Piping Material Selection for Firewater Systems on Offshore Platform using the Multi Criteria Decision Making Method

Fadzlin Sarah Mohd Ghazali* & Mohd Khairi Abu Husain

Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur

sarahghazali82@gmail.com

Article history

Received:
18 Oct 2019

Received in revised form:
7 Nov 2019

Accepted:
4 Dec 2019

Published online:
25 Dec 2019

*Corresponding author:
sarahghazali82@gmail.com

Abstract

The aim of this research is to evaluate the piping material selection using Multi-Criteria Decision-Making (MCDM) methods for a firewater system in offshore oil and gas industries. This study uses Cambridge Engineering Selector (CES) software, Analytical Hierarchy process (AHP) and The Technique for Order of Preference by Similarity to Ideal Solutions (TOPSIS) technique from MCDM to determine the weight factor and material ranking respectively. Results of the study would conclude that Glass Reinforced Epoxy (GRE) material ranked the most optimal pipe material selected for a firewater system.

Keywords: *Firewater system, Multi Criteria Decision Making Method (MCDM), Offshore Platform, Piping Material Selection*

1. Introduction

Over the years, the oil and gas industry has been facing various challenges that require innovation of the offshore drilling platform. An offshore platform is located deep away in the sea starting up to 1500ft and extending up to 'ultra-deep water' of 3000ft [1]. Among the challenges of deep water offshore developments are the materials, design and analysis, fire safety, durability in seawater, inspections, manufacturing, repairs, quality assurances, and regulations [2]. Particularly for a piping system, the main challenges include design and material selection with importance placed on the most economical method. The term piping itself by definition refers to an overall configuration system of pipes, fittings, flanges, valves, and other components that are used to transport liquid or gas or both [3]. Each piping system requires the most suitable material selected for service. In order to transport the liquid throughout the system, a good engineer and designer shall design the most suitable routing while optimising the space available in an offshore platform.

Firewater piping service is one of the most important piping systems in the design of offshore platforms. Fire cases most commonly occurring on offshore platforms are due to gas leakages with relatively high ignition frequencies, probable fire escalation, and material damages which increase the risk to personnel [4]. There will be no immediate emergency firefighting services that could get to them in time to prevent such an event from happening. A firewater system philosophy is to

* *Corresponding author: sarahghazali82@gmail.com*

provide cooling of the exposed surface of equipment containing liquid hydrocarbons. It can also minimise the fire escalation while providing protection against heat radiation for personnel during the escape and evacuation process [5]. A reliable firewater system shall have to be sustainable in a fire incident. It must also have a life expectancy of many years depending on the platform design life and must also be able to withstand any environmental factors. In this case, material selection plays a vital role in determining the reliability of the firewater system. A case study from Broadribb [6] has found that 50% of firewater sprinklers in gas compression areas are usually found to be corroded within the pipes which result in flow blockage thus limiting its effectiveness during fire incidents. A standard firewater piping system consists of a ring or header that supplies the sprinkler systems, firewater monitors, and fire hydrants with fire water.

The current pipe materials for firewater piping that uses raw seawater as a medium varies from non-metallic pipes such as GRE, to metallic pipes such as titanium and Cu-Ni [7]. GRE material is known for their low density, weight reduction and virtually maintenance-free material. However, these pipes have quite relatively high installation cost and it is not environmentally friendly as it is impossible to decompose naturally. For titanium pipes, the initial cost of fabrication and installation is relatively high compared to the Cu-Ni pipes. However, since it has high performance reliability, titanium is known to extend the routine maintenance interval and thus contribute to an increase in the overall life service of the pipes [8].

The aim of this research is to evaluate the piping material selection using Multi-Criteria Decision-Making (MCDM) methods for firewater systems in an offshore oil and gas industry. In order to achieve the objective, the following research objectives (RO) have to be fulfilled:

a. To identify the material candidate suitable for a firewater system in an offshore oil and gas industry
b. To determine the material attributes for a firewater system using seawater service
c. To analyse the material selection using the Multi-Criteria Decision-Making method (MCDM).

The next two sections, Methodology and Discussions, of this paper will discuss how these three objectives of the research are being achieved.

2. Methodology

The research follows a case study from the Sao Vang and Dai Nguyet project comprises of gas and condensate fields located in Blocks 05-1b and 05-1c in the Nam Con Son Basin which is approximately 300km south-east of Ho Chi Minh City offshore Vietnam as shown in Figure 1.

Figure 1. Gas Field location

The area of the study is its firewater system located throughout the platform. This system is vital in protecting sensitive equipment and personnel using the fire escape route. Currently their firewater system has selected Copper Nickel 90/10 material and has sizes ranging from 2 inches to 16 inches. The whole piping system schematic overview is shown in Figure 2.

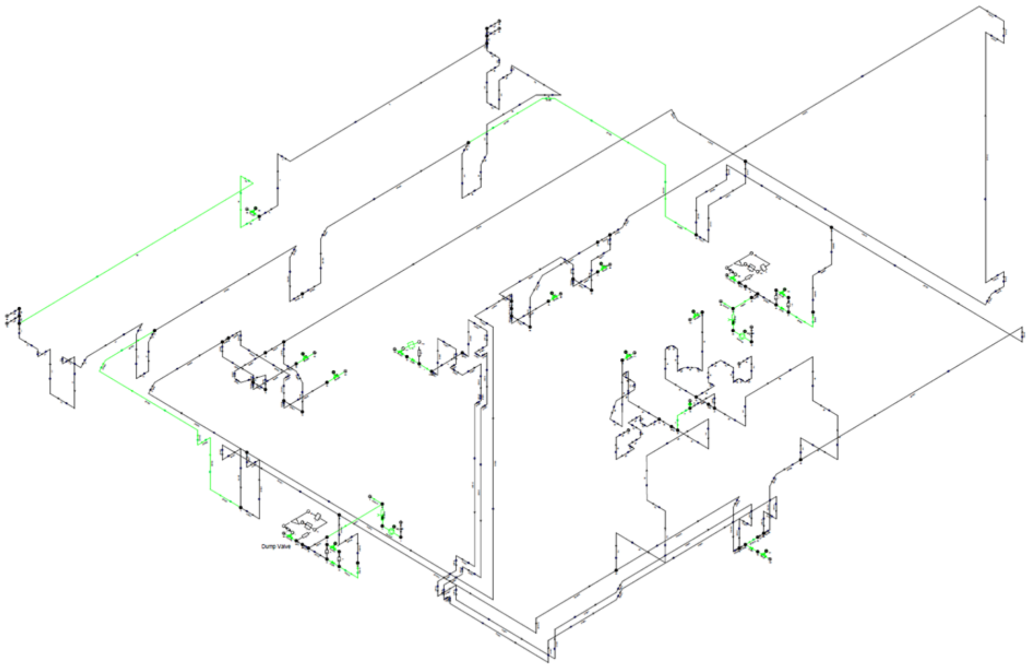

Figure 2. Firewater System Piping Network for SVDN Project

The data collection and data analysis uses Cambridge engineering system (CES) software and MCDM method respectively. CES software is developed by Cambridge Material Selector which is the core analysis tool for material screening. MCDM for data analysis will use a two-type approach for analysis; AHP method for weight factor and TOPSIS software for performance index (PI) calculation. Both data collection and analysis are essential in validating the most optimum material selected for a firewater system in an offshore oil and gas industry.

The research design will be divided into three phases and arranged in structured flow in order to respond to the research questions. The main phases for the research will be as follows;

I. Phase I – Material candidates' definition

II. Phase II – Data Collection

III. Phase III – Data Analysis

2.1. Phase I – Material Candidates Definition

Material selection was previously considered a small part of the design process and it was selected based on handbooks, past experience, and clients' preference [9]. However, oil and gas clients and engineers are always on the lookout for new materials and improved processes to be used in projects to reduce cost while improving their profit margin. Therefore the need to revise the material selection is needed now more than ever.

In this study, to simplify the material screening process, the CES software is used. From this software, the material screening process is much easier and creates flexible output for the study. The finalised material screening with its attributes are shown in Table 1.
(Note 1: Value units will be converted from the qualitative scale (Excellent =5, Very good= 4, Medium =3, Low = 2, Very low = 1)

Table 1. Material Attributes with Types and Units

No	Attributes	Type	Unit	Note
1	Seawater Corrosion	Qualitative	-	Note 1
2	Density	Quantitative	kg/m3	
3	Yield strength	Quantitative	Mpa	
4	Cost / weight	Quantitative	USD/ Kg	
5	Availability	Qualitative	-	Note 1
6	Ease manufacturing	Qualitative	-	Note 1

2.2 Phase II – Data Collection

The data collection will be from the research project which is required to achieve the second objective of the research which is to determine the material screening for the firewater piping system with seawater service. The data collected will be divided into parts of the study which is from quantitative and qualitative values.

2.2.1 Quantitative Value – Density, Yield Strength & Costing

The data from the quantitative value will be selected for the study and is the density in kg/m3, yield strength in Mpa and costs in RM/unit weight. Data are collected from the CES software and also some literature review. These data are being tabled into a summary shown in Table 2 below.

Table 2. Summary of Quantitative Data for Material Candidates

Material Candidate	Density (kg/3)	Yield Strength Min (Mpa)	*Price/cost (USD/kg)
GRE	1800	375	22
Cu-ni	8940	340	45
Titanium	4500	275	70
SDSS	7820	515	25
6 Mo	8000	300	40

Note: * For the purpose of this research, the values here are estimated based on Aker Cost Database Q4 2018.

2.2.2 Qualitative Value –Material Performance in Seawater Corrosion Resistance, Material Availability & Ease of Manufacturing and Installation

The firewater system with seawater services piping material has already been established before for all offshore oil and gas industrial projects. These materials must be able to withstand harsh environmental conditions such as salt laden atmospheres or extreme cold temperature such as -30 ° C depending on where the platform is located. Currently, the seawater property used for this study is as seen in Table 3.

Table 0. Seawater Properties

Parameter	Value	Units
Fluid	**Seawater**	**-**
Density	**1023**	**Kg/m3**
Viscosity	**0.837**	**cP**
Temperature	**32**	**^{o}C**
Bulk Modulus	**2.2**	**GPa**
Vapour Pressure	**0.03**	**bara**

Since qualitative values are intangibles, the values are converted into numbers for further analysis. The summary of the data collected for qualitative values from the project are presented in Table 4.

Table 4. Summary of Qualitative Value for Material Candidates

Material Candidates	Seawater Corrosion Performance	Availability (Critical material status)	Ease manufacturing & installation
GRE	5	5	2
Cu-ni	5	3	3
Titanium	5	2	2
SDSS	5	5	4
6 Mo	5	5	4

2.3 Phase III – Data Analysis

The method selected for data analysing the weight factor calculation is analytic hierarchy process (AHP) which is a theory of measurement which derives the ratio scales from both discrete and continuous paired comparisons [10]. In AHP, to model a problem of the hierarchy or a network structure to represent that problem, a pairwise comparison is established in relation to the structure. AHP provides a way to make complex decisions in the most general structures encountered in real-life by deriving at the priorities for all factors and synthesising them for an overall outcome which includes quantitative and qualitative values [11]. The scale of relative importance is identified by using Table 5.

Table 5. Fundamental Scale [10]

Intensity of importance on absolute scale	Definition	Explanation
1	Equal importance	Two criteria equally objective
3	Moderate importance	Experience and judgement strongly favours one activity over another
5	Strong importance	Experience and judgement strongly favours one activity over another
7	Very Strong importance	Experience and judgement is strongly favoured together with dominance
9	Extreme importance	Favouring one activity over another highest possible order of affirmation
2,4,6,8	Intermediate values	When compromised is needed
1/3, 1/5, 1/7, 1/9	Values for inverse comparison	One criteria value is inversed during comparison with another

2.3.1 Weightage Calculation using AHP Method

The special feature of AHP is that the pairwise judgement can be inconsistent in its measurement and dependent within the elements structure [10]. By using AHP, the decision-maker can estimate the weight factor for each material characteristic. The step-by-step AHP weight factor determination can be summarised as in Figure 3.

2.3.2 MCDM using TOPSIS Method

After the weight factor has been determined using the AHP calculation, the final step is to finalise the material selection by using the TOPSIS method. Basically, TOPSIS is a technique developed upon a concept that the chosen alternative should have the shortest distance from the ideal solution and the furthest from the negative-ideal solution [12]. It is best shown in Figure 4, the alternative A1 has shorter Euclidean distance from A- than A* as opposed to the other alternative A2 (A* denotes a negative ideal solution). Therefore in this example, A2 is the most optimum selection as compared to A1. Euclidean space as shown in Figure 5 by definition is the two-dimensional plane and three-dimensional space of Euclidean geometry as well as their higher dimensional generalisation.

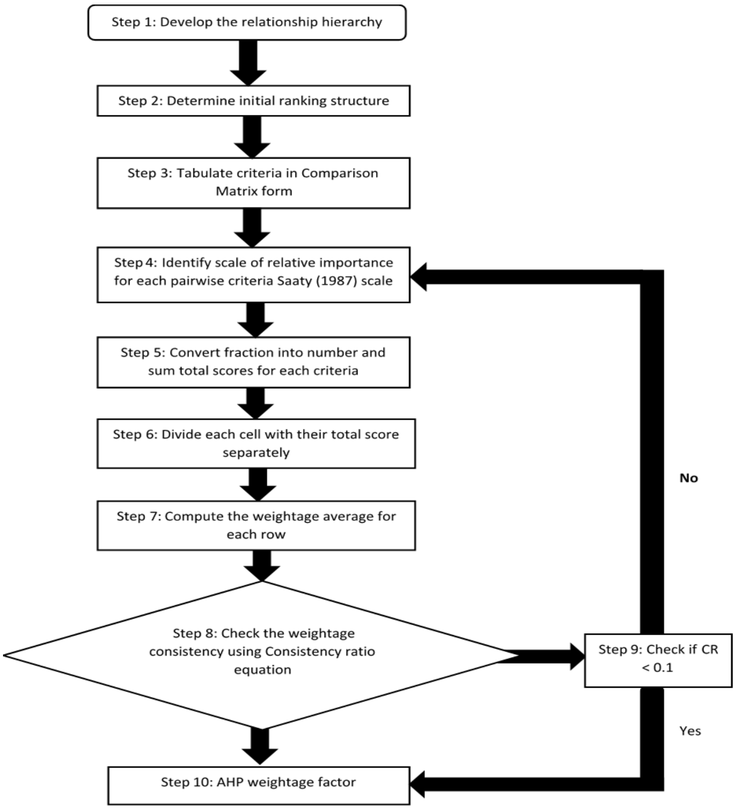

Figure 3. Step by Step Weight Factor Determination

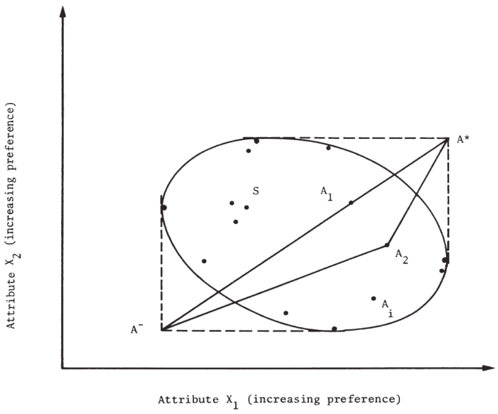

Figure 4. Euclidean Distance to the Ideal and Negative-Ideal Solutions in Two Dimensional Space [12]

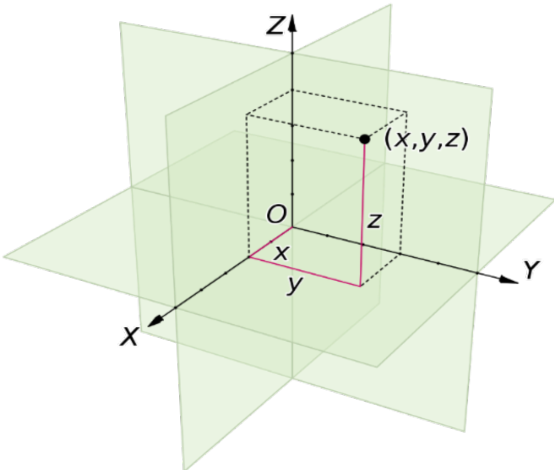

Figure 5. Coordinate (x,y,z) Showing in the Three Dimensional Euclidean Space [12]

The whole summary of the TOPSIS procedure are shown as per Figure 6.

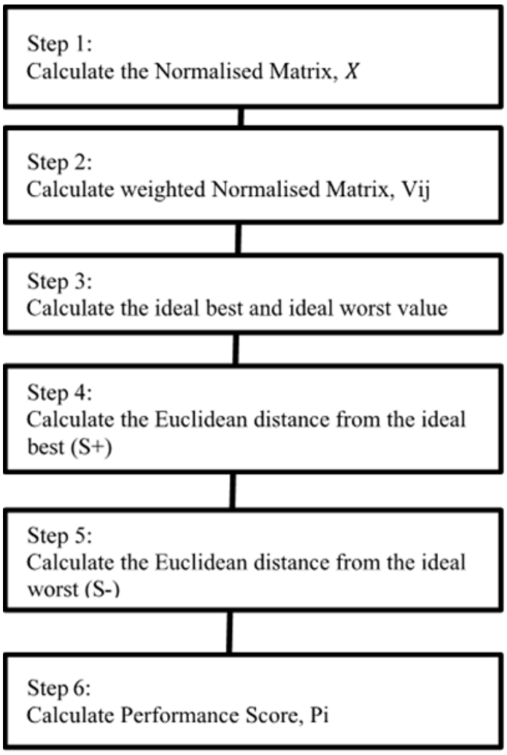

Figure 6. TOPSIS Procedure

The full result data collected from both quantitative and qualitative values and the weight factor from the AHP calculation will be consolidated into one summary table as shown in Table 6.

Table 6. Consolidated Summary Table of Weight Factor and Attributes Values

Weightage	W1 =0.42	W2=0.23	W3=0.14	W4=0.11	W5=0.06	W6=0.03
Material Candidate	**Seawater Corr. Perform.**	**Density (kg/m3)**	**Yield Strength Min (Mpa)**	***Price/ cost (RM/kg)**	**Availa (Critical material status)**	**Ease manu.& install**
GRE	5	1800	375	22	5	2
Cu-Ni	5	8940	340	45	3	3
Titanium	5	4500	275	70	2	2
SDSS	5	7820	515	25	5	4
6 Mo	5	8000	300	40	5	4

3. Discussions

Based on the case study by Sao Vang and Dai Nguyet project (2018), the Cu-Ni pipe material was the selected material for the firewater services. The total length for each size used for this service is as shown in Table 7 below.

Table 7. Summary of Length (m) and weight for Firewater Services in the SVDN Project

Sizes OD (mm)	Length (m)	GRE Weight (kg)	Titanium Weight (kg)	SDSS Weight (kg)	6Mo Weight (kg)	Cu-Ni Weight (kg)
20	6.2	7.99	6.20	10.41	10.65	8.03
25	604.5	423.12	750.13	1259.94	1288.94	1166.37
40	533.0	692.90	981.25	1649.98	1687.96	1567.32
50	323.3	452.57	752.89	1266.25	1295.39	1234.84
80	553.2	995.67	2114.69	3558.28	3640.18	3346.50
100	196.5	609.19	857.58	1638.13	1675.84	1733.22
150	1005.9	3520.49	8228.90	13852.84	14171.71	15328.98
200	343.1	1578.16	4055.54	6823.75	6980.82	9276.86
250	277.2	2051.20	4558.10	7671.38	7847.96	11162.46
300	24.8	206.25	529.31	890.75	911.25	1543.12
350	105.2	947.16	2575.95	4335.59	4435.38	8486.48
Total	**3972.8**	**11484.71**	**25410.55**	**42957.30**	**43946.08**	**54854.18**

Cu-Ni makes the heaviest in weight because Cu-Ni has the highest density when compared to the other materials. GRE has the lowest density hence making it the lightest among others. From a weight analysis point of view, GRE is definitely the most optimal pipe material for firewater services. The costing is also analysed on which material is the most expensive to use for the firewater system in this SVDN project. The total costing for each material is calculated and the weight versus the cost analysis graph is plotted and shown in Figure 7.

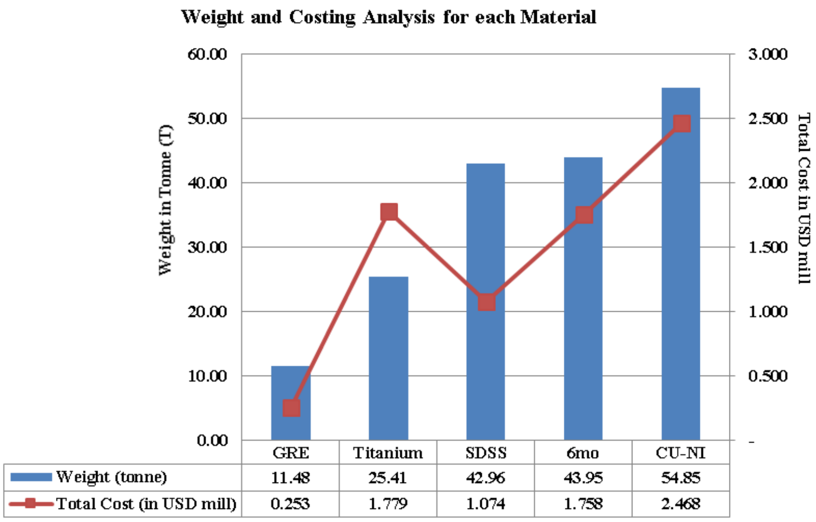

Figure 7. Weight and Costing Analysis for each Material

The lowest pipe weight for firewater services is GRE at 11.48 tonnes while the highest pipe weight is Cu-Ni with 54.85 tonnes. Cu-Ni weight is 4.7 times heavier when compared to GRE. GRE total costing for the entire firewater service is the lowest which is estimated at about USD 253,000. SDSS had the second lowest total cost at USD 1.08mil, whereas the cost of 6Mo cost was neck-and- neck with the titanium costing with 6Mo being slightly cheaper by USD 20,900. The highest cost for service is Cu-Ni pipes with a price of USD2.47mil. The difference in cost between GRE and Cu-Ni is about USD2.22mil or 89.8% more where Cu-Ni is in the lead. That is a tremendous difference of weight and price value when comparing GRE to Cu-Ni material.

4. Result

The data from the AHP calculations will give the estimated weight factors for each material criterion which was not available during the initial stage of the study and the data results from TOPSIS will yield the performance index, PI for each material. From Table 8, the highest weight factor computed for the material criteria is 0.42 or 42% which represents the seawater corrosion performance. Table 9 presents the PI results from the TOPSIS calculation and the rankings score. GRE leads the rank which is followed by titanium, SDSS, 6Mo and finally Cu-Ni for the material choices for firewater services.

Table 8. Weightage Factor for Each Criteria Based on AHP Calculations

Criteria	Ratio	%
Seawater Corrosion Performance	0.42	42%
Density	0.23	23%
Yield Strength	0.14	14%
Price/cost	0.11	11%
Availability	0.06	6%
Ease manu / install	0.03	3%

Table 9. Ranking of Each Material Candidate Based on TOPSIS Calculations

Material Candidate	PI	Rank
GRE	0.83	1
Titanium	0.45	2
SDSS	0.43	3
6 MO	0.29	4
Cu-Ni	0.21	5

5. Conclusion

The motivation of this study was to validate an alternative method in determining the most optimal material used in a firewater system for an offshore oil and gas industry. MCDM techniques do provide an insight on how decision-makers may select the best material with multiple criteria and different material comparison. From the PI results, it is clear that GRE is the most optimal material candidate for firewater services for offshore platform particularly for the Sao Vang and Dai Nguyet project. However, the result depends on different environmental conditions at different platform location. The scope of study only covered firewater systems located in south East Asian regions offshore. Future research should cover more services in the platform. The researcher recommends process services such as hydrocarbon, and produced water as a future research area.

Acknowledgments

The authors would like to acknowledge their appreciation towards Universiti Teknologi Malaysia (UTM) for their support in providing access to conduct this research.

6. References

[1] Gibson, A., Linden, J., Elder, D., & Leong, K. (2011). Non-metallic pipe systems for use in oil and gas. Plastics, Rubber and Composites, 40(10), 465-480.
[2] titiSalama, M. M. (1997). Some challenges and innovations for deepwater developments. Paper presented at the Offshore Technology Conference.
[3] Mohinder L Nayyar, P. E. (2000). Piping Handbook (Seventh ed.): Mcgraw-Hill.
[4] Pettersen, M. N. (2009). Reliability Analysis of Fire Water Systems on Offshore Installations. Institutt for matematiske fag,
[5] Ikhwan, K. (2018). Firewater System Transient Analysis Report. Technical Safety. AKER ENGINEERING INTERNATIONAL SDN BHD.
[6] Broadribb, M. P. (2015). What have we really learned? Twenty five years after Piper Alpha. Process Safety Progress, 34(1), 16-23.
[7] Standard, N. (2004). Materials selection. M-001, Rev, 4.
[8] Peacock, D., & Corr, M. (2000). Effective design of high performance corrosion resistant systems for oceanic environments using titanium. In: De Gruyter.
[9] Chiner, M. (1988). Planning of expert systems for materials selection. Materials & Design, 9(4), 195-203.
[10] Saaty, R. W. (1987). The analytic hierarchy process—what it is and how it is used. Mathematical modelling, 9(3-5), 161-176.
[11] Saaty, T. L. (2008). Relative measurement and its generalization in decision making why pairwise comparisons are central in mathematics for the measurement of intangible factors the analytic hierarchy/network process. RACSAM-Revista de la Real Academia de Ciencias Exactas, Fisicas y Naturales. Serie A. Matematicas, 102(2), 251-318.
[12] Hwang, C.-L., & Yoon, K. (1981). Methods for multiple attribute decision making. In Multiple attribute decision making (pp. 58-191): Springer.