MENG 411-CAPSTONE TEAM PROJECT

Eastern Mediterranean University

Faculty of Engineering

Department of Mechanical Engineering

Design & Manufacturing of a Solar Collector Storage/Pressure Vessel

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Abstract

Pressure vessels/storage tanks are widely used in todays practice. Different types of vessels with different shape are used in different type of engineering fields. They can be found in our homes in the form of aerosol cans, gas cylinders, water tanks etc., in industries and many other places. In other words, having them in our every day life is important and highly necessary. The main idea of this project is to design a hot water storage tank for a domestic solar heating system, which should withstand a pressure of 2 bars. The storage tank will be heated by the solar collector and by an auxiliary energy support system, this is known as a combi-store. So for this, firstly will select the proper material for the design of the pressure vessel, the material must have a yield strength good enough to sustain the internal pressure. Then we will designing a cylindrical pressure vessel and obtain the required thickness of the vessel based on the selected material. Then finally, we will show the manufacturing technique required used for the design, the integrity test of the design and the results of the test performed. We will show that the pressure vessel was able to withstand the design pressure of 2 Bars and also successfully overcome the test pressure of 3.8 Bars.

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Chapter 1

1.1 Introduction to Solar Collector Storage Tank/Pressure Vessel

In domestic, industrial or institutional residences, heating systems are required to give the people residing in the premises a good level of comfort during the cold seasons. In this modern day, the aim of engineers is to try to replace the use of fossil fuels as energy source by more natural and environmentally healthy sources of energy, in which solar energy is gradually gaining significance.

Apparently, a method of space and water heating used today is through the use of solar collectors. Solar collectors harness a certain fraction of energy from the sun and the thermal radiation absorbed is used for the heating process.

As solar energy is not continuous or steady, it is necessary to store this solar energy in order to realize a substantial contribution of solar energy to the total daily energy needs of the building. Solar energy absorbed by a solar collector can be stored in many forms i.e. electrically, chemically, mechanically etc. However, the most common means of storing solar energy is through the form of sensible or latent heat of a liquid, commonly water due to its high specific heat capacity. Hence, the need to design a water storage tank for a solar collector is necessary.

1.2 Background information of the Water Storage Tank

Water storage is the most commonly used heat storage medium in solar energy practices because it has many advantageous qualities such as its low cost and high specific heat. Table 1-1 shows a list of storage materials and their properties.

TABLE 1-1 PROPERTIES OF SENSIBLE HEAT STORAGE MATERIALS [1]

	Specific Heat	**Density**	**Volumetric specific heat**

Materials	KJ/Kg.K	Btu/lbm-$°F$	Kg/ m^3	lbm/ ft^3	KJ/ m^3 .K	Btu/ ft^3 - $°F$
Adobe	1.0	0.24	1700	106	1700	25
Aluminum	0.896	0.214	2700	169	2420	36.2
Brick	0.84	0.20	1920	120	1600	24
Concrete	0.92	0.22	2240	140	2100	31
Rock pebbles	0.88	0.21	1600	100	1410	21
Steel	0.48	0.11	7850	490	3800	54
Water	4.19	1.00	1000	62.4	4190	62.4

It can therefore be observed that the specific heat capacity of water is much greater than the other materials by over four times. The use of water as the storage medium is particularly of convenience when water is used as the medium for mass and heat transfer. A water solar water heating system, using water as the storage as well as the transport medium is shown in Figure 1-1 below.

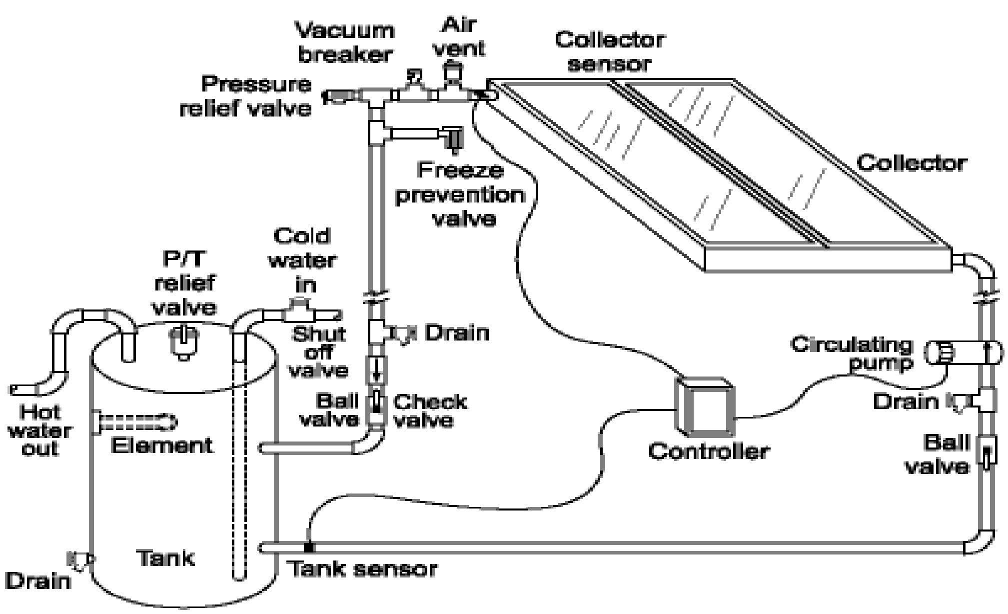


Figure 1-1 SOLAR WATER HEATING SYSTEM [2]

1.2.1 Stratification in Water Storage

Due to density difference, when hot water enters and leaves at the top of the storage tank and cold water flows at the bottom, the water in the tank is likely to have a stratum of temperature, and by buoyancy effect, the water circulates through the system naturally. The temperature of water in the tank will reduce from top to bottom; this is called stratification of water. Mostly in engineering practice, this process is advantageous as it increases the performance of the solar collector. However in some cases, when the buoyancy effect is not sufficient enough to cause a natural circulation of water in the system, then a pump may be integrated in the system and the stratification effect becomes insignificant.

1.2.2 ASME Boiler and Pressure Vessel Code, Section VIII

The American Society of Mechanical Engineers was organized in 1880 as an educational and technical society of mechanical engineers. Through years of development and response from the public engineers, the first edition of the Code, ASME Rules of Construction of Stationary Boilers and for Allowable Working Pressures, was published in 1914 and became officially adopted in the spring of 1915. The first Code rules for pressure vessels, entitled Rules for the Construction of Unfired Pressure Vessels, followed in 1925[3]. However, at this point, the code has now gradually evolved into eleven Section document, with multiple subdivisions, parts, subsections, and mandatory and non-mandatory appendices. Almost all pressure vessels used in the industry today in America are designed and constructed based on the Section VIII Division 1 of this code. In this project, some of the general ideas and regulations related to ASME Code Section VIII will be utilized. These include allowable stress, factors of safety and joint efficiency. Therefore, this code will be used in the design and manufacturing of the storage tank/pressure vessel in this problem.

1.3 Significance of a Water Storage Tank

Since solar heating is a clean, reliable and a cost friendly source of energy that reduces the utility bills of many homes and industries, it has grown a wide amount of awareness across the world. Almost every home in Cyprus has a solar collector installed. Hence a solar storage tank is of importance.

In domestic homes and industries, solar water tanks are used majorly for the following applications:

- Solar Water Heating
- Solar Space Heating
- Solar Cooling
- Solar Pool Heating

Water heating, space heating, and space cooling accounted for 72% of the energy used in an average household in the U.S. in 2010 as shown in Figure 1-2, representing a huge market potential for solar heating and cooling technologies [2]

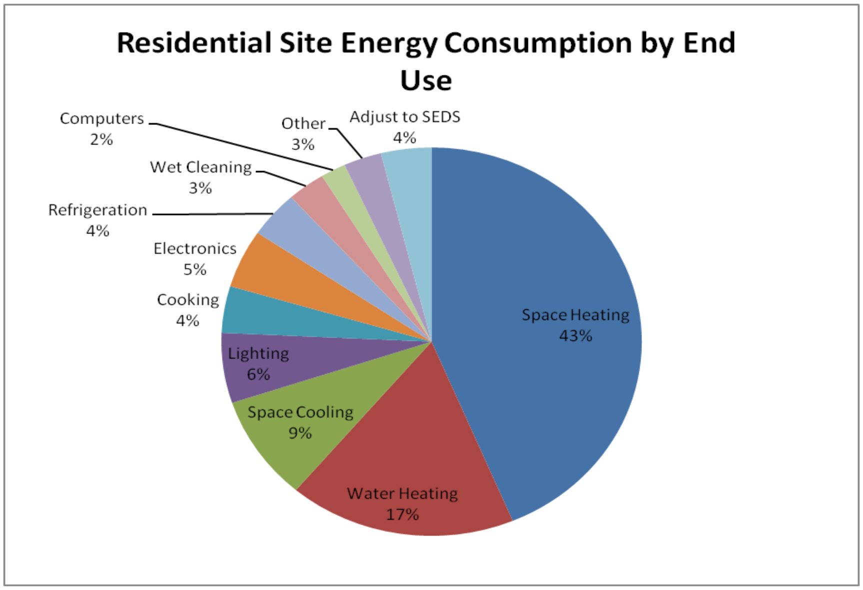


Figure 1-2 RESIDENTIAL SITE ENERGY CONSUMPTION BY END USE [2]

Solar heating and cooling technologies can displace the need for natural gas, fuel oil, and electricity to heat homes and businesses, thereby reducing the dependence on imported fuels.

1.4 Objective and Scope of this Project

1.4.1 Problem

The purpose of this project is to design and analysis a solar water storage tank/Pressure Vessel based on ASME Code Section VIII Division 1 and standards that can support the pressure of hot water for a domestic home residence. This project is concerned only with the design of the main parts of the pressure vessel i.e. the shell, heads, nozzles and supports and not the solar collector. The pressure vessel should withstand an internal pressure of 2 bars.

1.4.2 Direction

The aim is to construct a pressure vessel that will concur with the following steps given below

1. Working pressure will be identified

2. The dimensions and the volume of the vessel
3. Choose the best material with the best mechanical properties which are suitable for the for this project
4. Fabrication, testing

1.4.3 Learning Objectives

Hopefully after finishing this project we will get to have enough knowledge to design a proper working solar water storage tank/pressure vessel in accordance with the ASME Boiler and Pressure Vessel Code Section VIII. And also we hope to learn about the uses, types, the materials used for manufacturing pressure vessels, mechanism, and how it works in a real life.

1.5 Report Organization

In this report, chapter 1 discusses an introduction to solar collector storage tank/pressure vessels, including the types and use in today's application purposes and its areas of applications in different fields of engineering. In chapter 2, a literature review on the history of the development of design of pressure vessels will be discussed, and also, the general features of a pressure vessel will be discussed in details. Chapter 3 will include the design calculations of the project and the cost analysis of the project. Chapters 4 will give an elaboration of the manufacturing process utilized for the design. It will also contain the test of the design and its result will shown explained in chapter 5. This report will be concluded in chapter 6. The drawing schematics and other appendixes will be included in the latter part of this report.

Chapter 2

Literature Review

2.1 Background Information

The storage tank is the most important for the cost and performance of a conventional domestic solar collector hot water system. Measurements on eight marketed systems show that the thermal performance of the system is primarily based on the design of the hot water storage tank/pressure vessel [4].

A complete project survey carried out in 1994 by Lise Boye-Hansen of the solar heating systems that have been installed over a couple of years. On the bases of his survey, it was concluded that there is presently a demand for three different types of hot water tanks/pressure vessel for solar collector systems [5].

1. **Combi Store,** which works with both heating from a solar collector and an auxiliary energy source separate from the tank, most preferably electricity.
2. **Pre-heater,** which is only heated by the solar collector. The solar heating system is based on a pre-heater on

an existing hot water tank. These types of accounts for 75% of the solar heating systems installed these years and today it is used in all small solar heating systems.

3. **Hot water tank prepared for solar heating systems.** In this, the tank has a main heating system and the solar collector acts as the auxiliary system.

This project will be concerned with designing a pre-heater store storage tank/pressure vessel.

2.3 Pressure Vessel

The pressure vessels such as cylinder, pipeline or tanks are used to store fluids under pressure. The fluid to be stored may undergo change of states within the pressure vessel (steam boilers) or may mix up with other substances as in a chemical plant. Pressure vessels have to be designed with extreme care because rupture of pressure vessels may result in fatal casualties like an explosion, which may result in the loss of lives and properties. The components of a pressure vessel have to be known and understood to a good degree before design.

2.4 Components of a Pressure Vessel

Basically, a pressure vessel is divided into Four main parts following are the main parts of pressure vessels.

- End closures (Head)
- Shell
- Nozzles
- Support

2.4.1 Head

Heads are used as end closures for the cylindrical pressure vessels. They are mostly curved in shape (flat heads are also available) because curved heads can withstand more stress. Curve shape head are relatively lighter and cost less to manufacture if it compare to the flat ones. Sometimes heads are used inside a vessel; these types of heads are called intermediate heads as shown in Figure 2-1.

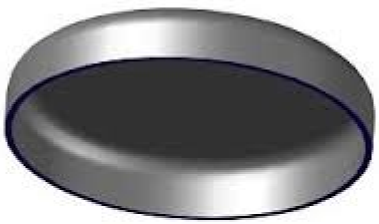


Figure 2-1 HEAD OF PRESSURE VESSELS

Typical head can be classified into two groups. The first is domed and the other one is conical. More details are as follows

Different types of heads are detailed as shows in the Figure 2-2.

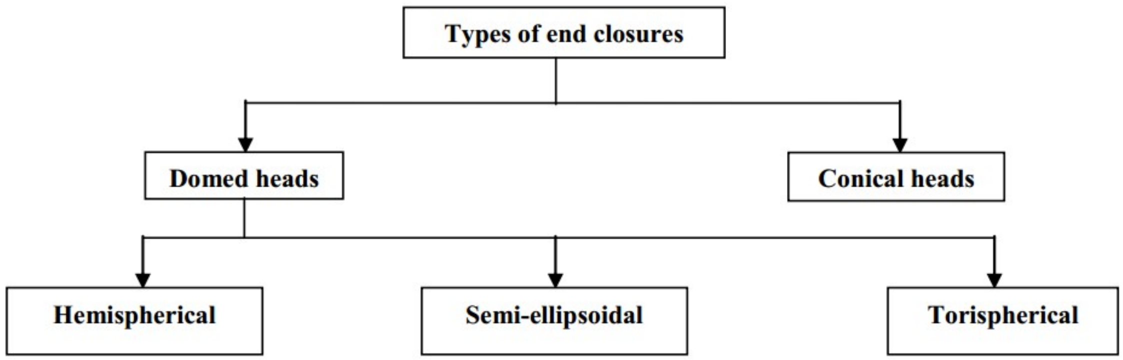


Figure 2-2 TYPES OF PRESSURE VESSEL HEADS

So as show in the figure there are two types of end closure the domed heads and the conical. Further the domed heads are divided into to three parts that are hemispherical head, semi ellipsoidal head, and tori spherical head.

1. **Hemispherical Head**

This sphere is the ideal shape for a head, because the pressure is divided equally across the surface of the head as in Figure 2-3.

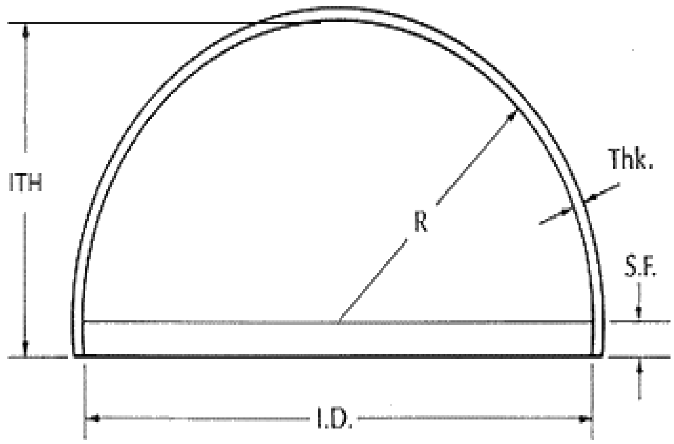


Figure 2-3 HEMISPHERICAL HEAD DIMENSIONS

2. Semi-ellipsoidal Head

This is also called a 2:1 elliptical head. The shape of this head is more economical, because the height of the head is just a quarter of the diameter as shown in Figure 2-4.

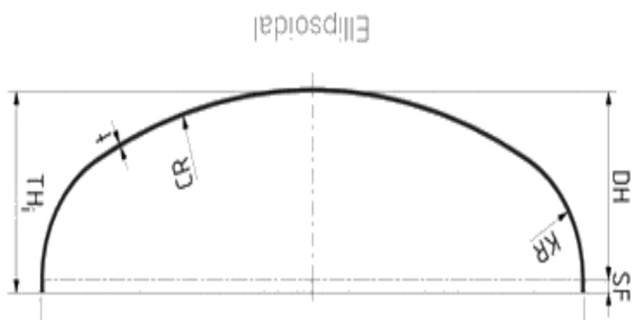


Figure 2-4 SEMI-ELLIPSOIDAL HEAD

3. Tori spherical Head

This type of a head has a dish with a fixed radius, the size of which depends on the type of tori spherical head. The transition between the cylinder and the dish is called the knuckle. The knuckle has a toroid shape. In this type of head the condition remains the same if it is compare with the other two head as shown in Figure 2-5.

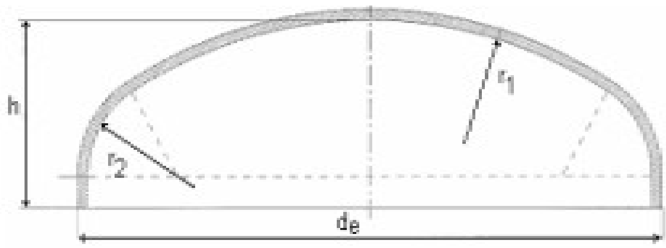


Figure 2-5 TORI SPHERICAL HEAD

4. Conical Head

Conical head have more strength than the flat heads but similar to the flat head. Conical bottoms depending on the angle of the cone provide good bottom drainage. Placing a nozzle at the bottom of a conical head will allow for solids and the precipitate to immediately get flushed out. The ASME code limits conical heads without a knuckle radius to maximum included half angle of 30 degrees as shown in Figure 2-6.

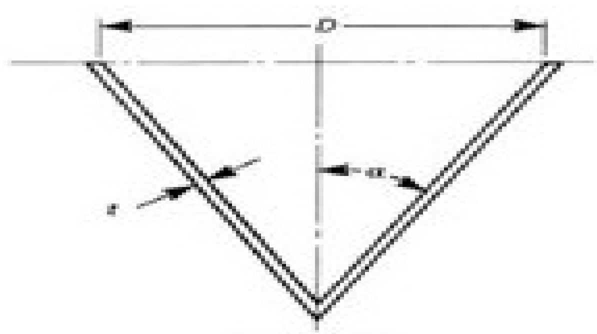


Figure 2-6 CONICAL HEAD SHAPE

5. Flat Head

This is a head consisting of a toroid knuckle connecting to a flat plate as shown in Figure 2-7. This type of head typically is not used on pressure vessels since it is inherently very weak

Figure 2-7 FLAT HEAD PRESSURE VESSELS

2.4.2 Shells

This is the primary component of a pressure vessel. It is located in the middle of the two heads. The shell is the part of the vessel in which most of the pressure is exerted on. Pressure vessel shells comprises of different form of plates of different materials welded together to form a structure that has a common rotational axis, depending on how large the pressure vessel is designed to be. The shell sections of a tall tower maybe constructed of different material, thickness and diameters due to process and phase change of process fluid. The Shell of a spherical pressure vessel is spherical as well.

2.4.3 Nozzles

Nozzles are also important component of the pressure vessels processing. Nozzles are cylindrical components that penetrate into the shell or head in the pressure vessels to satisfy certain requirements such as inlet or outlet connection, manholes, vents and drains etc. this nozzles are usually flanged, to allow necessary connections to external devices as shown in Figure 2-8.

Figure 2-8 NOZZLES ON A PRESSURE VESSEL [6].

2.5 Project decision

Based on the cost of production and the operating specification of a domestic solar collector, it has to be design a typical domestic solar collector water storage tank/pressure vessel with a preheater integrated in it. The volume of the pressure vessel is determined as 120% of the daily average volume water consumption in a domestic residence, which is approximately 100liters per day.

Chapter 3

Design and Analysis

This chapter will include the following contents:

- **Material Selection:** which will include the design materials identification, dimensions and tolerance.
- **Design:** which will include the applied mathematical design formula for selection for the sizing of the pressure vessel and its components.
- **Cost Analysis of design:** this will include a final detailed tabulated cost analysis of production of the design

3.1 Background Information

The purpose of this project is to design a cylindrical pressure vessel that will not fail during performance over the designed lifetime. To achieve this, the vessel has to operate in the elastic region of the material; the idea is therefore to select materials for the vessel that will has a yield strength that can overcome the stress brought about by the internal pressure of the fluid in the vessel the stress strain graph is shown in Figure 3-1.

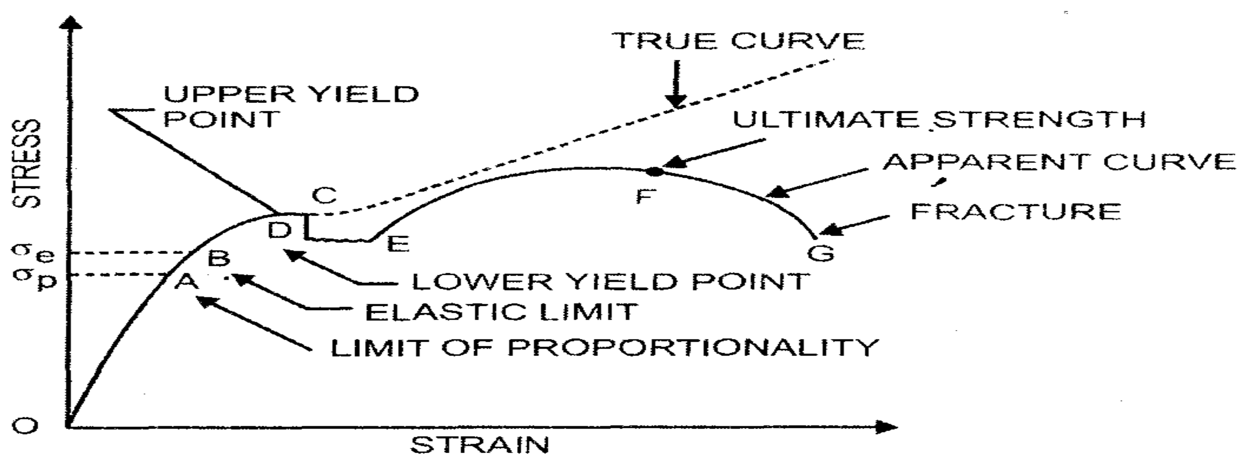


Figure 3-1 STRESS-STRAIN GRAPH OF LOW CARBON MILD STEEL [7].

However, in this design, it is restricted to the use of a material due to the availability and cost of materials in the market. Therefore, is is going to manipulate the design calculations, for example, by adjusting the thickness of the vessels shell thickness etc. in order to achieve the desired design requirements.

3.2 Material Selection:

Based on the ASME BPVC section VIII division 1, certain materials are recommended for this design purpose, however, certain rules apply to each of the materials available for this design purpose [8].

The list of materials recommended by ASME BPVC section VIII division 1 for this purpose include:

- Carbon and Low alloy steel
- Nonferrous metals
- High alloy steel
- Cast irons other than ductile irons
- Clad materials, weld overlaid materials
- Ductile iron castings
- Ferrous steel with tensile strength enhanced by heat treatment etc.

Due to its availability and low cost in the market, low carbon steel will be used for this project.

As this material is known for its fairly low resistance to corrosion, two considerations will be taken for this design process.

1. Corrosion allowance will be considered in the design of this pressure vessel.
2. Galvanized low carbon steel will be used. i.e. the steel will be coated with zinc by the hot dipping process. This zinc will

form a barrier by creating a zinc oxide passive protective layer and also act as an anode in an electrochemical cell setup by the material and its environment, therefore reducing corrosion/rusting to the minimum.

The specific material that will be used is: DIN EN 10346, Grade DX52D +Z

TABLE 3-1: MECHANICAL PROPERTIES AND CHEMICAL COMPOSITION OF MATERIALS [9](See Appendix D2).

Soft grades – hot-dip coated steel strip and sheet made of soft steels acc. to DIN EN 10346									
Mechanical properties (lat.)									
Steel grade/type		**Symbol for the type of surface finishing**	**Elongation limit (Yield Strength) MPa**		**Tensile strength MPa**		**Fracture elongation %min.**		
Code	**Material no.**								
DX52D	1.0350	+Z, +ZF, +ZA, +AZ, +AS	140 – 300		270 – 420		26		
Chemical composition (melt analysis) of soft steels for cold forming									
Steel grade/type		**Symbol for the type of surface finishing**	**Chemical composition Percentage by mass %**						
Code	**Material no.**		**C Max.**	**Si Max.**	**Mn Max.**	**P Max.**	**S Max.**	**Ti Max.**	
DX52D	1.0350	+Z, +ZF, +ZA, +AZ, +AS	0.12	0.5	0.60	0.10	0.045	0.30	

The corrosion allowance that will be used is as a result of the environmental conditions of Cyprus, based on the high humidity and salinity of the environment.

Corrosion Allowance is said to be safe at 1 mm

3.3 Design Calculations

3.3.1 Theory

The main purpose of a pressure vessel is to create a separation of between environments of two different pressures. Usually, pressure vessels in practice, have a higher internal pressure than its environmental pressure (otherwise in the case of a submarine that has a lower internal pressure). The difference in the internal and external pressure causes an exertion of stress on the walls of the vessels. Based on the material selected for the vessel, a wall thickness that can bear the stress exerted by this phenomenon is to be calculated.

This is a thin walled cylindrical pressure vessel therefore; calculations made will be based on ASME BPVC section VIII division 1 codes [10].

The Cylindrical Pressure Vessel consists of two main components;

- **The Cylindrical wall**
- **The head and transition section**

The sizing of the thickness of the wall of the cylinder will depend on the calculations of the individual parts as follows.

3.3.2 The Cylindrical wall

Consider a cylinder with internal pressure as shown in figure 3-2(a), if it is assumed to be a thin walled cylindrical vessel, this means that it has a small wall thickness to radius ratio, therefore the distribution of the normal stress across the wall thickness is assumed to be uniform. Figure 3-2(b) shows a section of length ΔL of the cylindrical vessel subjected to an internal pressure P. The Force F is the force caused by the pressure and the force W is the resultant internal force on the section.

Summing up the forces in the Y direction gives us a relation that helps us calculate the **Circumferential Stress** acting on the walls, and then the required thickness of the vessel walls can be calculated.

Thickness of vessel wall based on circumferential stress

Equation 1 WALL THICKNESS BASED ON CIRCUMFERENTIAL STRESS

$$t = \frac{PR}{SE - 0.6P}$$ *When t < 0.5R or P < 0.385SE*

(1)

Where

P: Internal Design Pressure

R: Internal Radius

E: Joint Efficiency Factor

S: Allowable stress in the material (yield strength of the material)

t: Wall thickness of the vessel

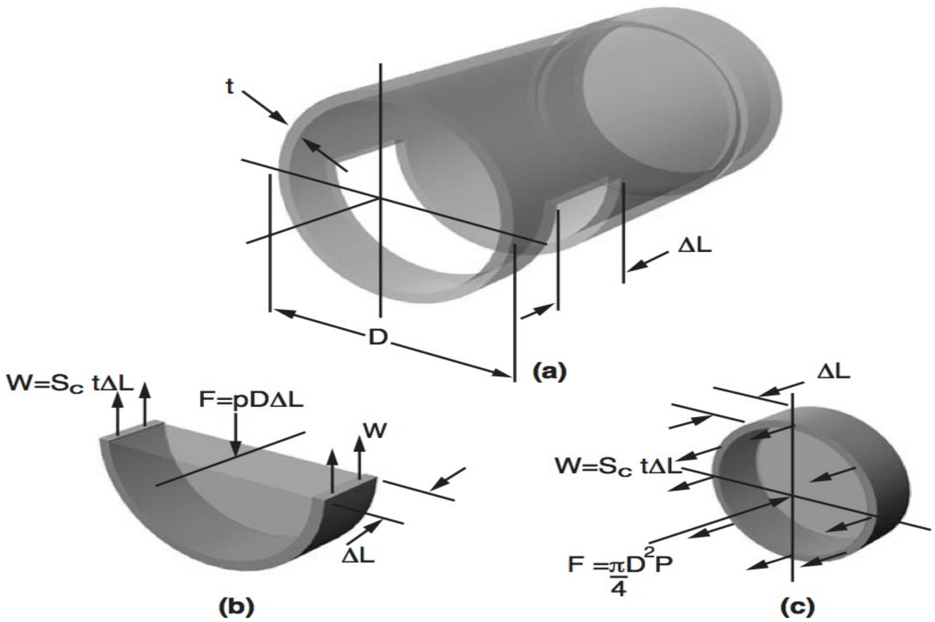


Figure 3-2 FORCE AND STRESSES IN A PRESSURISED CYLINDER

The stresses in the longitudinal direction may be determined by considering the forces present in the x direction as illustrated in Figure 3-2(c). If it is consider the forces present in the x direction, the summation of these forces will result in a relation that helps us calculate the **longitudinal Stress.**

Thickness of vessel wall based on longitudinal stress

Equation 2 WALL THICKNESS OF VESSEL BASED ON LONGITUDINAL STRESS

$$t = \frac{PR}{2SE + 0.4P} \quad \text{When } t < 0.5R \text{ or } P < 1.25SE \qquad (2)$$

Where

P: Internal Design Pressure

R: Internal Radius

E: Joint Efficiency Factor

S: Allowable stress in the material

t: Wall thickness of the vessel

3.3.3 The Heads and Transition section

The types of heads commonly used in todays practice are formed heads, i.e. ellipsoidal, tori spherical, hemispherical, and conical and tori conical heads. For the ease of manufacturing, the pressure vessel is designed with an ellipsoidal head. This design is based on that the ellipsoidal has a D to h ratio of 2:1 as shown in Figure 3-3.

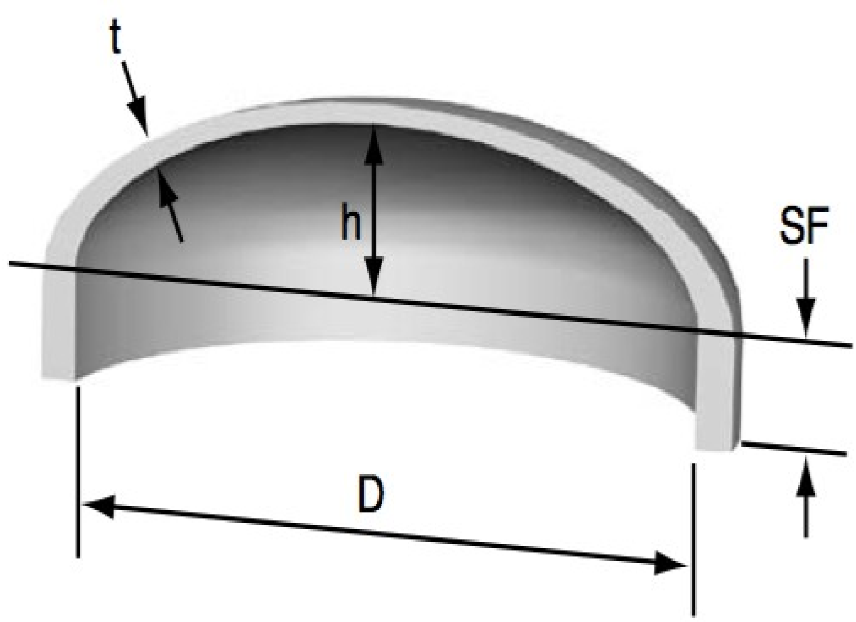


Figure 3-3 SECTIONED VIEW OF AN ELLIPSIODAL HEAD OF A PRESSURE VESSEL

The required thickness for an ellipsoidal 2:1 head is given by the equation

Equation 3 WALL THICKNESS OF VESSEL BASED ON ELLIPSOIDAL HEAD STRESS

$$t = \frac{PD}{2SE - 0.2P} \tag{3}$$

Where

P: Internal design Pressure

D: Internal Diameter of the major length of the head

E: Joint Efficiency Factor

S: Allowable stress in the material (yield stress of the material)

t: Wall thickness of the vessel

SF is the skirt length of the part that joins the head to the cylindrical part of the vessel.

To determine the overall thickness of the pressure vessel, all these calculations have to be made. The circumferential stress thickness, the longitudinal stress thickness and the head thickness will then be compared. Since it is trying to avoid failure, the maximum thickness amongst the three calculated thicknesses will be chose.

As it has been taking note of the factor of corrosion which may cause the material to degrade in its physical properties, it has to consider a corrosion allowance additional thickness. Therefore, the required corrosion allowance will be added to the final decision of the thickness calculated.

The volume of the vessel was designed to be 0.9 times the daily hot-water consumption therefore the tank has a volume of 120 Liters.

3.4 Calculation for the Thin Walled Cylindrical Pressure Vessel

Design Working Temperature 0 to 100 $^{\circ}C$

Design Internal Pressure 0.2MPa

Internal diameter 450 mm

Yield stress of material 140MPa

Factor of safety 2

Maximum allowable stress $\frac{140}{2}$ = 70MPa

Joint efficiency 0.85 (for all but welded joints)

3.4.1 Calculation for the cylindrical shell thickness

Circumferential thickness

From equation 1

$$t = \frac{PR}{SE - 0.6P} \quad (4)$$

$$t = \frac{(0.2 \times 10^6) \times (0.225)}{(70 \times 10^6)(0.85) - (0.6)(0.2 \times 10^6)}$$

$t =$ ¿ 7.5783×10^{-4} m

$$t = 0.758\, mm$$

Longitudinal thickness

From equation 2

$$t = \frac{PR}{2\,SE + 0.4\,P} \quad (5)$$

$$t = \frac{(0.2 \times 10^{6}) \times (0.225)}{2(70 \times 10^{6})(0.85) + (0.4)(0.2 \times 10^{6})}$$

$t =$ ¿ 3.779×10^{-4} m

$$t = 0.379\, mm$$

The Heads and Transition section thickness

From equation 3

$$t = \frac{PD}{2\,SE - 0.2\,P}(6)$$

$$t = \frac{(0.2 \times 10^{6}) \times (0.45)}{2(70 \times 10^{6})(0.85) - (0.2)(0.2 \times 10^{6})}$$

$$t=¿ \quad 7.564\times10^{-4} \text{ m}$$

$$t=0.756\,mm$$

The calculations show that the thickness required for the circumferential thickness, longitudinal thickness and the head and transition thickness are 0.758mm, 0.379mm and 0.756mm respectively. Therefore, it has been chosen to use the maximum thickness as the overall thickness of the pressure vessel.

Required thickness of the pressure vessel therefore is **0.758mm**

Since corrosion allowance is considered based on the worst-case environmental condition of the environment on a long life span of about 20yrs, it has been added a corrosion allowance length of **1.0mm**

Therefore the final selected thickness of the pressure vessel is

1mm + 0.758mm = **1.758mm**

Considering the availability of metal sheet size in the market, a **2mm** thickness galvanized steel plate will be used for the manufacturing of this project.

Therefore, the maximum amount of internal pressure this vessel should be able to hold can be calculated as follows

$$P=\frac{SEt}{R+0.6t} \quad (7)$$

$$P=\frac{\left(70\times10^{6}\right)\left(0.85\right)\left(2\times10^{-3}\right)}{0.225+0.6\left(2\times10^{-3}\right)}$$

$$P=0.53\times10^{6}\,Pa$$

The design should therefore withstand a maximum pressure of **0.53Mpa** in cases of extreme conditions. Other openings, nozzles and components will use the same thickness as per calculated for the wall thickness.

3.4.2 The Nozzles Calculations

The 1 inched pipe is used of the same material selected for the inlet and outlet nozzles. However, to determine the thickness of the pipe hence the pipe schedule that will withstand the pressure.

The thickness calculation is as follows:

1inch pipe = 33.4mm diameter (see appendix B1)

$$¿ equation(4)$$

$$t=\frac{(0.2\times10^{6})\times(0.0167)}{(70\times10^{6})(0.85)-(0.6)(0.2\times10^{6})}$$

$$t=¿ \quad 5.625\times10^{-5}m$$

$t=0.05625\,mm$ + Corrosion allowance

$t=0.05625\,mm$ + 1mm

$$t=1.05625\,mm$$

Therefore, a pipe is required with a thickness of 1.05625mm or more.

Nominal 1inch pipe sch. 5s having a thickness of 1.65mm is of good practice. (See appendix D1).

3.5 Solar Collector System Specification

Tank: Volume: 120 liters

	Height/diameter ration:	2.22
	Material:	Galvanized steel
	Cold Water inlets:	Through bottom 3/4”
	Hot Water outlets:	Through top 3/4 “
	Corrosion Protection	Protective coating/corrosion allowance
Heater:	Power:	3.0kW/240V
	Location:	Bottom of Tank

3.6 Cost Analysis

Material	Location	Cost
2mm Metal sheet 2X1		125.00TL
2pcs Pre-manufactured cylinder heads	**Ordered**	2 X 95.00TL
1 meter Long ¾” Pipes	**Yusuf Paralik**	80.00TL
Auxiliary Heater	**Yusuf Paralik**	50.00TL
Electrodes	**Yusuf Paralik**	35.00TL
Ball Valve	**Marshal shop**	19.00TL
Pressure Relief Valve	**Marshal shop**	12.80TL
Reducers and Fitting and tapes	**Marshal shop**	14.50TL
Workmanship	**SAFRITON**	150TL
	Total cost:	**827.3TL**

All parts were purchased at **Yusuf Paralik, and Marshal shop** in Famagusta, Cyprus.

Constructions and workmanship were done at **SAFTRITON DEPOLARI Buyuk Sanayi Bolgesi** Famagusta, Cyprus.

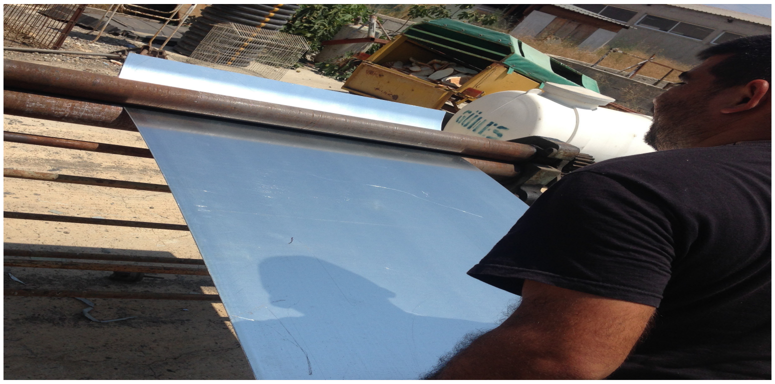
Chapter 4

MANUFACTURING PROCESS

4.1 Cylindrical Shell Manufacturing

The sheet metal was purchased at dimensions 2m X 1m therefore a cutting tool was used to resize the sheet metal to required size. The required lengths were extended by 2cm for extra tolerance due to the overlapping of the lap joints during welding.

Rollers were used to roll the sheet metal into the desired shape of a truncated cylinder as shown in Figure 4-1 (a) and (b).



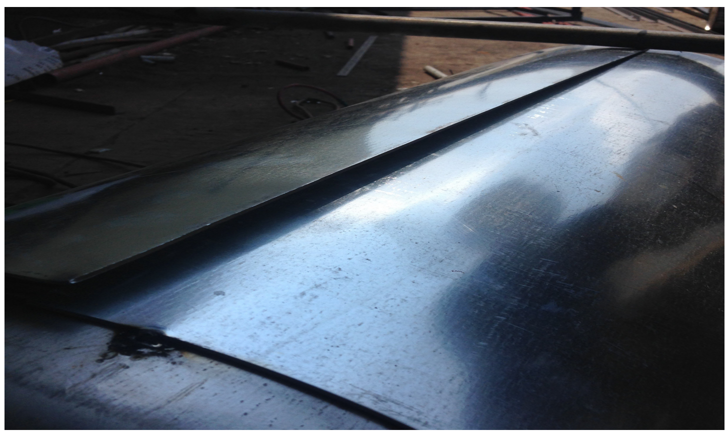
(a)

(b)

Figure 4-1 SHEET METAL ROLLING PROCESS

4.2 Ellipsoidal Head Manufacturing

The heads were pre-manufactured and brought by order because the workshop lacked the necessary equipment for the manufacturing process. These heads were made to sit on top of the already rolled truncated cylinder. Tack welding was performed on the jointing ends between the truncated cylinder and the ellipsoidal heads to hold them in place. Figure 4-2(a) and (b) shows the tack welding performed at these points.



(a)

(b)

Figure 4-2 TACK WELDING TO HOLD PARTS IN PLACE FOR EASIER CONSTRUCTION

4.3 Inlet and Outlet Nozzle fittings

Holes were perforated into the vessel through the use of arc welding electrodes. The holes made were carefully dimensioned and marked on the vessel, and then the electrode was used to trace the cut out. This cutting process needed to be precise and accurate therefore in order not to damage the part, help was required from a welder to perform this operation.

Grinding operation was performed to smoothen out all the rough edges created during the welding process as shown in Figure 4-3.

Figure 4-3 GRINDING OPERATION PERFORMED WITH A GRINDING MACHINE

The welding was performed using ac welding. Lap joints were used through the welding of the cylinder shell vertical weld and the circumferential welding between the cylinder and the ellipsoidal heads. Butt edge welds were made between the body of the vessel and the nozzle inlets and outlets. Figure 4-4 shows the complete look of the vessel with the weld types.

Figure 4-4 WELDED AND ASSEMBLED PRESSURE VESSEL

TESTING PROCESS

The idea of the test is to show that the design can withstand the required pressure it was designed for. This is achieved by testing for leakages in the vessel during test operation. The process used for the test operation is hydro-test.

During the test operation, the test conditions are exaggerated for the worst-case scenario. This is to ensure a factor of safety for the operation. In the testing operation it is hoped to achieve a factor of safety of 1.8, therefore the pressures of 0.38MPa applied to the vessel.

Process of Testing

- The openings of the vessel were sealed with the use of blind fittings and tapes to ensure no leakages under working pressure.
- The vessel was then filled with the water.
- A water pump and pressure gauge were connected to the vessel and water was pumped into the sealed vessel in order to increase the pressure inside the vessel, up to 3.8 bars equivalent to approximately 0.38MPa.
- The valves of the system were shut to keep the vessel pressurized for duration of about 2hrs.
- If there is any leakage, it will be observed. However if the leakage cant be observed physically by inspection, it will be observed based on a drop in pressure read by the pressure gauge after a time.

Chapter 5

Results and Discussion

Results

After several hours of waiting, the pressure in the tank got to a stable pressure of 3.8 Bars equivalent to 0.38MPa. Therefore it was observed that the vessel would sustain a pressure of 0.38MPa without leakages during operation. This pressure is almost 2 times greater than the design pressure. So it can conclude that the design was successfully accomplished.

Discussion

During the test operation, several difficulties were observed.

- Several leakages were observed. However these leakages were not due to faults in the welding operation. The leakages resulted from the connections and sealing of the inlets and outlets. Proper connections and sealing was not made therefore water was leaking from these areas.
- The test operation was canceled and the water was drained out and then the connections were properly sealed. The welding operation was carried out again.
- At the second test trial, a pressure of 5 bars was used. This pressure however was too great for the design of the vessel. However the integrity of the welds on the vessel were maintained, but profuse leakages were observed at the inlet and outlet. No matter how much it has been tightened the connections, these leakages were still observed

Therefore, it concluded that the vessel but not the inlet and outlet nozzles could withstand too high pressures. Therefore left of the pressure in the vessel to reduce until it gets to a stable pressure in which the vessel nozzles can withstand.

Chapter 6

Conclusions

The purpose of this project was to learn more about pressure vessels and to learn how to design and manufacture one depending on its purpose. In this project, the desire was to design and manufacture a solar collector storage tang/pressure vessel.

This project was challenging because it made us face real life situations and helped us mature in the design techniques. Initial designs were made during the course of the project, however the manufacturing wasn’t feasible based on the cost and manufacturing technique. So we learnt a great deal in the feasibility studies of a project.

In the future works, we will be more efficient in the designing of pressure vessels. We will be able to function well in manufacturing companies, and we will be able to inspect and tests vessels for faults. It was a great experience indeed.

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[9] http://www.pdhcenter.com/courses/m398/m398content.pdf

[10] ASME Boiler and Pressure Vessel Code Section VIII, BS 5500

Appendices

APPENDIX A

Muhammad Asim’s LOGBOOK

Dates	Details
24/11/2014	Firstly we selected the capstone project from Assist. Prof. Dr. Ghulam Hussain. He briefly explained the project to us. Next he gave us the pervious published capstone report to get the idea about how to write a report.
28/11/2014	Then we went to Assist. Prof. Dr. Neriman Özada (Vice Chair). She explained briefly and provides us with the project regulations, required report writing, and a layout sample of the report and enough information to write a proper and a good report.
02/12/2014	So I Muhammad Asim and my group mate victor meet up and decided to divide the work equally to each other. So we decided that I would do chapter 1 which is about introduction and the second chapter that is about literature review/background information and victor we will do the chapter 3 and the rest of the report.

17/12/2014	Start gathering the information about the project and start writing chapter 1
22/12/2014	I Went several times to Assist. Prof. Dr. Ghulam Hussain and Assist. Prof. Dr. Neriman Özada (Vice Chair) to get the help in the introduction part and the information about the structure of the report.
04/1/2014	Finish with chapter 1 and 2

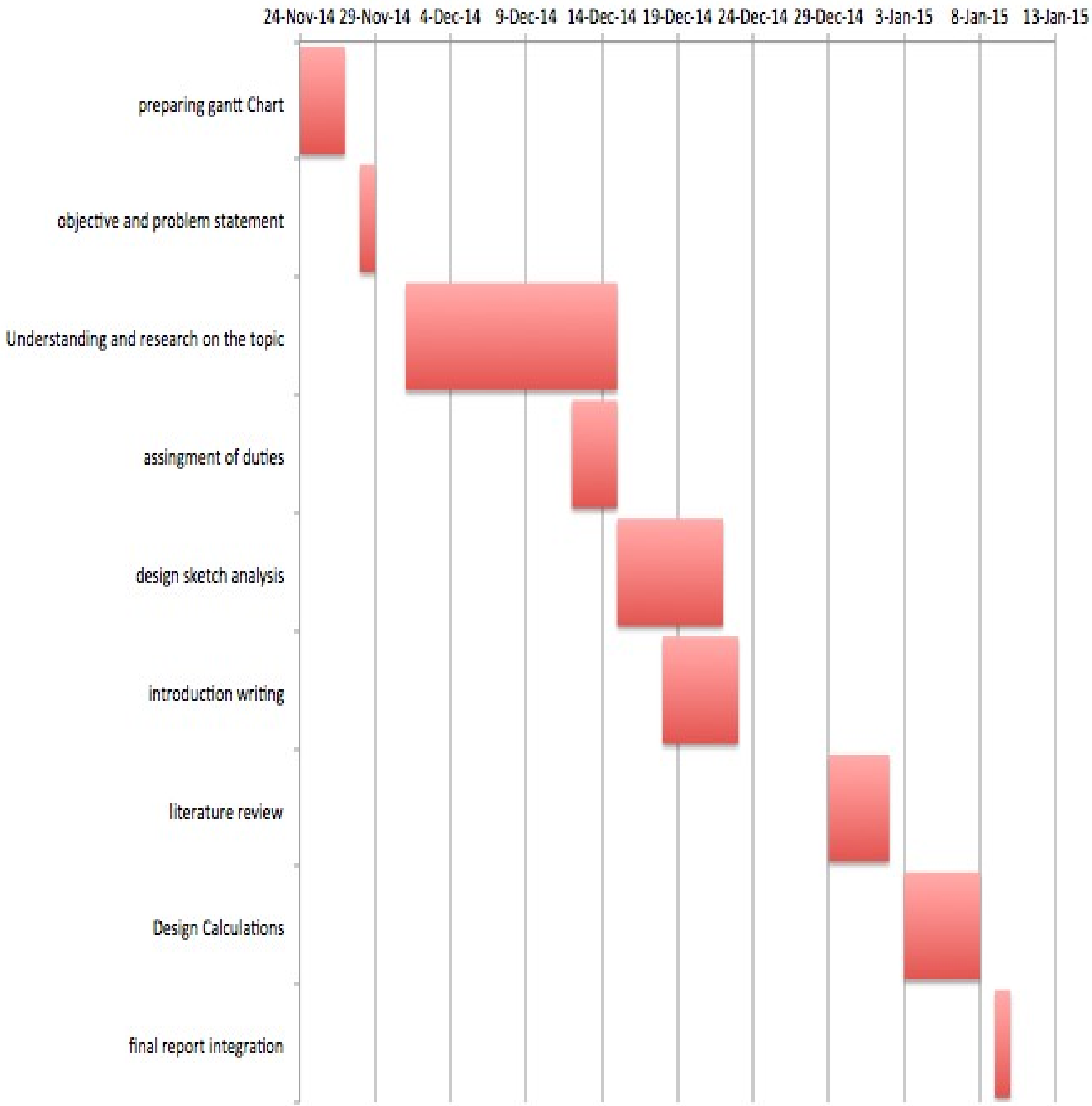
Victor Israel-Bolarinwa’s LOGBOOK

Dates	Details
24/11/2014	Firstly, Assist. Prof. Dr. Ghulam Hussain assigned us the project topic. We deliberated on the type of pressure vessel to design.
25/11/2014	I started preparing the Gantt chart.
26/11/2014	I wrote the abstract of the report
28/11/2014	We had a brief conversation with Assist. Prof. Dr. Neriman Ozada. She explained the rules guiding report

	writing to us. Then a Group meeting was held to discuss on the subject of concern. We assigned the duties to one another.
5/12/2014	I made researches on the internet on designed pressure vessels and the best dimensions that will be required for the design.
12/12/2014	I asked for assistance from lecturers to determine the most suitable corrosion allowance to be used for the design.
23/12/2014	I started working on the rough sketch of the design of the project.
03/01/2015	I officially finished the plan of the design and stated calculations and organization of chapter 3.
09/01/2015	All parts of the project were completed. A brief meeting with my group partner was organized to combine the projects.

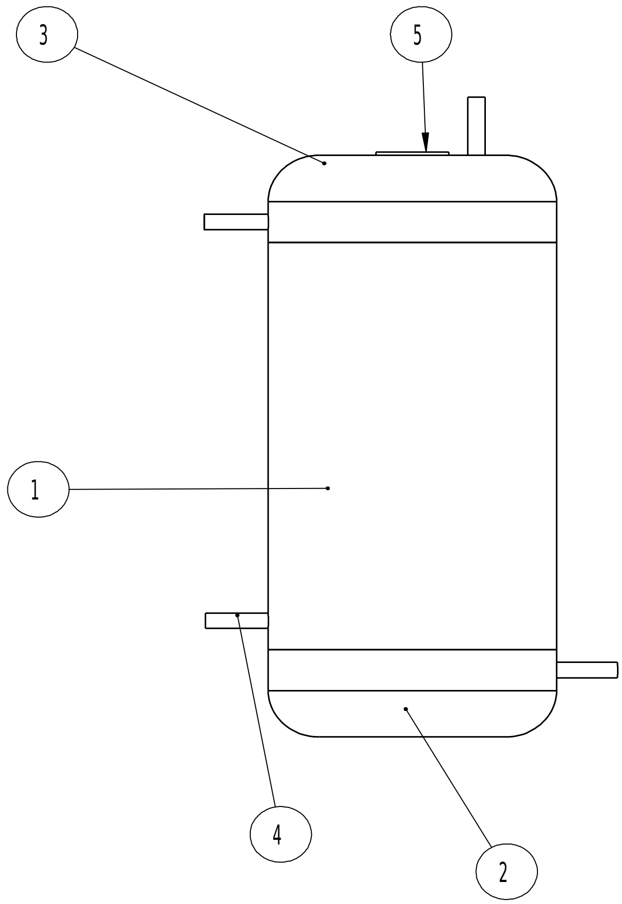
APPENDIX B

GANTT CHART


24-Nov-14
29-Nov-14
4-Dec-14
9-Dec-14
14-Dec-14
19-Dec-14
24-Dec-14
29-Dec-14
3-Jan-15
8-Jan-15
13-Jan-15
preparing gantt Chart
objective and problem statement
Understanding and research on the topic
assingment of duties
design sketch analysis
introduction writing
literature review
Design Calculations
final report integration

APPENDIX C

TECHNICAL DRAWINGS



5	HEATER HOLE	1	100MM OPENING FOR WATER HEATER
4	PIPES/NOZZLE	4	STEEL
3	BOTTOM HEAD	1	STEEL
2	TOP HEAD	1	STEEL
1	SHELL	1	STEEL
NO	NAME	AMT.	DESCRIPTION

	NAME	DATE	SIGN	
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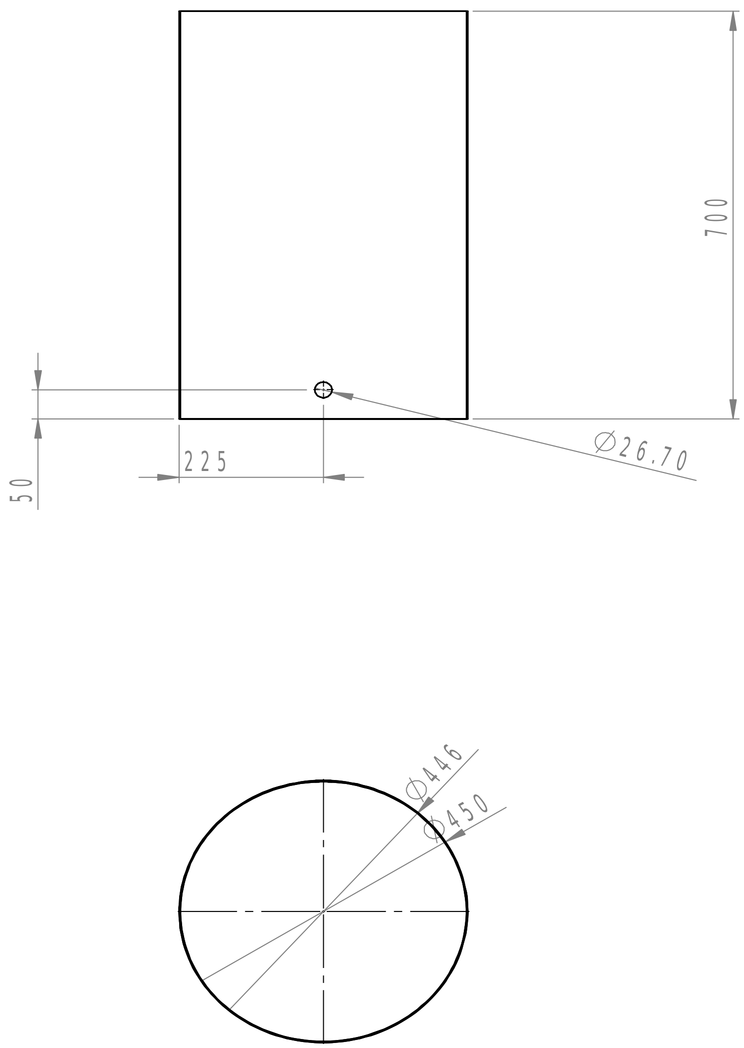
CHK BY				
scale 1:10	ASSEMBLY DRAWING			DRAW NO. 1



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CHK BY				
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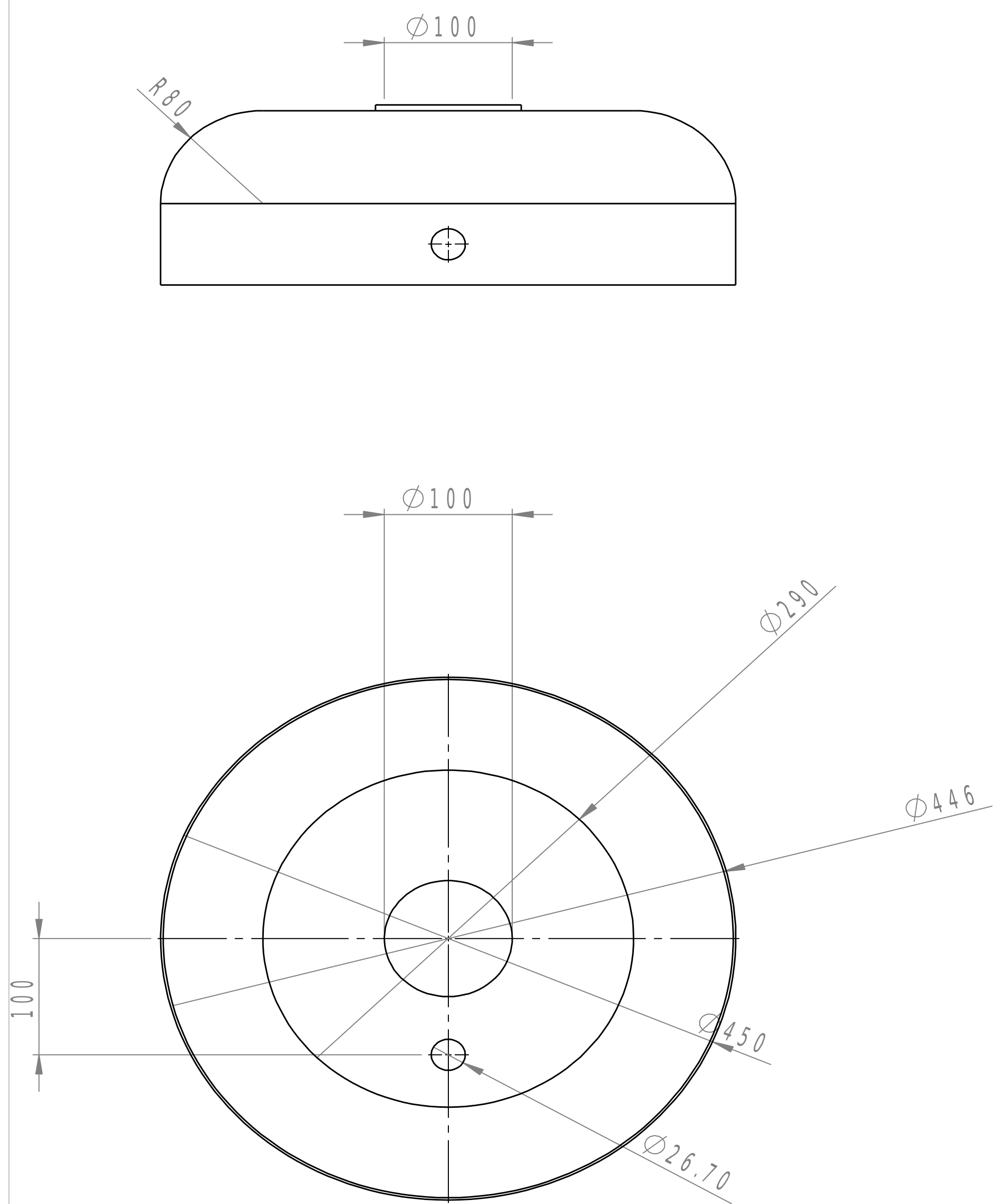

	NAME	DATE	SIGN	
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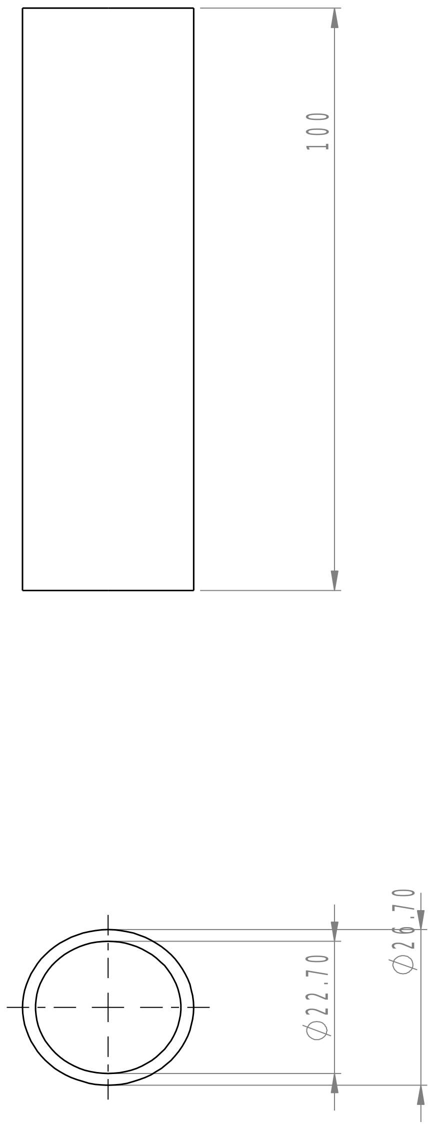

	NAME	DATE	SIGN
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CHK BY			
scale 1:1	PIPE		DRAW NO. 1-4

APPENDIX D

ENGINEERING STANDARDS

STANDARD PIPE SCHEDULE & INNER DIA DIMENSIONS (INCHES / METRIC)

High Pressure Materials

SIZE OD INCH OD MM	SCHEDULE (SCH)	INCHES W.T	INCHES I.D.	METRIC (mm) W.T	METRIC (mm) I.D.
1/4 0.540" 13.7mm	10S	.065	.410	1.65	10.41
	40STD, 40S	.088	.364	2.24	9.25
	80XS, 80S	.119	.302	3.02	7.67
3/8 0.675" 17.1mm	10S	.065	.545	1.65	13.84
	40STD, 40S	.091	.493	2.31	12.52
	80XS, 80S	.126	.423	3.20	10.74
1/2 0.840" 21.3mm	5S	.065	.710	1.65	18.03
	10S	.083	.674	2.11	17.12
	40STD, 40S	.109	.622	2.77	15.80
	80XS, 80S	.147	.546	3.73	13.87
	160	.188	.464	4.78	11.79
	XXS	.294	.252	7.47	6.40
3/4 1.050" 26.7mm	5S	.065	.920	1.65	23.37
	10S	.083	.884	2.11	22.45
	40STD, 40S	.113	.824	2.87	20.93
	80XS, 80S	.154	.742	3.91	18.85
	160	.219	.612	5.56	15.54
	XXS	.308	.434	7.82	11.02
1 1.315" 33.4mm	5S	.065	1.185	1.65	30.10
	10S	.109	1.097	2.77	27.86
	40STD, 40S	.133	1.049	3.38	26.64
	80XS, 80S	.179	.957	4.55	24.31
	160	.250	.815	6.35	20.70
	XXS	.358	.599	9.09	15.21
1 1/4 1.660" 42.2mm	5S	.065	1.530	1.65	38.86
	10S	.109	1.442	2.77	36.63
	40STD, 40S	.140	1.380	3.56	35.05
	80XS, 80S	.191	1.278	4.85	32.46
	160	.250	1.160	6.35	29.46
	XXS	.382	.896	9.70	22.76
1 1/2 1.900" 48.3mm	5S	.065	1.770	1.65	44.96
	10S	.109	1.682	2.77	42.72
	40STD, 40S	.145	1.610	3.68	40.89
	80XS, 80S	.200	1.500	5.08	38.10
	160	.281	1.338	7.14	33.99
	XXS	.400	1.100	10.16	27.94
2 2.375" 60.3mm	5S	.065	2.245	1.65	57.02
	10S	.109	2.157	2.77	54.79
	40STD, 40S	.154	2.067	3.91	52.50
	80XS, 80S	.218	1.939	5.54	49.25
	160	.344	1.687	8.74	42.85
	XXS	.436	1.503	11.07	38.18
2 1/2 2.875" 73.0mm	5S	.083	2.709	2.11	68.81
	10S	.120	2.635	3.05	66.93
	40STD, 40S	.203	2.469	5.16	62.71
	80XS, 80S	.276	2.323	7.01	59.00
	160	.375	2.125	9.53	53.98
	XXS	.552	1.771	14.02	44.98
3 3.500" 88.9mm	5S	.083	3.334	2.11	84.68
	10S	.120	3.260	3.05	82.80
	40STD, 40S	.216	3.068	5.49	77.93
	80XS, 80S	.300	2.900	7.62	73.66
	160	.438	2.624	11.13	66.65
	XXS	.600	2.300	15.24	58.42
4 4.500" 114.3mm	5S	.083	4.334	2.11	110.1
	10S	.120	4.260	3.05	108.2
	40STD, 40S	.237	4.026	6.02	102.3
	80XS, 80S	.337	3.826	8.56	97.2
	120	.438	3.624	11.13	92.0
	160	.531	3.438	13.49	87.3
	XXS	.674	3.152	17.12	80.1
5 5.563" 141.3mm	5S	.109	5.345	2.77	135.8
	10S	.134	5.295	3.40	134.5
	40STD, 40S	.258	5.047	6.55	128.2
	80XS, 80S	.375	4.813	9.53	122.3
	120	.500	4.563	12.70	115.9
	160	.625	4.313	15.88	109.6
	XXS	.750	4.063	19.05	103.2
6 6.625" 168.3mm	5S	.109	6.407	2.77	162.7
	10S	.134	6.357	3.40	161.5
	40STD, 40S	.280	6.065	7.11	154.1
	80XS, 80S	.432	5.761	10.97	146.3
	120	.562	5.501	14.27	139.7
	160	.719	5.187	18.26	136.7
	XXS	.864	4.897	21.95	124.4
8 8.625" 219.1mm	5S	.109	8.407	2.77	213.5
	10S	.148	8.329	3.76	211.6
	20	.250	8.125	6.35	206.4
	30	.277	8.071	7.04	205.0
	40STD, 40S	.322	7.981	8.18	202.7
	60	.406	7.813	10.31	198.5
	80XS, 80S	.500	7.625	12.70	193.7
	100	.594	7.437	15.09	188.9
	120	.719	7.187	18.26	182.5
	140	.812	7.001	20.62	177.8
	XXS	.875	6.875	22.23	174.6
	160	.906	6.813	23.01	173.1
10 10.750" 273.1mm	5S	.134	10.482	3.40	266.2
	10S	.165	10.420	4.19	264.7
	20	.250	10.250	6.35	260.4
	30	.307	10.136	7.80	257.5
	40STD, 40S	.365	10.020	9.27	254.5
	60XS, 80S	.500	9.750	12.70	247.7
	80	.594	9.562	15.09	242.9
	100	.719	9.312	18.26	236.5
	120	.844	9.062	21.44	230.2
	140, XXS	1.000	8.750	25.40	222.3
	160	1.125	8.500	28.58	215.9
12 12.750" 323.9mm	5S	.156	12.438	3.96	315.9
	10S	.180	12.390	4.57	314.7
	20	.250	12.250	6.35	311.2
	30	.330	12.090	8.38	307.1
	STD, 40S	.375	12.000	9.53	304.8
	40	.406	11.938	10.31	304.2
	XS, 80S	.500	11.750	12.70	298.5
	60	.562	11.626	14.27	295.3
	80	.688	11.374	17.48	288.9
	100	.844	11.062	21.44	281.0
	120, XXS	1.000	10.750	25.40	273.1
	140	1.125	10.500	28.58	266.7
	160	1.312	10.126	33.32	257.2
14 14.000" 355.6mm	10	.250	13.500	6.35	342.9
	20	.312	13.376	7.92	339.8
	30, STD	.375	13.250	9.53	336.6
	40	.438	13.124	11.13	333.3
	XS	.500	13.000	12.70	330.2
	60	.594	12.812	15.09	325.4
	80	.750	12.500	19.05	317.5
	100	.938	12.124	23.83	308.0
	120	1.094	11.812	27.79	300.0
	140	1.250	11.500	31.75	292.1
	160	1.406	11.188	35.71	284.2
16 16.000" 406.4mm	10	.250	15.500	6.35	393.7
	20	.312	15.376	7.92	390.6
	30, ST	.375	15.250	9.53	387.4
	40, XS	.500	15.000	12.70	381.0
	60	.656	14.688	16.66	373.1
	80	.844	14.312	21.44	363.5
	100	1.031	13.938	26.19	354.0
	120	1.219	13.562	30.96	344.5
	140	1.438	13.124	36.53	333.3
	160	1.594	12.812	40.49	325.4
18 18.000" 457.2mm	10	.250	17.500	6.35	444.5
	20	.312	17.376	7.92	441.3
	STD	.375	17.250	9.53	438.1
	30	.438	17.124	11.13	434.9
	XS	.500	17.000	12.70	431.8
	40	.562	16.876	14.27	428.7
	60	.750	16.500	19.05	419.1
	80	.938	16.124	23.83	409.5
	100	1.156	15.688	29.36	398.5
18 (cont.)	120	1.375	15.250	34.93	387.3
	140	1.562	14.876	39.67	377.9
	160	1.781	14.438	45.24	366.7
20 20.000" 508mm	10	.250	19.500	6.35	495.3
	20, STD	.375	19.250	9.53	488.9
	30, XS	.500	19.000	12.70	482.6
	40	.594	18.812	15.09	477.8
	60	.812	18.376	20.62	466.8
	80	1.031	17.938	26.19	455.6
	100	1.281	17.438	32.54	442.9
	120	1.500	17.000	38.10	431.8
	140	1.750	16.500	44.45	419.1
	160	1.969	16.062	50.01	408.0
22 22.000" 559mm	10	.250	21.500	6.35	546.3
	20, STD	.375	21.250	9.53	540.0
	30, XS	.500	21.000	12.70	533.6
	60	.875	20.250	22.23	514.5
	80	1.125	19.750	28.58	501.8
	100	1.375	19.250	34.93	489.1
	120	1.625	18.750	41.28	476.4
	140	1.875	18.250	47.63	463.7
	160	2.125	17.750	53.98	451.0
24 24.000" 609.6mm	10, 10S	.250	23.500	6.35	596.9
	20, STD	.375	23.250	9.53	590.5
	XS	.500	23.000	12.70	584.2
	30	.562	22.876	14.27	581.1
	40	.688	22.624	17.48	574.6
	60	.969	22.062	24.61	560.4
	80	1.219	21.562	30.96	547.7
	100	1.531	20.938	38.89	531.8
	120	1.812	20.376	46.02	517.6
	140	2.062	19.876	52.37	504.9
	160	2.344	19.312	59.54	490.5
26 26.000" 660.4mm	10	.312	25.376	7.92	644.6
	STD	.375	25.250	9.53	641.3
	20, XS	.500	25.000	12.70	635.0
28 28.000" 711.2mm	10	.312	27.376	7.92	695.4
	ST	.375	27.250	9.53	692.4
	20, XS	.500	27.900	12.70	685.8
	30	.625	26.750	15.88	679.4
30 30.000" 762mm	10S, 10	.312	29.376	7.92	746.1
	STD	.375	29.250	9.53	743.0
	20, XS	.500	29.000	12.70	736.6
	30	.625	28.750	15.88	730.2
32 32.000" 813mm	10	.312	31.376	7.92	797.2
	STD	.375	31.250	9.53	794.0
	20, XS	.500	31.000	12.70	787.6
	30	.625	30.750	15.88	781.2
	40	.688	30.624	17.48	778.0
34 34.000" 864mm	10	.312	33.376	7.92	848.2
	STD	.375	33.250	9.53	845.0
	20, XS	.500	33.000	12.70	838.6
	30	.625	32.750	15.88	832.2
	40	.688	32.624	17.48	829.0
36 36.000" 914mm	10	.312	35.375	7.92	898.2
	STD	.375	35.250	9.53	894.9
	20, XS	.500	35.000	12.70	888.6
42 42.000" 1067mm	STD	.375	41.250	9.53	1048
	20, XS	.500	41.000	12.70	1042
48 48.000" 1219mm	STD	.375	47.250	9.53	1200
	XS	.500	47.000	12.70	1194

ABBREVIATIONS

I.D : INNER DIA
O.D : OUTER DIA
W.T : WALL THICKNESS
N.P.S: NOMINAL PIPE SIZE
N.P.T: NOMINAL PIPE THREADS
B.E : BEVEL END
P.E : PLAIN END
STD : STANDARD

X. Hot-dip galvanized sheet

EMW delivery range	Coils	Slit strip	Cut-to-size sheet	
				
Thicknesses	from 0.30 – 4.50 mm	from 0.30 – 4.50 mm	from 0.40 – 3.00 mm	
Widths	up to 1,850 mm	up to 1,850 mm	up to 1,530 mm	up to 1,850 mm
Lengths	---	---	up to 8,000 mm	up to 3,000 mm
Tolerances	Acc. to DIN EN 10143; finer tolerances available by arrangement.			

Soft grades – hot-dip coated steel strip and sheet made of soft steels acc. to DIN EN 10346 : 2009

Mechanical properties (lat.)

Steel grade/type		Symbol for the type of surface finishing	Elongation limit R_e [1] MPa	Tensile strength R_m MPa	Fracture elongation A_{80} [2] %	Vertical anisotropy r_{90}	Work hardening exponent n_{90}
Code	Material no.				min.	min.	min.
DX51D	1.0226	+Z, +ZF, +ZA, +AZ, +AS	–	270 – 500	22	–	–
DX52D	1.0350	+Z, +ZF, +ZA, +AZ, +AS	140 – 300 [3]	270 – 420	26	–	–
DX53D	1.0355	+Z, +ZF, +ZA, +AZ, +AS	140 – 260	270 – 380	30	–	–
DX54D	1.0306	+Z, +ZA	120 – 220	260 – 350	36	1.6 [4]	0.18
DX54D	1.0306	+ZF	120 – 220	260 – 350	34	1.4 [4]	0.18
DX54D	1.0306	+AZ	120 – 220	260 – 350	36	–	–
DX54D	1.0306	+AS	120 – 220	260 – 350	34	1.4 [4,5]	0.18 [5]
DX55D [6]	1.0309	+AS	140 – 240	270 – 370	30	–	–
DX56D	1.0322	+Z, +ZA	120 – 180	260 – 350	39	1.9 [4]	0.21
DX56D	1.0322	+ZF	120 – 180	260 – 350	37	1.7 [4,5]	0.20 [5]
DX56D	1.0322	+AS	120 – 180	260 – 350	39	1.7 [4,5]	0.20 [5]
DX57D	1.0853	+Z, +ZA	120 – 170	260 – 350	41	2.1 [4]	0.22
DX57D	1.0853	+ZF	120 – 170	260 – 350	39	1.9 [4,5]	0.21 [4]
DX57D	1.0853	+AS	120 – 170	260 – 350	41	1.9 [4,5]	0.21 [4]

Chemical composition (melt analysis) of soft steels for cold forming

Steel grade/type		Symbol for the type of surface finishing	Chemical composition Percentage by mass %					
			C	Si	Mn	P	S	Ti
Code	Material no.		max.	max.	max.	max.	max.	max.
DX51D	1.0226	+Z, +ZF, +ZA, +AZ, +AS	0.18	0.5	1.20	0.12	0.045	0.30
DX52D	1.0350	+Z, +ZF, +ZA, +AZ, +AS	0.12	0.5	0.60	0.10	0.045	0.30
DX53D	1.0355	+Z, +ZF, +ZA, +AZ, +AS	0.12	0.5	0.60	0.10	0.045	0.30
DX54D	1.0306	+Z, +ZF, +ZA, +AZ, +AS	0.12	0.5	0.60	0.10	0.045	0.30
DX55D	1.0309	+AS	0.12	0.5	0.60	0.10	0.045	0.30
DX56D	1.0322	+Z, +ZF, +ZA, +AS	0.12	0.5	0.60	0.10	0.045	0.30
DX57D	1.0853	+Z, +ZF, +ZA, +AS	0.12	0.5	0.60	0.10	0.045	0.30

Z = Hot-dip galvanized **ZF** = Galvannealed **ZA** = Galfan **AZ** = Galvalume **AS** = Hot-dip aluminised

APPENDIX E

Pictures

Figure E - 1

Figure E - 2

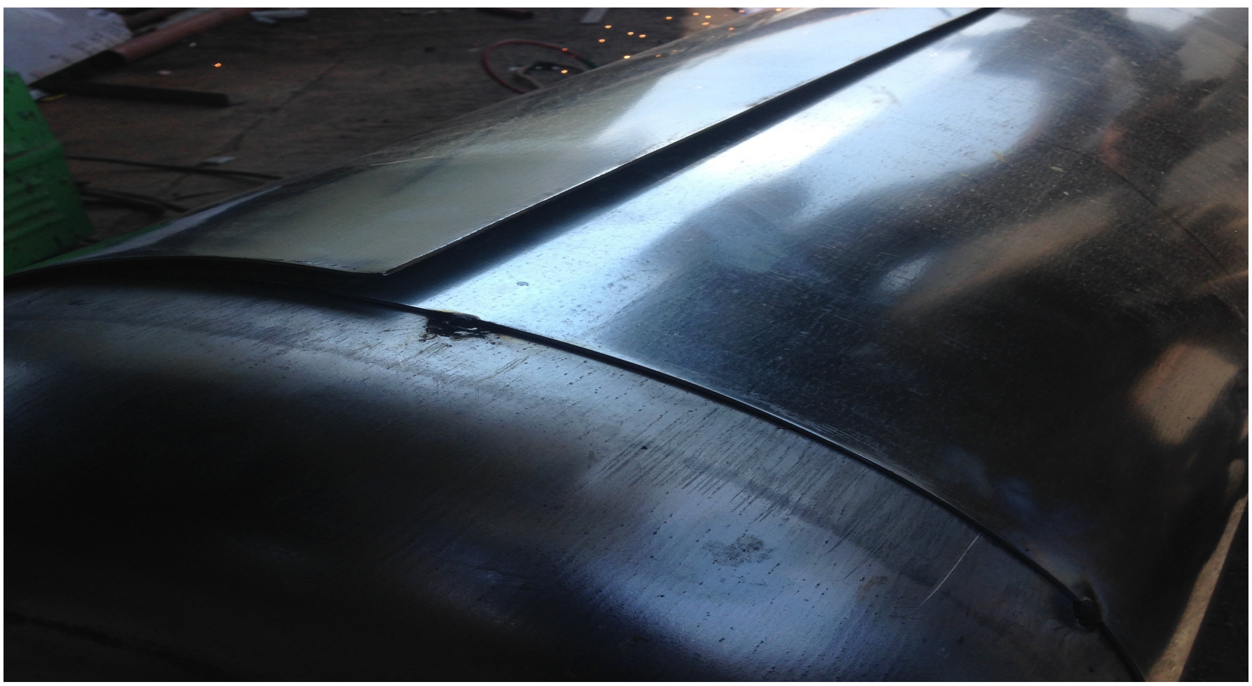

Figure E – 3

Figure E – 4

Figure E – 5

Figure E - 6