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ANALYSIS OF PIPELINE WALL THICKNESS FOR RIGID PIPELINE BY USING CARBON STEEL FOR OFFSHORE

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Abstract—Previously, Pandora field used 16 Inch outer diameter of grade X52 Carbon Steel for 26 km of Natural Gas pipeline. These topics are to propose a new design of gas pipeline as backup for future use for Pandora field by chose the best where offers the best trade-off in strength, weight, cost, weldability, durability and its usage records. Also, to increase the productivity and design life of the pipeline. Basically, this research project is to analyse which material grade of carbon steel is better based on previous case study by using the same field. Either stay with the grade X52 Carbon Steel or propose other material grade of carbon steel that compatible with the field environment, pipe and design parameters. The proposed offshore pipeline has to withstand the loads that will be applied to the pipeline from installation to hydro testing until operating. During installation, the pipe will subject to bending, torsion, tension and external pressure but when it goes to operation it will be loaded with internal pressure from the content, external pressure from the sea, thermal stress from the temperature changes as deeper the sea higher the temperature. This final year project presents an analysis of pipeline on existing field by calculating new wall thickness and choose best material grade selection using Mathcad software. The required wall thickness is discussed by checking the wall thickness against few design criteria such as pressure containment due to hoop stress, buckle initiation, buckle propagation and collapse pressure based on preferred standard such as API 5L Specification and ASME B31.8. Last but not least, all objectives are achieved successfully.

I. INTRODUCTION

Designing a pipeline wall thickness to resist all these loadings must be assessed with high level of accuracy as the deeper the well, the higher the pressure and temperature and the more things need to be consider for the pipeline. Other than wall thickness, material selection for the pipeline also an important thing as to avoid any circumstances during operation. Usually, for Oil and Gas industry will used carbon steel for the pipeline but for certain field that need to transport sour gas or water or in any corrosive fluids that require higher corrosion allowance that will make the pipe too thick, then pipeline engineers will study back by doing material option study (MOS) to choose the best option of material for the pipe.

For this final year project, the objective is to analyse and explore new things as to make an analysis on Pandora field which is located within the Pandora Delta in the South China Sea some 28 km NNW of Lutong in a water depth of 60-200ft. The Pandora Field was discovered in 1963 and brought into production in 1968.

Based on previous study that made by Alief Oil and Gas Sdn where the engineers choose the Grade X52 Carbon Steel for 16-Inch Natural Gas pipeline from Pandora Central Processing Platform (PCPP-B) to Zeyra Lightweight Wellhead Platform (ZWHP) for Pandora Integrated Re-Development project on 2010.

Basically, the pipeline system and associated facilities are designed for 20 years design life. After the design life or maybe before 20 years, the pipe might be rupture or occur failure earlier than it should be.

Table 1 Design and operating data for Pandora field

Table 2 Material Properties for Pandora field

Table 1 and 2 above are the design and operating data as the parameter that were used to analyze the new pipeline with the same function but lower in cost and thinner in wall thickness based on API 5L Specifications, ASME B31.8 and other preferred standards.

II. METHODOLOGY

A. *Mathcad Software*

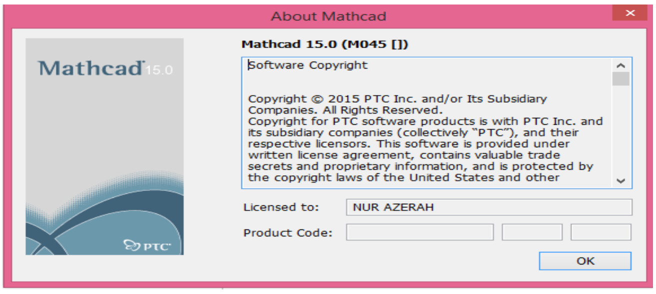

Figure 1 Mathcad software

For this project, Mathcad software is used to calculate and check for the pipeline wall thickness against buckle initiation, buckle propagation and collapse pressure. Mathcad 15.0 is Engineering Math software that allows all engineering student and engineers to perform, analyze and do the most vital calculations. Other than that, Mathcad is oriented around a worksheet in which the equations and expression that the student referring the suitable standards.

Mathcad, Parametric Technology Corporation's engineering calculation solution is used by engineers and scientist for various disciplines such as mechanical, chemical, electrical and civil engineering. This software originally conceived and written by Allen Razdow (co-founder of Mathsoft) but now Mathcad is now owned by PTC and generally become the first computer application to automatically compute and check consistency of engineering

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units such as the International Systems of Units (SI) throughout the entire set of the worksheet.

B. Input Data

For this Pandora field, the input data that needed to accomplish this project are the pipe itself, environmental and design parameter. All the input parameter were shown below;

Pipe parameter

Such as structure (ST) whether it is pipeline or riser. For pipeline the St=1, meanwhile for riser assumed that St=2. Type of pipeline either it is offshore or onshore. Assumed that if offshore the P=1 and for onshore the P=2. Outer diameter, OD of the pipe is given as refer to previous case study and this final year project is to analyse for the 16 Inch of Natural Gas Pipeline.

Table 3 Pipe Parameter

Parameter	Value
Structure	1
Type	1
OD	406.4 mm @ 16 Inch
	360 MPa for grade X52
	415 MPa for grade X60
	450 MPa for grade X65
Pipe Ovality	0.015 × OD
Young's Modulus	2.07×10^5 MPa
Poisson's Ratio	0.3

Environmental parameter

The environmental data for Pandora and Zeyra fields both are referenced based on previous case study respectively.

The astronomical tidal ranges and storm surge levels are presented as below;

Table 4 Tidal Levels and Storm Surge for Pandora and Zeyra field [4]

Properties		Level (m)	
		Pandora	Zeyra
Highest Astronomical Tide (HAT) ,m		1.28	0.9
Mean Sea Level (MSL), m		0.0	0.0
Lowest Astronomical Tide (LAT), m		-1.42	-1.2
Storm surge	1-Year Return Period	+0.45 / -0.0(2)	+0.3 / -0.3
	100-Year Return Period	+0.61 / -0.08(2)	+0.6 / -0.6

Based on data above, the environmental parameter for wall thickness calculation checked can be tabulated as below;

Table 5 Environmental Parameter refer to Mean Sea Level

Parameter	Value(s)
Water depth	0 to 31.8 m
HAT	1.28 m
LAT	-1.42 m
Storm Surge (100-yr)	0.6 m
Maximum Wave Height (100-yr)	9.5 m
Sea Water Density	1025 kg/m^3
Maximum Product Density	905.7 kg/m^3

Design Parameter

Below is the design parameter that based on preferred standards such as ASME B31.8. And note that, for temperature derating factor, T=1 if Design Temp<121degC based on ASME B31.8.

Table 6 Design Parameter

Input Parameter	Value (s)
Design Pressure	9.98 MPa
Hydrotest Pressure	14.97 MPa
Highest Elevation Point in the System	12 m
Temperature Derating Factor	1
Safety factor, fb	1.5
Corrosion Allowance, CA	6 mm
Longitudinal Joint Factor, Ej	1
Hoop Stress Factor	0.72

All of the input data parameter value(s) are used to calculate the net internal pressure and external pressure of the pipeline. Then can proceed to calculate for each design criteria of its nominal wall thickness such as nominal wall thickness for hoop, buckle initiation, buckle propagation and last one for collapse pressure.

C. Wall thickness calculation procedure

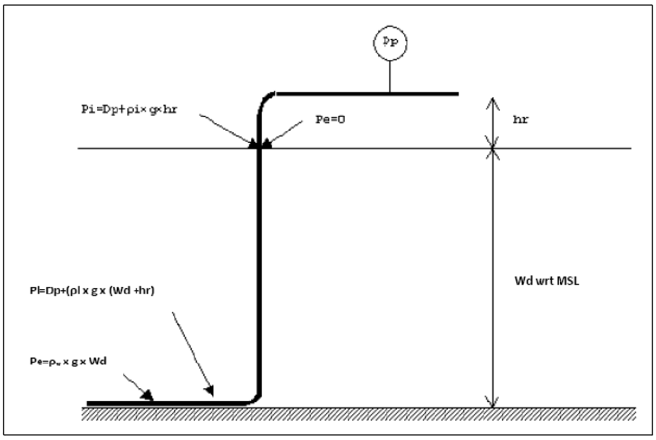

Figure 2 : Relationship between Design Pressure and Net Internal Pressure

Firstly, to calculate the wall thickness of the pipeline for all types of three (3) different carbon steel pipeline grade X52, X60 and X65 need to follow those procedures based on codes and standards.

i. **Internal Pressure**

$$Pi = Dp + \rho i \times g \times (Wd + hr)$$

Where;

Dp = Design Pressure, MPa

G = gravity constant, m/s2

Hr = height elevation, m

Pi = Internal Pressure, MPa

Wd = Water depth, m

ii. Water depth and external pressure

Minimum water depth can be calculated by using formula below.

Wd_{min} = (Wd – LAT) if LAT ≥ 0 m

(Wd + LAT) otherwise

Where;

Wd = Water depth, m

LAT = Lowest astronomical tide, m

$Pext_{min} = (p_w \times g \times Wd_{min})$ if pipeline

0 MPa otherwise

Wd_{max} = Wd + HAT + Surge + $\frac{Hmax}{2}$ $\frac{Hmax}{2}$

$Pext_{max} = \rho w \times g \times Wd_{max}$

For determine the nominal required wall thickness for all design criteria such as hoop stress, buckle initiation, buckle propagation and collapse are by using below formula. Note that every calculation must do for all three different depth; Water depth at Mean Sea Level, Minimum and Maximum Water Depth for all 3 different grade of carbon steel (X52, X60, X65)

Those steps are to compare for all different material grade of carbon steel wall thickness at each depth. As the deeper the depth, the higher the pressure and the thicker or higher the wall thickness that is required.

iii. Pressure Containment due to hoop stress

Internal pressure from the contained product is the most important loading which the pipeline has to carry. The internal pressure gives rise to hoop stress, which can yield the pipeline and leads to wall thinning and rupture if uncontrolled.

$$tnomX65_{hoop} = \frac{(Pi - Pext,min) \times OD}{2 \times F1 \times Tf \times SMYS \times Ej}$$

$$\frac{(Pi - Pext,min) \times OD}{2 \times F1 \times Tf \times SMYS \times Ej}$$

Where:

Ej = Longitudinal Joint Factor

F1 = Hoop Stress Factor

OD = Outer Diameter

Pext,min = Minimum External Pressure

Pi = Internal Pressure

SMYS = Specified Minimum Yield Strength

Tf = Temperature Derating Factor

Tnomhoop = Nominal wall thickness for hoop

iv. Buckle Initiation Wall Thickness

For a pipe in water depth where the net external pressure is less than that of propagation, any damage to the pipe will remain local. Even if the external pressure is higher than the propagation pressure, damage to the pipe still requires a pressure high enough to trigger unstable collapse for subsequent increase in wall thickness or lowering or pressure to below the characteristic propagation value.

For Carbon Steel grade X65

Assume t_{min} = 1mm

$$Pbi\ (t_{min}) = 0.02 \times E \times \left(\frac{tmin}{OD}\right)^{2.064}$$

$$0.02 \times E \times \left(\frac{tmin}{OD}\right)^{2.064}$$

$$Buck_{in}\ (t_{min}) = Pext,\max - \frac{Pbi\ (tmin)}{fb}$$

$$Pext,\max - \frac{Pbi\ (tmin)}{fb}$$

$tmin_{buckin0}$ = root $(Buck_{in}\ (t_{min})_0 , t_{min})$
$tmin_{buckin1}$ = root $(Buck_{in}\ (t_{min})_1 , t_{min})$
$tmin_{buckin2}$ = root $(Buck_{in}\ (t_{min})_2 , t_{min})$
$tnom_{buckin} = tmin_{buckin}$
$tnomBC_{in}$ = max($tnom_{buckin}$)

Where;

E = Longitudinal Joint Factor

Fb = Buckle safety factor

OD = Outer diameter

Pbi(tmin) = Pressure buckle initiation at minimum WT

Pext,max = Maximum External Pressure

tnomBCin = Nominal wall thickness for buckle initiation

WT = Wall thickness

From this formula, the maximum of the nominal wall thickness will be the nominal wall thickness for buckle initiation.

v. Buckle Propagation Wall Thickness

Buckle propagation is basically related to a situation where a transverse dent on the pipe that caused by excessive bending or any other causes which changes its original configuration into a longitudinal buckle and propagates along the pipe. If uncontrolled then can cause collapse of pipe along its travelling length. The driving energy which causes the buckles to propagate are the external hydrostatic pressure.

For Carbon Steel grade X65

$$Pbp\ (tmin) = 24 \times SMYS \times \left(\frac{tmin}{OD}\right)^{2.4}$$

$$24 \times SMYS \times \left(\frac{tmin}{OD}\right)^{2.4}$$

$$Buck_{prop}\ (tmin) = Pext,\max - Pbp\ (tmin)$$

$$Pext,\max - Pbp\ (tmin)$$

$tmin_{buckpr0}$ = root $(Buck_{prop}\ (t_{min})_0 , t_{min})$
$tmin_{buckpr1}$ = root $(Buck_{prop}\ (t_{min})_1 , t_{min})$
$tmin_{buckpr2}$ = root $(Buck_{prop}\ (t_{min})_2 , t_{min})$
$tnomX65_{buckpr} = tmin_{buckpr}$

$tnomX65_{pr} = \max(tnomX65_{buckpr})$

Where;

tnomX65pr= Nominal WT of X65 for buckle propagation

vi. Collapse Pressure Check

During pipeline installation, the pipe is required to sustain the net external pressure without yielding or collapse. This is particularly significant in deeper water where the external hydrostatic pressure alone may cause the pipe to collapse in plastic mode. Collapse pressure is usually defined as the pressure required causing a local collapse due to external water pressure, pipe imperfections, bending and torsion.

For Carbon Steel grade X65

Table 6 Wall thickness for Hoop

Pure Plastic Collapse Pressure

$$Py(tmin) = 2 \times SMYS \times \frac{tmin}{OD}$$

$$Py(tmin) = 2 \times SMYS \times \frac{tmin}{OD}$$

Pure Elastic Collapse Pressure

$$Pe(tmin) = \frac{2 \times E \times (\frac{tmin}{OD})^3}{1.4 \times (1-v^2) \times (1-\frac{tmin}{OD})^2}$$

$$Pe(tmin) = \frac{2 \times E \times (\frac{tmin}{OD})^3}{1.4 \times (1-v^2) \times (1-\frac{tmin}{OD})^2}$$

$$\frac{2 \times E \times (\frac{tmin}{OD})^3}{1.4 \times (1-v^2) \times (1-\frac{tmin}{OD})^2}$$

$$r(tmin) = \frac{Py(tmin)}{Pe(tmin)}$$

$$r(tmin) = \frac{Py(tmin)}{Pe(tmin)}$$

$$d(tmin) = do \times \frac{OD}{tmin}$$

$$d(tmin) = do \times \frac{OD}{tmin}$$

OOR Function

$$Grd(tmin) = \frac{[(1+d(tmin)^2)^{0.5} - d(tmin)] \times (1+r(tmin)^2)^{0.5}}{[1+r(tmin)^2 \times [(1+d(tmin)^2)^{0.5} - d(tmin)]^2]^{0.5}}$$

$$\frac{[(1+d(tmin)^2)^{0.5} - d(tmin)] \times (1+r(tmin)^2)^{0.5}}{[1+r(tmin)^2 \times [(1+d(tmin)^2)^{0.5} - d(tmin)]^2]^{0.5}}$$

$$grd(tmin) = \frac{[(1+d(tmin)^2)^{0.5} - d(tmin)] \times (1+r(tmin)^2)^{0.5}}{[1+r(tmin)^2 \times [(1+d(tmin)^2)^{0.5} - d(tmin)]^2]^{0.5}}$$

Collapse Pressure

$$Pcoll(tmin) = \frac{grd(tmin) \times Py(tmin) \times Pe(tmin)}{\sqrt{Py(tmin)^2 + Pe(tmin)^2}}$$

$$Pcoll(tmin) = \frac{grd(tmin) \times Py(tmin) \times Pe(tmin)}{\sqrt{Py(tmin)^2 + Pe(tmin)^2}}$$

$$\frac{grd(tmin) \times Py(tmin) \times Pe(tmin)}{\sqrt{Py(tmin)^2 + Pe(tmin)^2}}$$

$$Coll(tmin) = Pext,\max - Pcoll(tmin)$$

$$Pext,\max - Pcoll(tmin)$$

$tmin_{coll0} = root(Coll(t_{min})_0, t_{min})$

$tmin_{coll1} = root(Coll(t_{min})_1, t_{min})$

$tmin_{coll2} = root(Coll(t_{min})_2, t_{min})$

$tnomX65_{coll} = tmin_{coll}$

$tnomX65_c = \max(tnomX65_{coll})$

For collapse pressure, to calculate its required nominal wall thickness it is compulsory to determine its pure elastic and plastic collapse pressure, the out-of-roundness or ovality of pipe.

III. RESULTS AND DISCUSSION

Based on performed calculation spreadsheet by using Mathcad software of required wall thickness for Pandora field and check for the offshore pipeline against design criteria such as buckle initiation which if uncontrolled can lead buckle to propagates and lastly collapse pressure.

By calculate the net internal pressure by using given formula are tabulated below. As stated before in methodology, minimum and maximum water depth are based along the pipeline route from ZCPP-B to PWHP.

Table 7 Net Internal Pressure

From above results, as the depth for WD at MSL and minimum WD are the same at 0m, then the calculated internal pressure are the same. It also proven that the deeper the depth, the higher the pressure.

For nominal required wall thickness calculations for hoop stress due to pressure containment are calculated for each grade of carbon steel and for every water depth are tabulated in below.

Table 8 Wall thickness for Hoop

Carbon Steel Grade	Water Depth	Nominal Required Wall Thickness for Hoop, mm
X52	Water Depth at MSL	7.907
	Min WD	7.907
	Max WD	7.889
X60	Water Depth at MSL	6.859
	Min WD	6.859
	Max WD	6.844
X65	Water Depth at MSL	6.326
	Min WD	6.326
	Max WD	6.312

Based on wall thickness calculated above, it shows carbon steel grade X65 has the lowest or thinnest wall thickness that are t=6.326 for water depth at MSL and t=6.312 for maximum water depth compared to t=7.907 for water depth at MSL and t=7.889 for maximum water depth grade X52 which is used previously and t=6.859 for water depth at MSL and t=6.844 for maximum water depth for grade X60.

After get the result for nominal wall thickness due to hoop stress, next are the results of wall thickness check for buckle initiation. By assumed that minimum thickness is 1mm and for buckle initiation only calculated once and not repeated for every different material grades.

Table 9 Wall Thickness for Buckle Initiation

Material	**Water Depth**	**Nominal Wall Thickness for Buckle Initiation, mm**
For all grades of Carbon Steel	WD at MSL	2.355
	Min WD	2.355
	Max WD	5.517

The nominal wall thickness for buckle initiation at Mean sea level and minimum water depth are 2.355mm and the deeper the depth will require higher wall thickness which is 5.517mm.

Table 10 Wall Thickness for Buckle Propagation

Pipeline Material	**Material Grade**	**Water Depth**	**Nominal Required Wall Thickness for Buckle Propagation, mm**
Carbon Steel	X52	WD at MSL	3.011
		Min WD	3.011
		Max WD	6.261
	X60	WD at MSL	2.837
		Min WD	2.837
		Max WD	5.901
	X65	WD at MSL	2.743
		Min WD	2.743
		Max WD	5.705

From results of checking nominal wall thickness required for buckle propagation, the lowest wall thickness goes to carbon steel X65 which is t=2.743 for WD at MSL and t=5.705 at max WD meanwhile previous case study used grade X52 is thicker which is t=3.011 for WD at MSL and t=6.261 at max WD.

Next, for collapse pressure check, the parameter such as Pure Plastic Collapse Pressure, Pure Elastic Collapse Pressure and Pipe Ovality are calculated before proceed to get the wall thickness of the pipe.

Table 11 Wall Thickness for Collapse Pressure

Pipeline Material	**Material Grade**	**Water Depth**	**Nominal Required Wall Thickness for Collapse, mm**
Carbon Steel	X52	WD at MSL	2.39
		Min WD	2.39
		Max WD	4.293
	X60	WD at MSL	2.389
		Min WD	2.389
		Max WD	4.289
	X65	WD at MSL	2.389
		Min WD	2.389
		Max WD	4.287

After get the results for all minimum required nominal wall thickness by check with the design criteria for each material grade of carbon steel then Table 12 shows the required wall thickness by select the maximum wall thickness and add with corrosion allowances which are 6mm and by refer its requirement to know the governing case for each material grade.

Table 12 Required Wall Thickness and its Governing Case

Pipeline Material	**Material Grade**	**Required Wall Thickness, mm**	**Governing Case**
Carbon Steel	X52	13.907	Pressure Containment
	X60	12.859	Pressure Containment
	X65	12.326	Pressure Containment

In this case, the maximum wall thickness for every grade of carbon steel goes to wall thickness for pressure containment due to hoop stress and note that CA is 6mm. From the governing case requirement, it shows that Pressure Containment due to hoop stress do effect more to the pipeline wall thickness.

Table 13 Hoop Stress Check

Material	Grade	Developed Hoop Stress, MPa	Allowable Developed Hoop Stress, MPa	Acceptable
Carbon Steel	X52	240.226	259.2	Yes
	X60	240.226	298.8	Yes
	X65	305.909	324	Yes

For hoop stress, it is acceptable as the developed hoop stress for all material grade are less than the allowable developed hoop stress. (Developed Hoop Stress ≤ Allowable Developed Hoop Stress)

The tables shown below are based on selected wall thickness value, those wall thickness are checked for buckle initiation, buckle propagation and collapse in order to decide whether require buckle arrestor or not.

Table 14 Buckle Initiation and buckle propagation require buckle arrestor

Design criteria	Grade	Require Buckle Arrestor	Not require Buckle Arrestor
Buckle initiation and buckle propagation	X52		✓
	X60		✓
	X65		✓

From above results, it shows that the wall thickness check for buckle initiation and buckle propagation both are accepted and not require any buckle arrestor as the wall thickness selected are good enough to control from buckle to occur.

Table 15 Pressure collapse condition

Design criteria	Grade	Accepted	Not Accepted
Collapse pressure	X52	✓	
	X60	✓	
	X65	✓	

Based on result in table 15 it shows that design criteria of collapse pressure check for wall thickness selected are in accepted level for all material grade selection of carbon steel pipeline.

Table 16 Required Wall Thickness for every design criteria check.

Grade	Required Wall Thickness, mm				Govern Case
	PC	BI	BP	CP	
X52	7.91	5.52	6.26	4.29	PC
X60	6.86	5.52	5.90	4.29	PC
X65	6.33	5.52	5.70	4.29	PC

Note that;
PC = Pressure Containment
BI = Buckle Initiation
BP = Buckle Propagation
CP = Collapse Pressure

Table 17 Overall wall thickness

Grade	Governing Wall Thickness	API 5L Selected Thickness (mm)	Calculated Wall Thinning	Selected Mother Pipe Wall Thickness (mm)	Diameter Ratio
X52	13.91	14.27	14.27	15.88	28.48
X60	12.86	14.27	13.13	14.27	28.48
X65	12.33	12.70	11.68	14.27	32.00

From above table, we can conclude the diameter ratio for both Carbon Steel grade X52 which previously used by the field and X60 are the same. The greater the diameter ratio, the better the wall thickness for the pipe.

After all the calculation by using the Mathcad software, Pandora field instead of using previous material grade of carbon steel grade X52 can also replace with grade X65 with the wall thickness based on API 5L which is 12.7 mm.

IV. Conclusion

Based on the results, can be concluded that all section wall thicknesses selected are governed by pressure containment or hoop stress requirement. From the analyses results, it is concluded that the selected wall thicknesses which is 12.7mm have complied with the requirements of standards for diameter to wall thickness ratio.

As the cost of greater SMYS of Carbon Steel is higher, so Carbon Steel grade X60 is not recommended for replace the existing one even X60 have higher SMYS compared to X52 but as the thickness is the same and higher cost is needed so it is better to choose Carbon Steel grade X65 which has thinner wall thickness with greater strength to withstand the stress on the pipe.

The selected wall thickness for bend mother pipe is in compliance with the requirements after considering the bend wall thinning and is sufficient to satisfy the minimum required wall thickness.

From overall analysis, can be conclude that all objectives that stated in this project are achieved.

Acknowledgment

Praise to Allah the Most Merciful and Most Gracious. First of all I would like to thank to Allah SWT for all the strength, good health and blessing that He gave me throughout this semester to finish my final year project by overcome all the obstacles that I faced to complete this thesis. Next, I would like to express my special thanks to my final year project supervisor, Mr. Khalil B Abd Razak as he always gave his ideas and support towards my project. Not to forget to thanks to Mr. Hazim as he was willing to share all the knowledge that related to this pipeline project. In this opportunity, I would like to thank to all my lecturers and friends from this Faculty of Chemical Engineering UiTM Shah Alam especially who teaching engineering subjects that indirectly helped me a lot. Last but not least, I must always thanked both of my parents for their endless supports and doa's that keep encouraging me to accomplish this thesis. Thank you very much.

References

[1] API 5L. (2000). Specification for Line Pipe. *American Petroleum Institute*, *42*(January 2000), 153. https://doi.org/10.1520/G0154-12A

[2]Article, R. (2011). Poisson's ratio and modern materials, *10*(October), 823–837. https://doi.org/10.1038/NMAT3134

[3]Code, A., & Pressure, F. O. R. (2006). Gas transmission and distribution piping systems, *2003*.

[4] Provision of Conceptual Engineering Design Services for Integrated Redevelopment Project.