BASIC ENGINEERING STUDY OF A NATURAL GAS TRANSMISSION PIPELINE

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"BASIC ENGINEERING STUDY OF A NATURAL GAS TRANSMISSION PIPELINE"

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By

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CERTIFICATE

This is to certify that the work contained in this thesis titled "Basic Engineering Study of a Natural Gas Transmission Pipeline" has been carried out by Satyam Vishnoi under my/our supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

This Project involves the basic engineering study of Natural gas transmission pipeline. A pipeline was designed to deliver gas to MLNG (Malaysia LNG complex) at 750 MMSCFD. The adequacy of the design was manually checked to ensure that it met the present and the projected future requirements

Adequacy of this pipeline has been checked by using steady state hydraulic simulator, Pipeline Studio Version 3.0(TGNET), while maintaining the velocity of gas as specified by client documents.

The designing for this project is been done on the basis of client design using standards approved by the petroleum industry. The standards followed are ASME B 31.8, API 5L, PETRONAS standards Pipeline rule of thumb, Gas Pipeline Hydraulics, Mohitpour design .

Three different flow rates were examined in the manual calulations. After performing all the calculations of velocity it can be concluded that 36" gas pipeline is sufficient for 750 MMSCFD capacity, but it may require an additional compressor for maintaining the delivery pressure and gas velocity of 10 m/s as specified by client.

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NOMECLATURES

P_{avg} = average gas pressure, psig

T_f = average gas temperature, °R

G = gas gravity (air = 1.00)

t = wall thickness of the pipe in inches

K_t = Temperature derating factor

E = Seam joint factor

F = A design factor of 0.72,

P_b = base pressure, psia

T_b = base temperature, °R (460+°F)

P1 = upstream pressure, psia

P2 = downstream pressure, psia

G = gas gravity (air = 1.00)

L_e = equivalent length of pipe segment, mi

Z = gas compressibility factor at the flowing temperature, dimensionless

s = elevation adjustment parameter, dimensionless

H1 = upstream elevation, ft

H2 = downstream elevation, ft

u = upstream gas velocity, ft/s

Q_b = gas flow rate, measured at standard conditions, ft3/day (SCFD)

P = upstream pressure, psia

T = upstream gas temperature, °R (460 + °F)

Z = gas compressibility factor at upstream conditions, dimensionless

R = gas constant = 10.73 ft3 psia/lb-moleR

f = friction factor, dimensionless

e = absolute pipe roughness, in.

Re = Reynolds number of flow, dimensionless

D_i = internal diameter of pipe in inches

D_o = outer diameter of pipe in inches

CHAPTER 1
GENERAL PROJECT DESCRIPTION

1.1 INTRODUCTION

The Sabah-Sarawak Gas Pipeline (SSGP) Project involves the development of a natural gas pipeline system from Sabah Oil and Gas Terminal (SOGT) in Kimanis, Sabah to MLNG Complex in Bintulu, Sarawak. Approximately 522 kms of natural gas pipeline with following:

- Metering Stations at Kimanis and Bintulu.
- Regional Operation Offices at Kimanis and Bintulu.
- Main Gas Control Centre at Bintulu and Backup Control Centre at Kimanis.
- Compressor station within Bintulu Regional Office.
- Scraper launcher and receiver stations.
- Block valve stations.
- Tee-off station at selected locations.
- Transformer rectifier stations for Cathodic protection.
- SCADA, Telecommunication and Surveillance System

The pipeline routing starts from Kimanis, Sabah and ends at MLNG Complex in Bintulu, Sarawak in which about 90 km is in Sabah and the remaining 432 km in Sarawak.

The installation of Bintulu Compressor Station is to satisfy the need for compression capacity for pressure and flow by MLNG Complex in Bintulu. The required inlet pressure to MLNG Complex is between 74 barg to 80 barg. The pipeline system is designed to an initial flow rate of 500 MMSCFD and maximum future flowrate up to 750 MMSCFD.

1.2 OVERALL SYSTEM OVERVIEW

Line pipe of 36" NPS are used for gas- transmission .The line pipe of specified quantity is supplied by Owner. The entire SSGP system consists of the following facilities:

A) Pipeline Facilities

- Tie-in points at SOGT and MLNG.
- Future tie-in point at MLNG to replace the connection to other trunk line.
- 30 m wide ROW in Sabah and 40 m wide in Sarawak.
- 22 nos. of block valve stations with SCADA building and helipad.
- One launcher station at Kimanis Metering Station,3 intermediate scraper stations at Lawas, Long Lama and Bintulu Regional Office and one receiver station at Bintulu Metering Station (total of 4 piggable sections). Support building is built at Lawas and Long Lama and two other remote locations between Lawas and Long Lama.
- Minimum 5 nos. of Cathodic Protection (CP.) Stations.
- Future tee-off points at Kimanis, Sipitang, Lawas, Long Lama, near junction to Bakun and Bintulu.
- Bintulu Compressor Station within Bintulu Regional Office
- Compressor building with 2 × 100% GTCP Trains

B) Auxiliary Facilities

- Filtering and Metering System, located at:
    - Kimanis Metering Station.
    - Bintulu Metering Station.
- Gas Management System (GMS)
    - Simulation Software Application
    - Management Software
    - Leak Detection System
- SCADA and Telecommunication System
- IT Communication System
- Kimanis Regional Office within SOGT (by other contractors)

- Administration office (by other contractors)
- Operation & Maintenance office (by other contractors)
- Kimanis Metering Station, Control Room including Backup Gas Control Centre

➢ Bintulu Regional Office

➢ Administration office / Main office

- Operation & Maintenance office
- Main Gas Control Centre
- Compressor Station Control Room
- Warehouse / Workshop building
- Security building
- Helipad
- Open pipe yard
- Covered walkway
- Covered parking area

2.1 ABBREVIATIONS

APU	Auxiliary Power Unit
BCS	Bintulu Compressor Station
EIA	Environmental Impact Assessment
EPCC	Engineering, Procurement, Construction & Commissioning
ESD	Emergency Shut Down
GCC	Gas Control Center
GMS	Gas Management System
GTCP	Gas Turbine Compressor Package
HHV	High Heating Value
HMI	Human Machine Interface
ITB	Invitation To Bid document
IPF	Instrumented Protective Function
MLNG	Malaysia LNG Sdn Bhd
MAIP	Maximum Allowable Incidental Pressure
MAOP	Maximum Allowable Operating Pressure
MOP	Maximum Operating Pressure
PSV	Pressure Safety Relief Valve
RTU	Remote Terminal Unit for communication with the SCADA System
ROW	Right of Way
SCADA	Supervisory Control and Data Acquisition
SOGT	Sabah Oil & Gas Terminal
SSGP	Sabah-Sarawak Gas Pipeline
SMYS	Specified Minimum Yield Strength
UPS	Uninterruptible Power Supply

2.2 COMPRESSOR STATION SYSTEM

Compressor units are installed complete with gas coolers, unit support system and station utilities and piping. The compressor station are designed for continuous, manned and unmanned operation. The normal operating mode is as:

	Normal Operation	Infrequent Operation
Phase I	1 × 100% GTCP Online 1 × 100% GTCP Offline	2 × 100% GTCP In parallel
Future	3 × 33.3% GTCP Online 1 × 33.3% GTCP Offline	1 × 33.3% GTCP on test 2 × 33.3% GTCPs parallel startup

Table 1 : Compressor Station

2.3 METERING STATION SYSTEM

Two metering stations are to be installed for entire SSGP system, which are located at KP 0 at Kimanis and KP 500 at Bintulu. Bintulu Metering station is gazetted as custody transfer meter station meanwhile Kimanis Metering station functions as check/backup meter. The stations are capable of communicating with SCADA system and also be equipped with security system.The meter station consist of a number of meter runs, one run to be reference run and one run to be spare meter run. The overall flange-to-flange dimension for the meter run are the same as the meter runs designed to allow interchangeability. Kimanis metering station is only gazzeted with a gas chromatograph and moisture analyzer running as one online and one as backup configuration. The meter is also be equipped with a proportional to flow gas-sampling system for laboratory analysis. Two type of meter are provided:

- Ultrasonic Meter at Kimanis
- Rotameter at Bintulu

2.4 OVERALL FIRE PROTECTION SYSTEM

Firewater is supplied from the firewater feed pump to a firewater storage tank. The firewater tank is located above ground. Firewater is distributed to the firewater ring main by two diesel driven distribution pumps, in a duty standby arrangement.

The fire water is discharged through hydrants situated on the fire water ring main around the station and buildings are supplied with fire water hose stations also fed from the hydrant ring main. A Jockey pump is maintain the pressure within the hydrants system. Firewater is provided to the fire-fighting package, which forms part of the overall turbine package, to the requirements of the GTCP supplier.

2.5 UTILITIES DESCRIPTION

A. FUEL GAS SYSTEM

A completely independent fuel gas system is installed for the units. Fuel gas is drawn from the station suction header downstream of the station filter separators. It then passes through fuel gas filter separator equipped with a liquid reservoir. The fuel gas filter separator is capable of removing 99.5% of all particles and liquids one (1) micron and larger. The fuel gas flow meter is selected to measure gas accuracy from 90% of the idle fuel requirement up to the meter capacity. As a general rule for the fuel gas system, the maximum allowable gas velocity in pipe is 15m/s. The pressure drop in the piping shall be checked using flow or equivalent to ensure that the pressure at the regulators and at the unit skid is within the required operating range.

B. UTILITY GAS SYSTEM

A utility gas system is installed to supply gas to the auxiliary power unit (APU). The utility gas (and power gas) is supplied from common piping, taken off from two locations. The first take-off is tapped upstream site of scraper receiver valve. The second take-off is located on the discharge piping, downstream of the station discharge isolation valve. The pressure reduction and metering facility have two stages of pressure reduction with a rotary positive displacement meter located between the pressure reduction stages. The pressure reduction and metering system is designed for 110% of the maximum combined APU gas demand. Dual pressure reduction runs in parallel is utilized, each sized for the design flow. A single relief valve located after each pressure reduction section is sized for the wide open capacity of the two regulators at maximum inlet pressure. The flow meter is provided with isolation valves and a by-pass for maintenance purposes.

C. POWER GAS SYSTEM

A completely independent power gas system is installed for the station. The power gas system is supply power gas to all gas/hydraulic actuators in the station via an NPS 2 distribution header with size reduction and isolation valve at each service point. It is provide liquid free gas to valve operators (i.e. with filters) and is designed to remain pressurized during a station blow down or emergency shutdown.

D. COMPRESSED AIR SYSTEM

The compressed air system comprise of a utility air system and an instrument/buffer air system. Compressed air is to be generated on site using electrical motor driven air compressors. The hot air is cooled by air after coolers (cool air within 3°C of ambient temperature), located downstream of each compressor. A liquid separator is installed downstream of these coolers. A by-pass is provided across the liquid separator. The compressed air piping is divided into utility air system and an instrument/ buffer air system. The compressed air system is designed for future to cater for station flow rate of 750MMSCFD.

The air systems is designed to supply air to all points of use at the pressure and flow required. Instrument/buffer air designs assume all users are operating for determining design flow rates. Utility air users are intermittent. The utility air piping system design is largest user operating alone.

Instrument/ buffer air system capacities are calculated by summing the air requirements of each device on the system. A safety factor 1.25 is applied to this and 25% leakage on the system is assumed. Wherever possible, devices requiring air at a pressure lower than the air system operating pressure is supplied with the necessary pressure regulators.

The instrument/buffer air system consists of the following:

1) Two air pre-filters

Two air pre-filter in parallel is installed upstream of the air dryer and two air after filters is installed downstream. The filter is capable of removing 99% of all particles and liquids 0.6 microns and larger. The filter has a replaceable coalescing filter element and is designed for a minimum services life of 12 months. Each air filter has an automatic drain trap. The instrument air filter is sized for 150% of the instrument air and buffer air design capacity.

2) An air dryer

An air dryer is installed to provide dry air to the appropriate instruments. The dryer is a desiccant type with dual towers. It is a heatless, regenerative type with the necessary controls for four minutes and ten minutes cycling of towers. The dryer shall include a humidity indicator and pressure gauges.

3) Instrument air receiver & and Buffer Air Receiver

The receivers of both the instrument air and buffer air are sized to store a 60 minutes supply of air for normal operation i.e. above the low air system pressure alarm set point. Each storage tank is provided across each instrument air receiver and buffer air receiver. An alarm is provided to give a minimum of 30 minutes warning prior to shut down due to low pressure. Buffer air is supplied to compressor barrier seal between the dry seal and bearing cavity if required.

Instrument air shall be supplied to the following:

- Unit anti-surge control valve actuators
- Unit vent valve actuators
- Unit purge/ pressurizing valve actuators
- Filter/ separator dump system
- Dry seal panel (control gas)
- Station recycle valve actuator
- Quick connect / disconnect couplings in the controls workshop for testing and calibrating instruments.

4) Utility Air Receiver

The following equipments are to be supplied with Utility Air:

- Compressor unit water wash system.
- Pneumatic driven Pumps.
- Utility air stations.

E) WATER SYSTEM (POTABLE AND FIRE)

The raw water tank is located above ground. From the raw tank sets of pumps is provided to distribute water to the Fire Water tank, utility water users and via a water treatment package to the Potable Water tank. Utility water points are to be located in all the main plant buildings workshops, and in suitable locations to allow for maintenance use around the process area. Potable water points are supplied to the entire main plant buildings for cleaning, washing and use in lavatories. Firewater is supplied from the firewater Feed pump to a Fire Water storage tank. The firewater tank is to be located above ground. Firewater is distributed to the firewater ring main by two diesel driven distribution pumps, in a duty standby arrangement.

2.6 OPERATING PHILOSOPHY

Regional Offices is built at Kimanis (by other contractor) and Bintulu to carry out the operation and maintenance activities for SSGP system. In addition, Bintulu Regional Office is also accommodate the Operation Center, Gas Control Center and Compressor Station. Four support buildings are built along the pipeline ROW to cater for operation & maintenance activities at remote areas.

Due to the nature of the pipeline route, remote operation concept is used for SSGP system. The helicopter services should be optimized, thus, helipad is installed at all block valve stations. The metering stations, block valve stations and scraper stations are designed to be unmanned. Telemetry data from compressor station, metering stations, scraper stations and block valve stations are made available at Main Gas Control Centre and Backup Gas Control Centre through the SCADA system. Selected data from SOGT's compressor station shall also be available at Main Gas Control Centre and Backup Gas Control Centre.

Emergency operating condition is triggered when any of the critical equipment such as Leak Detection System initiating alarms. In this situation the operator investigate the cause of the trip alarms and able to close the telemetered block valve through SCADA System. Blowdown facility at each block valve station can be used to evacuate the gas contained in a particular section. After completion of investigation and repair, if required, the system is initiated for restart. All pipeline block valves can only be open manually and not by remote command.

Shut Down Valve (SDV) are provided at the starting point (Kimanis Metering Station) and end point (before tie-in to MLNG) to isolate the pipeline system, in the case of emergency. The SDV are operated and maintained by SOGT and MLNG only. Metering and Compressor Stations are operating in 1 running and 1 standby mode. This is to ensure SSGP shall maintain 100% availability for reliable gas supply to MLNG.

2.7 SCRAPER STATIONS

The pipeline is piggable for cleaning and intelligent pigging purposes during operation. Scraper traps for the pipeline are designed to accommodate the current generation instrumented In-Line Inspection (ILI) tools and other devices without interrupting the flow and the ongoing operation.

Intermediate scraper stations are located at Lawas, Long Lama and Bintulu Compressor Station. All fittings on the actual pipeline are sized to allow an unhindered and safe passage of pigs. The interior of the pipeline and general design of other related components shall be suitable for all types of pigs. These components include barred tees, insulating joints, pig traps, pig signallers, special long radius bends, pipeline valves and flanges.

The internal diameter of scraper barrels is sized larger than the pipeline to which they are attached to facilitate insertion and removal of inspection tools. The length of the scraper barrels is sufficient to accept the longest expected (ILI) tool in the industries for the particular NPS 36 pipeline size to which the scraper trap is attached. Pressure gauges and pig signalers are installed on all scraper launchers and receivers. Pig traps are also complete with balance and kicker lines.

For the launcher, one pig signaller is installed on the down stream side of the launcher barrel located after the main tee with minimum distance of at least the maximum length of the (ILI) tool to be used from the isolation valve and one pig signaller should be installed downstream of the mainline barred tee.

For the receiver, one pig signaller should be located on the receiver barrel at a distance from the pig trap isolation valve of at least the length of the maximum length of the (ILI) tool to be used and one pig signaller should be installed upstream of the mainline barred tee. The pig signaller installed on the pipeline is permanent non-intrusive type while the pig signaler on the barrel is the set-in mechanical intrusive type.

The pig traps are equipped with quick opening closures. Quick opening closures have fail safe mechanisms to ensure that closure cannot be opened whilst the pig trap is under pressure. Space is required beyond the enclosure door of the pig trap for safe pig handling. An equalizing line is installed on the launcher / receiver barrel to ensure the safe pigging operations. Pig trap is drained by gravity into the appropriate closed drainage system or temporary drained pit during commissioning.

All branch and straight tee pieces on the mainline section of the pipeline are barred if the branch diameter is equal to or greater than 50% of the mainline diameter to prevent pigs from being stucked in between.

Where bars are required, the design of the bar system ensure no passage of pigs into branch, no damage to pigs during transit, and that adequate strength is provided to ensure that bars do not vibrate excessively under high flows. All valves installed in piggable sections of the pipeline shall be full bore ball valves in accordance to API 6D and other relevant project specifications.

The launcher at Kimanis Metering Station and receiver and Bintulu Metering Station is equipped with double block and bleed isolation valve. All bends in the pipeline shall have a minimum bend radius of 6D. Lifting equipment and handling trolley is provided at all scraper stations to facilitate the handling of the tools during pigging operation. It is designed to accommodate a pig of 2.5 meter length and 1.5 tonne weight.

2.8 PIG LAUNCHING & RECEIVING FACILITIES

Pipeline pigs are devices that are inserted into and travel throughout the length of a pipeline driven by a product flow. They were originally developed to remove deposits which could obstruct or retard flow through a pipeline. Although each pipeline has its own set of characteristics which affect how and why pigging is used, there are basically three reasons to pig a pipeline:

- To batch or separate dissimilar products
- For displacement purposes
- For internal inspection

Basic Description of Pig system is as followed:

A) Pig Trap:

An ancillary item of pipeline equipment, with associated pipework and valves, for introducing a pig into a pipeline or removing a pig from a pipeline.

B) Pig Launching:

- Close Valves A and C
- Open valve D to vent launching trap to atmosphere pressure.
- When the trap is completely drained (0 psig) with Valves D and still open, open the closure door and insert the pig so the first cup forms a tight fit in the reducer at point (X)
- Close and secure the closure door. Close Valve C and leave vent Valve D open. Slowly fill the trap through Valve C by venting the air through Valve. When filling is completed, close vent Valve D to allow pressure to equalize, then close Valve C
- Open Valve A first and then open Valve C . The pig is now ready for launching.
- Partially close Valve B. This will increase the flow of gas through Valve B and behind the pig. Continue to close Valve B until the pig moves out of the trap into mainline stream as signaled by the PIG-SIG Indicator
- .When the pig leaves the trap and enters the mainline, open Valve. B fully

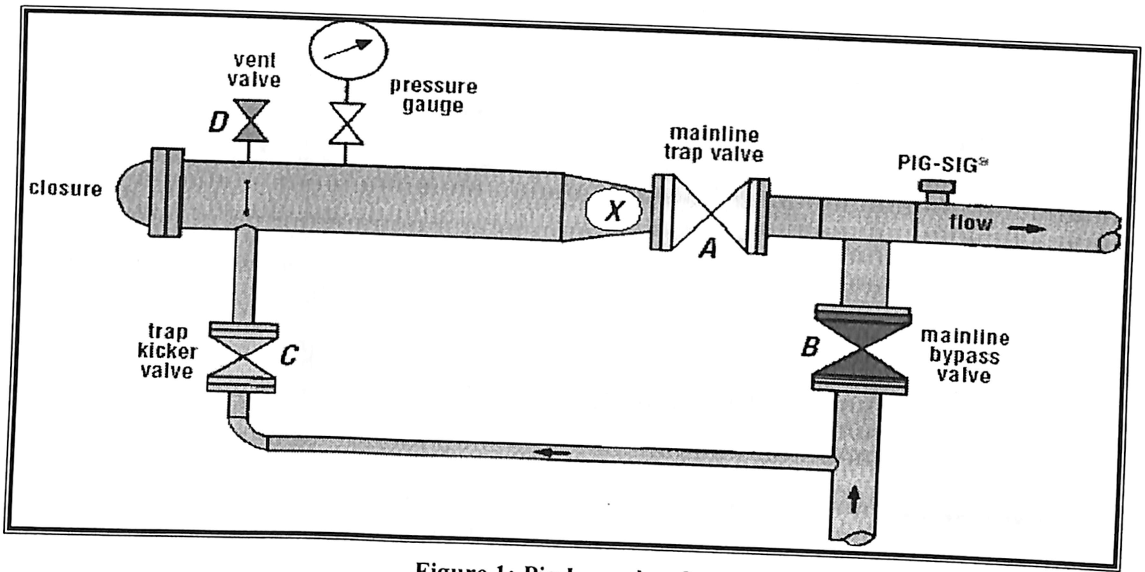

Figure 1: Pig Launcher System

C) Pig Receiving:

- Close drain Valve D Slowly fill trap by opening Valve C venting through Valve E.
- Close vent Valve E to allow trap pressure to equalize through Valve C.
- With Valve C open, open Valve A, Trap is now ready to receive pig.
- When the pig arrives, it may stop between trap Valve A and the tee point (x)
- Partially close Valve B. This will force the pig into the trap due to increasing flow through Valve C.
- When the pig is in the trap as signaled by the PIG-SIG Indicator, open Valve B completely and close Valves A and C.
- Open drain Valve D and vent Valve E and drain the trap.
- After the trap is fully drained (0 psig) with Valves D and E. still open, open the closure door and remove the pig.
- Close and secure the closure door.

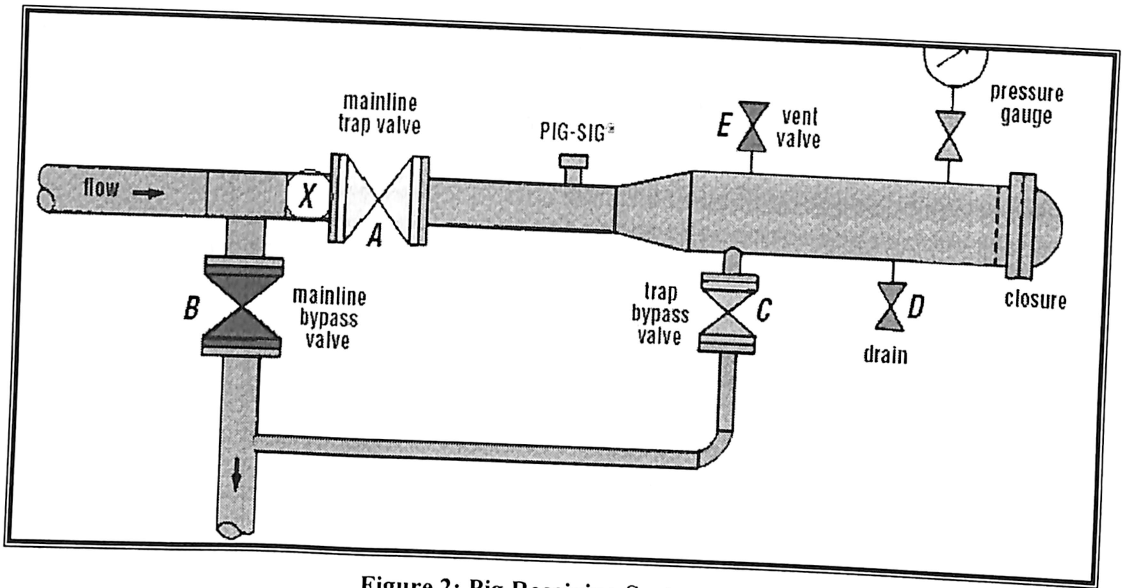

Figure 2: Pig Receiving System

D) Some Important Terms Used In Pigging Process:

Barrel: Section of pig trap from the pig trap valve up to and including the end closure which is required to launch & receive pigs. Three section of barrel are as followed:

- Major Barrel: An enlarge section of barrel used for loading pig.
- Reducer: Section between major barrel & minor barrel.
- Minor Barrel: Section between pig trap valve & reducer.

Both section of barrel should be designed for the longest pig which will be used (as intelligent pig).Barrel shall be 2 inches larger than the normal pipeline diameter for 10 inches.

Barred Tee: Tee-piece provided with bars across the internal bore of the branch pipe to prevent entry of a pig.

By Pass Line: connect the pipeline with related facilities as a booster station, tank.

Kicker line: A kicker line is required to connect the major barrel with by pas line to enable the diversion of fluid through the barrel to launch and receive the pig.

Balance Line: Provided on launcher to enable filling & pressuring of barrel on both side of pig at same time used for prevent a pig which is ready to be launched from moving either forward.

End Closure: It provide easy access to major barrel when open & seals the pore when closed.

Pig singnaller: A device set onto or into a pipe which gives an indication of the passage of a pig.

Vent/flare/blow down lines: A vent line shall he provided on top of the oversee section of the barrel and near the end closure to facilitate depressuring barrels filled with gas, allow venting during the draining of barrels filled with liquid and to enable purging.

2.9 CORROSION PROTECTION

The primary corrosion protection for the system is provided by the following:

a) External coating of 3 layer Polyethylene (3LPE) for buried pipeline
b) Heat shrink sleeve for joint
c) Painting for above ground piping
d) Epoxy for all other underground fittings

2.10 MAINLINE BLOCK VALVE STATION

Based on ASME B31.8 code requirements mainline valve stations is spaced in accordance with the particular location class. However, minimum spacing of location class 2 is used to cater for future development of highway system and other future development plan by the authorities.

All valves on the mainline is designed with full bore ball valves to permit passage of inline inspection tools. All valves are specified to API 6D and ANSI Class 600 rating. Valves are specified with fully welded body, body bleeds, drain line piped above ground, grease fittings led aboveground and equipped with check valves and drain line with valves. Block valve assemblies are equipped with instrument connections to permit the attachment of pressure and temperature transmitter.

2.11 SCADA SYSTEM

The entire SSGP system is equipped with SCADA system network for monitoring and controlling of the pipeline operation 24 hours a day, 365 days a year. Main Gas Control Centre is installed in Bintulu Regional Office while back-up Gas Control Centre (back-up system for SCADA Host) is installed at Kimanis Metering Station.

2.12 GAS MANAGEMENT SYSTEM (GMS)

A Gas Management System (GMS) facility is installed to enable access to information regarding deliveries of gas, etc. directly from the host computer. The GMS provide the following facility among others:

- Simulation Software Application
- Gas Management Software Application

2.13 REMOTE TERMINAL UNIT (RTU)

A Remote Terminal Unit (RTU) is provided at all block valve stations to collect operational data as well as to provide output signal for the actuation of the block valve as and when it is required. In principle, the RTU perform the following functions:

a) Gather data from transmitters, switches and contact points through hardwired I/O

b) Detect the occurrence of significant events, (alarms, status, change) and generate time stamped messages

c) Compare analog input values with predefined limits in its database and produce time stamped alarm messages when exceed

d) Communicate with local operator through a simple local display panel

The block valve RTU shall also provide the following functions:

a) Provide information on the local conditions (valve status, RTU status)

b) Provide the pipeline pressure and temperature reading

c) Provide reading and status of Solar Panel

d) Receive and react to remote "valve close" command sent by operator at the Gas Control Centre.

2.14 HEADERS

Headers at the meter station shall be sized to provide equal gas distribution to each of the meter runs. Headers shall either be extruded from pipe or fabricated from piping components.

2.15 METERING STRAINERS

Y-type strainers are installed in the piping upstream of the meters to remove particulate matter that could damage the meters. The strainers are provided with bleed valves and end flange to allow them to be vented and cleaned.

2.16 METERING FILTER/SEPARATOR

Two 100% filter/separator with liquid blow flask and drain tank are installed in parallel, with one in standby configuration. Each filter is specified to remove 99.5% particle and one (1) micron and larger over the full range of design flow. Manual drain and localized blowdown system is provided. Valves are installed on the upstream and downstream piping of each filter run to allow for isolation, switching and maintenance without interrupting flow through the station. Pressure drop across the filters in the clean condition shall be very minimum and to be specified by contractor. The filter/separator shall be sized for 750 MMSCFD.

2.17 ISOLATION VALVES

Station isolation valve assemblies are installed on the inlet and outlet of all meter stations. These assemblies are designed to permit bypassing and gas throttling around the isolation valve as well as for venting on either side of the valve.

2.18 BLOWDOWNS

A blow down is located at edge of the station, away from buildings & overhead. Power lines for Kimanis Metering Station, all gas release is connected to the common blow down system in SOGT. Since the meter station blow down stack could be used to blow down a section of pipeline, sizing of the vent stack shall be consistent with the criteria used for the pipeline.

2.19 PRESSURE RELIEF

All metering stations are equipped with pressure release system. A pilot operated relief valve is installed and sized to handle the design flow though the station at 10% over MAOP. An isolation valve is provided to permit maintenance of the relief valve. The isolation valve is locked seal open during normal operation.

2.20 SCADA INTERFACE

RTU shall be installed at each meter station for interrogating the station control system for data relative to the SCADA system. The interface from the meter station control system to the RTU comprises:

- a serial multi drop link and cabling to the flow computer
- a serial link and cabling to the station controller
- hardwired signals and wiring to the station controller
- hardwired signals and wiring to the flow computer
- hardwired signals and wiring to the gas chromatograph

2.21 CATHODIC PROTECTION FOR METERING STATION

Below ground portions of piping and vessels at meter stations are cathodically protected by the Impressed current system provided for the pipeline. The piping and vessels are coated Accordingly with an approved coating system. Good lengthwise conductivity along cathodically protected sections are ensured to allow for efficient CP current return path. All metal pipes or foundation shall be electrically isolated from the section conducting CP current.

2.22 SPECIFIC DEFINITIONS

Accumulated Pressure

Pressure which is built up in a pipeline during the period of activation of an over pressure protection system.

Internal Design Pressure

The maximum internal pressure at which the pipeline is (or sections) designed in accordance with the applicable design standard.

Incidental Pressure

Pressure occurring in a pipeline with limited frequency and duration.Pressures due to surges or heating of blocked-in static fluid are considered incidental pressures, providing they are not regular operating occurrences.

Maximum Allowable Incidental Pressure

The maximum pressure that is allowed to occur in a pipeline with a limited frequency and duration, determined in accordance with the applicable design standard.

Maximum Allowable Operating Pressure

The maximum pressure at which a pipeline system is (or sections thereof are) allowed to operate under steady state process conditions, in accordance with the applicable design standard.

Maximum Operating Pressure

The maximum pressure at which a pipeline system will be operated under steady state process conditions.

Surge Pressure

Pressure due to mass flow velocity changes caused by operational activities, e.g. valve closures, pump shutdown, or start-up.

Thermal Pressure

Pressure due to thermal expansion effects on a fluid in a blocked-in pipeline or blocked-in pipeline section.

Instrumented Protective Function

A function comprising one or more Initiators, a Logic Solver and one or more Final Elements whose purpose is to prevent or mitigate hazardous situations. An IPF is intended to achieve or maintain a safe state for the process, in respect of a specific hazardous event, e.g., overpressure.

Pressure Recorder Alarm (High)

System for warning and registering the occurrence of pressures in excess of allowable values.

Pressure Safety Relief Valve

Valve for protecting a pipeline against overpressure by releasing fluid from the pipeline.

.Specified Minimum Yield Strength

Minimum yield strength required by the specification or standard under which the pipeline material is purchased.

3.1 REFERENCE DOCUMENTS

The data sources used for providing the Design Basis for the overall Sabah Sarawak Gas Pipeline system are:

1. SSGP design basis of Client.
2. Process Flow Diagrams (PFDs).
3. Piping & Instrumentation Diagrams (P&IDs).
4. Hydraulic Simulation Study of Client.
5. General Information under client documents

3.2 SCOPE OF DESIGN BASIS

Scope of Design Basis involves Process aspects of the facilities which include and form basis but not be limited to the following:

- Establishing adequacy of 36" pipeline for the 750 MMSCFD capacity, to deliver Gas to MLNG at pre-decided pressures.

3.3 PIPELINE DESIGN PARAMETERS

PARAMETERS	VALUES
System Design Pressure / MAOP	96 barg
Minimum gas temperature	15 °C
Maximum gas temperature	72 °C
Base Temperature	15 ° C
Base Pressure	101.325 kPa (abs)
Ambient Temperature	15- 40 °C
Design Flow rate	375/500/750 MMSCFD
System Design Life	25 years
Design for sour service	NO
Wall Thickness	16.75 mm
Pipeline Roughness Factor	0.0006 in
Heat Transfer Coefficient	3.02 W/m2°C
Pipeline Coating	3 LPE
Maximum Black Bulb Temperature	65° C

Table 2 : Design Basis

3.4 GAS COMPOSITION

Gas composition (Mole%)	Rich Case	Lean Case
Methane	83.016	91.13
Ethane	05.021	04.040
Propane	02.918	01.51
i-Butane	0.751	00.30
n-Butane	0.612	00.32
i-Pentane	0.207	00.12
n-Pentane	0.118	00.08
Hexane	0.087	00.08
Benzene	0.014	00.01
Toluene	0.103	00.00
Nitrogen	0.51	00.15
Carbon dioxide	6.496	02.090
Hydrogen Sulphide	0.002	00.00
H2O	0.00	0.01
Total	100	100
HHV (BTU/scf)	1071	1074.5
Mol. Wt.	20.45	18.2

Table 3: Gas Composition

3.5 CONTAMINANTS / TRACE ELEMENTS (RICH CASE):

Carbon Dioxide	6.5 mol % max
Mercury	364 mg/Sm^3 maximum
Hydrogen sulphide	20 ppm mol maximum
Total Sulphur	30 ppm mol maximum
Other Sulphur	4 ppm mol maximum
Mercaptan	5 ppm mol maximum
Water	30 mg/Sm^3 typical
Oxygen	25 ppm mol maximum
Argon	75 ppm mol maximum
Helium	100 ppm mol maximum
Radon	200 Bq/Sm^3 maximum
Methanol	350 mg/Sm^3 maximum

Table 4 :Contaminants/Trace Elements

3.6 PIPELINE SYSTEM

General Pipeline System description is provided under section 1.2 of this report.

3.7 OVERALL HYDRAULIC STUDY

The objectives of the study is to check the adequacy of the 36" pipeline for meeting the future demand of 750 MMSCFD.

4.1 THEORETICAL TERMS USED

Specific Gravity:

Specific gravity of a gas, sometimes called *gravity*, is a measure of how heavy the gas is compared to air at a particular temperature. It might also be called *Relative density*, expressed as the ratio of the gas density to the density of air. Because specific gravity is a ratio, it is a dimensionless quantity.

$$G = \frac{M_g}{M_{air}}$$

Since natural gas mainly consists of a mixture of several gases (methane, ethane, propane, CO2etc.), the molecular weight M_g referred to as the apparent molecular weight of the gas mixture. So specific gravity is calculated with the ratio of this apparent molecular weight to the molecular weight of air.

So specific gravity calculated by this method is 0.65.(according to Gas Pipeline Hydraulic Chapter 1, Eq.1.4 page 4)

Viscosity:

The viscosity of a fluid represents its resistance to flow. The higher the viscosity, the more difficult it is to flow. Lower viscosity fluids flow easily in pipes and cause less pressure drop. Liquids have much larger values of viscosity compared to gases. For example, water has a viscosity of 1.0 centipoises (cP), whereas viscosity of natural gas is approximately 0.0008 cP. Even though the gas viscosity is a small number, it has an important function in determining the type of flow in pipelines.

Compressibility Factor:

The compressibility factor is a measure of how close a real gas is to an ideal gas. The compressibility factor is defined as the ratio of the gas volume at a given temperature and pressure to the volume the gas would occupy if it were an ideal gas at the same temperature and pressure. The compressibility factor is a dimensionless number close to 1.00 and is a function of the gas gravity, gas temperature, gas pressure, and the critical properties of the gas

$$Z = \frac{1}{\left[1 + \left(\frac{P_{avg}\, 344.400 (10)^{1.785G}}{T_f^{3.825}}\right)\right]}$$

This formula for the compressibility factor is valid when the average gas pressure, P_{avg}, is more than 100 psig. For pressures less than 100 psig, Z is approximately equal to 1.00

Where P_{avg} = average gas pressure, psig

T_f = average gas temperature, °R

G = gas gravity (air = 1.00)

In a gas pipeline, the pressure varies along the length of the pipeline. The compressibility factor Z also varies and must therefore be calculated for an average pressure at any location on the pipeline. If two points along the pipeline are at pressures $P1$ and $P2$, the following formula is used for a more accurate value of the average pressure:

$$P_{avg} = \frac{2}{3}\left(\frac{P_1^3 - P_2^3}{P_1^2 - P_2^2}\right)$$

Maximum Allowable Operating Pressure

MAOP = 2*SMYS*t*K_t*F*E/OD

Where

SMYS = Specified Minimum yield strength of the material in psi

t = wall thickness of the pipe in inches

OD = outer diameter of the pipe in inches

K_t = Temperature derating factor

E = Seam joint factor

F = A design factor of 0.72, except that a design factor of 0.60 is used for pipe, including risers, on a platform located offshore or on a platform in inland navigable waters, and 0.54 is used for pipe that has been subjected to cold expansion to meet the specified minimum yield strength and is subsequently heated, other than by welding or stress relieving as a part of welding, to a temperature higher than 900 °F (482 °C) for any period of time or over 600 °F (316 °C) for more than 1 hour.

Design Factor:

Class location	Design factor (F)
1	0.72
2	0.60
3	0.50
4	0.40

Temp. Derating Factor:

Temperature (°F)	Temp Derating factor (T)
250 or Less	1.00
300	0.967
350	0.933
400	0.90
450	0.867

Longitudinal Joint Factor:

Specification	Pipe class	Longitudinal joint factor (E)
ASTM A 53/A53M	Seamless	1.00
	Electric resistance welded.	1.00
	Furnace butt welded.	0.60
ASTM A 106	Seamless	1.00
ASTM A 333/A 333M	Seamless	1.00
	Electric resistance welded.	1.00
ASTM A 381	Double submerged arc welded.	1.00
ASTM A 671	Electric-fusion-welded.	1.00
ASTM A 672	Electric-fusion-welded.	1.00

ASTM A 691..................	Electric-fusion-welded.	1.00
API 5 L.....................	Seamless...........	1.00
	Electric resistance welded.	1.00
	Electric flash welded.	1.00
	Submerged arc welded	1.00
	Furnace butt welded.	0.60
Other.......................	Pipe over 4 inches (102 millimeters)	0.80
Other.......................	Pipe 4 inches (102 millimeters) or less.	0.60

Flow Equations:

Several equations are available that relate the gas flow rate with gas properties, pipe diameter and length, and upstream and downstream pressures. These equations are listed as follows:

1. General Flow equation
2. Colebrook-White equation
3. Modified Colebrook-White equation
4. AGA equation
5. Weymouth equation
6. Panhandle A equation
7. Panhandle B equation
8. IGT equation
9. Spitzglass equation
10. Mueller equation

General Flow Equation:

The most common form of this equation in the U.S. Customary System (USCS) of units is given in terms of the pipe diameter, gas properties, pressures, temperatures, and flow rate as follows.

$$Q = 38.77F\left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - e^s P_2^2}{GT_f L_e Z}\right)^{0.5} D^{2.5}$$

(This formula is given in Gas Pipeline Hydraulic, Chapter 2, page 35 eq.2.7)

Where Q = gas flow rate, measured at standard conditions, ft^3/day (SCFD)

F = transmission Factor

P_b = base pressure, psia

T_b = base temperature, °R (460+°F)

P1 = upstream pressure, psia

P2 = downstream pressure, psia

G = gas gravity (air = 1.00)

T_f = average gas flowing temperature, °R (460+°F)

L_e = equivalent length of pipe segment, mi

Z = gas compressibility factor at the flowing temperature, dimensionless

D = pipe inside diameter, in.

Where the transmission factor F and friction factor f are related by

$$F = \frac{2}{\sqrt{f}}$$

Where

$$L_e = \frac{L(e^s - 1)}{s}$$

The equivalent length, Le, and the term e^s take into account the elevation difference between the upstream and downstream ends of the pipe segment. The parameter s depends upon the gas gravity, gas compressibility factor, the flowing temperature, and the elevation difference. It is defined as:

$$s = 0.0375G\left(\frac{H_2 - H_1}{T_f Z}\right)$$

Where s = elevation adjustment parameter, dimensionless

H1 = upstream elevation, ft

H2 = downstream elevation, ft

e = base of natural logarithms (e = 2.718...)

Upon examining the General Flow Equation, we see that for a pipe segment of length L and diameter D, the gas flow rate Q (at standard conditions) depends on several factors. Q depends on gas properties represented by the gravity G and the compressibility factor Z. If the gas gravity is increased (heavier gas), the flow rate will decrease. Similarly, as the compressibility factor Z increases, the flow rate will decrease. Also, as the gas flowing temperature Tf increases, throughput will decrease. Thus, the hotter the gas, the lower the flow rate will be. Therefore, to increase the flow rate, it helps to keep the gas temperature low. The impact of pipe length and inside diameter is also clear. As the pipe segment length increases for given pressure P_1 and P_2, the flow rate will decrease. On the other hand, the larger the diameter, the larger the flow rate will be. The term $P_1^2 - P_2^2$ represents the driving force that causes the flow rate from the upstream end to the downstream end. As the downstream pressure P_2 is reduced, keeping the upstream pressure P_1 constant, the flow rate will increase. It is obvious that when there is no flow rate, P_1 is equal to P_2. It is due to friction between the gas and pipe walls that the pressure drop $(P_1 - P_2)$ occurs from the upstream point 1 to downstream point 2. The friction factor f depends on the internal condition of the pipe as well as the type of flow (laminar or turbulent).

Gas Velocity:

The velocity of gas flow in a pipeline represents the speed at which the gas molecules move from one point to another. Unlike a liquid pipeline, due to compressibility, the gas velocity depends upon the pressure and, hence, will vary along the pipeline even if the pipe diameter is constant. The highest velocity will be at the downstream end, where the pressure is the least. Correspondingly, the least velocity will be at the upstream end, where the pressure is higher.

The gas velocity at any point in a pipeline is given by

$$u = 0.002122\left(\frac{Q_b}{D^2}\right)\left(\frac{P_b}{T_b}\right)\left(\frac{ZT}{P}\right)$$

Where

u = upstream gas velocity, ft/s

Q_b = gas flow rate, measured at standard conditions, ft3/day (SCFD)

D = pipe inside diameter, in.

Pb = base pressure, psia

Tb = base temperature, °R (460 + °F)

P = upstream pressure, psia

T = upstream gas temperature, °R (460 + °F)

Z = gas compressibility factor at upstream conditions, dimensionless

Erosional Velocity:

The gas velocity is directly related to the flow rate. As flow rate increases, so does the gas velocity. As the velocity increases, vibration and noise are evident. In addition, higher velocities will cause erosion of the pipe interior over a long period of time. The upper limit of the gas velocity is usually calculated approximately from the following equation:

$$u_{max} = 100\sqrt{\frac{ZRT}{29GP}}$$

Where

Z = compressibility factor of gas, dimensionless

R = gas constant = 10.73 ft3 psia/lb-moleR

T = gas temperature, °R

G = gas gravity (air = 1.00)

P = base pressure, psia

Reynolds Number of Flow:

An important parameter in flow of fluids in a pipe is the non dimensional term Reynolds number. The Reynolds number is used to characterize the type of flow in a pipe, such as laminar, turbulent, or critical flow. It is also used to calculate the friction factor in pipe flow. We will first outline the calculation of the Reynolds number based upon the properties of the gas and pipe diameter and then discuss the range of Reynolds number for the various types of flow and how to calculate the friction factor. The Reynolds number is a function of the gas flow rate, pipe inside diameter, and the gas density and viscosity and is calculated from the following equation:

$$Re = 0.0004778\left(\frac{P_b}{T_b}\right)\left(\frac{GQ}{\mu D}\right)$$

Where P_b = base pressure, psia

T_b = base temperature, °R (460 + °F)

G = specific gravity of gas (air = 1.0)

Q = gas flow rate, standard ft^3/day (SCFD)

D = pipe inside diameter, in

μ = viscosity of gas, lb/ft-s

Laminar flow occurs in a pipeline when the Reynolds number is below a value of approximately 2000. Turbulent flow occurs when the Reynolds number is greater than 4000. For Reynolds numbers between 2000 and 4000, the flow is undefined and is referred to as critical flow.

Thus, For laminar flow, $Re \leq 2000$

For turbulent flow, $Re > 4000$

For critical flow, $Re > 2000$ and $Re \leq 4000$

Most natural gas pipelines operate in the turbulent flow region. Therefore, the Reynolds number is greater than 4000. Turbulent flow is further divided into three regions known as smooth pipe flow, fully rough pipe flow, and transition flow.

Friction Factor:

In order to calculate the pressure drop in a pipeline at a given flow rate, we must first understand the concept of friction factor. The term friction factor is a dimensionless parameter that depends upon the Reynolds number of flow.

$$\frac{1}{\sqrt{f}} = -2\,\text{Log}_{10}\left(\frac{e}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right) \quad \text{for } Re > 4000$$

Where

f = friction factor, dimensionless

D = pipe inside diameter, in

e = absolute pipe roughness, in.

Re = Reynolds number of flow, dimensionless

Transmission Factor:

The transmission factor F is considered the opposite of the friction factor f. Where as the friction factor indicates how difficult it is to move a certain quantity of gas through a pipeline, the transmission factor is a direct measure of how much gas can be transported through the pipeline. As the friction factor increases, the transmission factor decreases and, therefore, the gas flow rate also decreases. Conversely, the higher the transmission factor, the lower the friction factor and, therefore, the higher the flow rate will be. The transmission factor F is related to the friction factor f as follows:

$$F = \frac{2}{\sqrt{f}}$$

Pressure Required to Transport:

In the flow of incompressible fluids such as water, the pressure required to transport a specified volume of fluid from point A to point B will consist of the following components:

1. Frictional component
2. Elevation component
3. Pipe delivery pressure

In addition, in some cases where the pipeline elevation differences are drastic, we must also take into account the minimum pressure in a pipeline such that vaporization of liquid does not occur. The latter results in two-phase flow in the pipeline, which causes higher pressure drop and, therefore, more pumping power requirement in addition to possible damage to pumping equipment. Thus, single-phase incompressible fluids must be pumped such that the pressure at any point in the pipeline does not drop below the vapor pressure of the liquid.

When pumping gases, which are compressible fluids, the three components listed in the preceding section also contribute to the total pressure required. Even though the relationship between the total pressure required and the pipeline elevation is not straightforward (as in liquid flow), the dependency still exists.

4.2 FORMULA USED

1. Internal Diameter

$D_i = D_o - 2t$

Where D_i = internal diameter of pipe in inches

D_o = outer diameter of pipe in inches

t = wall thickness of the pipe in inches

2. Maximum Allowable Operating Pressure

$$MAOP = 2*SMYS*t*K_t*F*E/OD$$

Where

SMYS = Specified Minimum yield strength of the material in psi

t = wall thickness of the pipe in inches

OD = outer diameter of the pipe in inches

K_t = Temperature derating factor

E = Seam joint factor

F = A design factor of 0.72

3. Reynolds Number

$$Re = 0.0004778\left(\frac{P_b}{T_b}\right)\left(\frac{GQ}{\mu D}\right)$$

Where

P_b = Base pressure, PSIA

T_b = Base temperature, °R (460 + °F)

G = Specific gravity of gas (AIR = 1.0)

Q =Gas flow rate, (SCFD)

D = Pipe inside diameter, in

μ = Viscosity of gas, lb/ft-s

4. Friction Factor

$$\frac{1}{\sqrt{f}} = -2\text{Log}_{10}\left(\frac{e}{3.7D} + \frac{2.51}{\text{Re}\sqrt{f}}\right)$$

Where:

f = Friction factor, dimensionless

D = Pipe inside diameter, in

e = Absolute pipe roughness, in.

Re = Reynolds number of flow, dimensionless

5. Transmission Factor

$$F = \frac{2}{\sqrt{f}}$$

6. Compressibility Factor

$$Z = \frac{1}{\left[1 + \left(\frac{P_{avg}\,344.400(10)^{1.785G}}{T_f^{3.825}}\right)\right]}$$

Where

P_{avg} = Average gas pressure, psig

T_f = Average gas temperature, ^{o}R

G = Gas gravity (air = 1.00)

7. Equivalent Length

$$L_e = \frac{L(e^s - 1)}{s}$$

8. Elevation Adjustment Parameter

$$s = 0.0375\, G\left(\frac{H_2 - H_1}{T_f Z}\right)$$

Where

s = Elevation adjustment parameter, dimensionless

H1 = Upstream elevation, ft

H2 = Downstream elevation, ft

e = Base of natural logarithms (e = 2.718...)

9. General Flow Equation

$$Q = 38.77\, F\left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - e^s P_2^2}{G T_f L_e Z}\right)^{0.5} D^{2.5}$$

Where,

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

F = Transmission factor

P_b = Base pressure, psia

T_b = Base temperature, °R (460+°F)

P1 = Upstream pressure, psia

P2 = Downstream pressure, psia

G = Gas gravity (air = 1.00)

T_f = Average gas flowing temperature, °R (460+°F)

L_e = Equivalent length of pipe segment, mile

Z = Gas compressibility factor, dimensionless

D = Pipe inside diameter, in.

10. Gas Velocity

$$u = 0.002122\left(\frac{Q_b}{D^2}\right)\left(\frac{P_b}{T_b}\right)\left(\frac{ZT}{P}\right)$$

Where

u = Upstream gas velocity, ft/s

Q_b = Gas flow rate, ft3/day (SCFD)

D = Pipe inside diameter, in.

Pb = Base pressure, psia

Tb = Base temperature, °R (460 + °F)

P = Upstream pressure, psia

T = Upstream gas temperature, °R (460 + °F)

Z = Gas compressibility factor, dimensionless

11. Erosional Velocity

$$u_{max} = 100\sqrt{\frac{ZRT}{29GP}}$$

Where

Z = Compressibility factor of gas, dimensionless

R = Gas constant = 10.73 ft3 psia/lb-moleR

T = Gas temperature, °R

G = Gas gravity (air = 1.00)

P = Base pressure, psia

5.1 STUDY OBJECTIVES

The objective of the present project work is to carry out the study i.e., to study the increase in power consumption for the same line with the increase in capacity (Demand) from 375 MMSCFD to 500 and 750 MMSCFD.

5.2 SELECTION CRITERIA

Adequacy of 36" NPS pipeline for transferring the gas at higher capacity has been checked by calculation the gas velocity for the increase in capacity which should not increase above 10m/s as specified by client.

5.3 DESIGN BASIS FOR HYDRAULIC SIMULATION

The standard conditions are taken as 1.013255 bars and 15°C.

A) Gas Supply (As Per Client's Hydraulic Simulation Basis)

- Gas supplier battery limit- Sabah Oil and Gas Terminal (SOGT), Kimanis at KP0.
- Flow: 500 MMSCFD (Normal) : Phase I
  750 MMSCFD (Maximum) : Future.
- Pressure and Temperature at SSGP battery limit
  - Pressure (maximum) : 88 barg.
  - Pressure (minimum) : 78 barg.
  - Temperature : 25°C.

Note: Maximum pressure drop of 2 barg occurs across the Metering stations at Kimanis and Bintulu.

B) Bintulu Station and Machinery Parameters: (As per client's Hydraulic Simulation Basis)

Compressor Adiabatic efficiency	85%
Compressor Mechanical Efficiency	100%
Turbine Rated Fuel Usage	27%
Station outlet Maximum Pressure	88 barg.
Minimum Suction Pressure	52-60 barg.

5.4 SOLUTION TECHNIQUE

Pipeline Studio has a very stable numerical solution technique with fast error free convergence to the solution. The solution technique also captures second order effects in the flow.

5.5 ASSUMPTIONS

- The gas is considered to be single phase throughout the operational transients.
- The internal pipe roughness at pipeline field joints is ignored due to very short lengths.
- The entire pipeline route is considered of uniform thermal characteristics of the soil.

5.6 MODEL VALIDATION

- The section involves "validation" of the simulated models with respect to Client's Hydraulic Study.
- Validation is the activity involving verification of model, to ensure that the simulation model can be applied for further calculation analysis, and to confirm reliability of the simulation model.
- This validation is necessary to ensure that the results from the simulation model match the results of previous analysis (Client's), so that further calculations and predictions are in conformity with the design basis.

➢ Conducting a comprehensive model validation exercise performs this verification. For this purpose, validation is performed through following steps:

- Basic model development. Thermo-physical parameters were chosen as per Industry recommended practices.
- All inputs to the simulation model were matched with the inputs as in Client'sModeling/Hydraulic study.
- Used the same Pipe Sections as per the Client's Hydraulic study.
- Compared the simulation model's results with those mentioned in the Client's Hydraulics study.

CASE 1Ai – 375 MMSCFD RICH GAS (Max. discharge from both CSs)
As per Previous study

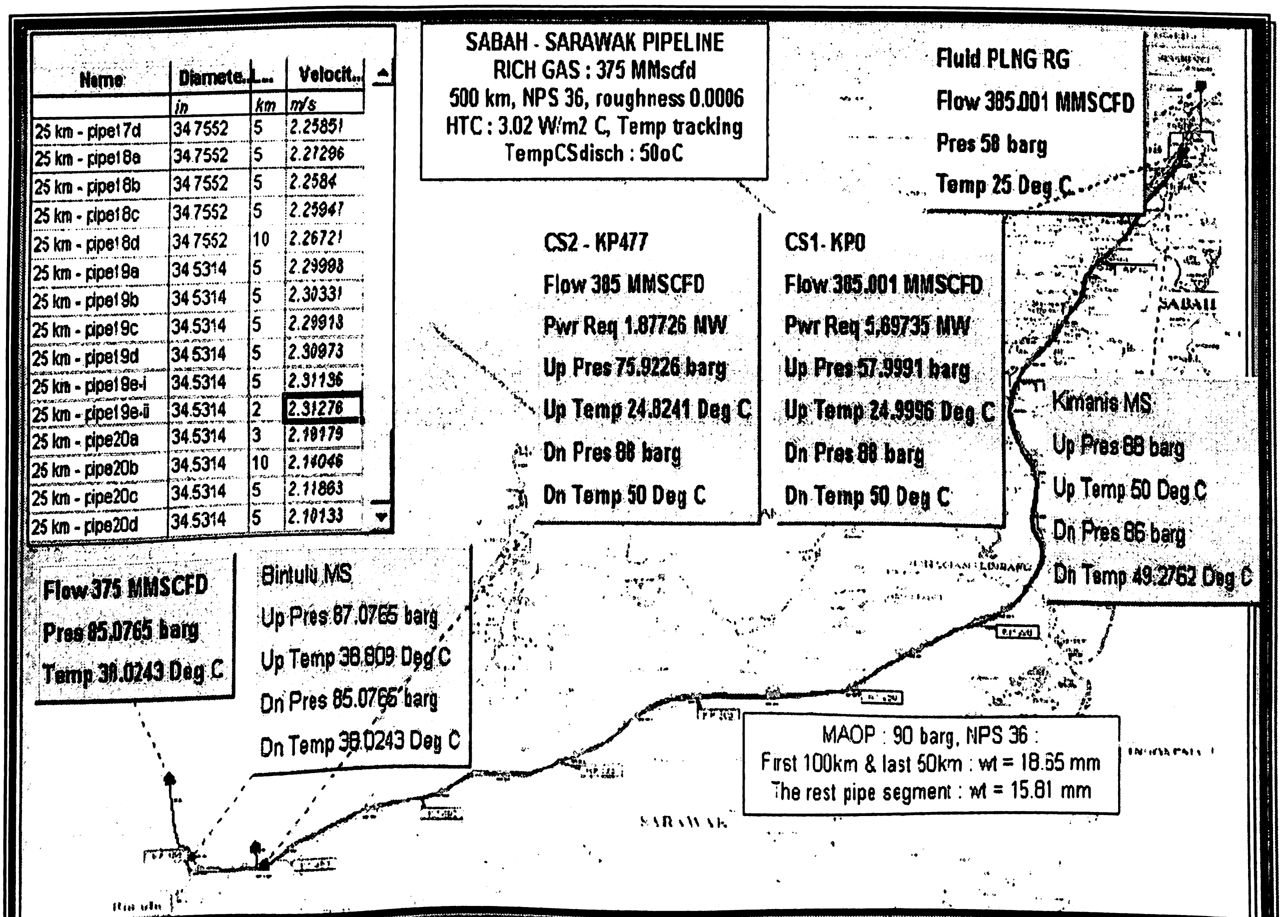

Figure 3:Model as per Client at 375MMSCFD

As per Current Study

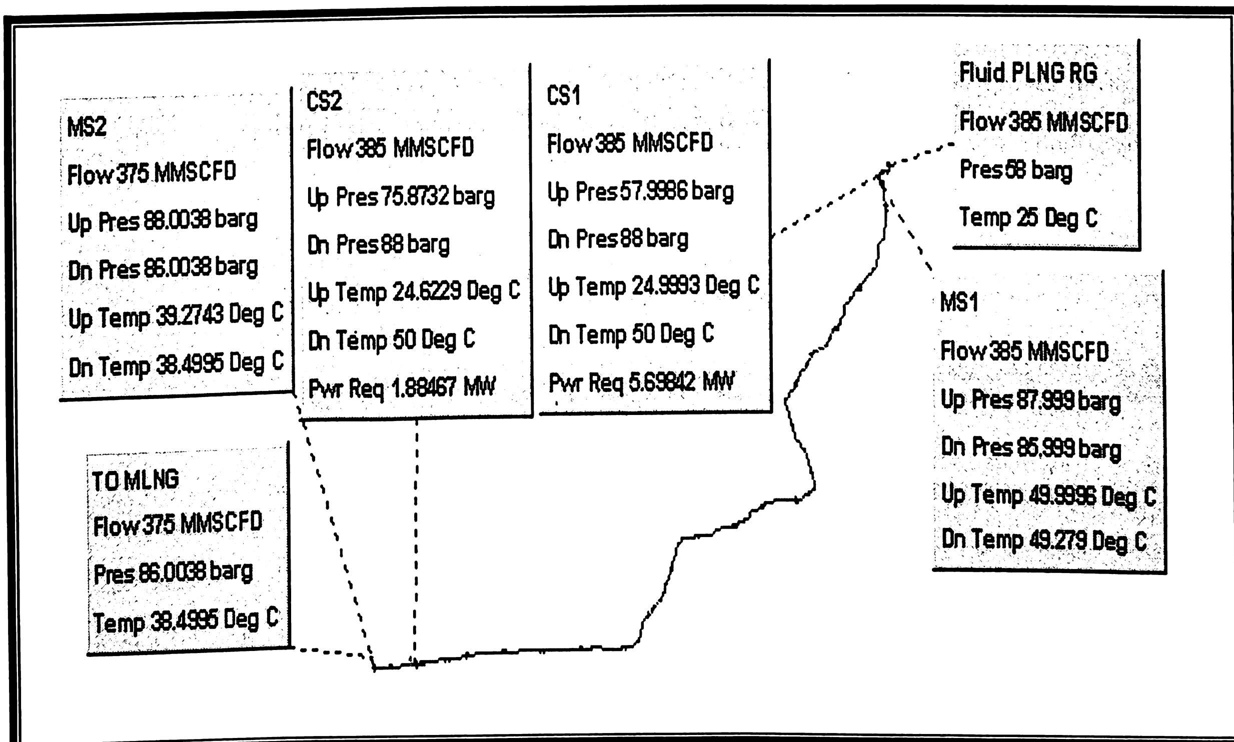

Figure 4: Model obtained at 375 MMSCFD

Model Comparison

Current outputs, on comparison with that of client, lead to following observations:

Property	As Per client	As Per contractor	Deviation	Remarks
Delivery Pressure (barg) at MLNG	85.07	86.00	0.96 (1%)	Acceptable match. **OK**
Suction Pressure (barg) of CS2.	75.92	75.87	0.05 (0.06%)	Matched. **OK**
Power requirement of CS2 (MW)	1.87	1.88	0.01 (0.5%)	Matched. **OK**

Table 5: Model Comparison at 375 MMSCFD

Conclusion

At 375 MMSCFD, both the Pressure and Power values calculated nearly match with that of Client's having a very low percentage deviation.

Hence Current model obtained is validated at 375 MMSCFD for further analysis

CASE 2Ai – 500 MMSCFD RICH GAS (Max. discharge from both CSs)

As per Previous Study

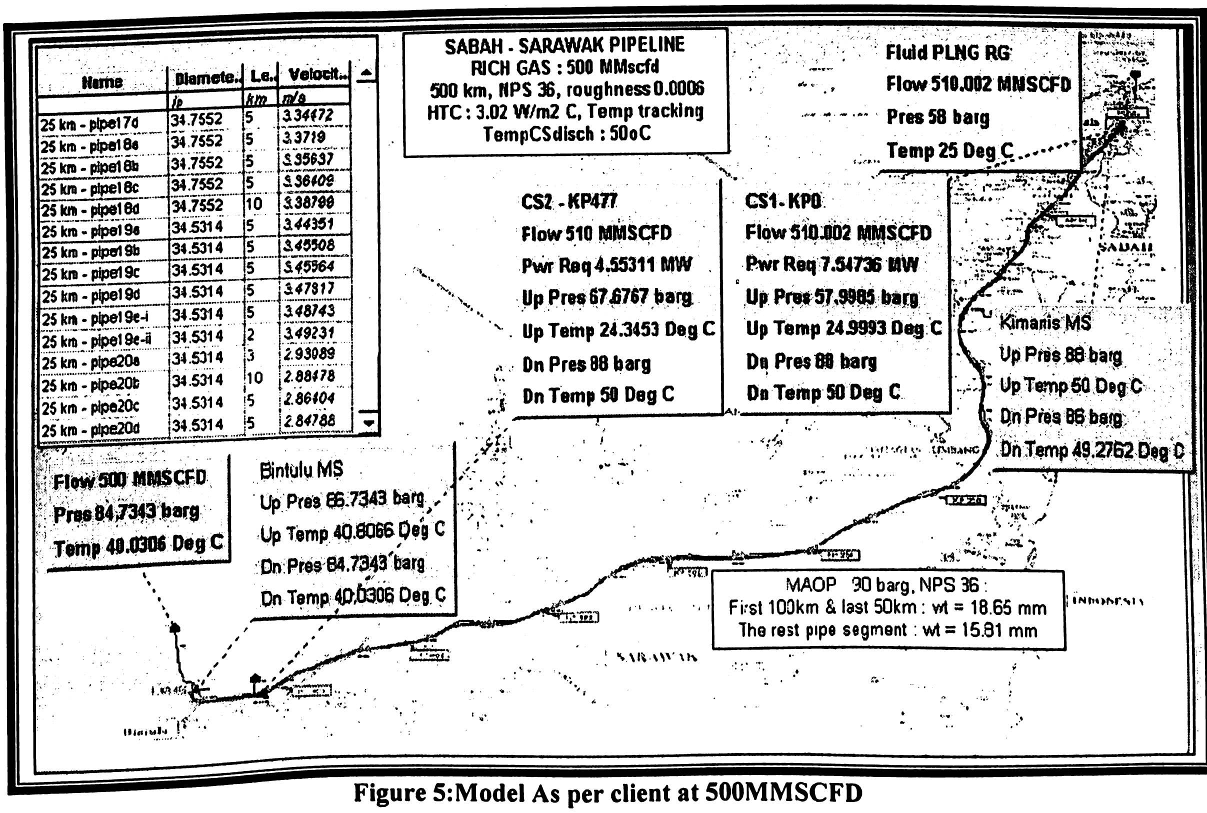

Figure 5:Model As per client at 500MMSCFD

As per Current Study

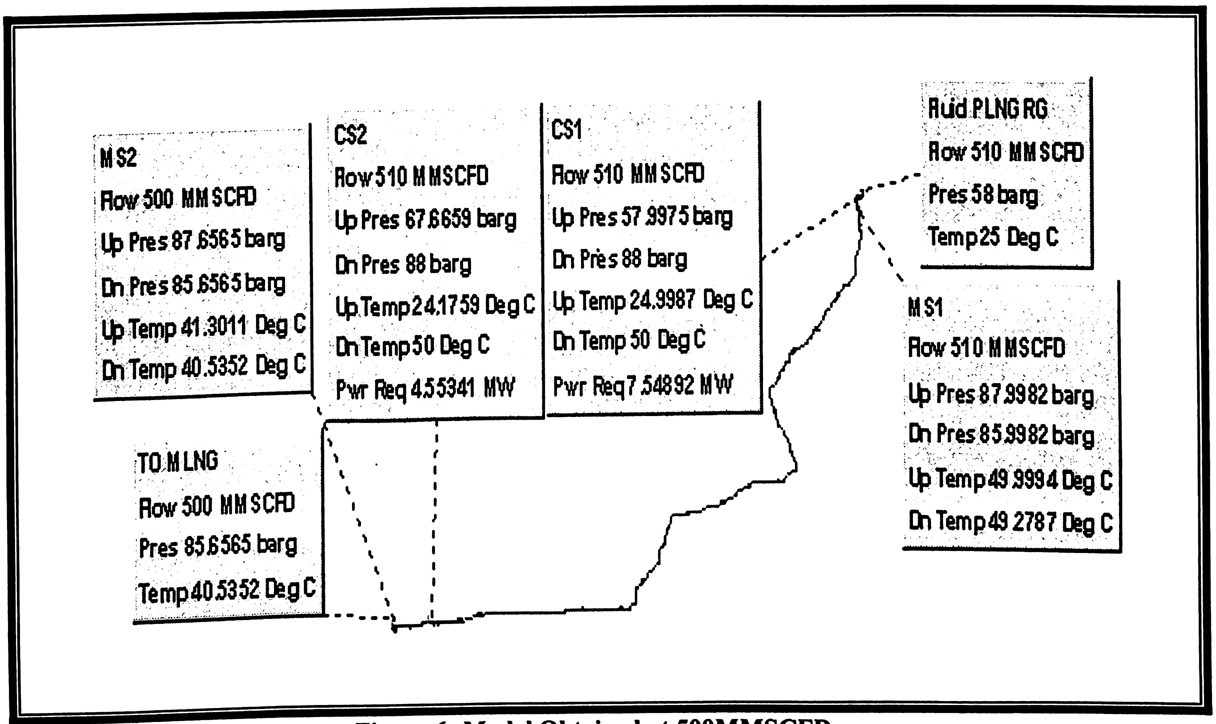

Figure 6: Model Obtained at 500MMSCFD

Model Comparison

Model outputs, on comparison with that of client, lead to following observations:

Property	As Per client	As Per contractor	Deviation	Remarks
Delivery Pressure (barg) at MLNG	84.73	85.65	0.92 (1.04%)	Acceptable match. **OK.**
Suction Pressure (barg) of CS2.	67.67	67.66	0.01 (0.01%)	Matched. **OK**
Power requirement of CS2 (MW)	4.55	4.55	0.00 (0.0%)	Matched. **OK**

Table 6: Model Comparsion at 500MMSCFD

Conclusion

At 500 MMSCFD, both the Pressure and Power values calculated nearly match with that of client's having a very low percentage deviation.

Hence client model is validated at 500 MMSCFD for further analysis
CASE 3Ai – 750 MMSCFD RICH GAS (Max. discharge from both CSs)

As per client

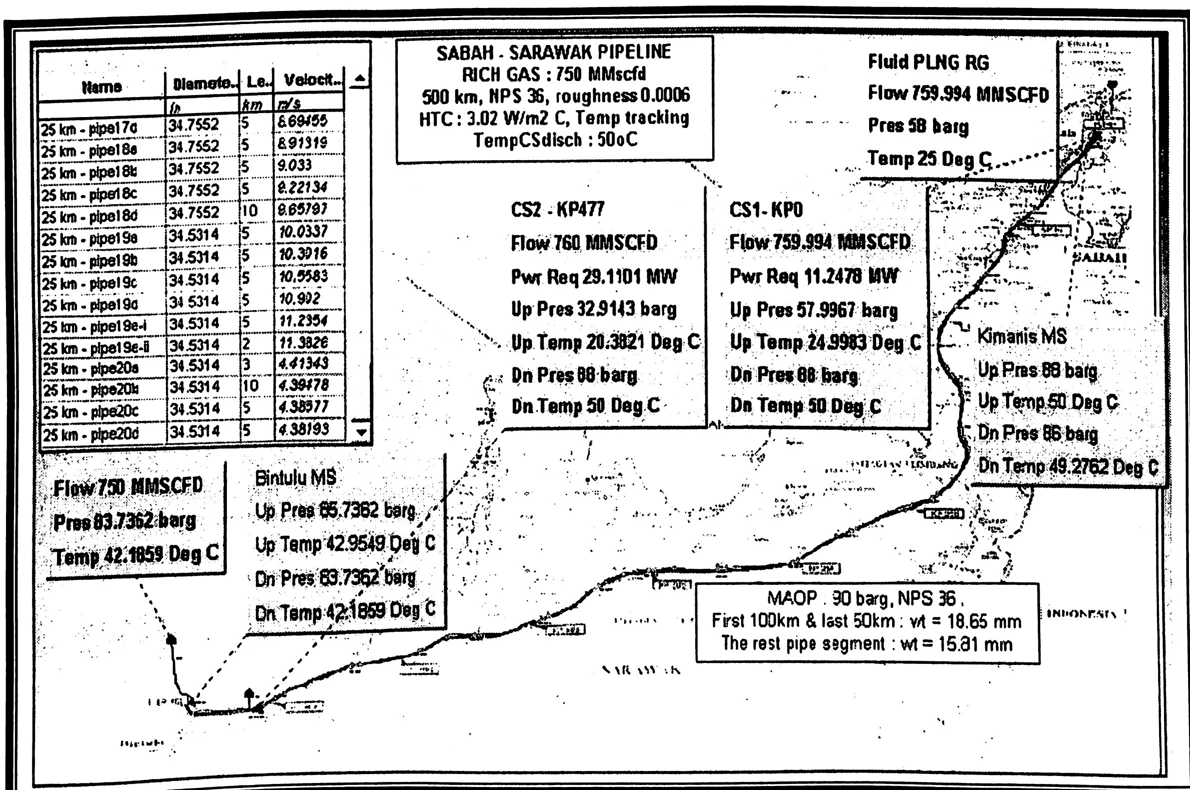

Figure 7: Model as per client at 750MMSCFD

As per current study:

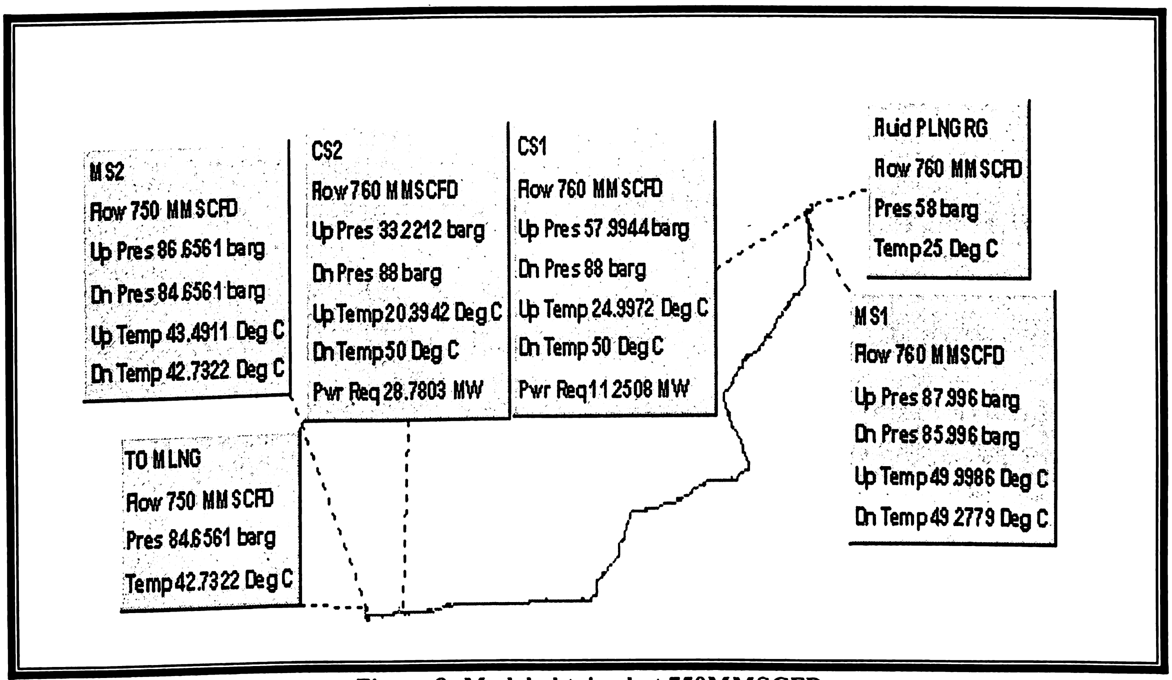

Figure 8: Model obtained at 750MMSCFD

Model Comparison

Model outputs, on comparison with that of Client, lead to following observations:

Property	As Per Client	As Per Contractor	Deviation	Remarks
Delivery Pressure (barg) at MLNG	83.73	84.65	0.92 (1.08%)	Acceptable match. **OK.**
Suction Pressure (barg) of CS2.	32.91	33.22	0.31 (0.9%)	Acceptable match. **OK.**
Power requirement of CS2 (MW)	29.11	28.78	0.33 (1.1%)	Matched. **OK**

Table 7: Model Comparison at 750MMSCFD

Conclusion

At 750 MMSCFD, both the Pressure and Power values calculated nearly match with that Client's having a very low percentage deviation.

Hence current model is validated at 750 MMSCFD for further analysis.

CASE :3AI DESIGN PROCEDURE: (375 MMSCFD AND 85.07 PSIA)

GIVEN DATA:

Diameter (OD)	36	in
Pipe Material Grade	X-70	
Wall Thickness (t)	0.65	in
Total Length of Pipeline (L)	324.356	Mile
Throughput (Q)	375000000	SCFD
Viscosity (v)	1.68E-05	lb/ft-s
Absolute Roughness (e)	0.0006	
Starting Elevation (H1)	10	M
End Elevation (H2)	11	M
Base temperature of Gas (T_b)	475	R
Base Pressure of Gas (P_b)	14.7	Psia
Average Gas Temp (Tf)	465	R
SMYS of Pipe Material	70000	Psi
Delivery pressure required (P2)	85.07	Psia
Safety Factor (F)	0.72	
Temp Derating Factor (Kt)	1	
Mechanical Efficiency	0.9	
Specific gravity (G)	0.65	

CALCULATION:

Step1:

$D_i = D_o - 2t$

Where D_i = Internal diameter of Pipe in inches

D_o = Outer diameter of Pipe in inches

t = Wall thickness of the pipe in inches

Calculated Value: **34.7 in**

Step2:

$MAOP = 2*SMYS*t*K_t*F*E/OD$

Where S = Yield Strength of the material in psi

t = wall thickness of the pipe in inches

F = Factor of Safety

D_o = outer diameter of the pipe in inches

Calculated Value: **1820 psi**

Step3:

Calculation of Friction factor:

$$Re = 0.0004778\left(\frac{P_b}{T_b}\right)\left(\frac{GQ}{\mu D}\right)$$

Calculated Value: **5959686.207**

$$\frac{1}{\sqrt{f}} = -2\text{Log}_{10}\left(\frac{e}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right)$$

Calculated Value: **0.00985 (by successive iteration)**

Step4:

Calculation of Transmission factor:

$$F = \frac{2}{\sqrt{f}}$$

Calculated Value: **20.1517**

Step5:

Calculation of pressure required at starting Point:

a) Calculation of P_{avg}:

Since the inlet pressure is unknown, we will calculate an approximate value of Z using an assumption a value of 110% of the delivery pressure for the average pressure. But it may deviate from actual value.

Calculated Value: **109.747 psig**

b) Calculation of Compressibility factor:

$$Z = \frac{1}{\left[1 + \left(\frac{P_{avg} 344.400(10)^{1.785G}}{T_f^{3.825}}\right)\right]}$$

Calculated Value: **0.966**

c) Calculation of Equivalent Length:

$$s = 0.0375\, G \left(\frac{H_2 - H_1}{T_f Z}\right)$$

Calculated Value: **5.4E-05**

$$L_e = \frac{L(e^s - 1)}{s}$$

Calculated Value: **324.364 miles**

$$Q = 38.77\, F \left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - e^s P_2^2}{G T_f L_e Z}\right)^{0.5} D^{2.5}$$

Calculated Value: **650.366 psi**

Step7:

Calculation of Gas Velocity:

$$u = 0.002122\left(\frac{Q_b}{D^2}\right)\left(\frac{P_b}{T_b}\right)\left(\frac{ZT}{P}\right)$$

Calculated Value: **3.48 m/sec**

Step8:

Calculation of Maximum Velocity of gas:

$$u_{max} = 100\sqrt{\frac{ZRT}{29GP}}$$

Calculated Value: **9.20 m/sec**

CASE :3AII DESIGN PROCEDURE: (500 MMSCFD AND 84.73 PSIG)

GIVEN DATA:

Diameter (OD)	36	in
Wall Thickness (t)	0.65	in
Total Length of Pipeline (L)	324.356	Mile
Throughput (Q)	500000000	SCFD
Viscosity (v)	1.68E-05	lb/ft-s
Absolute Roughness (e)	0.0006	
Starting Elevation (H1)	10	M
End Elevation (H2)	11	M
Base temperature of Gas (T_b)	475	R
Base Pressure of Gas (P_b)	14.7	Psia
Average Gas Temp (Tf)	465	R
SMYS of Pipe Material	70000	Psi
Pipe Material Grade	X-70	
Delivery pressure required (P2)	84.73	Psia
Safety Factor (F)	0.72	
Temp Derating Factor (Kt)	1	
Mechanical Efficiency	0.9	
Specific gravity (G)	0.65	

CALCULATION:

Step1:

$D_i = D_o - 2t$

Where D_i = Internal diameter of Pipe in inches

D_o = Outer diameter of Pipe in inches

t = Wall thickness of the pipe in inches

Calculated Value: **34.7 in**

Step2:

MAOP = 2*SMYS*t*K_t*F*E/OD

Where S = Yield Strength of the material in psi

t = wall thickness of the pipe in inches

F = Factor of Safety

D_o = outer diameter of the pipe in inches

Calculated Value: **1820 psi**

Step3:

Calculation of Friction factor:

$$Re = 0.0004778\left(\frac{P_b}{T_b}\right)\left(\frac{GQ}{\mu D}\right)$$

Calculated Value: **7946248.27**

$$\frac{1}{\sqrt{f}} = -2\text{Log}_{10}\left(\frac{e}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right)$$

Calculated Value: **0.00956 (by successive iteration)**

Step4:

Calculation of Transmission factor:

$$F = \frac{2}{\sqrt{f}}$$

Calculated Value: **20.455**

Step5:

Calculation of pressure required at starting Point:

a) Calculation of P_{avg}:

Since the inlet pressure is unknown, we will calculate an approximate value of Z using an assumption a value of 110% of the delivery pressure for the average pressure. But it may deviate from actual value.

Calculated Value: **109.373 psig**

b) Calculation of Compressibility factor:

$$Z = \frac{1}{\left[1 + \left(\frac{P_{avg} 344{,}400 (10)^{1.785G}}{T_f^{3.825}}\right)\right]}$$

Calculated Value: **0.966**

c) Calculation of Equivalent Length:

$$s = 0.0375\, G \left(\frac{H_2 - H_1}{T_f Z}\right)$$

Calculated Value: **5.4E-05**

$$L_e = \frac{L(e^s - 1)}{s}$$

Calculated Value: **324.364 miles**

$$Q = 38.77\,F\left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - e^s P_2^2}{GT_f L_e Z}\right)^{0.5} D^{2.5}$$

Calculated Value: **851.229 psi**

Step7:

Calculation of Gas Velocity:

$$u = 0.002122\left(\frac{Q_b}{D^2}\right)\left(\frac{P_b}{T_b}\right)\left(\frac{ZT}{P}\right)$$

Calculated Value: **4.45 m/sec**

Step8:

Calculation of Maximum Velocity of gas:

$$u_{max} = 100\sqrt{\frac{ZRT}{29GP}}$$

Calculated Value: **11.34 m/sec**

CASE :3AIII DESIGN PROCEDURE: (750 MMSCFD AND 83.73 PSIG)

GIVEN DATA:

Diameter (OD)	36	in
Wall Thickness (t)	0.65	in
Total Length of Pipeline (L)	324.356	Mile
Throughput (Q)	750000000	SCFD
Viscosity (v)	1.68E-05	lb/ft-s

Absolute Roughness (e)	0.0006	
Starting Elevation (H1)	10	M
End Elevation (H2)	11	M
Base temperature of Gas (T_b)	475	R
Base Pressure of Gas (P_b)	14.7	Psia
Average Gas Temp (Tf)	465	R
SMYS of Pipe Material	70000	Psi
Pipe Material Grade	X-70	
Delivery pressure required (P2)	83.73	Psia
Safety Factor (F)	0.72	
Temp Derating Factor (Kt)	1	
Mechanical Efficiency	0.9	
Specific gravity (G)	0.65	

CALCULATION:

Step1:

$D_i = D_o - 2t$

Where D_i = Internal diameter of Pipe in inches

D_o = Outer diameter of Pipe in inches

t = Wall thickness of the pipe in inches

Calculated Value: **34.7 in**

Step2:

$MAOP = 2*SMYS*t*K_t*F*E/OD$

Where S = Yield Strength of the material in psi

t = wall thickness of the pipe in inches

F = Factor of Safety

D_o = outer diameter of the pipe in inches

Calculated Value: **1820 psi**

Step3:

Calculation of Friction factor:

$$\mathrm{Re} = 0.0004778\left(\frac{P_b}{T_b}\right)\left(\frac{GQ}{\mu D}\right)$$

Calculated Value: **11919372.41**

$$\frac{1}{\sqrt{f}} = -2\mathrm{Log}_{10}\left(\frac{e}{3.7D} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right)$$

Calculated Value: **0.0094 (by successive iteration)**

Step4:

Calculation of Transmission factor:

$$F = \frac{2}{\sqrt{f}}$$

Calculated Value: **20.6284**

Step5:

Calculation of pressure required at starting Point:

a) Calculation of P_{avg}:

Since the inlet pressure is unknown, we will calculate an approximate value of Z using an assumption of 110% of the delivery pressure for the average pressure. But it may deviate from actual value.

Calculated Value: **108.273 psig**

b) Calculation of Compressibility factor:

$$Z = \frac{1}{\left[1 + \left(\frac{P_{avg} 344{,}400 (10)^{1.785G}}{T_f^{3.825}}\right)\right]}$$

Calculated Value: **0.96731**

c) Calculation of Equivalent Length:

$$s = 0.0375\, G \left(\frac{H_2 - H_1}{T_f Z}\right)$$

Calculated Value: **5.4E-05**

$$L_e = \frac{L(e^s - 1)}{s}$$

Calculated Value: **324.364 miles**

$$Q = 38.77\, F \left(\frac{T_b}{P_b}\right) \left(\frac{P_1^2 - e^s P_2^2}{G T_f L_e Z}\right)^{0.5} D^{2.5}$$

Calculated Value: **1262.8141 psi**

Step7:

Calculation of Gas Velocity:

$$u = 0.002122 \left(\frac{Q_b}{D^2}\right) \left(\frac{P_b}{T_b}\right) \left(\frac{ZT}{P}\right)$$

Calculated Value: **11.67 m/sec**

Step8:

Calculation of Maximum Velocity of gas:

$$u_{max} = 100\sqrt{\frac{ZRT}{29GP}}$$

Calculated Value: **18.46 m/sec**

CONCLUSION

Adequacy of 36" NPS pipeline has been checked by the use of steady state hydraulic simulations using TGNET, while maintaining gas velocity less than 10 m/s as specified in Client document. The simulated model predicts gas velocity less than 10 m/s for almost all the pipeline capacity i.e., 375 MMSCFD and 500MMSCFD except for demand of 750 MMSCFD where the velocity value is up to 11 m/s .

Pipeline hydraulic losses increase substantially for 750 MMSCFD capacity. Power requirement for CS2- Bintulu compressor also increases substantially due to increased pressure drop in pipeline. Delivery of 750 MMSCFD in future would require more operating compressors.

Above analysis has been conducted after performing a detailed validation exercise of the simulation model, and after establishing that the simulation model is accurate.

Hence, the NPS 36" is suitable to achieve the maximum flow of 750 MMSCFD at the required velocity values.

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