TURBOMACHINERY PROJECT

"Offshore Pipeline Mechanical Design"

By:

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Introduction to Offshore Pipelines:

Offshore pipelines are critical elements of the subsea transportation system for the transportation and delivery of carbon products from the resource sites to end users and markets. The design, construction, and operation of offshore pipelines require elements of risk management to mitigate potential adverse effects from the perspective of technical, business, environmental, and societal factors. The need, scope, requirements, and complexity of risk management have evolved over time in concert with the pipeline industry meeting the challenges for extending application into deep water environments and ice regimes, and capabilities to achieve more extreme operating conditions (e.g., internal pressure, temperature, and aggressive fluids) and envelopes (e.g., transient, cool down, and restart conditions). Marine pipelines transport oil and gas from subsea wells to the platform and subsequently gas or oil from the platform to the coast for further process and distribution. There are also large pipelines for the transportation of gas or oil from one country to another.

Pipelines Classification: [Figure 1.1]

Infield Pipelines	Export Pipelines:	Transmission pipelines:
Transport fluids within the field. They are often called flowlines or feeder lines. They carry a mixture of oil, gas and water from the subsea wells to a manifold or to the process platform.	Transport processed oil or gas from the platform to the coast. If the pipeline carries a mixture of oil and gas then it is a multi-phase pipeline. If the pipeline carries one fluid at a time, then it is a single-phase pipeline.	Carry oil or gas from one coast to another mainly, the same way as a tanker transfers oil for trading purposes.

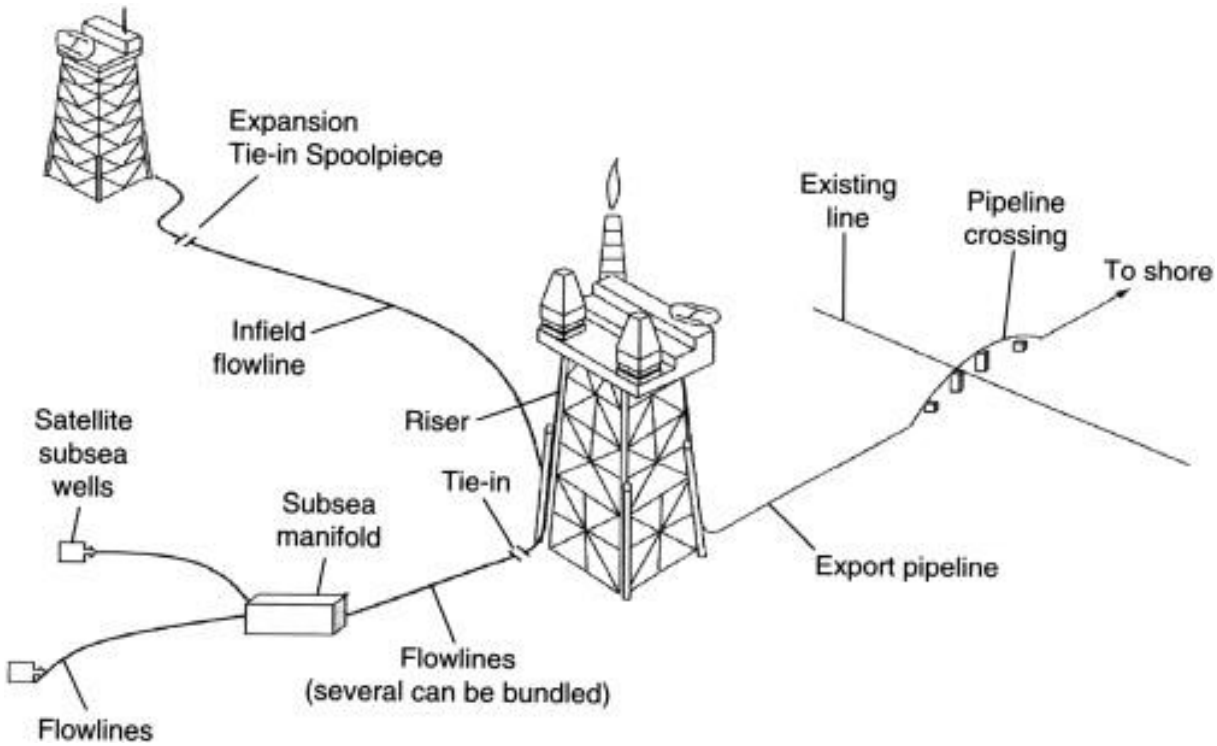

Figure 1.1- Offshore Pipelines Types

Pipeline design includes several general steps:

1) **Load determination.**
2) **Critical performance evaluation.**
3) **Comparison of performance with the limiting performance criteria established by codes and standards.**
4) **Final selection of the pipe and construction method based on the design.**

Design of pipelines has evolved separately in different industries that use pipelines. Petroleum industries and Natural Gas industries primarily use steel pipes with welded joints. This allows the pipeline to withstand very high pressures, often above 1000 psig and sometimes above 3000 psig. High pressures allows the use of long pipelines, often more than 1000 miles long, with only a few booster pump or compressor stations for each pipeline.

Pipeline design is based on three broad categories:

1. High-Pressure Pipelines
2. Intermediate-Pressure Pipelines
3. Low-Pressure Pipelines

High-Pressure Pipelines: -	Intermediate-Pressure Pipelines:	Low-Pressure Pipelines: -
Internal pressure of such line has very high pressures. Such type can be most efficient in using flow boosters since high pressures with limited pressure drop values, can deliver the fluid to the destination sufficiently. It dominates the design. Most long-distance Petroleum and Natural Gas pipelines belong to this category. Without doubt they need thick lines to ensure safety.	Internal pressure load and external pressure load are of similar magnitudes. Both loads must be considered. This category includes sewer pipes, water pipes, and certain Petroleum and Natural Gas pipes.	Internal Pressure is low or nonexistent. Design is governed by external load. Most sewer pipes and culverts belong to this category.

System Specifications: -

- Offshore Pipeline
- Gas: Natural Gas
- Mass Flow Rate: 1000 kg/h
- Inlet Pressure: 70 bar
- Pipe Length: 100 km
- Inlet Temperature: 25°C
- The pipeline wall thickness for the subsea pipeline section is designed in accordance with the guidance provided in (DNV OS – F101) submarine pipeline systems

Material Selection:

In our system, we chose Low Carbon Steel (AISI 1018) to be the material of the pipeline. AISI 1018 mild/low carbon steel has excellent weldability, produces a uniform and harder case and it is considered the best steel for carburized parts. AISI 1018 mild/low carbon steel offers a good balance of toughness, strength, and ductility plus good mechanical properties, improved machining characteristics and has a high Brinell hardness measure recording 126 as a hardness factor. [Figure 2.1]

Figure 2.1- AISI 1080

Chemical Composition

Element	Content
Carbon, C	0.14 - 0.20 %
Iron, Fe	98.81 - 99.26 % (as remainder)
Manganese, Mn	0.60 - 0.90 %
Phosphorous, P	≤ 0.040 %
Sulfur, S	≤ 0.050 %

Physical Properties

Physical Properties	Metric	Imperial
Density	7.87 g/cc	0.284 lb/in^3

Table Showing Chemical and physical properties of AISI 1018

Mechanical Properties

Mechanical Properties	Metric	Imperial
Hardness, Brinell	126	126
Hardness, Knoop (Converted from Brinell hardness)	145	145
Hardness, Rockwell B (Converted from Brinell hardness)	71	71
Hardness, Vickers (Converted from Brinell hardness)	131	131
Tensile Strength, Ultimate	440 MPa	63800 psi
Tensile Strength, Yield	370 MPa	53700 psi
Elongation at Break (In 50 mm)	15.0 %	15.0 %
Reduction of Area	40.0 %	40.0 %
Modulus of Elasticity (Typical for steel)	205 GPa	29700 ksi
Bulk Modulus (Typical for steel)	140 GPa	20300 ksi
Poissons Ratio (Typical For Steel)	0.290	0.290
Machinability (Based on AISI 1212 steel. as 100% machinability)	70 %	70 %
Shear Modulus (Typical for steel)	80.0 GPa	11600 ksi

Table showing mechanical properties of AISI 1018

Risk Basis for Design:

The design format is based upon a limit state and partial safety factor methodology, also called Load and Resistance Factor Design format (LRFD). The load and resistance factors depend on the safety class, which characterizes the consequences of failure.

- **Categorization of Fluids: -**

Fluids to be transported by the pipeline system shall be categorized according to their hazard potential as given by the table below.

Table 2-1	**Classification of fluids**
Category	*Description*
A	Typical non-flammable water-based fluids.
B	Flammable and/or toxic fluids which are liquids at ambient temperature and atmospheric pressure conditions. Typical examples are oil and petroleum products. Methanol is an example of a flammable and toxic fluid.
C	Non-flammable fluids which are non-toxic gases at ambient temperature and atmospheric pressure conditions. Typical examples are nitrogen, carbon dioxide, argon and air.
D	Non-toxic, single-phase natural gas.
E	Flammable and/or toxic fluids which are gases at ambient temperature and atmospheric pressure conditions and which are conveyed as gases and/or liquids. Typical examples would be hydrogen, natural gas (not otherwise covered under category D), ethane, ethylene, liquefied petroleum gas (such as propane and butane), natural gas liquids, ammonia, and chlorine.

Gases or liquids not specifically identified in the table above should be classified in the category containing fluids most similar in hazard potential to those quoted. If the fluid category is not clear, **the most hazardous category shall be assumed.** According to this table, it is clear that we are dealing with a Class D fluid.

- **Location classes:**

The pipeline system shall be classified into location classes as defined in the next table.

Table 2-2	**Classification of location**
Location	*Definition*
1	The area where no frequent human activity is anticipated along the pipeline route.
2	The part of the pipeline/riser in the near platform (manned) area or in areas with frequent human activity. The extent of location class 2 should be based on appropriate risk analyses. If no such analyses are performed a minimum horizontal distance of 500 m shall be adopted.

Based on the table above, the location of our pipeline is present in an area where non frequent human activity is present.

- **<u>Safety Classes:</u>**

Pipeline design shall be based on potential failure consequence. This is implicit by the concept of safety class. The safety class may vary for different phases and locations. The safety classes are defined in Table 2-3.

Table 2-3 Classification of safety classes	
Safety class	*Definition*
Low	Where failure implies insignificant risk of human injury and minor environmental and economic consequences
Medium	Where failure implies low risk of human injury, minor environmental pollution or high economic or political consequences.
High	Classification for operating conditions where failure implies risk of human injury, significant environmental pollution or very high economic or political consequences

Table 2-1: Classification of Safety Classes

In this system we classify the safety class to be High.

- **<u>Speed Constraint:</u>**

There are also considerations related to erosion due to high velocities which need to be taken into consideration. Companies like "Shell" recommend that gas velocities in transportation of natural gas through long-distance pipelines should be in the range of 5-10 m/s for continuous operation and a maximum up to 20 m/s for intermittent operation. In our design process, we assumed that the velocity of the Natural Gas flowing inside the pipeline to be 5 m/s.

<u>Design Principles-System Integrity:</u>

- Fulfill the specified transport capacity.
- Fulfill the defined safety objective and have required resistance against loads during planned operational conditions.
- Have sufficient safety margin against accidental loads or unplanned operational conditions.

Load Considerations:

Pipelines must be designed for many types of loads, including :

- Stress due to pressure generated by the flow (internal pressure)
- External pressure by fluid if the pipe is submerged underwater.
- External pressure generated by the weight of Earth and by live loads on underground (buried) pipelines.
- Loads due to thermal expansion, earthquakes, etc.

Failure Modes: -

- Pressure Containments
- System Collapse
- Propagation Buckling

➢ For gas composition (no water present), it is expected that there will be no internal corrosion. Thus, no internal corrosion allowance may be taken.

Diameter Calculations: -

$$P*Q = m.*R*T$$

$$(70*10^5)*Q = 0.2778*520*(25+273)$$

$$Q = 0.2778*520*(27+273) / (70*10^5)$$

Q = 6.15*10^-3 $\mathbf{m^3/s}$

= 22.2 $\mathbf{m^3/h}$

We assume gas velocity of 5 m/s. Then,

$$Q = A*V$$

$$6.15*10^{-3} = A * 5$$

A = 1.23*10^-3 $\mathbf{m^2}$

and $$A = \frac{\pi}{4} * (D)^2$$

so, D = 40 mm. (Pipe nominal diameter)

<u>Pipeline Sizing Chart: -</u>

DN NOMINAL PIPE SIZE CHART - DIMENSIONS IN MILLIMETRES (MM)

DIAMETERS		SCHEDULES																		
DN in mm	OD	5	5s	10	10s	20	30	40	40s	Std	60	80	80s	XS	100	120	140	160	XXS	DN in mm
6	10.3			1.24	1.24			1.73	1.73	1.73		2.41	2.41	2.41						6
8	13.7			1.65	1.65			2.24	2 24	2.24		3.02	3.02	3.02						8
10	17.1			1.65	1.65		1.85	2.31	2 31	2.31		3.20	3.20	3.20						10
15	21.3	1.65	1.65	2.11	2.11		2.41	2.77	2.77	2.77		3.73	3.73	3.73				4.78	7.47	15
20	26.7	1.65	1.65	2.11	2.11		2.41	2.87	2 87	2.87		3.91	3.91	3.91				5.56	7.82	20
25	33.4	1.65	1.65	2.77	2.77		2.90	3.38	3 38	3.38		4.55	4.55	4.55				6.35	9.09	25
32	42.2	1.65	1.65	2.77	2.77		2.97	3.56	3 56	3.56		4.85	4.85	4.85				6.35	9.70	32
40	48.3	1.65	1.65	2.77	2.77		3.18	3.68	3 68	3.68		5.08	5.08	5.08				7.14	10.16	40
50	60.3	1.65	1.65	2.77	2.77		3.18	3.91	3 91	3.91		5.54	5.54	5.54				8.74	11.07	50
65	73	2.11	2.11	3.05	3.05		4.78	5.16	5.16	5.16		7.01	7.01	7.01				9.53	14.02	65
80	88.9	2.11	2.11	3.05	3.05		4.78	5.49	5.49	5.49		7.62	7.62	7.62				11.13	15.24	80
90	101.6	2.11	2.11	3.05	3.05		4.78	5.74	5.74	5.74		8.08	8.08	8.08					16.15	90
100	114.3	2.11	2.11	3.05	3.05		4.78	6.02	6 02	6.02		8.56	8.56	8.56		11.13		13.49	17.12	100
125	141.3	2.77	2.77	3.40	3.40			6.55	6 55	6.55		9.53	9.53	9.53		12.70		15.88	19.05	125
150	168.3	2.77	2.77	3.40	3.40			7.11	7.11	7.11		10.97	10 97	10.97		14 27		18.26	21.95	150
200	219.1	2.77	2.77	3.76	3.76	6.35	7.04	8.18	8.18	8.18	10.31	12.70	12.70	12.70	15.09	18 26	20.62	23.01	22.23	200
250	273	3.40	3.40	4.19	4.19	6.35	7.80	9.27	9.27	9.27	12.70	15.09	12.70	12.70	18.26	21.44	25.40	28.58	25.40	250
300	323.8	3.96	3.96	4.57	4.57	6.35	8.38	10.31	9 53	9.53	14.27	17.48	12.70	12.70	21.44	25.40	28.58	33.32	25.40	300
350	355.6	3.96	3.96	6.35	4.78	7.92	9.53	11.13	9 53	9.53	15.09	19.05	12.70	12.70	23.83	27.79	31.75	35.71		350
400	406.4	4.19	4.19	6.35	4.78	7.92	9.53	12.70	9 53	9.53	16.66	21.44	12.70	12.70	26.19	30 96	36.53	40.49		400
450	457	4.19	4.19	6.35	4.78	7.92	11.13	14.27	9 53	9.53	19.05	23.83	12.70	12.70	29.36	34 93	39.67	45.24		450
500	508	4.78	4.78	6.35	5.54	9.53	12.70	15.09	9 53	9.53	20.62	26.19	12.70	12.70	32.54	38.10	44.45	50.01		500
550	559	4.78	4.78	6.35	5.54	9.53	12.70			9.53	22.23	28.58		12.70	34.93	41 28	47.63	53.98		550
600	610	5.54	5.54	6.35	6.35	9.53	14.27	17.48	9 53	9.53	24.61	30.96	12.70	12.70	38.89	46 02	52.37	59.54		600
650	660			7.92		12.70				9.53				12.70						650
700	711			7.92		12.70	15.88			9.53				12.70						700
750	762	6.35	6.35	7.92	7.92	12.70	15.88			9.53				12.70						750
800	813			7.92		12.70	15.88	17.48		9.53				12.70						800
850	864			7.92		12.70	15.88	17.48		9.53				12.70						850
900	914			7.92		12.70	15.88	19.05		9.53				12.70						900
950	965									9.53				12.70						950
1000	1016									9.53				12.70						1000
1050	1067									9.53				12.70						1050
1100	1118									9.53				12.70						1100
1150	1168									9.53				12.70						1150
1200	1219									9.53				12.70						1200

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According to the pipeline sizing chart above, it can be clearly noticed that for a pipeline with a nominal diameter of 40 mm, its outer diameter will be 48.3 mm.

We selected the pipeline with schedule of 80 so,

Nominal Diameter = 40mm.

Outer Diameter = 48.3 mm.

Pipe Schedule = 5.08 mm.

1- Pipeline Design according to internal fluid pressure (Hoop Stress): -[8]

Design Equation

$$P_{allowable} = 2 * S * \frac{t}{D} * F * E * T$$

Where,

$P_{allowable}$: maximum allowable pressure (MPa)

S : maximum allowable tensile stress (MPa)

t : pipeline thickness (mm)

D : pipeline outside diameter (mm)

E : longitudinal joint factor

F : design factor as per class location

T : temperature derating factor

$$P_{allowable} = 2 * 370 * \frac{5.08}{48.3} * 1.3 * 0.6 * 1$$

$P_{allowable}$ = 60.7 MPa

P_{system} = 7 MPa

- **Therefore, the designed thickness is acceptable.**

2- Pipeline Design according to external fluid pressure: -[9]

Design Equation

$$P_b = \frac{2 * E_p}{(1-\mu_p^2) * (D_m/t)^3}$$

Where,

P_b : buckling pressure (psf)

E_p : modulus of elasticity (psi)

μ : poisson's ratio

D_m : pipeline nominal diameter (inch)

t : pipeline thickness (inch)

- ***we assume a pipeline with 260 ft (80 m) depth underwater.***

$$P_b = 62.4 * 260$$

P_b = 16624 psf

$$16624 = \frac{2 *(205*20885433)}{(1-0.29^2) * (Dm/t)^3}$$

D_m/t = 82.5

$t_{min} = D_m/82.5$

t_{min} = 0.6 mm

t_{design} = 5.08 mm

- **Therefore, the designed thickness is acceptable**

Resources and References: -

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