Design and Analysis and Cost Imperative of A Prototype Pig Launcher for Upstream Oil Sector

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***Abstract*—** *This research is on design of and fabrication of a single barrel pig launcher. A 14 inches diameter pipe was used for the main launcher barrel and a 10 inches diameter pipe used for the minor barrel. These parts were joined by welding processes. Components such as signaler, vent, drainer, pressure gauge, eccentric reducer, etc, were welded alongside the pipe. The launcher was designed to withstand fluid pressure of 200bar and also accommodate a single pig during launching operation. Solid cast pig was employed and launcher designed to suit the upstream oil industries where it would find application for cleaning, inspection and monitoring of pipelines.*

Keywords*— *Design; Fabrication; Pig launcher; Cast pig; Cleaning; Inspection and Monitoring.

I. INTRODUCTION

A pig launcher is a mechanical device used for inserting pigs into a pipeline and launching them without flow obstruction. They are integral part of a pipeline network system for periodic cleaning of pipelines conducting crude oil and natural gas. Pig launcher could be installed in facilities handling products such as lubricating oil, paints, chemical, toiletries, cosmetics and foodstuffs. Usually pig launchers are located at compressor stations and at terminal points where special arrangement of pipings and valves allow the running of pigs with little or no disruption of ongoing pipeline operation. During installation of pipeline network system, temporary pig launcher stations can be located at convenient intervals to enable clearing construction debris from the pipeline.

Generally pig launchers are used in cleaning operations, corrosion control, distribution of corrosion inhibitors and internal inspection of gas pipeline network system. Having been acquainted with the areas of application of pig launcher in pipeline network system, the research focus is to design a prototype pig launcher that could perform its intended function optimally with economic viability as critical object of concern.

II. LITERATURE REVIEW

In oil and gas transmission industries pipeline is a form of stationary transportation system made up of pipes and fittings used in the construction of the facilities. The commodities being transmitted include crude oil, petroleum products, slurries etc, over a great distance without being seen in the piping system. For periodic cleaning of the internal surface of the pipeline, an equipment known as pig launcher is required to introduce the pig into the pipeline and retrieve it at the end of the segment being pigged (Antaki, A. G., 2003; Jim C., 2003; Jim, C. and Hershal, V, 2013).

According to (Tirasco, 2013; Meshner, T. O. and Leffler L. M., 2006; Nayyer, M. L., 2000) the history of transmission of fluid through pipelines dates back to 1904 when a 4 inches pipeline was installed in Montana. Cleaning and inspection of the line employed rubber balls (sphere) as displacement pigs. The era of displacement pigs using rubber balls led to the development of pig launcher. Three configurations of pig launchers in use in flow line stations to remove gases and condensates due to formation of waxes and condensates are as outlined: (i) Valve type multiple pig launcher, (ii) Vertical multiple pig launcher and (iii) Automatic sphere launcher.

The valve type multiple pig launcher is fitted with a set of launch valves for each pig in the launcher. This allows the pressure to be directed behind each in turn and so be launched individually as required (Antaki, 2003). Though the system is reliable, additional valving requirement makes the device cost ineffective.

The beauty of the vertical multiple pig launcher revolves around the space solution. It has additional hydraulically operated launch pins that protrude into the oversize barrel of the launcher. Though the system is reliable, it suffers the drawback of the valve type multiple pig launcher.

The third variation is automatic sphere launcher. Technically not a pig launcher, spheres are regularly used when large numbers of cleaning runs are required. The efficiency of operation is not a major concern when removal of unwanted fluid is the primary consideration.

III. RESEARCH SIGNIFICANCE

The design considerations of outlined pig launchers employed concentric reducers resulting in the awkward transition of the pig from the launcher to the mainline. This research noted this drawback and proposed design changes for eccentric reducer. More so a simple quick closure that will be more cost effective, time saving and having safety consideration in its design will be integrated.

IV. MATERIALS AND METHOD

4.1 Design Consideration

The launcher is designed for pipeline inspection gauge or to perform various maintenance operations in oil and gas pipelines to clean the pipes and protect the internal section from corrosion. Low cost materials are sourced to design the launcher.

4.1.1 Design Pressure and Pipe thickness:

The design pressure and nominal pipe thickness is subject to American Society of Mechanical Engineers (ASME) B31.8 standard code. The expression relating the design pressure and nominal pipe wall thickness is given as:

$$P = \frac{2St \times FET}{D} \tag{1}$$

Where,

P—Design pressure (bar)

S—Specific maximum yield strength (N/m^2)

D—Nominal outside diameter (m)

t—Nominal pipe thickness (m)

E—Longitudinal joint factor (=1 for API 5L specification)

T—temperature derating factor (=1, if T ≤ 25^{0}F)

F—Constructional type design factor. This factor is governed by the population density of the environment in view. The environment in question are classified as follows:

Type A—Sparsely populated area such as desert, mountains and farm land.

Type B—Areas around cities and towns.

Type C—Cities or towns with no building taller three storey.

Type D—Areas with building over three storey.

The construction type design factors for the different environment question are as specified in Table 1:

TABLE 1
VALUES OF BASIC DESIGN FACTORS (MOHINDER L. MAYYER, 2002)

Construction Type	Design Factor
A	0.72
B	0.60
C	0.50
D	0.40

4.1.2 Code and Criteria for the Design of the Pig Launcher

The design of the pig launcher is in accordance with American Society of Mechanical Engineer (2003): B31.8 Code for gas transmission and distribution piping system, ASME B31.3 Code for process piping and ASME SEC viii for Boiler and pressure vessel code. The design criteria for the launcher are as specified:

- A specified maximum design operating fluid pressure.
- Specified minimum design ambient temperature.
- Design factor for launcher of type B.
- Specified minimum yield strength of the main pipeline.
- The size of the launcher.

4.2 Design Equations:

The expression relating the barrel thickness to the design pressure of the mainline is as expressed in Equation 1.

The launcher is made up of the following component.

The barrel has the following details:

- A specified pipe diameter of a given length.
- An eccentric reducer.
- A flange connection for by pass-line.
- Connection for drain.
- Connection for vent.
- Provision for pressure indicator and signaler.
- A quick opening closure of a clamp nature.

The quick opening closure is a proprietary item and must be designed in accordance with ASME 36.10 section viii Division 1.

The weight of launcher barrel is determined as follows:

Pipe volume is given as:

$$V = A \times L = \pi R^2 L \tag{2}$$

Where,

A—area of pipe (m^2)

L—length of pipe (m)

R—internal pipe radius

Pipe mass is given as:

$$m = \rho V \tag{3}$$

ρ –pipe density (kg/m^3)

Weight of pipe is expressed as:

$W = \rho V g$ (4)

g—acceleration due gravity (m/s^2)

The clamping pressure are determined as follows:

The clamping pressure is given as:

$$P = \frac{F}{A} \tag{5}$$

F--clamping force (N)

The clamping pressure is equal to the pressure on inner part of the closure

Hoop stress acting on the barrel is determined as follows (Khurmi, R. S., and Gupta, J. K., 2006) :

$$\sigma_h = \frac{Pd}{t} \tag{6}$$

P—internal pipe pressure (N/m2)

d—internal pipe diameter (m)

t—pipe thickness (m)

The longitudinal stress acting on the barrel is given as:

$$\sigma_L = \frac{Pd}{2t} \tag{7}$$

The working stress in the flange given as:

$$\sigma_b = \frac{6FY}{n \times t_f^2}$$

Where,

F—force trying to separate the flange (N)

Y—a specified distance from the center of the bolts in vertical direction

n—number of bolts

x—center to center distance of two bolts with a bolt in between

t_f—thickness of flange

4.2.1 Choice of Pig

A solid cast pig is chosen. It is made of steel body with polyurethane cup or disc. The cup and disc are typically sized to be 1/16 to 1/18 inches larger in diameter than the pipe inner diameter.

B Design Calculations

4.2.2 Pipe Thickness Design

Operating Parameters:

P—Design pressure =200bar

S—Specific maximum yield strength =7860N/m2

D—Nominal outside diameter=0.356m

E—Longitudinal joint factor (=1 for API 5L specification)

T—temperature derating factor (=1, if T ≤ 25^0F)

F—Constructional type design factor=0.60

The nominal pipe thickness, t, can be obtained by rearrangement of Equation (1), hence,

$$t = \frac{PD}{2SFET} = \frac{200 \times 0.356}{2 \times 785 \times 0.6 \times 1 \times 1} = 0.07549m$$

4.2.3 Design for Weight of Quick Closure

Operating Parameters:

Diameter of closure, D=14”= 0.355.6mm

Length of Closure, L=0.78”=20mm

To determine volume of closure,

$V = \pi r^2 L = \pi \times 177.8^2 \times 20 = 1986550.9 mm^3 = 0.001986551 m^3$

To determine the mass of closure, m

Density of high carbon steel, ASTM-A242=7860kg/m^3

$m = \rho V = 7860 \times 0.00198551 = 15.61 kg$

Weight of closure, W=mg=15.61×9.81=153.13N

4.2.4 To calculate the weight of the main launcher

Area of cylindrical pipe, $A = \pi R^2 = \pi \times 0.178^2 = 0.099 m^2$

Length of the main pipe=2m

Volume of main pipe, $V = \pi R^2 L = 0.099 \times 2 = 0.198 m^3$

Mass of the main pipe, $m = \rho V = 7860 \times 0.198 = 1556.28 kg$

Weight of the main pipe, $W = mg = 1556.28 \times 9.81 = 15267.12 N$

4.2.5 To determine the weight of the minor launcher barrel

Area of cylindrical pipe, $A = \pi R^2 = \pi \times 0.127^2 = 0.05 m^2$

Length of the minor pipe=0.8m

Volume of minor pipe, $V = \pi r^2 L = 0.05 \times 0.8 = 0.04 m^3$

Mass of the minor pipe, $m = \rho V = 7860 \times 0.04 = 314.4 kg$

Weight of minor launcher barrel, $W = mg = 313.4 \times 9.81 = 3084.26 N$

TABLE 2
SUMMARY OF WEIGHT OF COMPONENTS

Components	Weight (N)
closure	153.13
Main launcher barrel	15267.12
Minor launcher barrel	3084.26
Total weight	18504.51

4.2.6 To determine the barrel clamping force

The clamping force of the barrel varies according to the fluid pressure or force emanating from the fluid pressure. In this scenario, the clamping force should be equivalent to design pressure of 200bar.

Thus, clamping force, $F = PA = 200 \times 10^5 \times \pi \times 0.165^2 = 1710.8 N$

To calculate the stresses acting on the barrel:

4.2.7 Hoop stress

Operating parameters

Internal fluid pressure, P=200bar

Radius of barrel R=0.178m

Wall thickness, t=0.02m

The hoop stress acting on the barrel is given by Equation (6)

$\sigma_H = \frac{Pd}{2t} = \frac{200\times10^5\times0.356}{2\times0.02} = 178MN/m^2$

The longitudinal stress acting on the barrel is as in Equation (7)

$\sigma_L = \frac{Pd}{4t} = \frac{200\times10^5\times0.356}{4\times0.02} = 89MN/m^2$

4.2.8 To calculate the working stress on flange

Referring to Equation (8), the working stress on the flange is expressed as:

$$\sigma_F = \frac{6FY}{n\times t_f^2} \quad (8)$$

With reference to appendix C, for 10 inches:

Pipe diameter, D=273mm (o.273m)

Fluid pressure, P=200bar

Pitch circle diameter of bolts, D_p=387mm (0.387mm)

The flange is connected using sixteen M12 bolts

Number of bolts, n=16 and bolt diameter, d=12mm

Wall thickness for 10 inches pipe, t=21mm (0.021m)

Thickness of flange, $t_F = 1.5t + 3 = 1.5 \times 21 + 3 = 34.5mm$

Diameter of bolt hole, d_1=d+2=12+2=14mm

Diameter of the circle tangential to the inner part of the bolt holes, D_1=D_p-d_1=387-14=373 mm (0.373)

Therefore, the force trying to separate flange, that is the force acting on the 16 bolts,

$F = \frac{\pi}{4}D_1^2P = \frac{\pi}{4} \times 0.373^2 \times 200 \times 10^5 = 2185433.22N$

Bending moment at section X-X tangential to the outside of the pipe

By measurement, X=150mm (0.15m)

Distance of section X-X, Y from the center of the bolt is given as:

$Y = \frac{D_p}{2} - \left(\frac{D}{2} + t\right) = \frac{387}{2} - \left(\frac{254}{2} + 21\right) = 45.4mm$

The bending moment on each bolt M_b due to force F:

$M_b = \frac{FY}{n} = \frac{2185433.33\times45.4}{16} = 6201166.76Nmm$

The resisting moment in the flange, M_{RF} is given as:

$M_{RF} = \sigma_b \times \left(\frac{1}{6}\right) \times X \times t_F^2 = \sigma_b \times \left(\frac{1}{6}\right) \times 150 \times 34.5^2 = \sigma_b \times 29756.25Nmm$

The bending and the resisting moment should be equal. Hence, σ_b then working stress is given as:

$\sigma_W = \frac{6201166.76}{29756..25} = 208\frac{MN}{m^2}$

V Launcher Cost Imperative

Material specification and cost estimation to build the launcher is as in Table 3.

TABLE 3
PRELIMINARY PIG LAUNCHER STATION MATERIAL LIST AND COST

Tag No.	Quantity	Item Description	Material Used	Material Cost (N)	Fabrication Cost (N)	Total (N)
HS01	1	14" fillet weld rolled pipe	200mm x 1118.5mm	12000	5000	17000
HS 02	1	10 fillet weld rolled pipe	2mm thickness, 1000mm x 85mm, 7.8mm thickness	9000	4500	13500
N12	1	14 WN RTJ flange 600#	Flange face thickness 62x1835mm for end closure, Flange neck 1118.6 x 1335.35mm	5000	4000	9000
-	-	-	-	-	-	-
PT		Paint		5000		5000
EL	2 Pkts	Electrodes		7000		7000
TP		Transportattion		25000		25000
CON		Contingencies		30000		30000
Grand Total						139,900.00

V. DISCUSSION OF RESULTS

The barrel of the prototype pig launcher was designed to handle fluid pressure of 200bar. The operating condition of the barrel demands that the hoop stress, the longitudinal stress and the working stress should be able to withstand the operating pressure of the barrel fluid. Design calculations confirmed the numerical value of the hoop stress as $178\times10^6 N/m^2$, longitudinal stress as $89x10^6 N/m^2$ and working stress as $208x10^6 N/m^2$. Subject to all safety precautions, it is evident that the barrel will not rupture or burst longitudinally or transversely. The working stress of the barrel is on the high side compared with barrel fluid operating pressure of $200x10^5 N/m^2$. The beauty of this research is that the materials are sourced locally. The unit cost of the pig launcher is one hundred and thirty nine thousand and nine hundred naira only (N139,900.00). The detailed designs for the various components of the pig launcher are as shown in appendix A, appendix B and appendix C.

VI. CONCLUSION

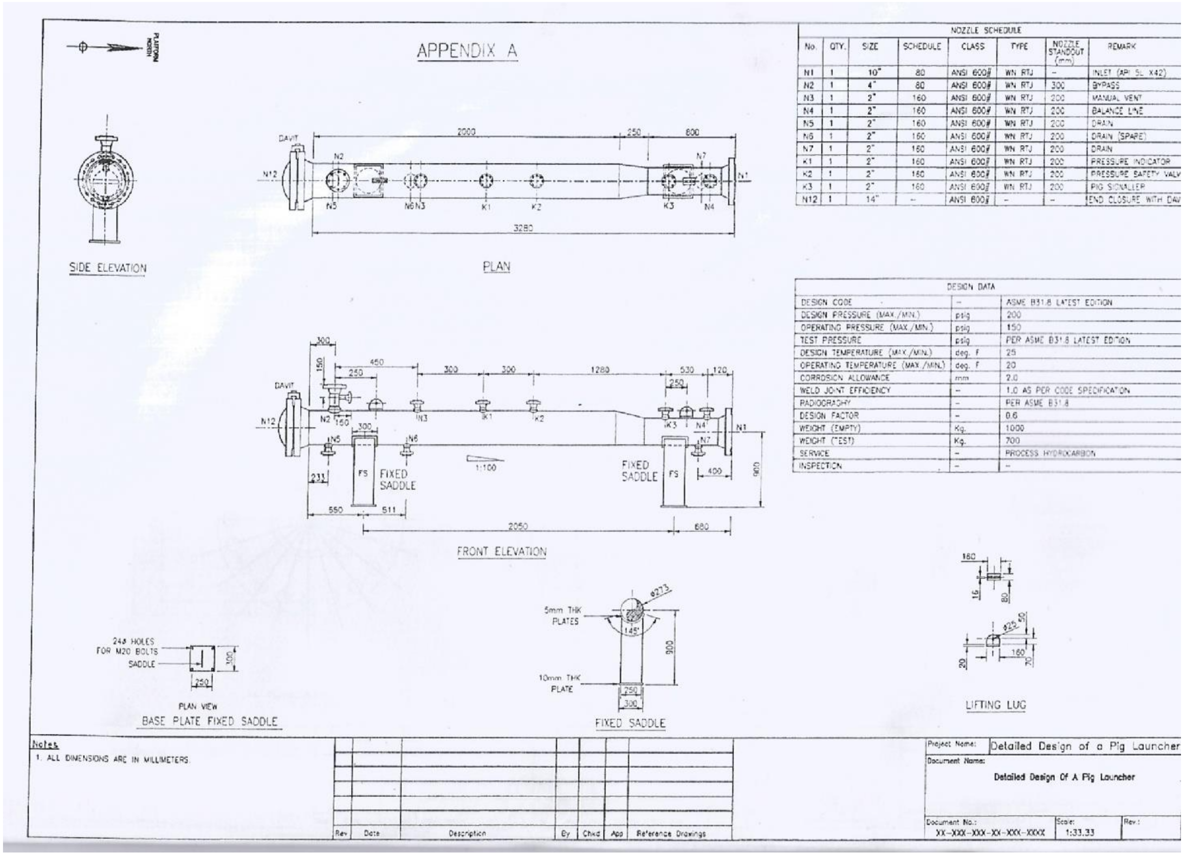
The research culminated in the design of a suitable quick closure and smoother means of transition of pig through the pipeline. In the course of research, fabrication was carried out and the problem of setting the eccentric reducer to the main and minor barrel, then locating the vents and the drains was handled with excellent practical superiority. The design pressure is 200bar and the barrel successfully accommodated a single pipeline pig. The launcher met the requirement to permit more efficient operation compared with the previous designs.

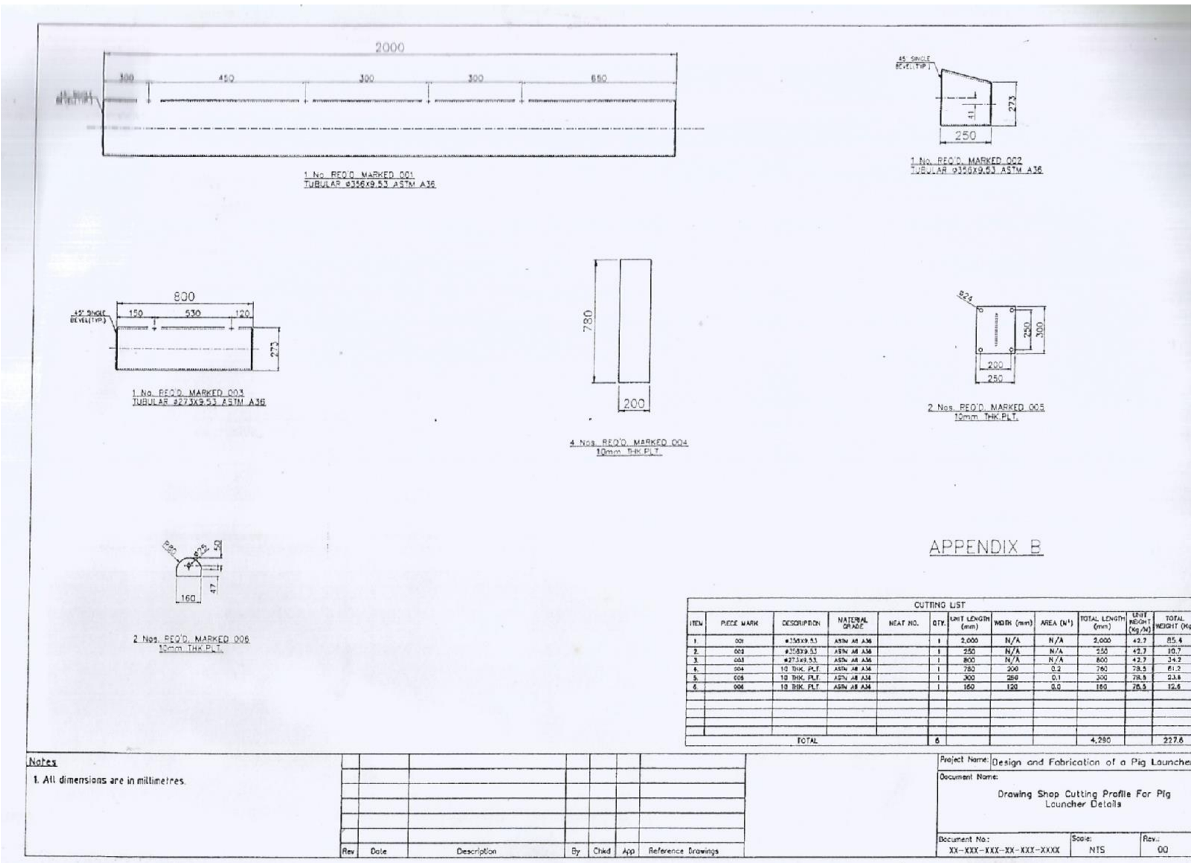
Despite just being a prototype, it was able to highlight its effectiveness which will lead to further development of this launcher to a larger scale.

REFERENCES

[1] Antaki, A. G. (2003). Piping and Pipeline Engineering, print edition, Mercel Dekker Inc., New York.
[2] Jim C. (2003). Pipeline Pigging Hankbook, third edition, Clarion publisher, Houston.
[3] Jim, C. and Hershal, V. (2006). Pigging Products and Services Association, An Introduction to Pipeline Piging, sixth edition, Pipeline World Publisher, Beaconsfield.
[4] Khurmi, R. S. and Gupta, J. K. (2005). Theory of Machines, first multicolor revised and updated edition, published by Eurasia publishing house Ltd, New Delhi.
[5] Mesner, T. O. and Leffler, L. W. (2006). “Oil and gas pipeline in non technical language”, Pennwell Corporation publisher, Oklahoma.
[6] Nayyar, M. L. (2000). Piping handbook, seventh edition, published by McGraw-Hill Co0mpanies, New York City.
[7] Tiratso, J. N. H. (2013). “pipeline pigging and integrity technology”, fourth edition, Clarion technical publisher, Houston.

APPENDICES


APPENDIX A
SIDE ELEVATION
PLAN
FRONT ELEVATION
FIXED SADDLE
LIFTING LUG
24Ø HOLES FOR M20 BOLTS
SADDLE
PLAN VIEW
BASE PLATE FIXED SADDLE
DAVIT
5mm THK PLATES
10mm THK PLATE
NOZZLE SCHEDULE
No. | QTY. | SIZE | SCHEDULE | CLASS | TYPE | NOZZLE STANDOUT (mm) | REMARK
N1 | 1 | 10" | 80 | ANSI 600# | WN RTJ | – | INLET (API 5L X42)
N2 | 1 | 4" | 80 | ANSI 600# | WN RTJ | 300 | BYPASS
N3 | 1 | 2" | 160 | ANSI 600# | WN RTJ | 200 | MANUAL VENT
N4 | 1 | 2" | 160 | ANSI 600# | WN RTJ | 200 | BALANCE LINE
N5 | 1 | 2" | 160 | ANSI 600# | WN RTJ | 200 | DRAIN
N6 | 1 | 2" | 160 | ANSI 600# | WN RTJ | 200 | DRAIN (SPARE)
N7 | 1 | 2" | 160 | ANSI 600# | WN RTJ | 200 | DRAIN
K1 | 1 | 2" | 160 | ANSI 600# | WN RTJ | 200 | PRESSURE INDICATOR
K2 | 1 | 2" | 160 | ANSI 600# | WN RTJ | 200 | PRESSURE SAFETY VALV
K3 | 1 | 2" | 160 | ANSI 600# | WN RTJ | 200 | PIG SIGNALLER
N12 | 1 | 14" | – | ANSI 600# | – | – | END CLOSURE WITH DAV
DESIGN DATA
DESIGN CODE | – | ASME B31.8 LATEST EDITION
DESIGN PRESSURE (MAX./MIN.) | psig | 200
OPERATING PRESSURE (MAX./MIN.) | psig | 150
TEST PRESSURE | psig | PER ASME B31.8 LATEST EDITION
DESIGN TEMPERATURE (MAX./MIN.) | deg. F | 25
OPERATING TEMPERATURE (MAX./MIN.) | deg. F | 20
CORROSION ALLOWANCE | mm | 2.0
WELD JOINT EFFICIENCY | – | 1.0 AS PER CODE SPECIFICATION
RADIOGRAPHY | – | PER ASME B31.8
DESIGN FACTOR | – | 0.6
WEIGHT (EMPTY) | Kg. | 1000
WEIGHT (TEST) | Kg. | 700
SERVICE | – | PROCESS HYDROCARBON
INSPECTION | – | –
Notes
1. ALL DIMENSIONS ARE IN MILLIMETERS.
Rev | Date | Description | By | Chkd | App | Reference Drawings
Project Name: Detailed Design of a Pig Launcher
Document Name: Detailed Design Of A Pig Launcher
Document No.: XX-XXX-XXX-XX-XXX-XXXX
Scale: 1:33.33
Rev.: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1 No. REQ'D. MARKED 002 TUBULAR ø356x9.53 ASTM A36
1 No. REQ'D. MARKED 003 TUBULAR ø273X9.53 ASTM A36
4 Nos. REQ'D. MARKED 004 10mm THK.PLT.
2 Nos. REQ'D. MARKED 005 10mm THK.PLT.
2 Nos. REQ'D. MARKED 006 10mm THK.PLT.
APPENDIX B
CUTTING LIST
ITEM | PIECE MARK | DESCRIPTION | MATERIAL GRADE | HEAT NO. | QTY. | UNIT LENGTH (mm) | WIDTH (mm) | AREA (M²) | TOTAL LENGTH (mm) | UNIT WEIGHT (Kg/M) | TOTAL WEIGHT (Kg)
1. | 001 | ø356X9.53 | ASTM A8 A36 | | 1 | 2,000 | N/A | N/A | 2,000 | 42.7 | 85.4
2. | 002 | ø358X9.53 | ASTM A8 A36 | | 1 | 250 | N/A | N/A | 250 | 42.7 | 10.7
3. | 003 | ø273x9.53 | ASTM A8 A36 | | 1 | 800 | N/A | N/A | 800 | 42.7 | 34.2
4. | 004 | 10 THK. PLT. | ASTM A8 A36 | | 1 | 780 | 200 | 0.2 | 760 | 78.5 | 61.2
5. | 005 | 10 THK. PLT. | ASTM A8 A36 | | 1 | 300 | 250 | 0.1 | 300 | 78.5 | 23.6
6. | 006 | 10 THK. PLT. | ASTM A8 A36 | | 1 | 160 | 120 | 0.0 | 160 | 78.5 | 12.6
TOTAL | 6 | 4,290 | 227.6
Notes
1. All dimensions are in millimetres.
Rev | Date | Description | By | Chkd | App | Reference Drawings
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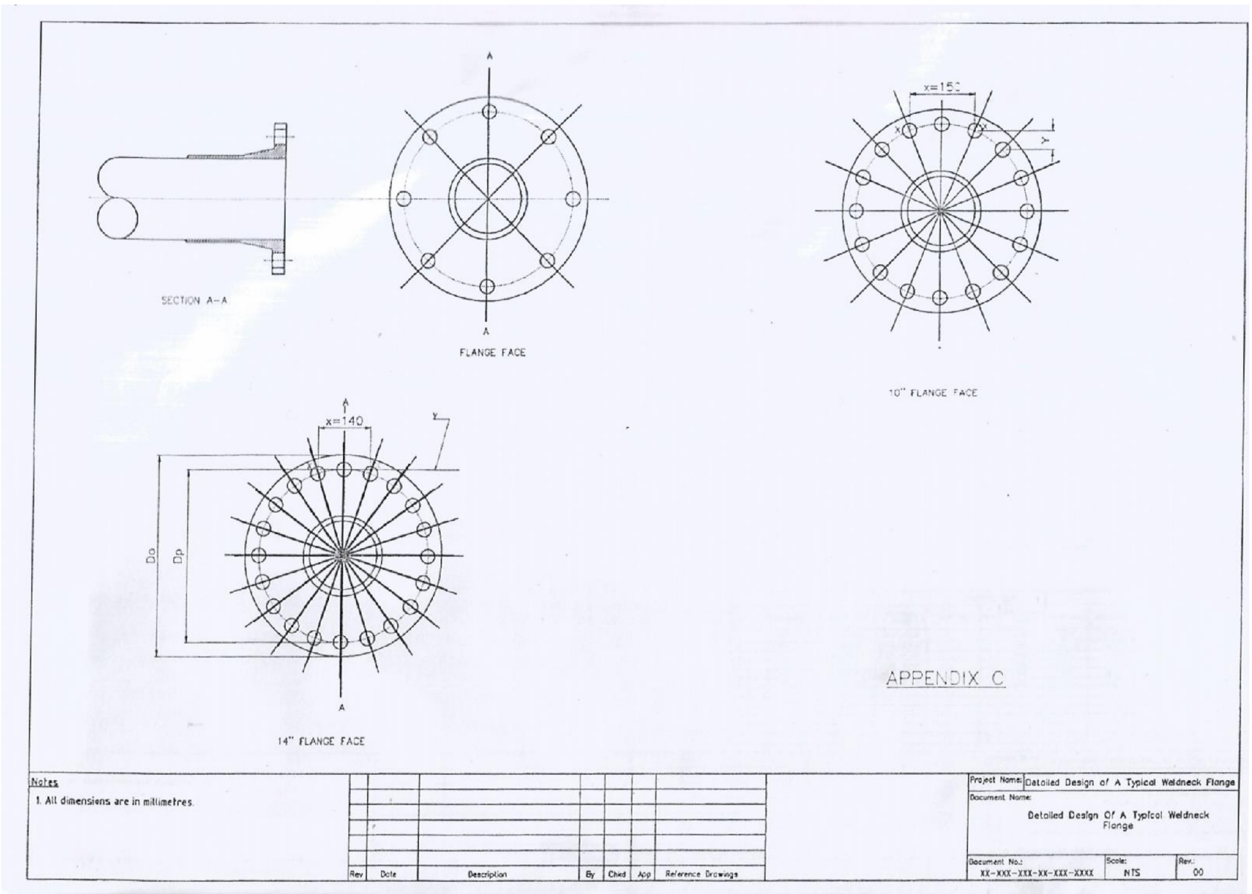
Document Name: Drawing Shop Cutting Profile For Pig Launcher Details
Document No.: XX-XXX-XXX-XX-XXX-XXXX
Scale: NTS
Rev.: 00


SECTION A-A
FLANGE FACE
10" FLANGE FACE
x=140
Do
Dp
14" FLANGE FACE
APPENDIX C
Notes
1. All dimensions are in millimetres.
Rev
Date
Description
By
Chkd
App
Reference Drawings
Project Name: Detailed Design of A Typical Weldneck Flange
Document Name:
Detailed Design Of A Typical Weldneck Flange
Document No.:
XX-XXX-XXX-XX-XXX-XXXX
Scale:
NTS
Rev.:
00