PARADIP- HALDIA- BARAUNI PIPELINE AUGMENTATION

By

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Dehradun

April, 2015

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A thesis submitted in partial fulfilment of the requirements for the

Degree of

Master of Technology

(Pipeline Engineering)

By

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ACKNOWLEDGEMENT

To begin with, I thank **Dr. Suresh Kumar**, Head of the Department (Mechanical Engineering) for giving me the permission to undertake my project at Indian Oil Corporation Ltd (Pipelines Division).

I also take this opportunity to thank my mentor **Mr. Bhalchandra Shingan**, Asst. Professor, Department of Chemical Engineering, for his whole hearted support as well as valuable inputs during the full course of the project period.

I am deeply thankful to my mentor at Indian Oil Corporation Ltd, **Mr. K Kittappa** (DGM- PJ Mechanical) for his help and for sharing his knowledge on pipelines.

I am also grateful to **Mr. G Venkataramanan**, Senior Manager (Training and Placement) for his assistance and contributions as well as for his prompt and timely help in the official clearances and valuable suggestions. Last but not least I also thank various professors from UPES as well as other staffs of Indian Oil Corporation Ltd for their gracious help and valued contributions.

ABSTRACT

Augmentation is a capacity boosting process. Pipeline augmentation process usually includes increasing capacity of booster pumps or increasing the number of booster pumps due to the increase in throughput. Some projects may have construction of additional loop lines to help facilitate the increase in capacity. Construction of a new boosting station may also be done in cases where the Static Discharge Head is way beyond the Maximum Allowable Pressure.

This Project contains the Augmentation aspects of The Paradip- Haldia- Barauni Pipeline. It includes the topics like Civil and Mechanical aspects of this pipeline.

The Hydraulics of the pipeline before and after augmentation has been calculated. This includes the Friction loss as well as the Static Discharge Head.

TABLE OF CONTENTS

Contents

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

1. Ch. – Chainage
2. HDPE- High Density Polyethylene
3. HDD- Horizontal Directional Drilling
4. O.D- Outer Diameter, m
5. I.D- Internal Diameter, m
6. WT – Wall Thickness, m
7. MMTPA – Million Metric Tons Per Annum
8. Sp.Gr – Specific Gravity of the Crude
9. υ - Crude Viscosity, cst
10. ε - Effective pipe Roughness, m
11. L- Length of the Pipeline, km
12. Q- Flow rate of the crude, Kl/Hr
13. v- Velocity of crude in the pipeline, m/s
14. Re – Reynold's Number
15. f- Friction Factor
16. F_h- Friction Loss
17. g- Acceleration due to gravity, m/s^2
18. SDH – Static Discharge Head, mcl
19. SMYS- Specified Maximum Yield Strength, psi (USCS)
20. MAOP – Maximum Allowable Operating Pressure, mcl
21. mcl- Meter Column of Liquid

COMPANY PROFILE

INDIAN OIL CORPORATION LTD

Indian Oil Corporation Limited is a Public Sector oil and gas company head quartered in New Delhi. It is a part of the Fortune 500 and is largest public corporation in India in terms of revenue. Indian Oil Corporation is given the status as a Maharatna company.

Indian Oil Corporation Ltd is a forerunner in cross country crude oil along with petroleum product pipeline. The Guwahati- Siliguri product pipeline was the first pipeline constructed by Indian Oil in the year 1964. Currently Indian Oil has beyond 11,214kms of pipeline networks in India.

Indian Oil pipelines have been accredited ISO 9000 and ISO 14001 for implementation of proven safety and environmental management systems. Currently the company has the domestic expertise to provide services in the pipelines which includes techno-economic feasibility studies, design and detailed engineering, project implementation, operations and maintenance, consultancy services in augmentation and modernization.

CHAPTER 1

INTRODUCTION

The Paradip- Haldia- Barauni pipeline currently has a capacity of 11 MMTPA in the Paradip- Haldia section and 7.5MMTPA in the Haldia- Barauni Section.

With the commissioning of the Paradip refinery this is set to increase to 15.2 MMTPA in the Paradip- Haldia Section and to 9.2 MMTPA in the Haldia- Barauni Section. The augmentation includes conversion of a scrapper station at Balasore into a full-fledged pump station in the Paradip- Haldia Section. It also includes extending existing loop lines of 18" OD from Haldia to Bholpur (existing till Khanna) and extending of the loop lines of 18" OD from Bolpur to Barauni (existing till Dumri).

The Capital cost of the proposed Augmentation construction activity is roughly ₹ 586 crores.

Fig Source: phbapl.plims.net

Figure 1- PHBPL Route

1.1 Objective

- To understand the Civil and Mechanical Aspects of Paradip- Haldia- Barauni Pipeline Augmentation.

- To calculate the Hydraulics of the pipeline before and after Augmentation.

CHAPTER 2

LITERATURE REVIEW

1. **Liquid Pipeline Hydraulics by E. Shashi Menon-** The hydraulics calculations for Transportation of liquid pipelines in this project has been used with the help of this book. Chapter 3 of this book is mostly used. The equations relating to liquid flow velocity in a pipe, Reynold’s number, Friction Factor by Colebrook- White Equation has been used. The Pressure Drop due to Friction equation and has been fextensively used in the Hydraulics calculations.

2. **ASME 31.4-- 2002: Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids-** This book has been referred to get an understanding of the codes and standards set for the Design of Liquid Pipelines.

3. **Pipeline Drag Reduction Technology report by ConocoPhillips Specialty Products Inc.-** This report has given an impression on Drag Reduction in pipelines due turbulent flow. This report also provided ideas on the Properties and Benefits of Drag Reducing Agents. My project will require adding Drag Reducing Agent to reduce the friction head.

4. **Installation of Pipelines by Horizontal Directional Drilling: An Engineering Design Guide by Paul D. Watson-** This manual gave thoughts on the pipeline construction with the help of Horizontal Directional Drilling. Its use is applicable since this project involves HDD to cross River Ganga and River Ajay. The stages of HDD construction has been briefed in this project.

5. **History and Physical Chemistry of HDPE by Lester H. Gabriel, Ph.D., P.E-** This book has given an insight into High Density Polyethylene coating. Its properties and uses have been explained in this project.

6. **Missouri Livestock Watering Systems Handbook: Route Selection and Surveys-** Chapter 4 of this handbook has provided me the necessary guidelines followed for selecting a route for pipeline construction. Since the Paradip- Haldia-Barauni Pipeline will have extension of loop-lines, this book has been very useful.

7. **Guidelines to Shielded Metal Arc Welding by Miller Electrical Mfg. Co.-** This handbook has provided the information required regarding to Shielded Metal Arc Welding. The handbook also provides the different safety procedures and precautionary guidelines to be followed during the welding procedure.

CHAPTER 3

THEORETICAL DEVELOPMENT

3.1 Route Selection:-

- The route selected should always be of the shortest possible one. The trenching process should be in accordance with Environmental regulation and safety of life and property.
- Environmentally sensitive areas such as Reserve Forests, Protected Forests, Wildlife Areas, Marine Parts, and Bird Sanctuaries etc. should be avoided as far as possible.
- Should be reachable from road during construction and subsequent operations/ maintenance stages.
- Minimum number if crossings with Railways, Roads, Rivers and canals.
- Use of bends along the route should be minimized.

3.2 Route Geography:-

Khanna- Bolpur Section

- The take-off point of the pipeline in this stretch is located at existing Khanna loop-line station.
- Pipeline route traverses through Bolpur and Bardhaman districts of West Bengal.
- No ecologically sensitive area is noticed along the pipeline route.
- The route has no sloping Right of Way and generally traverses through gently rising terrain.
- The pipeline route in this section crosses Ajay River at Ch. 204.00 kms.
- No rocky stretches along this stretch.
- Pipeline in this stretch will terminate at Bolpur Pump Station.

Dumri- Barauni Section:-

- Take-off point of the pipeline in this stretch is located at existing Dumri loop-line terminal station.
- Pipeline traverses through Patna and Begusarai District of Bihar.
- No ecologically sensitive area in this pipeline route.

- Pipeline has no sloping Right of Way and generally traverses through gently rising terrain.
- Pipeline in this stretch crosses Ganga River at Ch. 488.00km.
- No rocky stretches.
- Terminates at Barauni pump station.

3.3 Pipeline Construction:-

Haldia- Barauni Section

- Laying about 64 km long 18” OD for extension of existing loop lines in two stretches, i.e. from existing Khanna loop-line terminal station to Bolpur pump station (37kms) and from Dumri loop line station to Barauni Delivery station (27kms).
- Laying pipelines across obstacles/crossings designated as Cased crossings, submerged crossing, open cut Road and cart track crossings in the above section.
- Laying pipeline by HDD technique across Ajay River at Ch. 204 kms and at River Ganga at Ch. 488kms.
- Caliper survey of the entire newly laid 18” OD pipeline stretches from Khanna to Bolpur and Dumri to Barauni.
- Safeguarding of entire newly laid 18”OD pipeline expanses from Khanna to Bolpur and Dumri to Barauni.

3.4 Station Specifics:-

Paradip to Haldia Section

Sl No:	Station	Distance (km)	Altitude (m)
1	Paradip	0	0
2	Balasore	158	4
3	Haldia	328	4

Table 1 - Paradip to Haldia Station Details

Haldia to Barauni Section

Sl No:	Station	Distance (km)	Altitude (m)
1	Haldia	0	4
2	Bolpur	207	46
3	Barauni	498	40

Table 2 - Haldia to Barauni Station details

3.5 Horizontal Directional Drilling:-

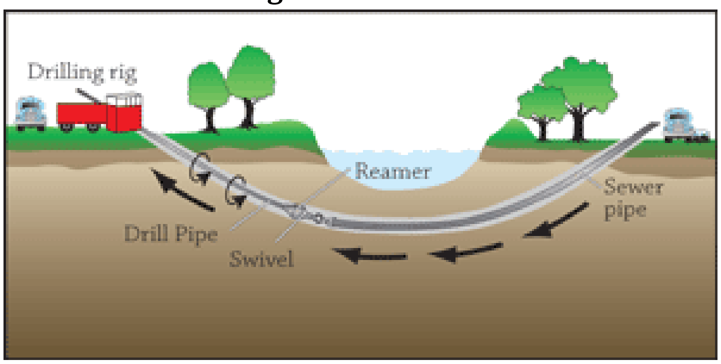

Fig Source: www.tiban.com

Figure 2 - HDD under a water body

- This is a trenchless method for installing buried pipelines.
- This method is mostly used in cases where, there is a lake, wet land, river, road, railway and sensitive wildlife habitat.
- For pipelines, HDD comprises of 4 stages-
  - **Stage 1- Pre-Site Planning**

    This stage generally defines whether an HDD process is technically feasible or not. Underground features are studied by analyzing the current geological data and by conducting field investigations. If an HDD is found to be feasible, a drill path is designed to meet the requirements of the crossing and suitable drill entry and exit locations are selected. An allowance is made in the design of the drill path for any possible changes.

- **Stage 2 – Drilling a Pilot Hole**

All the auxiliary equipment's are setup during the Pre-Site Planning stage. A Pilot hole is drilled along the designated path. Periodic readings from a probe situated close to the drill bit are used to determine the horizontal and vertical coordinates along the pilot hole in relation to the initial entry point; the pilot hole, path may also be traced using a surface monitoring system that determines the down hole probe location by taking measurements from a surface point. Drilling fluid is injected under pressure ahead of the drill bit to provide hydraulic power to the down hole mud motor, transport drill cuttings to the surface, clean buildup on the drill bit, cool the drill bit, decrease the friction between the drill and bore wall, and calm down the bore hole.

- **Stage 3 – Reaming of the Pilot Hole**

The down hole assembly is detached from the drill string upon breaking the ground surface at the exit location and is substituted with a back reamer. The drill string is pulled back through the bore hole and the back reamer enlarges the diameter of the drill hole. The reamer may be pulled from the pipe side of the HDD crossing if additional passes with the reamer are required to achieve the desired bore hole diameter. The reaming phase may not be essential during HDDs for small diameter pipelines where the bore hole created by the pilot hole drill is of satisfactory size to pull back the pipe string.

- **Stage 4 – Pipe String Pull-Back**

Pipe is welded into a pipe string or drag section, which is marginally longer than the length of the drill, on the exit side of the bore hole. The pipe is usually coated by a corrosion and abrasion resistant covering, and is normally hydrostatically pre-tested to ensure pipeline integrity. The pipe string is dragged over rollers into the exit hole and the pull-back continues until the entire pipe string has been pulled into the bore hole. The external coating of the pipe string visible at the entry point is inspected for damage upon completion of the pull back. An internal inspection of the pipe string is performed to identify any damage done to the pipeline during the pull back. Upon successful pull back of the pipe string, the drilling equipment is dismantled and demobilized. The pipe string is connected to the usually laid pipeline and work areas are reclaimed with the rest of the pipeline right-of-way.

3.6 Welding:-

- The welding procedure and finish will be within the limits set by API 1104.
- The Paradip- Haldia- Barauni Pipeline will use Shielded Metal Arc Welding.
- This is a manual arc welding procedure which uses a consumable electrode covered with a flux to lay the weld.
- An electric current, in the form of direct current from a welding power source, is used to form an electric arc between the electrode and the metals to be joined.
- The work piece and the electrode will melt to form a weld pool that cools to form a joint.
- As the weld is laid, the flux coating of the electrode disintegrates; giving off vapors that provide as a shielding gas and providing a layer of slag, both these protect the weld area from atmospheric contamination.
- This welding process is extremely versatile and the equipment operation and maintenance are rather simple.

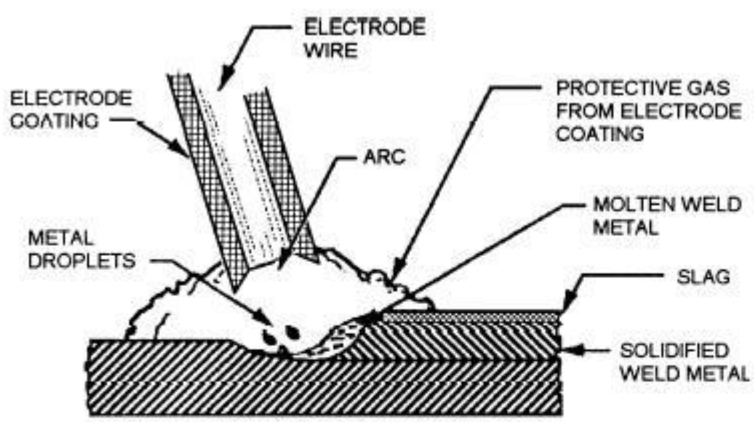

Fig Source: www.wikipedia.com

Figure 3 - Shielded Metal Arc Welding

Welding Methodology:-

- To create an electric arc, the electrode is brought in contact with the work piece by a mild touch with the electrode to the base of the metal and then pulled back slightly.

- This creates the arc, and the melting of the work piece and the electrode takes place.
- This causes small particles of electrode to be passed from electrode to the weld pool.
- As the electrode melts, the flux covering disintegrates, giving off shielding gases that protects the weld area from oxygen and other atmospheric gases.
- In addition, the flux delivers molten slag which covers the filler metal as it travels from the electrode to the weld pool.
- Once part of the weld pool, the slag floats to the surface and protects the weld from contamination as it solidifies.
- Once hardened, it must be chipped away to reveal the finished weld.
- As welding progresses and the electrode melts, the welder must periodically stop welding process to remove the remaining electrode stub and insert a new electrode into the electrode holder.

3.7 Corrosion Mitigation:-

Corrosion:-

Fig Source: www.hj3.com

Figure 4 - Corrosion in a Pipeline

- Corrosion is the degradation of a material through environmental interaction.
- The phenomenon of corrosion involves reactions which lead to the creation of ionic species, by either loss or gain of electrons.

- This phenomenon generally occurs in all materials, both naturally occurring and man-made including plastic, ceramics and metals.
- In general higher level of corrosion occur in the presence of moisture and the hostile gas species, such as chlorine, ammonia, sulphur dioxide, hydrogen sulphide and oxides of nitrogen, that are often present in the atmosphere.
- Corrosion of most common engineering materials at near-ambient temperatures occurs in aqueous (water-containing) environments and is electro-chemical in nature.
- One general example of corrosion is rusting of iron, where metallic iron is converted into various oxides or hydroxides when exposed to moist air. The equations of this reaction are:-

$$Fe \longrightarrow Fe^{++} + 2e^{-}$$

$$O_2 + 2H_2O \longrightarrow 4OH^{-}$$

$$2H_2O + 2e^{-} \longrightarrow H_2 + 2OH^{-}$$

- Because the iron loses electrons, this is referred as an oxidation process. In this case, the resulting product is a mix of hydroxides; where copper reacts with acid residues creating chlorides and sulphides, this would also be referred to as an oxidation process.
- The oxidation reaction is commonly called the anodic reaction and the reduction reaction is called the cathodic reaction. Both electrochemical reactions are necessary for corrosion to occur.
- The oxidation reaction causes the actual metal loss but the reduction reaction must be present to consume the electrons liberated by the oxidation reaction, maintaining charge neutrality.

Coatings:-

- A coating is a covering that is applied to the surface of a metal to protect it from external forces.
- Function of such a coating is to prevent the metal from direct contact with the surrounding electrolyte and to create a high electrical resistance so that the electrochemical reactions cannot readily occur.

- The Paradip- Haldia- Barauni Pipeline uses a 3 Layer coating system.
- Some of the important features of coatings are :–
  - It should be an effective electrical insulator.
  - It should be an active moisture barrier.
  - While applying on the pipeline it should not affect the properties of pipeline with a minimum of flaws.
  - It should resist the development of holes on the surfaces.
  - It should have good adhesive properties.
  - It should have ability to maintain substantially constant electrical resistivity with time.
  - It should not have the toxic interaction with the environment.

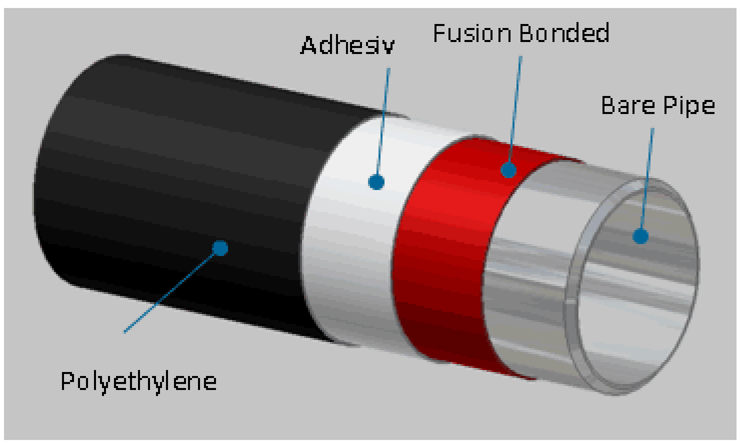

Fig Source: www.slideshare.net

Figure 5 - Cross Section showing 3 Layer Fusion Bonded Epoxy Coating

Fusion Bonded Epoxy:-

- Fusion Bonded Epoxy is an epoxy-based powder coating that is broadly used to protect steel pipe used in pipeline construction.
- FBE coatings are thermoset polymer coatings and they come under the class of protective coatings in paints.
- The term fusion-bond epoxy is due to resin cross-linking and the application method, which is different from a normal paint.
- The resin and hardener components in the dry powder FBE stock remain unreacted at normal storage conditions.

- At usual coating application temperatures, typically in the range of 180 to 250 °C (356 to 482 °F), the contents of the powder melt and convert to a liquid form.
- The liquid FBE film wets and flows onto the steel surface on which it is applied, and soon turns into a solid coating by chemical cross-linking, assisted by heat. This process is known as "fusion bonding".
- The chemical cross-linking reaction taking place in this case is permanent.
- Once the curing takes place, the coating cannot be returned to its original form in any way.

Grafted Polymer Adhesive:-

- This layer acts as a bonding agent between the Fusion Bonded Epoxy primary layer and the High Density Polyethylene outer coating.
- A polymer adhesive is a synthetic bonding agent made from polymers and is considered to be stronger, more flexible and has greater impact resistance than other forms of adhesives.
- A polymer adhesive may come in a variety of forms like urethanes, epoxies, resins, cyanoacrylates and Meta acrylates.

High Density Polyethylene:-

- HDPE is a thermoplastic material composed of carbon and hydrogen atoms fused together to form a product of high molecular weight.
- The polymer chain may be comprised of 500,000 to 1,000,000 carbon units.
- Applying HDPE on pipelines increases its durability, performance, structural integrity as well as hydraulic performance.

3.8 Drag Reducing:-

Drag: - It is frictional losses of a fluid flowing in a pipeline. Drag Reduction occurs due to formation of turbulent eddy currents near the pipeline wall during turbulent flow.

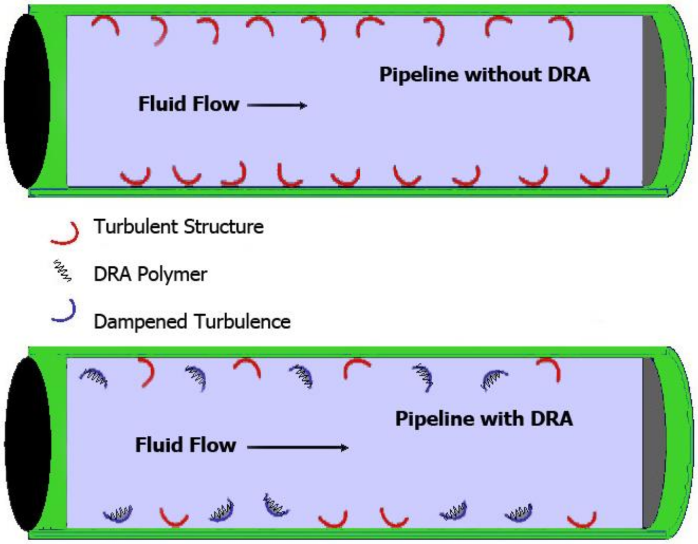

Fig Source: www.drag-reducer .com

Figure 6 - Diagram indicating turbulent flow with and without DRA

Properties of Drag Reducing Agents:-

- They do not modify viscosity or the density of the fluids.
- These are not coating agents for pipelines.
- Alter the turbulent flow.
- They are susceptible to shear points.
- Drag Reducing Agents will shear degrade as treated fluid moves down the pipeline.

Factors Affecting Drag Reducer Performance:-

- Turbulence
- Hydrocarbon Temperature
- Hydrocarbon Viscosity
- Water Content

Benefits of Drag Reducers:-

- Increases flow rates
- Reduces operating pressures

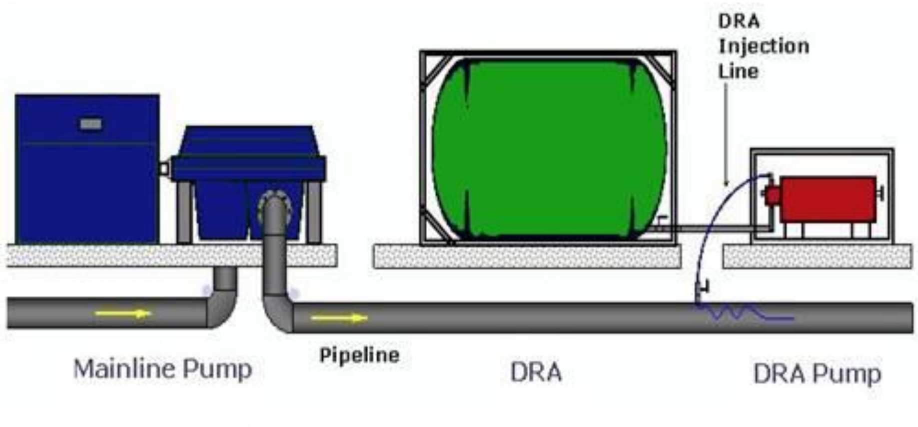

Fig Source: www.pipars.com

Figure 7 - DRA Injection System

3.9 API 5L X65:-

Chemical Composition with thickness (t) ≤ 25mm

X 65/ (%) element	X65-A	X65-B	X65-C	X65-D
C	0.1400	0.1000	0.0844	0.07
Mn	1.3100	1.2900	1.0290	1.48
Si	0.2360	0.2330	0.0322	0.25
P	0.0110	0.0160	0.0110	0.013
S	0.0300	0.0050	0.0082	0.002
Al	0.0023	0.0510	0.0219	0.040
Nb	0.0380	0.0470	0.0000	0.042
Cu	0.0130	0.0070	0.0130	0.09
Cr	0.1160	0.0130	0.0360	0.02
Ni	0.0220	0.1510	0.0356	0.8
Mo	0.0000	0.0000	0.0333	-
V	0.0030	0.0580	0.0536	0.064
Ti	0.0170	0.0160	0.0132	0.017
B	0.0004	0.0005	0.0000	-
Ca	0.000	0.0022	0.0000	-

Table 3- Chemical Composition of API 5L X65

Mechanical Properties:-

Thickness, t (mm)	**Yield, R_{eh} (MPa)**	**Tensile, R_m (MPa)**	**R_{eh}/R_m**	**CVN (-30^0C)**	**EL (%)**
-	Min. 450	Min. 535 Max. 760	Max. 0.93	Min $\geq$ 36J Avg. $\geq$ 42J Transverse	Min. 22

Table 4 - Mechanical Properties of API 5L X65

CHAPTER 5

HYDRAULICS

Formulae Used:-

1. Flow Rate, Q = Throughput / (Sp.Gr * Operational Hours)
2. Velocity, $v = Q / ((\pi/4)*d^2 *3600)$
3. Reynold's Number, $Re = (v*D) / \upsilon$
4. Friction factor, $1/\sqrt{f} = 1.12 + 2 \log (I.D/E) - 2\log (1 + 9.28 \div (Re*(\varepsilon/D)*\sqrt{f})$
5. Friction Head, $f_h = (f*l*v^2) / (2*g*I.D)$
6. Static Discharge Head = Friction Head+ Static Head + Residual Head
7. Maximum Allowable Pressure, MAOP=(SMYS*2*t*10*0.72) / (O.D*14.2*Sp.Gr)

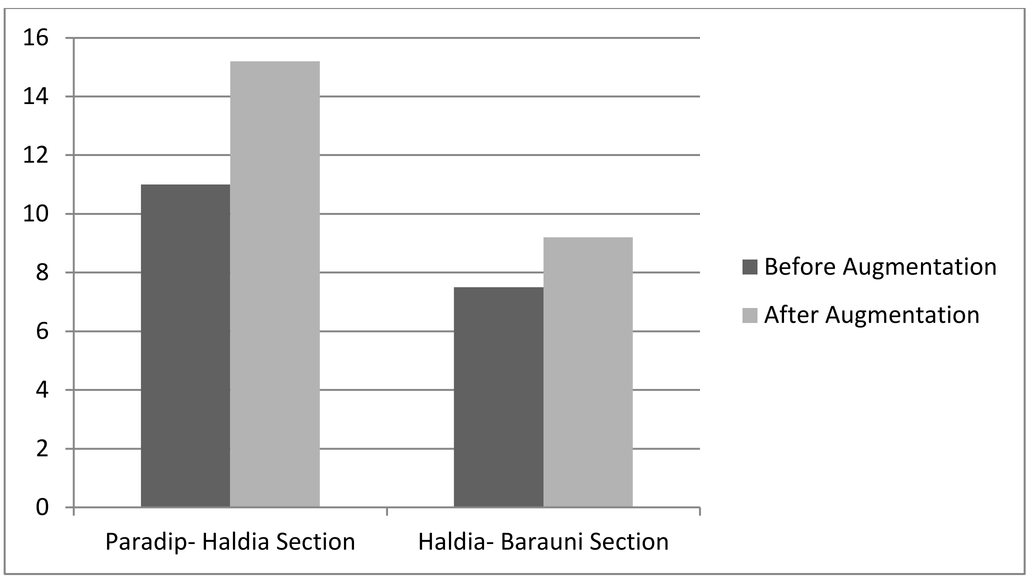

Figure 8 - Graph representing throughput before and after Augmentation

5.1 Before Augmentation:-

Paradip- Haldia Section:-

Figure 9 - Paradip – Haldia Route

Parameters:-

1. Throughput – 11.0 MMTPA
2. Pipe specifications – 30”*0.312”WT, API 5L-X65 Grade
3. Specific Gravity – 0.85
4. Operational hours -8000 Hrs
5. Viscosity ,υ - 25 cst
6. Roughness, ε - 0.0018”= $4.57*10^{-5}$m
7. Length, L – 328km

Calculation:-

Internal Diameter = 30- (2*0.312) = 29.36” = .7461m

Flow rate, Q= $11 * 10^6 \div (0.85 * 8000)$ =1617.64 KL/hr

Velocity, v = $1617.64 \div (\frac{\pi}{4} *.7461^2 * 3600)$= 1.0273m/s

Reynold’s number, Re = vD/υ = $1.0273*0.7461/ (25*10^{-6})$

Re = 30660.59

Friction factor, $1/\sqrt{f}$ = 1.12 +2 log $(.7461/4.57*10^{-5})$ – 2log (1 +9.28 $\div 30660.59 * \left(\frac{4.57*10-5}{.7461}\right) * \sqrt{f}))$

f = 0.0235

Friction head, $F_h = flv^2 / 2gd$

$F_h = .0235 * 328 * 10^3 * 1.0273^2 / (2 * 9.81 * .7461) = 556.132$ mcl

Static Head = 4-2 =2

Residual Head = 50

Static Discharge Head = 556.132+2+50 = 608.13mcl

MAOP= (SMYS *2*t*10*0.72)/ (O.D*14.2*Sp.Gr)

MAOP = (65000 *2 * 0.312*10*0.72)/ (30*14.2*0.85) = 806.49 mcl

Haldia- Barauni Section:-

The Haldia- Barauni Section of the pipeline has varying wall thickness pipeline due to soil conditions in the area. These are:-

1. Ch. 0- Ch. 207 km - 18”OD * 0.25WT, API 5L-X65 Grade
2. Ch. 207- Ch212km -18”OD* 0.375”WT, API 5L-X65 Grade
3. Ch. 212- Ch. 232 km - 18”OD* 0.312”WT, API 5L-X65 Grade
4. Ch. 232- Ch. 498 km - 18”OD* 0.25”WT, API 5L-X65 Grade

Parameters:-

1. Throughput –7.5 MMTPA
2. Specific Gravity – 0.85
3. Operational hours -8000 Hrs
4. Viscosity ,υ - 25 cst
5. Roughness, ε - 0.0018 = $4.57*10^{-5}$m

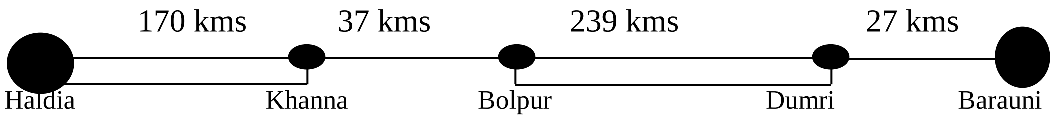

Figure 10 - Haldia- Barauni route

Khanna- Bolpur Section:-

Parameters:-

1. Length – 37 kms
2. Pipe Specifications – 18”OD * 0.25WT, API 5L-X65 Grade

Calculation:-

Flow Rate, Q= $7.5 * 10^6 / (0.85 * 8000)$ = 1102.94 KL/hr

Thickness = 0.25” = $6.35 * 10^{-3}$m

Internal Diameter = 18-(2* 0.25) = 17.5” = 0.4445m

Velocity, v = $1102.94 \div (\frac{\pi}{4} * 0.4445^2 * 3600)$= 1.1974m/s

Reynold’s number, Re = vD/υ = $1.974 * 0.4445 / (25*10^{-6})$

Re= 35103.28

Friction factor, $1/\sqrt{f}$ = $1.12 + 2\log(.4445/4.57*10^{-5}) - 2\log\left(1 + 9.28 \div \left(35103.28 * \left(\frac{4.57*10-5}{.4445}\right) * \sqrt{f}\right)\right)$

f = 0.0229

Friction head, $F_h = flv^2 / 2gd$

$F_h = .0229*37*10^3*1.974^2 / (2*9.81*.4445)$ = 378.58 mcl

Static Head = 46-4 = 42

Residual Head = 50

Static Discharge Head = 449.97+42+50 = 541.97

MAOP= (SMYS *2*t*10*0.72)/ (O.D*14.2*Sp.Gr)

MAOP = 65000 *2 * 0.25*10*0.72/ (18*14.2*0.85) = 1077.04 mcl

Haldia- Khanna Section:-

Parameters:-

1. Length- 170 kms
2. Pipe Specifications- 18"OD * 0.25WT, API 5L-X65 Grade

Calculation:-

Internal Diameter= 18"-(2*0.25")= 17.5"= 0.4445m

Thickness, t = 0.25"= $6.35*10^{-3}$m

Flow through 1 pipe = 1102.94/2 = 551.47Kl/Hr

Velocity, v = $551.47 \div (\frac{\pi}{4} * 0.4445^2 * 3600)$= 0.987 m/s

Reynold's number, Re = vD/υ = 0.987 * 0.4445/ ($25*10^{-6}$)

Re= 17551.641

Friction factor, $1/\sqrt{f}$ = 1.12 +2 log (.4445/$4.57*10^{-5}$) – 2log $(1 + 9.28 \div (17551.641 * \left(\frac{4.57*10-5}{.4445}\right) * \sqrt{f}))$

f = 0.0269

Friction head, F_h= $flv^2/ 2gd$

F_h= .0269 *170 *10^3 *0.987^2/ (2 *9.81 *.4445) = 510.86 mcl

MAOP= (SMYS *2*t*10*0.72) /(O.D*14.2*Sp.Gr)

MAOP = 65000 *2 * 0.25*10*0.72 / (18*14.2*0.85) = 1077.04 mcl

TOTAL FRICTION HEAD, F_h = 378.58+510.86 = 889.39 mcl

TOTAL STATIC DISCHARGE HEAD= 889.39+ 42+ 50= 981.39 mcl

Dumri- Barauni Section:-

Parameters:-

1. Length- 27 kms

Calculation:-

Outer Diameter= 18”

Internal Diameter, d= 18”-(2* 0.25”) =17.5” = 0.4445 m

Thickness, t = 0.25”= $6.35*10^{-3}$

Velocity, v = $1102.94 \div (\frac{\pi}{4} * 0.4445^2 * 3600)$= 1.974 m/s

Reynold’s number, Re = vD/υ = 1.974 * 0.4445/ ($25*10^{-6}$)

Re= 35103.28

Friction factor, $1/\sqrt{f}$ = 1.12 +2 log (.4445/$4.57*10^{-5}$) – 2log ($1+9.28 \div (35103.28 * \left(\frac{4.57*10-5}{.4445}\right) * \sqrt{f})$)

f = 0.0229

Friction head, F_h= $flv^2/ 2gd$

F_h= .0229 *27 *10^3 *1.974^2/ (2 *9.81 *.4445) = 260.57 mcl

MAOP= (SMYS *2*t*10)*0.72/ (O.D*14.2*Sp.Gr)

MAOP = 65000 *2 * 0.25*10*0.72 / (18*14.2*0.85) = 1077.04 mcl

Bolpur- Dumri Section:-

Parameters:-

1. Length- 264 kms

Calculation:-

I. Ch. 232-471km (18”OD* 0.25”WT, API 5L-X65 Grade)

Outer Diameter = 18”

Thickness, t = 0.25”= $6.35*10^{-3}$

Internal Diameter = 18- (2*0.25) = 0.4445m

Velocity, v = $551.47 \div (\frac{\pi}{4} * 0.4445^2 * 3600)$= 0.987 m/s

Reynold’s number, Re = vD/υ = 0.987 * 0.4445/ ($25*10^{-6}$)

Re= 17551.64

Friction factor, $1/\sqrt{f}$ = 1.12 +2 log (.4445/$4.57*10^{-5}$) – 2log (1+$9.28 \div (17551.64 * \left(\frac{4.57*10-5}{4445}\right) * \sqrt{f}$))

f = 0.0269

Friction head, F_h= flv^2/ 2gd

F_h= .0269 *239 *10^3 *0.987^2/ (2 *9.81 *.4445) = 718.27 mcl

MAOP= (SMYS *2*t*10)*0.72 / (O.D*14.2*Sp.Gr)

MAOP = 65000 *2 * 0.25*10*0.72 / (18*14.2*0.85) = 1077.04 mcl

II. Ch. 212 -232km (18”OD* 0.312”WT, API 5L-X65 Grade)

Thickness, t = 0.312”= $7.92*10^{-3}$m

Internal Diameter = 18- (2*0.312) = 17.376”= 0.4413m

Velocity, v = $551.47 \div (\frac{\pi}{4} * 0.4413^2 * 3600)$= 1.001 m/s

Reynold’s number, Re = vD/υ = 1.001 * 0.4413/ ($25*10^{-6}$)

Re= 17678.91

Friction factor, $1/\sqrt{f}$ = 1.12+2 log (.4413/4.57*10^{-5}) – 2log(1+9.28 ÷ (17678.91 * $\left(\frac{4.57*10-5}{.4413}\right) * \sqrt{f}$))

f = 0.0269

Friction head, F_h= $flv^2/2gd$

F_h= .0269 *20 *10^3 *1.001^2/ (2 *9.81 *.4445) = 62.261 mcl

MAOP= (SMYS *2*t*10*0.72)/ (O.D*14.2*Sp.Gr)

MAOP = 65000 *2 * 0.312*10*0.72 / (23.126*14.2*0.85) = 1344.152 mcl

III. Ch. 207 -212km (18"OD* 0.375"WT, API 5L-X65 Grade)

Thickness, t = 0.25"= 6.35*10^{-3}

Internal Diameter = 18 – (2*0.375) = 17.25" = 0.4381m

Velocity, v = 551.47 ÷ ($\frac{\pi}{4} * 0.4381^2 * 3600$)= 1.016 m/s

Reynold's number, Re = vD/υ = 1.016 * 0.4381/ (25*10^{-6})

Re= 17808.04

Friction factor, $1/\sqrt{f}$ = 1.12 +2log(.4381/4.57*10^{-5}) –2log(1+ 9.28 ÷ (17808.04 * $\left(\frac{4.57*10-5}{.4381}\right) * \sqrt{f}$))

f = 0.0268

Friction head, F_h= $flv^2/2gd$

F_h= .0268 *5 *10^3 *1.016^2/ (2 *9.81 *.4381) = 19.069 mcl

MAOP= (SMYS *2*t*10)/ (O.D*14.2*Sp.Gr)

MAOP = 65000 *2 * 0.375*10*0.72/ (18*14.2*0.85) = 1615.56 mcl

TOTAL FRICTION HEAD= 260.57+718.27+62.261+19.069= 1060.17 mcl

Static Head = 40-46= -6

Residual Head= 50

TOTAL STATIC DISCHARGE HEAD = 955.93+50 – 6= 1104.17 mcl

5.2 After Augmentation:-

Paradip- Haldia Section:-

Parameters:-

1. Throughput – 15.2 MMTPA
2. Pipe specifications – 30”*0.312”WT, API 5L-X65 Grade
3. Specific Gravity – 0.88
4. Operational hours -8000 Hrs
5. Viscosity ,υ - 40 cst
6. Roughness, ε - 0.0018 = $4.57*10^{-5}$m
7. Length, L – 328 km

Calculation:-

Internal Diameter, ID = 0.7461m

Flow Rate, Q= $15.2* 10^6/ (0.88 * 8000)$ = 2159.09 Kl/Hr

Velocity, v = $2159.09 \div (\frac{\pi}{4} * .7461^2 * 3600)$= 1.371m/s

Reynold’s number, Re = vD/υ = 1.371*0.7461/ $(40 *10^{-6})$

Re = 25587.12

Friction factor, f = 0.0245

Friction head, $F_h= flv^2/ 2gd$

$F_h= 0.0245*328 *10^3 *1.371^2/ (2 *9.81 *.7461)$ = 1031.08 mcl

Static Head = 4-2 =2

Residual Head = 50

Static Discharge Head = 1031.08 +2+50 = 1083.855 mcl

MAOP= (SMYS *2 *t*10*0.72) / (O.D *14.2* Sp.Gr)

MAOP = (65000 *2 * 0.312*10*0.72) / (30*14.2*0.88) = 779.001 mcl **(Solution 1)**

Static Discharge Head > MAOP

Hence an intermediate pumping Station in Required at Balasore

Paradip- Balasore Section:-

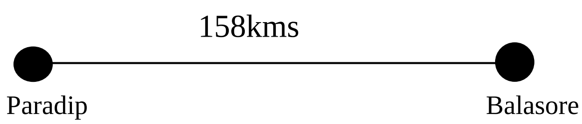

Figure 11 - Paradip to Balasore Route (After Augmentation)

Parameters:-

1. Throughput – 15.2 MMTPA
2. Pipe specifications – 30”*0.312”WT, API 5L-X65 Grade
3. Specific Gravity – 0.88
4. Operational hours -8000 Hrs
5. Viscosity ,υ - 40 cst
6. Roughness, ε - 0.0018 = $4.57*10^{-5}$m
7. Length, L- 158 km

Calculation:-

Internal Diameter, ID = 0.7461m

Flow Rate, Q= $15.2*10^6$/ (0.88 * 8000) = 2159.09 KL/hr

Velocity, v = $2159.09 \div (\frac{\pi}{4} * .7461^2 * 3600)$= 1.371m/s

Reynold's number, Re = vD/υ = 1.371*0.7461/ (40 *10^{-6})

Re = 25587.12

Friction factor, f= 0.0245

Friction head, F_h= $flv^2/ 2gd$

F_h =0.0245*158*10^3*1.371^2/ (2*9.81*0.7461) = 497.052 mcl

Static Head = 4 – 2= 2

Residual Head = 50

Static Discharge Head = 497.052 + 2+ 50 = 549.05 mcl

MAOP = 779.001 mcl **(From Solution 1)**

Balasore - Haldia Section:-

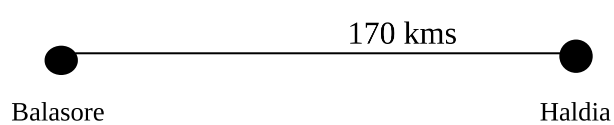

Figure 12 - Balasore to Haldia Route (After Augmentation)

Parameters:-

1. Throughput – 15.2 MMTPA
2. Pipe specifications – 30"*0.312"WT, API 5L-X65 Grade
3. Specific Gravity – 0.88
4. Operational hours -8000 Hrs
5. Viscosity ,υ - 40 cst
6. Roughness, ε - 0.0018"= 4.57*10^{-5}m
7. Length, L- 170 km

Calculation:-

Internal Diameter, ID = 0.7461m

Flow Rate, Q= 15.2* 10^6/ (0.88 * 8000) = 2159.09 KL/hr

Velocity, v = $2159.09 \div (\frac{\pi}{4} * .7461^2 * 3600)$= 1.371m/s

Reynold's number, Re = vD/υ = 1.371*0.7461/ (40 *10^{-6})

Re = 25587.12

Friction factor, f= 0.0245

Friction head, F_h= flv^2/ 2gd

F_h =0.0245*170*10^3*1.371^2/ (2*9.81*0.7461) = 534.80 mcl

Static Head = 4 – 2= 2

Residual Head = 50

Static Discharge Head = 534.80 + 2+ 50 = 584.05 mcl

MAOP = 779.001 mcl **(From Solution 1)**

Haldia- Bolpur Section:-

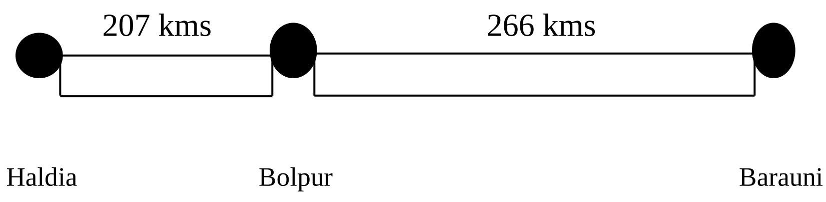

Figure 13 - Haldia to Barauni Route (After Augmentation)

Parameters:-

1. Throughput –9.2 MMTPA
2. Specific Gravity – 0.88
3. Operational hours -8000 Hrs
4. Viscosity ,υ – 40 cst
5. Roughness, E- 0.0018 = $4.57*10^{-5}$m
6. Length – 207 kms
7. Pipe Specifications – 18"OD * 0.25WT, API 5L-X65 Grade

Calculation:-

Flow Rate = $9.2 *10^6/ (0.88* 8000)$ =1306.818 Kl/Hr

Flow through 1 pipe = 1306.818/ 2 = 653.406 Kl/Hr

Thickness = 0.25" = $6.35* 10^{-3}$m

Internal Diameter = 18 – (2*0.25) = 17.5" = 0.4445m

Velocity, v = $653.409 \div (\frac{\pi}{4} * 0.4445^2 * 3600)$= 1.169 m/s

Reynold's number, Re = vD/υ = $1.169 * 0.4445/ (40*10^{-6})$

Re= 12997.53

Friction factor, $1/\sqrt{f}$ = $1.12 +2 \log (.4445/4.57*10^{-5}) – 2\log (1+9.28 \div (12997.53 * \left(\frac{4.57*10-5}{.4445}\right) * \sqrt{f}))$

f = 0.029

Friction head, $F_h= flv^2/ 2gd$

$F_h= .029 *207 *10^3 *1.169^2/ (2 *9.81 *.4445)$ = 940.646 mcl

Static Head = 46-4 =42

Residual Head = 50

Static Discharge Head = 940.646 +42+50 = 1032.646 mcl

MAOP= (SMYS *2*t*10*0.72)/ (O.D*14.2*Sp.Gr)

MAOP = 65000 *2 * 0.25*10*0.72/ (18*14.2*0.88) = 1040.33 mcl

Bolpur- Barauni Section:-

Parameters:-

1. Throughput- 9.2MMTPA
2. Specific Gravity – 0.88
3. Operational hours -8000 Hrs
4. Viscosity ,υ – 40 cst
5. Roughness, E- 0.0018 = $4.57*10^{-5}$m

Calculation:-

A. Ch. 232 -498 km (18"OD* 0.25"WT, API 5L-X65 Grade)

Thickness, t = 0.25"= $6.35*10^{-3}$m

Internal Diameter = 18 – (2*025) = 17.5" = 0.4445m

Velocity, v = $653.409 \div (\frac{\pi}{4} * 0.4445^2 * 3600)$= 1.169 m/s

Reynold's number, Re = vD/υ = 1.169 * 0.4445/ ($40*10^{-6}$)

Re= 12990.51

Friction factor, $1/\sqrt{f}$ = 1.12 +2 log(.4445/$4.57*10^{-5}$) – 2log(1+$9.28 \div (12990.51 * \left(\frac{4.57*10-5}{.4445}\right) * \sqrt{f})$)

f = 0.029

Friction head, F_h= $flv^2/ 2gd$

F_h= .029 *266 *10^3 *1.169^2/ (2 *9.81 *.4445) = 1208.75mcl

MAOP= (SMYS *2*t*10)/ (O.D*14.2*Sp.Gr)

MAOP = 65000 *2 * 0.25*10*0.72/ (18*14.2*0.88) = 1040.33 mcl

B. Ch. 212 -232km (18"OD* 0.312"WT, API 5L-X65 Grade)

Thickness, t = 0.312"= $7.92*10^{-3}$m

Internal Diameter = 18 – (2*0.312) = 17.376" = 0.4413m

Velocity, v = $653.409 \div (\frac{\pi}{4} * 0.4413^2 * 3600)$= 1.186 m/s

Reynold's number, Re = vD/υ = 1.186 * 0.4413/ ($40*10^{-6}$)

Re= 13091.78

Friction factor, $1/\sqrt{f}$ =1.12+2log (.4413/$4.57*10^{-5}$)–2log $(1+9.28 \div (13091.78 * \left(\frac{4.57*10-5}{.4413}\right) * \sqrt{f}))$

f = 0.029

Friction head, F_h= flv^2/ 2gd

F_h= .029 *20 *10^3 *1.186^2/ (2 *9.81 *.4413) = 94.22 mcl

MAOP= (SMYS *2*t*10)*0.72 / (O.D*14.2*0.88)

MAOP = 65000 *2 * 0.312*10*0.72 / (18*14.2*0.88) = 1298.33 mcl

C. Ch. 207-212km (18"OD* 0.375"WT, API 5L-X65 Grade)

Thickness, t = 0.375"= $9.525*10^{-3}$m

Internal Diameter = 18 – (2*0.375) = 17.25"= 0.4381m

Velocity, v = $653.409 \div (\frac{\pi}{4} * 0.4381^2 * 3600)$= 1.204 m/s

Reynold's number, Re = vD/υ = 1.204 * 0.4381/ ($40*10^{-6}$)

Re= 13187.409

Friction factor, $1/\sqrt{f}$ =1.12+2 log (.4381/4.57*10^{-5}) – 2log(1+9.28 $\div$ (13187.409 $*$ $\left(\frac{4.57*10-5}{.4381}\right) * \sqrt{f}$))

f = 0.0289

Friction head, F_h= flv^2/ 2gd

F_h= .0289 *5 *10^3 *1.204^2/ (2 *9.81 *.4381) = 24.86 mcl

MAOP= (SMYS *2*t*10*0.72)/ (O.D*14.2*Sp.Gr)

MAOP = 65000 *2 * 0.375*10*0.72/ (18*14.2*0.88) = 1560.49 mcl

TOTAL FRICTION HEAD= 20.86+1208.75+94.22 = 1327.83 mcl

Static Head = 40-46= -6

Residual Head= 50

TOTAL STATIC DISCHARGE HEAD = 1327.83 +50– 6= 1371.83 mcl

Since the Friction Head is more than the MAOP in Ch232- Ch498 km, a Drag Reducing Agent is added,

Drag Reduction = SDH – MAOP

Drag Reduction =1371.88-1040.33.05 = 331.55 mcl

Friction Factor for Ch. 232-498 km = 1204.75 – 331.55 = 873.2 mcl

Drag Reducing = (1208.75-873.2)*100/1208.75= 27.76%

CHAPTER 6

RESULTS AND DISCUSSION

STATION	FLOW RATE		FRICTION LOSS		SDH	
	Before (Kl/Hr)	**After (Kl/Hr)**	**Before (mcl)**	**After (mcl)**	**Before (mcl)**	**After (mcl)**
Paradip	1617.64	2159.09	556.132	497.05	608.132	549.05
Balasore	-	2159.09	-	534.80	-	584.80
Haldia	1102.94	1306.818	889.39	940.646	981.39	1032.646
Bolpur	1102.94	1306.818	1060.17	1327.83	1104.17	1371.83

Table 5 - Tabulated Result

- The above table represents the values of Friction Head and Static Discharge Head before and After the Augmentation.
- The Static Discharge Head before Augmentation at Paradip is 608.132 mcl, at Haldia is 981.39mcl and Bolpur is 1104.17mcl.
- After augmentation, these values have changed to 549.05 mcl at Paradip and the new Balasore pumping station is 584.80 mcl. The Haldia station will have 1032.646mcl and Bolpur station will have 1371.83 mcl.
- The Static Discharge Head at all stations and points except at section Ch. 232-498kms (Haldia -Barauni Section) falls within the MAOP.
- At Ch.232-498 section of the Haldia- Barauni Section, a 24.3% of Drag Reducing Agent is required to be added along with Crude Oil at section Ch. 232- 498kms. This helps to reduce the Friction Head lower than the required Maximum Allowable Pressure of 1040.33 mcl.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

- From this project the Augmentation aspects like Civil and Mechanical aspects of Paradip- Haldia- Barauni Pipeline has been studied.
- The Hydraulics of the pipeline has also been calculated.
- I propose adding additional berthing facilities for VLCCs at Paradip instead of Haldia due to the availability of deep draft at Paradip Coast.
- Additional SPM’s at Paradip is also another viable option.

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