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MATERIAL SELECTION OF PROPOSED AIR RECEIVER TANK APPLIED FOR ELECTRICAL GENERATOR

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Abstract

Air receiver tank in electrical generator used as pressured air vessel is mainly consisted of shell cylinder and head part. This work has searched for the more suitable material to be used for the shell and head of the proposed air receiver tank because the older material (SPV 355) has some limitations. This study has been conducted based on several parameters in standard references. The calculations have applied relevant technical formulas such as corrosion factor, thickness design, and Maximum Allowable Working Pressure (MAWP). There are three types of selected materials available that are expected to yield similar previous condition parameters addressing to operational pressure 10 bar and temperature 40°C, i.e., SA-36 (Type I), SA-516 Gr 70 (Type II), and SS-304 (Type III). The economic factor is also taken into consideration. Considering the economic cost and mechanical characteristics, finally the material of Type II is selected to be the most appropriate material to replace SPV 355 material for the proposed air receiver tank. In the upcoming, this study is useful for the knowledge of material design.

Keywords: Air Receiver Tank, Corrosion Factor, Thickness Design, MAWP

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1. Introduction

This study corresponds with the air receiver tank used in electrical generators. A new material air receiver tank will install an electric generator on Bali Island. Initially, The electric generation project in Java Island will be moved to Bali Island. However, the company will replace the older material of the air receiver tank (namely SPV 355) with another new material, which is expected to yield similar previous condition (operational pressure 10 bar and temperature 40°C) in terms of good mechanical strength, corrosive resistance, and high toughness.

The function of an air receiver tank is to store pressured air due to air compression for a moderate time; therefore, the material of the air receiver tank needs particular consideration. According to the company, the material SPV 355 has undergone decreased mechanical strength due to an aging factor. Initially, the company will still use new SPV 355 material to replace the older one. However, some investigations have reported that SPV 355 has no longer been produced[1]. Finally, a decision has been made to use another material whose characteristics are similar to SPV 355, addressing the yield condition of 10 bar operational pressure and 40°C temperature design.

Recently, many substantial problems have been faced by pressured air receiver tanks concerning material leakage, material fracture, fatigue, and material corrosion. Unstable internal pressure may cause a shorter air receiver tank lifetime. This matter can be due to inappropriate material used, inaccurate thickness design not adjusted with allowable working pressure and low corrosion resistance. Therefore, it needs a thorough study of material selection, including thickness design and MAWP, to avoid serious problems often faced by pressured air receiver tanks. Nevertheless, the study of engineering material addressing the air receiver tank is still challenging.

Ongoing with this matter, there are three types of materials on availability, i.e., the SA-36 (Type I), SA-516 Gr 70 (Type II), and SS-304 (Type III). The three types of materials of interest are examined for their corrosion factor, thickness design, and MAWP based on calculations using several standard formulas[2–4]. In addition, the economic factor will also be taken into consideration.

2. Experimental and Procedures

Table 1 lists the older material (SPV 355) and alternative proposed materials (Type I, Type II, and

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Type III). The characteristics of materials follow the manual guidance[2].

Table 1 The materials as object of this study

Type of material	Material characteristics
SPV 355	Possessing high mechanical strength and hardness (better than ordinary carbon steel) due to cold work treatment.
SA 36	Having characteristics of mild steel plate SA 36 for general construction due to hot work treatment. Low cost and more ductile. Generally used in shipping industry[5]. This material is taken into consideration on reason of easily machining and welding. In addition, SA 36 is fairly good for any hot treatment.
SA 516 Gr 70	Following the ASTM SA 516 standard in the form of carbon steel plate particularly for welding pressured vessel for low until moderate temperature. There are four grades, i.e. 55, 60, 65, and 70, particularly the SA 516 Gr 70 possessed high toughness[6]. Eventually, this type of material is specified as ASTM A516. Its high toughness is a strong reason for our consideration on material selection.
SS 304	Having similar stainless-steel characteristics particularly often used in food industry. High ductility, easy welding, and high corrosive resistance. This type of material contains 18% Cr and 8% Ni often referred as 18–8 stainless steel and also taken into our consideration, albeit it is rather expensive.

Table 2. Specification of air receiver tank

No	Parameter	Unit
1	Working fluid	Air
2	Operational pressure	10 bar
3	Design temperature	40 ^{O}C
4	Material density	7850 kg/m^3
5	Welding joint efficiency	0.80%
6	Corrosion allowed (CA)	1 mm
7	Vessel length	2975 mm
8	Vessel inner diameter	1200 mm

Table 3. Data of selected material[2]

No	Material type	Design temperature	Max stress
1	SA-36	40 ^{o}C	125 N/mm
2	SA-516 Gr 70	40 ^{o}C	138 N/mm
3	SS-304	40 ^{o}C	138 N/mm

The air receiver tank, as the focus of this study, is used as a unit part of an electrical generator. Table 2 shows the specification of an air receiver tank run by a company[3,7]. The operational pressure (10 bar) and temperature design (40^{o}C), as listed in Table 2, are referred to as the basic consideration for new material selection replacing the older material (SPV 355) of the air receiver tank. Fig. 1 shows the picture of the air receiver tank of interest.

Fig. 1. Air receiver tank.

After recording all the data of the air receiver tank as shown in Table 2, then conducted calculations using Equations (1–5)[2] to determine the corrosion factor, thickness design, and MAWP of the tank shell, head top and head bottom, for selected materials that should fulfill the requirements of operational pressure (10 bar) and design temperature (40oC) as shown in Table 2.
The steps of this study are presented as follows:

- Collecting data on the air receiver tank from the company in charge, including operational pressure, temperature, welding efficiency, vessel length, and diameter.
- Conducting calculation and analysis applying the data of air receiver tank, handbook data, and empirical formulas involving data of selected materials for tank shell and tank head. The formulas include operational pressure, material stress, welding efficiency, corrosion factor, thickness design, and maximum allowable working pressure (MAWP).
- Doing thorough discussions of result data in relation to thickness design, MAWP, and corrosion factor addressing the tank shell and tank head. Effects of material stress are considered in relation to material thickness and MAWP, which is important for material selection.
- Considering economic factors in material selection as the last consideration in making the final decision. Mechanical properties such as material toughness, impact, and corrosion

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resistance are also taken into account in material selection.

Table 3 shows the data of max stress at temperature 40OC were obtained from the handbook[2,4].

3. Results and Discussion

Equations (1) and (2) are used to determine the thickness design and MAWP of tank shell. In order to solve the equations, the data of maximum stress of selected material should be involved as shown in Table 3. Equations (1) and (2) have applied some of the data in both Table 2 and Table 3.

3.1. Thickness design and MAWP of tank shell

In order to protect a pressured air receiver tank from common problems like air leakage, material cracking, fatigue and failure, the material thickness and working pressure referred to MAWP are the important factors taken into primary consideration. Equations (1) and (2) below describe the material thickness and allowable working pressure for tank shell.

$$t = \frac{P \times R}{S \times E - 0{,}6 \times P} + CA \quad (1)$$

$$P = \frac{S \times E \times t}{(R + 0{,}60 \times t)} - P_s \quad (2)$$

where,

P_{10} = Operational pressure (10 bar)
R = Inner radius (600 mm)
S = Max stress (material type)
E = Efficiency of welding joint (0.80%)
CA = Corrosion allowed (1 mm)
t = Thickness design of tank shell
P_s = Static pressure of air (0.0000 bar)

The results of calculations using Equations (1) and (2) are shown in Table 4. The thickness design and MAWP of both materials Type II and Type III are equal. This is due to the same values of max stress of both materials Type II and Type III (Table 3).

The material thickness of tank shell is strongly influenced by operational pressure, material stress, and welding efficiency, as well as material corrosion (Equation 1). The material thickness should be adjusted with the operational pressure. Large operational pressure without taking material thickness into consideration may cause material fracture and accelerate fatigue failure, even worse material broken. Moreover, the allowable working pressure will be affected by the material thickness (Equation 2) and therefore, the maximum allowable working pressure (MAWP) should be adjusted with the thickness design. This is the reason that thickness design and MAWP for tank shell needed to be considered.

Table 4. Thickness design and MAWP of tank shell

No	Parameter	Type of material		
		SA-36	SA-516 Gr 70	SS-304
1	Thickness design	8.26 mm	7.57 mm	7.57 mm
2	MAWP	17.63 bar	16.38 bar	16.38 bar

3.2. *Thickness design and MAWP of tank head top and head bottom*

Besides the material thickness and allowable working pressure needed for pressured air receiver tank design, the corrosion factor is also substantial to be considered. Equation (3) below describes the parameter related to material corrosion.

$$K = \frac{1}{6}\ x\ [2 + (\frac{D}{2\ x\ h})^2] \quad (3)$$

$$T = \frac{P \times D \times K}{2 \times S \times E - 0{,}2 \times P} + CA \quad (4)$$

$$P = \frac{2 \times S \times E \times t}{K \times D + 0{,}2 \times t} - P_s \quad (5)$$

where,

K = Material corroded
CA = Corrosion Allowed (1 mm)
P_{10} = Operational pressure (10 bar)
D = Inner diameter (1200 mm)
S = Max stress (material type)
E = Efficiency of welding joint (0.80%)
h = Distance between head top and bottom
T = Thickness design of tank head
P_s = Static pressure of air (0.0000 bar)

The calculation results of Equations (3–5) are shown in Table 5. As shown in Table 5, with respect to corrosion factor, thickness design, and MAWP, the results of both materials Type II and Type III are equal due to same values of max stress of that both materials of interest (Table 3).

The reason for the substantial factors of thickness design and MAWP addressing to tank head top and bottom are similar to that of tank shell in terms of operational pressure and welding efficiency. Particularly for the tank head both top and bottom, the material corrosion takes special attention (Equation 3) due to air inlet and outlet causing unstable operational pressure. Corrosion issues for engineering materials are very

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critical[8,9]. Corrosion of materials may induce material fracture and fatigue failure that in turn leading to material shorter life time. Fahimuddin et al.[8] applied Charpy impact test to study corrosion of steel bridge material. On other occasion, Ayu Arwati et al.[9] investigated the corrosion of stainless steel 316L due to temperature effect in sulfuric acid environment.

Table 5. Thickness design and MAWP of tank head top and bottom

No	Parameter	Type of material		
		SA-36	**SA-516 Gr 70**	**SS-304**
1	Corroded	0.9977	0.9977	0.9977
2	Thickness design	8.20 mm	7.53 mm	7.53 mm
3	MAWP	13.6 bar	13.85 bar	13.85 bar

3.3. Economic consideration

Economic factors are also taken into considerations in the selection of materials. All economic calculations are determined using Autodesk Inventor software. The process detail related to economic factor of material is beyond the scope of this paper and therefore, the thorough discussion of economic matter is not included. The data for economic consideration were collected from the company, calculation results of corrosion factor, thickness design, and MAWP, and market price for technical materials as well[2 – 4, 10]. The results are shown in Tables (6 – 8).

Table 6. The weight of each component of air receiver tank

No	Component	Type of material		
		SA-36	**SA-516 Gr 70**	**SS-304**
1	Shell	690.806 kg	690.806 kg	690.806 kg
2	Head top	54.020 kg	54.020 kg	54.020 kg
3	Head bottom	54.020 kg	54.020 kg	54.020 kg

Table 7. The price of respected material per Kg

No	Material	Unit	Price
1	SA-36	1 kg	Rp. 25 218
2	SA-516 Gr 70	1 kg	Rp. 30 959
3	SS-304	1 kg	Rp. 44 239

As shown in Table 6, the weight of tank head top is equal to the weight of head bottom. All selected materials of interest (Type I, Type II, and Type III) are designed to have equal weight for their respected component unit. The weight data of each component (Table 6) is needed for economic reasons, since the material price is referred to material weight per kg (Table 7). The price results are presented in Table 8.

Moreover, Table 7 shows the price of respected selected material (Type I, Type II, and Type III) per kg following the update price in the market[10]. It shows that the price is getting more expensive from material Type I to Type III. It is reasonable the material Type I has the lowest mechanical properties compared to mechanical strength of the other two types of material (Type II and Type III). The highest price belongs to material Type III since this material is classified as high corrosive resistance stainless steel material with 8% nickel and 18% chromium commonly used in food industry[11]. The elucidation of this matter can be seen in Table 1.

Table 8. The total price of each selected materials

No	Material	Weight	Price
1	SA-36	798.846 kg	Rp20,145,298
2	SA-516 Gr 70	798.846 kg	Rp24,731,473
3	SS-304	798.846 kg	Rp35,340,148

Table 8 shows the price of total weight of each respected selected material. Of course, the highest price is shown for material Type III. The total weight is the summation result of all component weights (tank shell, head top, and head bottom) shown in Table 6.

4. Conclusions

This study is related to material selection for an air receiver tank of a company running electrical generator. With regard to its mechanical properties and economic factor, material of Type II (SA-516 Gr 70) is finally selected as the recommended material to replace the older material (SPV 355), which is no longer produced in small scale. Although, material Type II is more expensive than material Type I, however, the mechanical properties of material Type II is better than that of material Type I in terms of more ductile, more easily machining and welding, higher toughness, and low carbon content for mild steel as well. This study is valuable related to the knowledge of engineering material.

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