Sudan University of Science and Technology

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Department of Power

Design Thermal Storage For Cooling Unit

تصميم خزان حراري لوحدة تبريد

A project Submitted In Partial Fulfillment for the Requirements of the Degree of B.Eng (Honor) In Mechanical Engineering

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الاستهلال

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صدق الله العظيم

DEDICATION

To our parents

Who educated and enabled us to reach this level

To our families

Who supported us

To people who paved our way of science and knowledge

To all colleagues and friends

ACKNOWLEDGEMENT

This research would not have been possible without Allah then the help of many people. First of all, we would like to deeply thank our supervisor Dr.Tag alser Hasan Hassan, he improved our experience, knowledge and skills. We have to say that we have been lucky to work with hem, we wish hem all the best. Also engineer Hassan yahya,who presented helping hand to us. Also, we have to thank Department of mechanical engineering that supported us in this work. Lastly, Many thanks are should go to our colleagues in mechanical department.

These were the last words we wrote for our graduation project. We wish they would also be the best words, to acknowledge all who helped and supported us during this study.

ABSTRACT

The aim of this study work is to design and install a model of thermal storage work by principle of energy saving. Which to cover alack in cold water specially in crowded areas such as: university, schools and industrial areas.

The research methodology is designed and implemented by collecting of the research requirements and analyzing the existed data in the literature review (L.R.) , then designing and developing a thermal storage based on standard parameters affect in the energy saving mechanism, such as : the type tank 'material, variation in temperature of the ambient. In addition to that the consumption rate. It depends on the number of people in the area. To wate enough quantity of cold water and taking the factor of time.

finally Developing and installing of the final small thermal storage depending on the results of the produced, and determining what fraction of the energy required we can design a bigger thermal storage to decrease the cost, simplify the process, develop the performance and efficiency. We found out that the thermal storage system is very useful for users, cost effective due to availability of materials that build the system, also the system is very easy to install, operate and maintenance. In addition to save money and efforts.

المستخلص

الهدف من هذه الدراسة هو تصميم و تركيب خزان حراري يعمل بمبدأ حفظ الطاقة الحرارية و يخزن المياه الباردة بداخله،لتغطية النقص في مياه الشرب خاصة في الأماكن ذات الكثافة العالية كالجامعات و المدارس و المناطق الصناعية.

منهجية هذا البحث تقوم على أساس جمع البيانات من الدراسات السابقة و تحليل هذه البيانات. و على أساسها تم تصميم خزان حراري(بسعة 250 لتر) و دراسة بعض العوامل المهمة في عملية تخزين الطاقة الحرارية كنوع مادة الخزان المستخدمة و تفاوت درجات حرارة المحيط،بالاضافة الى ذلك معدل الاستهلاك الذي بدوره يعتمد على عدد الناس في المنطقة المقرر فيها التصميم. للوصول الى توفير مياه باردة كافية ،مع الأخذ في الاعتبار عامل الزمن.

بعد أن أجريت هذه التجارب تم استخلاص نتائجها لتطوير و تصميم خزان حراري بحجم اكبر، وذلك لتقليل التكلفة و تبسيط العملية و تحسين الأداء و الكفاءة.

تم التوصل إلى أن الخزان الحراري مفيد جداً للمستخدمين، و ذو تكلفة إنشائية منخفضة نظراً لتوفر المواد المطلوبة لتصنيعه ، و تكلفة تشغيلية منخفضة جدا(تقليل استهلاك الكهرباء)، بالإضافة إلى أن هذا النظام سهل التركيب و التشغيل و الصيانة و من ناحية أخرى فإنّه موفّر والجهد والمال.

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LIST OF ABBREVIATIONS

ICSP	In Circuit Serial Programming.
ES	Energy Storage.
PCM	Phase Changeable Material.
POE	Power Of Ethernet.
PWM	Pulse Width Modulation.
RISC	Reduce Instruction set computer.
ROM	Read Only Memory.
SPI	Serial peripheral interface.
SSME	Space Shuttle Main Engine.
TES	Thermal Energy Storage.

Nomenclature

A	area (m2)
C	specific heat (J/g K)
D	outlet diameter (m)
d	inlet diameter (m)
E	energy (J)
Ex	exergy (J)
h	specific enthalpy (J/kg); vector of hidden-layer neurons
h_e	latent heat of water (kJ/kg)
K	thermal conductivity (W/m K)
L	length (m)
M	mass of energy storage material (kg)
m	mass (kg)
n	data number
S	specific entropy (J/kg K)
T	temperature (℃)
t	time (s)
U	overall heat transfer coefficient (W/m2 K); velocity (m/s)
u	specific internal energy (J/kg)
v	velocity (m/s)
V	volume (m3)

CHAPTER ONE

INTRODUCTION

1.1 General Overview

One of the main problem these days in service residence and industrial and commercial organization is unavailable suitable water for drinking consciously ,that is obviously in educational organization .Although there are a lot of coolers there but it doesn't cover the need of drinking water .

Thermal energy storage (TES) is an advanced energy technology that is attracting increasing interest for thermal applications such as space and water heating, cooling, and air conditioning. TES systems have enormous potential to facilitate more effective use of thermal equipment and large-scale energy substitutions that are economic.

Thermal energy storage (TES) is one of the key technologies for energy conservation, and therefore, it is of great practical importance. One of its main advantages is that it is best suited for heating and cooling thermal applications. TES is perhaps as old as civilization itself. Since recorded time, people have harvested ice and stored it for later use. Large TES systems have been employed in more recent history for numerous applications, ranging from solar hot water storage to building air conditioning systems. The TES technology has only recently been developed to a point where it can have a significant impact on modern technology.

In general, a coordinated set of actions has to be taken in several sectors of the energy system for the maximum potential benefits of thermal storage to be realized. TES appears to be an important solution to correcting the mismatch between the supply and demand of energy. TES can contribute significantly to meeting society's needs for more efficient, environmentally benign energy use. TES is a key component of many successful thermal systems, and a good TES should allow little thermal losses, leading to energy savings, while permitting the highest reasonable extraction efficiency of the stored thermal energy. [1]

1.2 Project background

A lot of natural coolers are banded in previous years. People used it for drinking, but actually these coolers faced problems such as :

Environmental problems, it's clear that due to the changeable climate (temperature, air,ect).Also another problems uncomfortable water for drinking, also wastage in water when someone drinks, in addition to all that discharge still the big problem .

Mechanical coolers may be represent the solution ,but that in one case that if it use to feed specific number of people for example the teachers in school.

Also there are problems one of it is obviously the compressor needs big power to operate and we know it represents the heart of the cooler .So if there is electricity will operate, also the size of its storage so small that means it's difficult to cover huge number of people such as a students in the school.

It is clear that there is great scope to increase the production of cold water every kind of coolers has advantages and disadvantages. So it's good idea to take advantage from any cooler and create dihybrid cooler between natural cooler and mechanical cooler .By this way we can keep high energy from mechanical one and we can benefited from free energy from a natural cooler. But this idea is not considered as perfect idea in crowded places.

Instead of all that we can use the concept of energy storage for this propose. It represented in Thermal Energy Storage. This idea adopts on principle of storing the energy and uses it in later time. So if we connect between the cooler and thermal storage it will be great idea to cover the needing of suitable drinkable water quantity.

1.3 Problem Statement

In the crowded organizations like universities, commercial and residence organizations actually there is a lack of available cold water .Although these organizations pay high money but obviously it's still a big problem specifically in the summer .Also there is not enough suitable water even .It's clearly that in SUST there is much coolers but it don't cover the need due to the hugh number of students. The consumption is high on these coolers, so after few hours these cooler will stop cooling the water and the students drink the water of the source without cooling.

1.4 Project objectives

The aim of this project is to design thermal energy storage and control system for cooling unit .But the specific objectives are summarized in :

- To store cold water during the night.
- Increasing the flow rate of cold water by storing it during the night.
- To save the electrical energy by using cooler and thermal storage of cold water.

1.5 Project Significance

These days the energy represents important factor in the life, by the thermal storage the electrical energy can be saved and decrease the cost of it.

1.6 project scoop

Design thermal storage for cold water, and the mechanism of its control. In addition to that heat transfer process.

1.7 project layout

This research is divided into five chapters. Chapter 1 addresses the general background, declaration of the problem statement and discussion of the objectives. Chapter 2 presents the literature survey; with focus on TES, insulations, cooling and control and its process, technologies and application. This chapter also reviews the previously published works of researchers related to this study. Chapter 3 explains the methodology by detailing the experimental procedure and instrumentation used. Chapter 4 is showing the results obtained from the experimental work followed by discussion and analysis of the findings and comparing them with the existing results included in the literature. Chapter 5 is the Conclusion. It contains the theoretical and practical contribution of this research, followed by recommendations for future study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Literature review presents the critical past works related to this research work sorted out from international journals publications, conferences publications, reports and books. It provides an insight understanding about related issues on project topic. The review also reveals the limitations encountered in the research area which is related to the energy storage, insulations and cooling processes and its types in Sudan also covers control process.

This chapter presents a detailed literature review with aim to present a general overview of the thermal energy storage (TES) and its applications, natural and mechanical cooling. It also includes a detailed review of the control application.

2.2 Energy Storage Systems

Energy storage (ES) has only recently been developed to a point where it can have a significant impact on modern technology. In particular, ES is critically important to the success of any intermittent energy source in meeting demand. For example, the need for storage for solar energy applications is severe, especially when solar energy is least available, namely, in winter. ES systems can contribute significantly to meeting society's needs for more efficient, environmentally benign energy use in building heating and cooling, aerospace power, and utility applications.

The use of ES systems often results in such significant benefits as:

• Reduced energy costs.

• Reduced energy consumption.

• Improved indoor air quality.

• Increased flexibility of operation.
• Reduced initial and maintenance costs.

• Reduced equipment size.

• More efficient and effective utilization of equipment.

ES systems have an enormous potential to increase the effectiveness of energy-conversion equipment use and for facilitating large-scale fuel substitutions in the world's economy. ES is complex and cannot be evaluated properly without a detailed understanding of energy supplies and end-use considerations. In general, a coordinated set of actions is needed in several sectors of the energy system for the maximum potential benefits of ES to be realized. ES performance criteria can help in determining whether prospective advanced systems have performance characteristics that make them useful and attractive and, therefore, worth pursuing through the advanced development and demonstration stages. The merits of potential ES systems need to be measured, however, in terms of the conditions that are expected to exist after research and development is completed. Care should be taken not to apply too narrow a range of forecasts to those conditions. Care also should be taken to evaluate specific storage system concepts in terms that account for their full potential impact.

The versatility of some ES technologies in a number of application areas should be accounted for in such assessments. Today's industrial civilizations are based upon abundant and reliable supplies of energy. To be useful, raw energy forms must be converted to energy currencies, commonly through heat release. For example, steam, which is widely used for heating in industrial processes, is normally obtained by converting fuel energies to heat and transferring the heat to water. Electricity, increasingly favored as a power source, is generated predominately with steam-driven turbo generators, fueled by fossil or nuclear energy. Power demands, in general, whether thermal or electrical, are not steady. Moreover, some thermal and electrical energy sources, such as solar energy, are not steady in supply. In cases where either supply or demand is highly variable, reliable power availability has in the past generally required energy conversion systems to be large enough to supply the peak-demand requirements. The results are high and partially inefficient capital investments, since the systems operate at less than full capacity much of the time. Alternatively, capital investments can sometimes be reduced if load-management techniques are employed to smooth power demands, or if ES systems are used to permit the use of smaller power-generating systems. The smaller systems operate at or near peak capacity, irrespective of the instantaneous demand for power, by storing the excess converted energy during reduced-demand periods for subsequent use in meeting peak-demand requirements. Although some energy is generally lost in the storage process, ES often permits fuel conservation by utilizing more plentiful but less flexible fuels such as coal and uranium in applications now requiring relatively scarcer oil and natural gas. In some cases, ES systems enable the waste heat accompanying conversion processes to be used for secondary purposes. The opportunities for ES are not confined to industries and utilities. Storage at the point of energy consumption, as in residences and commercial buildings, will likely be essential to the future use of solar heating and cooling systems, and may prove important in lessening the peak-demand loads imposed by conventional electrical, space-conditioning systems. In the personal transportation sector, now dominated by gasoline-powered vehicles, adequate electrical storage systems might encourage the use of large numbers of electric vehicles, reducing the demand for petroleum.

The concept of ES using flywheels is not new. The ability of flywheels to smooth intermittent power impulses was recognized shortly after the invention of reciprocating engines in the 18^{th} century. Special purpose locomotives have been operated with stored, externally supplied steam for about 100 years. Electric cars were early automobile competitors.

The marked increases in fuel costs in recent years, the increasing difficulty in acquiring the large amounts of capital required for power-generation expansions, and the emergence of new storage technologies has led to a recent resurgence of interest in the possibilities for ES systems. To the energy supplier, energy is a commodity whose value is determined by the cost of production and the marketplace demand. For the energy consumer, the value of energy is in its contribution to the production of goods and services or to personal comfort and convenience. Although discussions abound about the merits of alternative national energy production and consumption patterns in the future, it is likely that energy decisions, in general, will continue to be made based on evaluations of the costs of alternative means to attain these needs. In particular, decisions on whether to use ES systems will likely be made on the basis of prospective cost savings in the production or use of energy, unless legislative or regulatory constraints are imposed. Thus, among criteria necessary for the commercialization of ES systems, potential economic viability is a major consideration. [2]

2.2.1 Energy storage method

- Mechanical energy storage.
- Chemical energy storage.
- Thermal energy storage.
- Magnetic Energy Method.

- Biological Energy Method.

2.2.2 Thermal energy storage (TES)

Thermal energy may be stored by elevating or lowering the temperature of a substance (i.e., altering its sensible heat), by changing the phase of a substance (i.e., altering its latent heat) or through a combination of the two. Both TES forms are expected to see extended applications as new energy technologies are developed. TES is the temporary storage of high- or low-temperature energy for later use. Examples of TES are the storage of solar energy for overnight heating, of summer heat for winter use, of winter ice for space cooling in summer, and of the heat or cool generated electrically during off-peak hours for use during subsequent peak demand hours. Solar energy, unlike fossil fuels, is not available at all times. Even cooling loads, which nearly coincide with maximum levels of solar radiation, are often present after sunset. TES can be an important means of offsetting the mismatch between thermal energy availability and demand.

Energy demands in the commercial, industrial, utility, and residential sectors vary on a daily, weekly, and seasonal basis. The use of TES in such varied sectors requires that the various TES systems operate synergistically and that they be carefully matched to each specific application.

The use of TES for such thermal applications as space heating, hot water heating, cooling, air conditioning, and so on has recently received much attention. A variety of new TES techniques has been developed over the past four or five decades in industrial countries. TES systems have enormous potential for making the use of thermal equipment more effective and for facilitating large-scale substitutions of energy resources economically. In general, a coordinated set of actions is needed in several sectors of the energy system for the maximum potential benefits of thermal and other types of ES to be realized.

Sensible heat changes in a material are dependent on its specific heat capacity and the temperature change. Latent heat changes are the heat interactions associated with a phase change of a material and occur at a constant temperature. Sensible heat storage systems commonly use rocks or water as the storage medium. Latent heat storage systems can utilize a variety of phase change materials, and usually store heat as the material changes from a solid to a liquid phase.

As an advanced energy technology, TES has attracted increasing interest for thermal applications such as space heating, hot water, cooling, and air-conditioning. TES systems have the potential for increasing the effective use of thermal energy equipment and for facilitating large-scale fuel switching. Of most significance, TES is useful for addressing the mismatch between the supply and demand of energy. There are mainly two types of TES systems, sensible (e.g., water and rock) and latent (e.g., water/ice and salt hydrates). The selection of a TES system mainly depends on the storage period required, for example, diurnal or seasonal, economic viability, operating conditions, and so on. Many research and development activities on energy have concentrated on efficient energy use and energy conservation, and TES appears to be one of the more attractive thermal technologies that has been developed.

TES is basically the temporary “holding” of energy for later use. The temperature at which the energy is held in part determines the potential application. Examples of TES systems are storage of solar energy for night and weekend use, of summer heat for winter space heating, and of ice from winter for space cooling in summer. In addition, the heat or cool generated electrically during off-peak hours can be used during subsequent peak demand hours. Solar energy, unlike energy from fossil, nuclear, and some other fuels, is not available at all times. Even cooling loads, which coincide somewhat with maximum levels of solar radiation but lag by a time period, are often present after sunset. TES can provide an important mechanism to offset this mismatch between times of energy availability and demand.

As an example of the cost savings and increased efficiency achievable through the use of TES, consider the following case. In some climates, it is necessary to provide heating in winter and cooling in summer. Typically, these services are provided by using energy to drive heaters and air-conditioners. With TES, it is possible to store heat from the warm summer months for use in winter, while the cold ambient temperatures of winter can charge a cool store and subsequently provide cooling in summer. This is an example of seasonal storage, which can be used to help meet the energy needs caused by seasonal fluctuations in temperature. Obviously, such a scheme requires a great deal of storage capacity because of the large storage timescales. The same principle can be applied on a smaller scale to smooth out daily temperature variations. For instance, solar energy can be used to heat tiles on a floor during the day. At night, as the ambient temperature falls, the tiles release their stored heat to slow the temperature drop in the room. Another example of a TES application is the use of thermal storage to take advantage of off-peak electricity tariffs. Chiller units can be run at night when the cost of electricity is relatively low. These units are used to cool a thermal storage, which then provides cooling for air-conditioning throughout the day. Not only are electricity costs reduced, but the efficiency of the chiller is increased because of the lower night-time ambient temperatures, and the peak electricity demand is reduced for electrical-supply utilities. [1]

2.2.3 TES methods

TES deals with the storage of energy by cooling, heating, melting, solidifying, or vaporizing a material; the thermal energy becomes available when the process is reversed.

Storage by causing a material to raise or lower in temperature is called sensible heat its effectiveness depends on the specific heat of the storage material and, if volume is important, on its density. Storage by phase change (the transition from solid to liquid or from liquid to vapor with no change in temperature) is a mode of TES known as latent heat storage. Sensible storage systems commonly use rocks, ground, or water as the storage medium, and the thermal energy is stored by increasing the storage-medium temperature. Latent heat storage systems store energy in phase change materials (PCMs), with the thermal energy stored when the material changes phase, usually from a solid to a liquid. The specific heat of solidification/fusion or vaporization and the temperature at which the phase change occurs are of design importance. Both sensible and latent TES also may occur in the same storage material. In this chapter, TES is considered to include the storage of heat through the reversible scission or reforming of chemical bonds.

PCMs are either packaged in specialized containers such as tubes, shallow panels, plastic bags, and so on, or contained in conventional building elements (e.g., wall board and ceiling) or encapsulated as self-contained elements.

The oldest form of TES probably involves harvesting ice from lakes and rivers and storing it in well-insulated warehouses for use throughout the year for almost all tasks that mechanical refrigeration satisfies today, including preserving food, cooling drinks, and air-conditioning. The Hungarian parliament building in Budapest is still air-conditioned, with ice harvested from Lake Balaton in the winter. [3]

2.2.4 Thermal energy quantity

Thermal energy quantities differ in temperature. As the temperature of a substance increases, the energy content also increases. The energy required E to heat a volume V of a substance from a temperature T_1 to a temperature T_2 is given by:

$$E = mc(T_{2} - T_1)$$
$$= \rho vc(T_{2} - T_1)$$

where c is the specific heat of the substance. A given amount of energy may heat the same weight or volume of other substances, and increase the temperature to a value greater or lower than T_2.

The value of c may vary from about 1 kcal/kg ◦C for water to 0.0001 kcal/kg ◦C for some materials at very low temperatures.

The energy released by a material as its temperature is reduced, or absorbed by a material as its temperature is increased, is called the sensible heat.

Latent heat is associated with the changes of state or phase change of a material. For example, energy is required to convert ice to water, to change water to steam, and to melt paraffin wax. The energy required to cause these changes is called the heat of fusion at the melting point and the heat of vaporization at the boiling point. To illustrate, let us consider water, and suppose that we wish to evaporate 1 kg of ice by converting it to liquid and then heating it until it boils. In this case, 80 kcal is required to melt the ice at 0 ◦C to water at 0 ◦C; then, about 100 kcal is needed to raise the temperature of the water to l00 ◦C; finally, 540 kcal is needed to boil the water, giving a total energy need of 720 kcal. The sensible heat for a given temperature change varies from one material to another. The latent heat also varies significantly between different substances for a given type of phase change. [4]

It is relatively straightforward to determine the value of the sensible heat for solids and liquids, but the situation is more complicated for gases. If a gas restricted to a certain volume is heated, both the temperature and the pressure increases. The specific heat observed in this case is called the specific heat at constant volume, C_V. If, instead the volume is allowed to vary and the pressure is fixed, the specific heat at constant pressure, C_P. , is obtained. The ratio $C_P./C_V.$ and the fraction of the heat produced during compression can be saved, significantly affecting the storage efficiency. [5]

2.2.5 Basic principle of TES

The basic principle is the same in all TES applications. Energy is supplied to a storage system for removal and use at a later time. What mainly varies is the scale of the storage and the storage method used. Seasonal storage requires immense storage capacity. One seasonal TES method involves storing heat in underground aquifers. Another suggested method is circulating warmed air into underground caverns packed with solids to store sensible heat. The domestic version of this concept is storing heat in hot rocks in a cellar. At the opposite end of the storage-duration spectrum is the storage of heat on an hourly or daily basis. The previously mentioned use of tiles to store solar radiation is a typical example, which is often applied in passive solar design. Charging (left), storing (middle), and discharging (right). Here the heat Q_1 is infiltrating and is positive in value for a cold thermal storage.

If it is released, it will be toward the surroundings and Q_1 will be negative. The heat flow is illustrated for the storing process, but can occur in all three processes while the specific heat of water is not as high as that for many solids, it has the advantage of being a liquid that can easily be pumped to transport thermal energy. Being a liquid, water also allows good heat-transfer rates. Solids have the advantage of higher specific heat capacities, which allow for more compact storage units. When higher temperatures are involved, such as for preheating furnace air supplies, solids become the preferred sensible heat stores. Usually refractoriness are then used as the storage material. If the storage medium needs to be pumped, liquid metals are often used.

TES using latent heat changes has received a great deal of attention. The most common example of latent heat storage is the conversion of water to ice. Cooling systems incorporating ice storage have a distinct size advantage over equivalent-capacity chilled-water units because of the relatively large amount of energy that is stored through the phase change. Size is the major advantage of latent heat thermal storage. NASA has considered using lithium fluoride salts to store heat in the zero-gravity environment of the space shuttle. Another interesting development is the use of PSMs in wall paneling. These panels incorporate compounds that undergo solid-to-solid structural phase changes. With the appropriate choice of material, phase change occurs at ambient temperature.

Then, these materials, when incorporated into the panels, act as high-density heat sinks/sources that resist changes in ambient room temperature.

The other category of storing heat is through the use of reversible endothermic chemical reactions, and in some literature this method is considered TES. In this method, the reactions involve the breaking and forming of chemical bonds; so, a great deal of energy can be stored per unit mass of storage material. Although not currently viable, a variety of reactions are being explored.

These include catalytic reactions such as the steam reforming reaction with methane and the decomposition of sulfur trioxide, and thermal dissociation reactions involving metal oxides and metal hydrides. These reactions are expected to be useful in high-temperature nuclear cycles and solar-energy systems, and as topping cycles for industrial boilers. At present, lower temperature reactions (<300 ◦C) have not proven promising. TES can be an effective way of reducing costs and increasing efficiency. While effective thermo chemical storage is still some way off, latent and sensible heat storage are already well established. In these cases, TES has the potential to produce significant benefits, particularly for low-temperature heating and cooling applications.

These benefits should allow TES to gain wider acceptance. [6]

2.2.6 Topic of investigation

TES systems combined with heating, cooling, and air-conditioning applications have attracted much interest in recent years. Many related studies have been carried out in a variety of countries, particularly in the United States, Europe, and Japan. These studies address technical issues arising from new TES concepts and the improvements required in the performance of existing TES systems. Studies have also investigated the design of compact TES systems and the use of TES in solar applications.

TES research and development has been broad based and productive, and directed toward both the resolution of specific TES issues and the potential for new TES systems and storage materials. The following discussions summarize many investigations and indicate the scope of TES studies.

During the past few decades, many articles have appeared in the literature reporting investigations of TES systems and their applications (especially with solar energy), field performance characteristics and evaluations, design fundamentals, transient behavior and thermal analyses, and system and process optimization. In addition, theoretical, experimental, and numerical studies have been undertaken on the thermo physical properties of new TES materials, TES selection criteria, the integration of TES systems into solar power plants, and the economics and environmental effects of TES. Some details on these studies are given below:

• For sensible heat storage, the performance and thermal characteristics of packed-bed storage systems, the use of different storage materials, and uses for aquifer TES, water TES, and solar ponds have been investigated, as have operating conditions, effectiveness's, economics, and so on, for these systems.

• Thermal analyses of PCMs and their use for energy conservation in buildings have been carried out. Experimental and theoretical investigations and performance evaluations of the PCMs in latent heat storage applications have also been undertaken.

• Aspects of TES systems and materials during operation have been studied, including heat and mass transfer, and transient behavior, and second-law optimization and performance.

• Many practical applications of solar heating using TES have also been reported.

• Numerous investigations have considered specific TES systems and applications, as well as the general objectives of TES and the energy conservation, and related benefits of different TES methods. [7]

2.2.7 Benefits of TES

Although TES is used in a wide variety of applications, all are designed to operate on a cyclical basis (usually daily, occasionally, and seasonally). The systems achieve benefits by fulfilling one or more of the following purposes:

• Increase generation capacity. Demand for heating, cooling, or power is seldom constant over time, and the excess generation available during low-demand periods can be used to charge a TES in order to increase the effective generation capacity during high-demand periods. This process allows a smaller production unit to be installed (or to add capacity without purchasing additional units), and results in a higher load factor for the units.

• Enable better operation of cogeneration plants. Combined heat and power, or cogeneration, plants are generally operated to meet the demands of the connected thermal load, which often results in excess electrical generation during periods of low electricity use. By incorporating TES, the plant need not be operated to follow a load. Rather, it can be dispatched in more advantageous ways (within some constraints).

• Shift energy purchases to low-cost periods. This measure constitutes the demand-side application of the first purpose listed, and allows energy consumers subject to time-of-day pricing to shift energy purchases from high- to low-cost periods.

• Increase system reliability. Any form of energy storage, from the uninterruptable power supply of a small personal computer to a large pumped storage project, normally increases system reliability.

• Integration with other functions. In applications where on-site water storage is needed for fire protection, it may be feasible to incorporate thermal storage into a common storage tank.

Likewise, equipment designed to solve power-quality problems may be adaptable to energy storage purposes.

The most significant benefit of a TES system is reducing electric bills by using off-peak electricity to produce and store energy for daytime cooling. Indeed, TES is successfully operating in offices, hospitals, schools, universities, airports, and other facilities in many countries, shifting energy consumption from periods of peak electricity rates to periods of lower rates.

This benefit is accompanied by the additional advantage of lower demand charges. [8]

2.2.8 Criteria for TES Evaluation

There are numerous criteria to evaluate TES systems and applications such as technical, environmental, economic, energetic, sizing, feasibility, integration, and storage duration. Each of these criteria should be considered carefully to ensure successful TES implementation.

Technical Criteria for TES Independent technical criteria for storage systems are difficult to establish, since they are usually case specific and are closely related to and generally affected by the economics of the resultant systems. Nevertheless, certain technical criteria are desirable, although appropriate trade-offs must be made with such other criteria as:

- Storage capacity.
- Life time.
- Size.
- Cost.
- Resources use.
- Efficiency.
- Commercial viability.
- Safety.
- Installation.
- Environmental standards.

Before proceeding with a project, a TES designer should possess or obtain technical information on TES such as the types of storage appropriate for the application, the amount of storage required, the effect of storage on system performance, reliability and cost, and the storage systems or designs available.

TES is difficult to employ at sites that have severe space restrictions. Also, TES tanks often have significant first capital costs. Financial analysis for TES-based projects can be complex, although most consulting energy engineers are now capable of performing financial calculations and evaluating TES benefits. [9]

2.2.9 TES Heating and Cooling Applications

The use of TES systems for thermal applications such as heating and cooling has recently received much attention. In various energy sectors, the potential benefits of TES for heating and cooling applications have been fully realized. In the following two subsections, we describe heating TES and cooling TES in detail.

2.2.9.1 Cooling TES

Cooling TES can reduce cooling energy costs while maintaining a comfortable environment. Summer air-conditioning bills have two components: an electric demand charge and an electric usage charge. The usage and demand charges are often further divided into peak and off-peak periods.

The peak operating period of electric air-conditioning systems normally occurs during the high-cost demand and usage periods (i.e., the summer afternoon). TES systems are designed to shift the peak operating period of electric air-conditioning systems to the less expensive night periods.

Air-conditioning systems cool by removing heat via a chilled-water network or directly from an air stream. Most air-conditioning systems produce a cooling effect precisely when cooling is needed in a building or room. Cool TES-based air-conditioning systems operate similarly, but remove heat from an intermediate substance when the building does not need cooling, producing a cool reservoir that is stored until there is a need for cooling.The intermediate substance is normally water, ice, or eutectic salt solutions.

The most popular thermal storage medium is ice. The conversion of 1 kg of water to ice at 0 ◦C requires the removal of 152 kJ of heat. Similarly, adding 152 kJ of heat to the ice causes water at 0 ◦C to be formed. Ice TES operates in this fashion. At night, heat is removed from water to produce ice (i.e., charging of the storage occurs). During the day when the building requires cooling, heat is removed from the building and added to the ice (i.e., discharge occurs). The melted ice is reused during the next charging period. The advantage of this cooling scheme is that the main electrically driven device in cooling systems, namely, the compressor motor, is operated during low-electrical cost periods.

The previous example illustrates one design possibility. In another common design, the compression system operates for the whole day to provide stored cooling at night and to partially meet the cooling load during the day. This design usually requires the least investment.

Many cooling TES systems use chilled-water systems to transfer the cooling capacity from the storage to the building air-distribution system. Although chilled-water distribution systems are usually confined to large buildings with conventional air-conditioning, chilled water distribution systems with TES are now being designed for smaller buildings.

Cooling TES systems are generally advantageous for a new facility that has large daytime cooling loads and little or no cooling load at night. For retrofit situations, cooling TES is usually difficult to justify unless the cooling system is being replaced because of old age or inadequate capacity.

TES can be a beneficial component of the refrigeration-based cooling technologies. TES can significantly reduce the size of a refrigeration system and its electrical use during peak demand periods. TES is typically employed at power plants that mainly meet peak loads or that have significantly differing revenue structures for off-peak versus peak power.

For example, if a peaking gas turbine operates only 4 h per day, it usually does not make much sense to build a refrigeration plant that also operates at full load for only 4 h per day. This is because cooling capacity, unlike electricity, can be easily stored. It is usually more sensible to size the refrigeration system to meet about 20% of the peak cooling load and, slowly, to make and store cooling capacity during other periods so that it can be discharged during peak conditions. [10]

2.3 Definition of insulation

Insulations are defined as those materials or combinations of materials which retard the flow of heat energy by performing one or more of the following functions:

1. Conserve energy by reducing heat loss or gain.
2. Control surface temperatures for personnel protection and comfort.
3. Facilitate temperature control of process.
4. Prevent vapor flow and water condensation on cold surfaces.
5. Increase operating efficiency of heating/ventilating/cooling, plumbing, steam, process and power systems found in commercial and industrial installations.
6. Prevent or reduce damage to equipment from exposure to fire or corrosive atmospheres.
7. Assist mechanical systems in meeting criteria in food and cosmetic plants.
8. Reduce emissions of pollutants to the atmosphere.

The temperature range within which the term "thermal insulation" will apply, is from (-75°C to 815°C). All applications below (-75°C) are termed "cryogenic", and those above 815°C are termed "refractory".

Thermal insulation is further divided into three general application temperature ranges as follows:

1. Low temperature thermal insulation.
2. Intermediate temperature thermal insulation.
3. High temperature thermal insulation.

2.3.1 General types and forms of insulation

Insulations will be discussed in this manual according to their generic types and forms. The type indicates composition (i.e. glass, plastic) and internal structure (i.e. cellular, fibrous). The form implies overall shape or application (i.e. board, blanket, pipe covering).

2.3.1.1Types

1. Fibrous Insulation - composed of small diameter fibers which finely divide the air space. The fibers may be perpendicular or parallel to the surface being insulated, and they may or may not be bonded together. Silica, rock wool, slag wool and alumina silica fibers are used. The most widely used insulations of this type are glass fiber and mineral wool. Glass fiber and mineral wool products usually have their fibers bonded together with organic binders that supply the limited structural integrity of the products.
2. Cellular Insulation - composed of small individual cells separated from each other. The cellular material may be glass or foamed plastic such as polystyrene (closed cell), poly isocyanurate and elastomeric.
3. Granular Insulation - composed of small nodules which may contain voids or hollow spaces. It is not considered a true cellular material since gas can be transferred between the individual spaces. This type may be produced as a

loose or pourable material, or combined with a binder and fibers or undergo a chemical reaction to make a rigid insulation. Examples of these insulations are calcium silicate, expanded vermiculite, prelate, cellulose, diatomaceous earth and expanded polystyrene.

2.3.1.2 FORMS

Insulations are produced in a variety of forms suitable for specific functions and applications. The combined form and type of insulation determine its proper method of installation. The forms most widely used are:

1. Rigid boards, blocks, sheets, and pre-formed shapes such as pipe insulation, curved segments, lagging etc.

Cellular, granular, and fibrous insulations are produced in these forms.

2. Flexible sheets and pre-formed shapes. Cellular and fibrous insulations are produced in these forms.
3. Flexible blankets. Fibrous insulations are produced in flexible blankets.
4. Cements (insulating and finishing). Produced from fibrous and granular insulations and cement, they may be of the hydraulic setting or air drying type.
5. Foams. Poured or froth foam used to fill irregular areas and voids. Spray used for flat surfaces. [10]

2.3.2 Properties of insulation

Not all properties are significant for all materials or applications. Therefore, many are not included in manufacturers' published literature or in the table of properties which follows this section. In some applications, however, omitted properties may assume extreme importance (i.e. when insulations must be compatible with chemically corrosive atmospheres.) If the property is significant for an application and the measure of that property cannot be found manufacturers' literature, effort should be made to obtain the information directly from the manufacturer, testing laboratory or insulation contractors association.

The following properties are referenced only according to their significance in meeting design criteria of specific applications. More detailed definitions of the properties themselves can be found in the Glossary.

2.3.2.1 Thermal properties of insulation

Thermal properties are the primary consideration in choosing insulations. Refer to the following glossary for definitions:

a. Temperature limits: Upper and lower temperatures within which the material must retain all its properties.

b. Thermal conductance "C": The time rate of steady state heat flow through a unit area of a material or construction induced by a unit temperature difference between the body surfaces.

c. Thermal conductivity "K": The time rate of steady state heat flow through a unit area of a homogeneous material induced by a unit temperature gradient in a direction perpendicular to that unit area.

d. Emissivity "E"**:** The emissivity of a material (usually written ε or e) is the relative ability of its surface to emit energy by radiation. It is the ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature.

e. Thermal resistance "R": Resistance of a material to the flow of heat.

f. Thermal transmittance "U": The overall conductance of heat flow through an "assembly".

2.3.2.2 Mechanical and chemical Thermal properties of insulation .

Properties other than thermal must be considered when choosing materials for specific applications. Among them are:

a. Alkalinity (pH) or acidity: Significant when moisture is present. Also insulation must not contribute to corrosion of the system.

b. Appearance: Important in exposed areas and for coding purposes.

c. Breaking load**:** In some installations the insulation material must "bridge" over a discontinuity in its support. This factor is however most significant as a measure of resistance to abuse during handling.

d. Capillarity: Must be considered when material may be in contact with liquids.

e. Chemical reaction**:** Potential fire hazards exist in areas where flammable chemicals are present. Corrosion resistance must also be considered.

f. Chemical resistance**:** Significant when the atmosphere is salt or chemical laden and when pipe content leaks.

g. Coefficient of expansion and contraction: Enters into the design and spacing of expansion/contraction joints and/or use of multiple layer insulation applications.

h. Combustibility**:** One of the measures of a material's contribution to a fire hazard.

i. Compressive strength**:** Important if the insulation must support a load or withstand mechanical abuse without crushing. If, however, cushioning or filling in space is needed as in expansion/contraction joints, low compressive strength materials are specified.

j. Density**:** A material's density may affect other properties of that material, such as compressive strength. The weight of the insulated system must be known in order to design the proper support.

k. Dimensional stability**:** Significant when the material is exposed to temperature; expansion or shrinkage of the insulation may occur resulting in stress cracking , voids, sagging or slump.

l. Fire retardancy**:** Flame spread and smoke developed ratings are of vital importance; referred to as "surface burning characteristics".

m. Resistance to ultraviolet light**:** Significant if application is outdoors and high intensity indoors.

n. Resistance to fungal or bacterial growth**:** Is important in all insulation applications.

o. Shrinkage**:** Significant on applications involving cements and mastics.

p. Sound absorption coefficient**:** Must be considered when sound attenuation is required, as it is in radio stations, some hospital areas where decibel reduction is required.

q. Sound transmission loss value**:** Significant when constructing a sound barrier.

r. **Toxicity:** Must be considered in the selection of all insulating materials. [12]

2.4 Cooling

Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature. One of the most important applications of refrigeration has been the preservation of perishable food products by storing them at low temperatures. Refrigeration systems are also used extensively for providing thermal comfort to human beings by means of air conditioning. Air Conditioning refers to the treatment of air so as to simultaneously control its temperature, moisture content, cleanliness, odor and circulation, as required by occupants, a process, or products in the space. The subject of refrigeration and air conditioning has evolved out of human need for food and comfort, and its history dates back to centuries. The history of refrigeration is very interesting since every aspect of it, the availability of refrigerants, the prime movers and the developments in compressors and the methods of refrigeration all are a part of it. The French scientist Roger ThÝvenot has written an excellent book on the history of refrigeration throughout the world. Here we present only a brief history of the subject with special mention of the pioneers in the field and some important events. [11]

2.4.1 Natural Cooling

In olden days refrigeration was achieved by natural means such as the use of ice or evaporative cooling. In earlier times, ice was either:

1. Transported from colder regions,
2. Harvested in winter and stored in ice houses for summer use or,
3. Made during night by cooling of water by radiation to stratosphere.

In Europe, America and Iran a number of icehouses were built to store ice. Materials like sawdust or wood shavings were used as insulating materials in these icehouses. Later on, cork was used as insulating material. Literature reveals that ice has always been available to aristocracy who could afford it. In India, the Mogul emperors were very fond of ice during the harsh summer in Delhi and Agra, and it appears that the ice used to be made by nocturnal cooling.

In 1806, Frederic Tudor, (who was later called as the “ice king”) began the trade in ice by cutting it from the Hudson River and ponds of Massachusetts and exporting it to various countries including India. In India Tudor’s ice was cheaper than the locally manufactured ice by nocturnal cooling. The ice trade in North America was a flourishing business. Ice was transported to southern states of America in train compartments insulated by 0.3m of cork insulation. Trading in ice was also popular in several other countries such as Great Britain, Russia, Canada, Norway and France. In these countries ice was either transported from colder regions or was harvested in winter and stored in icehouses for use in summer. The ice trade reached its peak in 1872 when America alone exported 225000 tons of ice to various countries as far as China and Australia. However, with the advent of artificial refrigeration the ice trade gradually declined.

Pot-in-pot refrigerator, clay pot cooler or Zeer is an evaporative cooling refrigeration device which does not use electricity. It uses a porous outer earthenware pot, lined with wet sand, contains an inner pot (which can be glazed to prevent penetration by the liquid) within which the food is placed - the evaporation of the outer liquid draws heat from the inner pot. The device can be used to cool any substance. This simple technology requires only a flow of relatively dry air and a source of water.

Zeer is constructed by placing a clay pot within a larger clay pot with wet sand in between the pots and a wet cloth on top.

The device cools as the water evaporates, allowing refrigeration in hot, dry climate. It must be placed in a dry, ventilated space for the water to evaporate effectively towards the outside. Evaporative coolers tend to perform poorly or not at all in climates with high ambient humidity, since the water is not able to evaporate well under these conditions.

If there is an impermeable separation layer between the food and the porous pots, undrinkable water such as seawater can be used to drive the cooling process, without contaminating the food. This is useful in arid locations near the ocean where drinkable water is a limited commodity, and can be accomplished by using a pot that has waterproof glaze or cement applied to the inner wall where the food is stored.

Extended operation is possible if the pots are able to draw water from a storage container, such as an inverted airtight jar, or if the pots are placed in a shallow pool of water. A strap can be used to tie the inner pot down instead of using sand to prevent it from floating.

Finding a healthy cool drinking water in the public areas, in hot dry developing countries , is really great problem in Sudan, People uses the traditional “Zeer” , which Causes many health hazards , the greatest of which the spread of infectious diseases, as well as it subjection to dust, animal use, gas production and insets. A functional problem is the long time needed to cool water when the Zeer is evacuated. One other Problem is the real need to periodic Cleaning. The merit of its cheap price is denied by subjection to being broken.

The Natural Cooling System Unit, is an efficient means to solve all these problems. The main concept is innovation of Mr. Abdueliza Altayeb Hassan – Senior Lecturer in Sudan University Of Science And Technology. The Natural Water Cooling System Unit Was then strongly Adopted and developed By SECS.

Using Tabs in the new systems doesn’t involve entering people’s hands the matter diminishes the Health Hazards. The gradual replacement of drinking water guarantees moderately cool water most of the time. Although its initial cost is a bit high we have to consider that it doesn’t need maintenance.

The Unit has a rectangle shape. It is composed of two concentric rectangles of bricks providing 20-cm distance between them, where a galvanized pipe coil passes through. This coil is Surrounded by Cooling Medium (Crushed Bricked) .The Main concept is cooling water passing through the coil by cooling medium while the spilled water from outer tabs is keeping this medium always wet. Users get the cooled water using the outlet tabs. [12]

A circular model was developed by Dr. Yahia Hassan Hamid. Based on the difference of the wind directions in sudan states. In this model, the ordinary bricks are placed by perforated brick and the Galvanized pipe by a plastic pipe.

Thus, the unit should be constructed under a tree shade to protect it from the direct sun radiation. It will be more efficient if it is located in a green open space to let the air flow help in cooling the medium and the water. The spilled water from the model can be used to irrigate the surrounding green environment. [13]

2.4.2 Artificial Cooling (Mechanical Method)

Refrigeration as it is known these days is produced by artificial means. Though it is very difficult to make a clear demarcation between natural and artificial refrigeration, it is generally agreed that the history of artificial refrigeration began in the year 1755, when the Scottish professor William Cullen made the first refrigerating machine, which could produce a small quantity of ice in the laboratory. Based on the working principle, refrigeration systems can be classified as:

- Vapor compression systems.
- Vapor absorption systems.
- Gas cycle systems.

❖ Solar energy based refrigeration systems. [14]

2.5 Introduction to Control System

Control systems are an integral part of modern society. Numerous applications are all around us: The rockets fire, and the space shuttle lifts off to earth orbit; in splashing cooling water, a metallic part is automatically machined controlled systems; these systems also exist in nature. Within our own bodies are numerous control systems, such as the pancreas, which regulates our blood sugar. In time of "fight or flight," our adrenaline increases along with our heart rate, causing more oxygen to be delivered to our cells. Our eyes follow a moving object to keep it in view; our hands grasp the object and place it precisely at a predetermined location. Even the nonphysical world appears to be automatically regulated. Models have been suggested showing automatic control of student performance. The input to the model is the student's available study time, and the output is the grade. The model can be used to predict the time required for the grade to rise if a sudden increase in study time is available. Using this model, you can determine whether increased study is worth the effort during the last week of the term.; a self-guided vehicle delivering material to workstations in an aerospace assembly plant glides along the floor seeking its destination. These are just a few examples of the automatically controlled systems that we can create. We are not the only creators of automatically. [15]

2.5.1The Definition of Control System:

A control system consists of subsystems and processes (or plants assembled for the purpose of obtaining a desired output with desire performance, given a specified input. For example, consider an elevator. When the fourth-floor button is pressed on the first floor, the elevator rises to the fourth floor with a speed and floor-leveling accuracy designed for passenger comfort. The push of the fourth-floor button is an input that represents our desired output. The performance of the elevator can be seen from the elevator response curve in the figure. Two major measures of performance are apparent:

(1) The transient response.

(2) The steady-state error.

In our example, passenger comfort and passenger patience are dependent upon the transient response. If this response is too fast, passenger comfort is sacrificed; if too slow, passenger patience is sacrificed. The steady-state error is another important performance specification since passenger safety and convenience would be sacrificed if the elevator did not properly level. [15]

2.5.2 Advantages Of Control Systems

With control systems we can move large equipment with precision that would otherwise be impossible. We can point huge antennas toward the farthest reaches of the universe to pick up faint radio signals; controlling these antennas by hand would be impossible. Because of control systems, elevators carry us quickly to our destination, automatically stopping at the right floor. We alone could not provide the power required for the load and the speed; motors provide the power, and control systems regulate the position and speed. We build control systems for four primary reasons:

1. Power amplification.

2. Remote control.

3. Convenience of input from.

4. Compensation for disturbances.

For example, a radar antenna, positioned by the low-power rotation of a knob at the input, requires a large amount of power for its output rotation. A control system can produce the needed power amplification, or power gain Robots designed by control system principles can compensate for human disabilities. Control systems are also useful in remote or dangerous locations. For example, a remote-controlled robot arm can be used to pick up material in a radioactive environment. Control systems can also be used to provide convenience by changing the form of the input. For example, in a temperature control system, the input is a position on a thermostat. The output is heat. Thus, a convenient position input yields a desired thermal output. Another advantage of a control system is the ability to compensate for disturbances. Typically, we control such variables as temperature in thermal systems, position and velocity in mechanical systems, and voltage, current, or frequency in electrical systems. The system must be able to yield the correct output even with a disturbance. For example, consider an antenna system that points in a commanded direction. If wind forces the antenna from its commanded position, or if noise enters internally, the system must be able to detect the disturbance and correct the antenna's position. Obviously, the system's input will not change to make the correction. Consequently, the system itself must measure the amount that the disturbance has repositioned the antenna and then return the antenna to the position commanded by the input. [16]

2.5.3 A History of Control Systems

Feedback control systems are older than humanity. Numerous biological control systems were built into the earliest inhabitants of our planet. Let us now look at a brief history of human-designed control systems:

1. Liquid Level-Control

The Greeks began engineering feedback systems around 300 a c a water clock invented by Ktesibios operated by having water trickle into a measuring container at a constant rate. The level of water in the measuring container could be used to tell time. For water to trickle at a constant rate, the supply tank had to be kept at a constant level. This was accomplished using a float valve similar to the water-level control in today's flush toilets. Soon after Ktesibios, the idea of liquid-level control was applied to an oil lamp by Phenol of Byzantium. The lamp consisted of two oil containers configured vertically. The lower pan was open at the top and was the fuel supply for the flame. The closed upper bowl was the fuel reservoir for the pan below. The containers were interconnected by two capillary tubes and another tube, called a vertical riser, which was inserted into the oil in the lower pan just below the surface. As the oil burned, the base of the vertical riser was exposed to air, which forced oil in the reservoir above to flow through the capillary tubes and into the pan. The transfer of fuel from the upper reservoir to the pan stopped when the previous oil level in the pan was reestablished, thus blocking the air from entering the vertical riser. Hence, the system kept the liquid level in the lower container constant.

2. Steam Pressure and Temperature Controls

Regulation of steam pressure began around 1681 with Denis Papin's invention of the safety valve. The concept was further elaborated on by weighting the valve top. If the upward pressure from the boiler exceeded the weight, steam was released, and the pressure decreased. Kit did not exceed the weight, the valve did not open, and the pressure inside the boiler increased. Thus, the weight on the valve top set the internal pressure of the boiler. Also in the seventeenth century, Cornels Dribble in Holland invented a purely mechanical temperature control system for hatching eggs. The device used a vial of alcohol and mercury with a floater inserted in it. The floater was connected to a damper that controlled a flame. A portion of the vial was inserted into the incubator to sense the heat generated by the fire. As the heat increased, the alcohol and mercury expanded, raising the floater, closing the damper, and reducing the flame. Lower temperature caused the float to descend, opening the damper and increasing the flame

3. Speed Control

In 1745, speed control was applied to a windmill by Edmund Lee. Increasing winds pitched the blades farther back, so that less area was available. As the wind decreased, more blade area was available. William Cubitt improved on the idea in 1809 by dividing the windmill sail into movable louvers. Also in the eighteenth century, James Watt invented the flyable speed governor to control the speed of steam engines. In this device, two spinning fly balls rise as rotational speed increases. A steam valve connected to the flyable mechanism closes with the ascending flyballs and opens with the descending flyballs, thus regulating the speed.

4. Stability, Stabilization, and Steering

Control systems theory as we know it today began to crystallize in the latter half of the nineteenth century. In 1868, James Clerk Maxwell published the stability criterion for a third-order system based on the coefficients of the differential equation. In 1874, Edward John Routh, using a suggestion from William Kingdon Clifford that was ignored earlier by Maxwell, was able to extend the stability criterion to fifth-order systems. In 1877, the topic for the Adams Prize was "The Criterion of Dynamical Stability." In response, Routh submitted a paper entitled A Treatise on the Stability of a Given State of Motion and won the prize. This paper contains what is now known as the Routh-Hurwitz criterion for stability, which we will study in Chapter 6. Alexander Michailovich Lyapunov also contributed to the development and formulation of today's theories and practice of control system stability. A student of P. L. Chebyshev at the University of St. Petersburg in Russia, Lyapunov extended the work of Routh to nonlinear systems in his 1892 doctoral thesis, entitled The General Problem of Stability of Motion. During the second half of the 1800s, the development of control systems focused on the steering and stabilizing of ships. In 1874, Henry Bessemer, using a gyro to sense a ship's motion and applying power generated by the ship's hydraulic system, moved the ship's saloon to keep it stable (whether this made a difference to the patrons is doubtful). Other efforts were made to stabilize platforms for guns as well as to stabilize entire ships, using pendulums to sense the motion. [16]

2.5.4 System Configurations

In this section, we discuss two major configurations of control systems: open loop and closed loop. We can consider these configurations to be the internal architecture of the total system. Finally, we show how a digital computer forms part of a control system's configuration:

1. Open-Loop Systems

A generic open-loop system is shown in. It starts with a subsystem called an input transducer, which converts the form of the input to that used by the controller. The controller drives a process or a plant. The input is sometimes called the reference, while the output can be called the controlled variable. Other signals, such as disturbances, are shown added to the controller and process outputs via summing junctions, which yield the algebraic sum of their input signals using associated signs. For example, the plant can be a furnace or air conditioning system, where the output variable is temperature. The controller in a heating system consists of fuel valves and the electrical system that operates the valves. The distinguishing characteristic of an open-loop system is that it cannot compensate for any disturbances that add to the controller's driving signal. For example, if the controller is an electronic amplifier and Disturbance 1 is noise, then any additive amplifier noise at the first summing junction will also drive the process, corrupting the output with the effect of the noise. The output of an open-loop system is corrupted not only by signals that add to the controller's commands but also by disturbances at the output The system cannot correct for these disturbances, either. Open-loop systems, then, do not correct for disturbances and are simply commanded by the input. For example, toasters are open-loop systems, as anyone with burnt toast can attest. The controlled variable (output) of a toaster is the color of the toast. The device is designed with the assumption that the toast will be darker the longer it is subjected to heat. The toaster does not measure the color of the toast; it does not correct for the fact that the toast is rye, white, or sourdough, nor does it correct for the fact that toast comes in different thicknesses. Other examples of open-loop systems are mechanical systems consisting of a mass, spring, and damper with a constant force positioning the mass. The greater the force, the greater the displacement. Again, the system position will change with a disturbance, such as an additional force, and the system will not detect or correct for the disturbance. Or assume that you calculate the amount of time you need to study for an examination that covers three chapters in order to get an A. If the professor adds a fourth chapter—a disturbance—you are an open-loop system if you do not detect the disturbance and add study time to that previously calculated. The result of this oversight would be a lower grade than you expected.

2. Closed-Loop (Feedback Control) Systems

The disadvantages of open-loop systems, namely sensitivity to disturbances and inability to correct for these disturbances, may be overcome in closed-loop systems. The input transducer converts the form of the input to the form used by the controller. An output transducer, or sensor, measures the output response and converts it into the form used by the controller. For example, if the controller uses electrical signals to operate the valves of a temperature control system, the input position and the output temperature are converted to electrical signals. The input position can be converted to a voltage by a potentiometer, a variable resistor, and the output temperature can be converted to a voltage by a thermostat, a device whose electrical resistance changes with temperature. The first summing junction algebraically adds the signal from the input to the signal from the output, which arrives via the feedback path, the return path from the output to the summing junction. The result is generally called the actuating signal. However, in systems where both the input and output transducers have unity gain (that is, the transducer amplifies its input by 1), the actuating signal's value is equal to the actual difference between the input and the output. Under this condition, the actuating signal is called the error. The closed-loop system compensates for disturbances by measuring the output response, feeding that measurement back through a feedback path, and comparing that response to the input at the summing junction. If there is any difference between the two responses, the system drives the plant, via the actuating signal, to make a correction. If there is no difference, the system does not drive the plant, since the plant's response is already the desired response. Closed-loop systems, then, have the obvious advantage of greater accuracy than open-loop systems. They are less sensitive to noise, disturbances, and changes in the environment. Transient response and steady-state error can be controlled more conveniently and with greater flexibility in closed-loop systems, often by a simple adjustment of gain (amplification) in the loop and sometimes by redesigning the controller. We refer to the redesign as compensating the system and to the resulting hardware as a compensator. On the other hand, closed-loop systems are more complex and expensive than open-loop systems. A standard, open-loop toaster serves as an example: It is simple and inexpensive. A closed-loop toaster oven is more complex and more expensive since it has to measure both color (through light reflectivity) and humidity inside the toaster oven. Thus, the control systems engineer must consider the trade-off between the simplicity and low cost of an open-loop system and the accuracy and higher cost of a closed-loop system. In summary, systems that perform the previously described measurement and correction are called closed-loop, or feedback control, systems. Systems that do not have this property of measurement and correction are called open-loop systems.

3. Computer-Controlled Systems

In many modern systems, the controller (or compensator) is a digital computer. The advantage of using a computer is that many loops can be controlled or compensated by the same computer through time sharing. Furthermore, any adjustments of the compensator parameters required to yield a desired response can be made by changes in software rather than hardware. The computer can also perform supervisory functions, such as scheduling many required applications. For example, the space shuttle main engine (SSME) controller, which contains two digital computers, alone controls numerous engine functions. It monitors engine sensors that provide pressures, temperatures, flow rates, turbo pump speed, valve positions, and engine servo valve actuator positions. The controller further provides closed-loop control of thrust and propellant mixture ratio, sensor excitation, valve actuators, spark igniters, as well as other functions (Rockwell International, 1984).

2.5.5 Analysis and Design Objectives

Analysis is the process by which a system's performance is determined. For example, we evaluate its transient response and steady-state error to determine if they meet the desired specifications. Design is the process by which a system's performance is created or changed. For example, if a system's transient response and steady-state error are analyzed and found not to meet the specifications, then we change parameters or add additional components to meet the specifications. A control system is dynamic: It responds to an input by undergoing a transient response before reaching a steady-state response that generally resembles the input. We have already identified these two responses and cited a position control system (an elevator) as an example. In this section, we discuss three major objectives of systems analysis and design: producing the desired transient response, reducing steady-state error, and achieving stability. We also address some other design concerns, such as cost and the sensitivity of system performance to changes in parameters. [17]

2.5.6 Microcontroller

A microcontroller is a computer present in a single integrated circuit which is dedicated to perform one task and execute one specific application.

It contains memory, programmable input/output peripherals as well a processor. Microcontrollers are mostly designed for embedded applications and are heavily used in automatically controlled electronic devices such as cell phones, cameras, microwave ovens, washing machines, etc. [17]

2.5.6.1 Features of a microcontroller

1. Far more economical to control electronic devices and processes as the size and cost involved is comparatively less than other methods.

2. Operating at a low clock rate frequency, usually use four bit words and are designed for low power consumption.

3. Architecture varies greatly with respect to purpose from general to specific, and with respect to microprocessor, ROM, RAM or I/O functions.

3. Has a dedicated input device and often has a display for output.

4. Usually embedded in other equipment and are used to control features or actions of the equipment.

5. Program used by microcontroller is stored in ROM.

7. Used in situations where limited computing functions are needed.

2.5.6.2 Embedded microcontroller

Simply an embedded controller is a controller that is embedded in a greater system. One can define an embedded controller as a controller (or computer) that is embedded into some device for some purpose other than to provide general purpose computing. Is an embedded controller is the same as a microcontroller? The answer is definitely no. One can state devices such as 68000, 32032, x86, Z80, and so on that are used as embedded controllers but they aren't microcontrollers.

We might be correct by stating that an embedded controller controls something (for example controlling a device such as a microwave oven, car braking system or a cruise missile). An embedded controller may also embed the on-chip resources like a microcontroller. Microcontrollers and microprocessors are widely used in embedded systems. Though microcontrollers are preferred over microprocessors for embedded systems due to low power consumption. [18]

2.5.6.3 A brief history of the Arduino

The Arduino got its start at the Interaction Design Institute in the city of Ivrea, Italy, in 2005. Professor Massimo Benzie was looking for a low-cost way to make it easier for the design students there to work with technology. He discussed his problem with David Cuartielles, a researcher visiting from

Malmoe University in Sweden who was looking for a similar solution, and Arduino was born. Existing products on the market were expensive and relatively difficult to use.

Banzi and Cuartielles decided to make a microcontroller that could be used by their

art and design students in their projects.

The target price was to be no more than a student would spend going out for a pizza and be a platform that anyone could use. David Cuartielles designed the board, and a student of Massimo's, David Mellis, programmed the software to run

the board. Massimo contacted a local engineer, Gianluca Martino, who also worked at the Design Institute helping students with their projects. Gianluca agreed to produce an initial run of 200 boards.

The new board was named Arduino after a local bar frequented by faculty members and students from the institute. The boards were sold in kit form for students to build themselves. The initial run was soon sold out, and more were produced to keep up with demand. Designers and artists from other areas heard about the Arduino and wanted to use it in their projects. Its popularity soon grew when the wider maker audience realized that the Arduino was an easy-to-use, low-cost system that could be used in their own projects, as well as a great introduction to programming microcontrollers.

The original design was improved upon and new versions were introduced. Sales of official Arduinos have now reached over 300,000 units, and they're sold all over the world through a range of distributors. [18]

2.5.6.4 The Arduino hardware

There have been a number of Arduino versions, all based on an 8-bit Atmel AVR reduced instruction set computer (RISC) microprocessor. The first board was based on the ATmega8 running at a clock speed of 16 MHz with 8 KB flash memory; later boards such as the Arduino NG plus and the Diecimila (Italian for 10,000) used the ATmega168 with 16 KB flash memory. The most recent Arduino versions, Duemilanove and Uno, use the ATmega328 with 32 KB flash memory and can switch automatically between USB and DC power. For projects requiring more I/O and memory, there's the Arduino Mega1280 with 128 KB memory or the more recent Arduino Mega2560 with 256 KB memory.

The boards have 14 digital pins, each of which can be set as either an input or output, and six analog inputs. In addition, six of the digital pins can be programmed to provide a pulse width modulation (PWM) analog output. A variety of communication protocols are available, including serial, serial peripheral interface bus (SPI), and I2C/TWI. Included on each board as standard features are an in-circuit serial programming (ICSP) header and reset button. [19]

2.5.6.5 Types of Arduino

1. Arduino Uno

"Dinner is Served" was the blog title announcing on September 25, 2010, the arrival of the Arduino Uno (meaning one in Italian), and its bigger brother, the Mega2560. The Arduino Uno is pin-compatible with previous Arduinos, including the Duemilanove and its predecessor the Diecimila.

The major difference between the Uno and its predecessors is the inclusion of an ATmega8U2 microcontroller programmed as a USB-to-serial converter, replacing the ageing FTDI chipset used by previous versions. The ATmega8U2 can be reprogrammed to make the Arduino look like another USB device, such as a mouse, keyboard, or joystick.

Another difference is that it has a more reliable onboard 3.3 volts, which helps with the stability of some shields that have caused problems in the past.

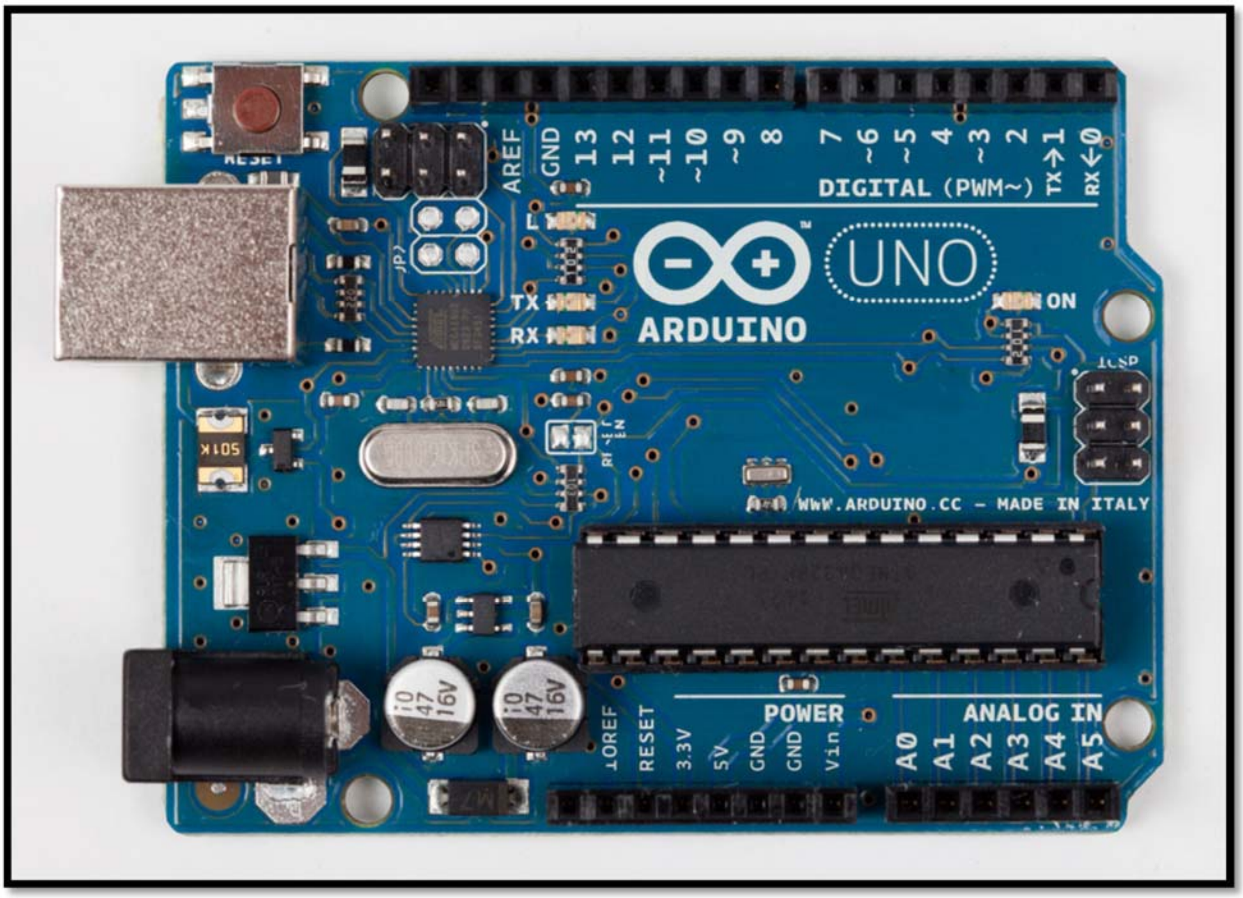


Figure (2.1): Basic board: the Arduino Uno.

The Uno is a good all-purpose Arduino and is your best bet for a starter board with its auto-switching power supply and regulated onboard 3.3 volts.

2. Arduino Ethernet

The Arduino Ethernet is a low-power version of the Arduino announced at the same time as the Uno. The main differences between it and other Arduino versions are that it has an onboard RJ45 connector for an Ethernet connection and a microSD card reader.

The Arduino Ethernet doesn't have an onboard USB-to-serial driver chip, but it does have a six-pin header that can be connected to an FTDI cable or USB serial board to provide a communication link so that the board can be programmed. It can also be powered by an optional Power over Ethernet (POE) module, which enables the Arduino Ethernet to source its power from a connected twisted-pair Category 5 Ethernet cable.

The Arduino Ethernet is ideally suited for use in remote monitoring and data logging stations with the onboard microSD card reader and a connection to a wired Ethernet network for power.

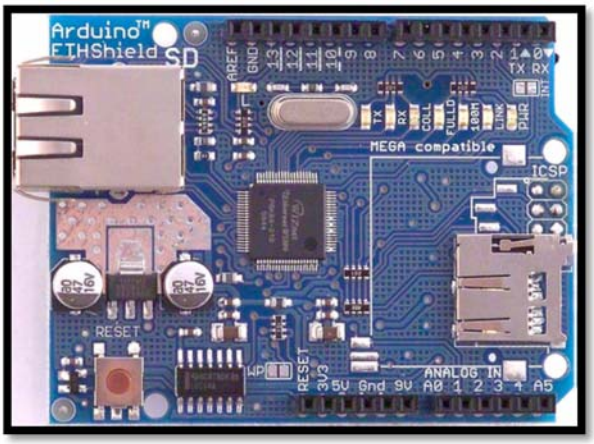


Figure (2.2): shows the board layout and pins of the Ethernet.

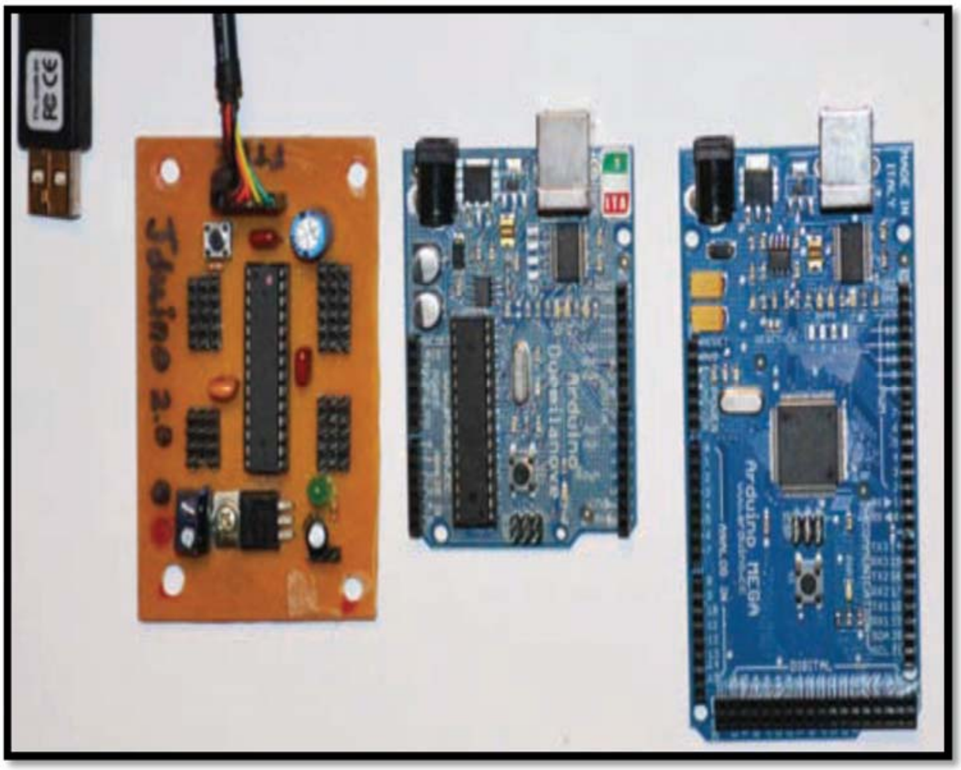
3. Arduino Mega

The big brother of the Arduino family, the Mega, uses a larger surface-mount microprocessor.

The ATmega1280, the Mega, was updated at the same time as the Uno, and the microprocessor now used is the ATmega2560. The new version has 256 KB of flash memory compared to the 128 KB of the original.

The Mega provides significantly increased input-output functionality compared to the standard Arduino, so with the increased memory, it's ideal for those larger projects that control lots of LEDs, have a large number of inputs and outputs, or need more than one hardware serial port—the Arduino Mega has four. The boards have 54 digital input-output pins, 14 of which can provide PWM analog output, and 16 analog input pins. Communication is handled with up to four hardware serial ports. SPI communication and support for I2C/TWI devices is also available. The board also includes an ICSP header and reset button. An ATmega8U2 replaces the FTDI chipset used by its predecessor and handles USB serial communication.

The Mega works with the majority of the shields available, but it's a good idea to check that a shield will be compatible with your Mega before purchasing it. Purchase the Mega when you have a clear need for the additional input-output pins and larger memory. See appendix C for the full technical specifications.



Figur(2.3): Three different types of Arduino boards.

CHAPTER THREE

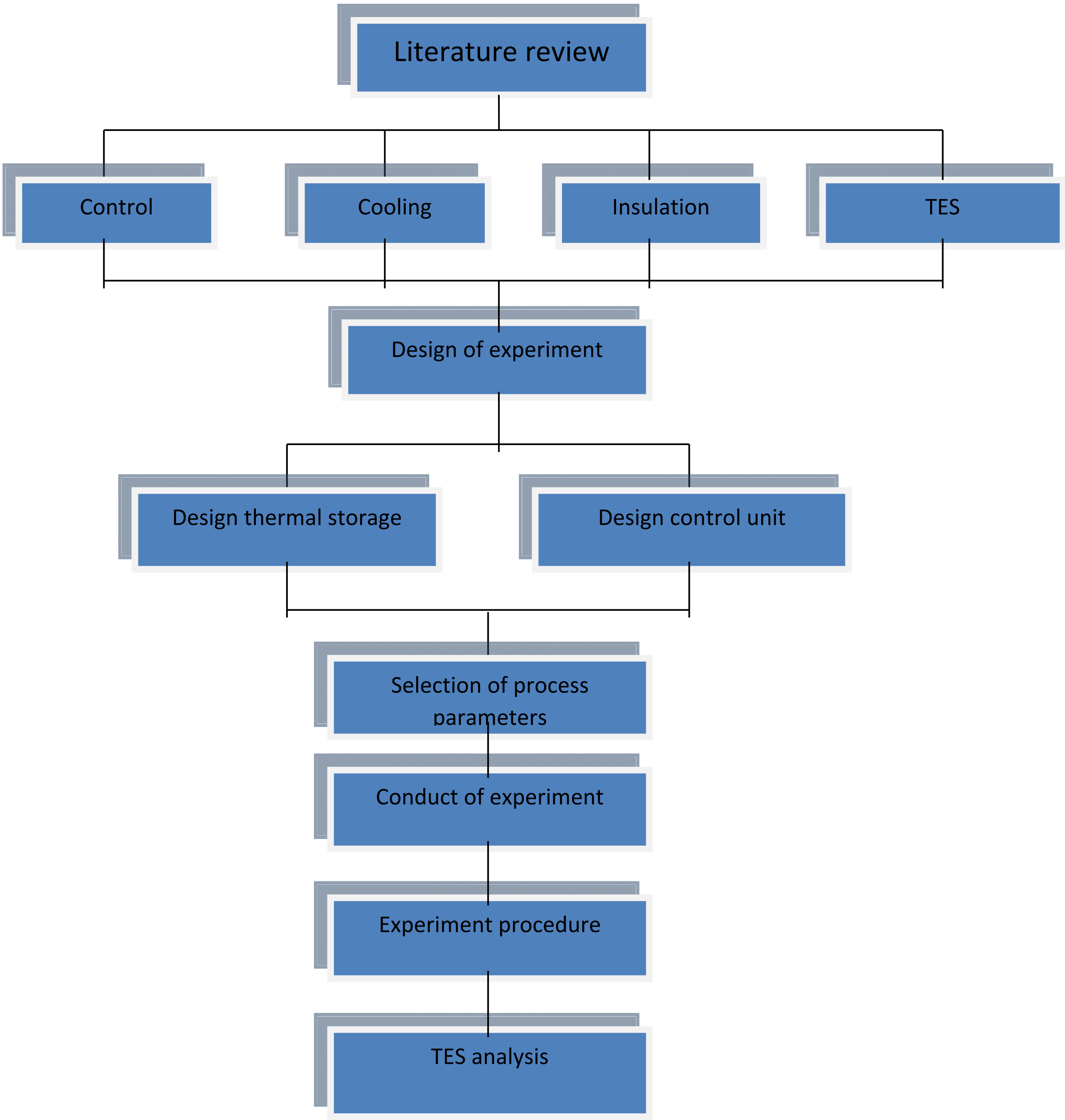
METHODOLOGY

3.1 Introduction

This chapter explains the method used in this project. It details the methods adopted for design and installation of thermal storage, the selection of process parameters for optimization and the experimental procedure used for this process lab . Based on the environmental factors, a model of tank has been designed for residential use. This design has been produced considering the process parameters which were optimized in the thermal energy storage systems. Based on this work, the proposed design of the tank was tested and validated at the last stage of this project. All equipment and tools used during the project work are also shown in this chapter. The methodology flow-chart of this project is shown in Figure 3.1.

3.2 Design of Experiments

The thermal storage is the main unit needed for anaerobic condition. The main factors effect on this tank is the situation of the ambient. For development of this thermal storage we have to study the conditions of environment using different process parameters, in order to optimize the mechanism of the thermal energy storage. The technology selected for the process is design incorporating tank with a water cooler, in addition to that we use sawdust for insulation. This selection was mainly to simplify the installation and handling of the tank during the experiments. The following sections discuss the detail of the method adopted for the design of thermal tank, and the process parameters selected for optimization.



Figure(3.1): Flow-chart of the project methodology.

3.2.1 Design of thermal storage

The thermal storage design consisted of two main parts: the tank and the control mechanism. The tank was made out of polyethylene material for its strength and durability in acid and basic environments. The volume of the tank was 250 liters, with an inlet at the top and outlet port at the bottom. The water comes from cooler through the inlet by pump was put inside the cooler's tank.

There is important assumption as follow:

The material of the tank is polyethylene (has a conductive factor 0.15kw/mk). The tank has a size as : head of 0.91m,the diameter is 0.66m and the thickness is 0.007m.

Firstly base was made for the tank on the head 1 m to be in suitable level for human, when he comes to drink. in addition to that the thickness of base tow brick(0.18m) due to load the tank . Figure 3.1 shows that

Figure(3.2): the base of thermal storage.

After that came metal plumbing pipes and fittings process.PPR was selected as a material for several reasons:

- Light weight, easy and quick assembly.
- Most suitable for carrying drinking water.
- Excellent corrosion and chemical.
- Low thermal conductivity.
- High impact strength.
- Safe and watertight joints.
- Resistance to scaling.
- Usable in seismic areas.
- Long operational dur ability.
- Overall economy.

3.2.1.1 Selection of insulation

Sawdust wood was chosen for insulation. Swedish wood is considered as a natural insulation, among its many great characteristics:

- It has a long life.
- It's highly durable and easy to work with.
- It's also hygroscopic, which means that it has the capacity to absorb and release a moderate amount of moisture without being damage.
- It's this property that also makes wood an excellent insulation material.

First priority we put a layer of Swedish wood on the base. It has a thickness about 10cm.Figure 3.3 shows that.

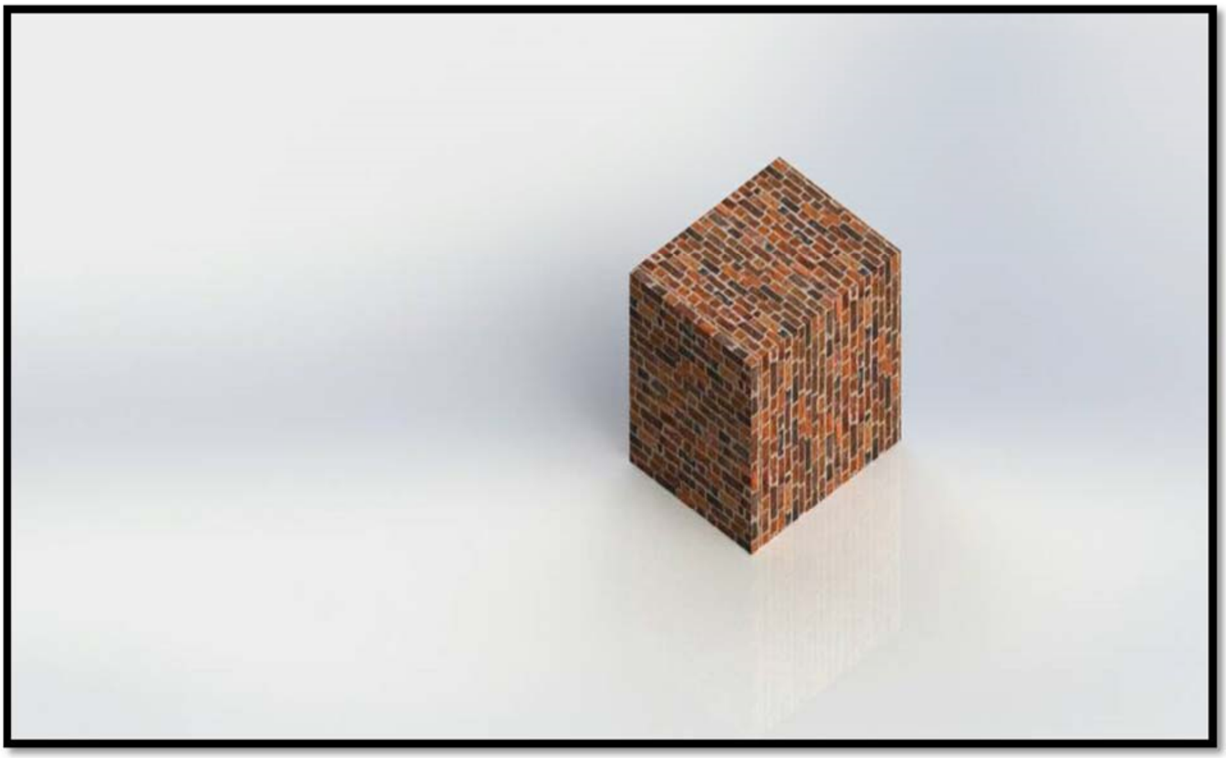
Figure(3.3): the layer of insulation on the base.

Second step the tank was put on the base ,obviously in figure (3.4).And walls were bult from all sides from canonize along 10cm from tank for insulaton.after this vacuum was filled with compressed Swedish wood. By same way up to tank head of 10cm for insulation also.

Figure(3.4): the position of the tank on the base

Figure(3.5): the main section of the last design.

Figure(3.6): final shape.



Figure(3.7) final assemblies by solid work.

3.2.2 Control unit

The control unit is microcontroller is represented on Arduino. The Arduino microcontroller is like little command center that is awaiting your orders.

With a few lines of code, you can make your Arduino turn a light on or off, read a sensor value a and display it on your computer screen, or even use it to build a homemade circuit to repair a broken kitchen appliance. Because of the versatility of the Arduino and the massive support available from the online community of Arduino users, it has attracted a new breed of electronics hobbyists who have never. This is to allow accurate measurement of the daily presenting of drinkable water.

3.2.2.1 Hardware and tools

There are many tools were used to create control circuit. Table (3.1) and Figure (3.2) summarize the equipment and tools used during the construction of control unit.

Table (3.1):the equipment and tools used during the construction of control .

No.	Item	No. of units	Purpose
1	Arduino uno	1	Receive the ordrs
2	USB printer cable	1	Connect the board with computer
3	Bread board	1	Contains the components
4	Coloured LED	3	Transfer the current to light
5	resistors	3	Control the current
6	relay	2	Operate big load through small voltage
7	Wires	12	Connect the components with each others.
8	Effectives tools	1	Fitting
9	Power source	1	Support the power

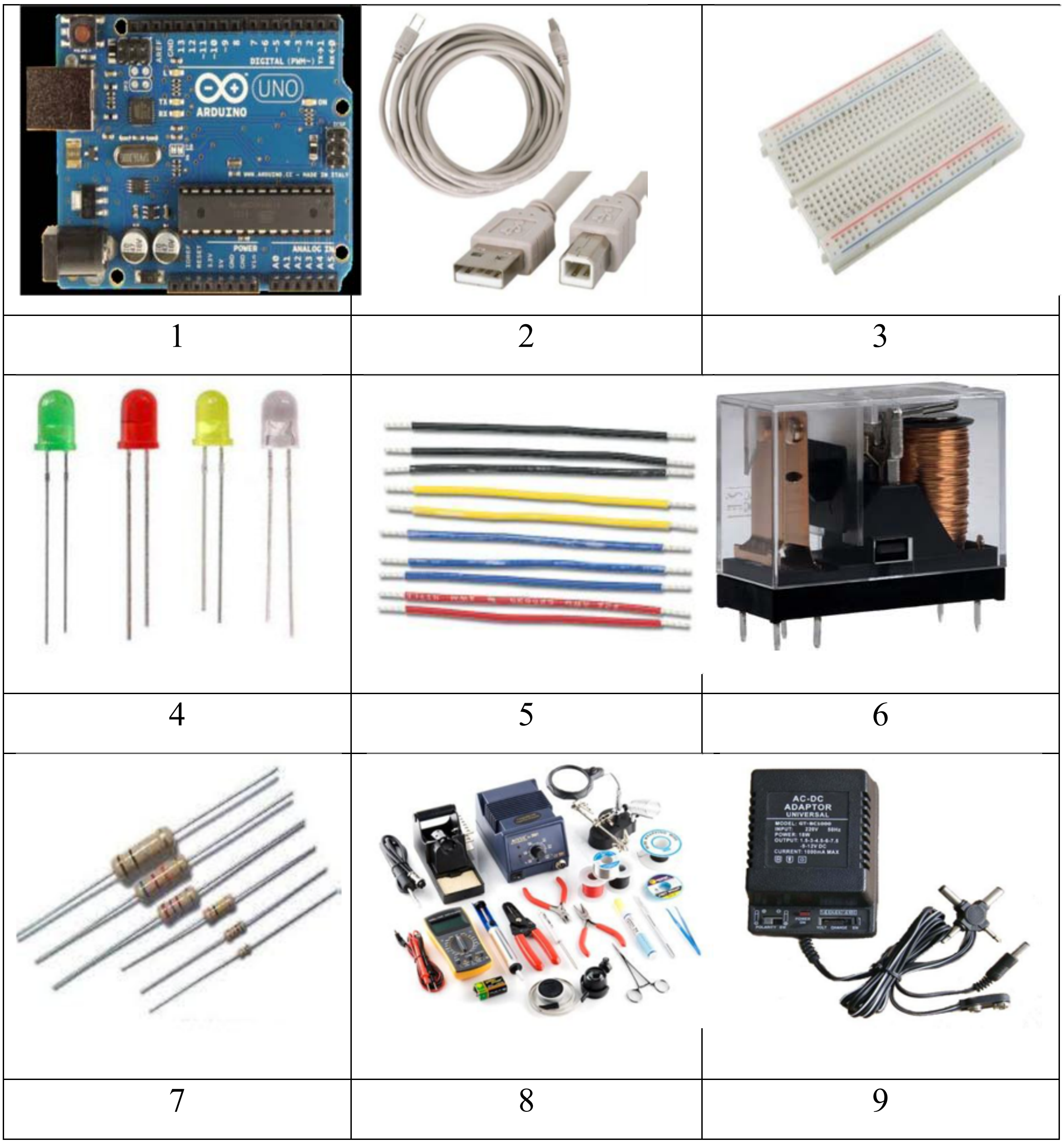


Figure (3.8) the equipment and tools used during the construction of control unit.

3.2.2.2 Software

The software was used about codes feed to Arduino to dominate the temperature of cold water by specific code, in addition to that to control the level of the water inside the tank. With taking the condition of water inside the tank(temperature and level) with the mechanism of pump and compressor. The codes as follow:

```
int ledr = 13;
int ledy = 12;
int ledg = 11;

int relay1 = 10;
int relay2 = 9;
const int buttonPin1 = 7;
const int buttonPin2 = 8;
int buttonState1 = 0;        // variable for reading the pushbutton status

int buttonState2 = 0;        // variable for reading the pushbutton status

void setup() {
 // initialize serial communication at 9600 bits per second:
Serial.begin(9600);
  pinMode(buttonPin1, INPUT);
  pinMode(buttonPin2, INPUT);

  pinMode(ledr, OUTPUT);
  pinMode(ledy, OUTPUT);
  pinMode(ledg, OUTPUT);
```

```
  pinMode(relay1, OUTPUT);

  pinMode(relay2, OUTPUT);
}
// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
  // Convert the analog reading (which goes from 0 - 1023) to a voltage (0 -
5V):
  float voltage = sensorValue * (5.0 / 1023.0);
  voltage =voltage *100;
  // print out the value you read:

  buttonState1 = digitalRead(buttonPin1);
buttonState2 = digitalRead(buttonPin2);

Serial.println("temp = ");
  Serial.println(voltage);

   Serial.println();

Serial.println("temp = ");
    Serial.print(voltage);
   Serial.println();

      delay(900);
     if(buttonState1 == HIGH && buttonState2 == HIGH&&voltage>=19) {
```

```
    digitalWrite(relay1, HIGH);
    digitalWrite(relay2, LOW);

    digitalWrite(ledr, HIGH);
      digitalWrite(ledy, LOW);
        digitalWrite(ledg, LOW);
    delay(900);
  }
    if(buttonState1 == HIGH && buttonState2 ==
HIGH&&voltage>=12&&voltage<=18) {
    digitalWrite(relay1, HIGH);
     digitalWrite(relay2, HIGH);

    digitalWrite(ledr, LOW);
      digitalWrite(ledy, HIGH);
        digitalWrite(ledg, LOW);
    delay(900);
  }
     if(buttonState1 == LOW && buttonState1 == HIGH
&&voltage>=12&&voltage<=18) {
    digitalWrite(relay1, HIGH);
     digitalWrite(relay2, HIGH);
    digitalWrite(ledr, LOW);
      digitalWrite(ledy, HIGH);
        digitalWrite(ledg, LOW);
   delay(900);

  }
```

```
    if(buttonState1 == LOW  && buttonState1 ==
LOW&&voltage>=14&&voltage<=18) {

    digitalWrite(relay1, LOW);
    digitalWrite(relay2, LOW);
    digitalWrite(ledr, LOW);
      digitalWrite(ledy, HIGH);
        digitalWrite(ledg, LOW);

   delay(900);
  }
    if(voltage<=13) {
    digitalWrite(relay1, LOW);
    digitalWrite(relay2, LOW);

    digitalWrite(ledr, LOW);
      digitalWrite(ledy, LOW);
        digitalWrite(ledg, HIGH);

   delay(900);
  }
  if(buttonState1 == LOW && buttonState2 == HIGH) {
       Serial.println();
     Serial.println("LEVEL  =  LEVEL 1 ");

  Serial.println();
  }
if(buttonState1 == LOW && buttonState2 == LOW) {
```

```
      Serial.println();
     Serial.println("LEVEL  =  FULL ");

 Serial.println();
}

if(buttonState1 == HIGH && buttonState2 == HIGH) {
      Serial.println();
     Serial.println("LEVEL  =  EMPTEY ");

 Serial.println();
   }
}
```

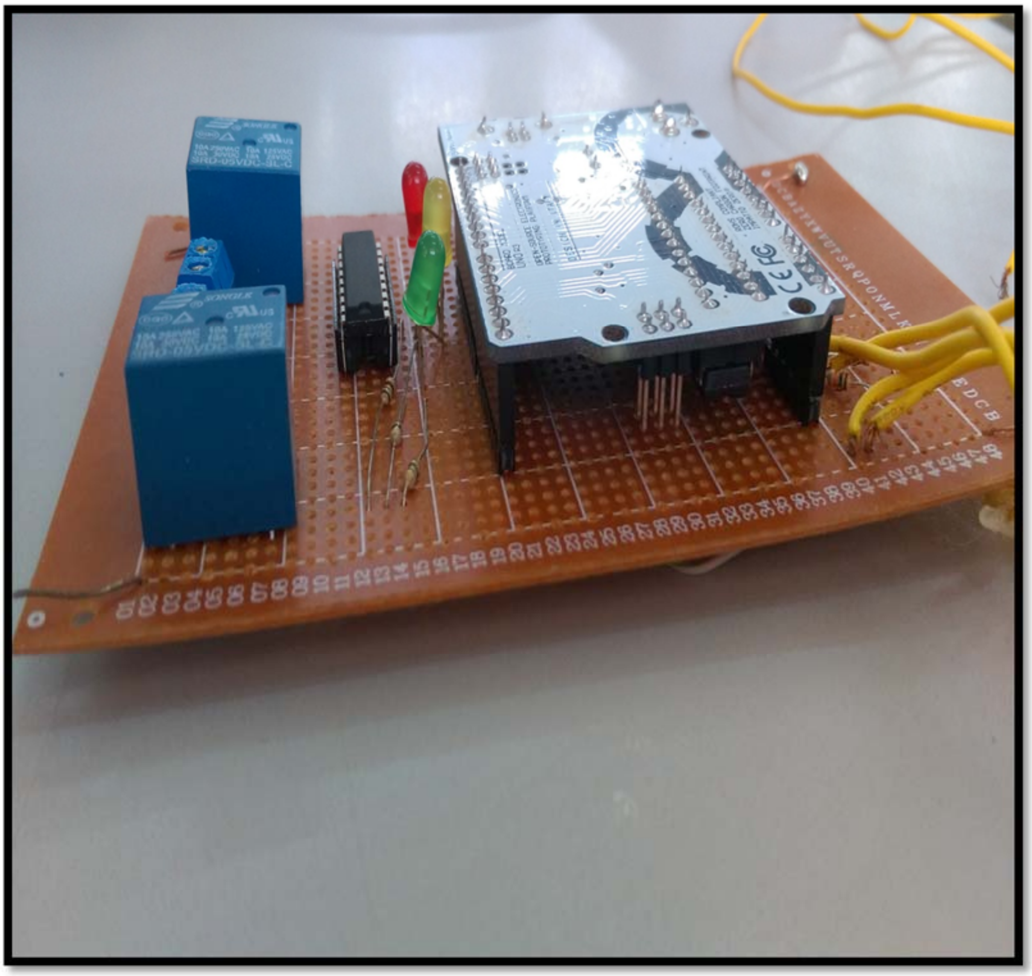
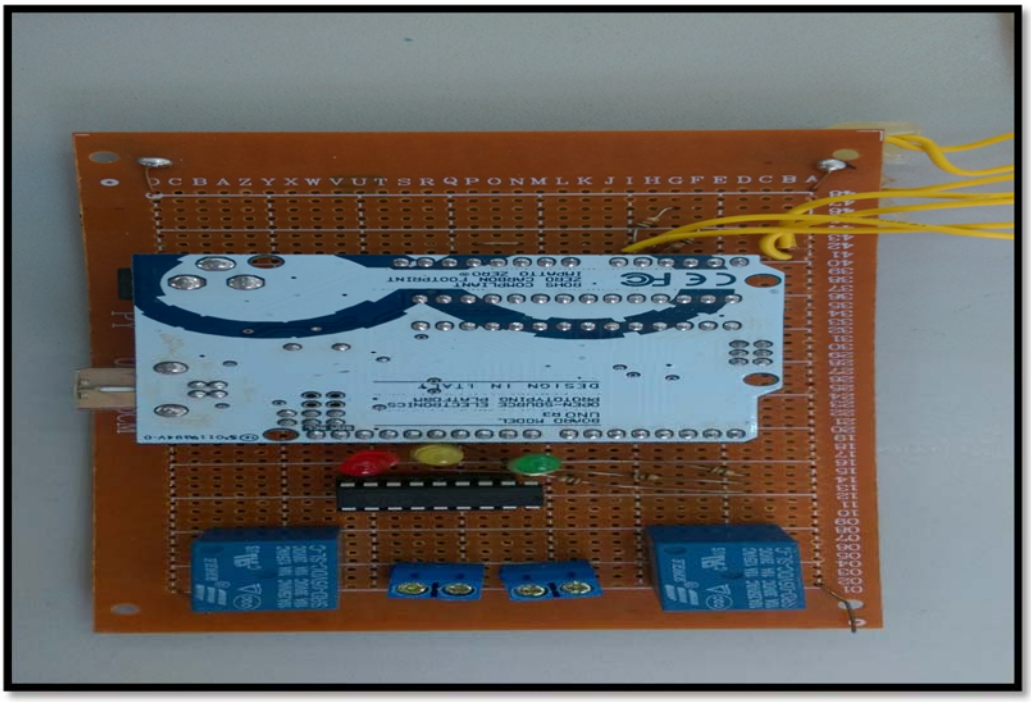


Figure (3.9): slide show of the control circuit.



Figure(3.10): vertical show of control circuit.

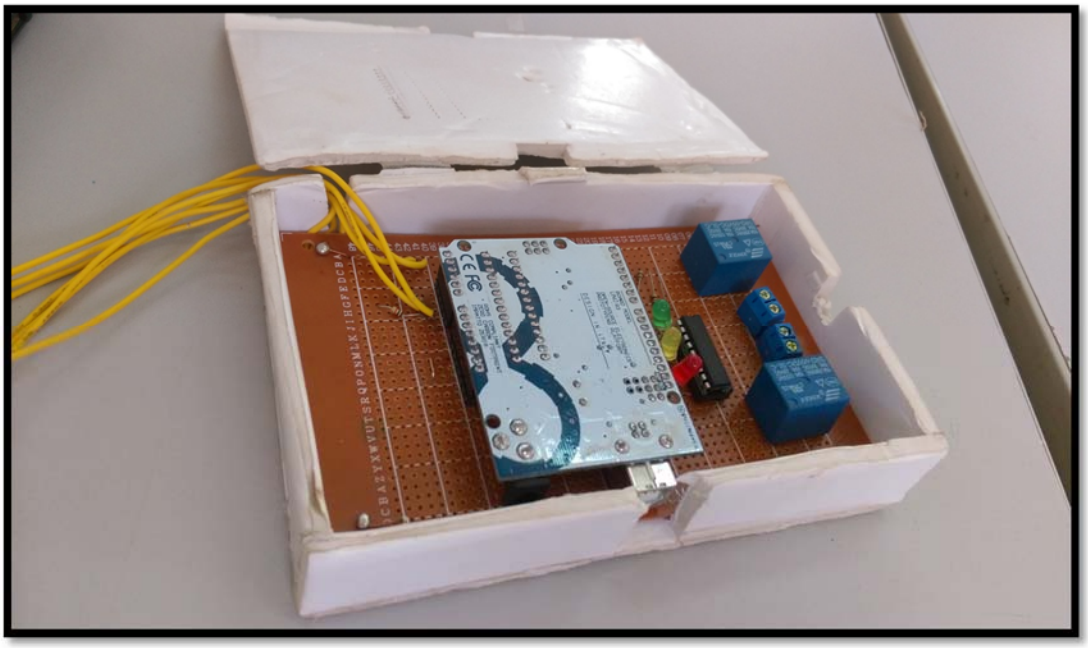


Figure (3.11): final assemblies of the components of the control circuit.

3.3 Selection of Process Parameters

The Thermal Energy Storage (TES) process is influenced by some critical parameters which could affect the efficiency of the process. The parameters selected for study in this project are: temperature, head of water and time

3.3.1 Temperature

Temperature is critical factor that may affect the efficiency of the TES process. The experiments in this project were conducted in different seasons (winter and summer). It is considered that the two main alternatives are of conditions of ambient. In summer the temperature in range between 39°C to 46°C .And in winter in the range between 29°C to 35°C.

3.3.2 Head

The head of water inside tank depends on the consumption ratio and the mechanism of cooler to cool much water in few time. It also depends on the number of people in that area.

3.3.3 Time

That time the tank is needed to be filled. Also the time required to be consumed .All of this depends on effective factors such as peack time, the condition of ambient and the number of people.

.3.4 Experimental procedure

The experiment depends on the temperature of air and temperature of water inside tank. The heat transfer from hot side to cold side as we know. The quantity of heat obtained by water equals the quantity of heat loosed by air.

The temperature of water and air were measured by thermal sensors at variable time (it's about every two hours).In addition to that the energy was measured also.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1Introduction

This chapter presents the experimental results obtained using the method and equipment described in chapter 3. The design and construction of the thermal storage shown in Section One, followed by calculation of thermal storage shown in section Tow. Followed by results obtained from experiments conducted as shown in Section Three.

4.2 Thermal energy storage

As shown in Chapter Three, the thermal storage consisted of two main units. These units are the thermal storage itself which is used for anaerobic fermentation process, and the control mechanism to dominate the degree of temperature before enter the tank. The main parts and the assembled thermal storage unit are shown in Figure (4.1) and Figure(4.2).

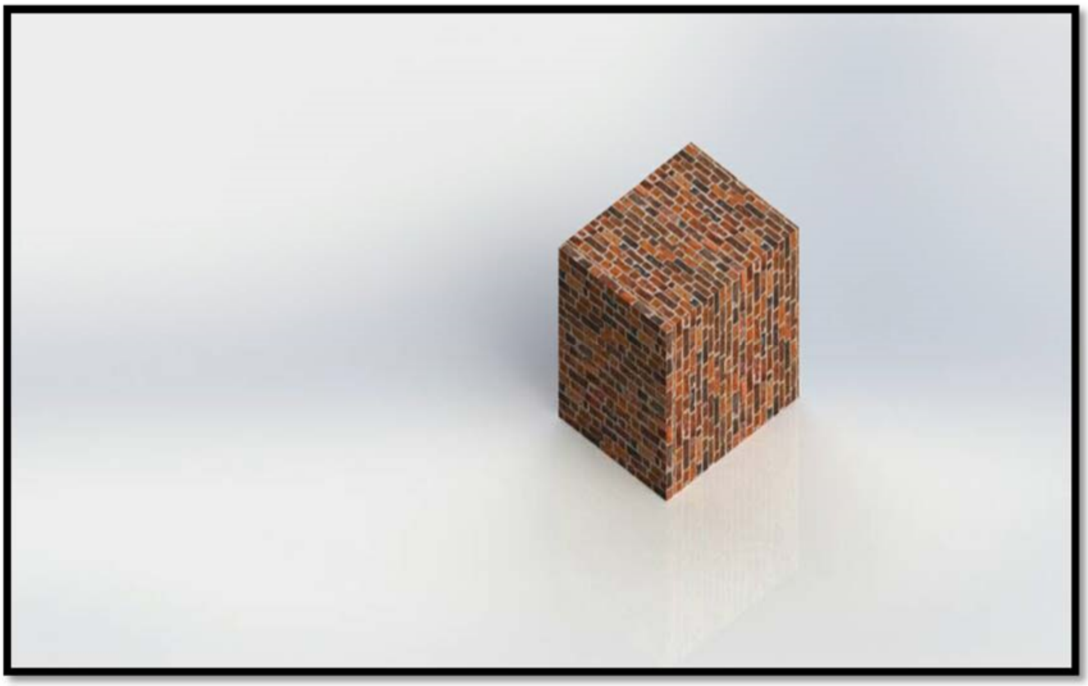


Figure (4.1): Main assembly for thermal storage design.

Figure (4.2) vertical section of the design assembly.

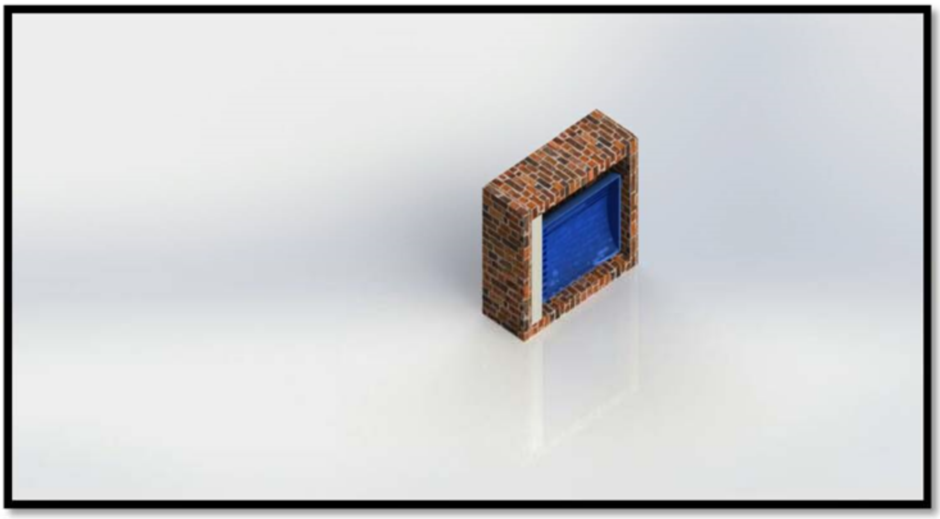


Figure (4.3): slideshow section of the design assembly.

4.3 Thermal storage calculation

The main characteristic of the cold storage cases is sensible heat storage. The following assumptions are made for these cases:

• Storage boundaries are no adiabatic.

• Heat gain from the environment during charging and discharging is negligibly small relative to heat gain during the storing period.

• The external surface of the storage tank wall is at a temperature 45°C(the maximum) greater than the mean storage-fluid temperature.

• The mass flow rate of the heat-transfer fluid is controlled so as to produce constant inlet and outlet temperatures.

• Work interactions and changes in kinetic and potential energy terms, are negligibly small.

Thermal storage calculation depends on the boundary condition inside the tank and the boundary condition in the ambient.

• Height of the tank is(0.91m), the diameter is(0.66m) and the thickness is (0.007m).

• The conductivity coefficient for components ‘materials as:

For sawdust wood is (0.059kw/m°C), polyethylene (0.15kw/m°C) and break (0.51kw/m°C).And the thickness of the insulation layer is(0.12m) and the for the break is(0.1m).

The mass of water inside the tank is calculated as:

$$m = \rho * v \tag{4.1}$$

m ≡ Mass of water (kg)

ρ ≡ Density of water (kg/m^3)

v ≡ Capacity of tank (m^3)

∴ m =1000*0.250=250kg

$$E_{air} = E_{water} \tag{4.2}$$

Heat loosed by air =Heat gained by water.

$$\Delta E = mc_p\Delta T \tag{4.3}$$

C_p ≡ heat capacity.

$$Q = U\Delta T \tag{4.4}$$

Q ≡ quantity of heat transfer.

U ≡ total heat transfer coeficient

$$U = \frac{1}{\frac{dx_1}{k_1A_1} + \frac{dx_2}{k_2A_2} + \frac{\ln {d_o}/{d_i}}{2\pi k_3 L}} \tag{4.5}$$

$$Ex = mS\Delta T \qquad (4.6)$$

S ≡ Entropy

$$W = \int_{t_1}^{t_2} mC_p\Delta T \qquad (4.7)$$

4.4 TES System model considered

Consider the overall storage process for the general TES system Heat Q_c is injected into the system at a constant temperature T_c during a charging period. After a storing period, heat $Q_d$is recovered at a constant temperature T_d during a discharging period. During all periods, heat Ql leaks from the system at a constant temperature T_1 and is lost to the surroundings. For normal heating applications, the temperatures T_c , T_d, and T_1 exceed the environment temperature T_o, but the discharging temperature cannot exceed the charging temperature. Hence, the exegetic temperature factors for the charged and discharged heat are subject to the constraint. To take the daily readings of the temperature by thermal sensor, the readings are shown in table (4.1).

Table(4.1): Relation between the temperature and time.

No.	$T_o(K)$	$T_i(K)$	t(h)
1	307	287	9:00
2	308.7	287.6	10:00
3	310	287.9	11:00
4	312.3	288.3	12:00
5	315.7	289.6	1:00
6	317	290.2	2:00
7	44.3	292	3:00

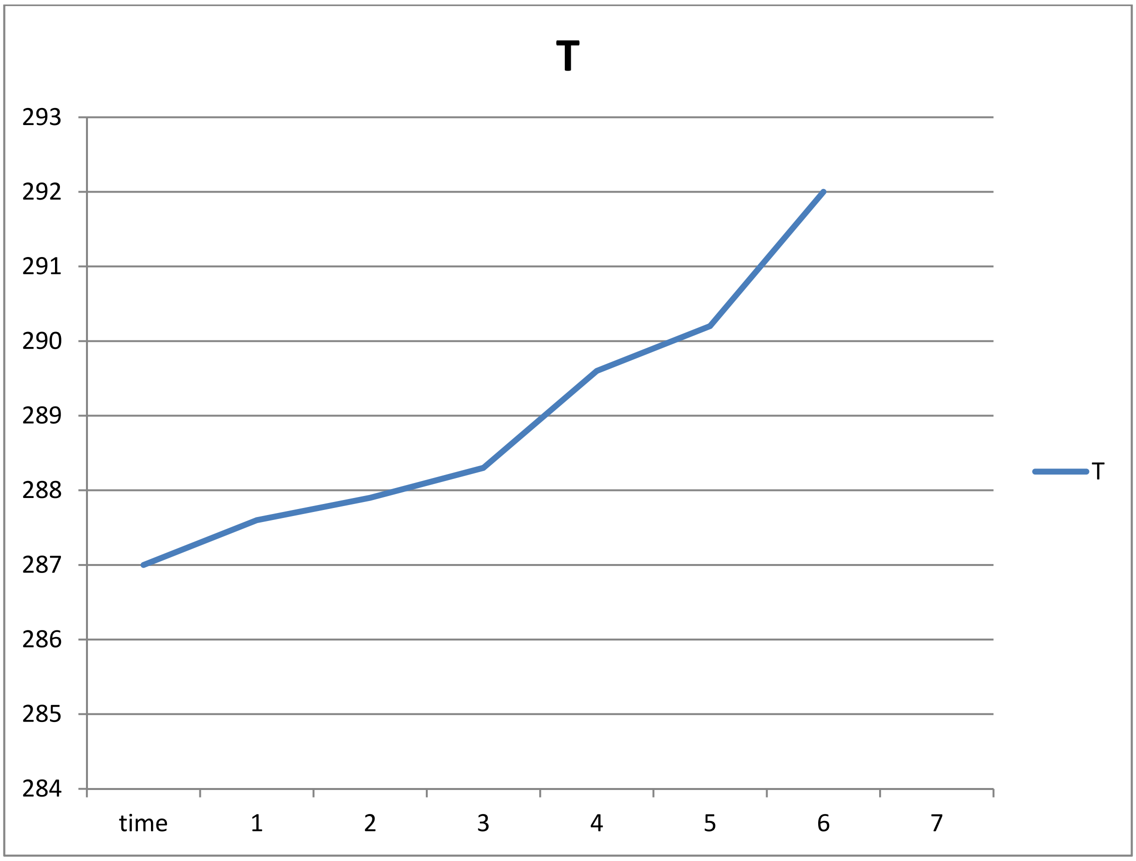
From the table(4.1) it's obviously the degrees of temperature are increasing during the day(from the morning to evening according to our readings).

The quantity of heat gained by water during the day is calculated by equation (4.4).Also the Exergy is calculated by equation (4.6).In addition to that the work done is calculated by equation (4.7).

All the values are shown in table (4.2).

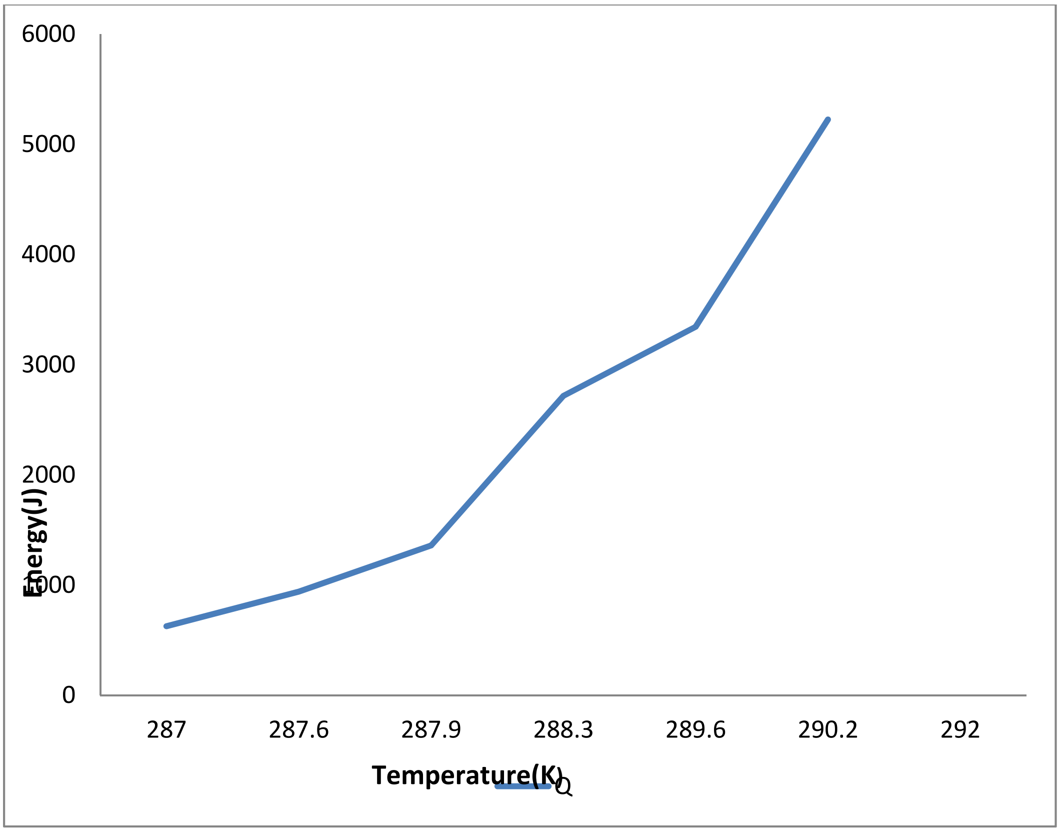
Table (4.2): Values of Heat, Work and Energy during the time.

t(hour)	Q_{add}(kJ)	W(kw)	Ex(kJ)
1	O	0	0
2	627	10.45	32.79
3	940.5	15.675	50.18
4	1358.5	22.6416	74.366
5	2717	45.2833	160.56
6	3344	55.733	231.84
7	5225	87.01	352.625

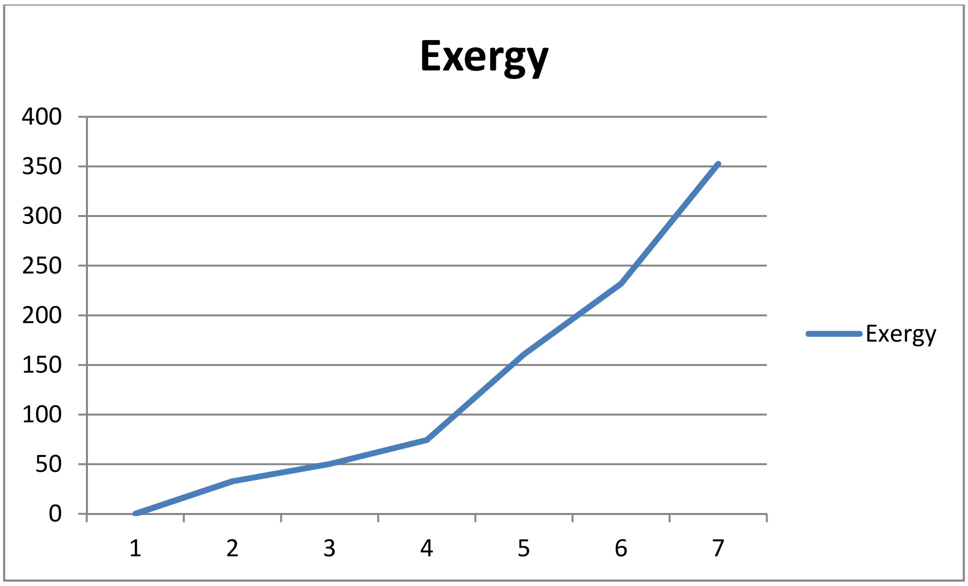


Figure(4.4): volume averaged temperature in the storage tank over 7 hours.

From the figure (4.4) is observed that the increasing in temperature of water inside the thermal storage is little during the day. That means this thermal storage has ability to store the thermal energy by high efficiency.



Figure(4.5): Total heat transferred to the water from walls.



Figure(4.6): Variation of Exergy quantity over 7hours period.

Both energy and exergy quantities increase from zero to maximum quantity in maximum temperature. That is clear in figure 4.5 and figure 4.6. The difference between two values of exergy or energy increase with the increasing in the temperature of water inside the tank.

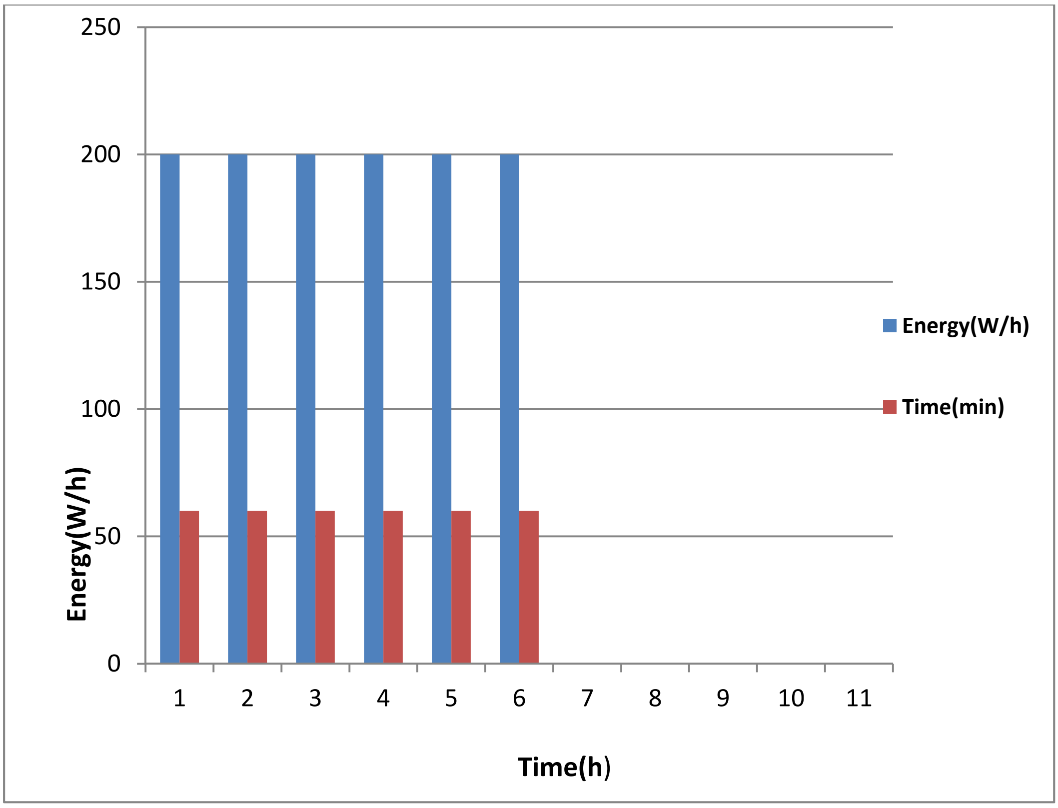
4.5 Electricity consumption:

Mechanical cooler has ability to cool 40 gallon/hr.

1 gallon =3.79Liter

Thermal storage capacity is 250 liter (65.96 gallon).

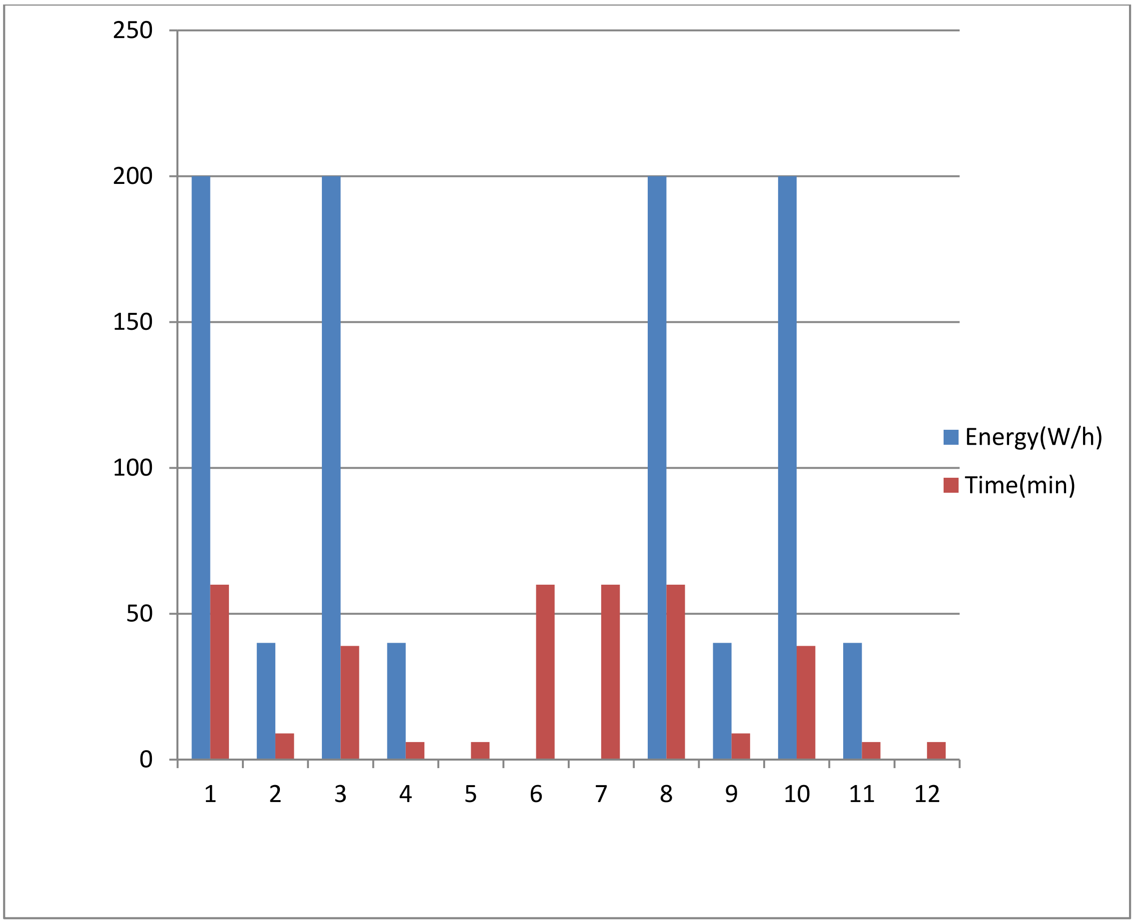
The cooler consumes approximately about 200watt/hr.The pump push 1000 liter/hr.That means it need 15 minutes to push the water(250 liter) from cooler to the tank. The pump consumption is 40 watt/hr.



Figure(4.7): Electricity consumption for cooler without TES.

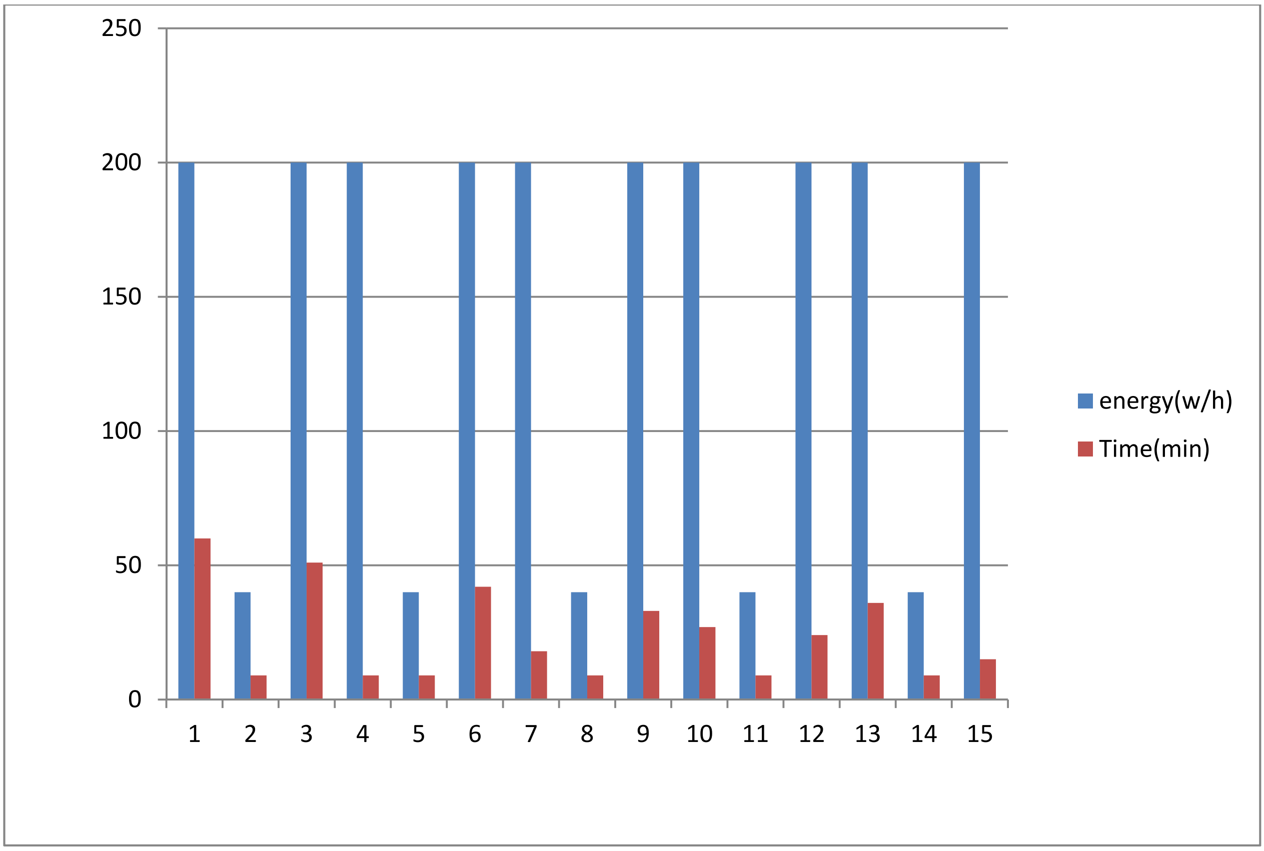
From figure 4.7 electricity consumption it's clearly is high, due to the mechanism of cooler adopted to cover a lack of water. So any alack means the cooler will work. The reading were taken for sex hours.

Approximately the electricity consumption is 1200(kw/6h).



Figure(4.8): Electricity consumption for cooler by using TES.

In a another side from Figure 4.8 we released that the electricity consumption when we used TES is(886(kw/6h)).



Figure(4.9): Maximum electricity consumption for cooler by using TES.

From the figure 4.9 shows the maximum consumption of electricity. The maximum consumption is 1080 (kw/6h) when the consumption is so high.

CHAPTER FIVE

CONCULATION AND RECOMINDATION

This chapter summarizes the work done in this project with the sets of the results achieved and which are within the objectives of the project. Finally, leading from this project, several recommendations are made for areas of possible future research**.**

5.1 Conclusion

The tank has been designed according to the principle of thermal energy saving, so the water inside the tank can be used for drinking at any time in the Elsahafa area.

Sawdust wood, glass wool and normal brick have been used as a thermal insulation.The size of the tank chosen due to the consumption. Water has been cooled and stored inside the tank (250L), and the temperature increased with small ratio about(14-19)℃ during 8 hours. Water is cooled during the night, therefore all the factors is available to achieve the process.

In addition to that by using thermal energy storage the electricity energy consumption is minimized obviously comparing without using the thermal energy.

5.2 Recommendation

On the basis of information gained in completing this project, these recommendations are suggested for incorporating into future studies:

1. Other experiments can help to recognize to use better insulation to reduce the thickness of the insulation.
2. Study ability of u00sing evaporator inside the tank directly.

Reverences:

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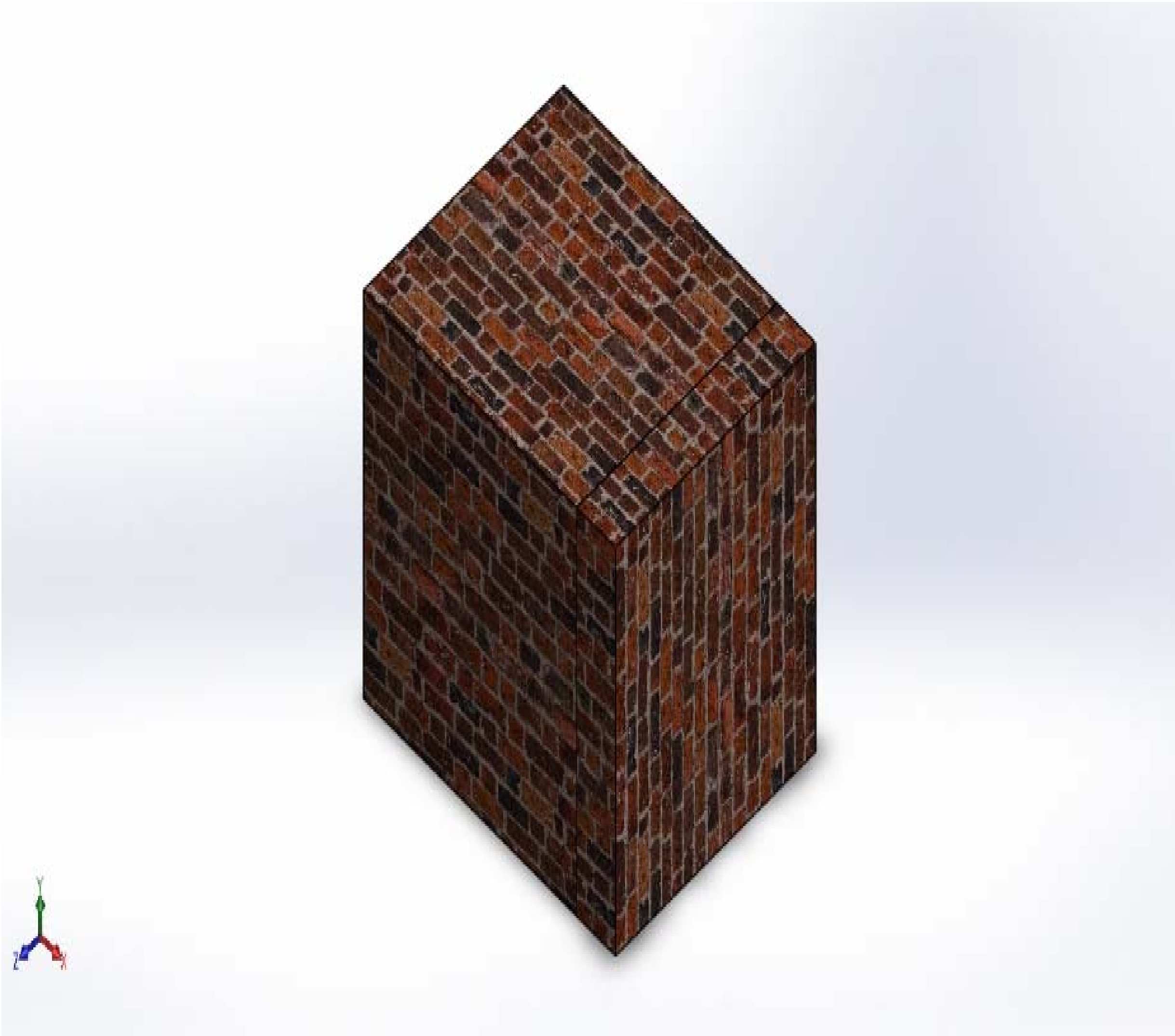
Appendix

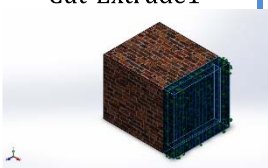
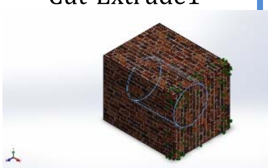
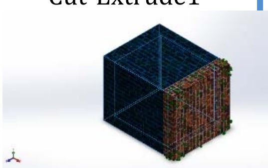
Simulation of thermal energy storage



Model Information

Solidwork design
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude1 	Solid Body	**Mass:2.44273 kg** **Volume:0.00239484 m^3** **Density:1020 kg/m^3** **Weight:23.9388 N**	**D:\MAX\COVER.SLDPRT** Oct 21 05:32:54 2017
Boss-Extrude1 	Solid Body	**Mass:58.32 kg** **Volume:0.0972 m^3** **Density:600 kg/m^3** **Weight:571.536 N**	**D:\MAX\DD.SLDPRT** Oct 21 05:48:17 2017
Cut-Extrude1 	Solid Body	**Mass:295.488 kg** **Volume:0.147744 m^3** **Density:2000 kg/m^3** **Weight:2895.78 N**	**D:\MAX\HAT.SLDPRT** Oct 21 05:54:31 2017
Cut-Extrude1 	Solid Body	**Mass:313.783 kg** **Volume:0.522971 m^3** **Density:600 kg/m^3** **Weight:3075.07 N**	**D:\MAX\Part1.SLDPRT** Oct 21 05:27:08 2017
Cut-Extrude1 	Solid Body	**Mass:17.5727 kg** **Volume:0.0172281 m^3** **Density:1020 kg/m^3** **Weight:172.213 N**	**D:\MAX\TANK.SLDPRT** Oct 21 05:31:49 2017
Cut-Extrude1 	Solid Body	**Mass:1014.12 kg** **Volume:0.50706 m^3** **Density:2000 kg/m^3** **Weight:9938.38 N**	**D:\MAX\WALL.SLDPRT** Oct 21 05:39:55 2017

Boss-Extrude1 	Solid Body	**Mass:265.485 kg Volume:0.265485 m^3 Density:1000 kg/m^3 Weight:2601.75 N**	**D:\MAX\WATER.SLDPRT** Oct 21 05:42:36 2017

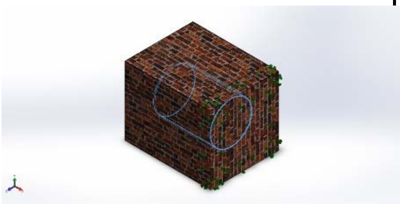
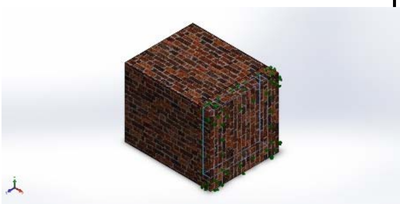
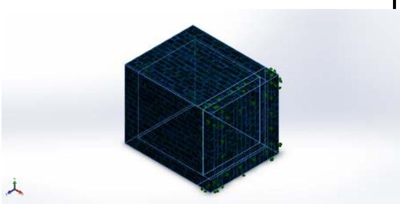
Study Properties

Study name	Thermal storage
Analysis type	Thermal(Steady state)
Mesh type	Solid Mesh
Solver type	FFEPlus
Solution type	Steady state
Contact resistance defined?	No
Result folder	SOLIDWORKS document (D:\MAX)

Units

Unit system:	SI (MKS)
Length/Displacement	Mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

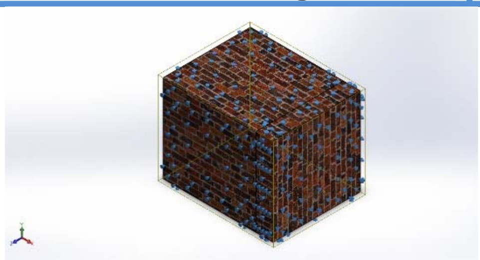
Material Properties

Model Reference	Properties	Components
	**Name:** tank (3) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Thermal conductivity:** 0.15 W/(m.K) **Specific heat:** 0 J/(kg.K) **Mass density:** 1020 kg/m^3	SolidBody 1(Boss-Extrude1)(COVER-1), SolidBody 1(Cut-Extrude1)(TANK-1)
Curve Data:N/A		
	**Name:** Sawdust wood **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Thermal conductivity:** 0.059 W/(m.K) **Specific heat:** 0 J/(kg.K) **Mass density:** 600 kg/m^3	SolidBody 1(Boss-Extrude1)(DD-1), SolidBody 1(Cut-Extrude1)(Part1-1)
Curve Data:N/A		
	**Name:** Brick (4) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Thermal conductivity:** 0.51 W/(m.K) **Specific heat:** 0 J/(kg.K) **Mass density:** 2000 kg/m^3	SolidBody 1(Cut-Extrude1)(HAT-2), SolidBody 1(Cut-Extrude1)(WALL-1)
Curve Data:N/A		
	**Name:** Water **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Thermal conductivity:** 0.61 W/(m.K) **Specific heat:** 4200 J/(kg.K) **Mass density:** 1000 kg/m^3	SolidBody 1(Boss-Extrude1)(WATER-1)
Curve Data:N/A		

Thermal Loads

Load name	Load Image	Load Details
Temperature-1		**Entities:** 1 face(s) **Temperature:** 288 Kelvin
Convection-1		**Entities:** 9 face(s) **Convection Coefficient:** 45 W/(m^2.K) **Time variation:** Off **Temperature variation:** Off **Bulk Ambient Temperature:** 318 Kelvin **Time variation:** Off

Contact Information

Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component (s) **Options:** Compatible mesh

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	115.978 mm
Tolerance	5.79891 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Mesh information – Details

Total Nodes	13375
Total Elements	8933
Maximum Aspect Ratio	28.294
% of elements with Aspect Ratio < 3	85
% of elements with Aspect Ratio > 10	12.3
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:05
Computer name:	ALMUSHARAF