). Note that these equations are only defined for the partially and fully turbulent zones. Critical flow is still a problem where some appropriate modifications must be made. As an example, the equation in (Chen, 1979) which is the most precise, is presented here:

$$\frac{1}{\sqrt{f}} = -4 \log\left(\frac{\varepsilon/D}{3.7065} - \frac{5.0452}{N_{Re}} \log\left(\frac{(\varepsilon/D)^{1.1096}}{2.8257} + \left(\frac{7.149}{N_{Re}}\right)^{0.8961}\right)\right) \qquad -2.13$$

The critical zone presents another more serious numeric problem. First it must be stated that normal pipes through which any significant amount of fluid is flowing and which have any measurable head-losses will have N_{Re} much greater than 3250. Still, very low pipes do occur in both liquid and gas systems. Since the friction factor can

over double very quickly and go in the "wrong" direction in the N_{Re} range of 2150-3250, gradient methods for solving a network using this equation simply may not converge to a unique solution.

One solution to this problem is to cut-off the laminar zone at the point where *f* drops to its value at the beginning of the partially turbulent zone and use that value as a constant for all points in between. This will make the fundamental pipe element inherently stable and introduce a maximum friction factor error of 45% at an N_{Re} of 2300, which translates to a 20% error in flow, but so what? There is no flow or pressure drop in the first place! This "error" disappears completely outside the N_{Re} range of 1400-3250 and should introduce no discernable change in simulation results for gas systems.

The "Practical" equations

The fundamental flow equation as described above are universally accepted as the full and complete statement of how flow works.

Although the equation (fundamental equation) after inputting different friction factor from various conditions may appear to be very different, any real equation may be equated to the fundamental equation and the result solved for friction factor. In this process many of the common factors cancel and friction factor relationship is much simpler. The friction factor equation may then be superimposed on the moody diagram to view the comparison, remembering that any difference in *f* affects flow as v*f*.

One starting point for simplification is to recall that originally gas was distributed in low-pressure systems measured in inches of water column. Under these conditions the flow can be considered non-compressible and the fundamental equation may be

reduced by factoring the ($P_1^2 - P_2^2$) term into ($P_1 - P_2$)($P_1 + P_2$)and assuming an appropriate average pressure. The equation then becomes:

$$Q = \frac{CT_b D^{2.5} e}{2P_b}\left(\frac{(P_1 - P_2)P_a}{LGT_a Zf}\right)^{0.5} \quad - \quad - \quad - \quad - \quad -2.14$$

One of the first flow equations in natural gas industry is (Schroeder, 2001):

$$Q = 1350 D^{2.5}\left(\frac{P_1 - P_2}{LG}\right)^{0.5} \quad - \quad - \quad - \quad - \quad -2.15$$

Where:

D = Pipe diameter (inches)

G = Gas specific gravity (dimensionless)

L = Pipe length (yards)

P_1 = Inlet pressure ("H_2O)

P_2 = Outlet pressure ("H_2O)

Q = Flow rate (standard cubic feet/hour)

The equivalent friction factor for this is:

$$f = 0.0291 \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad -2.16$$

Note that 0.0291 is just about what one expect for low pressure pipe under moderately low flow conditions. Constant friction factors are certainly not the most realistic. At the very least one would expect the friction factor to vary with the pipe diameter.

Spitzglass equation:

The Spitzglass equation comes in two types:

$$Q = 117 D^3 e \left(\frac{(P_1 - P_2) P_a}{LG\left(D + 3.6 + 0.03D^2\right)} \right)^{0.5} \qquad \text{-2.17} \quad \text{Low pressure (“}H_2O\text{)}$$

$$Q = 117 D^3 e \left(\frac{\left(P_1^2 - P_2^2\right) P_a}{LG\left(D + 3.6 + 0.03D^2\right)} \right)^{0.5} \qquad \text{-2.17} \quad \text{High pressure (PSIA)}$$

Where:

D = Pipe diameter (inches)

e = Pipe efficiency (dimensionless)

G = Gas specific gravity (dimensionless)

L = Pipe length (miles)

P_1 = Inlet pressure (psia)

P_2 = Outlet pressure (psia)

Q = Flow rate (standard cubic feet/day)

The equivalent friction factor for this is:

$$f = \frac{4\left(1 + 3.6/D + 0.03D\right)}{354} \qquad \text{- - - - - -2.19}$$

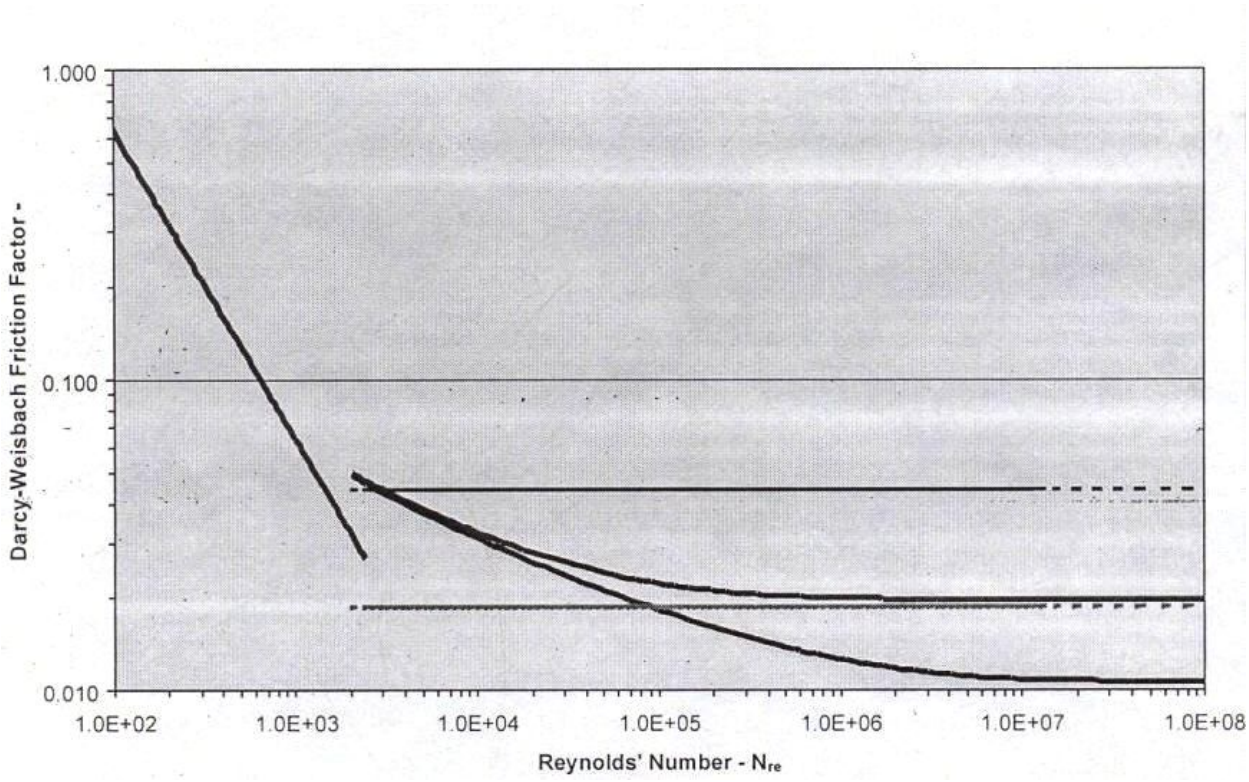


Figure 2.3: Moody Diagram- Spitzglass

This equation is a minor improvement in that it allows the friction factor to vary with pipe size. Note however that the friction factor decreases with increasing pipe size, which is what one would expect for a constant roughness, but only to a diameter of about 10.95 inches, then it starts increasing! This behavior obviously is counter to what should happen although the range over which it may be observed, 0.0187 – 0.0246 (from figure 2.1) is not too bad.

Weymouth equation

Turning to more transmission-like conditions, the Weymouth equation is another diameter varying friction equation, also dating from 1912:

$$Q = 433.49 \frac{T_b}{P_b} D^{8/3} e \left(\frac{(P_1 - P_2) - H_c}{LGT_a Z_a} \right)^{0.5} \quad - \quad - \quad - \quad -2.20$$

Where:

D = Pipe diameter (inches)

e = Pipe efficiency (dimensionless)

G = Gas specific gravity (dimensionless)

L = Pipe length (miles)

P_b = Pressure base (psia)

P_1 = Inlet pressure (psia)

P_2 = Outlet pressure (psia)

Q = Flow rate (standard cubic feet/day)

T_a = Average temperature (^oR)

T_b = Temperature base (^oR)

Z_a = compressibility factor (dimensionless)

The equivalent friction factor for this is:

$$f = \frac{4}{\left(11.18^{1/6}\right)^2} \qquad - \quad - \quad - \quad - \quad - \quad - \quad -2.21$$

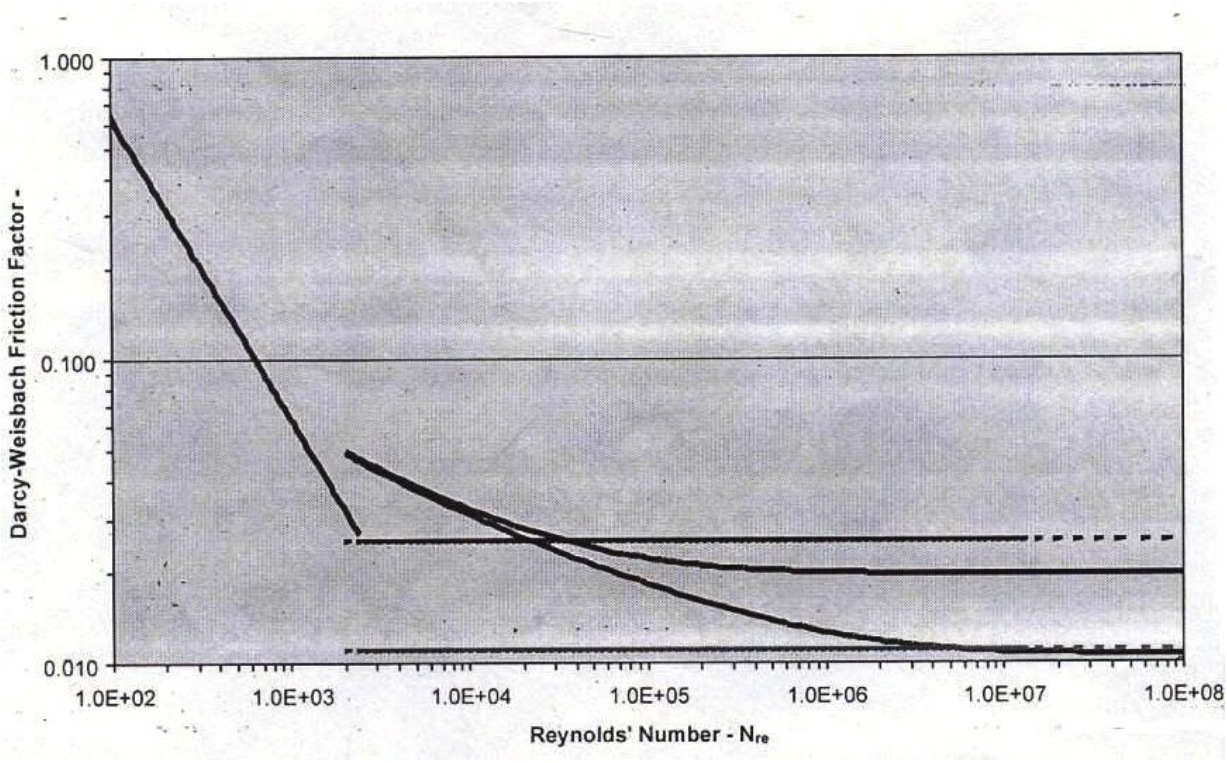


Figure 2.4: Moody diagram - Weymouth

Note that the friction factor decreases consistently with increasing pipe size, and it does so in a range of 0.008 – 0.02 that is more appropriate to high flow situations. This was one of the earlier transmission equations that have survived to this day. Proper tuning of efficiencies can make it work well, particularly in a design mode.

Panhandle equations

Panhandle A

The next improvement comes in the form of equations that show a friction factor that varies with Reynold's number and hence flow, but do so in an explicit form. The first of these is the Panhandle A equation:

$$Q = 435.87\left(\frac{T_b}{P_b}\right)^{1.0788} D^{2.6182} e\left(\frac{\left(P_1^2 - P_2^2\right) - H_c}{LG^{0.8538} T_a Z_a}\right)^{0.5394} \quad - \quad - \quad -2.22$$

Where:

D = Pipe diameter (inches)

e = Pipe efficiency (dimensionless)

G = Gas specific gravity (dimensionless)

L = Pipe length (miles)

P_b = Pressure base (psia)

P_1 = Inlet pressure (psia)

P_2 = Outlet pressure (psia)

Q = Flow rate (standard cubic feet/day)

T_a = Average temperature (^{o}R)

T_b = Temperature base (^{o}R)

Z_a = compressibility factor (dimensionless)

Equivalent friction factor for this is:

$$f = \frac{4}{\left(6.87 N_{\mathrm{Re}}^{0.07305}\right)^2} \quad - \quad - \quad - \quad - \quad - \quad - \quad -2.23$$

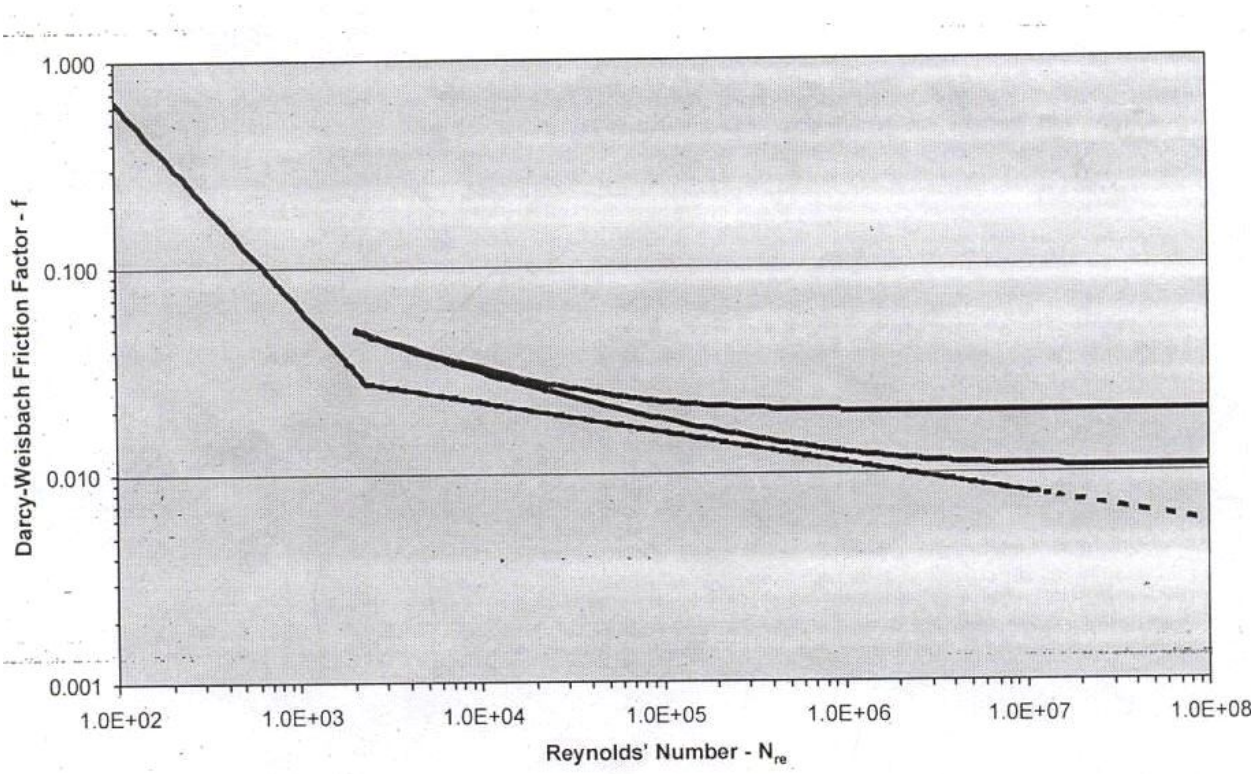


Figure 2.5: Moody Diagram – Panhandle A

It is important to note that this line falls slightly below the Colebrook-White lines in the Moody diagram (Figure 2.1) but it can be moved up or down by using an appropriate efficiency. Its slope is appropriate for low Reynold's numbers.

Panhandle B

After recognizing that flow-rates were increasing beyond those used in developing the correlation, the panhandle B equation was proposed (Schroeder, 2001):

$$Q = 737\left(\frac{T_b}{P_b}\right)^{1.02} D^{2.53} e\left(\frac{P_1^2 - P_2^2 - H_c}{LG^{0.961} T_a Z_a}\right)^{0.51} \quad - \quad - \quad - \quad -2.24$$

The equivalent friction factor for this is:

$$f = \frac{4}{(16.49\ \mathrm{N_{Re}}^{0.01961})^2} \quad - \quad - \quad - \quad - \quad - \quad -2.25$$

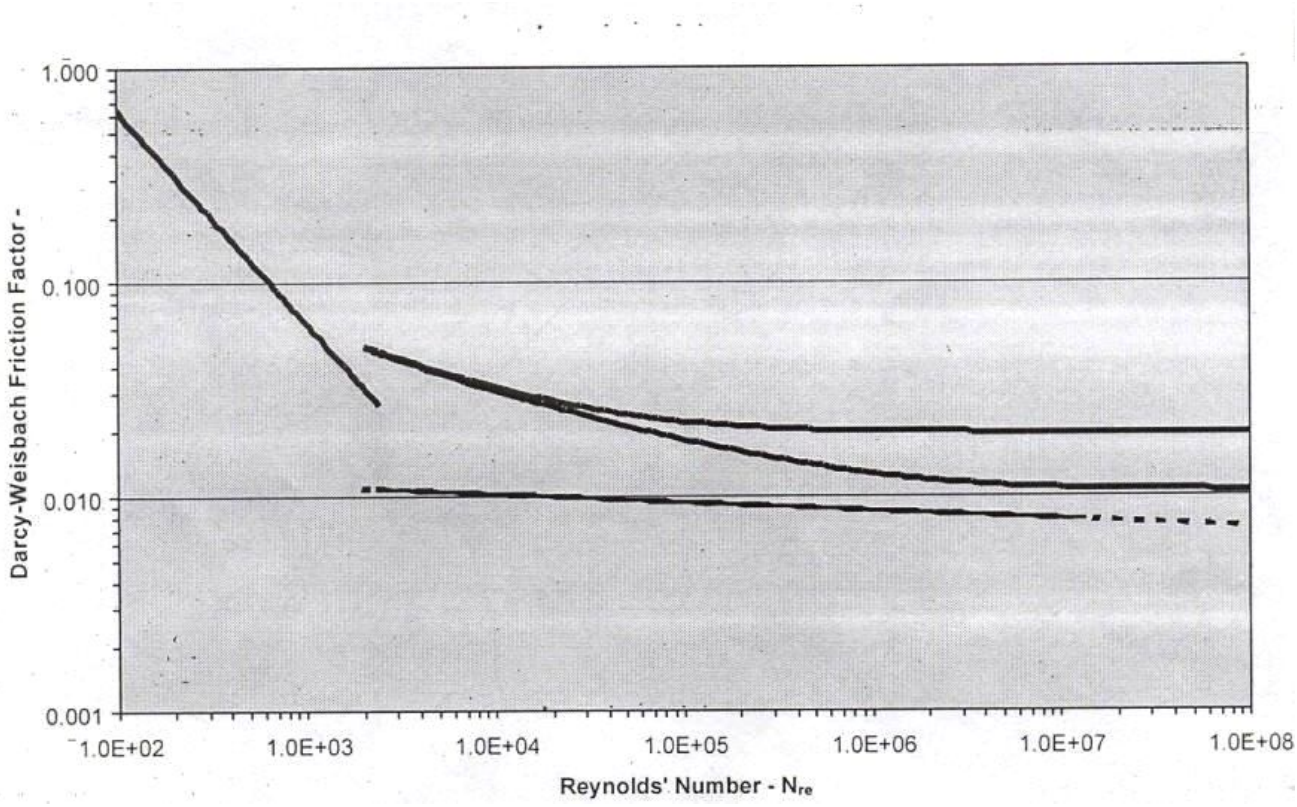


Figure 2.6: Moody Diagram – Panhandle B

It is important to note that this line falls below the Colebrook-White lines but that it can be moved up or down by using an appropriate efficiency. Its slope is appropriate for higher Reynold's numbers than the panhandle A.

Institute of Gas technology (IGT) equation

$$Q = 92.66 \frac{T_b D^{8/3}}{P_b g^{4/9} \mu^{1/9}} e \left(\frac{P_1^2 - P_2^2 - H_c}{LGT_a Z_a} \right)^{5/9} \qquad - \qquad \text{-2.26} \quad \text{(English)}$$

Where:

D = Pipe diameter (inches)

e = Pipe efficiency (dimensionless)

G = Gas specific gravity (dimensionless)

L = Pipe length (miles)

μ = Fluid viscosity (Ib_m/second-foot)

P_b = Pressure base (psia)

P_1 = Inlet pressure (psia)

P_2 = Outlet pressure (psia)

Q = Flow rate (standard cubic feet/day)

T_a = Average temperature (^oR)

T_b = Temperature base (^oR)

Z_a = compressibility factor (dimensionless)

The equivalent friction factor for this is:

$$f = \frac{4}{\left(4.619 N_{\mathrm{Re}}^{0.1}\right)^2} \quad - \quad - \quad - \quad - \quad - \quad - \quad -2.28$$

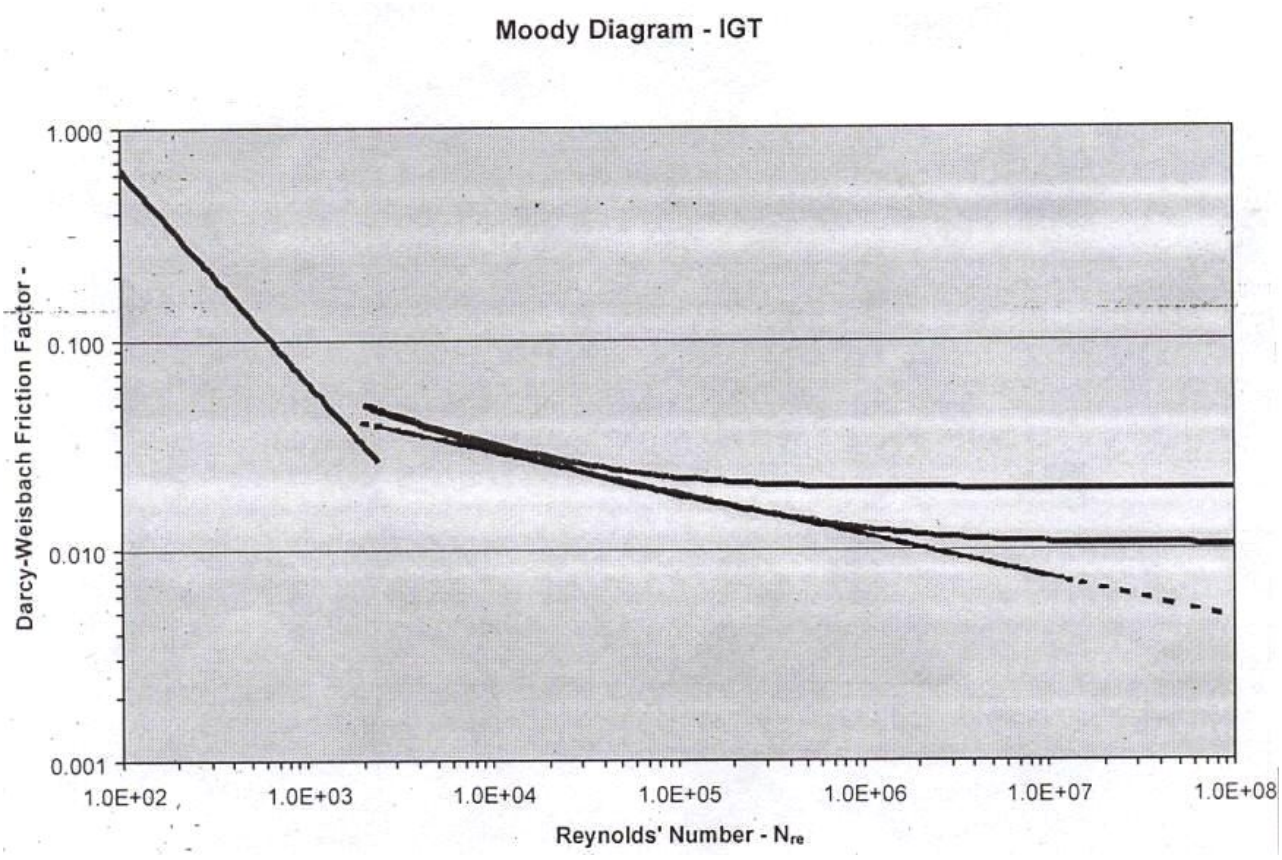


Figure 2.7: Moody Diagram - IGT

These entire flow dependent equations share one common attribute: at low flow they are conservative and under-predict flow while at high flow overly optimistic and over-predict flow. The main difference is where low and high is defined.

The assumptions made by the IGT are outlined in Gersten *et al*, (2000).

The choice of any of the equations above can give correct answers at some conditions particularly when tuned through proper use of efficiency. Modern computing technology has rendered the computational effort a non-issue and one cannot use any of these without carefully computing Reynold's numbers and checking each pipe in each system to determine when the equations is correct.

When final decisions are going to be taken for a given pipe line project, for example just before final engineering work commences complex software programs will have to be used to enhance the efficiency of handling the project, at that point, it can be rightly said that anyone continuing to use a fixed friction factor equation is not properly addressing the problem, and therefore anyone not using a Moody diagram based friction factor equation is not properly addressing the problem, probably the worst thing that can be done is to use either the panhandle A or IGT equations without checking Reynold's numbers since the friction factor, and hence the associated pressure drops, can decrease without bound.

Checking the performance of equations is in order since it is ultimately a balancing act between precision and performance. To attempt to measure this, a fairly typical large integrated natural gas distribution system having somewhere in excess of 200,000 nodes and 500 regulators was chosen. By choosing this kind of network, the friction factor computations will be exercised over a wide range of flows and

pressures. The following table shows the computational performance of this network relative to the most rigorous method, Darcy-Weisbach:

Table 2.1 Computational Performance of different friction factors

Friction Method	Relative Computational Time	Savings %
Darcy-Weisbach	1.000	-
Chen	0.913	9
Shacham	0.844	16
IGT	0.842	16

This indicates that there is not a wide range in performance over all. It can also be noticed that there is virtually no difference between the Shacham equation, which has the correct shape, and the IGT, which does not. Any differences become much less significant when we consider that this problem only requires nominally three minutes to solve on a fairly slow 333 megahertz Pentium II. Clearly we are talking about a difference of a few seconds on a more typical machine, not a high performance machine.

This leads to four sensible alternatives for approaching flow equations (Schroeder, 2001):

1. Use the full Moody diagram complete with the Hagen-Poiseuille equation for laminar flow, the Colebrook-White equation or the GERG approach for the rest of the flow and make some assumptions to traverse the critical zone. This is the most defendable course of action.
2. Use the Colebrook-White equation or the GERG approach for the flow above N_{Re} of 32500 and do something smooth with f for N_{Re} <3250 in gas flow,

misstating f in this range of N_{Re} makes no practical difference and does eliminate some potential convergence problems.

3. Use the Chen or Shacham equation instead of Colebrook-White. No significant difference in results should occur but performance will improve as shown above.
4. Use the smooth pipe law of von Karman and Prandtl (or an explicit fit thereof) intersected with the rough pipe law of Nikurudse. This will generally produce a somewhat lower friction factor than Colebrook-White. Since the difference is not large and disappears at the extremes, this is a perfectly safe approach that may follow observed data more closely.

It is suspected that using the new equation proposed by GERG as a means of interpolating between Colebrook-White and alternative 4 may be much more computationally intensive than any other; it is not sure what the basis for picking the degree of interpolation is. This can be a wonderful area for more research work.

At the end of this investigation alternative 3 is seen as the choice for gas systems combined with the mis-stated laminar 2. This should give good conservative answers with the least amount of computational problems. For liquid systems alternative 1 is preferred since the laminar region may be significant.

Some further comments on flow equation migration are in order. Ultimately pipeline efficiency should be used to calibrate a model to reality.

Matching reality involves three separate issues:

i. Accounting for problems with the flow equation,

ii. Accounting for problems with the pipe such as bends, fittings, junk inside, and the like, and

iii. Accounting for operational problems such as the relationship between daily and instantaneous flow.

The efficiencies used by many companies are a composite of these items. When considering a change in flow equation it is important to attempt to separate issue i from the others. It is reasonable to expect that the efficiency contributions from items ii and iii are to remain constant whatever flow equation is used, while issue i should change. For example, an efficiency of 85% could comprise:

I. A component because the friction is too low, and

II. A component because someone left a rag in the pipe, and

III. A component because the only flow we have is peak day and we need to design for peak hour.

Since the calibration is an overall process, this may not be a simple matter. What it means is that this is not a simple procedure of changing flow equations and using either the same efficiencies as before or ignoring efficiency and using 100%. Efficiency must be reviewed on a more local basis.

Design equations

For a preliminary gas pipeline design, a single formula can be applied as is the case in this project, (as the project is essentially to demonstrate cost effectiveness) which means that the flow conditions at each infinitesimal point along the pipeline are assumed to be the same. In reality numerous flow conditions occur, but due to the

nature of this project it is a fair assumption. Weymouth equation has been chosen as the design equation partly due to its simplicity, other reasons for choosing will be discussed further.

Weymouth equation

In actual practice, empirical flow formulas are used by many to solve the gas flow problems of field production operations as mentioned earlier. The Weymouth equation is the one most frequently used since results obtained by its use agree quite closely with actual values. Recent modification of the formula, by including the compressibility factor, Z, made the formula applicable for calculating of high pressure flow problems (McAllister, 1993).

$$Q = 433.45\frac{T_o}{P_o}\left(\frac{d^{16/3}}{GTL}\right)^{1/2}\left(P_1^2 - P_2^2\right)^{1/2} \qquad - \quad - \quad -2.29$$

Nomenclature for Weymouth equations

Q = Flow rate, scf/d

T_o = Absolute Temperature base, ^oR

P_o= Absolute Pressure base, psia

d = Internal diameter of pipe, in

G = Specific gravity of gas

T = Average Flowing temperature, ^oR

L = Length of pipeline, Miles

P_1 = Inlet (initial) pressure, psia

P_2 = Outlet (terminal) pressure, psia

It is important to remember that Weymouth equation is based on measurements of compressed air flowing in pipes ranging from 0.8 to 11.8 inches in the range of Moody diagram where the ε/d curves are horizontal (i.e. high Reynolds number). In this range the Moody friction factor is independent of the Reynolds number and dependent upon the relative roughness (API, 1991).

It is important to remember the assumptions used in deriving this equation and when they are appropriate. Short lengths of pipe with high pressure drops are likely to be in turbulent flow (high Reynolds Number) and thus the assumptions made by Weymouth are appropriate. Industry experience indicates that the Weymouth equation is generally too low for large diameter or low velocity lines where the flow regime is more properly characterized by the sloped portion of the Moody diagram (Figure 2.1).

Design data

Weymouth equation is another diameter varying friction equation, as mentioned earlier, the friction factor decreases consistently with increasing pipe size.

A part from the advantages of using Weymouth equation as mentioned above, a recommended design data based on Weymouth equation have been used in Nigerian environment successfully by Nigerian Gas Company (NGC). This includes the technical data of the Tie-In points along Oben-Ajaokuta gas pipeline. This project is essentially an extension/additions of the origin pipeline/existing that has been designed base on assumptions of Weymouth equation. Inline with the recommendation in Coulson and Richardson's that the experienced engineer will

wisely prefer the tried and tested methods, rather than possibly more exciting but untried novel designs (Sinnott, 2004).

i. The composition of gas at Alao-Ajaokuta metering station:

Table 2.2 Gas composition from Alao-Ajaokuta metering station (NNPC, 2001)

Component	Content (mol%)
Methane	97.3236
Ethane	1.5344
Propane	0.3483
Nitrogen	0.3360
Butane	0.1631
Pentane	0.0825
Hexane	0.0152
Carbon (IV) oxide	0.1960

ii. Inlet and delivery pressure

Inlet pressure ..... 19 barg

Delivery pressure ..... 2.5 or 1.2 barg (or as customer requires)

iii. Gross heating value

Minimum: ..... 850 Btu/scf

Maximum: ..... 1000 Btu/scf

Temperature (^{0}C)

Minimum: 15.00

Maximum: 40.00

iv. Gas quality (temperature)

Water dew point temperature <7.00^{0}c

Hydrocarbon dew point temp <15.00^{0}C

v. Specifications for pipeline

The specification for mainline steel material shall conform to API 5L. Gr. B.

vi. Design parameters **Code Ref**

1. Principal design code ASME B31.8, IGE/TD/3 IGE/TD/10

2. Fluid category:

Natural gas – Category D

3. Pressures:

NCL Tie-in design Pressure …….barg

Maximum nominal operating pressure ……....bar g

4. Temperatures:

Maximum operating Temperature ……40 deg C

Minimum operating Temperature ……..15 deg C

5. Location: ASME B31.8

Location classes ……..1 & 2

6. Design Factor (F):

Pipeline..…… 0.4

Fabricated assemblies…….0.6

Crossings (rivers, roads etc)…….. 0.6

7. Pipe Material:

API 5L Grade B

Minimum Specified Yield Strength ……241N/mm^2

8. Longitudinal Joint Factor (E):

E = 1

9. Temperature Derating Factor (T)

T = 1 (at or less than 60^oC)

2.10.2.1 Preliminary pipeline design

Preliminary Pipeline Sizing

The sizing for any piping system consists of two basic components; fluid flow design and pressure integrity design. Fluid flow design determines the minimum acceptable diameter of the piping necessary to transfer the fluid efficiently. Pressure integrity design determines the minimum pipe wall thickness necessary to safely handle the expected internal and external pressure and loads.

For sizing low and medium pressure distribution pipeline, the pipe flow equation due to Weymouth is normally applied. Thus the internal diameter of the pipe has been determined using the steady flow equation for isothermal, horizontal gas flow in a pipeline measured at base conditions P_b and T_b (neglecting elevation changes in system configuration) due to Weymouth expressed as:

$$Q = 433.45 \frac{T_o}{P_o} \left(\frac{d^{16/3}}{GTL} \right)^{1/2} \left(P_1^2 - P_2^2 \right)^{1/2} \quad - \quad - \quad - \quad - \quad -2.30$$

Where:

Q = Flow rate, scf/d

T_o = Absolute Temperature base, ^oR = 520

P_o= Absolute Pressure base, psia = 14.69

d = Internal diameter of pipe, in = ?

G = Specific gravity of gas = 0.70

T = Average Flowing temperature, ^oR = 495

L = Length of pipeline, Miles

P_1 = Inlet (initial) pressure, psia

P_2 = Outlet (terminal) pressure, psia

Determination of Pipe Wall Thickness

The nominal pipe wall thickness is derived from Barlow's formula (ASME B31.8 Section 841.11) expressed as:

$$t = \frac{PD}{2SFET} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad -2.31$$

where:

t = nominal wall thickness, mm

P = design Pressure, barg

S = specified minimum yield strength, N/mm^2

D = nominal outside diameter of pipe, mm

F = design factor = 0.4

E = longitudinal joint factor

T = temperature derating factor

Notes:

(I) The nominal wall thickness "t" derived from equation 2 above may not be adequate for other forces which the pipeline may be subjected to. These additional forces should be taken into consideration as necessary.

(II) Moreover, the minimum nominal wall thickness shall not be less than 6.3mm (0.252").

The diameter to wall thickness ratio should not exceed 96, unless it can be demonstrated that higher values are not detrimental to the construction (pipeline installation) and in-situ integrity of the pipeline.

(III) The Equivalent Stress should be calculated as necessary taking into consideration the following stress elements:

(i) Hoop stress due to pressure

(ii) Longitudinal pressure (due to pressure, bending and expansion)

(iii) Combined sheer stresses (due to torque and sheer forces)

(IV) Allowable Equivalent Stress (i.e. percentage of Specified Minimum Yield Strength) is tabulated as follows:

Table 2.3: Load design parameters

	Functional plus Environmental Loads
Installation	96
Hydrostatic	100
Operation	90

Hydraulic Profiles

When a pipeline route has been determined, elevation data and hydraulic pressure drop gradient data can be plotted in a hydraulic profile. The hydraulic profile can be used to establish line size and booster station spacing, and to show allowable pipe pressures. Data on pipe grade and wall thickness, pipe coating, and locations of block valves, scraper trap manifolds, and major river crossings can conveniently be incorporated on the same plot.

Hydraulic profiles plot the following data:

• Ground elevations along the route, including at least the significant high and low points, and pump station and branch line locations.

• The approximate terminal pressure (in feet of head) at the end of the line (or section of line) required, for example, for the fluid to pass through terminal man folding and piping and into tankage at design flow.

• Hydraulic gradient data, in feet of pressure drop per mile at design flow rate (or maximum and minimum rates), for one or several pipe sizes.

A basic plot of this data is indicated in Figure 2.8

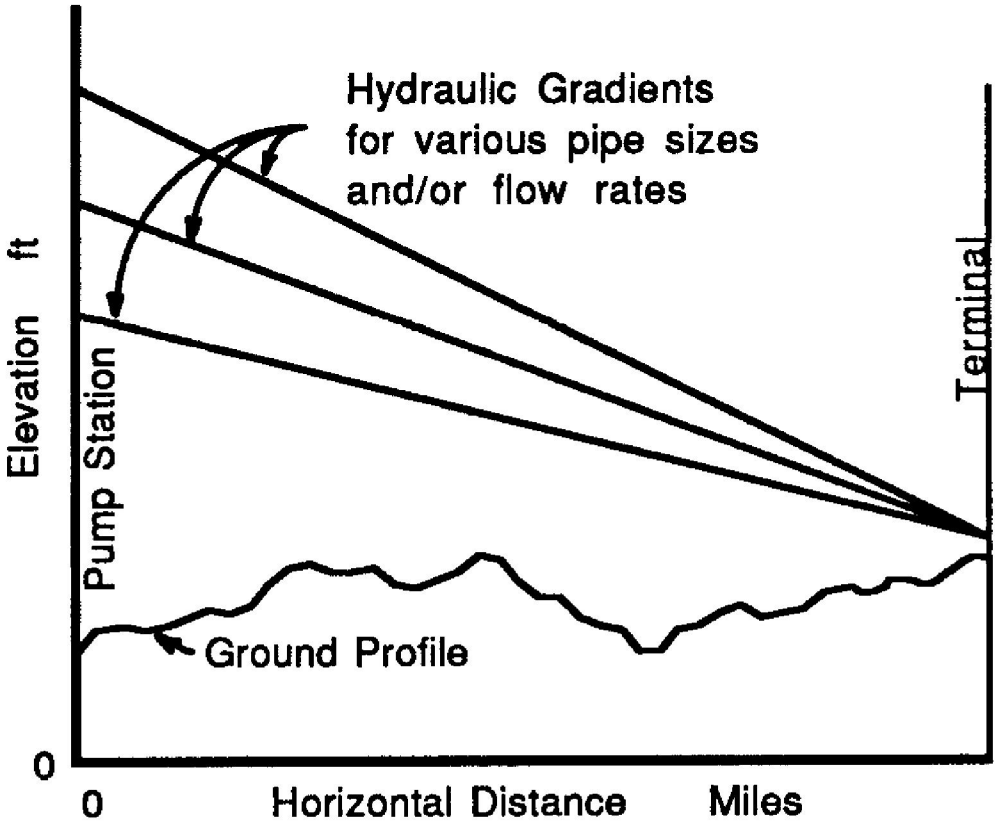


Figure 2.8: Hydraulic Gradients

Other important parameters include;

a. A hydraulic control point is a high-elevation point that governs the inlet head for its section of line. Often, hydraulic control points are encountered, and the

hydraulic gradient must clear the ground elevation control point. Two situations may result as indicated in Figure 2.8.

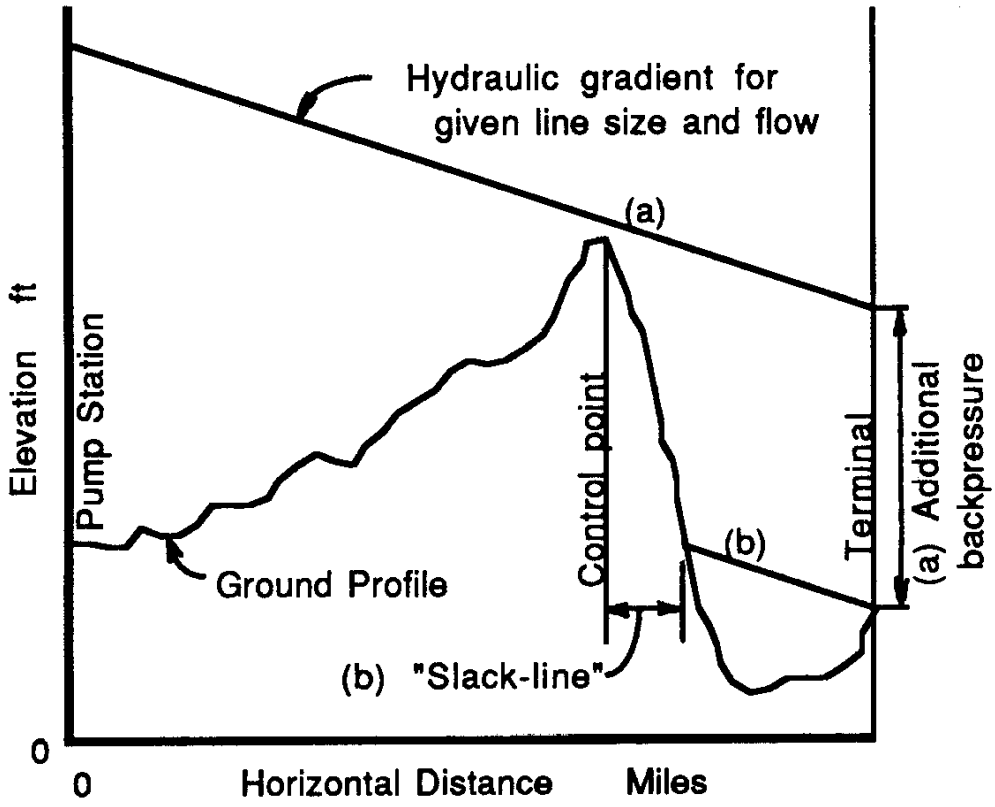


Figure 2.9: Hydraulic Pressure: Back Pressure control

i. The hydraulic gradient is continued to the end of the line, resulting in a residual pressure at the end of the line, for which back pressure control must be provided.

ii. Without back pressure control, a length of line will flow only partially full, in what is called a cascade or slack-line condition.

b. A slack line should be avoided because it results in erratic correlation of the line input and output meters, which makes leak detection by metering instrumentation impossible. For products pipelines the volume of interface mixture between successive products is uncontrollable in a slack-line, and product mixing is severe in downhill sections downstream from the control point. In rare instances slack-line operation may be considered so that back-pressure control is not required.

The actual pressure in the pipeline at any point along the route equals the difference between the hydraulic gradient and the ground elevation (see Figure 2.8).

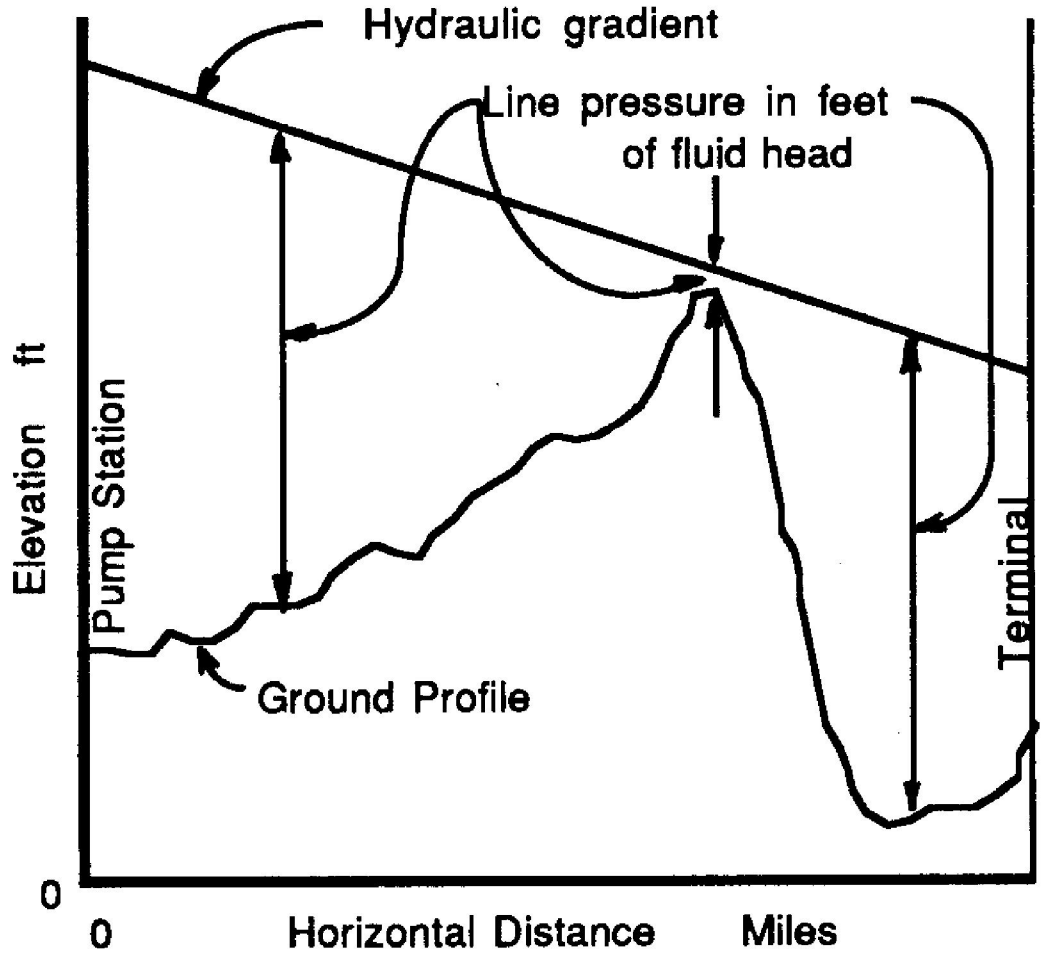


Figure 2.10: Hydraulic Profile: Line Pressure

2.10.3 Pipeline routing using GIS

Maps and field work are required for pipeline routing, pipeline design and construction. For this route the particular states/regions the pipeline is likely to pass through will be isolated giving the Area Of Interest (AOI). Relevant organizations in a country can provide such information. The AOI should contain areas from Kogi state, Abuja (FCT), Niger, Kaduna and finally and Kano State.

Various steps and initiatives are taken in order to arrive at the most suitable pipeline route using GIS (Geographic Information System), a route that will be used to design a comprehensive Trunk Gas Pipeline System. When a pipeline route has been determined, elevation data and hydraulic pressure drop gradient data can be plotted in a hydraulic profile.

Least Cost Pathway Analysis

This is one of the modern methods of pipeline routing, where GIS is used to differentiate areas that are traditionally known to be cheaper or more expensive. These different areas are expressed in different colors, this makes the choice of areas to be followed or avoided much easier during pipeline routing and construction. This is used from the on-set in deciding which route should be followed in order to reduce cost. For example the highest costs are in urban areas and in large bodies of water and roads. Moderate costs are in forest and wetland with high slope. The lowest costs were in areas with bare ground, dry grass, less dense native vegetation and agriculture.

2.10.4 Costing

Detailed information in McAllister (1993) has been provided covering:

i. Adjusting for inflation.

ii. Estimate for cost areas (Right of way (ROW), material, labor and miscellaneous)

iii. Cost estimating strategies for pipe lines, stations, terminals.

iv. Current, future estimating practices

v. Speeding computational procedure

vi. Three estimating strategies

Project evaluation: Cost estimate

In this section, the average cost of the pipe line per kilometer is stated. A percentage is then set aside to provide for contingencies/price escalation which gives the total capital investment cost. Miscellaneous expenses which consist of direct cost of utilities (fuel and electricity), wages and salaries, as well as indirect costs administrative and general expenses are also stated.

In cost estimates there is need to categorize costs into ROW, Materials, Labor and Miscellaneous Appa and Kalu (1999).

Nomograph for estimating interest rate of return on investment ("profitability index")

Pipe line cost models are numerous and their uncertainty is associated with the degree of generality.

Costs vary with distances from manufacturers, terrain, locality, labor costs, season of the year and other variables McAllister (1993).

Several methods are used for evaluating the profitability of a given project. A method for estimating profitability which has received considerable emphasis in the past few years is the "interest rate of return" Figure 2.11, also known as "profitability index" or "discounted cash flow" method. This profitability method takes into account the time value of money. Mathematically, interest rate of return may be defined as that

rate at which company's outstanding investment is repaid by proceeds from the project as shown in Appendix B.6.

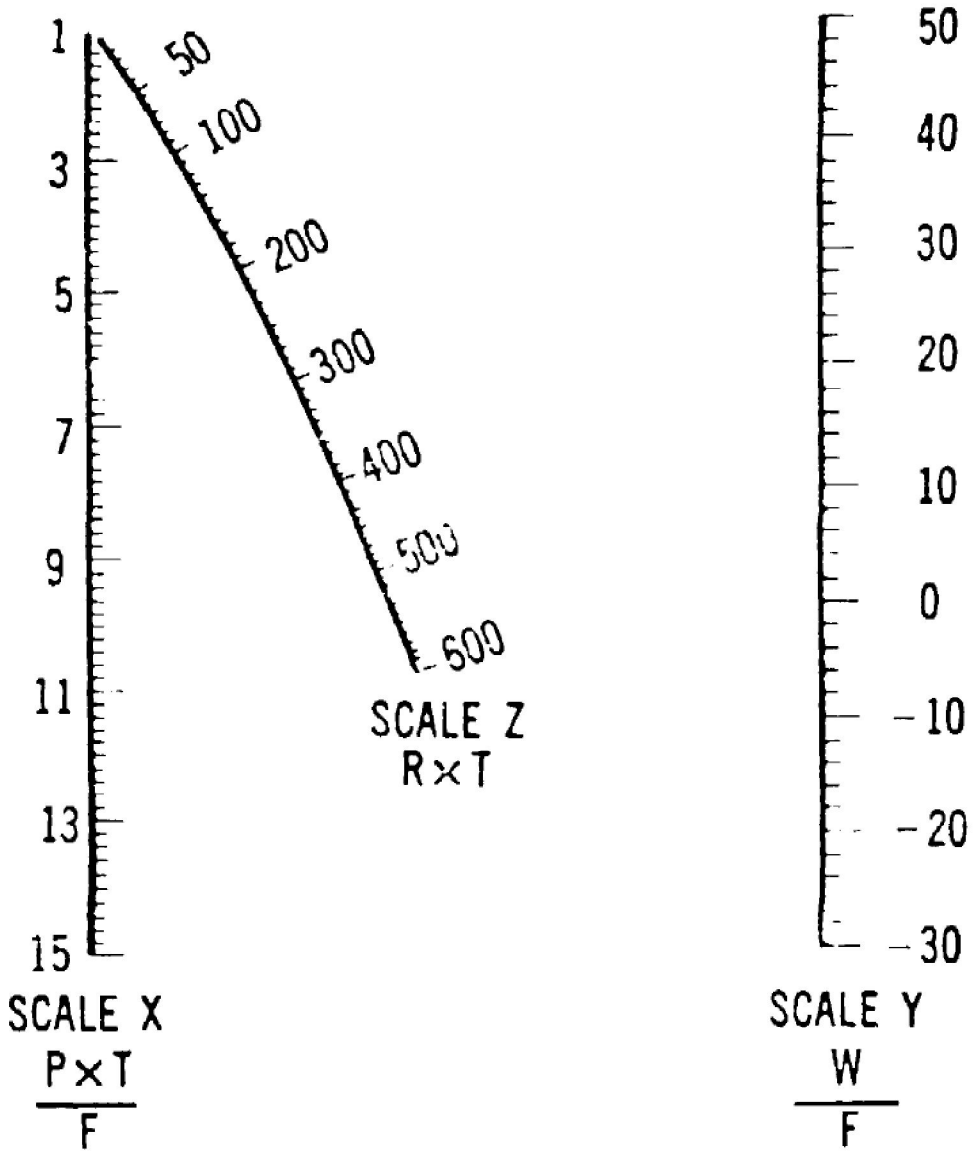


Figure 2.11: Nomograph for the Interest Rate of Return

The Nomograph was developed for the case in which the yearly profits (P) (or the difference between income and costs) are equal through the life of a project.

Depreciation

The provisions made for the economic loss of assets. This item does not always appear apart, sometimes it is included as "overhead" on the cost of goods sold.

Depreciation methods

Depreciation may influence largely the amount of tax to be paid and consequently the profit to be recorded in the income statement. There are several methods of depreciation:

1. Straight line: a uniform annual depreciation charge per year. This figure is arrived at by simply dividing the economic life of the asset into its total cost minus the estimated salvage value (disposal value).

$$\frac{\text{Cost salvage value}}{\text{Economic life}} = \text{depreciation charge per year}$$

2. Sum of years' Digits: the yearly depreciation charge is determined as follows:
   - calculate the sum of the years digit: for example gives 1+2+3+.....+10 = 55 digits.
   - divide the number of remaining years by the sum of years digits and multiply this fraction by the depreciable cost (total cost minus salvage value) of the asset.

3. Double Declining Balance: this method (DDB) requires the application of a constant rate of depreciation (mostly double the annual straight line rate) each year to the remaining undepreciated value of the asset at the close of the previous year. This rate initially applies to the full purchase price of the asset (not the depreciable cost of the asset).

The last two depreciation methods are providing for accelerated depreciation, which enables the firm to have much greater tax deductions (hence bigger cash-flow) in the early life of the asset.

The nomograph is based on the following assumptions:

i. Depreciation method is sum of the years-digits.
ii. Project economic life is equal to depreciable life (T).
iii. Construction time is zero, i.e., total investment occurs instantaneously at time zero.
iv. There is no salvage value at the end of the project life.
v. There is no start-up expense, (S=0).

Where these conditions apply, the nomograph gives the interest rate of return R, as a function of P and T, fixed investment (F), and working Capital (W), other assumptions are

vi. The cost of natural gas is N16.64 per $1000ft^3$
vii. The conversion rate is N130 per US Dollar.
viii. There are 340 days in a year instead of 365.
ix. Assuming working capital of 20% of total investment.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials and Equipment

The following were used in this project:

PC (Pentium IV, 60 GB Hard drive 1.7 GHz 3.1.2 Processor), GPS receivers and Vehicle for navigating off road locations.

3.2 Methods

For any preliminary pipeline design to be effective, five basic steps need to be followed. These are:

3.2.1 Consideration of the legal aspects

Consideration of the Legal aspects that will guide the pipeline design within the legal frame work of Nigeria was carried out.

3.2.2 Market survey for the determination of flow rate (Q) per day

The existing and future peak gas demands of the chosen location were assessed through evaluation of the actual amount of electricity supplied and the total amount required. The gas pipeline design involves the determination of how much volume of gas is needed for a particular location. The gas volume will translate to gas flow rate (gas throughput rate). Different companies/pipeline engineers have their way of determining their throughput rate. A preliminary estimate can be obtained using the number of industries in an industrial area by calculating their average energy demand per day. This can be done by carrying out a door to door inquest into the energy requirements of the companies in the industrial areas where natural gas is expected to be sold. For example in Ikeja and Ikorodu Industrial area in Lagos, door to door

survey was carried out by Gaslink Nigeria Limited in order to ascertain the precise needs of the companies and to convince them on the need to connect to the gas grid. This can be tedious especially for a preliminary design. This project is of preliminary nature, as such after several of consultations with Power Holding Company of Nigeria (PHCN) in Kaduna and Gaslink, the throughput was obtained by using the industrial energy demand data of Kano and Kaduna from Power Holding Company of Nigeria (PHCN), with some correlation with energy analysis data obtained from the United Nations Industrial Development Organization (UNIDO), as well as Manufacturers Association of Nigeria (MAN). The value calculated was converted to volume of gas needed per day (gas flow rate).

It is important to note that due to the conservative nature of the Nigerian energy market on use of natural gas especially in the Northern part of the country, an assumed patronage of 50% was reached after discussions with PHCN in Kaduna and Zaria. PHCH recommended that a suppressed factor of 1.5 should be introduced as a correction factor to cater for the lack of sufficient power supply by the PHCN to these locations. This decision allowed for a fair approximation of the required gas volume. The composition of the gas was obtained from Ajaokuta Metering Station.

3.2.3 Determination pipeline length (L) and hydraulic profile using Geographic Information System (GIS)

This was the step where GIS come to play. GIS was deployed to evaluate the length of the pipeline and elevation per km along the pipeline route. In order to reach the agreed requirement using GIS, three main goals were set to be achieved. Setting and

achieving these goals will help in determining some unknown variables that will be used in the design equation, namely the flow rate, Q. In this instance the unknown variable is the pipeline length (L), and the data obtained after the pipeline route and length have been determined used to obtain the hydraulic profile. The first goal achieved was to obtain the length by:

3.2.3.1 Developing a Geographical Location Map (using GIS) for the area along which the pipeline traverses up to the location of the existing industries

In order to achieve an accurate assessment of the extent of the area involved in the trunk pipeline design, picture/map of the whole region/area from where the pipeline originates to its final destination obtained.

In this project the region for the trunk gas pipeline design is in the Northern states of Nigeria which made a map of Nigeria sufficient for consideration. Two maps were obtained, a map of Nigeria from Nigeria Gas Company (NGC) which was in the form of hard copy and containing a "sketch of proposed route" for a gas pipeline from Ajaokuta to Kano (these routes were more of straight lines) and the other map which was obtained from a company called the IHS Energy Group Information Services. This map was in a soft copy but in analog format and contains a sketch of the existing and proposed pipelines for gas and existing for crude pipeline up to Kaduna. These maps were compared, studied, analyzed and then converted to digital format. Digitizing and analyzing the data (the maps) was done through a field survey of the existing crude pipeline network along Abuja-Kaduna-Kano axis. In most cases visual (field trips) and making use of GPS receivers to verify the location of the crude pipeline in the field (AOI) was employed especially where the data available did not

cover such locations. For example, along Kaduna-Kano route, after taking many data points of the existing crude oil pipeline from the field and comparing them with the available data from IHS and NGC, it was discovered that the sketches from the available maps do not conform to the field values. It was also observed that not much of the pipeline routing criteria was followed. In the end it was concluded that the sketch of the routes from both maps will not serve the purpose of this project and a decision to develop a new route was made, using the ones from IHS and NGC as the basis.

The next target was creating a corridor based on the existing crude pipeline route which allowed for the extraction of the exact Area of Interest (AOI). The main reason for extracting the AOI is for a more detailed analysis and to reduce cost. This corridor, the AOI covered the area from Ajaokuta to Kano.

3.2.3.2 Establishing Optimum Route

This second goal involves consideration of pipeline routing criteria as a guideline. Following this criteria is compulsory in order to obtain an optimum route, part of which necessitated that the routes were made as straight and as near to main roads as possible with fewest intersections with natural and artificial obstacles. This was to reduce cost during construction works and also for easy maintenance. If it was difficult to meet all these requirements, several variants were considered and the best chosen on its technical and economic merits.

Various layers of attributes for Area of Interest (AOI) were obtained before arriving at an optimal route and these included:

- Land use of the AOI

- Hydrology/Hydrography (Drainage) of the AOI
- Road and Rail lines of the AOI
- Settlement/Town of the AOI
- Soil; Nature (Rocky, Sandy or Caliche) and type (Acidity or Alkalinity) of the AOI
- Satellite images of the AOI

The Digital Elevation Model (DEM) was also obtained for use in the subsequent step. DEM is not a layer but a corridor with different characteristics different from the "Land use corridor". It was an AOI that gives three dimensional image showing mostly the hills, mountains, valleys, rivers etc (real time images), the DEM was obtained from satellite images (obtained by Integrated Engineering Associates). Obtaining the DEM helped in determining the height per kilometer along the pipeline. The next step involved data preparation. This was to make sure that all data sets listed above were subset onto the AOI of the "land use" as individual thematic layers. The next step was to overlay pipeline data on the thematic layers created on the AOI above, this involved the actual laying of the pipeline on the AOI using a computer. It was at this stage where the pipeline routing criteria was used before any line representing the pipeline was drawn. Careful analysis and choices had to be made, choices on how to avoid a given obstacle and the economic implications of making those choices had to be considered. If there is any doubt a field trip had to be under taken to ascertain the true nature of the terrain before an inch of the pipeline is drawn on the computer screen, a slight miscalculation (change in direction of the pipeline) can result in shooting the cost of laying the pipeline into thousands of naira. After

carefully laying the pipeline on the AOI of “land use and settlement”, the next item was getting the approved/optimum pipeline route obtained from the “land use and settlement” AOI on to a Digital Elevation Model of the AOI. The aim was in order to extract data of height above sea level per kilometer along the pipeline. This data was used to obtain the Hydraulic profile data table which will be used for constructing the Hydraulic Profile. This as mentioned earlier was achieved by generating two data, the horizontal distance per km along the pipeline and elevation at each kilometer distance along the pipeline.

The following steps were taken in order to obtain the two data for constructing the hydraulic profile:

- Using ArcView GIS 3.2, a software command was issued to generate points per Km along the optimum pipeline route obtained in the “land use and settlement” AOI.
- The points generated above were imported into the image processing software (ERDAS IMAGINE 8.6).
- The points representing real lines drawn on “land use” AOI were overlain on the base elevation data (DEM) in the form of pixels.
- Command was issued to convert pixel values corresponding to overlain points from digital elevation data into ASCII table data.
- The subsequent was a 3-column text table (Table A.1) data containing point coordinates (Northings and Eastings) and the corresponding Elevation at each point.

3.2.3.2 Establishment of Hydraulic Profile.

The hydraulic profile was obtained by plotting the data points obtained above on Microsoft Excel.

3.2.4 Determination of internal diameter (d) and pipeline thickness (t)

This involved design and sizing of the Pipeline using Weymouth and Barlow's equations

Determination of the internal diameter, d, from the Weymouth equation was the main reason for determining the other unknown variables such as flow rate Q and length of pipeline L. Barlow's formula was used for determining the pipe thickness t.

The internal diameter d and the pipe thickness t will allow for determining an effective economic system as illustrated in Appendix C.2.

3.2.5 Economic evaluation

3.2.5.1 Nomograph for estimating rate of return on investment (profitability index)

Pipe line cost models are numerous and their uncertainty is associated with the degree of generality. Costs vary with distances from manufacturers, terrain, locality, labor costs, season of the year and other variables.

Several methods were used for evaluating the profitability of a given project. A method for estimating profitability which has received considerable emphasis in the past few years is the "rate of return" also known as "profitability index" or "discounted cash flow" method. This profitability method takes into account the time value of money. Mathematically, interest rate of return may be defined as that rate at which company's outstanding investment is repaid by proceeds from a project

(McAllister, 1993). Detailed procedure employed in the determination of the interest rate of return is shown in Appendix A.7.3.

3.2.5.2 Project evaluation: Cost estimate

In this step, the average cost of the pipe line per kilometer was stated since it forms more than 50% of the total cost of the pipeline construction. Other costs were obtained based on the percentage cost of the pipeline material used. Then a percentage was set aside to provide for contingencies/price escalation which gives the total capital investment cost. Miscellaneous expenses which consisted of direct cost of utilities (fuel and electricity), wages and salaries, as well as indirect costs, administrative and general expenses were also calculated.

In this step there was the need to allocate the cost estimates under four categories, such as ROW, Materials, Labor and Miscellaneous, all expressed in percentages (Appa and Kalu, 1999). This was the method used to estimate the project cost estimate, details of which was shown in Appendix A.7.2.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

The following results and their discussions were reached at the end of this project:

4.1 Results and Discussions

4.1.1 Legal aspects and incentives offered by the government

DPR regulatory requirements for operation and maintenance of pipeline in Nigeria

The Oil Pipelines ACT CAP.388, 17 (1) 1995, provides guidelines for the operation and maintenance of pipelines. These guidelines are in fact statutory requirements and enforceable by the Department of Petroleum Resources (DPR). They are summarized in Appendix D.

4.1.2 Market survey and flow rate (Q) determination

Table 4.1 show the existing amount of energy supplied while Table 4.2 show the future energy demand of the chosen locations. From Table 4.2 it can be observed that the fourth row gives the total energy demand of Kano and Kaduna which was converted to volume of gas (row five) required per day 21.5730 * 10^6 ft^3/day.

Table 4.1: Existing Energy Supply (Capacity underutilization)

Description	Kaduna	Kano	Total
Average energy supplied (kWh)	61,993.70	55,663.00	117656.7
Installed Capacity (MW)	298	240	538
Peak Load (MW)	126.20	206.60	332.80
Required/Energy-demand (MW)	447	360	807
Percentage of available power	28	57	41.24

Table 4.2: Future energy demand

Description	Kaduna	Kano	Total
Estimated industrial electrical power demand (MW)	290.55	234	524.55
Assumed patronage of 50% (MW)	145.28	117	262.28
Assumed energy demand (kWh)	3486480	2808000	6294720
Estimated volume of gas demand on the gas grid (ft^3/day)	$1.1948x10^7$	$0.9623x10^7$	$2.1573x10^7$

The gas pipeline design involves the determination of how much volume of gas is needed for a particular location. This variable also known as gas flow rate "Q" (gas throughput rate) is the unknown dependent variable in Weymouth equation (design equation) the value was found to be 2.1573×10^7 ft^3/day (using some correction factors e.g. suppression factor and "gas use patronage" as elaborated in Appendix B.2 and safety factors as shown in Table 4.4).

4.1.3 Determination of length of pipeline (L) and hydraulic profile using Geographic Information System (GIS)

Figure 4.1 shows the map from IHS energy group, inset in red portion is the Area of Interest AOI, which was extracted from Figure 4.1 and shown in detail in Figure 4.2

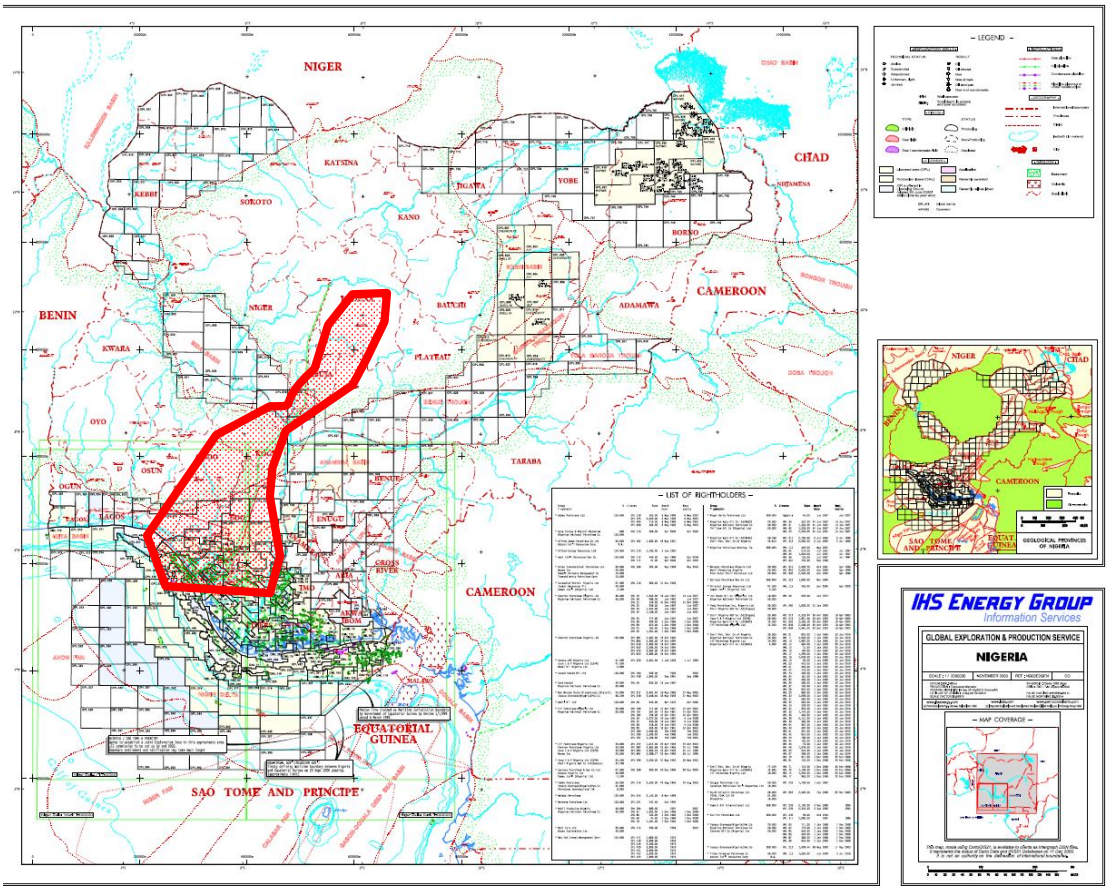


Figure 4.1 Analog map showing the proposed Nigeria Gas Company (NGC) route up to Kaduna (Note a section is cut to show details of the AOI in Figure 4.2)

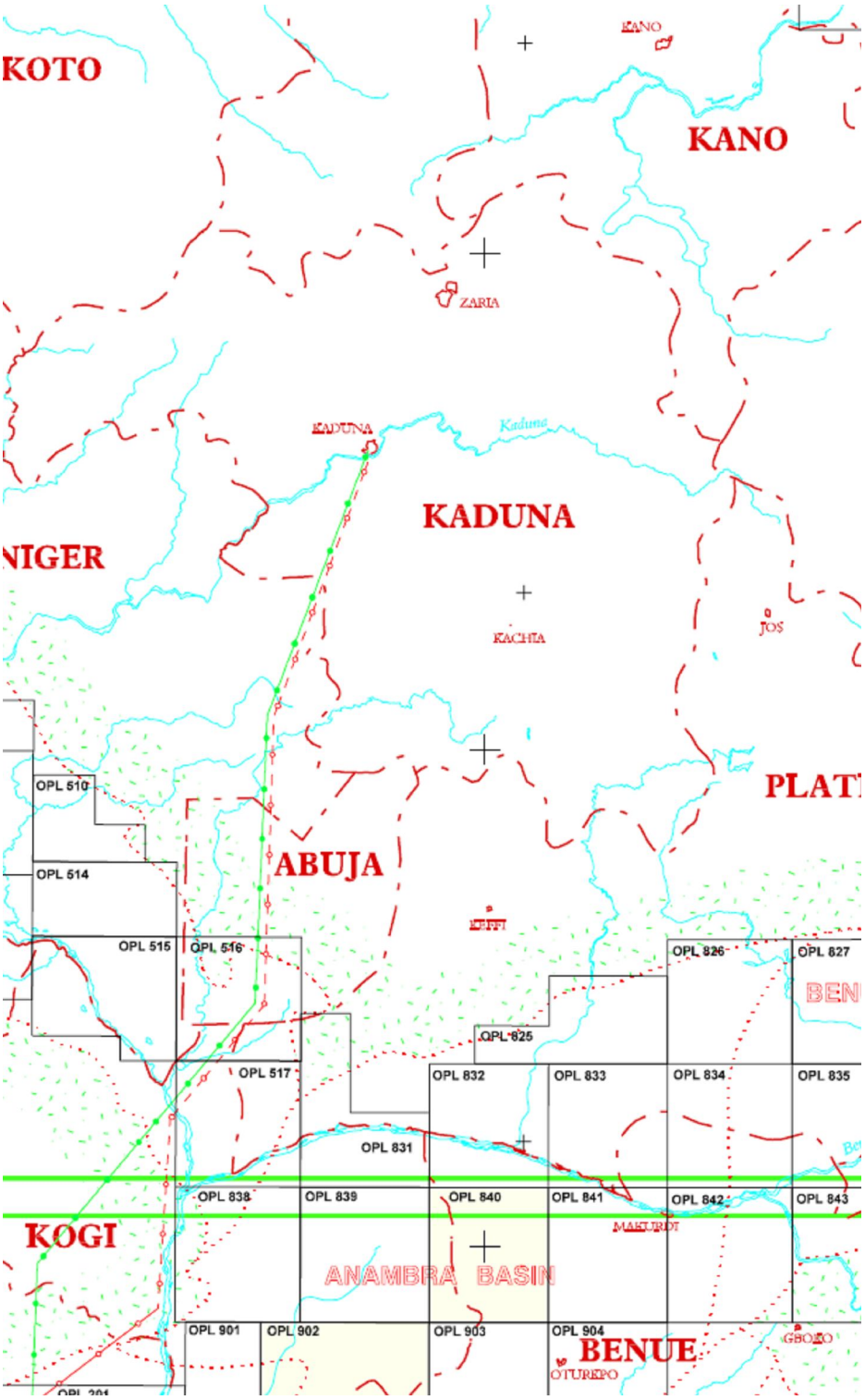


Figure 4.2 Details of AOI showing details of proposed NGC gas pipeline route shown in red broken line while the crude line is shown in green solid line from Ajaokuta up to Kaduna (cut from Figure 4.1)

Figure 4.3 shows “Land use and settlements” represented by different colors representing different attributes. These attributes can be farmlands, water reservoir, major or minor urban areas, forest reserves, roads, gullies, rock outcrop etc. On the map for example, all major towns were shown in red colors and their respective names were indicated, while livestock projects were shown in pink colors. While on the other hand, on the same corridor, the pipeline route was shown in yellow line. One of the advantages of using GIS is its flexibility in retrieving information from the corridor. For example, by clicking on any spot/point on the corridor of “Land use and settlements” the attribute of that point/location will be given in a small box including the GPS points and most importantly height above sea level. The attributes of the “Land use and settlements” corridor are shown in the legend, a small box at the left of the corridor. It is important to note that the legend of this “Land use and settlement” corridor, shown on the left side of the corridor is simply representing the “layers” that need to be placed on the “Land use and settlement” corridor to give it “life” or in other words the “layers” are the “natural obstacles” that need to be avoided or pass-through in order to obtain a good pipeline route as mentioned in the methodology/methods.

It is important to note that before drawing any “yellow line” (pipeline route) through any point, the information of the portion had to be obtained, this was done by clicking on the point, the nature of the area was displayed and then the pipeline routing criteria was applied e.g. to decide on whether the route can pass through that area or not. Effort was made to place the route as near roads as possible for easy maintenance and monitoring, natural obstacles like rocky areas, dams, military zone etc were also

avoided, at the same time effort was also made to avoid passing directly through towns. In order to show in detail how the pipeline route was placed in “Land use and settlement” a portion shown in a red rectangle have been cut out and shown in detail in Figure 4.4, even though the pipeline is suppose to start from Ajaokuta, the name Ajaokuta was not indicated due to some technical oversight but a town called Itope have been shown this town is in Ajaokuta area where the existing gas pipeline stops (after delivering gas to Ajaokuta steel rolling mill and it is the same point where the propose gas pipeline for this project starts).

The pipeline (shown in yellow line) in Figure 4.4 can be seen to pass through (from Itope) Lokoja, Osenseni, Toto, Kwali, Kafin and Beni while in the next portion which was cut from Figure 4.5 and shown in detail in Figure 4.6 shows the continuation of the gas pipeline from Beni, through Kaduna (refinery), near Zaria, near Gimi, near Yako and Bebeji, near Kura and to its final destiny, Kano. It is worth noting that the pipeline route passed through a fairly “obstacle free” area (areas with minimum natural obstacles), while passing as the same time near the towns but not through them (as mentioned earlier). Passing near the towns has significance in the sense that the town might decide to join the gas grid in future, and for safety reasons.

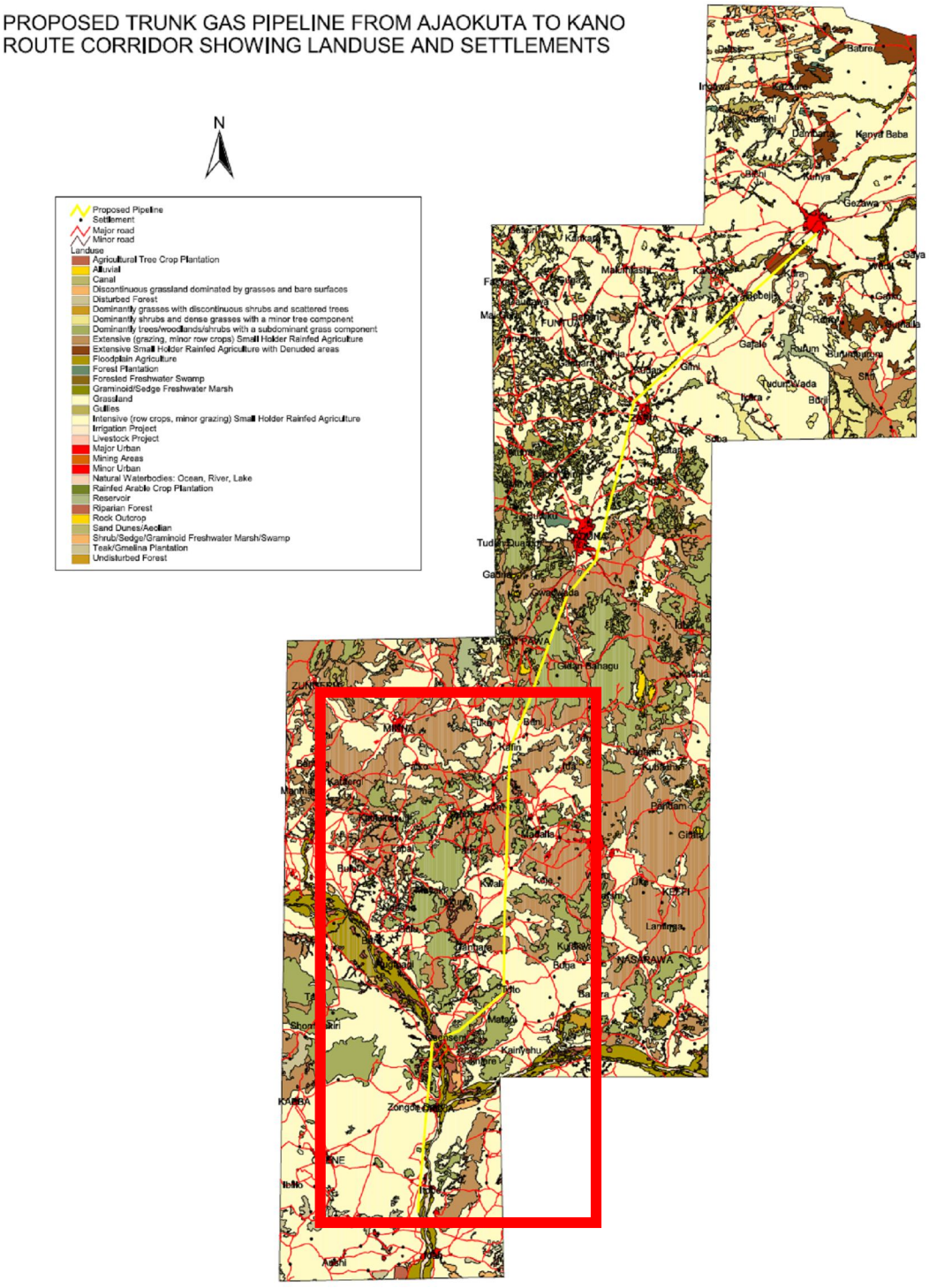


Figure 4.3 Trunk gas pipeline route corridor from Ajaokuta to Kano showing land use and settlements (Note a section is cut to show details in Figure 4.4) the pipeline route is represented with yellow line.

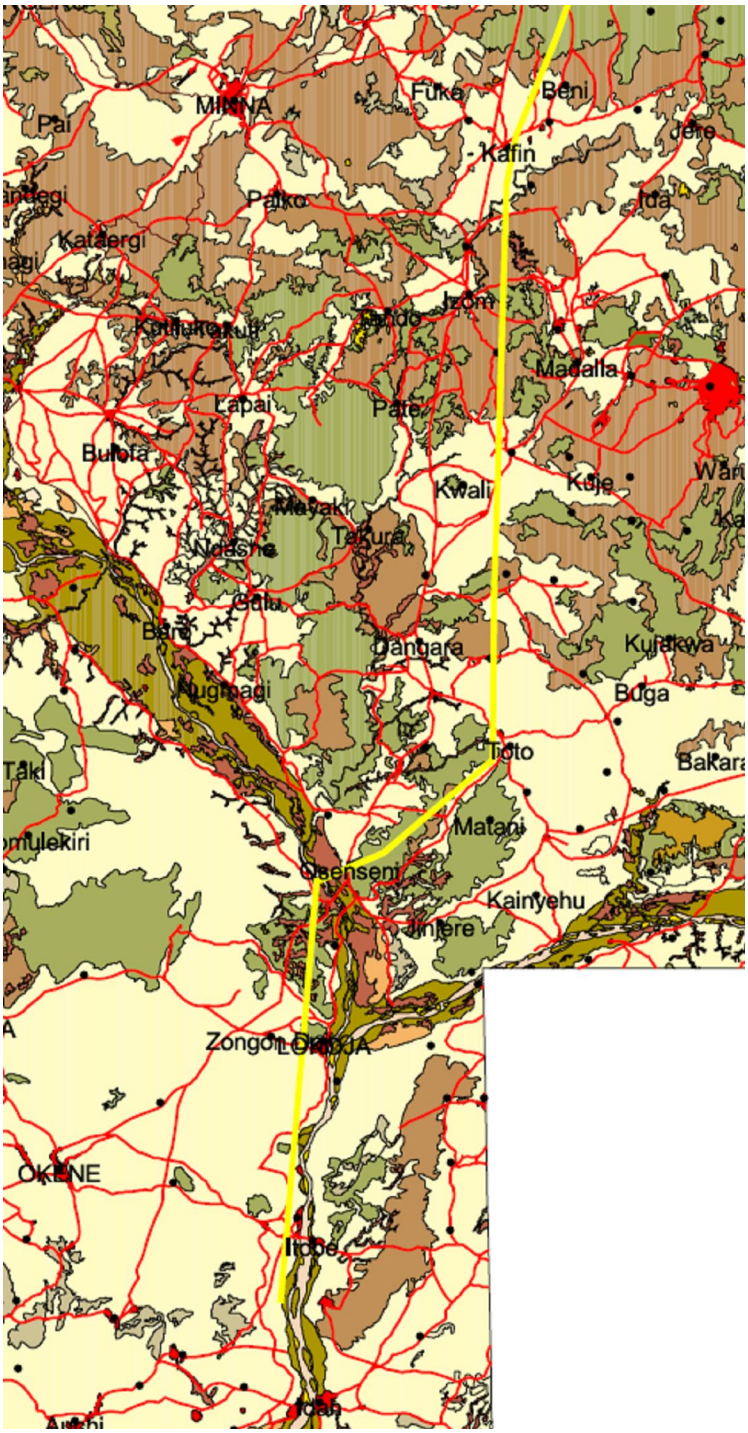


Figure 4.4 Details of pipeline route corridor cut from Figure 4.3 showing land use and settlements from Ajaokuta to Beni the pipeline route is shown in yellow line.

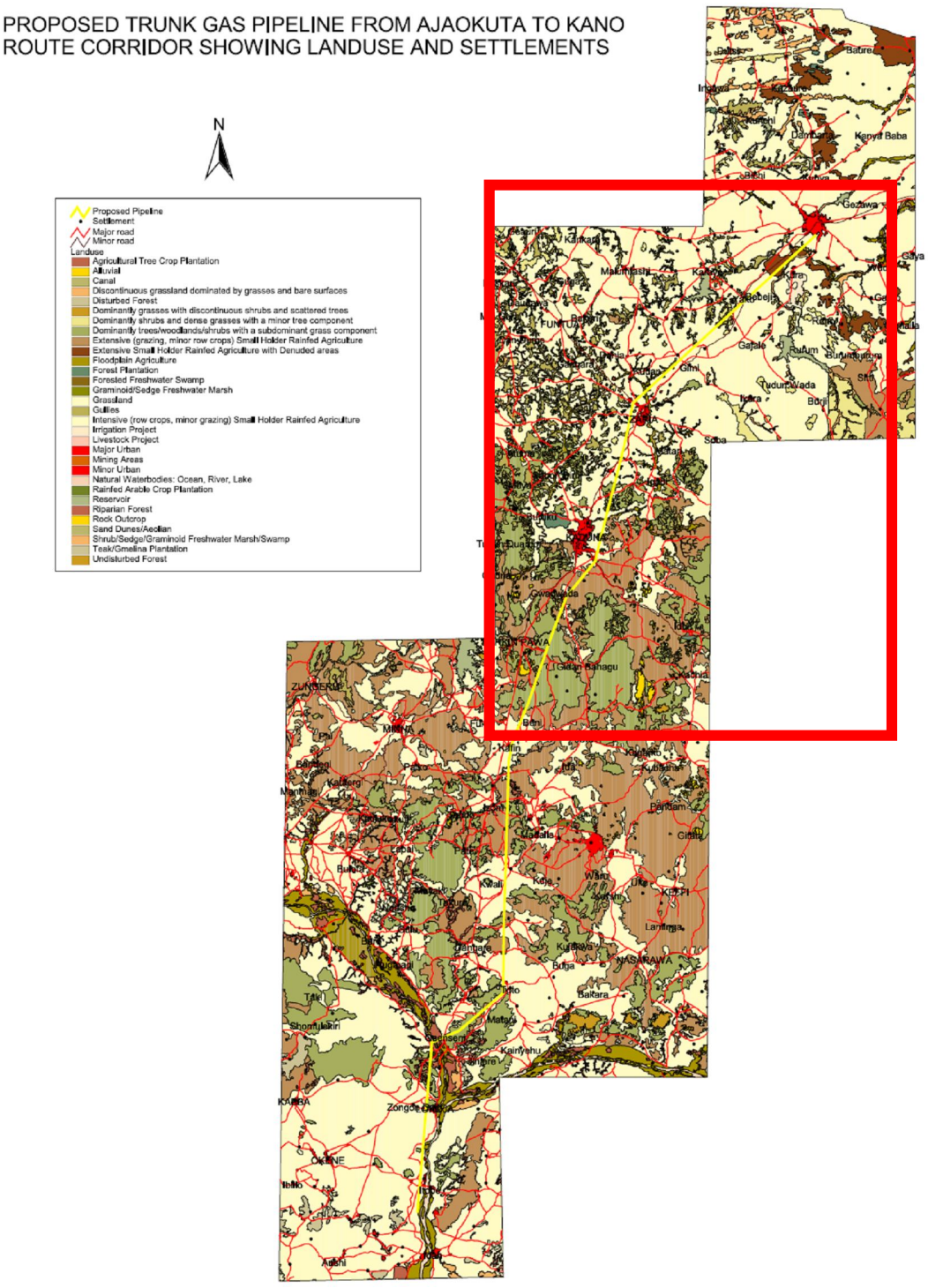


Figure 4.5 Trunk gas pipeline route corridor from Ajaokuta to Kano showing land use and settlements (Note a section is cut to show details in Figure 4.6) the pipeline route is shown in yellow line.

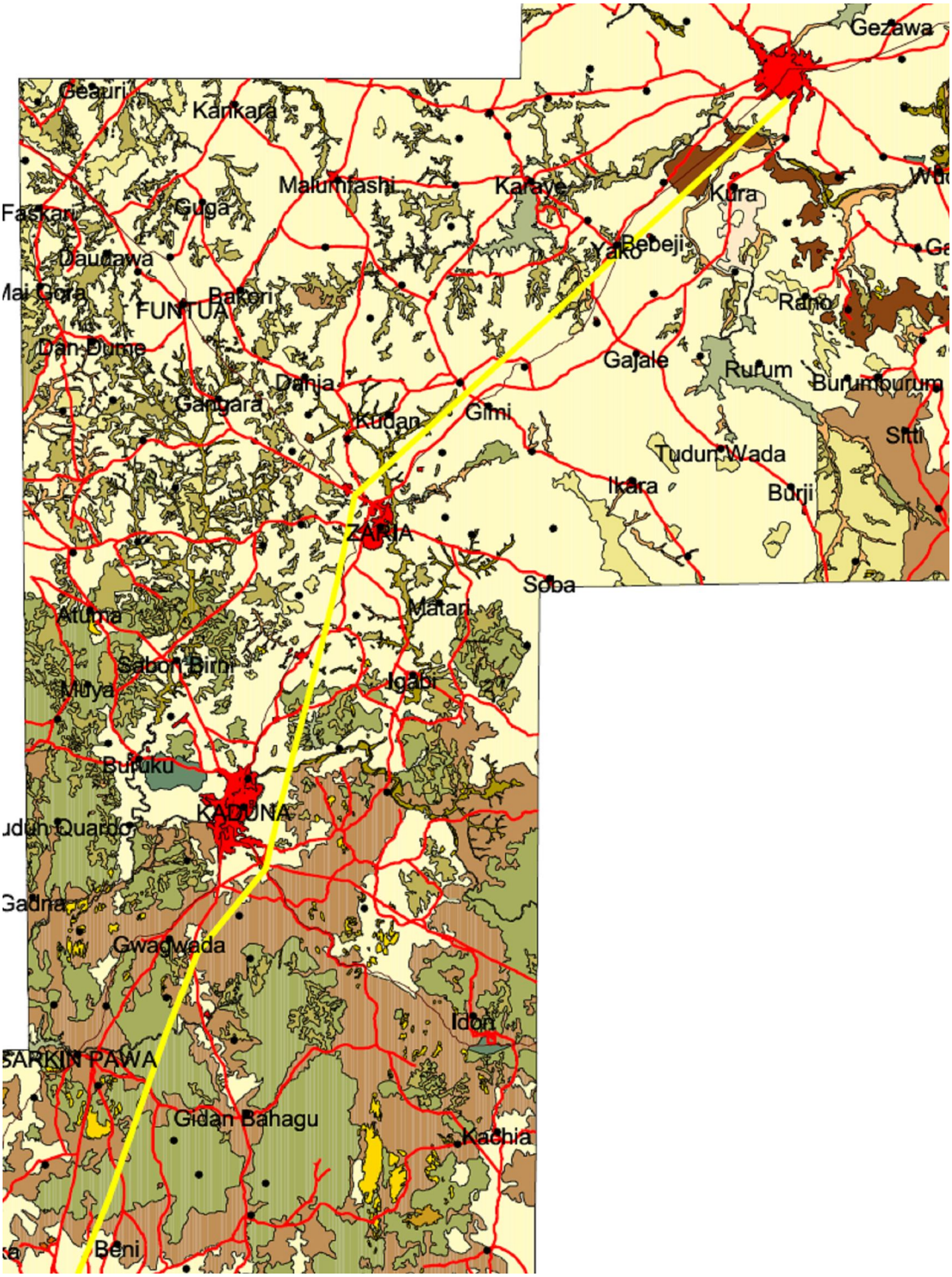


Figure 4.6 Details of pipeline route corridor showing land use and settlements from Beni to Kano pipeline route is shown in yellow line.

The Digital Elevation Model (DEM) or Digital Terrain Perspective shown in Figure 4.7 is meant to provide information to be used for the pipeline routing just as the "Land use and settlements" corridor was used dealing mostly with attributes, the DEM on the other hand is meant to lay more emphasis on the nature of the terrain (providing "real time" images of how the land was formed) showing mostly the mountain formations/ rock out crops, gullies/valleys or rivers within the area. The DEM satellite images were provided by the Integrated Engineering associates. The DEM shows in addition to the land formations, towns as can be seen in Figure 4.7.

The pipeline route shown in yellow line in Figure 4.7 was the same route that was lifted and superimposed on the DEM as shown in Figure 4.3 and 4.5 to allow for better view of how the pipeline route should pass through the corridor paying special attention to mountainous or gully areas as the case may be. The incorporation of DEM has become necessary because most of the cost of the pipeline comes from how well the mountain/gully areas were tackled. The DEM most importantly, give information on how the pipeline route passes over heights above sea level. It is also the DEM corridor that can allow the points per kilometer along the pipeline route from Ajaokuta to Kano to be used to evaluate the Hydraulic profile.

It can be seen from the inset of Figure 4.7 the portion in red rectangle has been cut to show in detail in Figure 4.8 how the gas pipeline passes over the land as far as the digital terrain perspective is concerned, the gas pipeline is seen to pass through near Itope, near Lokoja, Osenseni, also near Izem, kefin and Beni, the other rectangular red portion cut from Figure 4.9 is shown in detail in Figure 4.10 it is the continuation of the pipeline route from Beni, through Abuja area, through Kaduna, then Zaria, near

Gimi, near Yako, near Bebeji near Kura and finally to Kano. The trunk gas pipeline route is to terminate just outside Kano. To be precise, the terminal point is around "Unguwa uku round about" it is from this point that the local distribution network to industrial areas is expected to begin.

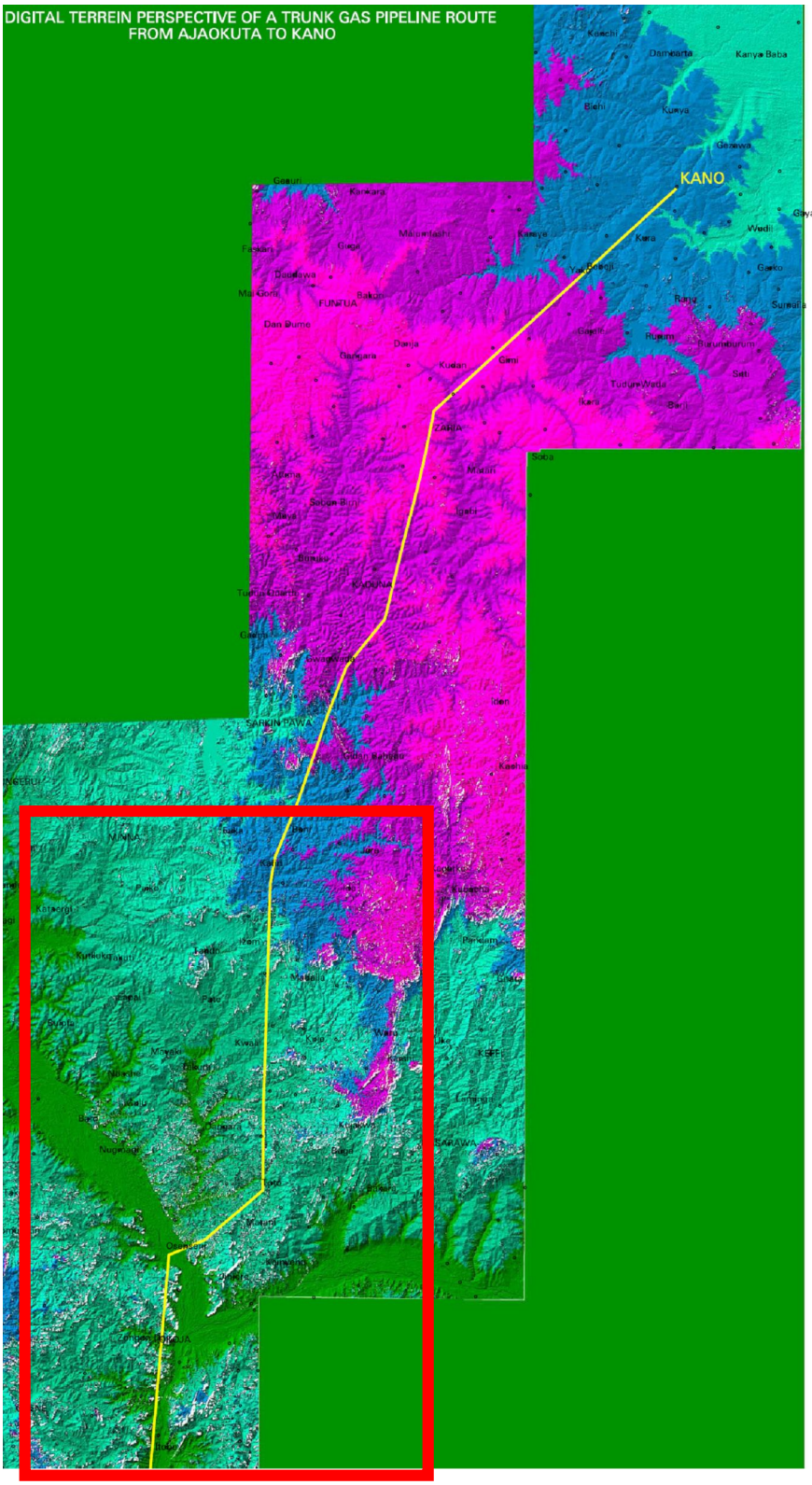


Figure 4.7 Trunk gas pipeline route corridor from Ajaokuta to Kano showing digital elevation and settlements (Note a section is cut to show details in Figure 4.8) the pipeline is shown in yellow line.

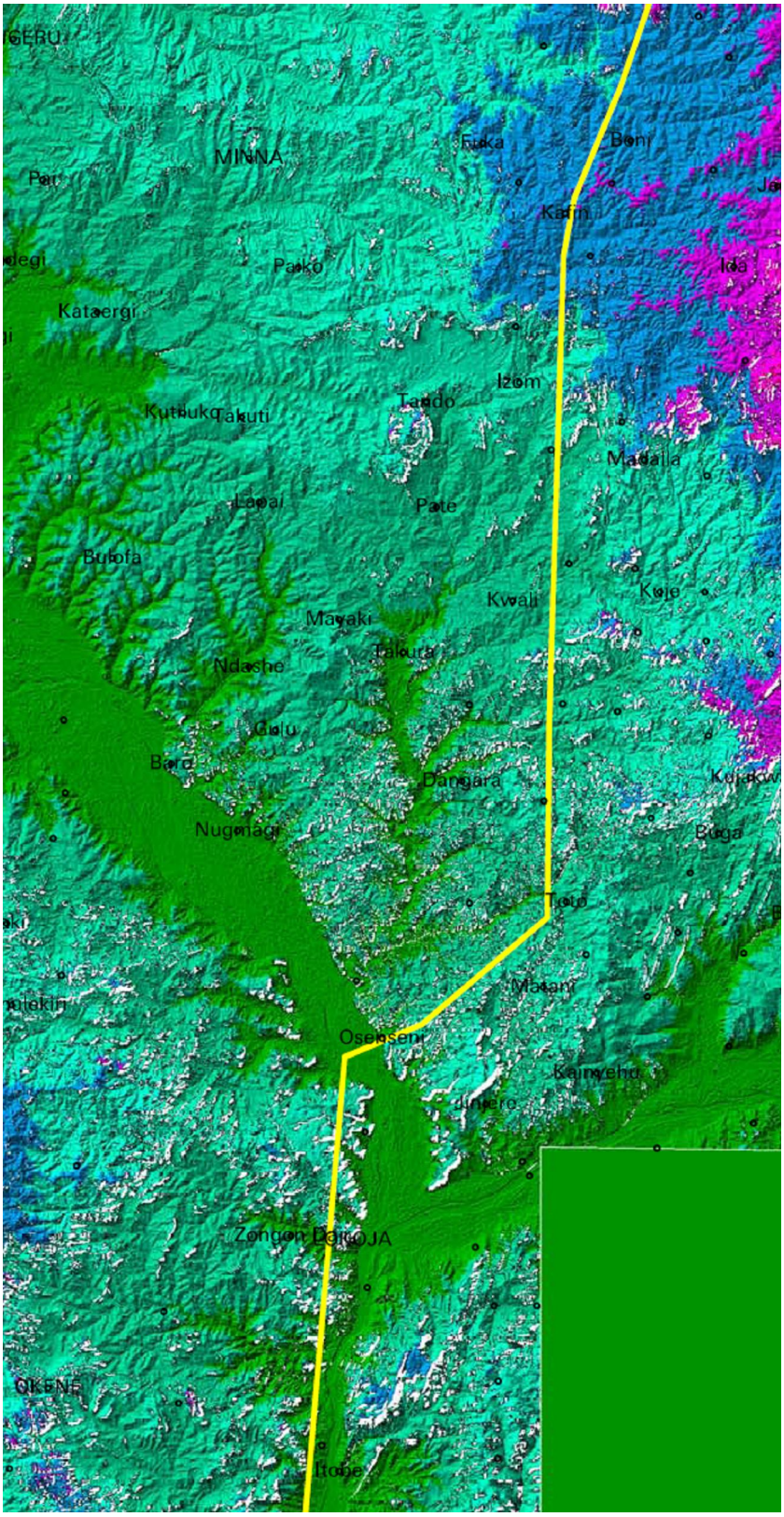


Figure 4.8 Details of pipeline route corridor (cut from Figure 4.7) showing digital elevation from Ajaokuta to Kano the pipeline is shown in yellow line.

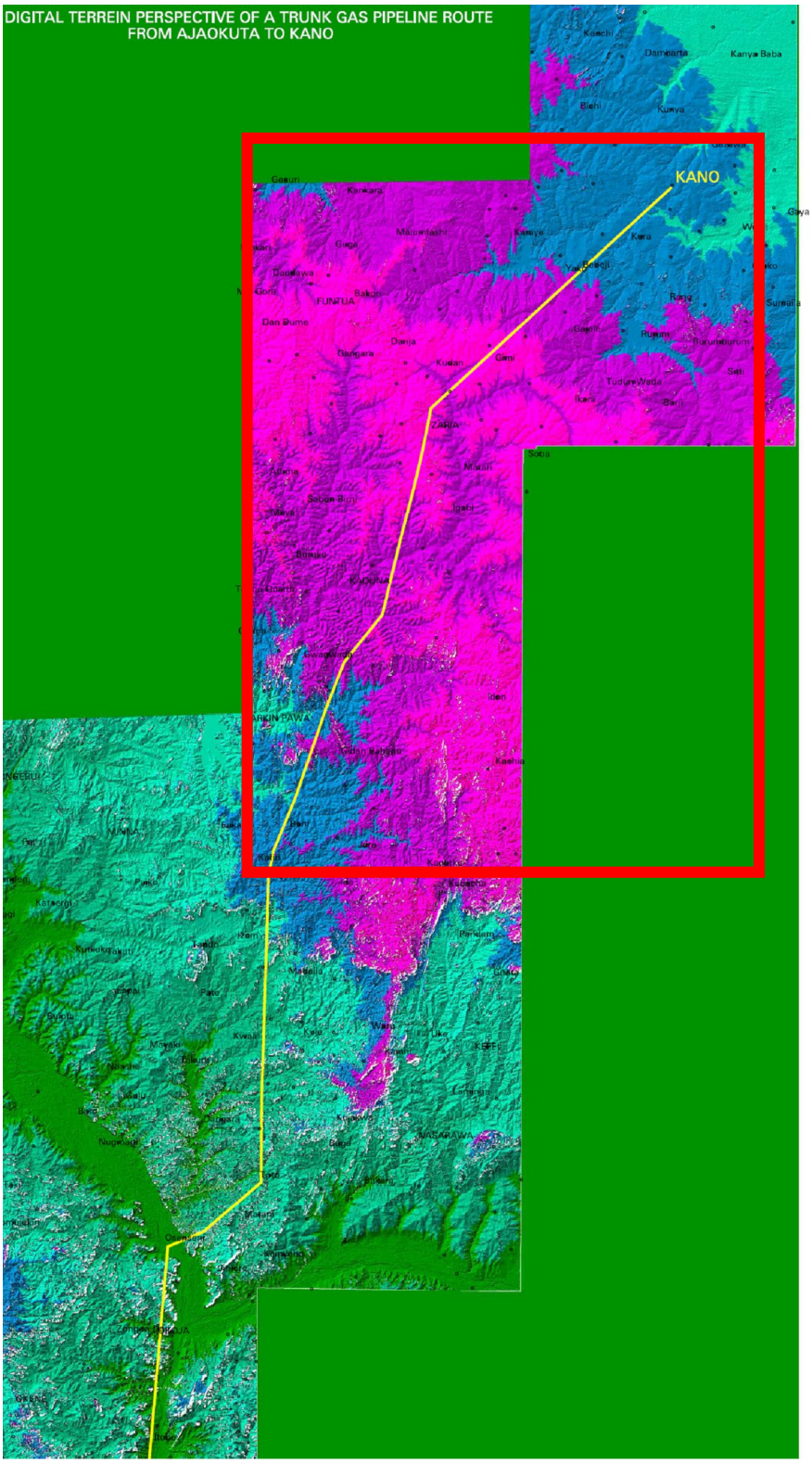


Figure 4.9 Trunk gas pipeline route corridor from Ajaokuta to Kano showing digital elevation and settlements (Note a section is cut to show details in Figure 4.10) the pipeline is shown in yellow line.

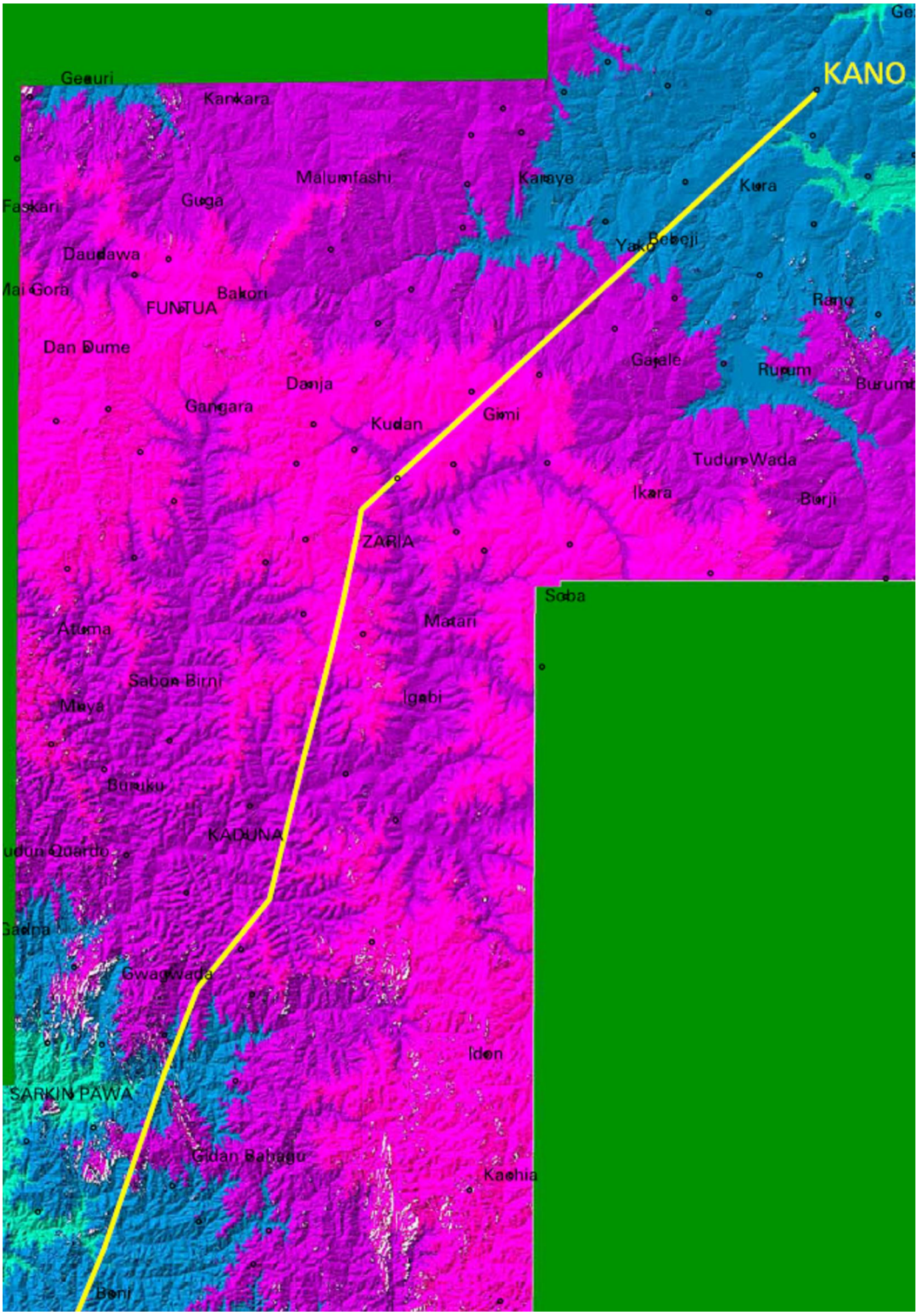


Figure 4.10 Details of pipeline route corridor (cut from Figure 4.9) showing digital elevation from Beni to Kano the pipeline is shown in yellow line.

Series of procedures (as mentioned in detail in the methodology) from GIS and engineering (pipeline routing criteria) were followed to arrive at the above figures/maps. The figures showed land use and digital elevation as well as the route traversed by the pipeline from Ajaokuta to Kano. These figures/maps were used to determine the length (L) of the pipeline, and pixel values corresponding to the points per kilometer from the digital elevation map (Figure 4.7) were converted to ASC II table data shown in appendix C, Table C.1. The table showed the eastings, northings and heights above sea level per kilometer along the pipeline route. Using Microsoft excell this table was used to plot the hydraulic profile shown in figure 4.1.1. Summary of Table C.1 is shown in Table 4.3

Table 4.3: Summary of Hydraulic profile Table

Eastings	Northings	Elevation (meters)	Horizontal Distance (km)
Ajaokuta	Ajaokuta	480	0.00
410037.0000	1283638.0000	545	50.00
370977.0000	1247818.0000	646	100.00
348297.0000	1204888.0000	664	150.00
335337.0000	1152508.0000	615	200.00
310587.0000	1107598.0000	495	250.00
241647.0000	810688.0000	517	300.00
287997.0000	1003288.0000	187	350.00
286557.0000	950278.0000	236	400.00
267387.0000	907078.0000	259	450.00
246237.0000	864418.0000	95	500.00
241737.0000	811678.0000	40	550.00

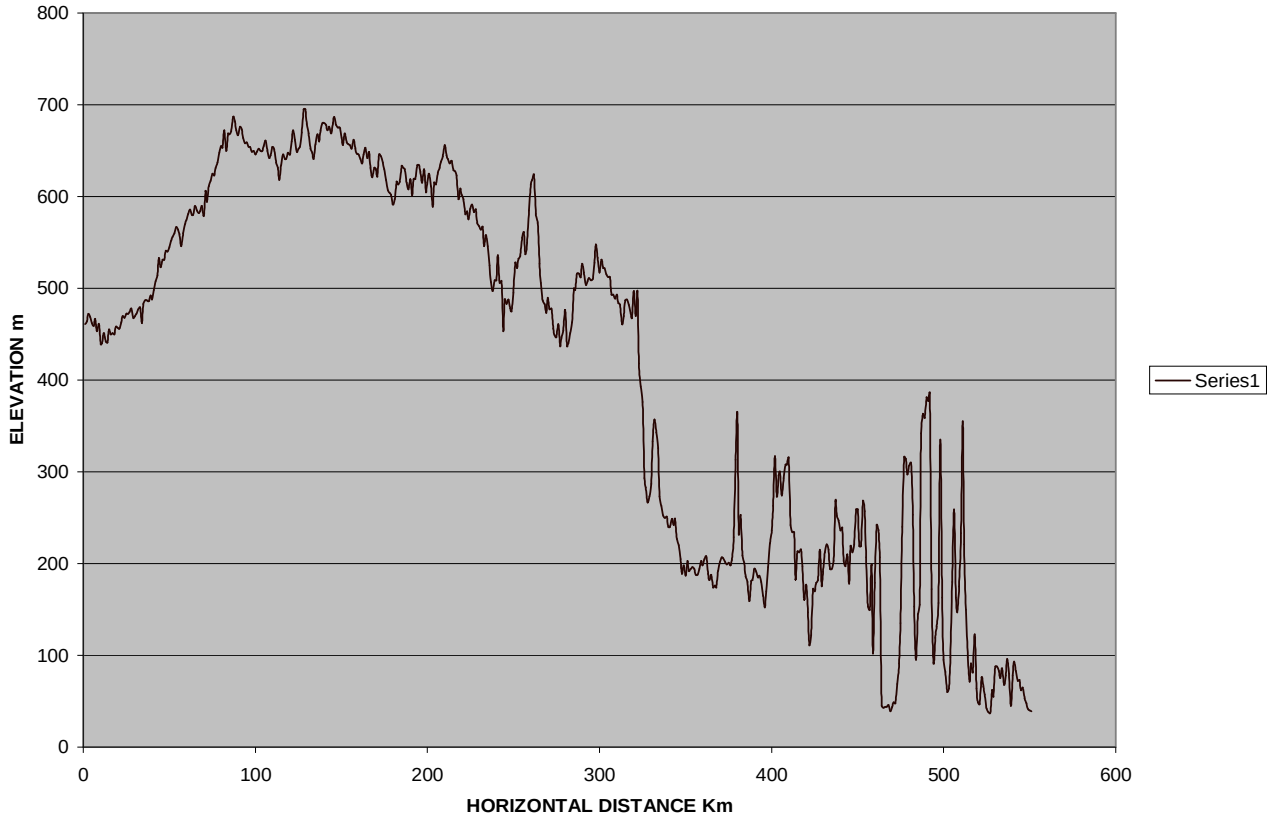


Figure 4.11: Hydraulic profile of the route of a trunk gas pipe line from Ajaokuta to Kano

4.1.4 Determination of internal diameter (d) and pipeline thickness (t)

4.1.4.1 Pipe internal diameter

Weymouth equation was used as the design equation to evaluate the internal diameter of the pipe as shown in Appendix A.4 and was found to be:

d = 16.40inches

4.1.4.2 Pipeline wall thickness (t)

Line sizing and Line design

After calculating the internal diameter, the pipe wall thickness was calculated using Barlow's formula. The corrosion factor was taken into consideration its value was

found to be 0.035 details shown in Appendix A.5, this factor gives the additional thickness needed for safety and it comes as an additional cost on the pipe line as illustrated in Appendix A.5.

Stress in the pipe due to internal pressure

For the purposes of field calculations, the stress in a pipe is the stress in pipe wall due to internal pressure and the value was found to be 27963.13 psi. This value is less than 35000psi minimum allowable stress, implying that the pipeline can be operated safely under the specified operating conditions as recommended by API (Appendix A.6).

Design pressure

Tie-In Pressure at OBEN-AJAOKUTA pipeline is 19barg = 20bar = 20*14.7 psia = 295 psia, therefore the operating pressure of Ajaokuta-Kano pipeline is also 295 psia. When working pressure is above 285 psia, the design pressure should be 740 psia or Class 300Ib (on shelf ANSI B31.8 Pipeline) (Appendix A.5).

P_{design} = 740 psia

Velocity of the gas in a pipe

The velocity of the gas in the pipe was found to be (Appendix A.3):

v = 81.29 ft/sec

Table 4.4: Design parameters

Design parameter	Description/Value
Principal design code	ASME B31.8, IGE/TD/3 IGE/TD/10
Fluid category	Natural gas –category D
Pressures: Tie-in design Pressure (bar) Maximum nominal operating pressure (psi)	 19 740*
Location factor	1 and 2
Design factor: Pipeline Fabricated assemblies Crossings (rivers, roads etc) Corrosion factor	 0.4 0.6 0.6 0.035
Pipe material: Grade Minimum Specified Yield Strength (N/mm^2)	 API 5L Grade B 241*
Longitudinal joint factor (E)	3
Temperature derating factor (T)	1
Flow rate (ft^3/day)	21.573×10^6*
Pipe inside diameter (inch)	16.4*
Thickness (inch)	0.217*
Stress inside pipe (psia)	27963.13*
Velocity of gas (ft/sec)	81.29*
Design pressure (psia)	740*
Pipeline length (miles)	343.02

* Calculated values

Table 4.4 show design parameters, some of the values were calculated indicated with an asterisk, some were obtained from the gas pipeline manuals (ASME B31.8). Details of the calculated values like flow rate, pipe inside diameter etc were shown in related sections of this project, while those obtained from manuals were fully discussed in the literature review.

Looking at the Table 4.4, some of the values obtained from the design manuals include what is known as the Principle design code (ASME B31.8), ASME B31.8

was taken as the design code as recommended by the Nigerian gas company (NGC). While the fluid category for natural gas is category D. Tie-in pressure at was 19bar at Ajaokuta metering station where the gas pipeline of this project connects from. The location factor is 1 and 2. The location factor is a safety factor used in design to distinguish between different locations where the pipeline is passing through. Class 1 location can be wastelands, deserts, rugged mountains, farmlands and similar areas with a factor 0.72. Fringe areas around cities or towns, and farm or industrial areas with a specified population density fall under Class 2 with a factor 0.60. It is worthy to note that in this project class 1 ought to be taken as the location factor but addition of class 2 was done (or class 1 and 2 are combined) to provide additional safety due to Nigerian environment (indiscriminate nature of carrying out human activities, for example, allocation of plots by state and local governments without notifying federal authorities). Details on various choices of location factors are given in Appendix B.4.1. Other safety factors shown in table 4.4 were the design factor for the pipeline (carbon steel pipes) which is 0.4, while its fabricating assemblies is 0.6 and for crossings (rivers, roads e.t.c) the safety factor was taken as 0.6, all the three factors (the design factors) were picked after considering the nature of pipe material (carbon steel) and the type of pressure the pipeline is likely to experience from railways and road crossings. From the pipe routing processes effort was made to avoid such crossings. The corrosion factor was calculated and found to be 0.035; this factor is to compensate for corrosion in the pipe. The corrosion factor was incorporated into the process of calculating the internal diameter. The corrosion factor plays a part in pipe wall thickness and consequently in pipe costs as shown in Appendix A.5. The

longitudinal joint factor J is to take care of the joints along the pipeline. The gas pipeline in this project is a seamless pipe, the joints are welded (no seams) its joint factor is 1. The temperature derating factor is a safety factor concerned with the temperature of the environment where the pipeline was placed. The temperature of northern Nigeria has never been seen to exceed 250^{o}F. It is recommended in ASME B31.8 that such temperature ranges (below 250^{o}F) should have a temperature derating factor of less than 1. Temperature derating factor for this project was taken to be 1 as its the factor corresponding to temperature falling below 250^{o}F.

The use of Geographic Information System (GIS) was in determining the length (L) of the pipeline and in determining the Hydraulic Profile Data Table (Appendix C). This table provides the horizontal distance in kilometer, the corresponding Elevation above sea level per each kilometer along the pipe line route. The table also provides the northings and eastings of each kilometer point. The Data in this Table gives the nature of the terrain, the pipe line is to traverse. This terrain nature is shown in the hydraulic profile a plot of Elevation Versus Distance, (Figure 4.1). the hydraulic profile plot informs the designer where to locate compressors for gas pipe line or pumps for oil pipe lines (booster stations).

Hydraulic profile is the essential information needed to know how much energy or work is required to transport the fluid. The knowledge of the Low and High Points give an idea of the pressure drops that are likely to be encountered along the route. It gives graphical information or the “anatomy” of the pipe line.

For Oil pipe lines, locating where slack lines are likely to occur can easily be achieved using the Hydraulic profile. Slack lines cause back pressure and hence fluid flow is going to be obstructed. This is undesirable. It is evident to notice that the need for hydraulic profile is most “intense” for oil pipe lines. For a gas pipeline design on the other hand especially where the pipe line traverses over “a gentle slope” (Szilas, 1975), the calculated differences between the inlet and outlet pressure have not been shown to have much difference from the theoretical and actual field values. In the same vein there will not be a need for compressor stations along the pipe line route in this project. One of the reasons for this is that in the original design of the pipeline, the pressure of 19 bar at the tie-in point at Ajaokuta was left at that value, this was done to allow for future pipeline extension projects without investing much money on booster stations.

Looking at the Hydraulic Profile and considering Ajaokuta Metering station as the starting point with a distance of 0 km while the final destination of the pipe line Kano is around 551 km, it will be observed that the fluid (gas) will only have to pass through a relatively lower ground initially (i.e. from 0 km up about 89km) as shown in figure 4.11 then a relatively higher ground around 90 to 250 km and then a relatively lower ground continuously till it reaches its destination. This is easily achievable as mentioned earlier because the gas has enough energy from the initial/inlet pressure (the tie-in point pressure at Ajaokuta) of 19bar (left at 19 bar for future extension of the pipeline) hence the gas will flow naturally up to its final destination, this route is likely to be good for a Crude oil line, for the same reason.

The inlet pressure of 19 bar at the tie-in point in Ajaokuta was obtained from Ajaokuta Metering Station and NGC, while the outlet pressure of 2.5 bar was chosen in the cause of design from recommendations due to experience in projects at Ikorodu areas by Gaslink, and from the use the gas will be put into, which is mostly for Gas Turbines, Boilers and as a raw material for petrochemical industries.

The composition of the Gas was obtained from Ajaokuta Metering Station.

The stress analysis in the pipeline is in many folds but in this work a detailed discussion and evaluation methods have been provided in relevant literatures (Appendix B.4.1, A.5 and A.6). While for the actual stress in the pipe a simple formula was used to evaluate stress due to internal pressure as indicated in (McAllister, 1993):

Stress inside the pipe due to internal pressure = ½ x internal diameter x pressure (psi)/wall thickness

The actual stress was found to be 27963.1336 psi. This value was compared with Minimum Allowable Stress of 35000 psi from ANSI B31.8 for a pipe line with the same specification (as specified in this project), the calculated stress (27963.1336 psi) is clearly less than the Specified Minimum Yield Strength (SMYS), which is the safety requirement. Stress due to internal pressure should be less than the Minimum Allowable Stress for the pipe line to able to handle the schedule it is design for.

The design Pressure was obtained by considering the Tie-In Pressure at OBEN-AJAOKUTA pipeline which is 20barg (295 psi). Therefore the operating pressure, which is the working pressure, is the minimum pressure inside the pipe during operation of the pipeline. The operating pressure was found to be 295 psia. When

working pressure is above 285 psia, the design pressure, which is the maximum pressure the pipeline can withstand during operation should be 740 psia or Class 300Ib (on shelf ANSI B31.8 Pipeline).

4.2 Economic analysis

The economic analysis was carried out as shown in Appendix B.7.3 and the results shown in table 4.5.

Table 4.5: Project cost estimate

S/N	Description	Amount USD (Million)	Naira (Million)
1	Right Of Way (ROW)	4.2991	558.8830
2	Materials	57.7334	7505.3420
3	Labor	47.5993	6187.9090
4	Miscellaneous	12.8979	1676.7270
	Sub – Total	122.5297	15928.8610
	Contingency (5%)	6.1265	796.4450
	Grand Total	**128.6561**	**16725.2930**
Conversion rate @ N130=$1			
Plant capacity and sales		N7.33x108 ft3/yr	
Profit before tax and depreciation		N9.55x109	
Working capital		N3.3.5 Billion	
Project life		15yrs	

For the preliminary evaluation of a project the following estimates were made:

- Plant Capacity and Sales (gas flow rate) = 21.58 x 10^6 ft^3/day

  = 21.58 x 10^6 x 340 = 7.3372 x 10^8 ft^3/year

- Average Price = 45% of NGC price + Cost Price = 45% of 16.64 + 16.64

=N24.12k NGC (2006)

- Unit Cost (at Capacity) = N16.64
- Overhead 15% of price = 0.15 x 24.13 = N3.62
- Project Life 15 years (T)
- Depreciation is sum of the years digits details in Appendix A.7.3
- Plant investment (F) =N 16.73 Billion
- Working Capital (W) = N 3.33 Billion
- Gross Income = Plant capacity and sales x Average Price = $7.34 \times 10^8 \times 24.13$ = $N1.77 \times 10^{10}$
- Less Overhead at 15% = Gross Income x Overhead 15% of price = $7.34 \times 10^8 \times 3.62 = N2.66 \times 10^9$
- Less Operating Cost = Plant Capacity and sales x Unit Cost (at Capacity) = $7.34 \times 10^8 \times 16.64 = 1.2209 \times 10^{10}$
- Profit before Tax and Depreciation = Less Operating Cost – Less Overhead at 15% = 1.2209 x 1010 – 2.6554 x 109 =9.55×10^9

The internal rate of return (ROR) was found to be 30%/year, details of this calculations is shown in Appendix A.7.3.

Table 4.5 shows the economic analysis or cost estimate of the project and details of the calculations and procedure is given in Appendix B.6 and A.7.3. The determination of the rate of return of the project was achieved using a Nomograph (Figure 2.11). Cost of pipe per kilometer which is standard world wide = $22382 per km. The total cost was broken down into portions/percentages as shown in Table 4.5. The right of

way (ROW) was N558.8830 million, Materials which include the pipe itself was N7,505.3420 million, labor was estimated as N6,1870 million and miscellaneous was N1676.7270 million, while contingency (5%) was N796.4450 million. The total cost of laying a pipe line from Ajaokuta to Kano through Kaduna was found to be N16.73 Billion with a working Capital of N3.35 Billion.

A Nomograph was used to calculate the Rate Of Return and was found to be 30%, details shown in Appendix A.7.2. In other words when the amount of N20.08 Billion (16.73 + 3.35) is invested there will be a return on investment at the rate of 30% per annum if the gas is bought at N16.64k and sold at N24 per standard cubic feet. It is important to note that to ensure security for investors the NGC has fixed the price of buying and selling of the gas into two scenarios from which one scenario has to be chosen before a license can be issued.

The project will be able to Pay-Back in 3.5 years, this rate of return is very good for a project of this magnitude bearing in mind that the life span of the project is about 15 years. Steady profit is expected at the end of the third quarter. Various Methods can be used to estimate the cost of laying a pipe line but the nomograph used in this project has been recommended worldwide and highlighted in McAllister (1993) for quick and accurate estimate of a pipe line costing. It is especially ideal for a project of this type which is preliminary in nature.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

At the end of the project work the following conclusions were made:

1. The industrial electrical energy demand data from a public utility company was used to asses the natural gas energy demand in Kano and Kaduna and was found to be 2.1573 x 10^7 ft^3/day.
2. The viability of trunk gas pipe line design was demonstrated using GIS. The total pipeline length was 343.02 miles with 16.4 inches diameter tie-in pressure of 19 bar, pressure at city gate at the pipeline terminal point 2.5 bar and a design pressure of 740 psia.
3. The capital needed for the project was found to be N20.08 Billion (16.73 billion as initial investment plus 3.35 billion Naira working capital) with a rate of return of 30%.

5.2 Recommendations

The following recommendations are suggested for further work and consideration:

1. The initial aim of the project was to encourage involvement of Nigerian engineers in gas pipeline design, especially chemical engineers and to involve a local company in the manufacture of Gas Pipelines, from the recommendations in (Ageh *et al*, 1999), so that there will be a reduction in cost of manufacture of pipes.

The company S.C.C Nigeria Limited, Bwari, Abuja, is involved in pipeline production in Nigeria (it was the company that handled the Gurara water transfer

project from Kaduna to Abuja) and the company has made contact with some Oil companies in Nigeria to see if they can form a partnership. Presently the company has not prepared a price list for its Oil or Gas pipelines because they have not started the manufacturing of such pipe lines, may be in the near future.

It is my recommendation that as soon as the price list of this company becomes available including the trenching cost per kilometer, the price should be quoted and used for cost analysis in the project. The company is committed to providing lower cost for indigenous projects, which is obvious. The interesting thing is that most of the countries in the world where effective use of natural gas has been achieved; it was through the design and manufacture of the pipeline by indigenous engineers/companies.

2. There should be an effective use of Software program to be able to further refine the most appropriate route. This software can be of GIS type e.g. 'the least cost path way analyses' to software that can be used in cost estimates. This will enhance accuracy and further reduce the cost of production and construction.

3. Furthermore, private sector participation holds the key to the effective utilization of Natural Gas in Nigeria. There should therefore be more liberalization of the downstream sector of oil and gas industry in Nigeria.

4. There should be a unified Natural Gas purchase price for all the franchise involved in buying and distribution of natural gas in Nigeria.

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APPENDIX A

Calculations of Results and Investigations

A.1 Capacity under utilization due to inadequate energy supply

It should be noted that the Energy consumption and supply assessment by Power Holding Company of Nigeria (PHCN) is mostly on monthly basis.

In the month of May 2006 the average energy supplied by PHCN to these locations (townships) Kaduna and Kano were 61, 993.70 kWh and 55, 663.00 kWh respectively with a peak load of 126.2 MW for Kaduna and 206.6 MW for Kano. The installed capacity of PHCN for Kaduna is 298MW while for Kano is 240MW.

For the month of May 2006:

Average energy supplied by PHCN

Kaduna = 61, 993.70 MWh

Kano = 55, 663.00 MWh

Peak load

Kaduna = 126.2MW

Kano = 206.6MW

Total 332.8MW

Installed capacity

Kaduna = 298 MW

Kano = 240 MW

The expected demand of these locations considering suppressed factor of 1.5 on monthly basis:

Kaduna: 298 x 1.5 = 447 MW

Kano: 240 x 1.5 = 360 MW
807 MW

- The total expected power demand of these locations is 870MW
- The total peak load available is 332.8MW
- Percentage of available power from the expected/required power is:

$$\frac{332.8}{807} \times 100 = 41.24\%$$

From the above only 41.24% of the required power is supplied to these locations, the remaining 58.76% will have to be provided by other sources of power (PHCN Mando, 2006).

Note that the maximum peak demand of 332.8MW is not sustained on continuous basis for 24 hours daily due to diversity factor. The actual power consumed must therefore be based on historical data.

Likewise, energy demand is divided into two different users Domestic and Industrial

- The industrial Electrical Power demand of Kano and Kaduna is about 60 – 70% of the total (807MW) Electrical power required by these areas.

  807 x 0.65 = 524.58MW (Taking 65% as the definite value of average industrial demand of the areas)
- Assuming that initially not all the industries in this area are likely to connect to the gas grid. The assume patronage of about 50% was assigned (on the Gas line).

524.55 MW x 0.5 = 262.28 MW

- The assumed Power demand in terms of energy will be:

  262.28MW x 24 hours x 30 day

  = 188838 MWh (monthly basis)

  = 6294.72 MWh (Daily basis)

  = 6294720 kWh (Daily basis)

Estimated Energy Demand of these areas (per day) is:

= 6294720 kWh (Daily basis)

10.3KWh = $1m^3$ = $(3.2808)^3$ ft^3 = $35.5ft^3$ of natural gas

$$6.2974 * 10^6 \text{ KW} = \frac{35.3ft^3 * 6.2974 * 10^6 \text{ KWh}}{10.3\text{KWh}}$$

$$= \frac{2.2220 * 10^8}{10.3}$$

$$= 2.1573 * 10^7 \text{ ft}^3 \text{ (per day).}$$

A.2 Design flow rate

The next item is determination of the flow rate.

Estimated Energy Demand on the Gas Grid is:

2.62MW * 24 *30 = 18884.6MWh (per month)

OR 6294.72MWh (per day)

6294.72MWh*1000 = $6.2974 * 10^6$ kWh.

10.3kWh = $1m^3$ = $(3.2808)^3$ ft^3 = $35.5ft^3$ of natural gas

$$6.2974 * 10^6 \text{ kW} = \frac{35.3\text{ft}^3 * 6.2974 * 10^6 \text{ kWh}}{10.3\text{kWh}}$$

$$= \frac{2.2220 * 10^8}{10.3}$$

$$= 2.1573 * 10^7 \text{ ft}^3 \text{ (per day).}$$

Estimated Volume of gas Demand on the Gas Grid is $2.1573 * 10^7$ ft^3 (per day), this value is the flow rate which will be used in the design equation.

A.3 Velocity of the gas in the pipe

$$v = \frac{0.75\ Q}{d^2 P}$$

where:

v = velocity expression in ft/sec

Q = gas volume, Mcf/hour at standard conditions

D = inside diameter of the pipe, in.

P = pressure, psia.

$$v = \frac{0.75 \text{ x } 2.1573 \text{ x } 10^7}{16.4^2 \text{ x } 740}$$

$$= 81.29 \text{ ft/sec}$$

A.4 Pipe internal diameter.

Using Weymouth equation, the design flow rate will be:

$$Q = 4.335 * \ T_b/P_b * ((P_1^2 - P_2^2)/GLTZ))^{0.5} * d^{2.662} * E$$

Q = 2.1573 * 10^7 ft^3 (per day).

L = 1928275.20 ft = 365.22 miles

P_2 = 2.5barg = 36.26psig = 36.26 + 14.7 = 50.96psia

P_1 = 19barg = 275.5psig = 275.5 + 14.7 = 290.20psig

T_b = 520^{o}R

P_b = 14.7 psia

d = Internal diameter

G = 0.7

T= 495^{o}R

to calculate z, the value of average pressure has to be obtained

P_{avg} = 2/3 $(P_1+P_2 – (P_1*P_2))$

P_{avg} = 2/3 ((290.20 + 50.96) – (290.20* 50.96)) / (290.20 + 50.96).

= 2/3 ((341.16 – (14788.59) / (341.16))

= 2/3 (297.81)

= 198.54psia

Then look-up on Compressibility chart for natural gas for value of Z at 198.54psia & 35^{0}F from Figure A.1.

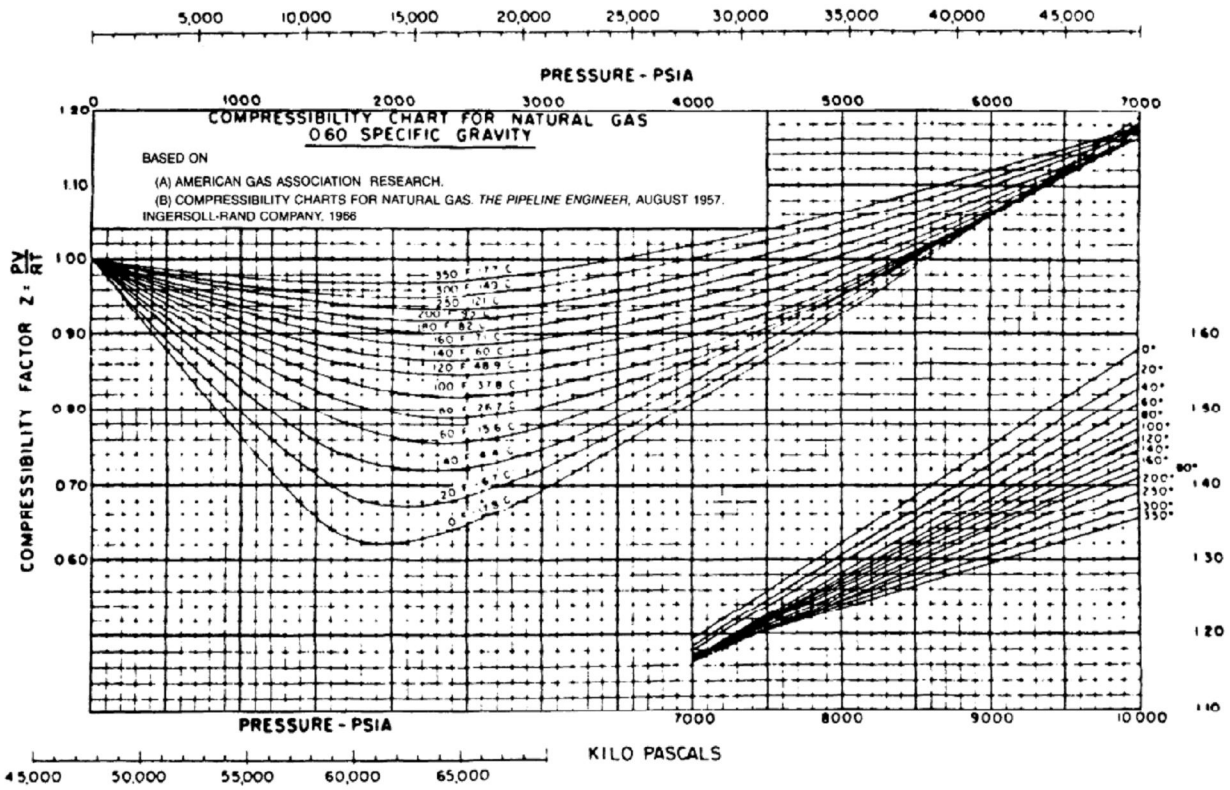


Figure A.1: Compressibility chart for natural gas (McAllister, 1993).

Subtituting all the values into Weymouth equation we get:

$21.581 * 10^6 = 433.5\ (520/14.7) * ((290.20^2 - 50.96^2) / (0.7 * 365.23 * 495 * 0.96))^{0.5}$

$* d^{2.662} * 1 = 15334.96 * ((84216.04 - 2596.92) / (121490.10))^{0.5} * d^{2.662}$

$1407.33 = (81619.12 / 121490)^{0.5} * d^{2.662}$

$1407.33 = (0.6718)^{0.5} * d^{2.662}$

$= 0.8196 * d^{2.662}$

$1717.00 = d^{2.662}$

$1717.00^{\ 0.3757} = d$

$d = 16.40$inches.

A.5 Pipe wall thickness and design pressure

Tie-in Pressure at OBEN-AJAOKUTA pipeline is 19barg = 20bar = 20*14.7 psia = 295 psia, therefore the operating pressure of Ajaokuta-Kano pipeline is also 295 psia. When working pressure is above 285 psia, the design pressure should be 740 psia or Class 300Ib as recommended by on shelf ANSI B31.8 Pipelinemanual.

P_{design} = 740 psia

For pipeline thickness:

$t_{design} = \frac{PD}{2SFET}$ McAllister (1993).

where,

P_{design} = Design pressure = 740 psia

D = Outside diameter

S = Specific Minimum Yield Strength 35,000 = (35,000 – 14.7) 35725.30psig

F = Location Design Factor = 0.6

E = Longitudinal Factor = 1

T = Temperature Derating Factor = 1

$t_{design} = \frac{740 * 16.22}{2(35725.30 * 1 * 1 * 0.6)}$

t_{design} = 0.280 inches

now,

t_{min} = Minimum allowable wall thickness (API, 2000).

$t_{min} = t_{design} + c$

c = Corrosion Factor = 1/8 of t_{design}

$c = 0.125 * 0.280 = 0.035$

now,

$t_{min} = 0.28 + 0.035$

$= 0.315$

$t_{nominal} = \frac{0.315}{0.875}$

$= 0.36$ inch

After calculating the internal diameter, the pipe wall thickness was calculated using Barlow's formula, the corrosion factor was then put into consideration, the corrosion factor gives the additional thickness needed for safety and it comes as an additional cost on the pipe line.

A.6 Stress in the pipe due to internal pressure

For the purposes of field calculations; the Stress in a pipe is the stress in pipe wall due to internal pressure, it is obtained quickly by using the formula:

½ x internal diameter x pressure (psi) /wall thickness.

½ x16.4 x740/0.217 = 27963.13 psi

The value 27963.13 psi is less than 35000psi Minimum Allowable Stress, this simply means that the pipe line can take the Operating Pressure safely.

A.7 Economic analysis

Gas purchase price

Chosen scenario:

1. 45% of gas Sales Price to end users as gas purchase price to NGC from 1st contract year to 15th contract year

Gas sales price

The Natural Gas Purchase and Sales Agreement in line with the current Government Policy stipulates that the price of gas shall be a percentage of the prevailing pump price of fuel oil (Low Pour Fuel Oil) and shall escalate in the following order:

First Contract Year	60% of LPFO price
Second Contract Year	65% of LPFO price
Third Contract Year	70% of LPFO price
Fourth Contract Year	75% of LPFO price
Fifth to Twentieth Contract Year	80% of LPFO price

A.7.1 Prices of natural gas per 1000scf as sold by NGC as at April 2006

Ajaokuta, DSC, WRPC, and PHCN (NEPA) = N16.64

NAFCON = N78.00

WAPCO Ewekoro = N313.37

WAPCO Shagamu = N438.29

PZ = N410.90

Ejeba = N31.38

A.7.2 Nomograph for estimating interest rate of return on investment ("profitability index")

Several methods are used for evaluating the profitability of a given project. A method for estimating profitability which has received considerable emphasis in the past few years is the "interest rate of return" (Figure 2.11), also known as "profitability index" or "discounted cash flow" method. This profitability method takes into account the time value of money. Mathematically, interest rate of return may be defined as that rate at which company's outstanding investment is repaid by proceeds from the project.

The Nomograph was developed for the case in which the yearly profit (P) (or the difference between income and costs) is equal through the life of a project. The nomograph is based on the following assumptions:

1. Depreciation method is sum of the years-digits.
2. Project economic life is equal to depreciable life (T).
3. Construction time is zero, i.e., total investment occurs instantaneously at time zero.
4. There is no salvage value at the end of the project life.
5. There is no start-up expense, (S=0).

   Where these conditions apply, the nomograph gives the interest rate of return R, as a function of P and T, fixed investment (F), and working Capital (W), other assumptions are

   6. The cost of natural gas per N16.64 per $1000ft^3$

   i. The conversion rate is N130 per US Dollar.

ii. There are 340 days in a year. The 340 days instead of 365.

iii. Assuming working capital of 20% of total investment.

a. Cost of laying a pipe line is $22382 per km.

b. Cost of 16 inch pipe line and length of 343.0128 miles = 22382 x 16 x 343.0128 = $122836999.8.

c. Cost due to inflation = 0.04^{12} x 122836999.8 = 2.06×10^{-9}

d. Actual Cost = Cost of 16 inch pipe line and length of 343.0128 + Cost due to inflation = 2.06×10^{-9} + 122836999.8 = $122836999.80.

Results of Cost estimates:

A. Right Of Way (ROW): 122836999.80 x 3.5/100 = $4299294.99

B. Material : 122836999.80 x 47/100 = $57733389.90

C. Labor : 122836999.80 x 38.75/100 = $47599337.42

D. Miscellaneous : 122836999.80 x 10.5/100 = $12897884.98

Total Cost = A + B + C + D = $122529907.30

Contingency = 5% x 122529907.30 = $6141849.99

Actual Cost of Project = $122529907.30 + $6141849.99 = $128.9788 = N16.7253 Billion Naira.

A.7.3 Project cost estimate

TABLE A.1: Cost estimate

S/N.	DESCRIPTION	AMOUNT USD Million	AMOUNT NAIRA Millions
1	Right Of Way (ROW)	4.2991	
2	Materials	57.7334	
3	Labor	47.5993	
4	Miscellaneous	12.8979	
	Sub – Total	122.5297	
	Contingency (5%)	6.1265	
	Total	**128.6561**	
	Summary Total @ N130 = $1		**16725.2930**

For the preliminary evaluation of a project the following estimates are available:

- Plant Capacity and Sales = 21.58 x 106 ft^3/day = 21.58 x 10^6 x 340

  = 7.3372 x 10^8 ft3/year
- Average Price = 45% of NGC price + Cost Price = 45% of 16.64 + 16.64

  =N24.12
- Unit Cost (at Capacity) = N16.64
- Overhead 15% of price = 0.15 x 24.13 = N3.62
- Project Life 15 years (T)
- Depreciation is sum of the years digits
- Plant investment (F) =N 16.73 Billion

- Working Capital (W) = N 3.33 Billion
- Gross Income = $7.34 \times 10^8 \times 24.13 = N1.77 \times 10^{10}$
- Less Overhead at 15% = $7.34 \times 10^8 \times 3.62 = N2.66 \times 10^9$
- Less Operating Cost = $7.34 \times 10^8 \times 16.64 = 1.2209 \times 10^{10}$
- P, Profit before Tax and Depreciation=1.2209x1010–2.6554 x 109=9.55×10^9

The Nomograph for evaluating the interest rate of return can now be used as follows:

Compute

$$\frac{P \times T}{F} = \frac{9.55 \times 10^9 \times 15}{16.73 \times 10^9} = 8.57$$

Compute

$$W/F = \frac{3.35 \times 10^6}{16.73 \times 10^6} = 0.2$$

On the nomograph:

Connect	With	Read
$\frac{P \times T}{F} = 8.57$	$\frac{W}{F} = 0.2$	R x T = 450

Since R x T = 450 and T = 15, solving for R the interest rate of return for the project,

R x 15 = 450

$$R = \frac{450}{15} = 30$$

R = 30%/year

This is equivalent to saying that the outlay of capital of N16.73 Billion in plant facilities plus N3.35 Billion in working capital when invested in the project would

generate enough cash to pay back the total investment plus interest at the rate of 30%/year.

A.8 Natural gas can be used to compliment the energy demand of Kano and Kaduna

Estimated volume of gas demand on the Gas Grid is $2.1573 * 10^7$ ft^3 (per day).

Comparing 'the costs of the energies' sold to industries by PHCN and current average costs sold by gas companies in Nigeria;

PHCN = 8.5 Naira/kilowatt

Average cost of gas = 4 Naira/kilowatt

Total cost of energy demand as sold by PHCN

6294720kWh x 8.5 ₦/kWh = 53505120 ₦ daily

Total cost of energy demand as sold by gas franchise

6294720 kWh x ₦/kWh= 25178880 Naira daily

Percentage savings will be:

53505120 – 25178880 = 28326240 Naira daily

$$\frac{28326240}{53505120} \times 100 = 52.94\%$$

An average saving of over 50% (to be exact 52.94%) will be expected if the companies/industries were to use gas as their energy source. This fact is further backed by the remarkable energy savings achieved by Dunlop Nigeria PLC. In Lagos after joining a gas grid as shown below:

A.9 Savings recorded by Dunlop Nigeria plc.

Dunlop PHCN bills per month (estimated) = ₦ 17 MILLION

Cost per unit of electricity in Lagos = ₦10/kWh (Industrial Tariff)

Natural Gas cost per unit of electricity = ₦ 4

Energy savings using natural gas as compared with PHCN

PHCN = ₦ 10/kWh

Natural gas cost per unit of electricity = ₦ 4/kWh

10 – 4 = ₦ 6 savings

Percentage savings will be:

$$\frac{6}{10} \times 100 = 60\% \text{ savings.}$$

Now in monetary terms;

₦ 17,000,000 x 0.6 = ₦ 10,200,000 per month.

APPENDIX B

Additional technical information

B.1 Elements to Determine an Economic System

To size a pipeline, one must identify the significant elements necessary to evaluate and compare alternatives, estimate costs, and perform an economic analysis of the alternatives. Cost differentials for alternative line sizes must include the following elements:

• Annual throughput rates for the period selected as the analysis basis.

• Pipeline and pumping facilities with capacity to handle the throughput rates.

• Pumping energy to transport the stock at throughput rates.

Alternative forecast throughputs often consist of a most-likely case, and less likely cases at lower and higher rates. Sensitivity analyses should be made to determine the effects of the other cases or a composite case given the line size selected by the most-likely case analysis.

In some situations, other elements may affect economic evaluation of alternatives, such as:

• Line routing

• Heated-line facilities, heating method, initial line temperature, pipe insulation, and heating energy

Sensitivity analysis may be appropriate if alternative routes involve uncertainties in comparative construction costs or costs for permitting, right-of-way acquisition and damages, or if heated-line systems involve uncertainties in line heat losses and heating energy cost.

B.2 Preliminary Pipe Selection and Line Operating Pressure

B.2.1 Standard pipe sizes

A pipe (as oppose to a tube or "tubing") may be designed as a cylinder whose dimensions (inner & outer diameters and wall thickness) comply with dimensional standards ASME B36:10 or ASME BE36:19. A line pipe is a pipe commonly used for oil, hydrocarbon products and Gas pipelines, whose dimensions comply with API 5L.

A pipe is called out by its nominal pipe size (NPS) and its schedule. Up to NPS12, the nominal pipe size is a rounded approximation of the outer diameter (for example NPS 4 is a pipe with an outside diameter of 4.5"). Above NPS 12, the NPS is the actual diameter of the pipe (an NPS 20 pipe has an outer diameter of 20"). There used to be three schedules of pipe: standard (std), extra strong (XS), and extra-extra-strong (XXS). The current commercial schedules are 5 and 10 for stainless steel (followed by letter s to designate stainless steel: 5s and 10s), and 40, 60, 80, 100, 120, 140, and 160. But, as indicated in the enclosed tables, not all schedules are commercially available for all sizes.

If t = nominal wall (in), D = outside diameter OD (in) d = inside diameter ID (in), then;

The weight of steel pipe per foot is $W_p = 10.6802t\ (D - t)$ Ib/ft

The weight of water per foot is $W_w = 0.3405d^2$ Ib/ft

The moment of inertial of the metal cross section is $I = 0.0491(D^4 - d^4)$ in^4

The section modulus of the metal cross-section is $Z = 0.0982(D^4 - d^4)/D$ in^3

Antaki (2003).

B.2.2 Stress analysis in pipe

Stress, expressed in pounds per square inch, is the resultant internal force that resists change in the size or shape of a body acted on by external forces. In this Code, "stress" is often used synonymously with unit stress, which is the stress per unit area.

a. Operating stress is the stress in a pipe or structural member under normal operating conditions.

b. Secondary stress is stress created in the pipe wall by loads other than internal fluid pressure, such as backfill loads, traffic loads, loads caused by natural hazards, beam action in a span, loads at supports, and at connections to the pipe.

These type of Stress and deflections occur in pipe lines at the transition from below ground (fully restrained) to the above ground (unrestrained) condition.

Analysis of the stresses and deflections in transition areas, resulting from internal pressure/temperature change, is necessary in determining anchor block requirements and design. Longitudinal deflections are used to determine whether an anchor block is required, Anchor block forces required to maintain the pipe in a fully constrained position are then determined. McAllister (1993).

B.2.3 Hoop stress and Longitudinal stress

The simplest and most commonly used procedure for determining the initial wall thickness of a pipeline, be it onshore or offshore, is to calculate it based on the specified (internal) design pressure. If other design criteria or other stress limits or strain limits such as combined stresses, hydrostatic collapse, or the occurrence of

local buckling or wrinkling during the installation process do not result in a need to increase the pipe wall thickness, then the hoop stress determination of the pipe wall thickness determined on the basis of the specified (internal) design pressure will also represent an optimum pipeline design.

Hoop stress, σ_H

This is the stress in a pipe of wall thickness, t, acting circumferentially in a plane perpendicular to the longitudinal axis of the pipe, produced by the pressure, P, of the fluid in a pipe of diameter, O, and is determined by Barlow's formula:

$$\sigma_H = \frac{PD}{2t} \quad \text{- - - - - - - -B.8}$$

where

σ_H = hoop stress, psi

P = internal pressure, psi

D = outside diameter, in

t = nominal or minimum wall thickness, in.

Longitudinal Stress, σ_L

We call this stress in a cylinder the "longitudinal stress" because it acts parallel to the long axis of the cylinder, and its given by the formula

$$\sigma_L = \frac{PD}{4} \quad \text{(Half Hoop Stress)} \quad \text{- - - - -B.9}$$

For the stress inside a pipe we have as mentioned above the two major stresses Longitudinal and Hoop stresses, the most stress considered in the field is the stress in pipe wall due to internal pressure and it is usually the combination of the two only (in the Nigeria Environment there is not much Earth Quakes or Land slides or large temperature differences to cause any damage to the pipe line) but for an open pipe (pipe opened at both ends) or a very long pipe as is the case in this project; only the Hoop Stress is usually considered, this Hoop stress is the radial pressure being exerted on the inside wall of the pipe.

For the purposes of field calculations; the Stress in a pipe is the stress in pipe wall due to internal pressure, it is obtained quickly by using the formula:

½ x internal diameter x pressure (Psi) /wall thickness.

B.3 Wall thickness/pipe grade

The thickness of gas transmission lines varies with the pipe grade, location and design pressure. The design pressure which is specified by the system designers for any specific location should not be less than the maximum operating pressure (MOP) of the pipeline at the location where all the forces are considered. The pipe wall thickness and material selected by designer should provide adequate strength to prevent deformation and collapse by handling stresses, external reactions, and thermal expansions and contractions.

The designer should also consider the low temperature properties of materials. Since they are likely to be exposed to; low-temperature media during installation, pressure

testing, start-up, and operation. According to the pipeline codes (ANSI-ASME-B31.8) or (SA2662-96) the stress design requirements to be considered are limited to normal design conditions for operating pressure, thermal expansion and contraction ranges, temperature differential, and other forces acting on the pipeline additional loadings could include Occasional extreme loads (earthquake), Slope movement, Fault movement, Seismic related earth movement, Thaw settlements, Frost heave, Loss of support, Cyclical traffic loads, Construction and maintenance deformations, Mechanical vibrations, Hydraulic shock, Vortex shedding.

These loadings require supplemental design criteria (such as heavier wall thickness or stronger material) to ensure a safe and operational pipeline Mohitpour (2003).

B.3.1 Relationship between design pressure, wall thickness and safety factors.

The equation that relates design pressure to wall thickness can be derived by performing a force balance on a pipe segment under a specified design pressure

Force F_1 that is exerted on the pipe wall due to the design pressure is

$$F_1 = \Pi \; x \; D_o \; x \; L \; x \; P_{design.} \quad - \quad - \quad - \quad - \quad - \quad - \quad \text{-B.10}$$

Force F_2 is the pipeline specified minimum yield strength over the specified thickness.

$$F_2 = (\Pi D_0 L - \Pi D_1 L) \quad - \quad - \quad - \quad - \quad - \quad - \quad \text{-B.11}$$

$$F_2 = S(\Pi \; (D_1 + 2t)L - \Pi D_1 L)$$

after simplifications

$F_2 = 2\Pi LSt$

to balance the forces $F_1 = F_2$ or

$\Pi D_0 L P_{design} = 2\Pi LSt$

which gives P_{design} as:

$P_{design} = 2St/D_o$

in this equation

P_{design} = pipeline design pressure, Psia.

S = Specified minimum yield strength of the pipe, psia.

t = pipeline thickness, inches.

D_o = pipeline outside diameter, inches

The design pressure for a given wall thickness, also called basic hoop stress formula, considering all these safety factors, will then be determined by

$$P_{design} = \frac{2St \times F \times L \times J \times T}{D_o} \quad \text{- - - - - -B.11}$$

Where

F = design factor

L = Location factor

J = Joint factor

T = temperature correction factor or temperature derating factor.

These factors (F = design factor, L = Location factor, J = Joint factor, T = temperature correction factor or temperature derating factor) lower the allowable operating pressure.

Construction Factors (*F*) used in this equation are designated in USA standard B 31-8, code for pressure piping, Gas Transmission and Distribution piping systems for areas:

I Type A Construction: is that done in class 1 locations which include wastelands, deserts, rugged mountains, farmlands and similar areas. The factor for designing steel pipelines for these areas is 0.72

II Type B Construction, class 2 locations, includes fringe area around cities or towns, and farm or industrial areas with a specified population density. This class is between class 1 and class 3 locations, and the construction type factor is 0.60.

III Type C Construction, class 3 locations includes areas subdivided for residential or commercial purposes with a specified building density of a specified type. The construction type factor is 0.50.

IV Type D Construction, class 4 locations includes areas where multistory buildings are prevalent, where traffic is dense or where there are numerous underground utilities. The type D construction Factor is 0.40.

Construction type factors are also specified in pipeline codes for pipe that crosses or runs parallel to roads and railroads.

The effect of the construction type factor is to lower the allowable operating pressure for a given size, weight and grade of pipe as the construction is becomes more populated and the failure of pipe line would be more serious. The other two factors in the design pressure formula also derate the allowance operating pressure, providing an additional safety margin. The longitudinal joint factor varies with the type of joint used in manufacturing the pipe, for seamless pipe and some longitudinally welded

pipe, the factor is 1. There is no longitudinal joint in seamless pipe; it is essentially a hoop. A factor of 1 permitted when using some longitudinally welded pipe means the weld is as strong as a seamless pipe. When pipe is manufactured by other longitudinal welding methods, however, a factor of 0.6, or 0.8, must be used to calculate maximum allowable operating pressure.

The temperature derating factor T_1 for steel pipe varies from 1 for operating temperatures of 250^{O}F or less or 0.867 for an operating temperature of 450^{O}F.

There are other specifications and limits that may apply to pipeline pressures. Limits on operating pressure may be set by the fluid being transported. For example L-P gas and natural gas liquids pipelines must be operated at pressures above the vapor pressure of the fluid. At ambient temperature the yield stress used in the minimum wall design equation is the minimum value of the material's yield stress obtained from the pipe material specification.

Table B.1: Example of longitudinal weld joint factor (ASME 313 to 8)

Material	Pipe Class	E
ASTM A53, A106	Seamless	1.0
ASTM A53	ERW	1.0
ASTM A134	Furnace Butt Welder	0.6
ASTM A134	Electric fusion Arc Welding	0.8
ASTM A135	Electric Resistance Welding (ERW)	1.0
API 5L	Seamless	1.0
API 5L	Submerged Arc welding or ERW	1.0
API 5L	Furnace butt welded	0.6

Location design factor [ASME B31.85]

Location	F
Class 1 Div 1: Deserts, farmland, Sparsely populated	0.8
Class 1 Div 2: Class 1, with line tested to 110% design	0.72
Class 2: Industrial areas, town fringes, ranch etc	0.6
Class 3: Suburban housing, Shopping centers etc.	0.5
Class 4: Multistory buildings, heavy traffic etc	0.4

Note: lower location design factors apply at crossing, compressor stations, etc. The pipe line designer must refer to codes and regulations for the applicable location design factor.

Table B.2: Temperature deration factor [B31.8]

Tempt ^{0}F	T
250 or less	1.0
300	0.967
350	0.933
400	0.9
450	0.867

The weld quality or joint efficiency factor E is a factor introduced to account for the quality of the longitudinal or spiral seam in a pipe. It is a function of the reliability and quality of fabrication and the extent of inspections performed in the pipe mill. An electric resistance welded pipe is fudged to have a superior seam quality, and to weld joint factor is assigned the maximum value 1.0. On the other hand; the seam weld of a

furnace butt-welded pipe was judged to have a seam weld factor of only 0.6 (Mohitpour *et al* 2003).

B.3.2 Minimum handling thickness

Pipe wall must be thick enough to resist damage and maintain roundness during construction handling and welding. Other factors affect pipe wall thickness, but for line sizing suggested minimum thicknesses are as follows:

Table B.3: Minimum handling thickness

NPS	Min.Wall, in
4 – 12	0.188
14 – 24	0.219
26 – 30	0.250
30 – 36	0.281
36 – 40	0.312
42 – 48	0.375

B.3.3 Other pressure level factors

Mechanical limits on pump discharge pressures and ratings for valves and flanges also influence maximum design pressure levels for the pipeline. Maximum Operating Pressure (MOP) ratings for carbon steel pipeline valves conforming to API Spec 6D and valves and flanges conforming to ANSI Standards B16.34 and B16.5 often

determine maximum pressure for pipeline design. Although valves and flanges do not usually comprise a significant portion of the system cost, going to the next higher rating to provide for only a slight increase in line pressures would not be incrementally economic.

Section 402.2.1 of Code B31.4 states that pressure ratings shall conform to ratings at 100^{o}F in the material standards. Accordingly, MOP's for valves and flanges are as follows:

Table B.4: Maximum operating pressures for valves and flanges

Class	Valves API 6D MOP, psi	Flanges ANSI B16.34 ANSI B16.5 MOP, psi
300	720	740
600	1440	1480
900	2160	2220
1500	3600	3705

B.4 Hydraulic profiles and pump station locations

Refer to 400 Design Pipeline Manual, Chevron corporation (1999).

B.5 Cost estimates

There are two Cost estimates The Investment costs and Operation costs

B.5.1 Order-of-Magnitude Estimates for Investment Costs

For line sizing, order-of-magnitude investment cost estimates are necessary for the overall systems, alternative line sizes and, possibly, alternative routes.

Costs that are functions of pipe size, number of pump stations and installed pumping horsepower are more important than costs that are essentially independent of line size. Cost analysis may also be required for selection of route alternatives, involving costs that are functions of line length, terrain, permitting and right-of-way problems, line access, construction damages, etc.

Line sizing estimates should focus on the elements of cost that constitute the bulk of the investment cost differentials for the alternatives under consideration. Usually the pipeline itself represents 75% to 85% of the investment, and pump stations, terminals, etc., account for the balance. Consequently, a substantial error in estimating the cost of pump stations will have a minor effect on the overall estimate.

The two major elements in the cost of a pipeline are the cost of the pipe and the cost of construction. The cost of the pipe can generally be determined easily and quickly; therefore, the major portion of the time available should be directed toward developing a construction cost.

i. Pipe Cost

The cost of the pipe generally represents 25% to 50% of the total line cost, and the use of a reliable cost will go a long way toward assuring a realistic total estimate. Experience has shown that market fluctuations make it risky to use pipe costs from previous jobs and escalate them by an index.

ii. Coatings

Reference should be made to Section 340 to Section 920 of Design Pipeline Manual, Chevron corporation (1999), and to the Coatings Manual for full descriptions of these coatings.

iii. Miscellaneous Materials

Block valve installations, scraper traps, cathodic protection equipment, line markers, casing pipe and other items of material may be required. It is generally accurate enough to estimate all these items together as a percentage of pipe cost. The figure should be at least 5%; for short lines or lines with an unusual number of appurtenances the figure can be as high as 10%.

iv. Taxes and Duties

Applicable sales or use taxes must be determined and included as a part of the material cost. In addition, foreign projects generally entail added costs for import duties, permits and custom clearances. This can be a very significant item.

v. Pipeline Construction

A realistic estimate of the construction cost requires judgment in evaluating such factors as terrain, weather, availability of labor and competent welders, access, and remoteness from living and service facilities. In preparing an order-of-magnitude estimate it is not possible to evaluate these individually, but their composite effect on costs must be appraised.

The basic construction cost covers clearing and grading, stringing pipe, ditching, welding, application of coating as required for the particular coating system, lowering, backfilling, cleanup and testing. It is generally estimated on the basis of dollars per linear foot. Unit construction costs for many existing pipelines are available from various sources, such as Company project cost statements and magazines such as the Oil and Gas Journal which publish data on pipeline projects.

vi. Pipeline Technical Services

Pipeline technical services include the following:

• Project management

• Design engineering and drafting

• Services for purchasing, inspection and expediting, governmental and public relations, etc.

• Outside specialist technical services for environmental surveys; geophysical, geotechnical, hydrographic, hydrological and meteorological surveys; radiographic inspection; etc.

• Route and land surveys, including aerial photography

• Field supervision and inspection, including travel and living expenses.

For order-of-magnitude estimates it suffices to lump all these technical services together and estimate their total cost as a percentage of total pipeline material and construction costs. The percentage will generally be 5% to 20% depending on the size and complexity of the pipeline. Experience on past Company jobs should be used as a guide in determining the percentage to use.

vii. Permitting, Right-of-Way and Land Acquisition

Permits and rights-of-way are needed for the pipeline, and land must be acquired for stations and similar facilities. These costs are usually very difficult to estimate, and all available sources should be consulted— past projects, published data, and, above all, Company land specialists and local operating organizations. Charges and expenses for agents and personnel involved in developing land information and acquiring rights-of-way and land are included in acquisition costs. For order-of magnitude estimates, permitting and right-of-way acquisition costs are usually estimated in dollars per mile, and land for station and similar facilities in dollars per acre.

viii. Construction Damages and Restoration

Construction damages pertain to the present use of the land, and the extent to which construction will damage crops or developments. Although route restoration, such as revegetation, is considered as a pipeline construction cost, the extent and type of restoration is usually determined by the special conditions of the permits and rights-of-way. Costs for construction damages and restoration are usually estimated in dollars per mile for the specific sections of line affected.

ix. Pump Stations/Compressor Station

For the preliminary estimate, four major decisions must be made regarding pump stations:

• Type of pump.

• Type of driver.

• Type of operation.

• Amount of standby capacity.

• Fixed cost.

• Variable cost.

• Technical services.

x. Other System Facilities

Pipeline system facility costs not required for line sizing include the following:

• Supervisory control and data acquisition (SCADA) facilities and associated metering, instrumentation, and control facilities

• Communications

• Station tankage

• Cathodic Protection

xi. Contingency, Escalation

Contingencies must be provided for, including costs which have been overlooked and factors contributing to cost that have not been realistically evaluated. The percentage allowed for contingencies depends on the time available to prepare the estimate and the confidence in the figures developed. The minimum contingency should be 10%, although 15% is normally used and a higher figure may be appropriate.

If the pipeline is an unusually large project, requiring two or three years to design and construct, an allowance for future escalation should be included. If no escalation is included, this should be clearly stated in the estimate.

B.5.2 Order-of-Magnitude Estimates for Operating Costs

The operating cost component most important for comparing alternatives in line sizing is the electric power or fuel required for pumping. Reduction in total pumping horsepower and, possibly, the number of stations, form the basis for justifying a larger line.

Other operating costs, significant for comprehensive economic analysis but not for line sizing analysis, include the following:

• Direct labor for station operation

• Pipeline maintenance supplies, labor, and equipment

• Pump station and terminal maintenance supplies, labor, and equipment

• Property taxes

• Management and administration

• Services, such as communications

B.6 Economic Analyses for Line Sizing

The objective of an economic analysis for line sizing is to establish the comparative attractiveness of different line sizes. Usually the system with the smallest feasible line size requires the smallest investment. The first alternative that should be analyzed is the system with the next larger line size, which costs more to build but less to operate for a given throughput.

This analysis can be repeated for successive line sizes until the ROR no longer justifies the incremental investment.

B.7 Improving cost estimates

This section recommends additional design and estimating work useful in upgrading order-of-magnitude estimates and making designs final. See also the design development guidelines contained in other sections of this manual.

B.8 Route and profile

It has been established from experience that the type of route chosen for a particular pipeline design/construction is largely/entirely responsible for total cost of the project.

Route selection therefore is among if not the main item that can be used for improving cost estimate.

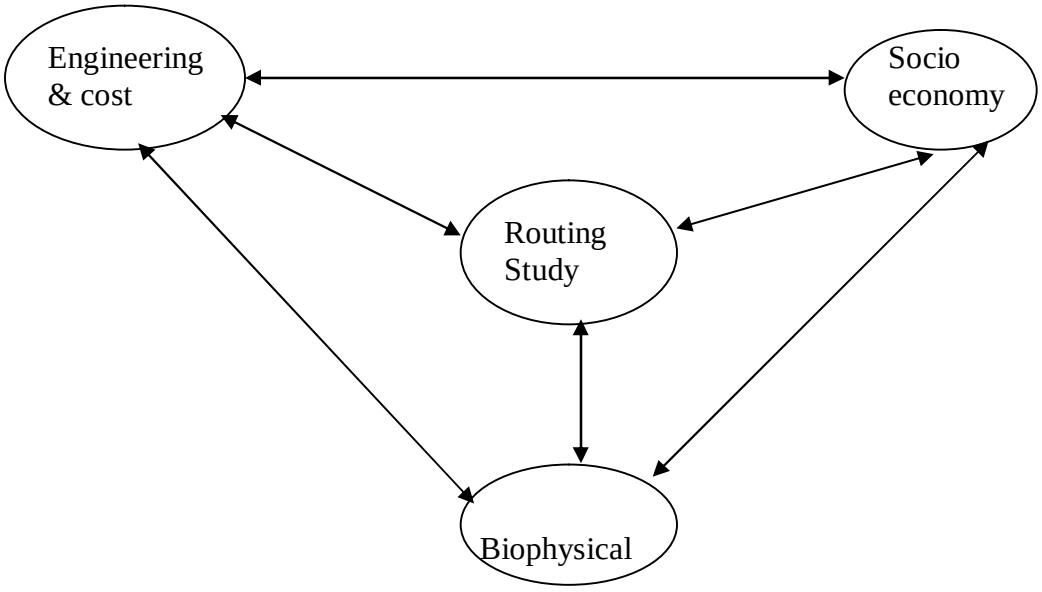


Figure B.1: Major considerations during all phases of Route Selection (Passey and wooley, 1980).

The preliminary route selection involves planning the route on available maps or photo mosaics in the office. The office work is followed by a field reconnaissance to verify the acceptability of the route. Mohitpour *et al* (2003).

B.9 Pipeline routing using GIS

Pipeline Routing using GIS can be used for the purpose of preliminary assessment and for further analysis during any pipeline project it will give engineers and surveyors a first hand information on possibilities available during the design and preliminary costing.

What is GIS (Geographical Information System)

According to the International GIS Dictionary, GIS is a "computer system for capturing, managing, integrating, manipulating, analyzing and displaying data which is spatially referenced to the Earth" (McDonnell & Kemp, 1995).

GIS draws on several related disciplines. What distinguishes GIS from other forms of information systems, such as databases and spreadsheets, is that GIS deals with spatial information. GIS has the capability to relate layers of data for the same points in space, combining, analyzing and, finally, mapping out the results. Spatial information uses location, within a coordinate system, as its reference base. The most common representation of spatial information is a map on which the location of any point could be given using latitude and longitude, or local grid references such as the National Grid.

Some applications of GIS are obvious, for example water supply companies use GIS as a spatial database of pipes and manholes; local governments can use GIS to manage and update property boundaries, emergency operations and environmental resources. GIS may also be used to map out the provision of services, such as health care and primary education, taking into account population distribution and access to facilities. Increasingly, GIS is being used to assist businesses in identifying their potential markets and maintaining a spatial database of their customers.

In broad terms, a Geographic Information System could be defined as a set of principles and techniques employed to achieve one (or both) of the following objectives:

- Finding suitable locations that have the relevant attributes. For example, finding a suitable location where an airport, a commercial forest or a retail outlet can be established. This is usually achieved through the use of Boolean (logical) operations.
- Querying the geographical attributes of a specified location. For example, examining the roads in a particular locality, to check road density or find the shortest path, and so on. This is often achieved by 'clicking' onto the location or object of interest, and examining the contents of the database for that location or object.

GIS data are usually stored in more than one layer in order to overcome the technical problems caused by handling very large amounts of information at once. It is easier to work with complex spatial problems one layer at a time, to enable the revision of the

data without having to overhaul the entire information system. This is a fundamental aspect of GIS, and working with layers of geographical information is known as data integration. For example, a comprehensive GIS of an LGA might consist of several layers of data:

- layer 1 property boundaries and land use types (as area maps)
- layer 2 road and railway networks (as line maps)
- layer 3 terrain characteristics (as spot-height or contour maps)
- layer 4 hospital and school locations (as point maps)

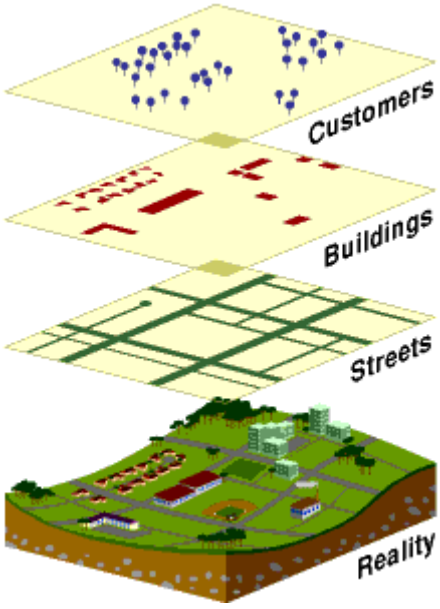


Figure B.2: Layers of GIS.

Spatial data may be represented in GIS in one (or both) of the two following formats:

- Vector model, as geometric objects: points, lines, polygons.
- Raster model, as image files composed of grid-cells known as pixels.

The importance of geospatial data

The nature of any natural or economic activity with a spatial dimension cannot be properly understood without reference to its spatial qualities. Spatial data have two essential parts: location and attributes.

- A GIS requires locational references. Typical locational references are latitude and longitude and national grid references such as the National Grid. However, other geospatial codes can also be used to identify location, such as postcodes.
- Attributes. Any locality would have a number of characteristics or properties associated with it. These attributes are usually kept in tables, containing such information as vegetation types, population, annual income, and so on.

GIS systems store and process data in two formats, vector and raster.

In the vector data model, the world is represented as a mosaic of interconnecting lines and points representing the location and boundaries of geographical entities. In vector data models, the data are represented as:

- arcs (lines)
- polygons (traversed areas)
- points (labelled nodes)
- nodes (intersection points)

The raster (or grid-cell) data model has come out of aerial and satellite imaging technology, which represents geographical objects as grid-cell structures known as pixels.

Each data model has particular strengths and weaknesses, and the type of model used is determined by the nature of the work being undertaken and the data available.

The main advantage of the vector data format is that it allows precise representation of points, boundaries, and linear features. This makes it particularly useful for analysis tasks that require accurate positioning, for example in engineering or cadastral boundary databases. It is also possible in a vector-based GIS to define the spatial relationship (ie the connectivity and adjacency) between coverage features. This aspect of GIS is known as topology, and is important for such purposes as network analysis (for example to find an optimal path between two nodes in a complex transport network). By contrast, raster-based GIS defines the position of features in terms of x,y coordinates where topological associations are more difficult to represent. However, the main disadvantage of vector data is that the boundaries of the resulting map polygons are discrete (enclosed by well-defined boundary lines), whereas in reality the map polygons may represent continuous gradation or gradual change, as in soil maps.

Grid Data Models use a raster matrix (a grid of image cells) to represent information. Grid data are also known as raster data. The resolution (visual definition) of the raster depends on its pixel (cell) size. In other words, pixel resolution represents the size of the ground area covered by each pixel in the image. The smaller the cell size, the

higher the resolution. The raster data model is, therefore, good for representing indistinct boundaries, such as thematic information on soil types, soil moisture, vegetation, ground temperatures, and so on. Furthermore, as reconnaissance satellites and aerial surveys use raster-based scanners, the information (i.e. scanned images) can be directly incorporated into GIS programmes capable of working with raster data. However, the higher the grid resolution, the larger the data file is going to be. This is the main limitation of raster based GIS.

The question of which data model to use in GIS depends on the nature and objective of the GIS project. Primarily the model type will depend on the nature of the data. Issues of concern are the volume of the data generated, ease of analysis and accuracy. Generally, vector data sets are economical in terms of file size, and have a high level of positional precision, but are relatively difficult to use in mathematical computations. On the other hand, grid data sets tend to take up more file space and have a coarser resolution, but are easier to work with mathematically.

Table B.5: Geographical feature analysis

Geographical Feature	Data Collection Technic	Data Presentation Format
Transport networks	Land Surveys	Topographic Maps
Rock Types	Geological Mappings	Geology Maps
Agricultural Land-Use	Satellite Remote sensing	Hard-Copy and Digital Images
Urban Land-use	Aerial Photography	Aerial photography
Relief of Land	Satellite Altimetry	Digital Elevation Model
Population Characteristics	Census Programmes	Database tables
Ocean Temperatures	Automated Buoys with Global Positioning Systems.	Isotherm maps
Crime patterns	Police Recording	

Geospatial data processing

There are several techniques for processing and analyzing geospatial data in GIS, some of these are explained below.

i. Data capture

A GIS cannot analyze the information in a map, if the data are not already in digital form which the computer can recognize. Maps can be digitized (hand-traced with a computer mouse) to collect the coordinates of the map features. Electronic scanning devices can also be used to convert map lines and points to digital information.

ii. Information retrieval

With a GIS we can point at a location, object, or area on the screen and retrieve recorded information about it from the Database Management System (DBMS) which holds the information about the map's features.

iii. Spatial measurements

GIS makes spatial measurements easy to perform. Spatial measurements can be the distance between two points, the area of a polygon or the length of a line or boundary. Calculations can be of a simple nature, such as measuring areas on one map, or more complex, such as measuring overlapping areas on two or more maps.

vi. Overlays (data integration).

Overlaying is an important procedure in GIS analysis. Overlaying involves superimposing two or more map layers to produce a new map layer. Consider the following example: a new genetically engineered variety of wheat grows well in dry environments, with long growing seasons and alkaline soils. Given the availability of data on the length of the growing season, moisture regime and soil alkalinity, where is the best place to plant the wheat? The answer can be found by overlaying (superimposing) several maps showing (separately) water-budget, growing season length, soil pH, sodium content, and so on. The GIS analysis can establish the locations where all the favourable soil conditions coincide, as the places where the wheat will grow best.

v. Spatial interpolation.

A GIS can be used to estimate the characteristics of terrain or ecological conditions from a limited number of field measurements. For example, a rainfall map can be created from the interpolation of rainfall point measurements taken at a number of different locations on a map.

vi. Buffering and corridors.

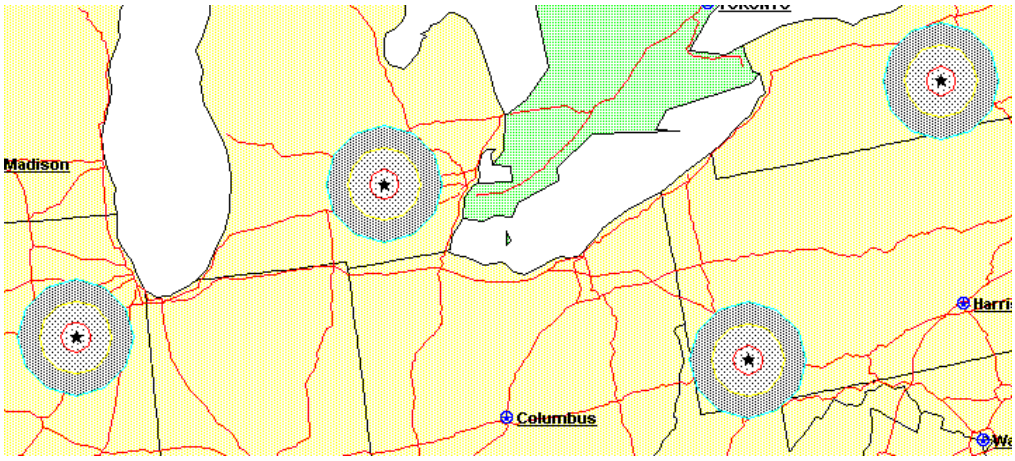


Figure B.3: Buffering and Corridors.

Buffers are used when distance from a point or line is important to measure. For example a classic use of GIS in earth sciences involves estimating the damage caused by an earthquake, in terms of distance belts away from the epicenter. If the influence of the earthquake is grouped into four classes then the buffers around the epicenter might look like a map of semi-concentric zones of earthquake damage.

vi. Network analysis.

GIS can handle complex network problems, such as road network analysis. A GIS can work out travel times and the shortest path from A to B. This facility can be built into more complicated models that might require estimates of travel time, accessibility or impedance along a route system. An example is how a road network can be used to calculate the risks of accidents. There are, of course, other types of network analysis, involving stream networks. For example, GIS could be used to

model the flow of water through a river system, to plan a flood warning system. Real time data would be transmitted by flood warning monitors, such as rain gauges and river height alarms, which could be received and passed to a GIS system to assess the hazard. If the amount and intensity of rain exceeds a certain limit, determined by the GIS flood model for the area, a flood protection plan could be put into operation with computer-generated maps demarcating the vulnerable areas at any point in time.

viii. Registration and warping.

Before they can be used in GIS, maps and images should be geometrically rectified. The process begins by registering the raw maps and images to known (control) coordinates. The registration record is then used to warp (or georectify) the map or image in need of rectification. The latter step is also known as rubber-sheeting.

ix. Map projection.

Map projection is a fundamental aspect of mapmaking. A map projection is essentially a geometric model that transforms the locations of features on the Earth's surface to corresponding locations on a two-dimensional map. It is impossible to project a spheroid perfectly onto a plane; but some projections can preserve shape, while others preserve area, distance, or direction. Different projections are used for different types of maps because each projection is particularly appropriate for certain uses. For example, a projection that preserves the shape of the continents may distort their relative size.

x. Digital terrain analysis.

GIS can build three dimensional models, where the topography of a geographical location can be represented with an x, y, z data model known as Digital Terrain (or Elevation) Model (DTM/DEM). The x and y dimensions of a DTM represent the horizontal plane, and z represents spot heights for the respective x, y coordinates. As illustrated in Figure 10, the data are represented by a DEM array (grid cells) or a Triangulated Irregular Network (TIN). The data sets derived from a Digital Terrain Model can be used to analyze environmental phenomena or engineering projects that are influenced by elevation, aspect or slope, as in forestry and stream sedimentation studies. The visualization (display) power of the computer allows the terrain data to be visualized in three dimensional form, often from any angle of view (this is known as point-of-view analysis). For example, using a DTM, civil engineers can assess how well a new structure (say, an open-cast mine) is screened by the surrounding terrain, and estimate how much additional screening might be needed to conceal the structure or reduce noise levels.

Applications of GIS

The ability of a GIS to capture, store and process geographical data in an integrated environment makes it an ideal tool for practitioners, in a wide range of fields, seeking to address complex issues, questions and problems found in the environment. The range of problems to which GIS is presently deployed demonstrates the significance of this technology in contemporary society.

GIS is now routinely used by government departments, local authorities, commercial organizations and environmental groups for an enormous range of tasks. These include land-use planning, market analysis, industrial development, management of emergency services, transport planning, environmental impact assessment and wildlife conservation. Whether the concern is the siting of a new out of town supermarket, the routing of a controversial rail link, examining the social and economic characteristics of the population within an hours drive of a new theme park or identifying clusters of disease incidents GIS now provides the ability to integrate information, solve problems, develop effective solutions and visualize scenarios in a way that was simply not possible even a decade ago.

Global Positioning System (GPS) and GIS

GPS is a system of Earth-orbiting satellites, each providing precise time and position information which enables GPS receiving devices to compute positions on the Earth. Signals must be received from at least three satellites in order to establish the receiver's position in latitude and longitude (or a national coordinate system provided with the equipment). Measurement from a fourth satellite is required to calculate altitude (height) position.

GPS configuration consists of three parts:

- Twenty four US Navy satellites orbiting the earth.
- Portable mobile receiver (aerial plus portable console).

- Base station receiver positioned at a known geographic position, in order to perform differential correction of the raw satellite signals.

Each satellite in orbit carries a computer and an accurate (atomic) clock. The computer onboard calculates the satellite's orbit a week or so into the future, predicts ionospheric conditions over that period. By consulting its clock and computer-generated data, the satellite can tell where it is in the sky at any given microsecond, and transmits its position and the current time continuously.

Mobile GPS receivers in the filed do not provide accurate readings of position. The reason for this apparent inaccuracy is due to US. The satellites are programmed to 'dither' the transmitted values of their clock and locational data. This is done mainly to prevent a foreign military power from using the GPS for hostile purposes.

Therefore, where greater positional accuracy is required, the underlying carrier wave of the signals can be analyzed after capture, and compared with signals received simultaneously at a control ground station. The difference between these two sets of data yields more accurate information. This procedure is known as differential correction.

Remote Sensing and GIS

Remote sensing is the study of phenomena sensed from air or satellites. The use of remote sensing provides scientists with an opportunity to interpret data as seen from space. This facility is particularly useful in surveying very large areas at relatively little cost. Remote sensing is therefore widely used in such locations as the arctic

zones, deserts, forested areas, marshlands and mountainous regions, where small-scale maps of an adequate quality can be reproduced relatively cheaply from satellite images. In general, remote sensing is suitable for studying extensive areas with difficult or inhospitable terrain, or where conventional surveys may be very costly.

Satellite and aerial remote sensing provide an almost infinite pool of information. They provide the experienced interpreter with knowledge of ground conditions, including geomorphology, vegetation, soils and mineral composition. A great deal of time and cost can be saved, through remote sensing, by reducing the necessary amount of field work. Taken at regular intervals and over a long period of time, satellite remote sensing can also help scientists to identify the extent of change in ground conditions over the seasons, such as seasonal soil moisture changes. This is particularly useful in mapping areas that witness frequent changes in land cover, like agricultural lands, tidal areas and marshlands.

Stereoscopy (three dimensional view), which is important for such purposes as topographic and forest canopy studies, is possible through remotely sensed images. Stereoscopy is made possible by the overlap of adjacent images (neighboring images which cover common areas). This can be achieved through the overlap of orbit paths, or the tilting of the sensor to get a sideways view of adjacent areas. Images taken by the French satellite SPOT, for example, are especially popular with land resource scientists using remote sensing techniques, because they combine fairly high resolution (maximum 10 meters) with some overlap.

Visible light (the colors sensed by our eyes) constitutes only a narrow band (wavelength range) within the vast electromagnetic spectrum. One distinct advantage of remote sensing is that it offers the opportunity to use many *invisible* bands outside the spectrum of visible light. There are many natural phenomena which could only be sensed from distance by using invisible bands in the electromagnetic spectrum. For example, satellites can identify geothermal reserves close to the earth's surface by sensing the heat emanating from such spots. The procedure is similar, in principle, to the use of infrared (night-vision) security cameras to detect intruders in the dark. The results of sensing invisible phenomena can be developed for human use by assigning false colors to the picture (or false grey shades in black-and-white prints).

In land use applications, several bands of the electromagnetic spectrum are often used to sense the same place at once. This is useful because each band is especially sensitive to a given phenomenon: showing vegetation boundaries in one case, soil-moisture differences in another, and so on. Therefore, by using multiband images, more information can be obtained as a result of having more color combinations available for analysis.

Sensors can be divided into two groups: passive and active. Passive sensing resembles the way our eyes operate, by detecting the radiation reflected by the sensed objects from the sun (or another source of illumination). Active sensing is achieved in the reverse manner: the energy is transmitted by the sensor itself, bounces back on impact with the object, giving a 'backscatter' echo which is registered by the sensor.

In remote sensing, microwave radar (Radio Detection and Ranging) operates by active sensing.

Because of Radar's ability to penetrate clouds, water, snow and (thin) vegetation, a radar image offers the possibility of obtaining a view of the examined phenomena through such obstacles. The technique is especially suitable for surveying areas with frequent cloud cover or under grass.

Radar is also very useful because it accentuates surface roughness on remote sensing images. This occurs because *relative* height increases when the wavelength of the sensing radiation becomes longer. Relative height also increases when the angle of incidence (the degree of camera tilt from vertical position) is widened. To the soil scientist, this facility can be very useful when studying such phenomena as stoniness where relative height must be accentuated in order to improve detection. An image of a stony soil surface, taken by a side-looking radar sensor, can show a distinctly mottled texture.

Before any remote sensing image can be made available for mapping, it must be cleared of errors caused by geometric displacement or atmospheric interference. The common sources of error in satellite imagery are:

- orbit and flight errors,
- earth curvature,
- earth rotation and
- rough terrain

- atmospheric interference (cloud, fog and smog).

However, image correction is not generally recommended in soil and vegetation inventories, because it may give false data (as image corrections usually involve pixel-value manipulations).

Images marred by significant interference from atmospheric phenomena (such as clouds) should be avoided. Atmospheric errors are especially difficult to correct, because guess work is often inevitable. Similarly, images marred by 'noise' (communication errors, which occur during the transmission of images from satellites to the receiving stations) should also be avoided.

Digital correction of image errors is made possible by computerized image processing techniques. Remote sensing images are normally kept in digitized form (recorded in binary code). Correcting the geometric errors of individual images is usually undertaken by giving the computer the correct coordinates of a number of control points (points whose position is known exactly) on each image. The image is then automatically stretched (rescaled and rotated) to produce a geographically-correct image map.

B.10 Pipeline routing criteria

The routes are made as straight and as near to roads as possible with fewest intersections with natural and artificial obstacles, this is to reduce cost. If it is difficult to meet all these requirements, several variants are considered and the best chosen on its technical and economic merits.

The factors influencing pipeline route selection are technical and engineering requirements, environmental considerations and population density. However, these factors are chosen to balance engineering and construction costs against environmental costs and future liability (Montemurro and Gale,1996).

The above considerations can be found in detail under “Route and Profile” above.

The engineering and technical considerations used in this research include pipeline length, topography, surface geology, river and wetland crossings, road and railroad crossings and the proximity to large population centers.

High relief terrain would result in higher construction costs and increase the need for pump stations Hicken and Krumbach (1998).

B.11 Gas compressor stations

Compressor stations equipped with reciprocating, centrifugal or rotary compressors driven by gas engines, gas turbines or electric motors are required to compress the gas, compression is necessary for transmission, storage, treatment or utilization of gas. Vacuum compressor stations, which are used to collect casing head gas, operate at an intake pressure below atmospheric.

Reciprocating compressors characterized by high efficiency and affording unlimited possibilities for increasing gas pressure, are the most widely used by the gas industry.

Detailed information on Gas Compressor Stations can be obtained from Muravyov (1962).

B.12 Gas storage

Domestic gas consumption is subject to strong fluctuations. At certain period, gas consumption sharply increases. Such peaks occur during winter, in the day time, on Saturdays, Sundays and on holidays. In summer, and at night, gas consumption declines to a minimum.

Since the gas is delivered at a uniform rate, storage capacity must be provided to meet the peaks in gas demand Gas is stored in gas holders during periods of low consumption and is consumed during peak hours (Muravyov 1962).

The following types of gas storage facilities are used:

i. Vertical or horizontal cylindrical or spherical goo-holders of constant volume and variable pressure.
ii. dry or wet gas holders of variable volume at constant pressure;
iii. gas pipelines with variable operating pressure in which a certain amount of compressed gas can be stored;
iv. high pressure tubular gas holders
v. metal surface storage tanks for liquefied gas (cylindrical or spherical);
vi. special stores in which the gas is held in sorbent, solutions or in the form of hydrates;
vii. natural underground reservoirs.

B.13 Utilization of natural gas in Nigeria

The expected growth rate of natural gas in the energy mix of industrialized countries which in itself guarantees a demand for gas from developing economies with abundant reserves, further emphasize the need to pay more attention to the establishment of the necessary structures for gas development especially in Nigeria.

It is in recognition of the global development the industry that may have informed the Federal Government of Nigeria to hinge its future export earnings on such gas related projects as;

- Liquefied Natural Gas (LNG)
- Eleme Petrochemicals
- National Fertilizer Plants at Onne
- The OSO Gas Condensates
- The Aluminium Smelting Plant Project at Ikot-Abasi
- GTL Gas-to-Liquid.
- West African Gas pipeline project.
- Methanol.
- Trans Sahara Gas pipeline project.

B.14 Nigeria Gas Company Limited (NGC)

Consequently, government is making concerted efforts to diversify the investment base and emphasize the role natural gas can play in the economy. It is this new awareness of gas development that led to the creation of the NIGERIA GAS COMPANY LIMITED (NGC), in 1988 by government as a subsidiary of the NNPC.

The primary objective of this company is to develop an efficient gas industry capable of serving the domestic energy and feedstock markets of the country and establish presence in the international energy markets particularly the West African sub-region through the export of gas and its derivatives.

B.15 Gas industry in Nigeria today

Table B.6: Existing gas supply systems

S/N	Gas Supply System	Gas Consumers	Pipeline Length (km)	Line Diameter (Inches)	Design Capacity (MMSCFD)
1	Aladja gas pipeline system	Gas consumers	130	6,8,14, & 18	70
2	Oben-Ajaokuta gas pipeline	Ajaokuta steel plant	198	24	200
3.	Sapele system	NEPA (PHCN) Power station	44	10 & 18	200
4.	Obiubo north-Afam	NEPA (PHCN) Afam	28	12	35
5.	Imor river-Aba	IGI, PZ, ABATEX Aba, EQUITABLE			
6.	Alakiri-Owne	NAFLOW, Onne	17	14	90
7	Escravos-Lagos pipeline (ELP) and the spur lines	NEPA (PHCN) Egbin spur, NEPA (PHCN) Delta iv spur, Ughelli warri refinery, WAPCO Ewe koro, WAPCO Shagamu, Ikeja city gate/Otta/OGBARAPE Industries, Ikorodu Edjeba and Ogunu housing estate.	16, 4, 1, 27, 15, 15, 13-5 and 13 respectively		
8	Alakiri Obigbo north Ikot Abasi	Aluminium Smelting Company (ALSCON)	117	14,16 & 24	450

Table B.7: On going and proposed gas supply projects

S/N	Pipeline system	Gas consumers	Pipeline length in (km)	Line diameter (inch)	Design Capacity (MMSCFID)
1	Ajaukuta Geregu Abuja/Kaduna	NEPA (PHCN) and Industrial Consumers	480	14" 20"/36"	1000
2.	Ikorodu spur	Spintex, Ital Tile & Other Indust.	13.5	4"	10.0
3.	Eyan Spur	Industries in Benin	3	4"	3.0
4.	OTTA, OGBARA & ECOWAS	OTTA, OGBARA & ECOWAS	50	20"/24"	300
5.	Iwopin Spur	Nigerian News-Print Man. Co (NNPMC)	30	8"	15.0
6.	Athena Invest Lapeleke	Brick Industry	2	4"	5.0
7.	PRESCO Industries	Agric Industry	2.	4"	3.0
8	OSUBI Airport	SPDC	1	4"	2.5

B.16 Various uses of natural gas

Natural gas could be put into various uses. These include among others;

i. Power Generation

ii.. Industrial Fuel

iii. Chemicals

iv. Metallurgical

v. Agricultural/Food Processing.

vi. Domestic

vii. Automotive Fuel

B.17 Investment opportunities

The gas industry in Nigeria could be classified into four phases viz: Production, Transmission and Distribution, each with its own inherent opportunities for would investors.

i. Production.

ii. Transmission

iii. Distribution

iv. Downstream Gas Business

B.18 Prices of natural gas per 1000scf as sold by NGC as at April 2006

Ajaokuta, DSC, WRPC, and PHCN (NEPA) = N16.64k

NAFCON = 60 cent

WAPCO Ewekoro = N313.37

WAPCO Shagamu = N438.29

PZ = N410.90

Ejeba = N31.38

B.19 Safety

Principles of flammable gas detection

For each flammable gas or vapor only a certain range of concentrations of mixture with air can be caused to ignite. Above the Upper Explosive Limit (UEL) there is sufficient oxygen present, and below the Lower Explosive Limit (LEL) there is insufficient fuel.

These explosive (or flammable) limits are expressed as percentages by volume in air. Table 5 lists the these properties for gases more commonly found in oil and gas installations together with their densities relative to air. The latter figures indicate whether the gas is lighter or heavier than air, and therefore whether it is necessary to place a detector above or below a prospective source of leakages.

Table B.7: Explosive (or flammable) limits

Compound	Specific Gravity	LEL (%)	UEL (%)
Hydrogen	0.07	4.0	75.6
Methane	0.55	5.0	15.0
Ethane	1.04	3.0	15.5
Propane	1.56	2.0	9.5
Butane	2.05	1.5	8.5
Pentane	2.48	1.4	8.0
Hexane	2.79	1.7	7.4
Heptane	3.46	1.1	6.7

Techniques for detection

Many different means have been employed to determine the concentration of gas mixtures with air. These have relied on physical principles such as thermal conductivity, diffusion and absorption of infra-red radiation.

The principle used most in the oil industry is that of Catalytic Oxidation. The gas-air mixture is caused to burn by being heated in the presence of a catalyst. The resultant heat produced is a measure of the gas concentration, and determined by detecting the rise in temperature.

In practice, a detector head contains two elements matched for electrical and thermal properties but only one being capable of catalytic action. The presence of the reference element compensates for changes in atmospheric temperature, and in the

voltage of the power supply. The elements in the detector head are arranged as two arms of a wheatstone bridge with the other two arms, together with power supply and meter located in an associated control unit.

Another detection based on infrared absorption called “infra-red absorption techniques” is also employed. The principle of these techniques is the property of all gases and vapors to absorb electromagnetic radiation in characteristic combination of narrow frequency bands.

Many frequency lines of infra-red radiation are absorbed by hydrocarbon gases, and by selection on a particular frequency a detector can be made which is either specific to unique gas or, if the frequency is common to several gas spectra, capable of detecting a particular group of gases.

APPENDIX C

Route profile Data table

Table C.1 Hydraulic profile data table from Ajaokuta to Kano

Eastings	Northings	Horizontal Distance Km	Elevation m
449007.0000	1319548.0000	1.0000	461
448287.0000	1318828.0000	2.0000	464
447567.0000	1318198.0000	3.0000	472
446847.0000	1317478.0000	4.0000	469
446037.0000	1316848.0000	5.0000	462
445317.0000	1316128.0000	6.0000	459
444597.0000	1315498.0000	7.0000	467
443877.0000	1314778.0000	8.0000	453
443157.0000	1314148.0000	9.0000	461
442437.0000	1313428.0000	10.0000	439
441627.0000	1312798.0000	11.0000	440
440907.0000	1312078.0000	12.0000	451
439467.0000	1310728.0000	13.0000	442
437937.0000	1309378.0000	14.0000	441
437217.0000	1308658.0000	15.0000	455
436497.0000	1308028.0000	16.0000	450
435777.0000	1307308.0000	17.0000	451
435057.0000	1306678.0000	18.0000	450
434337.0000	1305958.0000	19.0000	458
433527.0000	1305328.0000	20.0000	457
432807.0000	1304608.0000	21.0000	456
432087.0000	1303978.0000	22.0000	463

431367.0000	1303258.0000	23.0000	470
430647.0000	1302628.0000	24.0000	468
429837.0000	1301908.0000	25.0000	472
429117.0000	1301278.0000	26.0000	472
428397.0000	1300558.0000	27.0000	474
427677.0000	1299928.0000	28.0000	478
426957.0000	1299208.0000	29.0000	468
426237.0000	1298578.0000	30.0000	470
425427.0000	1297858.0000	31.0000	472
424707.0000	1297228.0000	32.0000	477
423987.0000	1296508.0000	33.0000	479
423267.0000	1295878.0000	34.0000	462
422547.0000	1295158.0000	35.0000	483
421737.0000	1294528.0000	36.0000	487
421017.0000	1293808.0000	37.0000	487
420297.0000	1293178.0000	38.0000	486
419577.0000	1292458.0000	39.0000	492
418857.0000	1291828.0000	40.0000	488
418137.0000	1291108.0000	41.0000	498
416607.0000	1289758.0000	42.0000	508
415167.0000	1288408.0000	43.0000	514
414447.0000	1287688.0000	44.0000	533
413637.0000	1287058.0000	45.0000	523
412917.0000	1286338.0000	46.0000	531
412197.0000	1285708.0000	47.0000	531
411477.0000	1284988.0000	48.0000	541
410757.0000	1284358.0000	49.0000	540
410037.0000	1283638.0000	50.0000	545

409227.0000	1283008.0000	51.0000	552
408507.0000	1282288.0000	52.0000	556
407787.0000	1281658.0000	53.0000	560
407067.0000	1280938.0000	54.0000	567
406347.0000	1280308.0000	55.0000	564
405537.0000	1279588.0000	56.0000	559
404817.0000	1278958.0000	57.0000	546
404097.0000	1278238.0000	58.0000	560
403377.0000	1277608.0000	59.0000	570
402657.0000	1276888.0000	60.0000	574
401937.0000	1276258.0000	61.0000	581
401127.0000	1275538.0000	62.0000	586
400407.0000	1274908.0000	63.0000	580
399687.0000	1274188.0000	64.0000	580
398967.0000	1273558.0000	65.0000	590
398247.0000	1272838.0000	66.0000	585
397437.0000	1272208.0000	67.0000	582
396717.0000	1271488.0000	68.0000	584
395997.0000	1270858.0000	69.0000	590
395277.0000	1270138.0000	70.0000	579
393747.0000	1268788.0000	71.0000	606
393027.0000	1268068.0000	72.0000	594
392307.0000	1267438.0000	73.0000	611
391587.0000	1266718.0000	74.0000	617
390867.0000	1266088.0000	75.0000	625
390147.0000	1265368.0000	76.0000	623
389337.0000	1264738.0000	77.0000	631
388617.0000	1264018.0000	78.0000	637

387897.0000	1263388.0000	79.0000	648
387177.0000	1262668.0000	80.0000	655
386457.0000	1262038.0000	81.0000	653
385647.0000	1261318.0000	82.0000	672
384927.0000	1260688.0000	83.0000	650
384207.0000	1259968.0000	84.0000	669
383487.0000	1259338.0000	85.0000	668
382767.0000	1258618.0000	86.0000	671
382047.0000	1257988.0000	87.0000	687
381237.0000	1257268.0000	88.0000	682
380517.0000	1256638.0000	89.0000	672
379797.0000	1255918.0000	90.0000	667
379077.0000	1255288.0000	91.0000	676
378357.0000	1254568.0000	92.0000	673
377547.0000	1253938.0000	93.0000	664
376827.0000	1253218.0000	94.0000	658
376107.0000	1252588.0000	95.0000	659
375387.0000	1251868.0000	96.0000	654
374667.0000	1251238.0000	97.0000	654
373947.0000	1250518.0000	98.0000	649
372417.0000	1249168.0000	99.0000	650
370977.0000	1247818.0000	100.0000	646
370257.0000	1247098.0000	101.0000	649
369447.0000	1246468.0000	102.0000	652
368727.0000	1245748.0000	103.0000	650
368007.0000	1245118.0000	104.0000	650
367287.0000	1244398.0000	105.0000	655
366567.0000	1243768.0000	106.0000	661

365847.0000	1243048.0000	107.0000	650
365037.0000	1242418.0000	108.0000	642
364317.0000	1241698.0000	109.0000	645
363597.0000	1241068.0000	110.0000	654
362877.0000	1240348.0000	111.0000	651
362157.0000	1239718.0000	112.0000	637
361347.0000	1238998.0000	113.0000	631
360627.0000	1238368.0000	114.0000	618
359907.0000	1237648.0000	115.0000	634
359187.0000	1237018.0000	116.0000	646
358467.0000	1236298.0000	117.0000	641
357747.0000	1235668.0000	118.0000	641
356937.0000	1234948.0000	119.0000	648
356217.0000	1234318.0000	120.0000	646
355497.0000	1233598.0000	121.0000	660
354777.0000	1232968.0000	122.0000	672
354057.0000	1232248.0000	123.0000	662
353877.0000	1231348.0000	124.0000	649
353697.0000	1230358.0000	125.0000	652
353607.0000	1229368.0000	126.0000	654
353337.0000	1228378.0000	127.0000	670
353157.0000	1227388.0000	128.0000	695
352977.0000	1226398.0000	129.0000	695
352797.0000	1225408.0000	130.0000	679
352527.0000	1224418.0000	131.0000	669
352347.0000	1223428.0000	132.0000	652
352167.0000	1222438.0000	133.0000	648
351987.0000	1221538.0000	134.0000	641

351717.0000	1220548.0000	135.0000	657
351537.0000	1219558.0000	136.0000	668
351357.0000	1218568.0000	137.0000	660
351177.0000	1217578.0000	138.0000	672
350907.0000	1216588.0000	139.0000	680
350727.0000	1215598.0000	140.0000	680
350547.0000	1214608.0000	141.0000	678
350097.0000	1212718.0000	142.0000	672
349917.0000	1211728.0000	143.0000	676
349647.0000	1210738.0000	144.0000	669
349467.0000	1209748.0000	145.0000	680
349197.0000	1208758.0000	146.0000	687
348927.0000	1207858.0000	147.0000	678
348747.0000	1206868.0000	148.0000	675
348477.0000	1205878.0000	149.0000	675
348297.0000	1204888.0000	150.0000	664
348027.0000	1203898.0000	151.0000	656
347577.0000	1202008.0000	152.0000	669
347307.0000	1201018.0000	153.0000	659
347127.0000	1200028.0000	154.0000	657
346857.0000	1199038.0000	155.0000	656
346587.0000	1198138.0000	156.0000	652
346407.0000	1197148.0000	157.0000	662
346137.0000	1196158.0000	158.0000	652
345867.0000	1195168.0000	159.0000	647
345417.0000	1193278.0000	160.0000	646
345147.0000	1192288.0000	161.0000	641
344877.0000	1191298.0000	162.0000	636

344337.0000	1189408.0000	163.0000	646
344157.0000	1188418.0000	164.0000	653
343887.0000	1187428.0000	165.0000	642
343347.0000	1185538.0000	166.0000	649
343167.0000	1184548.0000	167.0000	631
342897.0000	1183558.0000	168.0000	621
342627.0000	1182568.0000	169.0000	631
342357.0000	1181668.0000	170.0000	630
342087.0000	1180678.0000	171.0000	622
341907.0000	1179688.0000	172.0000	646
341637.0000	1178698.0000	173.0000	644
341367.0000	1177798.0000	174.0000	637
341187.0000	1176808.0000	175.0000	630
340917.0000	1175818.0000	176.0000	618
340737.0000	1174828.0000	177.0000	607
340467.0000	1173838.0000	178.0000	604
340197.0000	1172938.0000	179.0000	602
340017.0000	1171948.0000	180.0000	591
339747.0000	1170958.0000	181.0000	597
339567.0000	1169968.0000	182.0000	616
339297.0000	1168978.0000	183.0000	613
339027.0000	1168078.0000	184.0000	616
338847.0000	1167088.0000	185.0000	633
338577.0000	1166098.0000	186.0000	631
338307.0000	1165108.0000	187.0000	630
338127.0000	1164118.0000	188.0000	615
337857.0000	1163218.0000	189.0000	608
337677.0000	1162228.0000	190.0000	619

337407.0000	1161238.0000	191.0000	601
337137.0000	1160248.0000	192.0000	619
336957.0000	1159258.0000	193.0000	619
336687.0000	1158358.0000	194.0000	634
336507.0000	1157368.0000	195.0000	634
336237.0000	1156378.0000	196.0000	627
335967.0000	1155388.0000	197.0000	615
335787.0000	1154398.0000	198.0000	630
335517.0000	1153498.0000	199.0000	605
335337.0000	1152508.0000	200.0000	615
335067.0000	1151518.0000	201.0000	625
334797.0000	1150528.0000	202.0000	611
334527.0000	1149628.0000	203.0000	589
333897.0000	1148818.0000	204.0000	615
333267.0000	1148098.0000	205.0000	613
332637.0000	1147288.0000	206.0000	626
332007.0000	1146478.0000	207.0000	631
331377.0000	1145758.0000	208.0000	638
330747.0000	1144948.0000	209.0000	644
330117.0000	1144138.0000	210.0000	656
329487.0000	1143418.0000	211.0000	645
328857.0000	1142608.0000	212.0000	641
328227.0000	1141798.0000	213.0000	636
327597.0000	1141078.0000	214.0000	639
326967.0000	1140268.0000	215.0000	629
326337.0000	1139458.0000	216.0000	628
325707.0000	1138738.0000	217.0000	623
325077.0000	1137928.0000	218.0000	597

323817.0000	1136398.0000	219.0000	609
323187.0000	1135588.0000	220.0000	602
322557.0000	1134868.0000	221.0000	597
321927.0000	1134058.0000	222.0000	581
321297.0000	1133248.0000	223.0000	584
320667.0000	1132528.0000	224.0000	575
320037.0000	1131718.0000	225.0000	587
319497.0000	1130908.0000	226.0000	591
319047.0000	1130008.0000	227.0000	583
318327.0000	1128118.0000	228.0000	586
317967.0000	1127218.0000	229.0000	571
317607.0000	1126228.0000	230.0000	568
317247.0000	1125328.0000	231.0000	564
316887.0000	1124428.0000	232.0000	567
316527.0000	1123438.0000	233.0000	546
316167.0000	1122538.0000	234.0000	558
315807.0000	1121638.0000	235.0000	546
315447.0000	1120648.0000	236.0000	525
315087.0000	1119748.0000	237.0000	507
314727.0000	1118848.0000	238.0000	497
314367.0000	1117858.0000	239.0000	509
314007.0000	1116958.0000	240.0000	509
313647.0000	1116058.0000	241.0000	536
313287.0000	1115068.0000	242.0000	506
312927.0000	1114168.0000	243.0000	508
312567.0000	1113268.0000	244.0000	453
312207.0000	1112278.0000	245.0000	488
311847.0000	1111378.0000	246.0000	483

311577.0000	1110388.0000	247.0000	488
311217.0000	1109488.0000	248.0000	478
310857.0000	1108498.0000	249.0000	475
310587.0000	1107598.0000	250.0000	495
310227.0000	1106608.0000	251.0000	528
309867.0000	1105708.0000	252.0000	522
309597.0000	1104718.0000	253.0000	532
309237.0000	1103818.0000	254.0000	535
308967.0000	1102828.0000	255.0000	555
308607.0000	1101928.0000	256.0000	561
308247.0000	1100938.0000	257.0000	537
307977.0000	1100038.0000	258.0000	550
307617.0000	1099048.0000	259.0000	585
307347.0000	1098148.0000	260.0000	613
306987.0000	1097158.0000	261.0000	618
306627.0000	1096258.0000	262.0000	624
306357.0000	1095268.0000	263.0000	581
305997.0000	1094368.0000	264.0000	571
305637.0000	1093378.0000	265.0000	527
305007.0000	1091488.0000	266.0000	506
304377.0000	1089598.0000	267.0000	487
303747.0000	1087708.0000	268.0000	483
303117.0000	1085818.0000	269.0000	473
302757.0000	1084828.0000	270.0000	490
302397.0000	1083928.0000	271.0000	477
302127.0000	1082938.0000	272.0000	478
301767.0000	1082038.0000	273.0000	456
301497.0000	1081048.0000	274.0000	449

301137.0000	1080148.0000	275.0000	447
300777.0000	1079158.0000	276.0000	461
300507.0000	1078258.0000	277.0000	437
300147.0000	1077268.0000	278.0000	447
299787.0000	1076368.0000	279.0000	454
299067.0000	1074478.0000	280.0000	476
298707.0000	1073578.0000	281.0000	437
298347.0000	1072678.0000	282.0000	440
297987.0000	1071688.0000	283.0000	451
297537.0000	1070788.0000	284.0000	463
297177.0000	1069888.0000	285.0000	500
296817.0000	1068988.0000	286.0000	498
296367.0000	1067998.0000	287.0000	516
296007.0000	1067098.0000	288.0000	516
295647.0000	1066198.0000	289.0000	512
295287.0000	1065298.0000	290.0000	527
294837.0000	1064308.0000	291.0000	517
294477.0000	1063408.0000	292.0000	504
294117.0000	1062508.0000	293.0000	508
293757.0000	1061608.0000	294.0000	511
293307.0000	1060618.0000	295.0000	509
292947.0000	1059718.0000	296.0000	510
292587.0000	1058818.0000	297.0000	528
292227.0000	1057918.0000	298.0000	548
291777.0000	1056928.0000	299.0000	533
291417.0000	1056028.0000	300.0000	517
291147.0000	1055038.0000	301.0000	531
290967.0000	1054048.0000	302.0000	522

290607.0000	1052158.0000	303.0000	522
290427.0000	1051168.0000	304.0000	515
290247.0000	1050178.0000	305.0000	512
290067.0000	1049188.0000	306.0000	512
289887.0000	1048198.0000	307.0000	493
289707.0000	1047208.0000	308.0000	493
289527.0000	1046218.0000	309.0000	489
289257.0000	1045228.0000	310.0000	493
289257.0000	1044238.0000	311.0000	484
289257.0000	1043248.0000	312.0000	482
289167.0000	1042258.0000	313.0000	461
289167.0000	1041268.0000	314.0000	470
289167.0000	1040278.0000	315.0000	487
289077.0000	1039288.0000	316.0000	488
289077.0000	1038208.0000	317.0000	482
289077.0000	1037218.0000	318.0000	473
288987.0000	1036228.0000	319.0000	468
288987.0000	1035238.0000	320.0000	497
288987.0000	1034248.0000	321.0000	470
288897.0000	1033258.0000	322.0000	496
288897.0000	1032268.0000	323.0000	418
288897.0000	1031278.0000	324.0000	393
288807.0000	1030288.0000	325.0000	376
288807.0000	1028218.0000	326.0000	293
288717.0000	1027228.0000	327.0000	283
288717.0000	1026238.0000	328.0000	267
288717.0000	1025248.0000	329.0000	273
288627.0000	1024258.0000	330.0000	287

288627.0000	1023268.0000	331.0000	333
288627.0000	1022278.0000	332.0000	357
288537.0000	1021288.0000	333.0000	343
288537.0000	1020298.0000	334.0000	326
288447.0000	1019218.0000	335.0000	273
288447.0000	1018228.0000	336.0000	263
288447.0000	1017238.0000	337.0000	252
288357.0000	1016248.0000	338.0000	250
288357.0000	1015258.0000	339.0000	251
288357.0000	1014268.0000	340.0000	240
288267.0000	1013278.0000	341.0000	240
288267.0000	1012288.0000	342.0000	249
288267.0000	1011298.0000	343.0000	242
288177.0000	1009228.0000	344.0000	249
288177.0000	1008238.0000	345.0000	227
288087.0000	1007248.0000	346.0000	220
288087.0000	1006258.0000	347.0000	205
288087.0000	1005268.0000	348.0000	189
287997.0000	1004278.0000	349.0000	198
287997.0000	1003288.0000	350.0000	187
287997.0000	1002298.0000	351.0000	203
287907.0000	1001308.0000	352.0000	192
287907.0000	1000228.0000	353.0000	194
287907.0000	999238.0000	354.0000	196
287817.0000	998248.0000	355.0000	194
287817.0000	997258.0000	356.0000	188
287817.0000	996268.0000	357.0000	188
287727.0000	995278.0000	358.0000	194

287727.0000	994288.0000	359.0000	203
287727.0000	993298.0000	360.0000	198
287637.0000	992308.0000	361.0000	205
287637.0000	990238.0000	362.0000	208
287547.0000	989248.0000	363.0000	189
287547.0000	988258.0000	364.0000	182
287547.0000	987268.0000	365.0000	188
287457.0000	986278.0000	366.0000	174
287457.0000	985288.0000	367.0000	176
287457.0000	984298.0000	368.0000	174
287367.0000	983308.0000	369.0000	192
287367.0000	981238.0000	370.0000	202
287277.0000	980248.0000	371.0000	207
287277.0000	979258.0000	372.0000	206
287277.0000	978268.0000	373.0000	202
287187.0000	977278.0000	374.0000	199
287187.0000	976288.0000	375.0000	201
287187.0000	975298.0000	376.0000	198
287097.0000	974308.0000	377.0000	204
287097.0000	973318.0000	378.0000	229
287097.0000	972238.0000	379.0000	313
287007.0000	971248.0000	380.0000	363
287007.0000	970258.0000	381.0000	233
287007.0000	969268.0000	382.0000	253
286917.0000	968278.0000	383.0000	209
286917.0000	967288.0000	384.0000	201
286917.0000	966298.0000	385.0000	186
286827.0000	965308.0000	386.0000	180

286827.0000	964318.0000	387.0000	159
286737.0000	962248.0000	388.0000	181
286737.0000	961258.0000	389.0000	182
286647.0000	960268.0000	390.0000	194
286647.0000	959278.0000	391.0000	191
286647.0000	958288.0000	392.0000	185
286647.0000	957298.0000	393.0000	187
286647.0000	956308.0000	394.0000	180
286647.0000	955318.0000	395.0000	165
286557.0000	954328.0000	396.0000	152
286557.0000	953248.0000	397.0000	170
286557.0000	952258.0000	398.0000	196
286557.0000	951268.0000	399.0000	222
286557.0000	950278.0000	400.0000	236
286557.0000	949288.0000	401.0000	263
286557.0000	948298.0000	402.0000	317
286557.0000	947308.0000	403.0000	273
286557.0000	946318.0000	404.0000	296
286557.0000	945328.0000	405.0000	300
286467.0000	944248.0000	406.0000	274
286467.0000	943258.0000	407.0000	293
286467.0000	942268.0000	408.0000	308
286467.0000	941278.0000	409.0000	308
286467.0000	940288.0000	410.0000	315
286467.0000	939298.0000	411.0000	242
286467.0000	938308.0000	412.0000	234
286467.0000	937318.0000	413.0000	234
286467.0000	936328.0000	414.0000	183

286467.0000	935248.0000	415.0000	213
286377.0000	934258.0000	416.0000	212
286377.0000	933268.0000	417.0000	215
286377.0000	932278.0000	418.0000	197
286377.0000	931288.0000	419.0000	161
286377.0000	930298.0000	420.0000	177
286377.0000	929308.0000	421.0000	147
286377.0000	928318.0000	422.0000	111
286377.0000	927328.0000	423.0000	122
286377.0000	926248.0000	424.0000	172
286287.0000	925258.0000	425.0000	170
286287.0000	924268.0000	426.0000	179
286287.0000	923278.0000	427.0000	182
285657.0000	922648.0000	428.0000	215
284847.0000	921928.0000	429.0000	176
284127.0000	921298.0000	430.0000	191
283317.0000	920668.0000	431.0000	212
282597.0000	920038.0000	432.0000	221
281067.0000	918688.0000	433.0000	215
280257.0000	918058.0000	434.0000	194
279537.0000	917428.0000	435.0000	194
278727.0000	916798.0000	436.0000	203
277287.0000	915448.0000	437.0000	268
276477.0000	914818.0000	438.0000	252
275757.0000	914188.0000	439.0000	247
274947.0000	913558.0000	440.0000	236
274227.0000	912838.0000	441.0000	239
273417.0000	912208.0000	442.0000	203

272697.0000	911578.0000	443.0000	197
271887.0000	910948.0000	444.0000	210
271167.0000	910318.0000	445.0000	178
270357.0000	909598.0000	446.0000	219
269637.0000	908968.0000	447.0000	212
268827.0000	908338.0000	448.0000	221
268107.0000	907708.0000	449.0000	259
267387.0000	907078.0000	450.0000	259
266577.0000	906358.0000	451.0000	219
265857.0000	905728.0000	452.0000	219
265047.0000	905098.0000	453.0000	268
264327.0000	904468.0000	454.0000	257
263517.0000	903838.0000	455.0000	207
262707.0000	903298.0000	456.0000	153
261807.0000	902938.0000	457.0000	150
260817.0000	902488.0000	458.0000	198
259917.0000	902128.0000	459.0000	102
259017.0000	901768.0000	460.0000	179
258117.0000	901318.0000	461.0000	242
257127.0000	900958.0000	462.0000	236
256227.0000	900598.0000	463.0000	207
255327.0000	900148.0000	464.0000	45
254427.0000	899788.0000	465.0000	43
253437.0000	899428.0000	466.0000	44
252537.0000	898978.0000	467.0000	44
251637.0000	898618.0000	468.0000	46
250737.0000	898258.0000	469.0000	39
249027.0000	897358.0000	470.0000	44

248937.0000	896368.0000	471.0000	49
248847.0000	895378.0000	472.0000	48
248757.0000	893308.0000	473.0000	69
248667.0000	892318.0000	474.0000	91
248577.0000	891328.0000	475.0000	135
248487.0000	890338.0000	476.0000	240
248397.0000	889348.0000	477.0000	316
248307.0000	888358.0000	478.0000	314
248217.0000	887368.0000	479.0000	297
248127.0000	886378.0000	480.0000	307
248037.0000	885388.0000	481.0000	310
247947.0000	884398.0000	482.0000	253
247857.0000	883408.0000	483.0000	153
247767.0000	882418.0000	484.0000	95
247677.0000	881428.0000	485.0000	145
247497.0000	879358.0000	486.0000	155
247407.0000	878368.0000	487.0000	342
247317.0000	877378.0000	488.0000	363
247227.0000	876388.0000	489.0000	359
247137.0000	875398.0000	490.0000	381
247137.0000	874408.0000	491.0000	377
247047.0000	873418.0000	492.0000	386
246957.0000	872428.0000	493.0000	172
246867.0000	871438.0000	494.0000	92
246777.0000	870448.0000	495.0000	119
246687.0000	869458.0000	496.0000	131
246597.0000	868468.0000	497.0000	157
246507.0000	867478.0000	498.0000	335

246327.0000	865408.0000	499.0000	163
246237.0000	864418.0000	500.0000	95
246147.0000	863428.0000	501.0000	82
246057.0000	862438.0000	502.0000	60
245967.0000	861448.0000	503.0000	64
245877.0000	860458.0000	504.0000	98
245787.0000	859468.0000	505.0000	180
245697.0000	858478.0000	506.0000	259
245607.0000	857488.0000	507.0000	163
245517.0000	856498.0000	508.0000	147
245427.0000	855508.0000	509.0000	175
245427.0000	854518.0000	510.0000	233
245337.0000	853528.0000	511.0000	355
245157.0000	851458.0000	512.0000	221
245067.0000	850468.0000	513.0000	150
244977.0000	849478.0000	514.0000	98
244887.0000	848488.0000	515.0000	71
244797.0000	847498.0000	516.0000	91
244707.0000	846508.0000	517.0000	82
244617.0000	845518.0000	518.0000	123
244527.0000	844528.0000	519.0000	64
244437.0000	843538.0000	520.0000	49
244347.0000	842548.0000	521.0000	47
244257.0000	841558.0000	522.0000	76
244167.0000	840568.0000	523.0000	66
244077.0000	839578.0000	524.0000	57
243987.0000	838588.0000	525.0000	42
243807.0000	836518.0000	526.0000	38

243807.0000	835528.0000	527.0000	37
243717.0000	834538.0000	528.0000	62
243627.0000	833548.0000	529.0000	55
243537.0000	832558.0000	530.0000	88
243447.0000	831568.0000	531.0000	88
243357.0000	830578.0000	532.0000	83
243267.0000	829588.0000	533.0000	75
243177.0000	828598.0000	534.0000	86
243087.0000	827608.0000	535.0000	68
242997.0000	826618.0000	536.0000	78
242907.0000	825628.0000	537.0000	96
242817.0000	824638.0000	538.0000	80
242637.0000	822568.0000	539.0000	45
242547.0000	821578.0000	540.0000	78
242457.0000	820588.0000	541.0000	93
242367.0000	819598.0000	542.0000	83
242277.0000	818608.0000	543.0000	72
242187.0000	817618.0000	544.0000	73
242097.0000	816628.0000	545.0000	62
242097.0000	815638.0000	546.0000	65
242007.0000	814648.0000	547.0000	53
241917.0000	813658.0000	548.0000	48
241827.0000	812668.0000	549.0000	42
241737.0000	811678.0000	550.0000	40
241647.0000	810688.0000	551.0000	39

APPENDIX D

DPR regulatory requirements for operation and maintenance of pipeline in Nigeria

The Oil Pipelines ACT CAP.388, 17 (1) 1995, provides guidelines for the operation and maintenance of pipelines. These guidelines are in fact statutory requirements and enforceable by the Department of Petroleum Resources (DPR). They are summarized in Appendix D

A licensee shall:

- Not begin to operate a pipeline unless approval from the DPR in the form of license has been obtained.

- Establish a written Emergency Plan for implementation in the event of systems failure, accidents or other emergencies. This shall include procedures for prompt and expedient remedial action for control of accidental discharge from the pipeline, safety of the public, property and the environment. The emergency plan shall incorporate for adequate training and personnel involved in the handling of emergencies.

- Ensure that maximum steady state operating pressure and static conditions do not exceed the internal design pressure, or the pressure ratings of the components, which ever is less, and the pressure surges or the momentary pressure variations do not exceed 10 per cent.

- Carry out maintenance of pipeline markers at crossings indicating clearly the name of the pipeline and the name of the company.

- Inspect and re-certify once in 26 months all pressure relief devices and report the inspections and re-certification to the DPR.

- Carry out maintenance of the ROW to provide clear visibility and give access to the maintenance crew. Ensure clear access to valve locations, and protect ditches against washout of the pipeline.

- Regularly patrol ROW for prompt detection of any line break, encroachment or any other situation that may endanger the safety of the pipeline and report any detection to the DPR.

- Carry out inspection of all underwater crossings, not less than once in 5 years, to ensure the safety and sufficient cover of the pipeline.

- Ensure that repairs to the pipeline are carried out in accordance with good pipeline practice and follow the safety provisions contained in API RP 1107 and API RP 1111 or other recognized equivalent standards.

- Ensure that repaired sections are pressure tested at the same expected operating conditions.

Cathodic protection and corrosion control.

- The department specifies that the Cathodic Protection System shall be maintained in a serviceable condition and be electrically tested at least once in two years.

- Where a cathodic test reveals a weakness in the cathodic protection system, appropriate measures shall be taken and report of the test and the measurement taken shall be promptly sent to the DPR.

- All sources of impressed current such as rectifiers and other associated devices in the cathodic protection system shall be inspected and tested every 4 months to ensure their proper functioning.

- Periodic checks of the effectiveness of the cathodic protection system shall be carried out by electrical measurements.

- The internal corrosion in a pipeline shall be monitored by running an intelligent pig or other internal survey instrument through the pipeline at least once in 5 years. A report of the findings of such survey shall be sent to the DPR.

Incentives offered by federal government through NGC to encourage natural gas use in Nigeria

Some of the incentives offered by the Federal Government through NGC are:

- Implementation of Associated Gas Utilization Fiscal Incentives (AGUFI) of 1999.
- **Upstream Sector**

  I- Capital allowance of 20% per annum for the first four years, 19% in the fifth year, with 1% remaining in the book.

  II- Gas development projects to be taxed under the provision of the companies Income Tax Act and not on the Petroleum Profit Tax Act (PPTA).

  III- All expenditure pertaining to an integrated oil and gas project would be chargeable under the Petroleum Profit Tax (PPT).

  IV- Investment Credit Tax of 15%.

  V- Gas is transferred to downstream users at 0% PPT and 0 % royalty.

  VI- Tax deductible interest on loans.

- **Downstream sector**

  I- Duty and VAT free import of machinery and equipment.

  II- Tax holiday of five years.

  III- Zero percent royalty.

  IV- Zero percent PPT for gas used by producing companies.

  V- Tax deductible interest on loans.

VI- Tax free dividends during tax holiday.

VII- Normal fiscal regime (Company Tax Act).

VIII- Gas flaring tax of N10.00 per 1000scf.

All fiscal incentives under the gas utilization scheme for downstream operations were to be extended to industrial projects that use gas, e.g. power plants (PHNC), fertilizer plants (NAFCON), heating plants (WAPCO) , gas distribution and transmission pipeline. Further more, the Liquefied Natural Gas project was given specially enhanced incentives which include a tax holiday of 10years, investment tax credit of 19% to be applied from the end of the tax holiday; capital allowance of 33% per year for the first 3years with 1% remaining in the books.