Teknomekanik, Vol. 5, No. 2, pp. 63-71, December 2022
e-ISSN: 2621-8720 p-ISSN: 2621-9980

# Material selection for raw gas pipeline at SBR#2 gas field

**Rado Riady[1*], Johny Wahyuadi Soedarsono[1], Rini Riastuti[1] and Iman Adipurnama[2]**

[1]Prof Johny Wahyuadi Laboratory, Department of Metallurgy and Material Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, INDONESIA

[2]International Advanced Technology Program, College of Engineering, National Taiwan University of Science and Technology, Taipei 106335, TAIWAN

*Corresponding Author: radoriady@gmail.com
Received July 12nd, 2022; Revised Aug 26th, 2022; Accepted Sep 25th, 2022
DOI: https://doi.org/10.24036/teknomekanik.v5i2.13372

**ABSTRACT**

*In engineering design, material selection is the process of choosing the best material for a specific process via a systematic material selection approach. This article described the material selection process for SBR#2 pipeline, which will be installed to flow raw gas from SBR#2 field to the nearest tie-in point. The material selection process starts with design requirement analysis to generate primary function and objectives, including its constraints, determine primary criteria to be evaluated, screen materials candidates based on criteria evaluation, and select the most suitable materials based on very specific requirements. The criteria were evaluated by performing value engineering with the performance criteria matrix tool. Materials selection, in this case, was determined by two main criteria: corrosion resistance and construction ability. Corrosion resistance was evaluated semi-quantitatively by applying NORSOK M-506 2005 spreadsheet, and construction ability were evaluated qualitatively based on field experience. Solid Corrosion Resistance Alloy (CRA)-Stainless Steel 316L pipe is the most suitable for this case.*

***Keywords:*** Pipeline; Material selection; $CO_2$ Corrosion; Value Engineering.

***How to Cite:***

R. Riady, J. W. Soedarsono, R. Riastuti, I. Adipurnama. “Material selection for raw gas pipeline at SBR#2 gas field”, *Teknomekanik,* vol. 5, no. 2, pp. 63-71, Dec. 2022. https://doi.org/10.24036/teknomekanik.v5i2.13372



## 1. INTRODUCTION

The production, processing, and distribution of crude oil and natural gas need to be supported by a safe and reliable infrastructure because crude oil and natural gas are flammable substance and can pollute the environment if it is not handled properly. A pipeline is one of the main facilities in the oil and gas industry. The main function of the pipeline is to flow hydrocarbon products from one point to another point with certain operating parameters for further processing and transmission. Hydrocarbon products themselves are non-corrosive. However, raw hydrocarbon products, taken from the bowels of the earth, are generally impure. There are several inherited substances such as formation water, $CO_2$ gas, $H_2S$ gas, solid content, and even bacteria. These impurity substances can make a pipeline badly corroded. Corrosion is one of the main causes of failure in an oil and gas pipeline system [1]. If corrosion is not handled and anticipated properly, it can lead to failure in the form of a leak that causes financial loss, environmental pollution, property damage, and endanger the safety of workers and local residents. In the project life cycle's design and/or early phases, material selection is very important to control corrosion in the oil and gas industry. Wrong material selection can cause serious accidents, environmental hazards, and financial loss. Therefore, the material selection process requires basic knowledge of materials engineering, process engineering, corrosion, pipeline manufacturing, and construction [2].

The corrosion aspect discussed how materials resist internal $CO_2$ corrosion. $CO_2$ corrosion or “sweet corrosion”, first reported in the early 1940s, has been a long-standing challenge in the oil and gas industries. It is the most predominant type of corrosion attack in the oil and gas industries [3]. $CO_2$ corrosion in carbon steel pipelines is a complex phenomenon and still requires further study [3]. Various $CO_2$ corrosion mechanisms have been proposed and postulated. However, the mechanisms are only valid for very specific conditions [3], [4]. Various factors including environmental, physical, metallurgical, and operating parameters affect the complexity of $CO_2$ corrosion in carbon steel pipelines [5]–[8]. The study is still developing until now with various parameters. The mechanism is very dependent on environmental conditions such pH, water chemistry, pressure, temperatures, velocity, etc. It has been reviewed and summarized in some literature [3], [5], [6], [9]. With understanding the mechanism, some models to predict $CO_2$ corrosion have been developed. The model validity and applicability are very dependent on the mode of failure assumption and availability of factual operating parameter pipeline data. With some additional experiments that are adjusted with the factual conditions in the field, the model can be more reliable to predict the lifetime service of pipelines in $CO_2$ environment. Therefore, $CO_2$ corrosion control and mitigation strategy can be applied during an early stage of the life cycle of an asset such as Front-End Engineering Design (FEED) phase. The type of $CO_2$ corrosion attack in the pipeline could be uniform, localized, and a mixture of both. According to fluid flow velocity intensity, this localized corrosion attack can be categorized and named as pitting (at relative-low velocity), mesa (at relative-moderate velocity), and flow induce localized corrosion (at relative-high velocity) [9], [10]. The majority of about 60% of the failures in oil and gas industries are related to $CO_2$ corrosion. Insufficient knowledge about the corrosion mechanism will aggravate the situation [1], [3], [11].

The material selection process in the oil and gas industry shall consider requirements from design philosophy, service lifetime expectation, operation philosophy, inspection aspect, maintenance aspect, and economic aspect [12]. In design engineering, material selection is the process of choosing the most suitable material for a specific process or environment via a systematic approach [13]. The decision-making process in material selection is affected by many factors. Various quantitative and qualitative methods have been applied in the industry to solve such problems, but there is no one particular method that is applicable to all problems or that covers all the considerations together [14]. It presented that no single material or alloy is applicable to all service conditions [15]. In practice, pipeline materials should be selected based on their functional suitability and ability to maintain their function safely for an economical period of time at a reasonable cost. The material selected should be accurately specified [16].

An oil and gas company plans to develop SBR#2 onshore field located in Jambi, Indonesia. The field development was performed by installing a raw gas pipeline from SBR#2 Field to accommodate production from gas wells at SBR#2 Well Pad area that consists of Sbr-D3, Sbr-2, and Sbr-D5 Wells. The pipeline is approximately 2 km in length; start from the gas test group manifold SBR#2 well pad and then tie into the existing 12" SBR Gathering line at SBR's Bridge. This article described the material selection process for SBR#2 pipeline which will be installed to flow raw gas from SBR#2 field to the nearest tie-in point. The material selection process generally follows the basic principle of materials selection. It starts with design requirement analysis to generate primary function and objectives including its constraints, determine primary criteria to be evaluated, screen materials candidates based on criteria evaluation, and select the most suitable materials based on very specific requirements.

## 2. MATERIAL AND METHODS

The material selection process is translating the requirements by defining criteria to meet the functional objectives. Then, screening and ranking of the material candidates based on their performance in defined criteria [17]. Then, refining is based on economic considerations. The first step is to analyze design requirements. We collected design information and operation parameter data in this step to generate specific functional objectives. We assumed that the pipe sizing has been performed by the process engineer. The diameter of the pipeline has been determined by considering the erosional velocity and pressure drop of the pipeline networking system. Therefore, Nominal Pipe Size (NPS) was determined or given. Below is design information that determines the functional objectives:

1. Pipeline installation location description: On-shore, industrial forest, swampy area, peat soil.
2. Nominal pipe size: 6 Inch and inside diameter (ID): 154.1 mm
3. Design lifetime: 20 years
4. Design pressure: 1,050 psig
5. Operating pressure: 800 psig
6. Operating temperature: 110 $^{o}$F
7. Fluid service: Raw Gas
8. Flow rate: 9 mmscfd gas, 200 blpd (include condensate and produce water).
9. Corrosive Species Identification:
   a. Water cut: 5%
   b. Gas $CO_2$ Content: 7.8% mole
   c. Chloride from water analysis of produced water: 13,000 ppm
   d. pH: 6

Based on the information above, a possible threat is $CO_2$ corrosion. $CO_2$ partial pressure in this case is:

$$800\ psig\ x\ 7.8\% = 62.40\ psig \quad (1)$$

The partial pressure is more than 30 psig, according to NACE SP0106-2018, this condition is usually a corrosive environment in the presence of water [4]. Failure mode could be general and or localized thinning due to internal corrosion. The pipeline will be installed underground (90% of the sections are buried) in a swampy area environment. External corrosion from soil and water corrosion could be a threat too. The second step is to look for material options. A list of materials candidates was generated based on similar experience and or industrial standards which are relevant to our case. According to ISO-21457 and Norsok M-001, below are materials that are common in the oil and gas industry for raw gas service [12]:

Table 1: Materials candidate

| No. | Candidate of Materials | Applicable Standard | Short Named Identification |
|---|---|---|---|
| 1 | Carbon Steel | API 5L | CS |
| 2 | Solid CRA-Stainless Steel 316 L | API 5LC30-1812, ASTM A312 TP 316L | SS |
| 3 | Solid CRA-Duplex Stainless Steel 22Cr | API 5LC65-2205, UNS S31803 | DP |
| 4 | Cladded / Lined CRA (outer Carbon Steel) | API 5LD | CLD |

Carbon steel is the base case for material selection in the oil and gas industry because it is extensively used and relatively low cost [18]. The philosophy for materials selection, in this case, is to adopt a combination of Carbon Steel with an adequate corrosion allowance, combined with an inhibition program, rather than the use of Corrosion Resistant Alloys (CRA) where possible. In addition to the corrosion allowance, rigorous corrosion monitoring and inspection will be required to verify the performance of the inhibition program during operation for Carbon Steel systems relying on inhibition. Alternative material options, including CRA materials, are also discussed if inhibition cannot be supplied, or its availability guaranteed, and the requirement corrosion allowance is too much which makes the pipe too heavy and too thick. Composite material such as Fiber or Glass Reinforced Plastic was not considered in this case due to the design pressure being more than 580 psig [12] and SBR#2 Field location is an area prone to forest fires in the dry season and has a peat soil type.

The third step is to define the main criteria which will be evaluated based on functional objectives and constraints based on common practice. The evaluation was performed by utilizing value engineering with the Performance Criteria Matrix tool. A pair-wise comparison is used to determine the weight values for each criterion defined [13]. The semi-quantitative approach was applied in this case to evaluate the most important factor to select the most suitable materials. Screening and ranking of material candidates are performed based on Value Engineering results. Other considerations as constraints are availability, weldability, material cost, installation cost, operation, and maintenance cost. In this article, the criteria are defined as:

1. Mechanical Properties (Yield Strength). It is symbolized as P1
2. Corrosion resistance (corrosion rate, PREN or Pitting Resistance Equivalent Number). It is symbolized as P2
3. Availability (easy to procure with reasonable delivery time). It is symbolized as P3
4. Construction ability (weldability, construction experience, welder skill). It is symbolized as P4

The four items of the above criteria were evaluated by performing value engineering with the Performance criteria matrix tool. Pair-wise comparison was used to determine the weight values for each parameter defined [13]. Table 2 describes the performance criteria matrix.

Table 2: Performance criteria matrix

| **Criteria** | **P1** | **P1** | **P1** | **P1** | **Total Score** | **Normalized (Weight Factor)** |
|---|---|---|---|---|---|---|
| **P1** | P1 | 0 | 1 | 0 | 1 | 0.14 |
| **P2** | 1 | P2 | 1 | 1 | 3 | 0.43 |
| **P3** | 0 | 0 | P3 | 1 | 1 | 0.14 |
| **P4** | 1 | 0 | 1 | P4 | 2 | 0.29 |
| | | **Sum** | | | **7** | **1** |

According to Table 2, the corrosion parameter (P2) has the highest score which is the most important factor to be considered. The construction ability factor (P4) is 2nd rank after P2. While mechanical properties (P1) and availability (P3) have the same weight. All materials listed in table 1 have proven mechanical properties to withstand hoop stress and are available on the market. Therefore, this article is more focused on the corrosion aspect and construction aspects.

In this case, the general corrosion rate is predicted using NORSOK M-506 2005 spreadsheet. The corrosion modeling process for carbon steel has been performed using NORSOK M-506, which incorporates the corrosion modeling program into the Microsoft Excel interface. The model can calculate corrosion rates on bare steel. NORSOK M-506 is a calculation model, presented in excel-based software. The model is a semi-empirical corrosion rate model for carbon steel in water containing $CO_2$ at different temperatures, pHs, $CO_2$ fugacity and wall shear stresses. It is based on de ward-milliam model and flow-loop experiments at temperatures from 5 °C to 160 °C. A large amount of data at various temperatures, $CO_2$ fugacity, pHs, and wall shear stresses are used. This model only provides a consideration of using carbon steel. The engineers shall however make the final decision of the material selection based on NORSOK M-001 as a reference, considering the corrosion rate provided by NORSOK M-506. Figure 1 informed the corrosion rate calculation result according to design data.

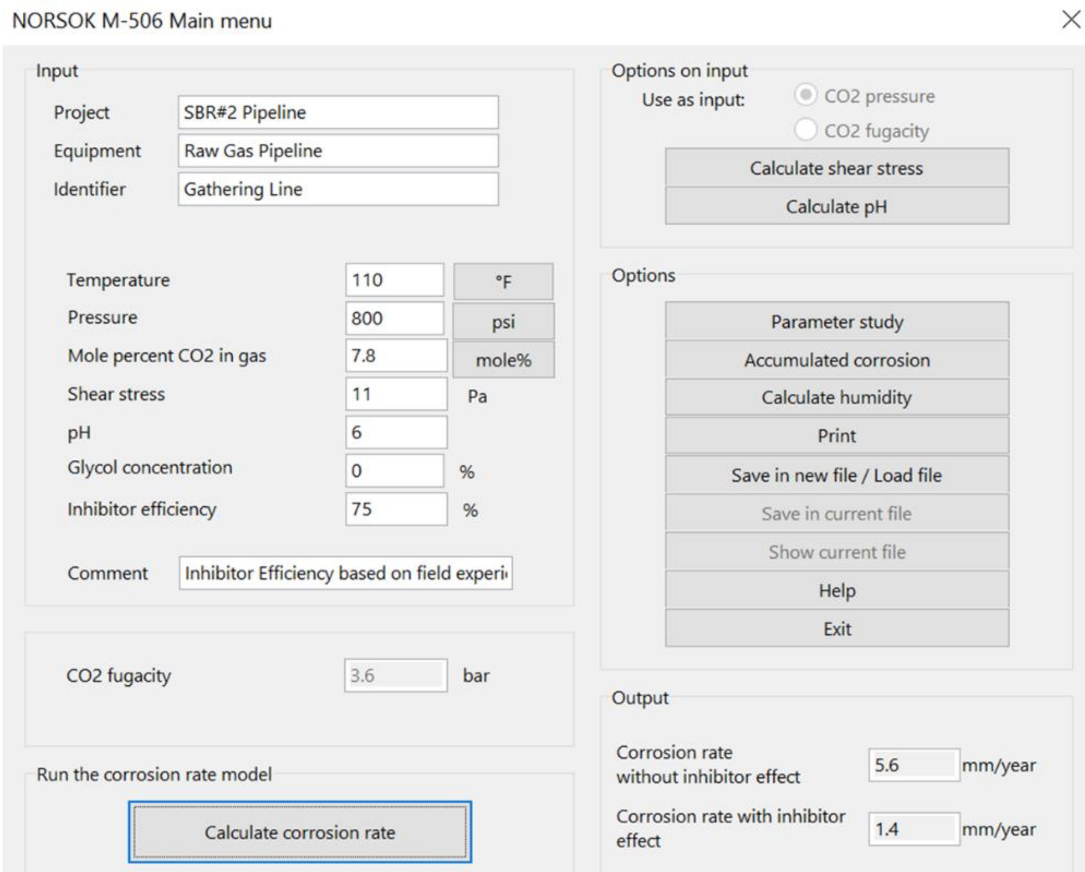


Figure 1: Corrosion rate prediction with NORSOK M-506 2005

For scoring and weighing determination, a semi-quantitative approach has been developed based on relevant standards, literature, and field experience. Table 3 and Table 4 described it.

Table 3: Qualitative categorization of carbon steel general corrosion rate [19]

| General Corrosion Rate | Qualitative Categorization | General Corrosion Resistance Assessment | General Corrosion Resistance Score Index |
|---|---|---|---|
| Less than 0.025 mm/yr | Low | Excellent | 4 |
| 0.025 – 0.12 mm/yr | Moderate | Good | 3 |
| 0.13 – 0.25 mm/yr | High | Poor | 2 |
| Over 0.25 mm/yr | Severe | Very Poor | 1 |

In table 3, general corrosion was considered for the corrosion aspect. The value was categorized based on the NACE standard. According to the NORSOK M-506 simulation, the corrosion rate prediction result was 5.6 mm/yr without the inhibitor and became 1.4 mm/yr with the inhibitor effect. This value was categorized as severe corrosion. In table 4, localized corrosion was considered. The most probable localized corrosion form and mechanism, in this case, is pitting corrosion. The main factor that influences localized corrosion attack is the passive film formation properties [7], [18]. The non-uniform or porous passive film will be susceptible to localized corrosion [22], [23]. For corrosion resistance alloy (CRA) such as the stainless-steel family, the Pitting Resistance Equivalent Number (PREN) value is one of the main metallurgy parameters to evaluate the resistance of CRA to pitting corrosion due to the existence of chloride. CRA which has PREN >= 30 has relatively better-pitting corrosion resistance in case of chloride existence in hydrocarbon service [12].

Table 4: Qualitative categorization of localized corrosion resistance [3], [10]–[12], [18], [20], [21]

| **Localized Corrosion Parameter** | **Localized Corrosion Attack Probability** | **Localized Corrosion Attack Assessment** | **Localized Corrosion Resistance Index** |
|---|---|---|---|
| Pipe materials have PREN >=30 OR the service fluid is nearly dry with almost no water and no $Cl^-$ detected. | Low | Good | 3 |
| Pipe materials have passive layer to inhibit interaction with corrosive environments but $Cl^-$ and water are detected and existed. | Medium | Poor | 2 |
| Passive layer possibly exists in the pipe wall as a corrosion product or scale locally but easy to peel or not dense. | High | Very poor | 1 |

The higher value of the corrosion resistance indexes, the more resistance of the material to corrosion. According to table 5, duplex stainless-steel material is the most excellent corrosion resistance in this case due to its high resistance to general and localized corrosion. Otherwise, carbon steel without inhibitor is clearly not suitable for this service. Construction ability was considered and explained in table 6 and the value engineering result was informed in table 7.

Table 5: Corrosion index scoring

| **No.** | **Candidate of Materials** | **General Corrosion Rate** | **General Corrosion Rate Index Score** | **Localized Corrosion Attack probability** | **Localized Corrosion Index Score** | **Total Corrosion Resistance Index Score** |
|---|---|---|---|---|---|---|
| 1 | CS | 5.6 mm/yr | 1 | High | 1 | 2 |
| 2 | CS + Inhibitor | 1.4 mm/yr | 1 | Medium | 2 | 3 |
| 3 | SS | 0 | 4 | Medium | 2 | 6 |
| 4 | DP | 0 | 4 | Low | 3 | 7 |
| 5 | CLD | 0 | 4 | Medium | 2 | 6 |

Table 6: Construction Index Scoring

| No. | Construction Point of View (Score) | CS (API-5L-X52 6" SCH.40) | CS + Corrosion Allowance (API-5L-X52 6" SCH.80) | SS | DP | CLD |
|---|---|---|---|---|---|---|
| 1 | Fabrication (4 to 1) | Common fabrication process (4) | Common fabrication process (4) | Common fabrication process (4) | Common fabrication process (4) | Special fabrication process (3) |
| 2 | Availability (4 to 1) | Local manufacturer (4) | Very limited local manufacturer (3) | Import (3) | Import (3) | Import for raw materials and local for fabrication (3) |
| 3 | Duration of Delivery (4 to 1) | 2 months (4) | 3 - 4 months (3) | 3 - 4 months (3) | 3 - 4 months (3) | more than 4 months (2) |
| 4 | Weldability (4 to 1) | Excellent (4) | Excellent (4) | Good (3) | Good (3) | Lack of qualified welder (2) |
| 5 | Field experience in Quality Control and Installation (4 to 1) | Excellent (4) | Excellent (4) | Excellent (4) | Experience (4) | Less experience (3) |
| **Total Scoring** | | **20** | **18** | **17** | **17** | **13** |

Table 7: Value Engineering Result

| Criteria \ Material | CS + Corrosion Inhibitor + Corrosion Allowance | SS | DP | CLD |
|---|---|---|---|---|
| P1 Value | 0.036 | 0.036 | 0.036 | 0.036 |
| P2 Value | 1.286 | 2.571 | 3.000 | 2.571 |
| P3 Value | 0.036 | 0.036 | 0.036 | 0.036 |
| P4 Value | 5.143 | 4.857 | 4.857 | 3.714 |
| Sum Value | 6.500 | 7.500 | 7.929 | 6.357 |
| Rank | 3 | 2 | 1 | 4 |

## 3. RESULTS AND DISCUSSION

Every criterion has been evaluated. The value engineering has been performed with the result in table 7. Scoring for mechanical properties (P1) is negligible since the mechanical properties of all listed materials are sufficient to withstand the hoop stress as per ASME B31.8. Scoring for the material availability (P3) has been counted and included in P4. Therefore, P3 is negligible too. Materials selection, in this case, was determined by two main criteria: corrosion resistance and construction ability. According to corrosion location, pipeline corrosion is categorized as internal or external [10], [24]. Internal corrosion is affected by fluid properties or characteristics which flow inside the pipeline with certain operating parameters [8]. Corrosion does not change the mechanical properties of a metal. Corrosion will change the dimension and or form of structural metal that degrades its function. The pipeline wall thickness can be lost due to corrosion and the strength of the pipeline to withstand pressure will be degraded. Corrosion types can be classified into general corrosion and localized corrosion [10]. General corrosion usually is a uniform type which is the wall gets thinning uniformly. Localized corrosion usually is pitting form which is wall thinning at a specific point. By experience, internal corrosion control and mitigation in pipelines are relatively more complex than external corrosion control in the case of multiphase hydrocarbon service. Some literature also presents the fact that in the last 20 years, cases of internal corrosion were more dominant than cases of external corrosion [10]. According to NACE (National

Association of Corrosion Engineers), localized pitting corrosion mechanism has a dominant contribution to failure in pipeline systems [4]. Stainless steel materials have better general corrosion resistance compared to carbon steel materials.

Corrosion rate described how fast the thickness losses in terms of general corrosion due to interaction with service fluid. According to service fluid data, it was confirmed qualitatively that the service fluid is corrosive to carbon steel pipelines. The $CO_2$ partial pressure is more than 30 psig. This condition is usually a corrosive environment in the presence of water [4]. Failure mode could be general and or localized thinning due to internal corrosion [20]. The corrosion rate can be determined by the model-simulation approach, laboratory tests, and periodic inspection in a consistent location [20]. The general corrosion rate prediction result was 5.6 mm/yr without the inhibitor and became 1.4 mm/yr with the inhibitor effect. To comply with 20 years design lifetime, we may apply for a corrosion allowance with a value of 28 mm as an additional thickness requirement. However, corrosion allowance which has a value of more than 10 mm is not effective and efficient for this field application. The thicker a pipe, the greater its mass, the more difficult it is to handle, and the installation cost will be higher. Localized corrosion can be triggered by passivity breakdown and or porous scale of the corrosion deposit [3], [10]–[12], [18], [21]. Chloride ions may inhibit or destabilize the formation of a passive layer, especially in steel pipe materials [18].

Construction ability is one of the important aspects to be considered in pipeline material selection. The construction ability may vary for each pipeline owner, and it depends on their resources, specific location, and specific pipeline construction project. All metallic materials in this case have been common in the oil and gas industry as piping and pipeline materials. Therefore, availability in the market has been confirmed. The fabrication aspect of each material candidate has been evaluated in table 6. Cladded or lined CRA pipe requires special fabrication due to combining two different materials and requires the special joint method to mitigate galvanic corrosion [25]. Therefore, the fabrication of cladded or line CRA pipe is relatively more complex than solid line pipe. The availability and delivery duration aspect, which have been evaluated in table 6, was considered local pipe manufacturers conditions. Carbon steel material can be provided by pipe manufacturers in Indonesia. However, CRA materials require import from pipe manufacturers in other countries. It will affect to project schedule and cost requirements.

In this case, we only consider metallic pipe material that requires welding during construction and site installation. Carbon steel pipe materials have excellent weldability. The welding process is common and no need for a special welding procedure to achieve a “well-sound” welded joint. Solid stainless steel pipe materials may require a special welding procedure since solid stainless steel materials have more alloying elements compared to carbon steel materials. Cladded or lined CRA pipe requires a special welding joint procedure since it is layered by dissimilar metal. A qualified welder for cladded or lined CRA pipe is relatively rare compared to solid stainless steel materials [25]. The field experience to install the pipeline with specific materials, certain locations, and performing its quality control may be subjective. In this case, the pipeline owner has operated carbon steel pipelines, stainless steel pipelines, and duplex pipelines for more than 15 years.

According to table 7, Duplex Stainless steel 22Cr solid line pipe is the first rank followed by Stainless Steel 316L. Carbon Steel line pipe with stringent corrosion control and mitigation can be considered as an alternative material. Cladded / lined pipe has the lowest score index in terms of construction aspect. According to the previous study report, Cladded or lined pipe is relatively more difficult to fabricate and construct in this case [25]. Therefore, selecting cladded or lined CRA pipe material is too risky. Duplex stainless steel 22Cr is relatively pricier than stainless steel 316L [13]. In raw gas service with a temperature less than 200 $^oF$, Duplex Stainless Steel will be selected if the chloride content is more than 50,000 ppm and pH is less than 4.5 [21]. Design data informed the Chlorine contents is 13,000 ppm which is less than 50,000 ppm and pH is 6. Stainless steel 316L solid line pipe is the most preferable in this case.

## 4. CONCLUSION

Material Selection for SBR#2 Pipeline has been performed. Value Analysis was applied as the method for the material selection process. The sources of data were referred to the previous similar project and relevant international standards. The assessment and semi-quantitative approach were based on study reports and field experience. Solid Corrosion Resistance Alloy (CRA)-Stainless Steel 316L pipe is the most suitable for this case. Carbon Steel material with proper corrosion mitigation and control could be an alternative option. However, the probability of failure is higher than Stainless Steel 316L if corrosion control and mitigation are not performed properly. Further corrosion modeling assessment and corrosion inhibitor evaluation shall be required if Carbon Steel material is considered as an alternative selection. Then, life-cycle cost analysis may be required to evaluate the economic aspect of Carbon Steel and stainless-steel material selection. The risk appetite of the pipeline owner should be taken into consideration during life-cycle cost analysis.

## ACKNOWLEDGEMENTS

We are grateful to “Prof Johny Wahyuadi Laboratory Team”, Department of Metallurgy and Material Engineering, Faculty of Engineering, University of Indonesia, for good cooperation in this work. We also thank Engineering Team from PT. XYZ for providing the SBR#2 field data and technical report.

## DECLARATIONS

### Author contribution

Rado Riady: Writing - Original Draft, Writing -Review & Editing, Conceptualization, Formal analysis, Investigation, Resources. Johny Wahyuadi Soedarsono and Rini Riastuti: Investigation, Supervision. F. Iman Adipurnama: Investigation, Method verification.

### Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

### Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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