Modeling and Design of Electrical Water Boiler Using Composite Materials

Dr. Elfetori F. Abdewi & Muammar M. Asbiga
Dept. of Mechanical Engineerin, Libyan Academy

Abstract:

The main objective of this paper is to study the effect of replacing the internal casing of water boiler that made of metallic material by a similar one made of composite materials. An intensive theoretical study have been carried out on domestic electrical water boiler using modeling technique. Analysis and modeling process was performed using Finite Element Method. Thermal conductivity which is the main parameter affecting heat transfer hase been tested for composite material as well as for metallic materials. Results showed that it is more convenient to use composite material for inner case of water boiler instead of metallic material. Composite materials are lighter than metallic material, much

safer (eliminate possibility of electrical shock), and it hasn't corrosion problems. It is found that it is possible to replace the internal case of water boiler made of metallic material with a wall thickness of 7 mm by an equivalent composite material case made of glass fiber with the same thickness. Obtained results showed that seven layers of composite materials forming similar wall thickness is an optimum case with respect of heat transfer and thermal conductivity.

***Keywords**: Electrical water boiler; Thermal conductivity; FEM Modeling; glass fiber.*

I. Introduction

In real life, there are several applications which highly depended on thermal conductivity of the materials such as boilers. Heat transfer between the outer surface and inner surface of the boiler is highly affecting the performance of such items. This point has been studied carefully, and most of boilers used nowa days are made of different layers of metals. A large number of researchers have been conducted on the influence of the boiler thermal efficiency. Some of These researches presents development of boiler design through different parameters that effect of thermal efficiency for boiler [1-5]. Development technology in materials science introduced new advanced materials such as composite materials.

Boilers are one of the main items used in houses, restaurants, schools, hotels …etc. These boilers need to be changed from time to time because of failure resulting mainly of corrosion. This problem becomes worse if the used water is salty which is the case in different places at Libya. However, in the presence of advanced materials such as composites, this problem can be eliminated. Since composite has longer

working life than metals because it is not corroded. In addition to that, composites are applicable in a medium with a temperature up to 250 C^o. This temperature is much higher than the working temperature of boilers. Moreover, composite material is safe for electrical shock which is a great hazard affecting people's life in case of using metallic material. In addition to that, it is well known that the energy demand keeps increasing every year due to growth of population, industrial activities and new lifestyle with the intervention of various energy dependent technological innovations. Higher demand for energy certainly exert pressure to utility companies for sustainable and reliable energy generation and supply. This leads to innovation in design of boilers working more efficiently. All of these aspects makes development of boiler's material an attractive research area, in order to contribute in this aspect.

Therefore, this research aims to investigate theoretically thermal conductivity of metallic and non metallic materials (composite materials). The task will be performed using modeling technique with the help of power full design tool (finite element code). It aims also to find the equivalent number of layers of composite materials to the metallic boiler walls. Consequently, the research will allow to investigate new structures which can replace the current used structure of boilers with higher efficiency.

II. Problem statement

although ordinary metallic boiler is widely used, but it has many problems such as corrosion, hazard of electric shock, and relatively short working life that make it costly. Figure 1, shows the environmental effects which lead in the end to a worn boiler, consequently direct failure and malfunction. These effects result from the wrong selection of the materials in old boilers. Double layered Steel, which used to be a covering for mineral water, is a bad choice from the durability point of view. This is because mineral water causes metal corrosion. In addition,

mineral water acts as a catalyst that speeds up the chemical reactions causing corrosion, which directly leads to worse side effects and finally leakage. Not only that, this problem also contaminates water. Hence, the water becomes unhealthy for human use.

In the presence of composite material, these disadvantages can be eliminated with similar or higher efficiency. Replacement of metallic boiler with composite material for domestic water boiler is the field of the current research.

Figure 1. Horizontal cross-section of metallic boiler showing the environmental effects

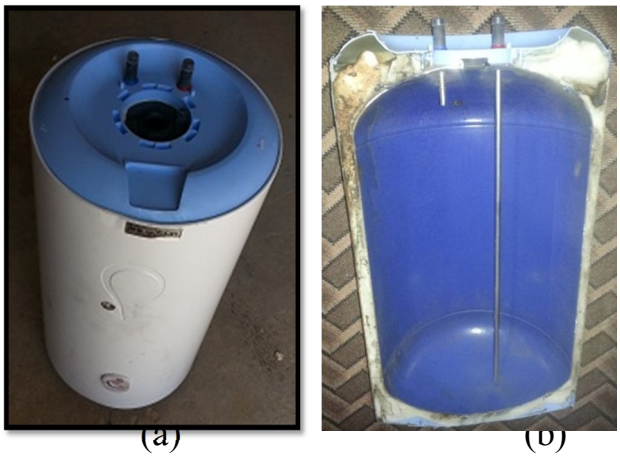
Modelling process:

As mentioned before, the main scope of this study is to obtain representative computational results by testing the applicability of using glass fiber as a thermal insulator for domestic water boiler. For this purpose an intensive study is carried out to optimize the boiler thickness of different materials that leads to design a lighter weight water boiler compared to traditional metallic one. An ordinary metallic boiler of 80L capacity has been chosen for the current study, since it is the most widely used. It is aimed to be replaced with a same size boiler made of advanced material that makes it much lighter and overcome almost all the problems of traditional metallic water boiler. Finite element code (ANSYS) is used for this task. ANSYS is a commercial finite element analysis software

with the capability to analyze a wide range of different problems including thermal problems [6]. Physical and mechanical properties of glass fiber and resin those used as a raw material for composed material are assigned to ANSYS software as defined in hand books of material science and composite material [7-8]. The type of matrix material used is Epoxy Hexcel 920, however, glass fiber used is E-Glass 0/90 woven roving, and its properties are as following:

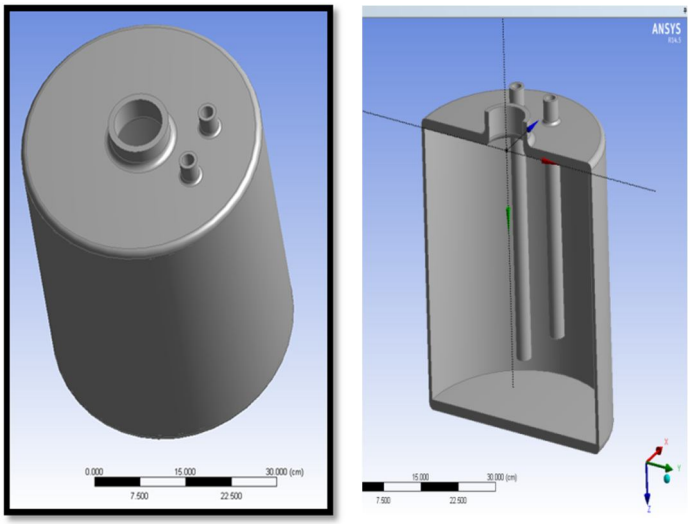
Specific gravity	2.6
Stiffness	73 GPa
Specific stiffness	1.1
Ultimate strain	3.5 %
Strength	3.5 GPa
Specific strength	11.2
Maximum use temperature	350 C^o

The inner part of metallic water boiler is made of thick metal sheet painted with blue color to avoid corrosion. It is surrounded with a layer of foam about three times thicker than metallic part. The layer of foam is followed with a gap of air, then covered with the outer metallic sheet of metal usually painted with white color as shown in figure 2 a, and 2 b. the overall thickness of ordinary metallic boiler is about 21.5 mm. Modeling process carried out included design and analysis of domestic water boiler made of composite material. The composite material used is woven roving glass fiber and resin. The study focuses on temperature distribution and heat transfer through the boiler's wall between the inner and outer sides. Glass fiber was chosen due to its significant advantages such as good insulating properties, resistance to chemical attack, stiffness, and inertness. Figures 3 a, and 3 b, show modeling of new design of water boiler made of composite material and its cross-section.



(a) (b)

Figure 2. (a) Ordinary metallic boiler, (b) Vertical cross-section showing the inner part of metallic water boiler



(a) (b)

Figure 3. (a) Modeling of new design, (b) Vertical cross-section showing the inner part of composite water boiler

It should be noted that the boundary condition is set to be conformal to the real case and the operating condition tuned to be as follows:

1- The inner tank sides was maintained to be at the water temperature of 80 c°.
2- The outer surface is set to be fully exposed to the air cooling by convection. The ambient stationary air temperature is 25 c°.

results

A number of eight cases have been studied in order to find an optimum case for boiler design using composite material. Modeling process hase been carried out through eight steps over boiler's wall thickness. Analysis process is repeated with an increment of 2mm in thickness. Analysis starts with 1mm thickness and ended with 15mm.

Results obtained can be illustrated in different forms. ANSYS has the capability to plot results graphically in form of contours and other options. The direction of heat flux across the boiler thickness is prescribed as shown in figure 4.

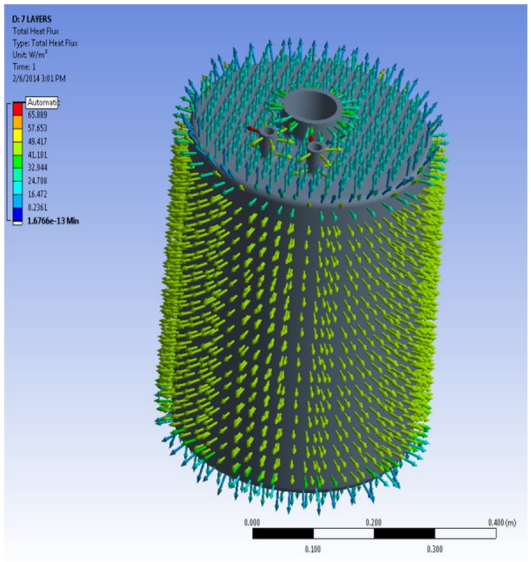


Figure 4. Direction of heat flux across the boiler thickness

Recorded results for the eight cases of heat transfer analysis between the internal and external side of water boiler is summarized in Table 1. It is observed that as wall thickness increases, outside wall temperature decreases. It is found that the temperature of the external side of water boiler made of composite material becomes within the range of ambient temperature at a thickness of 9 mm. The temperature of outside wall becomes almost close to ambient temperature at 15 layers of composite materials (15 mm).

TABLE I. HEAT TRANSFER THROUGH BOILER'S WALL THICKNESS

Thickness (mm)	No. of layers	Inside wall temp. c°	Outside wall temp c°	Ambient temp. c°
1	1	80	60.797	25
3	3	80	43.614	25
5	5	80	35.242	25
7	7	80	30.943	25
9	9	80	28.832	25
11	11	80	27.392	25
13	13	80	26.344	25
15	15	80	25.55	25

The new design of water boiler made of composite materials hase been studied carefully, and the temperature distribution over the boiler wall thickness. Results obtained have been recorded at each stage. Some of these results are given in form of temperature contours as shown in figures 5 and 6, for wall thickness of 7mm, and 13mm respectively.

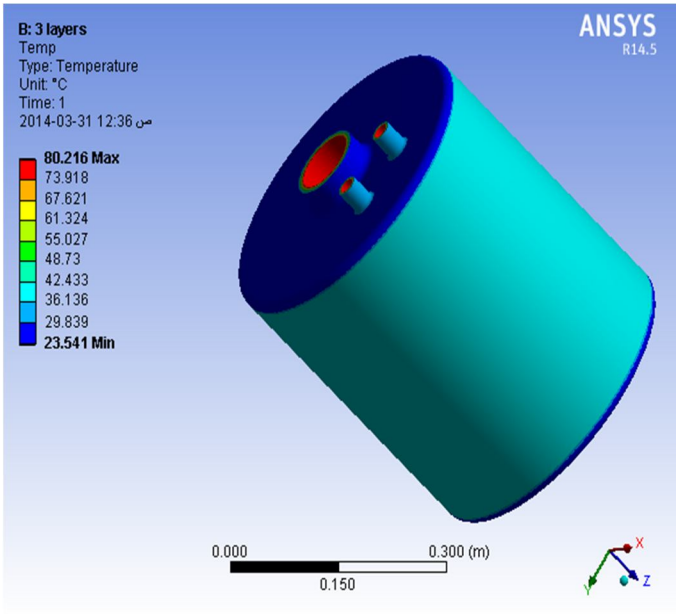


Figure 5. Temperature distribution at a wall thickness of 3mm

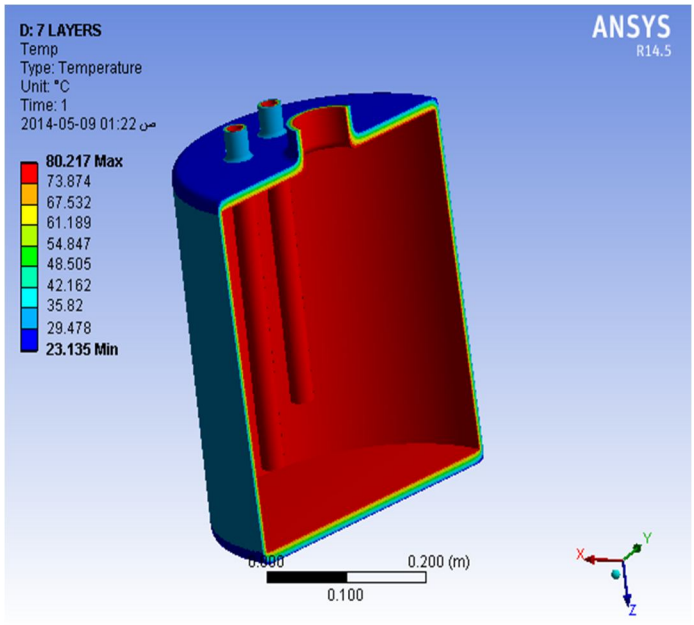


Figure 6. Temperature distribution at a wall thickness of 7mm

In the above results, figure 7 shows the effect of increasing wall thickness on temperature distribution. And it illustrated clearly the dramaticall decrease of outside temperature of boiler's wall thickness. It also obviously shows that the external wall temperature becomes close to ambient air temperature which is assumed to be 25 °C.

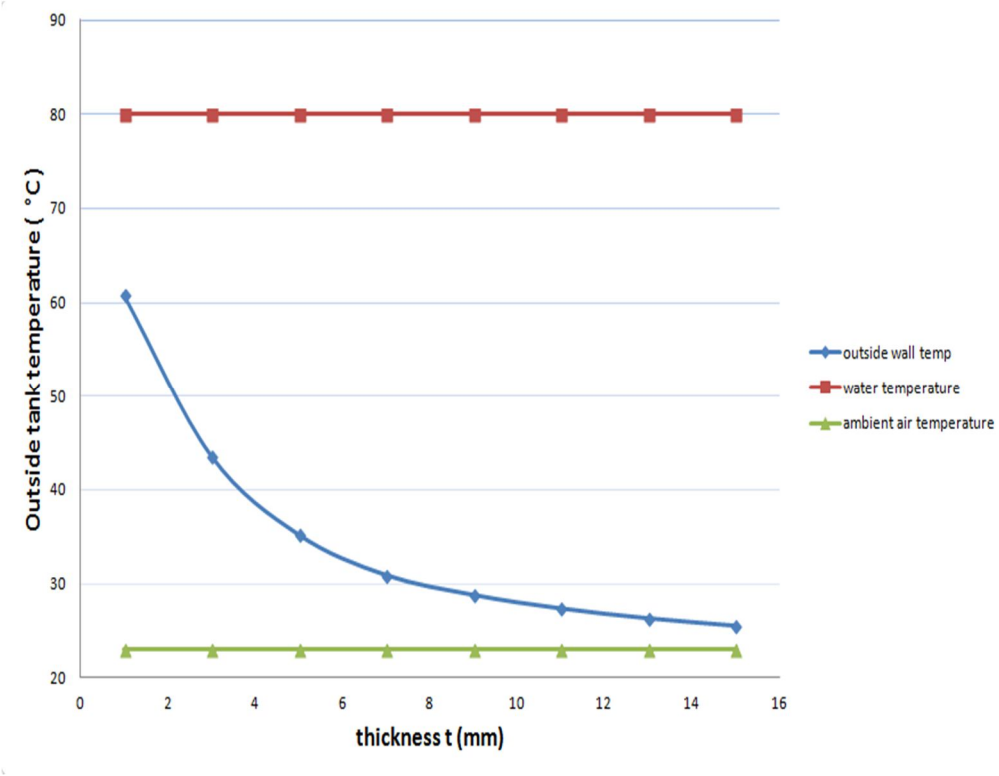


Figure 7. Temperature distribution over boiler's wall thickness

Conclusion:

This paper resents a solution to overcome problems highlighted due to using of metallic material for internal casing of water boiler. By using composite materials instead of metallic materials, corrosion problems and hazard of electrical shock are eliminated. In addition to that

new design of water boiler proves that it is much lighter than metallic boiler and it can last for longer life. Design and analysis process was performed successfully using computational approach. FEM exhibits high ability and power full technique to find an optimum shape and geometry of a new design. Replacing of metallic material with composite material (glass fiber) for domestic boiler is very convenient. Used metallic wall of 21.5 mm wall thickness, can be replaced with composite material (glass fiber/resin) wall thickness of 7 mm. A theoretical results matches thermal trend and response for the domestic boiler design. Type of material and its thickness are highly affecting heat transfer rate between inner and outer side of water boiler. Increasing of boiler thickness leads to thermal damping and lower the outside surface temperature of new designed boiler. In addition to that, as it was expected, heat flux flows out sinks and temperature gradient across wall thickness satisfies design requirements.

Finally, it can be said that the main objectives of the current paper have been achieved. Overall results indicates clearly that composite materials have good and comparable mechanical and thermal properties better than metallic materials for water boiler design.

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