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COMPRESS USAGE FOR DESIGN OF A STORAGE TANK AND COST ANALYSIS OF SPOT AND FULL RADIOGRAPHIC CONTROL

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ABSTRACT

Storages or transmission tanks as a pressure vessel are important engineering equipments and appear in various areas. The main goal of this study is to propose a simple method to solve, with minimum effort and acceptable reasonable accuracy, the problem of designing a storage vessel subjected to uniform internal pressure by using a commercial program. For this purpose the COMPRESS program, which is preferred for obtaining quick results in the design of this type of tank, has been introduced in detailed, and the design makes use of this program and also meets the ASME Boiler & Pressure Vessel Code, Section VIII, Rules for Construction of Pressure Vessels Division 1 standards. Then the use of stainless steel and carbon steel which is preferred in general in the construction of tanks for full and spot radiographic control was performed. For this purpose a storage tank has been designed for 10atm of internal pressure and a temperature of 120oC and capacity of 1500 lt.

INTRODUCTION

Pressure vessels and storage tanks are used to store and transmit liquids, vapours and gases under pressure. In recent years they are widely used in space vehicles, aircrafts, nuclear power plants and many other engineering applications such as recompression chamber, reactor technology, the chemical industry, distillation towers and hyperbaric oxygen therapy chamber [1]. The design of pressure vessels is an important and practical topic which has been explored for decades. Pressure vessel design consists in defining a structure, whose characteristics (shape, material, thickness, etc) will enable this to sustain a given service loading safely. Storage tanks are specific kinds of pressure vessels. The primary function of a storage tank is to store liquid substance such as organic liquids, non-organic liquids, vapours and can be found in many industries. These tanks can have different sizes, ranging from 1 to 60 m diameter or more. The storage tanks can be divided into two basic types: Atmospheric storage and Pressured storage. They are usually constructed of steel or fiberglass-reinforced polyester. They are generally small storage tanks and constructed such that the length of the tank is not greater than six times the diameter. Operation cost and cost effectiveness are the main factors in selecting the type of storage tank [2-3].

As reported by Altınbalık and Kabak [4], a pioneering work on optimization techniques for designing pressure vessels has been presented by Middletown and Owen. The authors also discussed the use of stainless steel instead of pressure vessel steel P275 GH by means of cost and weight analysis. Guidelines for choosing appropriate shape and size for the vessels that minimize material and manufacturing cost for cylindrical vessels was performed by Proczka et al [5]. Recently, considerable research effort has been devoted to the analysis, design, and evaluation of the liquid storage tanks by Zingoni [6]. Gong et al [7] performed a finite element analysis of open top tanks. Ghisi [8] studied the parameters affecting the sizing of rainwater tanks for domestic use. Jordan and Furbo [9] adapted an often used storage tank model by including a fully mixed zone near the inflow with a height dependent on the local densimetric Froude number. Tam et al [10] compared the cost of procurement, installation and operation of rainwater tanks to the benefits of the use of a rainwater tank in an empirical study to aid residential decision-making. Santos and Pinto [11] concluded that variation in rainfall profile has the most significant effect on the optimal tank size when they applied different criteria in the sizing of rainwater storage tanks. Okoye et al [12] proposed an optimization model to determine the optimal tank size of a single residential housing unit for rainwater harvesting and storage.

On the other hand non-destructive testing (NDT) are usually used for monitoring and ensuring the integrity of structures especially for tanks used in the oil and gas industry. Inspection of welded structures is essential to ensure that the quality of welds meets the requirements of the design and operation. For critical welded structures such as high-pressure vessels, the nature, location, and magnitude of the flaws must be mapped in order to determine their acceptability by further mechanics analyses [13]. A variety of NDT are available for identification, and

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evaluation of defects in welded joints of pipes, being the ultrasound and radiography the most relevant [14]. Radiographic methods are based on the partial absorption of penetrating radiation as it passes through the object under investigation [15].

In the present study a storage tank has been designed for 10atm of internal pressure and a temperature of 120°C and capacity of 1500 lt. The use of two different materials has been chosen for the tank. The *COMPRESS* program, which is preferred for obtaining quick results in the design of this type of tank, has been briefly introduced, and the design makes use of this program. Also, the application of spot rt and full rt for the tank made of two different materials was examined in terms of cost analysis.

THEORETICAL ANALYSIS AND COMPRESS

In design by calculations, two methodologies are usually described in storage tanks named; design by formulae and design by analysis. Almost every pressure vessel or storage tank in the process industry is designed according to ASME Section VIII, Division 1, better known as the design by formulae approach. The thickness of the cylinder is only one part of the design. Other factors which affect the design are the length of the cylinder and size. Design by analysis is performed by the commercial programs.

COMPRESS is an engineering productivity tool that models, calculates and creates reports for ASME pressure vessels and heat exchangers. COMPRESS 3D solid models integrate with leading drafting and plant design systems. It is a very powerful and user-friendly program and eliminates the time-consuming, manual iteration required by other software to design entire vessels or individual components. When designing a storage tank some parameters are taken into consideration and then sheet thickness values of the main body and the head is calculated by empirical formulas according to given in ASME sec VIII Div I. Then these results are compared the results with obtained from COMPRESS programme. Finally the results are controlled by the Authorized Inspector (AI) and accepted. For rating mode COMPRESS calculates the MAP (Maximum Allowable Pressure) and MAWP (Maximum Allowable Working Pressure) and minimum thickness for existing geometry. Maximum allowable pressure (MAP) value is the maximum unit pressure permitted in a given material used in a vessel constructed under ASME Design rules. Maximum allowable working pressure (MAWP) for a vessel is the maximum internal or external pressure permissible at the top of the vessel in its normal operating position at the designated coincident temperature specified for that pressure. The COMPRESS main screen has several components and shown in Figure 1.a.

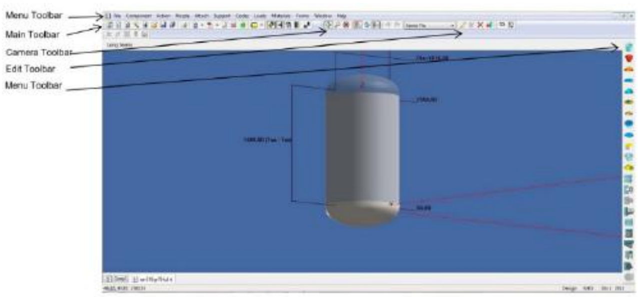

Fig. 1. Sample screenshot of COMPRESS

RELATED EQUATIONS

In a cylindrical shell the minimum required thickness of shell is given as;

$$t = \frac{PR}{SE - 0.6P} \tag{1}$$

On the other hand the minimum required thickness at the thinnest point after forming of ellipsoidal head under pressure is calculated by appropriate formulas given in literature. For ellipsoidal heads the thickness is calculated as;

$$t = \frac{PD}{2SE - 0.2P} \tag{2}$$

where:

P= Internal design pressure

R= Inside radius of the shell course under consideration

D= Inside diameter of the head

S= Maximum allowable stress value

E= Joint efficiency (When the tank design is required full radiographed it is equal to 1.00)

In ASME BPVC standards the minimum required thickness of shells under internal pressure should not be less than that calculated by the formulas.

MATERIAL SELECTION AND DESIGN

Firstly, SA-285-GRC was chosen in order to manufacturing the vessel. SA-285-GRC is a pressure vessel steel and it is used for non-critical pressure vessel applications of low to intermediate strength requirements. The alloy is welded by conventional methods. Austenitic stainless steel was chosen the other material. Austenitic (18-8) stainless steel alloys are strong, light, ductile and readily available in a variety of forms. They resist corrosion and oxidation. They have also exhibited good strength and toughness. There are many grades of austenitic stainless steels, the most popular of which are 304 and 304L. In the presented study SA 240-304L was chosen as a compare material with the SA-285-GRC. Some important elements and flow stress of the all three steels are given in Table 2. After choosing the materials design parameters was determined and these parameters was entered the COMPRESS program screen. Maximum allowable stress values of the chosen materials for 120°C were read from ASME-BPVC 2013 Sec II Part D.

RESULTS AND DISCUSSION

a) SHEET THICKNESSES

Following the process steps which described above display of COMPRESS program is obtained. COMPRESS makes calculations at the background and the results are given both the mathematical formulations and the table.

In the company in which the presented study performed, all welded joints to be radiographed is examined in accordance with ASME BPVC Sec VIII Div.I. This NDT procedure can be performed by two ways: Full or spot radiography. Full radiography means that every inch of weld length be radiographed. For a big vessel this would mean hundreds of shots and a long process to complete, but the manufacturer could then be assured that there are no flaws. Spot radiography on the other hand would use a particularly critical spots like junctions to get 10% of the length. If there are no flaws found then pass. If a flaw is found then do another 10% just to make sure it is a one off. Typically if the vessel is very critical (high pressure, containing toxic or corrosive material) it should be chosen full radiography. If the vessel is a water tank, spot radiography is generally good enough. Acceptance criteria for welding defects in full radiography is stringent. These criteria are stated in UW-51 and UW-52 in ASME Code Section VIII Div. 1. It means there is a defect if interpreted based on the full radiography criteria in UW-51, and it might be rejected, but if it is interpreted by the spot radiography criteria in UW-52, it might be accepted. One spot is examined on each vessel for each 50 ft (15.2 m) increment of weld or fraction. The location of spot is determined by the AI after completion of the increment of welding. The minimum length of spot radiography is chosen 6 in.

Main body sheet thickness values calculated by the program for the spot and the full radiography of thickness calculation values for SA-285-GRC are shown in Figure 2.a–2.b. As seen in these figures, the sheet thickness value for the main body was calculated to be 8.41mm. for the spot radiography and 7.59 mm. for the full radiography. The value entered by the user, which is suitable according to the ASME BPVC standards and from experience, is 10mm for the spot radiography and 8mm for the full radiography, and MAP and MAWP calculations are made by the program using this value.

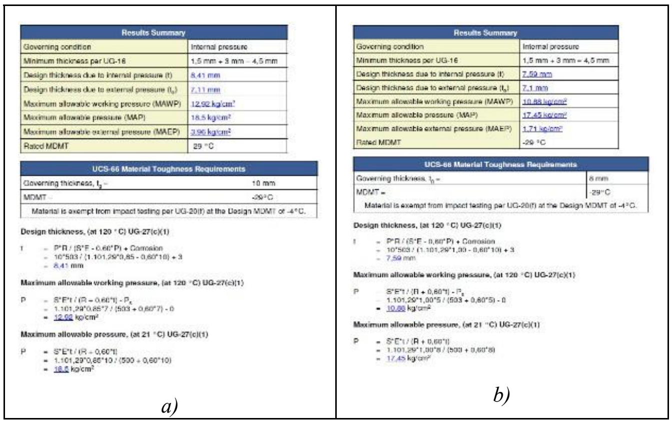

Fig.2. Thickness calculation summary screen of main body for SA-285 GRC
a) Spot radiography; b) Full radiography

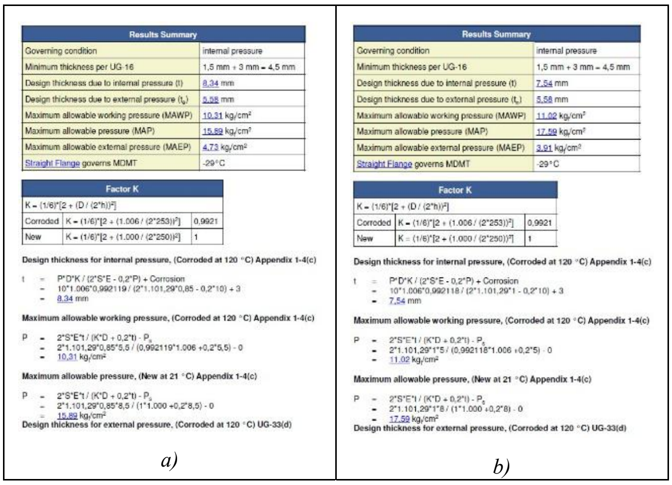

***Fig.3.** Thickness calculation summary screen of head for SA-285 GRC*
a) Spot radiography; b) Full radiography

The next step is the calculation of the head sheet thickness. The sheet thickness of the head calculated by the program, and the sheet thickness that are entered by the user in the program in accordance with ASME BPVC standards are presented in Figure 3.a–3.b. For ellipsoidal heads, body and head sheet thicknesses are preferred to be as close as possible to each other. Consequently, the values used in the program take into consideration the body thickness values shown in the calculation screens of Figure 3.a–3.b. When entering these values, the manufacturing characteristics of the heads are also important. The design assumes that ellipsoidal head will thin down to between 8 and 8.5mm from the initial sheet thickness of 10mm during the drawing stage, and the chosen value is entered to the program.

Main body and the head thicknesses calculated in Figure 2 and Figure 3 are corrected to standard values and these values are tabulated and presented in Figure 4.a.-4.b. and Figure 5.a.-5.b. as general summary screen. In these screens user has opportunity to see all the required values (design pressure, design temperature, nominal thickness, minimum thickness, radiographic condition, weight and capacity) for manufacturing of main body and heads of storage tank. As shown in Figure 5.a. and 5.b. nominal thickness for starting of drawing and desired finish thickness for ellipsoidal head is seen at the bottom of the screen.

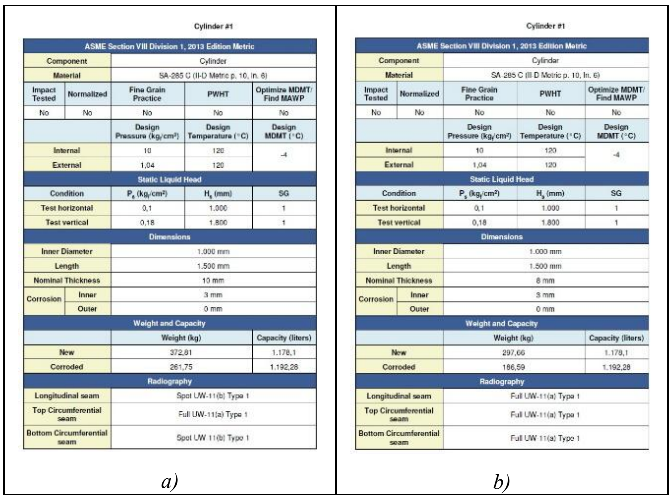

Fig.4. General summary screen of main body for SA-285 GRC
a) Spot radiography; b) Full radiography

Main body sheet thickness values calculated by the program for the spot and the full radiography of thickness calculation values for the use of SA-240-304L are shown in Figure 6.a–6.b. As seen in these figures, the sheet thickness value for the main body was calculated to be 5.05mm. for the spot radiography and 4.29mm. for the full radiography. The value entered by the user, which is suitable according to the ASME BPVC standards and from experience, is 6 mm for both the spot radiography and the full radiography and MAP/MAWP calculations are made by the program using this value. In some cases it may not be possible to select the sheet thicknesses very close to the values calculated by the COMPRESS program. Although it can be selected 5 mm. sheet thickness for the full radiography, depending on the customers' requests of the cooperated company the sheet thickness is selected as 6 mm. as in the spot radiography as seen in Figure 7.a. and 7.b.

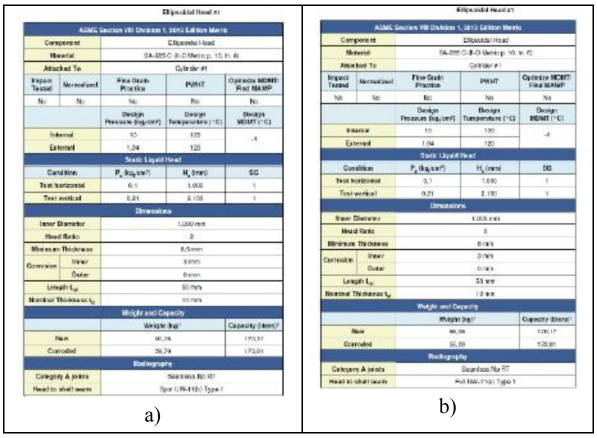

***Fig.5.** General summary screen of head for SA-285 GRC*

a) Spot radiography; b) Full radiography

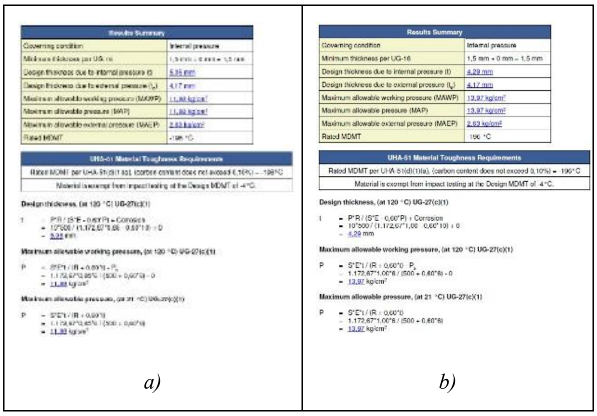

***Fig.6.** Thickness calculation summary screen of main body for SA 240-304L*

a) Spot radiography; b) Full radiography

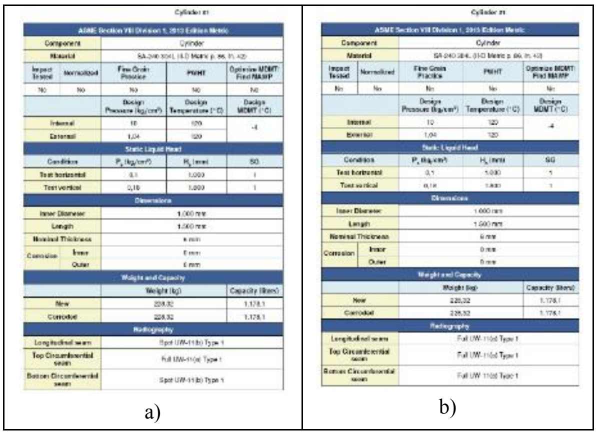

***Fig.7.** General summary screen of main body for SA 240-304L*

a) Spot radiography; b) Full radiography

Calculated sheet thicknesses screen of the head by the program is shown in Figure 8.a and 8.b. As seen in these figures, the sheet thickness value for the main body was calculated to be 5.02mm. for the spot radiography and 4.27 mm. for the full radiography. Although head sheet thickness values calculated for the spot radiography and the full radiography are different from each other according to experience, both heads will be drawn when using 8mm sheet and a head thickness of 6.5mm will be obtained at the end of the process as shown in Figure 9.a. and 9.b.

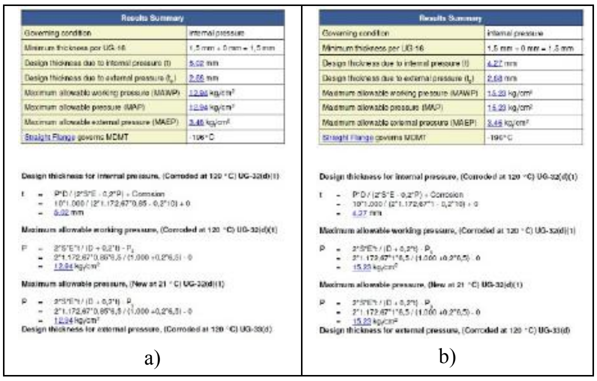

***Fig.8.** Thickness calculation summary screen of head for SA-240-304L*

a) Spot radiography; b) Full radiography

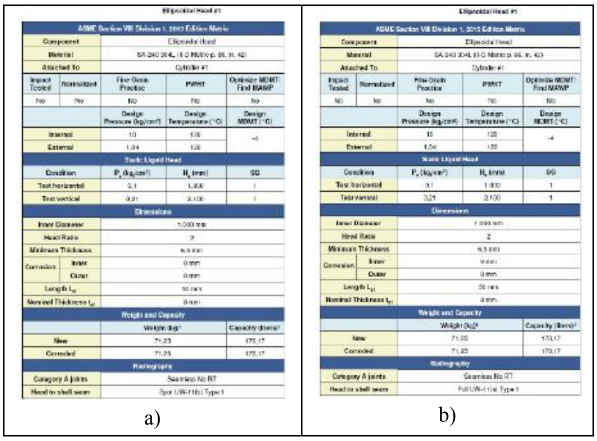

***Fig.9.** General summary screen of head for SA 240-304L*

a) Spot radiography; b) Full radiography

b) WEIGHT and COST ANALYSIS

In order to make a comparison in terms of cost analysis, the weight of the tanks, with respect to their material have been calculated with the help of the *COMPRESS* program. In order to general summary screens of SA-285-GRC the tank weight full radiography performed is 17% lighter than with the spot radiography option. According to the results there is no significant weight difference between spot and full radiography conditions. For full radiographic controlled tank is only 80 kg. lighter and just 80$ cheaper than spot radiographic controlled condition. Radiographic control prices taken from the cooperated company are as: 470$ for full RT 470$ and 380$ for spot RT. As seen there is only a 90$ difference between them and the material gain is lost. In the case of using stainless steel material, it is not possible to mention a gain since the tank weights are exactly the same for full and the spot RT.

In the presented study the selected tank size is quite small and the tank is a storage tank not a pressure vessel. So, in larger sized and highly pressured tanks, the calculations will be much different. On the other hand, numerous factors play a role in the production of a tank, aside from the design criteria that are present in the literature. Customer expectations, information obtained by experience and company production routines are some of these factors. Therefore, the aim of this study is to increase people’s options, instead of presenting accurate information on a specific design.

CONCLUSION

Working principles of the user friendly program COMPRESS program has been described in detailed in the presented study. In order to explain the program a storage tank has been designed for 10atm of internal pressure and a temperature of 120^{o}C and capacity of 1500 lt. The use of two different materials has been chosen for the tank. Besides, weight and cost analyze of the tank design according to full or spot radiographic control has been made with respect to the different types of material. All the calculations are in accordance with the ASME Boiler & Pressure Vessel Code, Section VIII, Rules for Construction of Pressure Vessels Division 1 standards.

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