Design, Construction and Performance Evaluation of Electric Steam Boiler

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***Abstract*: - This paper presents the design, construction and performance evaluation of steam boiler. It is aimed at improving an existing steam boiler through the incorporation of a heating element and a thermostat. The joining techniques and handling of the equipment for optimum usage was explained in details. The INVENTOR design shows the pictorial views, lines and dimensions for its mass production purposes. The electric steam boiler was put to test in order to determine its function ability and effectiveness through some experiment. When the electric steam boiler was tested, higher efficiency is obtained when compared with the already existing one. Therefore, it can be deduced that the constructed boiler can be operated with optimum efficiency when compared with existing one.**

Keywords: **Electric steam boiler, heating element, thermostat, joining techniques, equipment, higher efficiency, optimum efficiency**

I. INTRODUCTION

A boiler is an enclosed vessel in which fluid is heated. The steam or hot water under pressure is then usable for transferring the heat to the end user. Water is a useful and cheap medium for transferring heat to a process. When water boiled into steam its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder (source). This causes the boiler to be an extremely dangerous item that must be treated with almost respect.

The first real development in boiler design came about with the invention of the Plain Cylinder Boiler. It is necessary to develop comprehensive boiler monitoring systems and better instrumentation to improve the understanding of operating conditions and to provide information that will help the operator minimize ash deposition problems. There are two types of boiler which are fire in tube boiler and water in tube boiler. They are used in crude fashions for several centuries but development was slow because contraction techniques were crude and the operation was extremely dangerous. By industrial revolution of the mid 1800.s, boiler had become the main source of energy to power industrial operations and transportation. The process of heating a liquid until it reach it's gaseous state is called Evaporation. The heating surface is any part of the boiler metal that has hot gases of combustion on one side and water on the other. Any part of the boiler metal that actually contributes to making steam is heating surface. This amount of heating surface a boiler has is expressed in square feet. The larger the amount of heating surface of a boiler, the more efficient it becomes.

Gauge (sight) glass it is a tube that indicate the water level in the boiler, Feed water System provide water to the boiler and regulate it automatically to meet the demand for steam. Valves provide access for maintenance and repair. Steam System collect and control the steam produced in the boiler. Steam is directed through piping to the point of use. Steam pressure gauge regulates the pressure inside the cylinder before and after generating steam. Safety valve prevents over-pressurization of the pressure vessel and is the primary safety control on all boilers. It is also called relief valves, pop-off valves, or safety relief valves. Steam trap allows condensate, to pass through but not the steam. The condensate passes through the condensate return line and is collected and directed back to the boiler to repeat the system to water process. Electric resistant heater is a heating element that used electricity to produced heat.

Sanga et al. [1] present review paper that involves comprehensive study of design and analysis of Lancashire Boiler. Adeyemo et. al. [2] construct a dry steam boiler incorporated with super heater that was electrically operated. Waheed et al. [3] projected the laboratory steam boiler designed from the conceptual physical geometry of fire-tube boiler which elucidated the primary units making up a boiler. Dimensions of major and secondary parts were estimated from computations from the theoretical framework and 3D modelling process for the steam boiler was then carried out to present various working drawings of the steam boiler for possible construction. Gutiérrez et al. [4] developed a complete dynamic model of a full-scale fire-tube boiler based on the mass, energy, and momentum balances together with constitutional equations. A first nonlinear physical model has been presented and after reduced to shorten the computational time, but providing reasonable results. A case study has been simulated using an 800 HP fire-tube boiler and dynamic performances predicted by the model are in good qualitative agreement with data taken from the literature.

Samaras et al. [5] presented simulation and optimization results of a 300 MW lignite-fired power plant. The results showed an absolute improvement of 0.55% of the overall thermal efficiency which is important for plants of that size since the resulting benefits were lower fuel consumption. This work could lead to the creation of a decision tool for the

control room of the unit where the model, through the use of real time data, will allow the engineer in charge to make instant. Pressure vessels always works under certain pressure and temperature along with lethal substances which are hazardous for both human and environment [6]. To assure minimum safety standards, several design codes have prepared and developed. The result fully complied with standard code and had been employed on practical design of pressure vessel.

Boiler provides the major source in industries to burn fuel to generate process steam and electric power P. [7]. It is the main device of power plant to generate steam by efficiently burning available fuels used to generate power. The researcher's designs going to the integration between the geometry and flow through the tube to reduce heat loss and system costs. In general, thermal power installations emit various polluting matter to the atmosphere that contribute to the greenhouse effect and the deterioration of the environment [8]. In this study the evaluation of the optimum operation conditions for two three-stage piro tubular boilers, connected in parallel and using gas oil is developed. The efficiency of the boiler is obtained as a function of the losses by using the TESTO model 300 M-Ianalyser whose probe was placed at the exit of the boiler.

Ikechukwu [9] fabricated and tested fire tube boiler to evaluate its performances, efficiency and determine its evaporation ratio. The result in this case is a torque produced at a steam pressure of 1.5 bar and a steam temperature of 111.40 °C also raising the temperature of the water from 300°C to a generated steam quantity of 61.34 kg/hr, with a diesel quantity of 5.2 Htres/hr. The efficiency of the burner after getting an adequate combustion air/fuel ratio and heat delivery from the burner resulted into 64.3%. The efficiency of the boiler was also calculated to be 69%.

Heat is transferred from one body to another by means of conduction, convection and radiation. Conduction transfer heat by actual physical contact, molecule to molecule while Convection transfer heat by conveying, such as air or water and radiation transfer heat from a hot body to the cold body without physical contact or a conveying medium. The new development has led to the invention of better performance steam boiler, fire-tube Scotch Marine Boiler, John Thompson fire-tube boiler, Muira water tube boiler etc. The above mentioned machines are complex and expensive. Therefore, there is a need for a portable, simple and less expensive boiler that can perform the same operation but at minimal cost with an appropriate output. To overcome the afore-mentioned problem, a portable and improved steam boiler is to be designed and fabricated.

The purpose of this research work is to design, construct and test the performance evaluation of steam boiler which is portable, efficient and cheaper than the modern means of boiler.

II. OPERATIONAL PRINCIPLE OF ELECTRIC STEAM BOILER

The operational principle of the steam boiler is the process of heat transfer. Heat transfer tends to occur whenever there is a temperature difference, and the three ways in which heat may be transferred are conduction, convection and radiation.

2.1 Conduction

Conduction of heat in solid is partly due to impact of adjacent molecules that vibrate internal radiation. The heat will now flow from hotter end to the coldest end. The greater the temperature difference, the faster the heat will flow. There is a law governing the heat transfer by conduction based on the observation of one dimensional steady heat flow through a solid. Fourier's law of conduction in one dimensional state that the rate of flow of heat through a single homogenous solid is directly proportional to the area A of the section at right angle to the direction of heat flow and to change of angle to the direction of heat flow and to the change of temperature with respect to the length of the path of the heat flow DT/DX.

Mathematically expressed as:

$$Q = KADT/DX \quad (1)$$

Q = The rate of heat flows in KW

K = Thermal conductivity of the material (W/mk)

DT = Temperature difference between the surfaces of metal

DX = Thickness of the material (m)

A = Area of the section at right angle

2.2 Convection

This is the transfer of energy from one place to another by the motion of a mass of materials between the two points. In a natural convection, the motion of the fluid is entirely as a result of differences in density resulting from temperature differences. Naturally, convection occurs when a solid surface is in contact with a fluid of different temperature from a surface. Density differences provided the body force required to move the fluid.

Mathematically, it can be expressed as;

$$Q = hA[T_2 - T_1] \quad (2)$$

h = Coefficient of corrective heat transfer

A = Area of surfaces not perpendicular to direction of heat flow

$T_2 - T_1$ = Temperature difference

In the cylinder, the fluid involved is the enclosed air and the burner surface or heating element, which provides the sold surface, while the cylinder walls serve as the solid surfaces.

The rate at which heat is transferred across an enclosed space (cylinder) is calculated from a coefficient based upon the temperature differences of the surfaces.

2.3 Radiation

This type of heat transfer requires no materials medium. It is accomplished by means of wave motion through space. All objects can emit and absorb radiation, and radiation carries energy. When an object emits radiation, it gives of energy, and when it absorbs radiation, it takes in energy. Sometimes, the emission or absorption will take place only in certain parts of the spectrum and sometimes they are distributed all across the spectrum. When an object gives off some radiation, then the energy stored in the object must decrease by the amount of energy given off in the radiation.

The total radioactive flux throughout the hemisphere from black surface of area "A" and absolute temperature T is given by the Stefan- Boltzmann law, which state that:

$$Q = A\sigma T^4 \qquad (3)$$

Where;

Q =Heat flux, energy per Time.

A =Area of heat flux intensity.

σ =Stefan Boltzmann constant (5.67 x 10-8) 10/m^2 (K^4)

T=Absolute Temperature.

These three (3) phenomena may take place in a given system one at a time or may occur simultaneously.

III. METHODS AND MATERIALS

Improved steam boiler was designed and constructed. It consists of housing unit thermostat, gauge glass, feed water system, steam pressure gauge, safety valve, steam strap and heating element. The housing units represent the entire outlook of the steam boiler. It was divided into two units, namely Mechanical unit and Electrical Unit. The Mechanical Unit is known as the bigger unit and meant only for the steam generating. The dimension of the unit is 300 mm by 500 mm cylindrical in shape. The Electrical Unit is the source through which electric power is supplied. This unit makes the mechanical unit perform function of generating steam. The unit comprises of the interlock switch, thermostat and heating element. The electrical unit was dimensioned as 270 mm x 120 mm x 85 mm rectangular in shape.

Thermostat is a device used for regulating the heat intensity. The element is very essential in a cylinder system but can be dangerous if not properly controlled. The thermostat is connected to the boiler chamber through a thermocouple arrangement. The thermocouple senses the temperature of the chamber convert it to electrical voltage and feeds it into the thermostat. The boiler is equipped with safety valve which release excess steam into the atmosphere. A principal component of the interlock switches is the interlock monitor switch. The major function of pressure gauge is to sense the amount of pressure inside the cylinder. Light Indicator is fixed to the boiler so as to know the working condition of the boiler that is, when the boiler is ON, the light glows, and when it is not working, it does not glow. Thus, for this boiler the light indicator is green.

3.1 Material Selection

Table 1 shows the material required for the design and fabrication of an electric steam boiler. Thus, the materials selected for this project was mild steel. The reasons considered in the selection of this material are it's resistance to rusting, affordability, durability, insulating properties and availability in large quantities. The procedure for assembling and installing of the Parts was shown in Table 2.

Table 1. Part Names, Selection of Materials and Quantity

S/N	Part name	Materials	Quantity
1	Top cover	Mild steal	1
2	Safety pipe	Mild steal	2
3	Bolt and nut	Iron	6
4	Boiler wall	Mild steal& fiber	3
5	Electrical housing	Mild steal	1
6	Thermostat	Bi-metallic	1
7	Electrical wire	Cable	1
8	Water inlet &outlet pipes	Mild steal	2
9	steam strap	Mild steal	1
10	Element	Bimetallic	1
11	Insulator	Plastic	1

Table 2. Procedures for Assembling and Installing of the Parts

Procedures	Operation	Descriptions	Tools
1		Collection of the materials for the constitution and installation of the parts	Free hand
2	Measurement	Making out the measured points on the mild steel	Scriber mater rule
3	1. Drilling (Hand drilling 2. Clamping 3. Welding Operation	Hole drilled on the front view i.e. façade view at the lower part of the cylinder. Another hole was made on the rear side (back view) at the upper part.	Bench vice drill bit and electrical welding machine.
4	Bending	Bend some of the parts cut to 30mm as shown in the inventor design	Plate bending machine
5	Installation	The installation of the electrical component to it unit orderly (whichever come first)	Screw driver and tester
6		Placing of the parts cut to their appropriate shape and sizes.	Free hand
7	Insulation	Putting fibers into the cylinder walls as shown in the inventor design before welding operation	Electrical welding machine.
8	Welding Riveting	Welding of the mechanical unit and joining the electrical unit to the mechanical unit by riveting the pins.	Electrical welding machine.
9	Welding electrical connection	Fixing of the element to the interior part of the boiler and fixing of thermostat as shown in the inventor design.	i. Electric welding machine ii. Free hand for the connection
10	Grinding machine	Grind all the welded parts on the oven	Plate grinding machine
11	Electrical Connectivity	Connection of the electrical wire from the electrical component to the heating place at the interior side.	Free hand
12	Painting	Paint the entire interior and exterior views of the steam boiler as shown when seen.	Painting brush
13	Electrical connectivity	Insert the plug into the socket	Free hand

The bill of Engineering Measurement and Evaluation and total Engineering Evaluation for the electric steam boiler was as shown in the table 3 and table 4 respectively.

Table 3. Bill of Engineering Measurement and Evaluation (BEME)

S/N	Construction	Amount(~~N~~)	Inventor	Amount	Typing & Biding	Amount
1	Mild steal	7000	Inventor	4000	Typing seven copies	5000
2	Iron rod	1000	Drawing		Spiral bound seven copies	1500
3	Thermostat	2000				
4	Element	3000				
5	Cylinder	2500				
6	Insulation materials	500			**Total**	6500
7	Galvanize steel	500				
8	Pressure gauge	4500				
9	Safety valve	3000				
10	Transport	3000				
11	Paint	500				
12	Hiring of generator and fueling(3 days)	3000				
	TOTAL	30500				

Table 4. Total Engineering Evaluation of the Electric Steam Boiler

S/N	DESCRIPTION	AMOUNT IN NAIRA (N)
1	Construction	30500
2	Inventor	4000
3	Typing and Biding	6500
	TOTAL	41000

3.2 Experimental Procedure

The electric steam boiler was put to test so as to determine its function ability and effectiveness through some series of sound box experiment ; (i.e. steam injection only, steam injection with electro-magnetic field, steam injection with vibration, steam injection with both electro-magnetic field and vibration.) groundwater remediation experiment. The experiment was performed for each of them while measurement were taken with respect to correspondent temperature and time-taken for particular turning level of the thermostat knob as well as the working pressure and steam flow rate was determine throughout the experiment. The thermostat was set at 99℃ and water was discharge into the boiler through inlet manifold. The machine was put on while the thermostat was set to the expected marked point gradually. After 30mins; the steam have already been generated and reading was taken at the deflection of pressure-gauge. Steam was supplied to the sound-box, and time-taking, steam flow rate and working pressure were recorded. The results obtained during the various experiments conducted were shown in Table 5.

IV. RESULTS AND DISCUSSION

The results obtained during the various experiments conducted were shown in Table 5.

Table 5.Steam Injection Pressure and Flow Rate for water remediation

S/N	Steam injection pressure, bar	Working pressure (bar)	Time-taken (min)	Flow rate (cm^3/min)
A	3.4	1.2	45	13.962
B	3.6	1.4	38	16.535
C	3.6	1.6	30	20.944
D	3.8	1.8	26	24.166

The following graphical plots were obtained for analysis (fig. 1-2).

i. Graph of working pressure against steam flow rate

ii. Graph of time-taken against steam flow rate

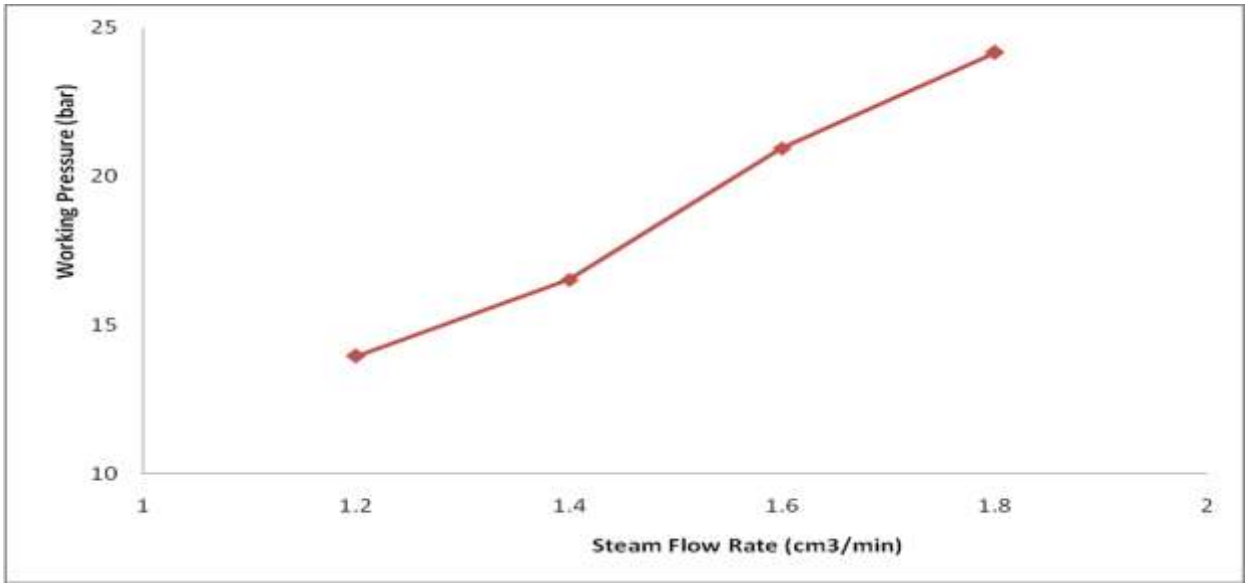

Figure1.Graph of Working Pressure against Steam Flow Rate

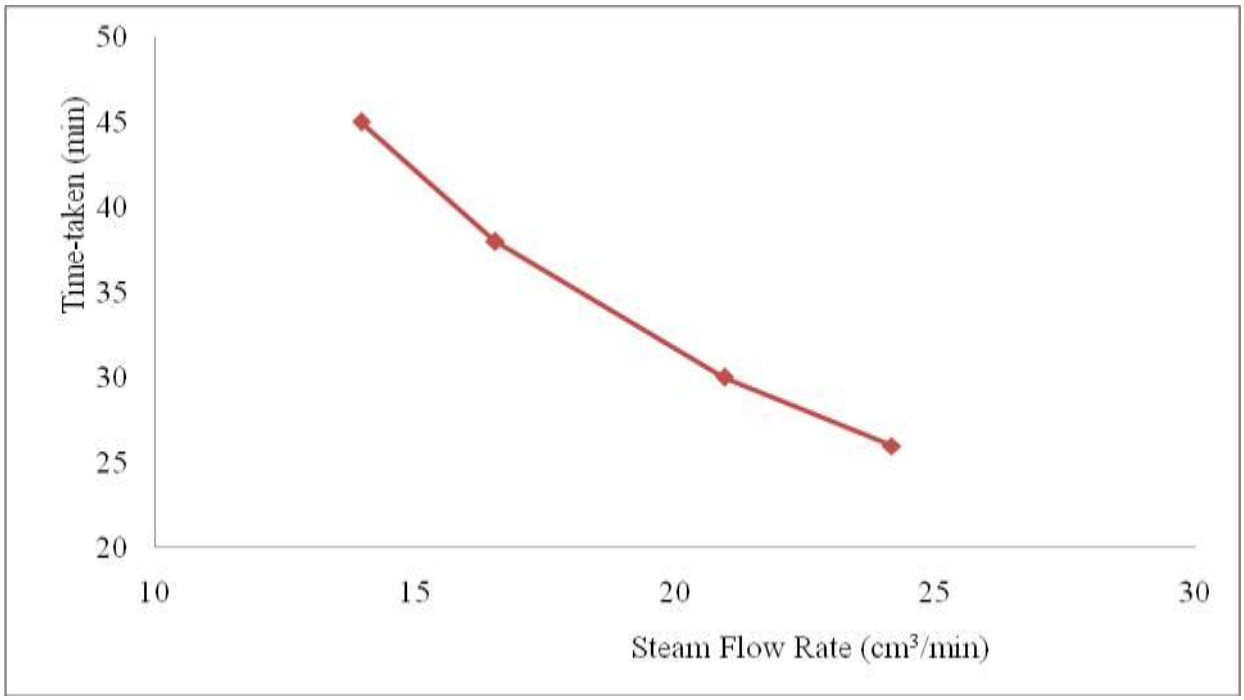

Figure 2.: Graph of Time-taken against Steam Flow Rate

The graph of working pressure against the steam flow rate (Figure 1) reveals increase in working pressure with increase in steam flow rate. The graph of time-taken against steam flow rate (Figure 2) reveals that as the steam flow rate is increased, the time-taken for the next experiment were reduced. In summary, the table above shows the corresponding time-taken to perform each experiment under varying working pressure. After the steam boiler has been tested, it was realized that: It is efficient and faster. It has a very easy mode of operation. Then comparing the electric steam boiler with charcoal or oil fired steam boiler, the following advantages were obtained: Electric steam boiler uses electricity as the power source while other uses firewood, charcoal and kerosene fuel respectively as their source of power. Electric steam boiler designed is safer if properly insulated while kerosene fuel and gas steam boiler are liable to explosion because of the un-even distribution of fuel.

V. CONCLUSIONS

The design, construction and performance evaluation of the steam Boiler was carried out. When the electric steam boiler was tested, higher efficiency is obtained when compared with the already existing one. The steam boiler is portable, efficient and cheaper than the modern means of boiler. Therefore, it can be deduced that the constructed boiler can be operated with optimum efficiency when compared with existing one.

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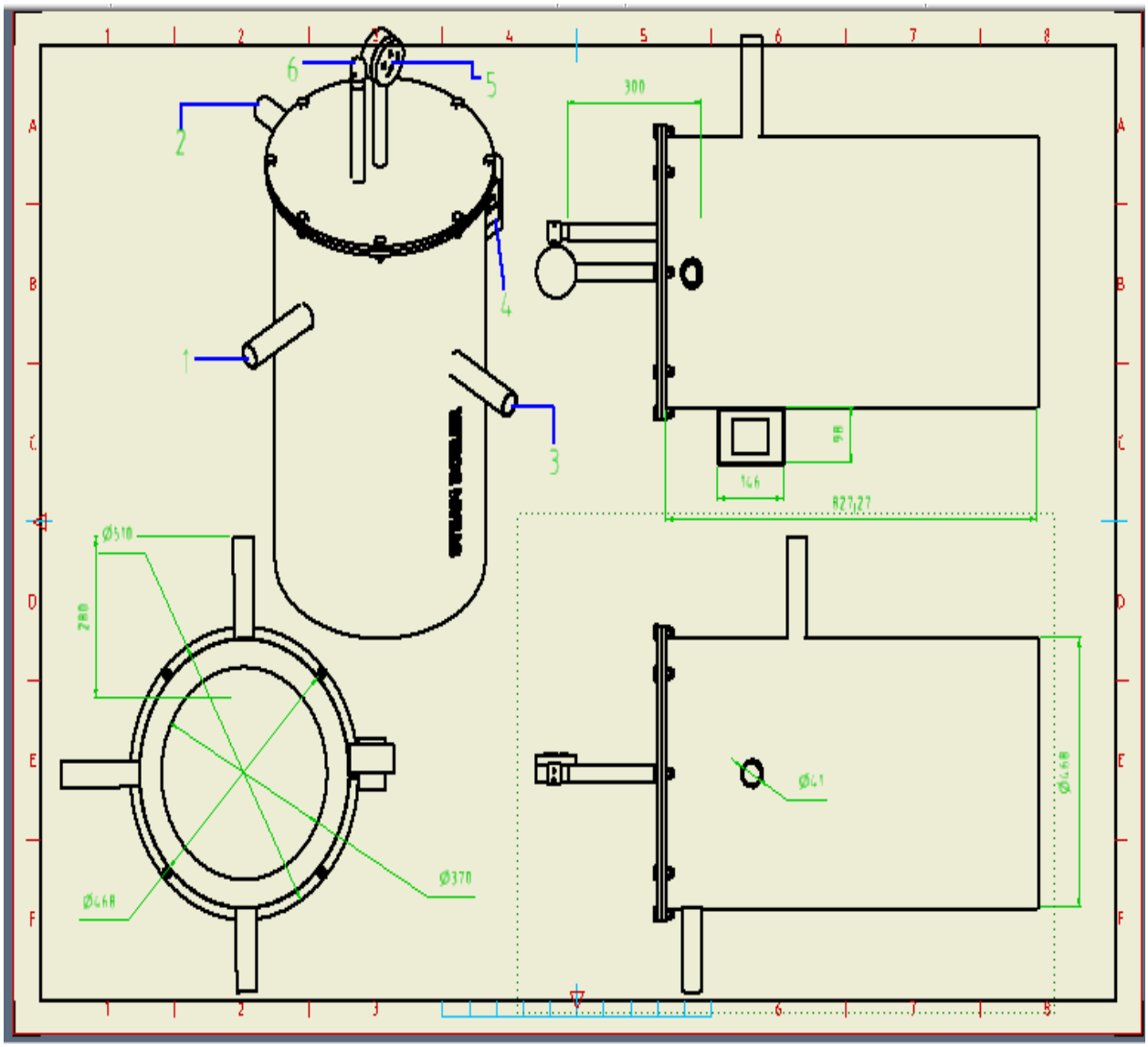
Appendix 1



1. **Water inlet**
2. **Steam outlet**
3. **Water drainage**
4. **Thermostat**
5. **Pressure gauge**
6. **Relive valve**

Appendix 2