Iranian Journal of Mechanical Engineering
The Iranian Society of Mechanical Engineers
Research Paper

DOI: 10.30506/JMEE.2022.547225.1280
DOR: 20.1001.1.16059727.2022.23.2.2.1

Effect of Selecting the Suitable Design on Production Costs of Pressure Vessels

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In addition to standard design and production, its economics is also vital. Design and production organizations must pay special attention to the design process's cost category, selecting materials and determining production methods continually. Flexibility, access to data and information from multiple materials and the possibility of examining production methods based on the material and dimensions designed are the features of this research's results. Identifying and selecting suitable and accessible materials can be helpful in design dimensions using pressure vessel design formulas. The design and its outputs can significantly affect the weight and price of materials, production method and cost. The actual design, effects of permitted structures on material and production cost and the final total cost of a pressure vessel have been studied. The total cost values were compared and validated with target values compared with past research results. This method *can be used as a general cost-based method for selecting suitable designs to identify and produce other products considering strengths, reliability and safety factors.*

Keywords: Product design, Production cost, Cost analysis, Engineering design, Cost evaluation.

1 Introduction

Pressure vessels are used as pressure containers with simple and complex types in different industries. Pressure vessels are usually made for oil, petrochemical, power plants, and transportation have particular and considerable applications. Depending on the geometry of the tanks and the type of pressurized liquids in these tanks, they are used in various dimensions [1]. Pressure vessels are divided from different perspectives as horizontal or vertical layout, gas or liquid fluid type and spherical, cylindrical, or conical shape. The following factors must be

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Receive: 2022/01/20 Accepted: 2022/05/08

considered to ensure that pressure vessels meet all requirements, such as corrosion resistance, container weight, content, ambient temperature, performance, static and dynamic pressures, residual and heat pressures, and reaction forces [2]. Also, the thickness of the sheet used in the pressure vessel can be considered a factor in the design. Accordingly, pressure vessels are divided into two groups:

- Thin-shelled pressure vessels whose diameter is ten times or more than their thickness.
- Thick-walled pressure vessels whose diameter is less than ten times its thickness.

Therefore, according to the stated cases, their design and production are of particular importance. Most pressure vessels have an internal and external pressure difference equal to or more significant than 15 psi (103kPa) and less than 3000 psi (20684kPa), and their inner diameters of more than 6 inches (152 mm) with a volume of 120 gallons (454Liter). Pressure vessels are designed and manufactured in two forms, cylindrical and spherical, and made of carbon steel or stainless steel and assembled. Figure (1) shows a schematic image of a pressure vessel with two hemisphere heads as a sample.

Kouvelis et al. proposed a theoretical control model to study the complex interaction of quality, price, and cost factors in the life cycle. This model considers the initial processes of design, production, and marketing and focuses on determining the optimal price, design quality, and production methods in a dynamic environment according to production costs [3]. In the design of pressure vessels, prevention of "plastic collapse" and "excessive overall plastic deformation" issues should be considered based on the ASME BPVC Section VIII Division 2 and EN 13445 [4]. One of the primary steps for designing pressure vessels is a material selection, definition of working temperature, manufacturability, cost, wear, corrosion, strength requirements, and availability [5]. Colosimo et al. presented a cost model to evaluate the economic impact of process defects and instability in manufacturing metal additives. The proposed formula adopts the main framework of previous negative studies. It extends it by considering the contribution of scrap waste and on-site monitoring functions to process and material costs, including pre- and post-processing operations [6]. Disk pressure relief device service is the last security barrier to prevent catastrophic pressure tank overpressure.

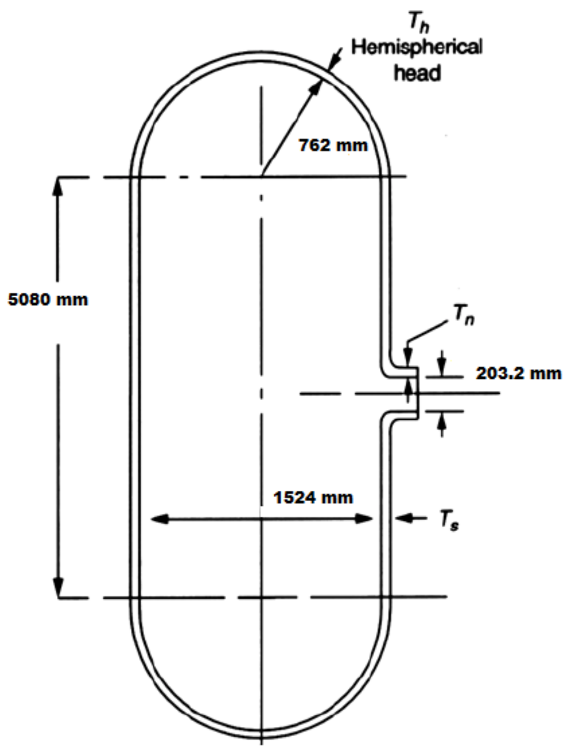

Figure 1 Schematic diagram of a sample vertical pressure vessel

The ultra-high pressure bursting disc device design is a tough engineering issue as it requires both strength and sealing reliability under ultra-high working pressure [7]. Design optimization should be done for increasing attractiveness through technical and economic activities in the design and manufacturing of pressure vessels. Finding the cost and market approaches need to be tailored to alternative schemes by giving the strategic behavior of suppliers and providing the exact target costs; also, before making any decision, it is better to estimate and determine the price and performance for different purposes [8].The cost is a continuous random variable that, by changing the price, the optimal profit can switch to the desired amount, which makes it challenging to make the right decision and choice [9]. The value of thin-walled pressure vessels in mechanical design makes them complex in pressure, temperature, and thickness. Facilities such as pipes or bottles that can withstand internal pressure have been significant in science and technology history [10]. The product development process with design thinking & concurrent engineering approaches can create a product in a manner of reasonable and competitive price [11]. Pressure vessels are closed containers used to hold gases or liquids utterly different from the ambient pressure. Also, the vessel's design, production, and process are regulated by engineering authorities and the law's supporters [12]. Designing or optimizing is crucial for designers choosing the appropriate design parameters such as thickness, design pressure, or allowable stresses. Design can change the performance, efficiency, and safety because codes and standards govern the pressure vessel's design [10]. The platform business model's hardware product introduces three critical issues that are not yet well understood in the operating system pricing literature: downward potential, rising production costs, product quality, and strategic consumption behaviors [13] Too-loaded cylindrical pressure vessels have to sustain design loads with stringent reliability, keeping in mind the potential dangers of overloading atomic reactors [14]. Breakdown analysis of thick-walled cylindrical structures, which may undergo plastic deformation or elastic-plastic, has been crucial to the safety of these structures [15]. The safe dimensions of the vessel could be estimated from the same regulations and standards. However, the selection of head, location nozzles, and supports is mainly decided by the designer. In selecting the essential pressure vessel parts, it must be ensured that the design can carry the applied load and operate safely and reliably. Thus, finding an optimal combination of vessel parts and locating the nozzles and supports is necessary [16]. The use of newly developed tools (machining inventory and cost optimization) has been used to determine the production cost of machining steels. In addition to increasing productivity, this method reduces production costs by reducing lubrication costs [17]. The ASME VIII (2) is widely used to design low-temperature and high-temperature pressure boundary components operating at high temperatures in the creep range [18]. The maximum and minimum design temperatures for a vessel will determine the maximum allowable stress value permitted for the material to be used in the vessel's fabrication. The design pressure for a vessel is called its "maximum allowable working pressure" (MAWP) or "working pressure." [19]. The previous study presents data-driven cost estimation methods based on artificial neural networks (ANN) and regression models. The methods have been applied in a real case, where the input parameters of the models are assigned based on the critical issues involved in spherical tank construction [20]. This paper proposed a cost-effective data collection method to reconstruct a three-dimensional model of a pavement surface, which is a good idea for using a cost-based thickness variation function based on data collection [21]. The use of cost-effective methods, techniques, and materials to reduce costs in the operation and equipment of oil processes and drilling methods is also common and significant [22].A combined approach that bridges both design areas is still lacking. It contributed to this underdeveloped research area to explore the design business environment [23]. Reliability is the probability of a component, device, and the process performing its desired function for a certain time without failure works well in a specific environment. Reliability analysis helps production management product failure while life cycle cost analysis deals with cost consequences, reliability analysis is important throughout product life because the uncertainty has several undesirable consequences, and therefore for many products, poor reliability is a serious threat [24].

2 Materials and method

This method has focused on the three essential elements of a designed and produced product's cost price. The correct selection of materials will be affected by product dimensions' design and designed sizes at production costs. It means that in the design principles, selection of materials, and production methods, attitudes to cost are considered and evaluated. The Production methods are:1) Welding, in the welding method, first, the base metal is selected and calculations related to the tank design are performed. The method's basis is that first the body of the tank is rolled and its head is made separately. Then, using welding, different parts are connected.2) Forging weld is called a type of welding method that is used in the production of pressure vessels. in this method, two metal plates that must be connected are placed on each other and heated Until the junction of the two sheets becomes doughy and are joined by pressing until a connection is established between the plates. The forging method is applicable for parts with high strength and durability, parts under high pressure, parts in which the presence of porosity and cavitation is not acceptable, and strong mechanical parts are used without the expensive alloys. Forging materials are also used in the manufacture of equipment and fittings for pressure vessels, such as seamless rolling, shell layer, rings, heads, nuzzle forging, discs, cavities, tubular sheets, and elbow fittings, valve connections to the body, and special forging. Cost-effectiveness is an essential criterion, except when other factors such as corrosion resistance, impact resistance, and lifecycle overshadow the issue of cost-based design and production also the rules in the UF(1-13) sections apply to forged pressure vessels without longitudinal joints, including their parts that are made of carbon and low aluminum steels or from high aluminum steels within the limitations of the UHA part. These rules shall be applied together with the requirements applicable in Sub-A, and with specific requirements in sub-C which relate to the relevant classes of all materials [2]. Cost-reduction studies in design and production will have the best results when focusing on design factors that effectively reduce materials and production costs. In this methodology, we focus on the dimensional characteristics of the designed product. Our method's basis is based on determining the operating temperature of pressure vessels based on the correct choice of type and material of raw materials. The material and grade of selected materials according to design rules affect the product's dimensional characteristics. This means that the designed product specifications will be a factor in estimating the final cost, which we will discuss below. Our methodology is considered as follows a flow process chart. In this section, each step is discussed according to Figure (2).

Step 1: Determine the design temperature and pressure

The design temperature is typically used as the highest operating temperature due to the start-up and shutdown events and determining the allowable stress. The working pressure is the pressure at which the process usually operates, and design pressure is the pressure on which the design is based, which must be considered more than the operating pressure.

Step 2: Determine the codes of materials for shell (plate), head (plate/forging material) and nozzle (pipe/forging material)

For identifying suitable materials in the selection tables of materials, temperature use is essential. We can obtain the acceptable materials through this stage for determining the sufficient pressure vessel materials by ASME Boiler and Pressure Vessel Code. Table (1) shows the acceptable materials for pressure vessels according to the ASME code and it is established by the approach of identifying all materials that can be used in a clustering method [25].

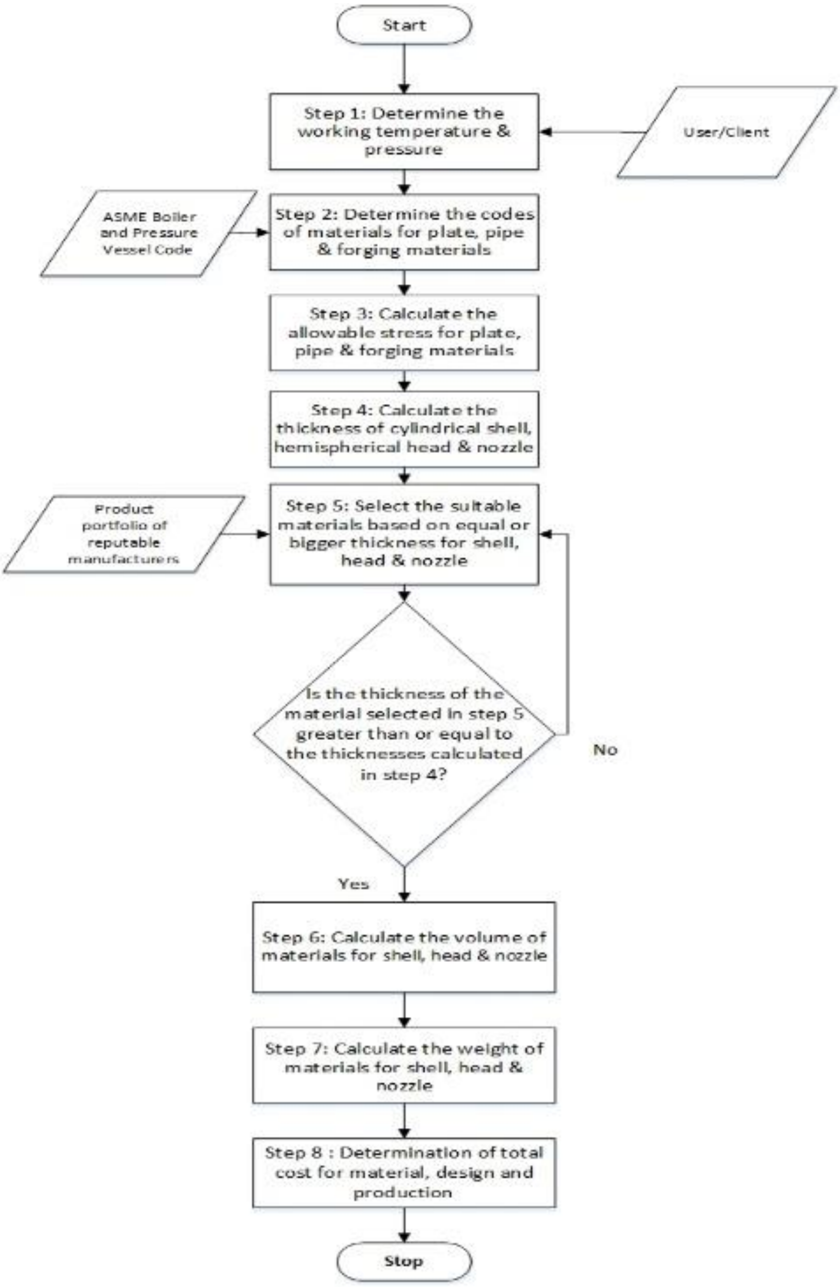

Figure 2 Schematic flow chart of the methodology

Table 1 Several typical pressure vessel materials

Temperature Use Limit °F	Plate Material	Pipe Material	Forging Material
Down to (-50)	SA-516 Gr 60/65/70	SA 333 Gr. 1	SA 350 Gr. LF1/LF2
33 to (+775)	SA-285 Gr. C	SA-53/106	SA-181 Gr. I/Gr.II
33 to (+775)	SA-515 Gr. 55/60/65	SA-53/106	SA-181 Gr. I/Gr.II
(+776) - (+1000)	SA-204 Gr. B	SA-335 Gr. P1/P11/P12	SA-182 Gr. F1/F11/F12
(+776) - (+1000)	SA-204 Gr. C	SA-335 Gr. P1/P11/P12	SA-182 Gr. F1/F11/F12
(+776) - (+1000)	SA-387 Gr. 11	SA-335 Gr. P1/P11/P12	SA-182 Gr. F1/F11/F12
(+776) - (+1000)	SA-387 Gr. 12 Class 1	SA-335 Gr. P1/P11/P12	SA-182 Gr. F1/F11/F12

SA-516 is carbon steel with unique specifications and is used as pressure chamber plates and services with medium or lower temperatures. The A516 sheet is mainly used in welded pressure vessels where final toughness is essential. These materials are produced in grades 55, 60, 65, and 70. These sheets also have elongation properties. The lenticular shape of these sheets is used when needed. Grade C A283 has a strength of 60 ksi, is evenly transmitted, and is safe in terms of abrasion heat grade. Its low carbon level provides excellent chip removal and ductility, which is why temperature-controlled tanks are produced using these sheets.

Step 3: Calculate the allowable stress for shell (plate), head (plate/forging material) and nozzle (pipe/forging material)

In this step, using the material specifications in Table (1)s, the allowable stress (MPa) is determined according to the operating temperature working of the pressure vessels at centigrade degrees. For example, material SA-515 Gr.60, temperature 371 ^{oC} allowable stress 105 (MPa), and some references can also be used in this regard [26].

Step 4: Calculate the thickness of the cylindrical shell, hemispherical head and nozzle

By using the code of calculation formulas (BPVC-VIII-1 Section VIII, Rules for Production of Pressure Vessels, Division 1.), the thickness of the thin-walled vessel components is calculated according to the following formulas, and the component's thickness (shell thickness(T_s), head thickness(T_h), and nozzle thickness(T_n)) are calculated [2] :

- Peripheral stress: when the thickness does not exceed half of the inner radius or P does not exceed 0.385SE.

$$T_s=P * R/(SE-0.6P) \quad (1)$$

- Spherical shells: when the shell thickness of a perfectly spherical container does not exceed 0.356R, or P does not exceed 0.665SE

$$T_h =P*R/(2SE-0.2P) \quad (2)$$

- For nozzle thickness

$$T_n=P*R/(SE-0.6P) \quad (3)$$

P = design pressure (psi / MPa)

R = inner radius (in / cm)

S = allowable stress (psi / MPa)

E = Welding efficiency coefficient, which is determined based on the connection location and the degree of examination

Step 5: Select the suitable materials based on equal or more significant thickness for the shell, head and nozzle

In this step, by using the thicknesses calculated in the previous step and comparing them with the existing standard products' thicknesses, the thicknesses are rounded upwards to match the suitable materials available.

Step 6: Calculate the volume of materials for shell (plate), head (plate/forging material) and nozzle (pipe/forging material)

To calculate the volume of materials, we should use the standard volume formula to calculate the cylinder's volume.

It is determined by multiplying the sheet thickness, the average inner diameter, and the cylinder's outer diameter based on the sheet's neutral thread.

Step 7: Calculate the weight of materials for shell (plate), head (plate/forging material) and nozzle (pipe/forging material)

In this step, calculate the raw materials' weight by the density of the steel, which is equivalent to 7850 kg / m^3 or 125745 lb / ft^3 with ±%5 tolerance.

Step 8: Determination of cost for material and production

In the final step, the cost of raw materials by weight and price of steel producers. To estimate the production cost, we evaluated the cost price of similar products and determined the construction price according to experimental production methods, cost analysis of production, and expert opinions. Also, in this method, the average thickness of sheets is more used in constructing cylinders, hemisphere heads, and nozzles. The production cost can be increased between two to three times the costs of materials; this calculation also considers this factor. Production cost is specified in Table (4).

3 Result and discussion

According to the proposed method, the sample pressure vessel's design with dimensional specifications in Figure (1) has been implemented for all the codes presented in Table (1) to achieve the results. This method can be used for other materials based on temperature and working pressure, but we have considered the sample vessel with the following specifications: Overall length: 6604 mm (260 inches), head hemisphere radius: 762 mm (30 inches), the inner diameter of the cylinder: 1524 mm (60 inches), nozzle inside diameter: 10.16 mm (8 inches).

Step 1: Design pressure of 700 Psi (4.83 MPa) and 700$^{\circ F}$ (371.1 $^{\circ C}$) for all of the codes defined in Table (1).

Steps 2 and 3: In these steps, based on step 1, The ASME codes of materials have been selected for plate, pipe, and forging (Table 2).

Table 2 The pressure vessel materials with allowable stresses

Design No.	Plate Material	Allowable stress (MPa)	Pipe Material	Allowable stress (MPa)	Forging Material	Allowable stress (MPa)
01	SA-285 Gr. C	98	SA-53	81	SA-181 Gr. I	98
02	SA-285 Gr. C	98	SA-53	81	SA-181 Gr. II	118
03	SA-285 Gr. C	98	SA-106	99	SA-181 Gr. I	98
04	SA-285 Gr. C	98	SA-106	99	SA-181 Gr. II	118
05	SA-515 Gr. 55	95	SA-53	81	SA-181 Gr. I	118
06	SA-515 Gr. 60	105	SA-53	81	SA-181 Gr. I	98
07	SA-515 Gr. 65	115	SA-53	81	SA-181 Gr. I	98
08	SA-515 Gr. 55	95	SA-53	81	SA-181 Gr. II	118
09	SA-515 Gr. 60	105	SA-53	81	SA-181 Gr. II	118
10	SA-515 Gr. 65	115	SA-53	81	SA-181 Gr. II	118
11	SA-515 Gr. 55	95	SA-106	99	SA-181 Gr. I	98
12	SA-515 Gr. 60	105	SA-106	99	SA-181 Gr. I	98
13	SA-515 Gr. 65	115	SA-106	99	SA-181 Gr. I	98
14	SA-515 Gr. 55	95	SA-106	99	SA-181 Gr. II	118
15	SA-515 Gr. 60	105	SA-106	99	SA-181 Gr. II	118

16	SA-515 Gr. 65	115	SA-106	99	SA-181 Gr. II	118
17	SA-516 Gr 60	105	SA-53	81	SA-181 Gr. I	98
18	SA-516 Gr 65	115	SA-53	81	SA-181 Gr. I	98
19	SA-516 Gr 70	124	SA-53	81	SA-181 Gr. I	98
20	SA-516 Gr 60	105	SA-53	81	SA-181 Gr. II	118
21	SA-516 Gr 65	115	SA-53	81	SA-181 Gr. II	118
22	SA-516 Gr 70	124	SA-53	81	SA-181 Gr. II	118
23	SA-516 Gr 60	105	SA-106	99	SA-181 Gr. I	98
24	SA-516 Gr 65	115	SA-106	99	SA-181 Gr. I	98
25	SA-516 Gr 70	124	SA-106	99	SA-181 Gr. I	98
26	SA-516 Gr 60	105	SA-106	99	SA-181 Gr. II	118
27	SA-516 Gr 65	115	SA-106	99	SA-181 Gr. II	118
28	SA-516 Gr 70	124	SA-106	99	SA-181 Gr. II	118

Steps 4 and 5: In these steps, we first calculated the thicknesses of the shell, the hemispherical head, and the nozzle in millimeters, and then they have been increased to current standard materials (Table 3).

Steps 6, 7 and 8: According to step 6; first, the volume of materials of cylinder parts, two heads, and nozzles were determined, then based on the seventh step, the weights were calculated using the considered density, and in the eighth step, considering the average world price of steel, about $ 500 per ton [27]. Materials and construction were calculated by cutting and welding methods. In calculating the manufacturing price, it has been taken into account that the thicker the material, the higher the construction price, so that the production(Prod.) cost increases by approximately 2 to 3 times(step by step) the material cost by increasing the thickness of the material, which is based on sales prices. All the results of steps 6 to 8 in Table (4) are provided with complete details.

Table 3 Thicknesses of the shell (T_s), heads (T_h) and nozzles (T_n), and upgraded thicknesses of cylinders, heads, and nozzles

Design Number	T_s (mm)	T_h (mm)	T_n (mm)	Design Number	T_s (mm)	T_h (mm)	T_n (mm)
01	39	23	5	15	36	19	5
02	39	23	5	16	33	19	4
03	39	19	5	17	36	23	5
04	39	19	5	18	33	23	4
05	40	23	5	19	31	23	4
06	36	23	5	20	36	23	5
07	33	23	4	21	33	23	4
08	40	23	5	22	31	23	4
09	36	23	5	23	36	19	5
10	33	23	4	24	33	19	4
11	40	19	5	25	31	19	4
12	36	19	5	26	36	19	5
13	33	19	4	27	33	19	4
14	40	19	5	28	31	19	4

Table 4 Results of weights and costs of sample pressure vessel

Design Number	Weight Cylinder (kg)	Weight heads (kg)	Material Cost ($)	Prod. Cost ($)	Total ($)
01	7 609	1 404	4 507	11 267	15 773
02	7 609	1 404	4 507	10 816	15 323
03	7 609	1 135	4 372	12 242	16 615
04	7 609	1 135	4 372	10 931	15 303
05	7 857	1 404	4 631	12 040	16 670
06	7 088	1 404	4 246	11 888	16 134
07	6 456	1 404	3 930	9 824	13 754
08	7 857	1 404	4 631	11 577	16 207
09	7 088	1 404	4 246	10 615	14 860
10	6 456	1 404	3 930	9 431	13 361
11	7 857	1 135	4 496	12 589	17 086
12	7 088	1 135	4 111	11 512	15 624
13	6 456	1 135	3 795	9 488	13 284
14	7 857	1 135	4 496	11 241	15 737
15	7 088	1 135	4 111	9 867	13 979
16	6 456	1 135	3 795	9 109	12 904
17	7 088	1 404	4 246	11 888	16 134
18	6 456	1 404	3 930	9 824	13 754
19	5 976	1 404	3 690	9 225	12 914
20	7 088	1 404	4 246	10 615	14 860
21	6 456	1 404	3 930	9 431	13 361
22	5 976	1 404	3 690	8 487	12 176
23	7 088	1 135	4 111	11 512	15 624
24	6 456	1 135	3 795	9 488	13 284
25	5 976	1 135	3 555	8 533	12 088
26	7 088	1 135	4 111	9 867	13 979
27	6 456	1 135	3 795	9 109	12 904
28	5 976	1 135	3 555	8 178	11 733

4 Comparison, Validation and Accuracy Analysis

By studying the total cost in Table (4), it is determined that the highest price is related to design # 11 with material specifications sheet, heads, and nuzzle, respectively as SA-515 Gr. 55, SA-106, and SA-181 Gr. The lowest price is design #28 as SA-516 Gr. 70, SA-106, and SA-181 Gr. II.

If categorizing the total cost results into three cost groups such as (Low: 11000-13500), (medium: 13500-16000), (high: 16000-18000), and comparing the data frequency in Figure (3). The horizontal axis represents the number of designs in each cost category and the vertical axis represents the cost categories.

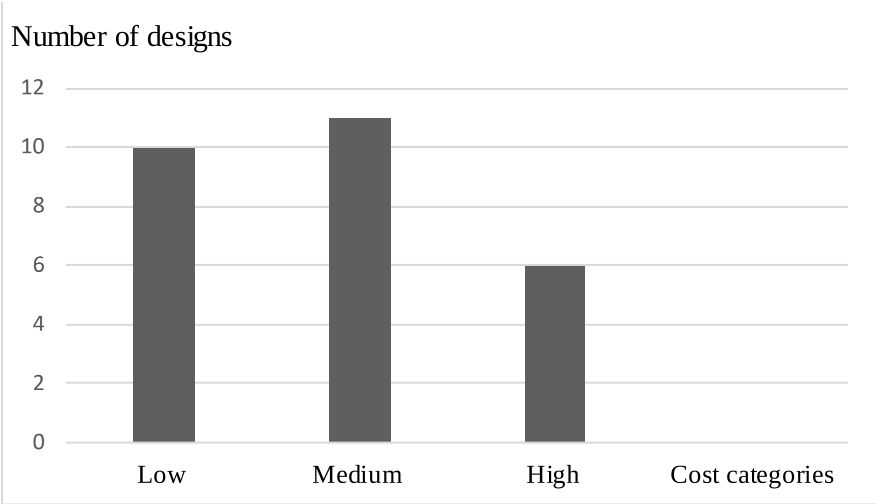

Figure 3 Comparison of the number of designs in each cost category

The pressure vessel with the lowest cost is manufactured with SA-516 Gr. 70 (for thickness refer to Table (3), row numbers:19,22,25 and 28) that it is a part of refractory alloy sheets or the same tank to achieve a high-quality carbon steel sheet. It has the property of bending and becoming a lens. This carbon steel sheet is mainly made for use in welding pressure vessels where final toughness is essential. It is used for medium and low-temperature services. It is carbon steel with particular specifications used as pressure chamber plates and services with medium or lower temperatures. The SA516 sheet is used in welded pressure vessels where final toughness is essential. These materials are produced in grades 55, 60, 65, and 70. These sheets also have elongation properties. The lenticular shape of these sheets is used when needed. The pressure vessel with the highest cost is constructed SA-515 Gr. 55 with a medium tensile strength at medium or higher temperatures. It offers excellent combinations of strength, weld-ability, and strength to design pressure vessels under the ASME pressure vessel code. This steel sheet is used for boilers and other pressure vessels from medium to high temperatures., and High-temperature work has high corrosion resistance. It is used where corrosion resistance is an important design factor that justifies its high cost. Design modes have been selected with the lowest price for analysis (Figure 4).

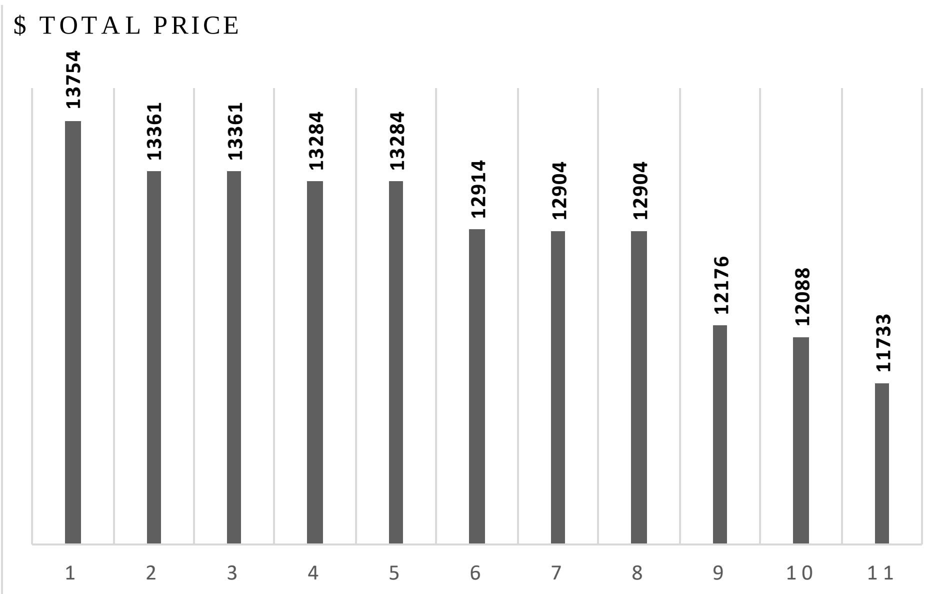

Figure 4 Designs of pressure vessels with an acceptable total price in descending order

The following table is showing the relationship between the design number and the lowest total cost that is introduced in Figure (4). Also, the design numbers could be identified with the selected material in Table (2).

To validate the results, we compared the reference values and Arabzadeh et al. [20]. If the data obtained from the output of our proposed method can create a lower error rate than the data of the desired range, we can say that the proposed process has a better performance. According to Table (6), Statistic Root Mean Square Error (RMSE) [28], has been calculated for comparison. According to Table (6), comparison the error rate of our method with the results of Arabzadeh et al. [20]. In addition to alignment, there is also a lower error rate, which is a reason for validating our method. Suppose we want to study the design factor from the design reliability factor, considering that the design reliability coefficient is the ratio of maximum tensile strength to allowable design stress. In that case, the reliability will be considered in the following Figure.

Table 5 Relationship between design number and the total cost in the low range

Design No.	07	18	10	21	13	24	19	16	27	22	25	28
($) Total	13 754	13 754	13361	13361	13284	13284	12914	12904	12904	12716	12088	11733

Table 6 Results of our method and Arabzadeh's work with the reference results and error calculation

Normalized Reference Value	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	Cost Estimation Generic Algorithm										
Arabzadeh et al.'s Values (LMNN)	0.47	0.72	0.76	0.56	0.33	0.59	0.32	0.70	0.63	0.66	0.29
Arabzadeh et al.'s Normalized Value	0.08	0.12	0.13	0.09	0.05	0.10	0.05	0.12	0.10	0.11	0.05
Root Mean Square Error (RMSE)	**0.06**										
	Lowest Cost Designs										
Normalized Estimated Value	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.1
Root Mean Square Error (RMSE)	**0.05**										

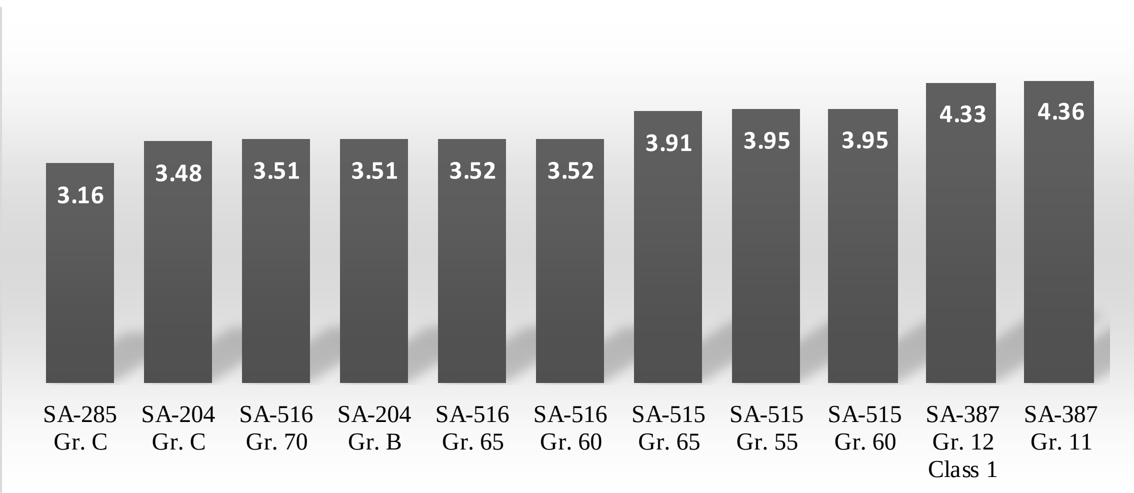

Figure 5 Safety factor of designs based on materials used in the pressure vessels

Figure (5) shows that the design reliability varies between 3 and 4.5 depending on the material, which ensures the safety of the designed product.
According to steps (6), (7) and (8), Figure (5), and Table (4) show design #28 has the lowest price has a safety factor of 3.51, and design # 11 as the highest price has a safety factor of 3.95. In this way, the correct choice of materials in addition to creating the optimal thickness and weight directly affects the reduction of the initial price, and identifying the thickness of suitable sheets also affects the cost of tank construction, so the results presented in Figure (5), indicate the appropriate design factor and therefore capability. Also, the pressure tank, design # 28 of SA-516 Gr 70 sheet, has been used by the welding method, which has a desirable toughness. These sheets also have tensile and become lens properties. It indicates that this design, in addition to the appropriate and effective cost, has the desired reliability and durability and in practice can meet the needs and expectations of the design. Reliability is acceptable also, high reliability could be a reason for more excellent durability justifying the higher cost.
According to previous calculations regarding the thickness of the cylinder, head, and nozzle and the total cost of the pressurized tank, we can determine an average thickness prediction function (mm) according to the cost price pressurized tank ($). The following function that is presented in Figure (6) could be the average thickness of the design is based on the customer's budget (client), and it is used for determining the optimal thickness.

5 Conclusion

Important factors are influential in the product's final price, but raw materials, design, and production costs play [24] a significant role. Mechanical product design is a process that is important in the type, material, and weight of raw materials. Determining the dimensions of products in the production method and production cost is crucial. It means that if the mechanical design is done with an optimal economic approach on the final, it will be sufficient. Based on appropriate rules and codes in creating pressure vessels based on a proposed method, we achieved dimensional changes, material weight, and cost effects of materials and design with various mechanical designs. Advantages of this method include flexibility and applicability in various fields of design and production. This flexibility in design allows a wide range of materials to be identified so that design and production organizations can identify and supply accessible materials with more action. This proposed method in the design of pressure vessels makes it possible to reduce the vessel's total cost by determining the minimum thickness of the body and nozzle's cylindrical section and the hemispherical head's thickness simplest and least costly production method. The critical point in this method is that regardless of the type of steel pressure vessels. This method can estimate and determine the cost, and has sufficient flexibility.

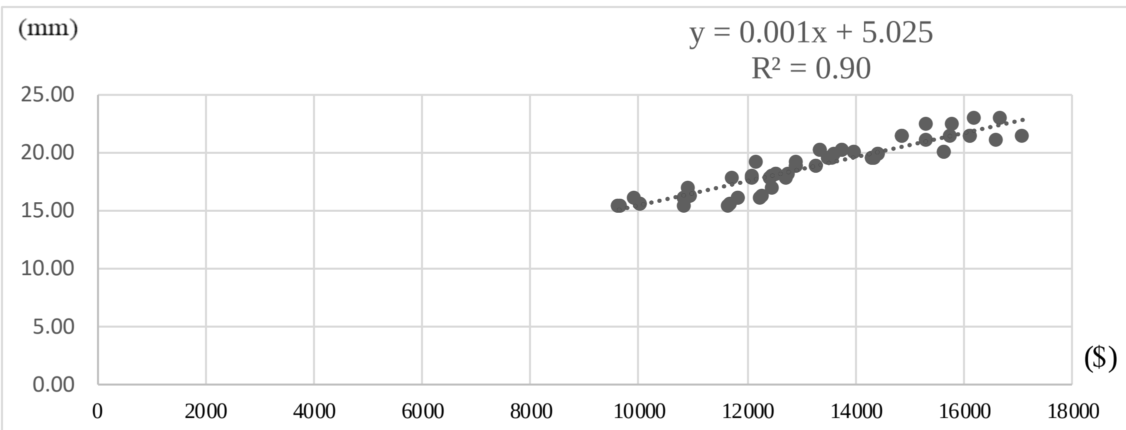

Figure 6 Graph of average thickness (y) prediction functions in terms of the total cost(x)

It is even possible that by changing the operating conditions of pressure vessels, such as operating temperatures, more standard designs can be easily considered in terms of cost. If the working temperature is at the lowest possible level, to achieve the lowest cost, SA-516 Gr 70 steel sheet and SA 333 Gr.1 steel pipe used that corrosion resistance will not be achievable in these conditions. When we want to increase the working temperature, corrosion resistance, and strength to a great extent and have an acceptable cost, we must use SA-204 Gr. C and steel pipe SA-335 Gr. P12. If we want to increase the working temperature and corrosion resistance, strength, and durability to a great extent, but we do not have any limitations in increasing the cost, we must use SA-387 Gr. 12 Class 1 and steel pipe SA-335 Gr. P11 used. This proposed method in the design of pressure vessels makes it possible to reduce the vessel's total cost by determining the minimum thickness of the body and nozzle's cylindrical section and the hemisphere's thickness with the simplest and least costly production method. It is not considered that the working temperature of the pressure vessel as a barrier in the choice of materials. We can achieve more than 70 different mechanical designs based on acceptable ASME codes in implementing the introduced plan under the pressure vessel's working temperature. It is reduced to the number of 28 mechanical methods. Also, comparing the obtained results with the previous research's target values, due to the smaller number of error values, clearly proves the method's accuracy and effects.

Declaration of Competing Interest: There is no conflict of interest concerning the authors.

Funding: No individual or organization has supported this article and has not received any financial support.

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