EXPERIMENTAL INVESTIGATION OF DOMESTIC DISHWASHER GREYWATER THERMAL ENERGY RECOVERY BY COMPACT HEAT EXCHANGER

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ABSTRACT

M. Sc. Thesis

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In this study, we investigated to recover heat energy by a heat exchanger which is in two different type is used from the greywater of the dishwasher to heat the tap water comes to the dishwasher during the washing process. We aimed to get saving from the consuming energy of dishwasher to heat water during the dishwashing process. Shell and tube, and shell and wire on tube type heat exchangers separately connected to the dishwasher during experimentations. Experiments were completed on the device, in two cases that were unloaded and loaded and in three different dishwashing programs such as economy, quick and intense. The saving rate was dependently compared and estimated for each program, type of attached heat exchanger and the load condition of the dishwasher. As a result, in unloaded case by the attachment of shell and tube heat exchanger, the saving rate were calculated about 1.49%, 1.90%, and 2.71% for

programs in the order as economy, quick and intense. In loaded case, the same experiments were repeated, and the saving rates were determined about 1.65%, 1.27%, and 4.17%. Then, we had changed the heat exchanger with shell and wire on tube type, and in the unloaded case the experiments were repeated to get the new configuration energy saving performance. For the case, the saving rates were assessed about 13.10%, 13%, and 16.68%, in some washing program order. Lastly, dishwasher was fully loaded again, and the experiments were done in the same order. The energy efficiency increase was gotten in this new configuration were reached about 14.11%, 15.48% and 15.70% for three programs. The average energy consumption of dishwasher with heat exchanger attachment under loaded case was calculated by estimating the average of three different programs dependently the usage habit of an average family under loaded case. Annual, 280 washing cycle consumption of an average family were determined about 51 kWh. The economic value of this saving approximately equals to $ 5.61 for per device by heat recovery application. The estimated price of the equipping a dishwasher with a heat exchanger approximately is $ 35. The payback period could be estimated about at least 6.2 years. By the saving of electricity, annual carbon emission of a dishwasher could be eliminated about 18.83 kg annually for per machine, too. The indirect positive effect of this study raising the awareness about the possibility of wasted energy recoverability from dishwashers to the producers and researchers who are busy to decrease energy consumption of these goods.

Key Words : Dishwasher, heat exchanger, greywater thermal energy recovery, carbon emission.

Science Code : 91408

ÖZET

Yüksek Lisans Tezi

EV TİPİ BULAŞIK MAKİNESİ ATIK SU TERMAL ENERJİSİNİN KOMPAKT ISI EŞANJÖRÜ İLE GERİ KAZANIMININ DENEYSEL OLARAK ARAŞTIRILMASI

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Bu çalışmada, yıkama işlemi sırasında bulaşık makinesine alınan şebeke suyuna iki farklı ısı eşanjörü kullanarak bulaşık makinesi atık suyunun ısıl enerjisinin geri kazanımını araştırdık. Bulaşık yıkama sürecinde bulaşık makinesinin suyu ısıtmak için tükettiği enerjiden tasarruf sağlamayı amaçladık. Gövde borulu ısı değiştirici ve gövde borulu tel kanatlı ısı değiştirici olmak üzere ayrı ayrı bulaşık makinesine bağlanan eşanjörlerle deneyler tamamlanmıştır. Deneyler makinenin yüklü olmadığı ve yüklü olduğu iki farklı durumu ve üç farklı ekonomi, hızlı ve yoğun programları için tamamlandı. Tasarruf miktarı her bir programa, bağlanan ısı değiştiricinin türüne ve bulaşık makinesinin yüküne bağlı olarak karşılaştırıldı ve değerlendirildi. Sonuçta, bulaşık makinesinin yüklü olmadığı ve gövde borulu ısı değiştiricinin makineye bağlandığı durum için sağlanan tasarruf oransal miktarı yaklaşık olarak %1,49, %1,90,

ve %2,71 olarak ekonomi, hızlı ve yoğun programları için hesaplandı. Yüklü durum için, aynı deneyler tekrarlandı ve tasarruf oransal miktarları %1,65, %1,27, ve %4,17 olarak belirlendi. Sonra, ısı değiştiricini gövde borulu tel kanatlı ısı değiştirici ile değiştirdik ve deneyleri bu yeni durum için makinenin yüklü olmadığı durumda tekrarlayarak enerji tasarrufu performansını elde ettik. Bu durumda, tasarruf oransal miktarları yaklaşık %13,10, %13, ve%16,68, olarak aynı program sırası ile belirlendi. Son olarak bulaşık makinesi tamamen yüklenerek deneyler aynı sırada tekrarlandı. Enerji verimindeki artış, bu yeni durumda yaklaşık%14,11, %15,48 ve %15,70 değerlerine üç farklı program için ulaştı. Bulaşık makinesinin ısı eşanjörü bağlantısı ile ortalama enerji tüketimi sıradan bir ailenin kullanım alışkanlıklarına bağlı olduğu için üç farklı programın enerji tüketimi ortalaması alınarak hesaplandı. Yıllık, ortalama bir ailenin 280 çevrim bulaşık yıkama süreci için enerji tüketimi 51 kWh olarak belirlendi. Enerji geri kazanımı ile tasarruf ekonomik değeri makine başına yaklaşık $ 5,61 olarak belirlendi. Bir bulaşık makinesinin ısı değiştirici ile donatımı yaklaşık olarak $ 35 olarak değerlendirilmektedir. Geri ödeme süresi 6,2 yıl olarak belirlenir. Yıllık makine başına 18,83 kg karbon emisyonunun elimine edilmesi elektrik tüketiminden sağlanan tasarruf ile mümkün olabilir. Çalışmanın dolaylı pozitif katkısı, bulaşık makinesi atık ısının geri kazanılabilirliği konusunda beyaz eşyaların enerji tüketiminin azaltılması konusuna ilgi duyan üreticiler ve araştırmacılarda farkındalığın artırılması ve katkı sunmasıdır.

Anahtar Kelimeler : Bulaşık makinesi, ısı eşanjörü, atık su termal enerjisi geri kazanımı, karbon emisyonu.

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SYMBOLS

A : Heat transfer area

A_{in} : Outer heat exchange surface area

A_{out} : Outer heat exchange surface area

AEc : Annual energy consumption of the household dishwasher

c_p : Specific heat

D_{in} : Inner diameter of tube

D_{out} : Outer diameter of the tube

EEI : The energy efficiency index

f_i : The inner side friction coefficient

h_{in} : Inner side heat transfer coefficient

h_{out} : Outer side convection coefficient

k : Thermal conductivity

$\dot{m}$: Mass flow rate

R : Total thermal resistance

R_{in} : Inner thermal resistance

R_{out} : Outer thermal resistance

Re : Reynolds number

Pr : Prandtl number

$\dot{Q}$: Heat transfer rate

$SAEc$: Standard annual energy consumption of the household dishwasher

ΔT : Temperature difference

T_{in} : Inlet temperature

T_{out} : Outlet temperature

ΔT_{lm} : Logarithmic mean temperature difference

$T_{hw,in}$: Inlet hot fluid temperature

$T_{cw,out}$: Outlet cold fluid temperature

U : Overall heat transfer coefficient

ABBREVITIONS

$WWHR$	: Waste Water Heat Recovery
$PN-EN\ 12056-1:2002$	: International Standard for Greywater Reuse
COP	: Coefficient of Performance
BSH	: Bosch Company

PART 1

INTRODUCTION

Technological developments increase in income and well-being, easy access, and increase in the amount of consumption cause large consumption of energy sources, and thus consumption that increases the rates of environmental pollution. Where the residential sector represents about 25% of global energy consumption and 17% of global CO_2 emissions [1]. Increased energy demand, observed worldwide, is forced to take measures aimed at managing it more effectively. The European Union countries are applying with regard to improving energy efficiency by increasing the share of renewable energy sources and reducing the negative impact of the energy economy on the environment. One practical way to achieve these goals is to use waste heat from wastewater. Currently, many European countries are implementing technical solutions that allow the recovery of part of the lost heat and the management of recovered energy as an alternative energy source for the building, for heating water or heating buildings or as a source of refrigeration for air conditioning during the summer. All this can be accomplished by using appropriate devices such as heat exchangers that can be installed in buildings and sewage systems [2]. Gray wastewater is water consumed from bathtubs, automatic washing machines, or dishwashers. a temperature of about 30 °C. In the regulations an important reference is the record number PN-EN 12056-1: 2002 for the possibility of using gray wastewater, separating the greywater sewage system to install a heat recovery system [3]. Modern technologies allow the collection of heat from wastewater also in its transmission stages, i.e. in the collecting tube. The temperature of the wastewater decreases before it flows to the wastewater treatment plant, which can adversely affect the biological processes taking place there [4]. Sewage heat energy can be obtained in several places in the sewage system: near the place of its formation and its exit to the sewage system, in its transmission stage, i.e. in the collecting pipe, and when the collector exits the sewage treatment plant, near the hot water outlet from hardware [5].

1

Domestic greywater could be evaluated as energy losing point of houses because 60% of the water is heated to use in showers, sinks, dishwashers, and clothes washers. This heat, nowadays lost into the sewer system, could be make the greywater a carrier of heat [6]. Recently, investigations on improving energy efficiency are getting more important for domestic appliance sector like the other sectors [7]. There are various design options for improving the energy efficiency of dishwashers, which show the potential for energy savings [8]. These reports published with design options that have technical feasibility in the future and provide economically low energy consumption values for the consumers [9,10].

There are two ways to achieve dishwashing thermal improvement:

- Increase thermal insulation
- Reduce cabin energy storage

Reducing energy storage in the cabinet is possible by using materials with a lower thermal capacity. Steel, which is generally used, has a much lower heat storage coefficient (0.5 kJ/kg °C) than most materials including polypropylene (1.3-1.7 kJ / kg °C). These values indicate that at least 3 times lighter construction is required to use polypropylene as the boiler material [11]. Recovery of the waste heat energy of dishwasher greywater line could be a new subject of the researchers and producers who are working on the field to decrease energy consumption of the dishwashers. In this thesis, we have tried to recover the heat from the drain greywater of a dishwasher to preheat the refill water. We aimed to decrease energy usage of the dishwasher for per cycling dishwasher process. A household dishwasher has some of different washing procedures. Most of the dishwashers have quick, economy, and intensive programs to use. Each program has subprocesses due to the load and time requirements. Quick program generally specialized for lightly soiled dishes, to clean them speedily. It composts main washing, rinsing and drying subprocesses. Economy program or called normal program is a daily useable program for normally dirty dishes. It generally consists prewashing, main washing, rinsing and drying subprocesses. Intensive program is the heavily soiled dishes cleaning requirement could be satisfied with an order of sub processes that are prewashing, main washing, first rinsing, second

rinsing and drying. Some of the sub processes needs heating of water and at the end of process heated water is directly rejected to the drain. The heat content of this drained water could be saved to the refill water of the ongoing water required process. In this thesis, a compact heat exchanger attachment is between the drain line of the dishwasher and the refill tap water line was studied. Devices for which heat transfer between the hot fluid and the cold fluid are generally referred to as heat exchangers. Heat exchangers are a good field of application of materials, strength, thermodynamics, and heat transfer science which are the basic subjects of engineering branches. In engineering applications, heat transfer between two or more fluids at different temperatures is important. The heat transfer between the fluids takes place by conduction and convection. Fluids often used in heat exchangers are separated by a solid surface, which is generally metal material, where heat transfer is carried out without mixing with each other. Such heat exchangers are called surface heat exchangers. Heat exchangers are used in various processes; they are used in power, automotive, air-conditioning, cooling, cryogenics, heat economy, manufacturing industry, electronic devices, and alternative energy sources. They can be in different designs, sizes, types, and capacities depending on the purpose of use. The design of the heat exchangers is quite complex. Heat transfer, pressure drop analysis, dimensioning, size, performance determination and economical are important factors for design. Cost-effective factors for power plants and chemical processing units are among the key factors in places that require extensive placement and use, but the weight and size limitation is the deciding factor.

By combining the pipes in which hot and cold fluids flow, and by assembling the ends of the pipes in a sleeve, it is possible to obtain large heat transfer surfaces in a very economical and practical manner. The simplest of these types of heat exchangers are single pass. If the current in the pipes is low, low heat transfer coefficient and low pressure drop. Disadvantages due to low speed in single pass hot flow pipes can be removed by using multiple pass pipes [12]. A multi-pass design reduces the cross section of the fluid but increases the fluid speed. As a result, heat transfer coefficient, friction losses and input losses increase. If a heat exchanger is economically designed, the increased energy consumption for pumping the fluid in the pipes must be met by a reduction in the cost of the device. In these heat exchangers, the pumping costs at low

speeds are also low, but the heat exchange is too slow. Therefore, the increase in speed increases both energy consumption and heat exchange. If more than one pipe is required for each inlet, a double pipe heat exchanger is recommended as the simplest heat exchanger. This type of heat exchanger consists mainly two pipes in the same center. The fluid flows through the internal pipe, while the other flows in parallel or in the opposite direction, through the spaces between the pipes [13]. In the heat exchangers, the works for saving materials and energy have increased. Especially because the world is entering into a big energy bottleneck, more efficient use of existing energy comes to the fore. For this purpose, the design of smaller size heat exchangers for a certain capacity has been prioritized. By using techniques to increase the efficiency of heat transfer, it is aimed to reduce the size of the heat exchangers, increase the thermal efficiency by adapting the different flow profiles while reducing the need for pumping and additional energy. By reducing the temperature difference between hot and cold fluids and improving the heat transfer coefficient, the efficiency of the heat exchangers is increased.

The heat exchangers used in practice are classified according to the following parameters:

- Form of heat transfer process
- Unit volume of heat transfer area
- Design shape
- Flow regulation of fluids
- Heat transfer mechanism

According to that, heat exchangers can be examined in two classes as direct-contact and indirect-contact heat exchangers. In the direct-contact heat exchangers, the heat is transferred from the hot fluid in contact with each other to the cold stream. Generally, one of the fluids is liquid and the other one is the vapor pressure is very low. In the case of indirect-contact heat exchangers, the heat is first transferred from the hot fluid to the wall separating the two fluids and from the wall to the cold fluid [14]. According to the shape of the structure, heat exchangers can be grouped as tube, sheet, flap-tube, vane-plate and regenerative heat exchangers. Tube heat exchangers are easily

manufactured and cheap and are the most widely used heat exchangers in practice. It generally consists of a bundle of tubes placed in a cylindrical body. Routers are used to guide the flow and support the pipe bundle. One fluid flow through the tube bundle and the other. The flow of two fluids is also provided by pumps. Heat transfer mechanism is also forced transport. If one of the fluids is gas, fins are added to the surface of the gas fluid to increase the heat transfer area. The cylindrical body is closed by two ends [15].

Tube heat exchangers: in this type of heat exchangers, elliptical, rectangular and generally circular section pipes are used. It provides great convenience in projecting due to the easy change of pipe diameter, length and arrangement. In addition, this type of heat exchangers can be used at high pressures because the circular section pipes can withstand high pressures compared to other geometric shapes. In practice, as well as double-pipe ones, varieties made of pipe bundle are also found. The ones with double pipes are the simplest type of heat exchanger. The system is usually made of two pipes with the same axis. When one of the fluids flows through the inner tube, the other fluid flows through the outside pipe. Fluid flow directions may be parallel or inverse flow. It can be installed in series to increase the thermal capacity and heat transfer surface.

Spiral plate heat exchangers: vertical and longitudinal sections of these heat exchangers are obtained by spiraling the two thin metal plates. A proper spacing can be provided with studs placed between two sheets. Both sides of the plates are sealed with gasketed caps. Fluids can flow in parallel or opposite directions. Since it is easy to clean, this heat exchanger is very suitable for viscous fluids which can make residues. Pressure losses are less than that of body tube and plate seal heat exchangers. Therefore, such heat exchangers are particularly preferred in paper, cellulose industry, sulphate and sulfite plants [16]. If desired, spiral plate heat exchangers can also be used as evaporators. Due to the limited size of the material, maximum 10 bar pressure and 500 ºC temperature due to the sealing material and the difficult to repair can be counted as the drawbacks of these heat exchangers.

Lamella Heat Exchangers: this heat exchanger is obtained by placing a tube bundle which is flattened into a body. These pipes are called lamellae and are usually attached

to each other by point or electric seam welding. One fluid flow through flattened lamella tubes, while the other fluid flows through these lamellae. There are also no detonation plates in the body. The flow is single-pass and the fluids can flow in reverse or parallel with each other. Since the hydraulic diameter is small, the heat transfer coefficients can be obtained quite high.

Wing surface heat exchangers: in general, the surface area density (compactness) is less than 300 m^2/m^3 and the thermal efficiency is less than 60%. If the heat and heat efficiency of such heat exchangers is to be increased, the heating area can be increased by adding the protuberances to the main heating surfaces. In principle, wings are placed on the side of the fluid (usually gas, sometimes liquid) where the heat transfer coefficient is small. In this case, the additional pressure losses generated by the protuberances added to the surfaces should not be kept out of sight, although a smaller volume of heat transfer can be provided. Therefore, the most suitable additional surfaces (wing profiles) should be investigated [17].

Tubular fin heat exchangers: on one side of the gas, on the other side of the liquid-flowing heat exchangers, the heat transfer coefficient on the liquid side is higher, so mostly the fluid side does not require a wing. On the other hand, because the geometry of the strength is cylindrical, the high-pressure fluid in the heat exchangers (usually the pressure on the fluid-side side is higher than the pressure on the gas side, so liquid fluid) flows through the pipe. Accordingly, in practice, the circular or oval section is more often compared to the winged surfaces outside the pipe. Another example of pipe-finned heat exchanger is the hot gas used in gas turbines and the recuperate where the combustion air is heated. The high-pressure gases flow through the pipes and the air flows out of the pipes. Since air velocity on the air side with low pressure is smaller and the heat transfer coefficient is smaller than the inner side, axial vanes are added to this section. In cases where the heat transfer coefficient of the fluid in the pipe is small, wings may be added to both the inner surface and the outer surface if the heat transfer coefficient is relatively small on both sides of the pipe or on both sides of the pipe. These vanes are generally designed in axial position. Wings can be manufactured together with the pipe, or subsequently welded to the pipe by welding, soldering or tight fitting. The operating temperature of the heat exchanger depends on this type of

detection, the surface area density of β can reach up to 3300 m^2/m^3. The application areas of these types; power plants, propeller chillers, vehicles, air conditioning and cooling installations [18].

1.1. DESIGN PARAMETERS OF HEAT EXCHANGERS

The design of a heat exchanger should also calculate the pumping power spent in order to allow the fluid to move at a certain speed in the heat exchanger channels as it must be between the intergranular heat transfer in a specified construction frame. Accordingly, the required surface area. In heat exchangers using high density fluids, the energy consumed for pumping is considerably lower than the amount of heat transferred. In heat exchangers with low density (such as air) fluids, it may be necessary to spend an energy equal to the amount of heat energy transferred to ensure the movement of the fluid. This should be taken into consideration especially in applications for thermal power plants where mechanical energy is more important than equivalent heat energy. In general, although the heat passed through the unit area of the heat exchanger surface is directly proportional to the fluid velocity, the mechanical energy need to move in the fluid exchanger channels is directly proportional to a value between the second and third force of the speed. Considering this behavior of the fluid, it should be tried to find the optimum design parameters between heat transfer and pressure drop [19]. Designing an optimum heat exchanger within the framework of the specified data is a very complex process. Therefore, despite the arithmetic complexity encountered, qualitative evaluations should be reached.

As qualitative evaluations in heat exchanger:

- Production cost
- Ease of cleaning
- Fluid temperatures
- Fluid pressure
- Leakage between fluids or from a fluid to the environment

For the solution of heat transfer and fluid dynamics equations for heat exchanger design, optimum solution is reached within the framework of an evaluation method to be applied by the manufacturer in accordance with the information about:

- The limits of the heat exchanger
- The physical properties of the heat exchanger
- The surface heat transfer and friction characteristics

This method of evaluation includes the qualitative factors mentioned earlier, as well as the limitations on the transport of the heat exchanger to the installation site, such as timely completion of production. In the case of a heat exchanger design, the worst operating conditions for which the heat exchanger can operate are determined and the type of heat exchanger that best fits these conditions is selected. Then the standard heat exchanger is measured. For example, the highest pollution at the highest ambient temperature and the design of a working coolant at the highest possible water temperature can be given [20]. After selecting the type of heat exchanger, the detailed calculations should be carried out in parallel with the construction standards by creating the constructive shape of the heat exchanger.

The following factors are determined by evaluating which of the fluids is the body and which is on the pipe side:

- Cleaning: generally, it is more convenient to clean the body side of the pipe bundle and the fluid with low pollution effect is more suitable on the side of the body
- Corrosion: corrosion-resistant heat exchanger manufacturing, corrosion-resistant alloy material is used. If pipes are made of alloy material instead of the body, the cost is reduced. It should be passed through corrosive fluid pipes
- Pressure: high pressure causes the wall thickness to be large. Thus, as the cost of the heat exchanger increases, the bulky appearance also wins. The high-pressure fluid should be on the pipe side
- Temperature: high-temperature fluid on the side of the body causes additional plant costs such as body insulation, as well as the thermal stresses that may

arise, reduce the value of the safety limits. The high temperature fluid should be on the pipe side

- Hazardous and expensive fluids: fluids which influence the cost of the facility due to leakage (toxic) or the loss of the plant due to leakage should be located on the leak side of the exchanger

- Mass flow rate: in general, low flow rate fluid should be located on the body side. Due to the feature of the body side, turbulent flow is obtained in low Reynolds numbers

- Viscosity: if the fluid is flowing on the side of the housing but shows laminar flow, it must be passed through the pipes. Because pipe side heat transfer and pressure drop calculation can be done in a healthier way

- Pressure drop: if the pressure drop is the critical factor in the heat exchanger design, the fluid in which the pressure drop is important should be located on the pipe side [21].

In general, heat exchangers are designed for many applications and performance criteria differ depending on the application. Performance criteria affecting the heat exchanger design include minimum initial investment cost, minimum operating cost, minimum volume, or minimum heat transfer surface area. Defining a single performance value and ensuring its lowest or maximum value is called the objective function in design optimization. In addition, the design can be targeted to meet some of the previously proposed requirements. For example, limitations such as the required heat transfer rate, permissible pressure drop, changer height, width or length can be specified in advance. These values are called design optimization boundary conditions. Many surface geometries can be developed for the given problem and each surface geometry can contain different geometric parameters. For example, the body to pipe heat exchangers may have geometric parameters related to the pipe, deflector, body, rear and front head. As mentioned above, a heat exchanger design comprises a plurality of design variables. The desired result in these conditions is that these design variables are adjusted to give an optimum objective function within the limits given. The mathematical optimization of a heat exchanger design is impossible. For this reason, the various stages in the design require decisions based on experience. However, once the general shape and surface of the heat exchanger have been determined, the

optimum heat exchanger design can be realized if the limitations brought to the heat exchanger and the objective function can be defined mathematically [22].

1.2. HEAT TRANSFER THEORIES

When the flow in a pipe with a circular section is considered, the flow velocity at the beginning after the fluid enters the pipe is changed due to friction in the wall and the viscosity of the fluid. If there is no temperature difference between the wall and the fluid, the velocity distribution varies along the pipe until it gets a certain shape and then does not change along the pipe. The part of the velocity distribution, which is changed from the pipe entrance, is called hydrodynamic input zone and the part where it stays constant is called full developed current zone. Although there is a heat transfer between the fluid and the wall, if the physical properties of the fluid do not change with the temperature, the velocity distribution remains constant after taking its final shape. In the case of heat passing through the pipe walls to the fluid, a temperature boundary layer is formed in the fluid and this layer thickens along the pipe until the axis. This part is called the thermal input zone, and the next part is called the thermally developed zone. If both velocity and temperature distribution are fully formed in the flow, such current is called hydrodynamic and thermally fully developed zone. Because the characters are different, forced transport in the pipe must be examined separately for laminar and turbulent flows [23].

1.2.1. Heat Transfer in Same Directional with Flow Heat Exchangers

In parallel flow heat exchangers in the same direction, one of the fluids generally flows through small diameter pipes, while the other flows through a large diameter pipe through which the pipes are placed, through the intervals between the small diameter pipes. They enter the hot and cold fluid heat exchanger in the same direction.

1.2.2. Heat Transfer in Opposite Directional with Flow Heat Exchangers

In the opposite direction parallel flow heat exchangers, one of the fluids flows through the pipes and the other flows in the opposite direction from the outside of the pipes. If

the section where the hot fluid enters the heat exchanger is defined as the intersection, then the temperature difference in this section is indicated.

1.3. AUTOMATIC DISHWASHERS

The first dishwasher models with automatic continuous water spray system appeared in the 1900 s and were developed with the optimization of washing, rinsing and drying steps, such as basket, propeller, detergent compartment [24]. In this part of the study the working principle of the dishwasher will be explained. When the working principle of the dishwashers varies according to the manufacturer and the washing program, in general; it is seen that it consists of cold and hot washing steps, rinsing and then drying steps. The dishes, cups and cutlery placed in the baskets in a closed system are washed at high temperature fresh water, with mechanical effect and detergent, in hot washing steps. After washing, the rinsing step to remove the detergent and finally the drying of the dishes takes place [6].

This paper provides empirical data on consumers' dishwashing habits in everyday life in four European countries, deals with the influence of their behavior on the efficiency of the dishwashing process and highlights savings potentials in the usage of dishwashers. It reports on the results of a survey involving a total of 1209 online interviews conducted in winter 2006/2007 people answered that the 'normal/regular wash' and 'intensive' programmers get chosen in about 42% of all cycles to clean the dishes. This also implies that in these cases, the dishwasher works with water temperatures around 55–75 °C, the more energy and water-efficient 'eco-wash' programmer, usually working with water temperatures around 50–55 °C, is found in around 80% of all dishwashers but gets chosen in only 17% of all dishwasher cycles. [25]. Water taken into the machine; First it is passed through the water pocket and then through the resin and transferred to the washing chamber. In the washing process, the detergent box is opened, and the detergent is taken into the machine. In the hot washing step, the electric heater is operated, and the washing water is heated to a certain temperature. Circulation continues in this washing step. Washing is continued for a

certain period after the heater has been deactivated, after which the washing step is completed, and the water is discharged.

After completion of the hot wash, water is taken again through the water pocket and resin for rinsing. First rinsing step is carried out with the water taken in this way, after the rinse water is discharged, water is taken for the second rinse again. In the second rinsing step, rinse water is heated to increase the drying efficiency and rinse aid is used in this step. With the use of rinse aid, it becomes difficult to hold the water on the dish surfaces and the dishes are provided to appear brighter at the end of washing [26].

The heating process in the second rinsing step is like the main washing step, after reaching a certain temperature, the step is terminated, and the water is discharged. The last process is drying and for this subprocess dishwasher does not need any water filling.

PART 2

LITERATURE REVIEW

The University of Bonn has produced several papers comparing resource use of different manual dishwashing behaviors and machine dishwashers. These studies involved observing participants manually wash a set of soiled dishes in a laboratory. European manual dishwashing behavior is characterized by three different motives: "super dishwashers" who focused most on cleaning results, "economizers" who cared most about using as few resources as possible, and "carefree washers" who had no regard for cleaning results or resource use [27]. As about 80-90% of energy is wasted in domestic hot water from various applications that are barely used and large energy. The present work examined the characteristics of the greywater heat exchanger as follows: A solution to recover heat from gray water to increase efficiency in buildings. With the study of fluid mechanics involved in greywater heat, the effectiveness of greywater heat exchanger increases with its length and diameter, being the largest tube diameter to achieve higher values. An increase in the number of coils reduces the efficiency of the heat exchanger but is useful for reducing the pressure drop on the device [28]. And much of the water is wasted in sewage and is not treated in many cases. A system has been developed that can extract heat that is present in greywater. In fact, the energy content of that home water is from the heater water, dishwasher, and regular water used in the kitchen: Energy recovery provides heat recovery from 3 to 5 ° C, for the mass flow rate of tap water. The water drain heat exchanger provides real energy savings in the long run, depending on the length of the heat exchanger; we can extract the required amount of heat according to the temperature of the water used [29].

A multifunctional heat pump system is proposed to efficiently utilize greywater as a heat sink for laundries and heating. The heat is retrieved from the heat exchanger of the installed plate at the compressor outlet to provide sufficient hot water for

residential use. The performance of the hot water heating system from 30 °C to 48.9 °C has been studied. The multifunctional heat pump system shows superior performance in heating mode compared to the traditional air source heat pump system. The heating capacity of the space heating of the multifunctional heat pump system in space heating in addition to the hot water supply mode is smaller than that in the space heating mode. However, the COP in the system is in space heating plus the hot water supply mode is even higher in the heating mode in space. The difference in heating capabilities in two modes is less than 12%, while the difference in heating in two modes is less than 6%. Spatial heating in addition to the hot water supply mode is suitable for many operating conditions [30].

Chini et al. quantified water, energy, and electricity demands in the average single family US household, pointed out that appliances and fixtures directly and indirectly use these resources through the energy-water nexus; in this nexus, energy is necessary for the production of water and vice versa. A four-occupant home residence uses 100 gallons per day and the average citizen uses 13,000 kWh of electricity and 720 cubic feet of natural gas annually [31].

A study characterized three different manual dishwashing methods in Europe: dishwashing under running tap water, dishwashing in a water bath, and a combination of both methods. If more than 80% of dishwashing was associated with a behavior, then it was categorized into one of the three manual dishwashing methods [32].

Residential hot greywater and cost-saving, qualitative heat recovery. Energy savings and comparison of recovery times for indoor WWHR systems more accurately. Greywater recovery will reduce the city's residential fuel consumption by 6.3%. Combining greywater heat recovery for preheating hot water and a heat pump produces up to 28% and 41% electricity savings for individual homes and multi-family buildings, respectively. Detailed description and end use, the energy saving quantification has been improved [33].

One person consumes between 40 and 60 liters of hot water daily for bathing and washing. The record for washing dishwasher temperature is between 48 °C and 63 °C, greywater temperature is between 35 °C and 55 °C. The collected dishwasher data

gave that the greywater temperature of the washer was desirable high. It lies within the working temperature range of the proposed heat exchanger for experiment. Data from the dishwasher system led to heat transfer calculations to simulate a proposed heat exchanger system model used in conjunction with this dishwasher [34].

Instead of using a different material for the boiler, it is more reasonable to go to the boiler weight reduction studies. A 5% reduction in weight for a temperature of 65 °C means a total energy gain of 20 Wh. Improvement in thermal insulation can be achieved by reducing thermal bridges between the inner body and the outer body. At 65 °C water temperature, the loss value is 450 W for 2 steel connections that surround the inner body between the inner body and the outer body [35].

Only 50 W of the loss occurs through the insulated space between the inner body and the outer body. If 2 of the 5 connections between the inner boiler and the outer boiler are canceled, the instantaneous heat loss can be reduced to 250 W if there is insulation foam between the boilers. The total loss can be reduced from 340 W to 230 W per cycle [36].

Cleaning of dishes is a function of time, temperature, detergent, and mechanical effect. Heat loss with convection and radiation is around 400 W at 60 °C. This means a heat loss of 7 Wh per minute. Heat loss is 350 W under 55 °C conditions. During the washing phase, the main wash pump draws energy per minute to 2.3 Wh [37].

The temperature drops of 10 °C for the first hot wash will save 197 Wh in standard baseline and 174 Wh in actual baseline. In the basic case, the temperature value is 29 °C instead of 20 °C, since approximately one-fourth of the energy used in the previous washing stages during hot rinsing is stored in the machine and on the dishes [38].

If the water temperature used during the hot wash is lowered, the starting temperature of the hot rinse is also reduced, and the temperature will be 29 °C instead of 34 °C. When all these possibilities are evaluated, the energy consumption value will be 1355 Wh instead of 1476 Wh for the standard baseline and 1205 Wh instead of 1347 Wh in the actual baseline. At the beginning of each phase, the machine receives some water

from the network. While this amount is 5.4 liters per phase, 2.4 liters of water is taken for the renewal of the water softening material [39].

In Garmsiri et al. study, a novel heat pump named multi-functional heat pump systems for dishwashers is introduced. 45 $^{\circ}$C hot water cycle and hot air cycle are provided by the single-stage heat pump cycle to complete the cleaning and drying process. The results show that COP (coefficient of performance) of the system is above 3.2 under all four conditions, which meets the energy efficiency rating index [40].

In other study, a heat recovery system for a dishwasher is proposed and analyzed. The idea is to use the heat coming from the greywater of the dishwasher to heat the fresh water entering the dishwasher. With this an improved design is proposed. Recovery of the heat in the greywater is proven to be economically beneficial [41].

John et al. installed a heat exchanger on the hot water output of the dishwasher to recover the heat from the greywater and transfer it to the cold water feeding the washing machine. Due to the innovative arrangement of drain valves, volume control, and separation of intermediate and cleaning liquid tanks connected to a pump according to the invention, a pre-determined volume of cleaning fluid adapted to the volume of fresh water to be supplied in the intermediate container is then provided ideally in terms of time and volume of the heat exchanger. In this way, it became possible to make smaller dimensions of the heat exchanger [42].

Voorhees et al. used a heat exchanger with a dishwasher-type dishwasher, and the present invention provided an improved heat recovery system in which much of the heat energy in the hot wash solution is drained. It has been tested with many manufactured commercial dishwashers as the energy needed for the dish-washing cycle has been reduced by up to 58 percent [43].

The energy performance requirements appear to be at a high level nowadays. However, an abundance of models with the highest energy class may indicate that technological progress is not fully exploited. Consequently, the energy label categories of the European Union must be revised, to maintain continuous progress - it creates an

incentive for manufacturers to further improve their devices. For household dishwashers, the average power consumption specified for standard programs is reduced by 34% from 1.43 kWh per cycle in 1998 to 0.94 kWh in 2014. Design options "automatic door opening" or "fan" resulted in an average saving of 5% to 8% in impact categories of total power and electricity consumption for design options including "heat exchanger [44].

Greywater contains a large amount of thermal energy irreversibly lost, so it is worth thinking about the possibilities of recovering it. It is estimated that in an entire residential building about 70% of all tap water is discharged to greywater and can be reused [2].

Initial models of the dishwasher and the washing machine, in which the tap water is heated by a hot gray water circulation ring and the heat is transferred to the feeder water of the dishwasher via a heat exchanger [45].

A traditional dishwasher consuming around 1.05 kWh to 0.80 kWh per wash cycle leads to energy savings of about 24%. The average production and operation of dishwasher in BSH is about 2 million per year. Assuming an average of 250 wash cycles per year and a 10-year-old dishwasher, energy savings of 1.125 terawatt hours. Other, these results limit the 500 526 tons of CO_2 emissions within 10 years assuming CO_2 emission 0.5 kg per kilowatt hour [46].

The researchers investigated the possibility of increasing the efficiency of the dishwasher by connecting a solar heating unit to the dishwasher's waterline. After taking and analyzing the results, energy consumption was reduced from 0.76 kWh to 0.66 kWh [47].

Santori et al. done an experimental test of a adsorbent dishwasher that uses various dryers, such as 13X zeolite, small silica gel, and SAPO-34 zeolite. The aim of the work is to improve the performance of the dishwasher using an improved absorbent bed. They got 41% lower energy consumption compared to a standard dishwasher that works with the standard cycle and the energy mark A [48].

PART 3

THEORETICAL BACKGROUND

In this thesis, two different type of heat exchanger was used to recover the energy from the greywater of a dishwasher. The first one is shell and tube and other one is shell and wire on tube heat exchanger. The theoretical base of the study is summarized with equations from eqs. (3.1) to (3.10). The rate of heat transfer could be calculated by the equations are given as eq. (3.1) and eq. (3.2).

$$\dot{Q} = \dot{m}c_{avg}(T_{in} - T_{out}) \tag{3.1}$$

$$\dot{Q} = UA\Delta T_{lm} \tag{3.2}$$

The logarithmic mean temperature difference (ΔT_{lm}) is described as in eq. (3.3).

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln \Delta T_1 / \Delta T_2} \tag{3.3}$$

ΔT_1, and ΔT_2, present the temperature differences between hot and cold fluid and are given in eq.(3.4) and eq. (3.5).

$$\Delta T_1 = T_{hw.in} - T_{cw.in} \tag{3.4}$$

$$\Delta T_2 = T_{hw.out} - T_{cw.out} \tag{3.5}$$

Logarithmic mean temperature difference for the finned coil heat exchanger is given in eq. (4.6).

$$\Delta T_{lmtd} = \frac{\Delta T_1 - \Delta T_2}{\ln \Delta T_1 / \Delta T_2} = \frac{(T_{hw.in} - T_{cw.in}) - (T_{hw.out} - T_{cw.out})}{\ln(\frac{T_{hw.in} - T_{cw.in}}{T_{hw.out} - T_{cw.out}})} \tag{3.6}$$

The overall heat transfer coefficient (U) is the reciprocal of the total thermal resistance (R). Total thermal resistance is given in eq. (4.7).

$$\frac{1}{UA} = R = R_{in} + R_{cw} + R_{out} = \frac{1}{h_{in}A_{in}} + \frac{I_nD_{out}/D_{in}}{2\pi KL} + \frac{1}{\eta_o h_{out}A_{out}} \tag{3.7}$$

The tube inner side heat transfer coefficient (h_{in}) is given in eq. (4.8) [49].

$$h_{in} = \left[\frac{k}{D_{in}}\right] \frac{(Re_{in}-1000)\,Pr(f_i/2)}{1+12.7\,\sqrt{f_i/2}\,(Pr^{2/3}-1)} \tag{3.8}$$

The inner side friction coefficient (f_i) is given in eq. (4.9) [49].

$$f_i = (1.58In(Re_{Di}) - 3.28)^{-2} \tag{3.9}$$

Household appliances classed and labeled due to their energy efficiency. The energy efficiency rate is determined by the energy efficiency index (EEI) as seen in eq. (3.10).

$$EEI = \frac{AE_c}{SAE_c} \times 100 \tag{3.10}$$

AE_c is the annual energy consumption of the household dishwasher, SAE_c = standard annual energy consumption of the household dishwasher.

PART 4

METHODOLOGY

This study aims to raise the efficiency of a dishwasher by connecting a heat exchanger that is between the greywater discharge line and fresh refilling water line to recover heat from discharge greywater, as can be seen in Figure 4.1.
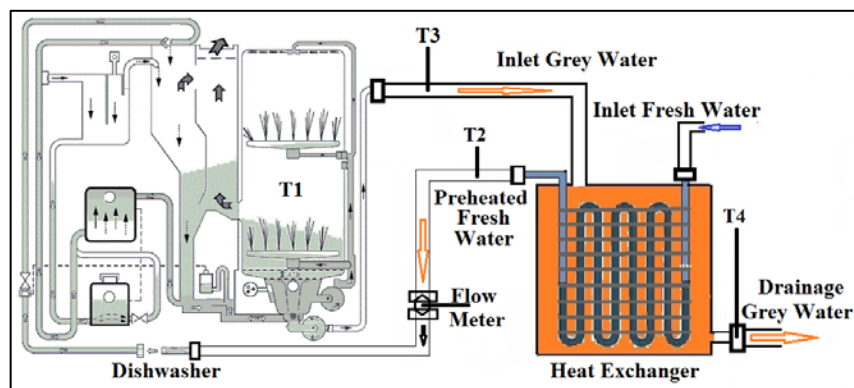
Figure 4.1. The scheme of experimentation setup [50].

The equipment's described in the Figure 4.1 will be used and they are the following:

- Dishwasher
- T-TechnicPM6907C digital wattmeter
- Four-pole heat exchanger input and output temperature measuring by CEM DT – 3891G datalogger and K-type thermocouple
- YF-S201 water flow sensor and Arduino Uno couple
- Heat exchangers (a shell and tube and shell and wire on tube)
- Connection pipes and fixing equipment's

Where the heat exchanger is connected the output of the greywater from the dishwasher and the input water feeding the dishwasher. The process of heat exchange between the water coming out of the dishwasher to the water entering. Connected a

flow meter on the tap water line to measure the amount of water entering each wash subprocess. Positioned thermocouples were used to measure the water temperatures the input and the output line of the greywater of the heat exchanger, and preheated water inlet point of dishwasher. This experimental study will try to reduce the consumption of electricity used to operate the dishwasher by installing two types of compact heat exchangers with a different surface area, as shown in the following figures. Most shell-and-tube heat exchangers are either 1, 2, or 4 pass designs on the tube side. This refers to the number of times the fluid in the tubes passes through the fluid in the shell. In a single pass heat exchanger, the fluid goes in one end of each tube and out the other. The used heat exchanger in the experimentations were given in Figures 4.2 and 4.3.
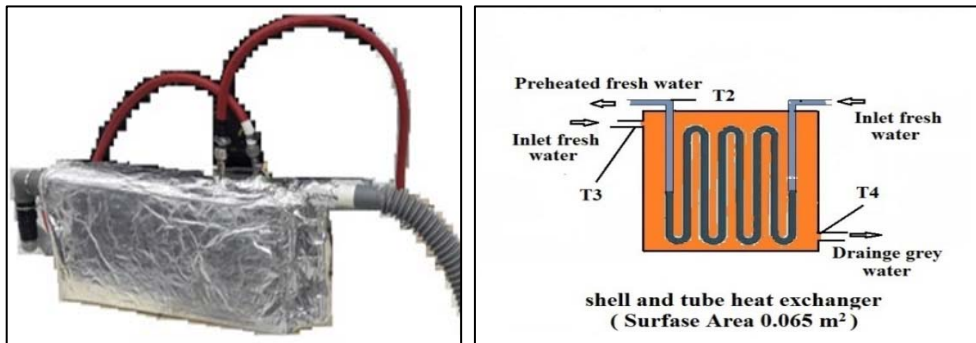
Figure 4.2. Shell and tube heat exchanger.

The first heat exchanger is attached to the dishwasher is shell and tube type and flow configuration is given in Figure 4.2. The heat exchange surface area of it is about 0.065 m^2.
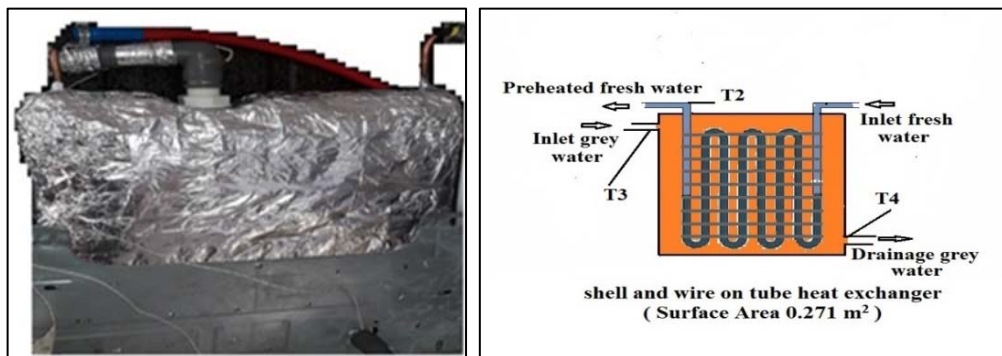
Figure 4.3. Shell and wire on tube heat exchanger.

The second heat exchanger that is attached to the dishwasher is shell and wire on tube heat exchanger and the flow configuration is seen in Figure 4.3. The surface area of this type of heat exchanger is approximately 0.271 m².
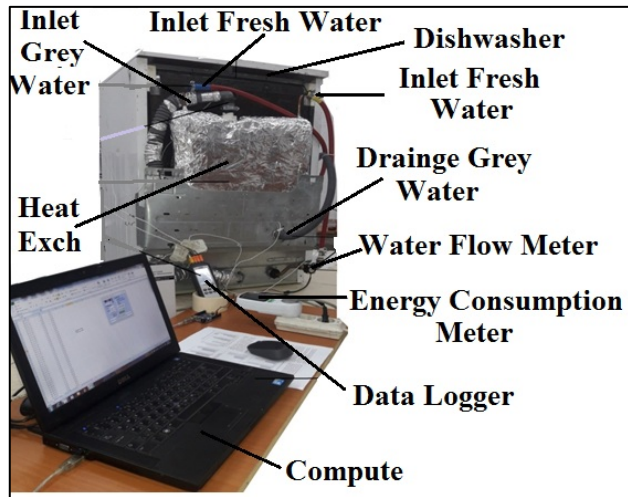
Figure 4.4. The experimentation setup and its components.

The figure 4.4 shows the experimentation setup and its components that are:

- Computer
- Energy consumption meter
- Water flow meter
- Dishwasher
- Greywater drainage (outlet from heat exchanger)
- Water outlet from heat exchanger (inlet to dishwasher)
- Water inlet to heat exchanger (cold tap water)
- Greywater inlet to heat exchanger (outlet of machine)
- Heat exchanger
- Temperature measuring device (Data logger)
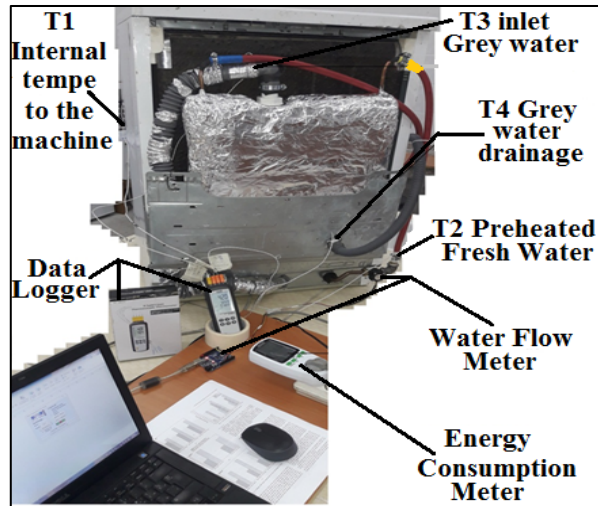
Figure 4.5. The temperature reading points on the experimentation setup.

The Figure 4.5 shows the temperature reading points on the experimentation setup.

- T1 (Internal temperature to the machine)
- T2 (Inlet tap water to the dishwasher from the exit of heat exchanger)
- T3 (Greywater inlet to heat exchanger from dishwasher)
- T4 (Greywater drainage to main drain)

Four points were taken to read the temperature in the experiment to compare them in each wash cycle and each stage in each wash cycle (T1, T2, T3 and T4). The tap water temperature was measured separately before the experimentations and was determined about 20 °C. We have determined and compared the heat recovery performance of the two different heat exchanger attachments to the dishwasher. The dishwasher energy consumption and saving capability by the heat exchangers attachment were compared for fully load and unloaded conditions of the dishwasher.

The specifications of the shell and tube heat exchanger can be defined as below:

- Length of pipe of small heat exchanger: 2.60 m
- Size of tank of small heat exchanger: 40.5 cm x 21 cm x 6.5 cm
- Capacity of shell side: 5.350 L
- Heat exchange surface area: 0.065 m^2

Figure 4.6 (a, b) presents the shell and tube heat exchanger with and without isolation. The components of shell and tube heat exchanger as can be seen in Figure 4.6 (b), are as follow:

- Tank
- Pipe
- Greywater inlet to the heat exchanger from dishwasher
- Water outlet from heat exchanger to in the dishwasher
- Water inlet to heat exchanger from the tap
- Greywater outlet from heat exchanger to main drain.

| (a) | (b) |
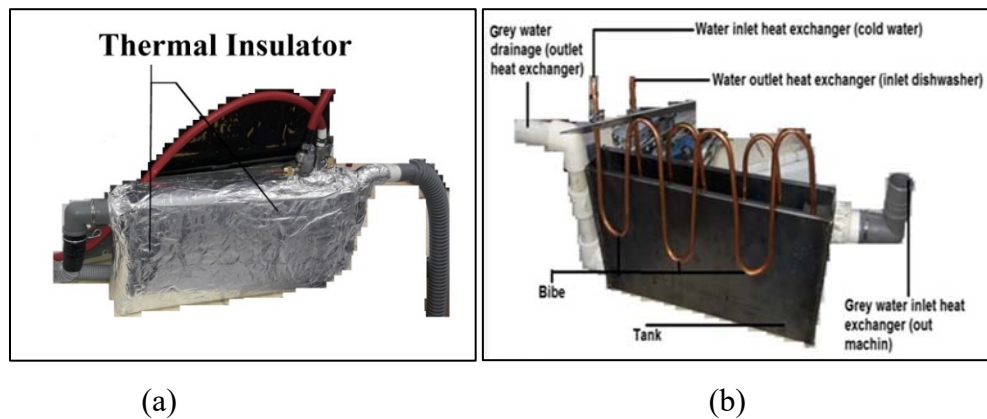
Figure 4.6. The shell and tube heat exchanger with (a) and without (b) heat isolation.

The specifications of shell and wire on tube heat exchanger can be summarized as:

- Length of pipe of big heat exchanger: 10.80 m
- Size of tank of big heat exchanger: 45 cm * 40 cm * 5 cm
- Capacity of tank of big heat exchanger: 7.200 L
- Surface Area of big heat exchanger: 0.271 m^2

Figure 4.7 (a, b) presents the shell and wire on tube heat exchanger with and heat isolation.

The components of shell and wire on tube heat exchanger as can be seen in Figure 4.7 (b), are as follow:

- Tank
- Pipe
- Greywater inlet to the heat exchanger from the dishwasher
- Water outlet from heat exchanger to inlet dishwasher

<center>(a)   (b)</center>
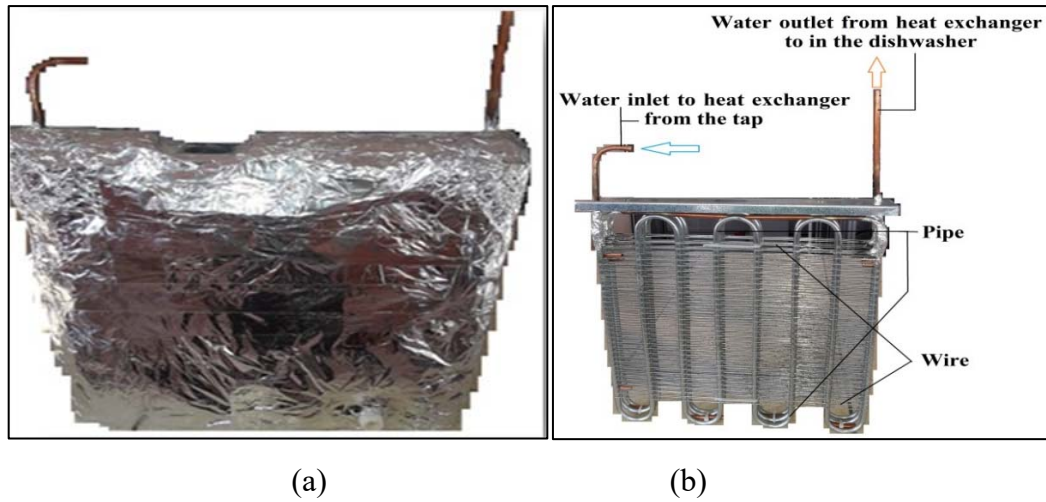
Figure 4.7. The shell and wire on tube heat exchanger with (a) and without (b) heat isolation.

PART 5

RESULTS AND DISCUSSION

In this section we assessed the measured data by the attachment of two different type of the heat exchanger to the dishwasher. The black curves on the graphs designates the temperature inside the dishwasher (T1). Red curves show the temperature of the preheated water in the heat exchanger and enters to dishwasher (T2). Blue curves present the temperature of the greywater leaves from the dishwasher and fills into the heat exchanger (T3). Green curves present the temperature of the greywater discharging from heat exchanger to main drain line (T4). The time is given in the horizontal axis of the graphs and the temperature data were shared in the vertical axis of the graphs.

5.1. EXAMINING THE ECONOMY PROGRAM FOR THE CASE THAT THE DISHWASHER IS UNLOADED

The Figure 5.1 present the measured temperature data of the dishwasher without heat exchanger attachment and for unloaded condition of dishwasher.

Figure 5.1. Temperature variation during the economy cycle in unloaded case of dishwasher without heat exchanger attachment.

The full time of cycle takes approximately about 135 minutes. The economy cycle also composts of prewashing, main washing, first and second rinsing and lastly drying subprocess in the order. The average water temperature for prewashing is approximately 21.8 °C. The prewashing process also takes about 15 minutes. At the end of prewash, the water is discharged and dishwasher refills from tap to do main washin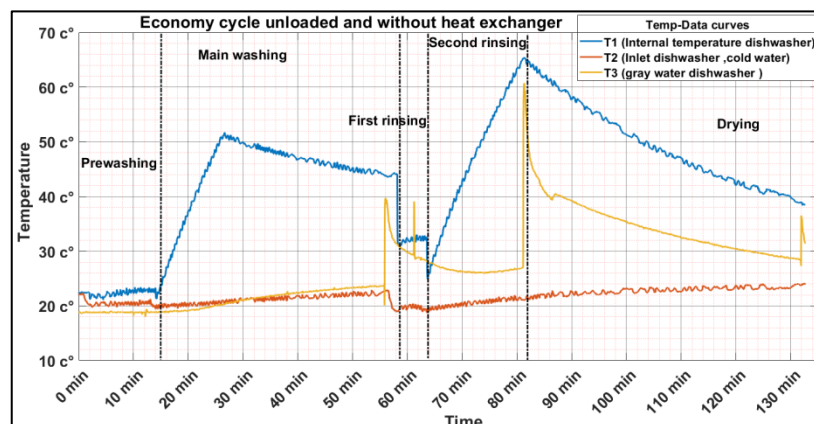g. Then, the main washing process occurs with the average water temperature is approximately about 46.6 °C and the process takes about 43 minutes. By the completion of main washing, the water discharged again, and the dishwasher refilled with tap water. The first rinsing process completes about in 5 minutes and the water discharged from dishwasher at an average temperature about 32.5 °C. By the refilling of the dishwasher, the second rinsing starts and takes about 18 minutes. The average water temperature is approximately about 48 °C during the second rinsing process. The cycle completes with the drying process and it takes about 54 minutes. The total energy consumption of the dishwasher was measured about 0.872 kWh.

The Figure 5.2 shows the measured temperature data of experimentation process of the dishwasher for the economy cycle unloaded case with the attachment of shell and tube heat exchanger.
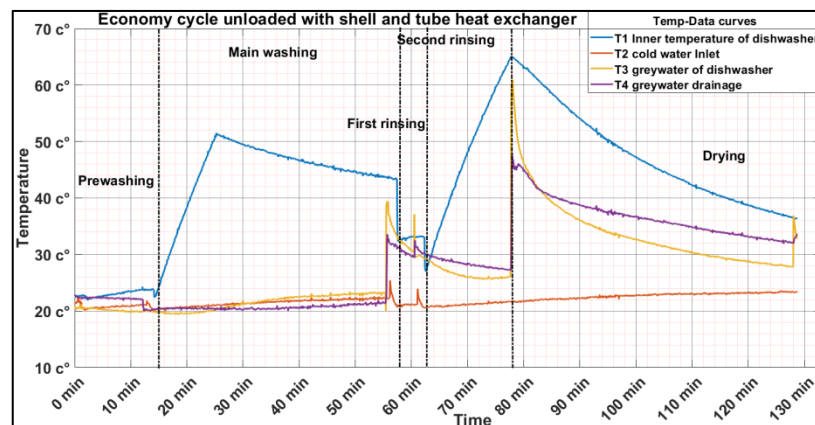

Figure 5.2. Temperature variation during economy cycle in unloaded case of dishwasher with shell and tube heat exchanger.

The total cycle time is approximately about 133 minutes. The prewashing period occurs approximately at 12.8 °C and completes in 15 minutes. The discharge water of prewashing meets with the refilling water to main washing. The tap water heated to 21

ºC. The main washing takes about 43 minutes at an average temperature of 45.5 ºC. By the completion of the main washing the discharge water heats the refill water 24.7 ºC in the heat exchanger during the refilling process. The first rinsing process takes about 5 minutes and with the average temperature of 33.5 ºC, the second rinsing starts and takes about 15 minutes. The average water temperature is approximately about 48 ºC during the second rinsing process. The cycle completes with the drying process and it takes about 55 minutes. As the amount of electricity consumption in this cycle is 0.859 kWh. Energy consumption of dishwasher is decreased about 1.49% by recovering energy with shell and tube heat exchanger.

Figure 5.3 shows the economy cycle unloaded case of the dishwasher with attached shell and wire on tube heat exchanger.
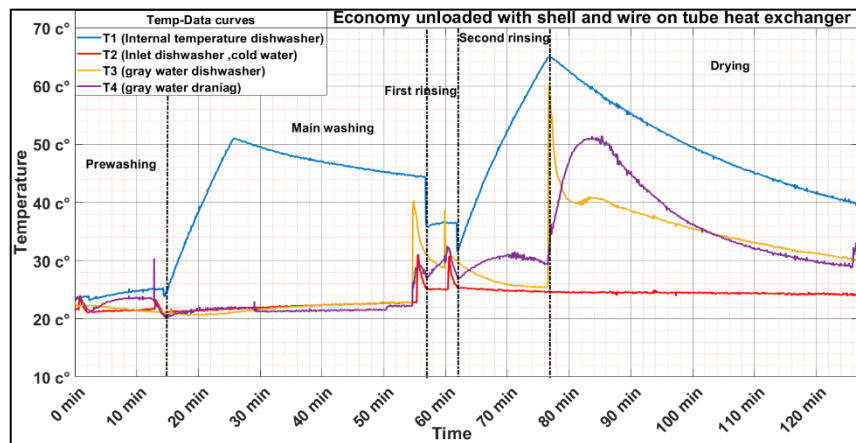
Figure 5.3. Temperature variation during economy cycle in unloaded case of dishwasher with shell and wire on tube heat exchanger.

The Figure 5.3 shows the measured temperature data of experimentation process of the dishwasher for the economy cycle unloaded case with the attachment of shell and wire on tube heat exchanger. The total cycle time is approximately about 127 minutes. The prewashing period occurs approximately at 22 ºC and completes in 15 minutes. The main washing takes about 42 minutes at an average temperature of 40.5 ºC. By the completion of the main washing the discharge water come together with the refill water in the heat exchanger and some of the heat that is recovered to refill tap water. The refill water is preheated to 27 ºC. The first rinsing process takes about 5 minutes

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and with the average temperature of 36 °C, the second rinsing starts and takes about 15 minutes. The first rinsing discharge water heats the refill water to 24 °C. The average water temperature is approximately about 52 °C during the second rinsing process. The cycle completes with the drying process and it takes about 50 minutes. Total amount of electricity consumption in this cycle is 0.758 kWh. Energy consumption of dishwasher is decreased about 13.1% by recovering energy with shell and tube heat exchanger.

Preheated water temperatures by the recovery of heat from dishwasher greywater with the heat exchangers were compared to each other in Figure 5.4 for unloaded case of dishwasher and economy program.
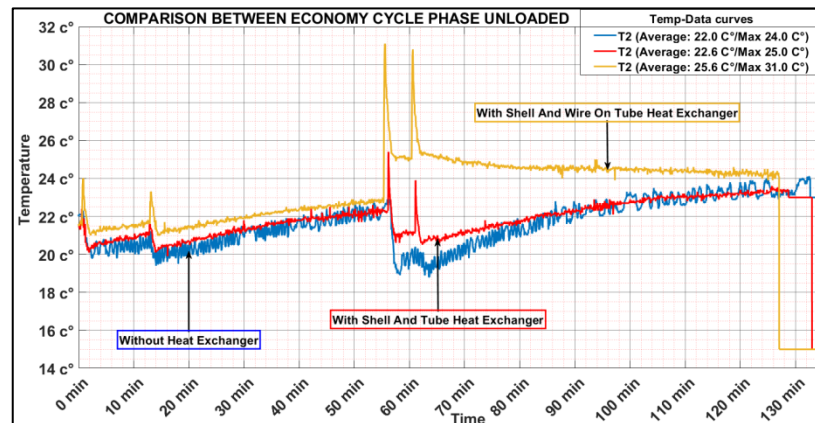
Figure 5.4. Comparison of the temperature of the water entering the dishwasher in the economy program unloaded.

We noticed from the Figure 5.4 the followings: the blue curve, which represents the temperature of the tap water in the economy cycle without attachment of the heat exchanger, where the average preheated water temperature is approximately 21.60 °C. The red curve after installing the shell and tube heat exchanger and the average temperature reached 21.86 °C with a rate of 1.20% Yellow curve after installing the shell and wire on tube heat exchanger, the average temperature reached approximately 23.51 °C, with increase of 8.85%.

Table 5.1 shows the energy consumption of the dishwasher for unloaded case of the dishwasher for the economy cycle.

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Table 5.1. The energy consumption of the dishwasher for unloaded case and the economy cycle.

Type of heat exchanger	Quantity of water (L)	Total time of cycle (min)	Temperature of tap water (°C)	Environment temperature (°C)	Surface area of heat exchanger (m²)	Energy consumption per dishwasher without heat exchanger (kWh)	Energy consumption per dishwasher with heat exchanger (kWh)	Percentage reduction in energy [%]
Without heat exchanger	16.501	135	20	19 - 20	-	0.872	-	
Shell and tube	16.485	133	20.5	19 - 20	0.065	-	0.859	1.49
Shell and wire on tube	15.471	127	20.5	19 - 20	0.271	-	0.758	13.1

Figure 5.5 shows the rate of reductions in energy, and time consumption by the attachment of heat exchangers in the unloaded case of dishwasher in the economy program.

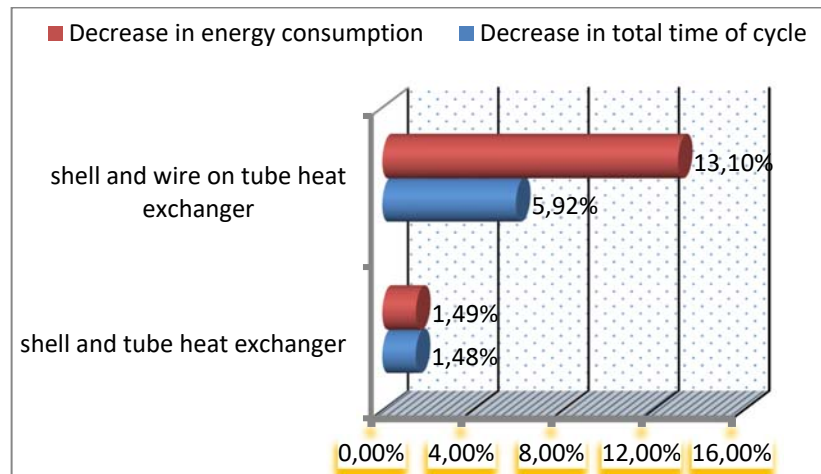Figure 5.5. The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in unloaded case and economy cycle.

The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in unloaded case and economy cycle. The rate of energy

consumed without the heat exchanger installation is 0.958 kWh and attaching the shell and tube heat exchanger it declines to 0.872 kWh and the shell and wire on tube heat exchanger 0.758 kWh. Decrease rate of energy which is shown in the red column in the Figure 5.5 is 1.49% and 13.10% for two heat exchangers. The time of washing is 135 minutes, and it was reduced to 133 minutes by attaching shell and tube heat exchanger, for the shell and wire on tube heat exchanger is 127 minutes. The rate of decrease is shown by the blue column in the Figure 5.5 with a decrease rate of 1.48% to 5.92%.

5.2. EXAMINING THE QUICK PROGRAM FOR THE CASE THAT THE DISHWASHER IS UNLOADED

Figure 5.6 shows the measured temperature data for quick cycle unloaded case of the dishwasher and without heat exchanger attachment.
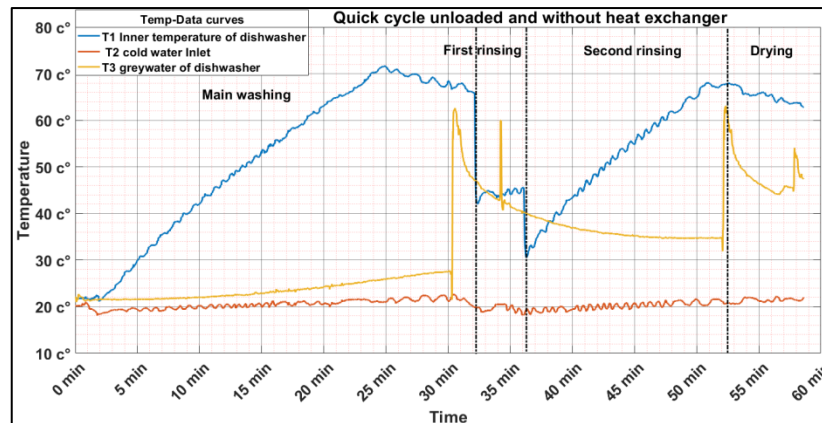
Figure 5.6. Temperature variation during quick cycle in unloaded case of dishwasher without heat exchanger attachment.

The total time for the quick cycle is 60 minutes, when the operation process of the cycle begins with a process of main washing where the average temperature is about 51 °C and the time is 33 minutes. And then the first rinsing process, the average temperature is 44.5 °C and the time of the process is 4 minutes. The second washing process has a temperature of 56 °C and time 16 minutes, and finally the drying process with a time of about 7 minutes. The total energy consumption of the dishwasher was measured about 1.016 kWh.

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Figure 5.7 shows the quick cycle unloaded case of dishwasher with shell and tube heat exchanger attachment.
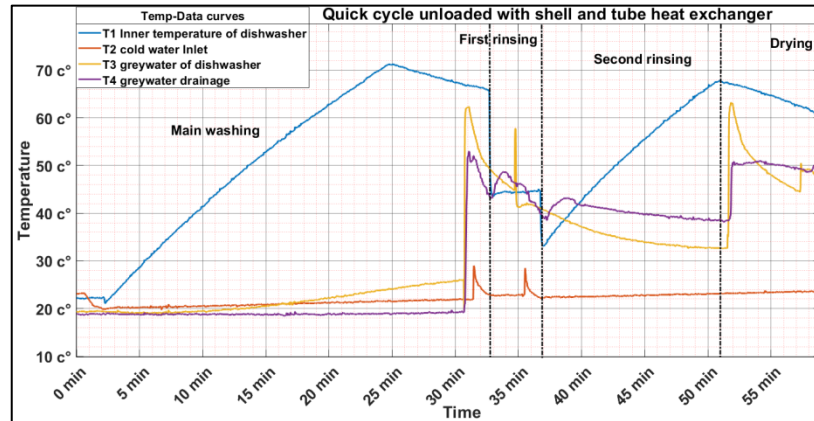
Figure 5.7. Temperature variation during quick cycle unloaded case of dishwasher with shell and tube heat exchanger attachment.

Figure 5.7 shows the measured temperature data of experimentation process of the dishwasher for the quick cycle unloaded case with the attachment of shell and tube heat exchanger. The total time for the quick cycle is 59 minutes, when the operation process of the cycle begins with a stage main washing where the average temperature is about 48 ℃ and the time is 33 minutes. And then the first rinsing stage, the average temperature is 44 ℃ and the time of the stage is 4 minutes. The discharge water of the first rinsing process heats the refill tap water to 27.7 ℃. The second rinsing process has a temperature of 56 ℃ and time 15 minutes, and finally the drying process with a time of about 7 minutes. The total energy consumption of the dishwasher was measured about 0.997 kWh. Energy consumption of dishwasher is decreased about 1.9% by recovering energy with shell and tube heat exchanger.

Figure 5.8 shows the quick cycle unloaded case of dishwasher and with shell and wire on tube heat exchanger attachment.
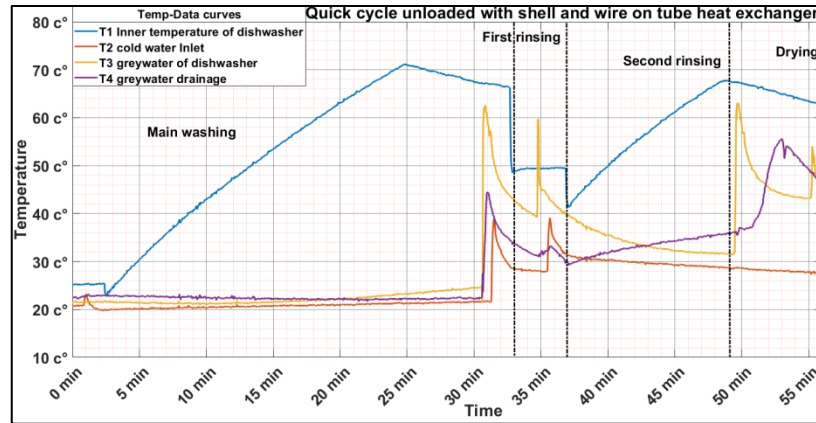
Figure 5.8. Temperature variation during quick cycle in case of dishwasher is unloaded with shell and wire on tube heat exchanger.

Figure 5.8 shows the measured temperature data of experimentation process of the dishwasher for the quick cycle unloaded case with the attachment of shell and wire on tube heat exchanger. The total time for the quick cycle is 56 minutes, the process of the cycle begins with a stage main washing where the average temperature is about 52 °C and the time is 33 minutes. The discharge water is directed into the heat exchanger at the end of the process and heats up the refill tap water to 35 °C. And then the first rinsing stage, the average temperature is 49.5 °C and the time of the stage is 4 minutes. The refill water of the second rinsing is heated by the discharge water of first rinsing from tap water temperature to approximately 36 °C The second rinsing stage has a temperature of 58.5 °C and time 12 minutes, and finally the drying stage with a time of about 7 minutes. The total energy consumption of the dishwasher was measured about 0.884 kWh. Energy consumption of dishwasher is decreased about 13% by recovering energy with shell and wire on tube heat exchanger.

Preheated water temperatures by the recovery of heat from dishwasher greywater with the heat exchangers were compared to each other in Figure 5.9 for unloaded case of quick program.
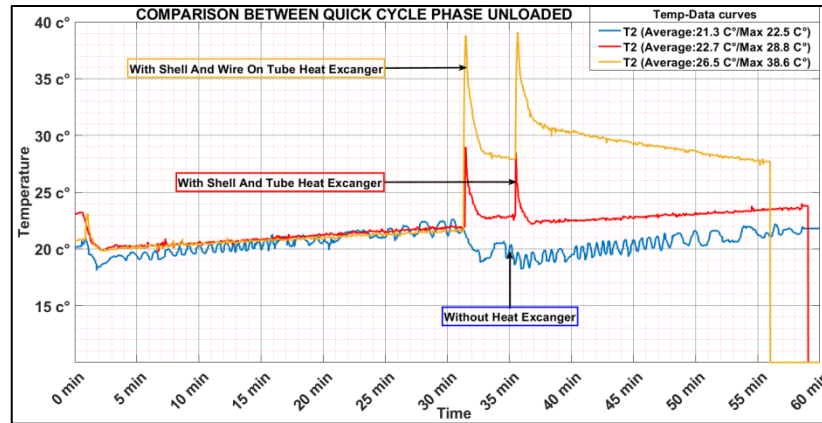
Figure 5. 9. Comparison of the temperature of the water entering the dishwasher in the quick cycle unloaded.

We notice from the Figure 5.9 the followings: the blue curve, which represents the temperature of the tap water in the quick washing cycle without installing the heat exchanger, where the average heat was approximately 20.46 ºC. The red curve after installing the shell and tube heat exchanger and the average temperature reached 21.97 ºC with rate of 7.38% Yellow curve after installing the shell and wire on tube heat exchanger, the average temperature reached to approximately 24.64 ºC, with an increase of 20.43%.

Table 5.2 shows the energy consumption of the dishwasher with the heat exchanger in the unloaded case of the dishwasher for the quick cycle.

Table 5.2. The energy consumption of the dishwasher in unloaded case of dishwasher for the quick cycle.

Type of heat exchanger	Quantity of water (L)	Total time of cycle (min)	Temperature of tap water (°C)	Environment temperature (°C)	Surface area heat exchanger (m²)	Energy consumption per dishwasher without heat exchanger (kWh)	Energy consumption per dishwasher with heat exchanger (kWh)	Percentage reduction in energy [%]
Without heat exchanger	12.891	60	20.5	19 - 20	-	1.016	-	
Shell and tube	12.745	59	20.5	19 - 20	0.065	-	0.997	1.90
Shell and wire on tube	11.610	56	20.5	19 - 20	0.271	-	0.884	13

Figure 5.10 shows the rate of reductions in energy, and time consumption by the attachment of heat exchangers in the unloaded case of dishwasher in the quick program.

Figure 5.10. The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in unloaded case and quick cycle.

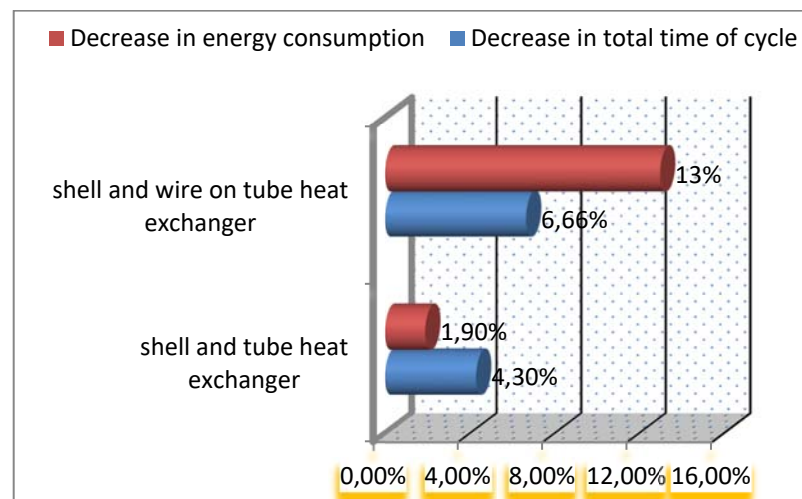The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in unloaded case and quick cycle. The rate of energy consumed without the heat exchanger installation is 1.016 kWh and attaching the shell and tube heat exchanger it declines to 0.997 kWh and the shell and wire on tube heat exchanger 0.884 kWh. Decrease rate of energy which is shown in the red column in the Figure 5.10 is 1.90% and 13% for two heat exchangers. The time of washing is 60 minutes, and it was reduced to 59 minutes by attaching shell and tube heat exchanger, for the shell and wire on tube heat exchanger is 56 minutes. The rate of decrease is shown by the blue column in the Figure 5.10 with a decrease rate of 4.30% to 6.66%.

5.3. EXAMINING THE INTENSE PROGRAM FOR THE CASE THAT THE DISHWASHER IS UNLOADED

Figure 5.11 shows the intense cycle unloaded case of the dishwasher and without installing a heat exchanger.

Figure 5.11. Temperature variation during intense cycle in unloaded case of dishwasher without heat exchanger attachment.

Figure 5.11 shows the full time of cycle takes approximately about 110 minutes. The Intense cycle also composts of prewashing, main washing, first and second rinsing and lastly drying subprocess in the order. The average water temperature for prewashing is approximately 38 °C. The prewashing process also takes about 22 minutes. At the end of prewash, the water is discharged and dishwasher refills from tap to do main washing. Then, the main washing process occurs with the average water temperature

is approximately about 58 °C and the process takes about 36 minutes. By the completion of main washing, the water discharged again, and the dishwasher refilled with tap water. The first rinsing process completes about in 7 minutes and the water discharged from dishwasher at an average temperature about 43 °C. By the refilling of the dishwasher, the second rinsing starts and takes about 16 minutes. The average water temperature is approximately about 56 °C during the second rinsing process. The cycle completes with the drying process and it takes about 29 minutes. The total energy consumption of the dishwasher was measured about 1.325 kWh.

Figure 5.12 shows the intense cycle unloaded case of the dishwasher with attachment of the shell and tube heat exchanger.
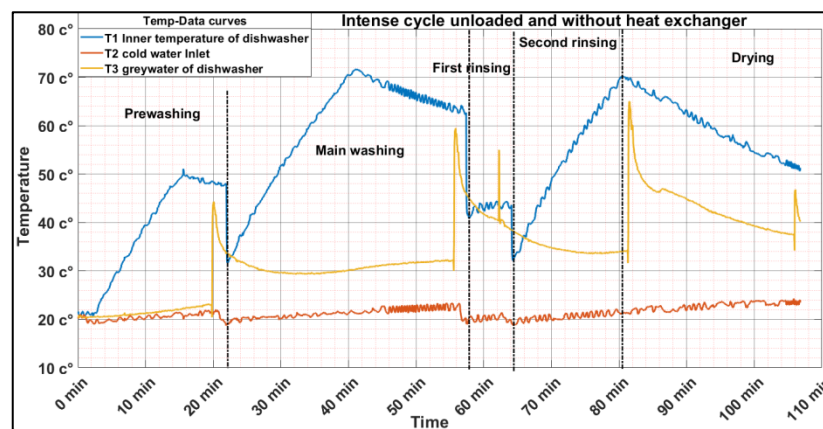

Figure 5.12. Temperature variation during intense cycle in unloaded case of dishwasher with shell and tube heat exchanger attachment.

Figure 5.12 shows the measured temperature data of experimentation process of the dishwasher for the Intense cycle unloaded case with the attachment of shell and tube heat exchanger. The total cycle time is approximately about 108 minutes. The prewashing period occurs approximately at 38 °C and completes in 22 minutes. The prewashing completion requires the refreshing of water by discharging and refilling rom tap. The tap water comes together with the discharging water in the heat exchanger and heats up to 24.1 °C. The main washing takes about 34 minutes at an average temperature of 57 °C. The discharge water heats the refill water approximately about 30.2 °C during the discharge at the end of main washing and refilling to first rinsing. The first rinsing process takes about 7 minutes and with the average temperature of 44

ºC. Then the first rinsing completes and discharge water of the first rinsing heats the refill water up to 28.2 ºC, the second rinsing starts and takes about 15 minutes. The average water temperature is approximately about 55 ºC during the second rinsing process. The cycle completes with the drying process and it takes about 30 minutes. As the amount of electricity consumption in this cycle is 1.289 kWh. Energy consumption of dishwasher is decreased about 2.71% by recovering energy with shell and tube heat exchanger.

Figure 5.13 shows the intense cycle unloaded case of the dishwasher with the attachment of the shell and wire on tube heat exchanger.
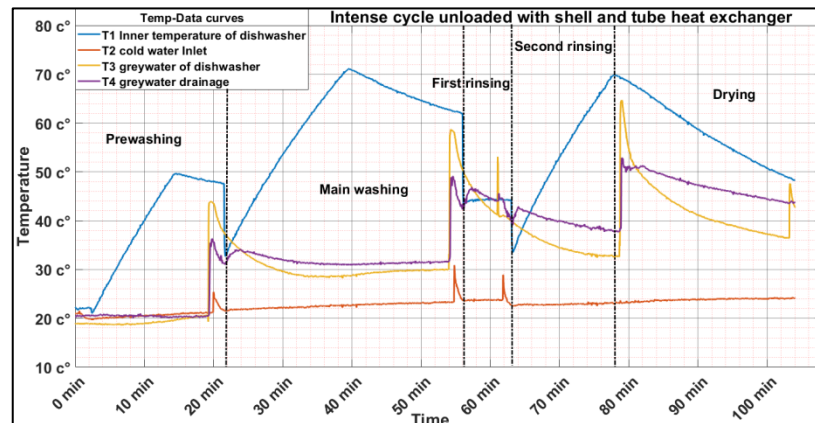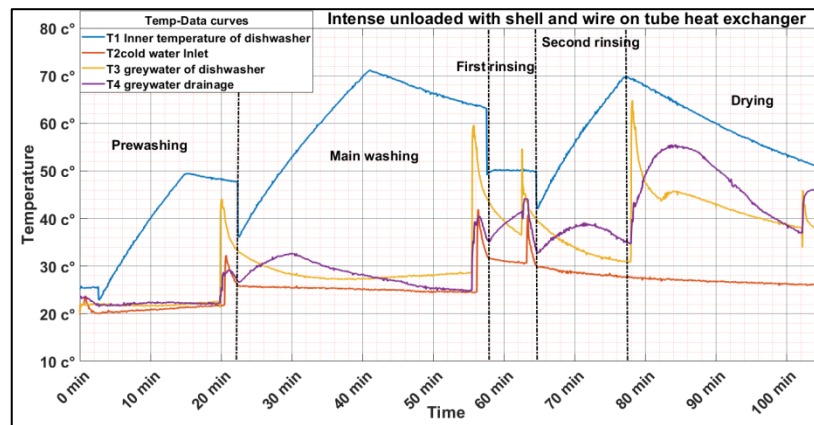

Figure 5. 13. Temperature variation during intense cycle in unloaded case of dishwasher with shell and wire on tube heat exchanger attachment.

Figure 5.13 shows the measured temperature data of experimentation process of the dishwasher for the intense cycle unloaded case with the attachment of shell and wire on tube heat exchanger. The total cycle time is approximately about 105 minutes. The prewashing period occurs approximately at 40.5 ºC and completes in 22 minutes. At the end of prewashing the water is discharged through the heat exchanger and meet with the refilling fresh tap water. It preheats the tap water to 29 ºC. The main washing takes about 38 minutes at an average temperature of 60 ºC. The discharge water energy recovered to preheat the refill water to 36 ºC. The first rinsing process takes about 6 minutes and with the average temperature of 50.5 ºC Discharge water of the first rinsing is used to preheat the refill water of the second rinsing process up to 31 ºC. The second rinsing starts and takes about 12 minutes. The average water temperature is

approximately about 59 °C during the second rinsing process. The cycle completes with the drying process and it takes about 27 minutes.

As the amount of electricity consumption in this cycle is 1.104 kWh. Energy consumption of dishwasher is decreased about 16.68% by recovering energy with shell and wire on tube heat exchanger.

Preheated water temperatures by the recovery of heat from dishwasher greywater with the heat exchangers were compared to each other in Figure 5.14 for unloaded case of intense program.
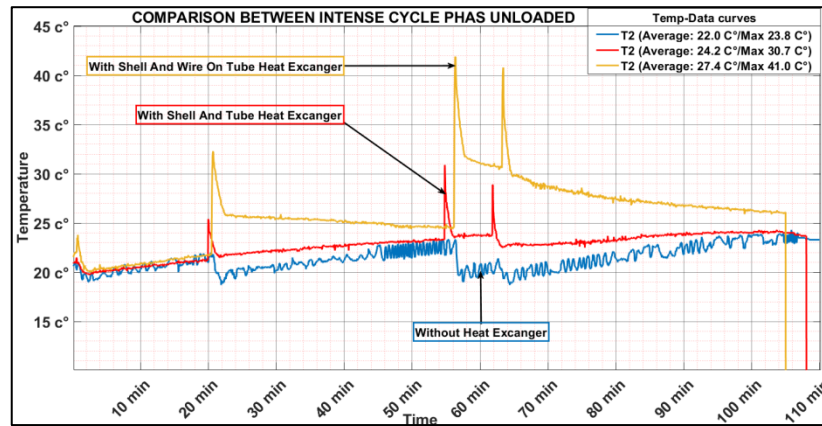
Figure 5.14. Comparison of the temperature of the water entering the dishwasher in the intense cycle unloaded.

We notice from the Figure 5.14 the followings: The blue curve, which represents the temperature of the tap water in the intense washing cycle without installing the heat exchanger, where the average heat was approximately 21.29 °C. The red curve after installing the shell and tube heat exchanger and the average temperature reached 22.68 °C with a rate of 6.53% increase. Yellow curve after installing the shell and wire on tube heat exchanger, the average heat reached approximately 25.83 °C, with an increase of 21.32%.

Table 5.3 shows the energy consumption of the dishwasher in unloaded case of dishwasher for the intense cycle.

Table 5.3. The energy consumption of the dishwasher in unloaded case of dishwasher for the intense cycle.

Type of heat exchanger	Quantity of water (L)	Total time of cycle (min)	Temperature tap water (°C)	Environment temperature (°C)	Surface area heat exchanger (m²)	Energy consumption per dishwasher without heat exchanger (kWh)	Energy consumption per dishwasher with heat exchanger (kWh)	Percentage reduction in energy [%]
Without heat exchanger	18.907	110	20.5	19 - 20	-	1.325	-	
Shell and tube	18.524	108	20.5	19 - 20	0.065	-	1.289	2.71
Shell and wire on tube	17.461	105	20.5	19 - 20	0.271	-	1.104	16.68

Figure 5.15 the rate of reductions in energy, and time consumption by the attachment of heat exchangers in the unloaded case of dishwasher in the intense program.

Figure 5.15. The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in unloaded case and intense cycle.

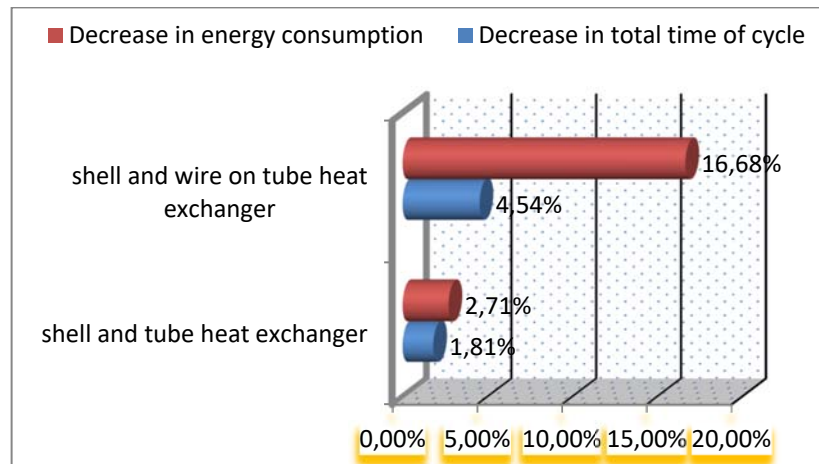The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in unloaded case and intense cycle. The rate of energy consumed without the heat exchanger installation is 1.325 kWh and attaching the shell

and tube heat exchanger it declines to 1.289 kWh and the shell and wire on tube heat exchanger 1.104 kWh. Decrease rate of energy which is shown in the red column in the Figure 5.15 is 2.71% and 16.68% for two heat exchangers. The time of washing is 110 minutes, and it was reduced to 108 minutes by attaching shell and tube heat exchanger, for the shell and wire on tube heat exchanger is 105 minutes. The rate of decrease is shown by the blue column in the Figure 5.15 with a decrease rate of 1.81% to 16.68%.

5.4. EXAMINING THE ECONOMY PROGRAM FOR THE CASE THAT THE DISHWASHER IS LOADED

Figure 5.16 shows the economy cycle by loaded case of the dishwasher and without installing a heat exchanger:

Figure 5. 16. Temperature variation during economy cycle in loaded case of dishwasher without heat exchanger attachment.

The full time of cycle takes approximately about 133 minutes. The economy cycle also composts of prewashing, main washing, first and second rinsing and lastly drying subprocess in the order. The average water temperature for prewash is approximately 22 °C. The prewashing process also takes about 15 minutes. At the end of prewashing, the water is discharged and dishwasher refills from tap to do main washing. Then, the main washing process occurs with the average water temperature is approximately about 44 °C and the process takes about 44 minutes. By the completion of main washing, the water discharged again, and the dishwasher refilled with tap water. The

first rinsing process completes about in 5 minutes and the water discharged from dishwasher at an average temperature about 33.5 °C. By the refilling of the dishwasher, the second rinsing starts and takes about 18 minutes. The average water temperature is approximately about 48.5 °C during the second rinsing process. The cycle completes with the drying process and it takes about 51 minutes. The total energy consumption of the dishwasher was measured about 0.907 kWh.

Figure 5.17 shows the measured temperature data of experimentation process of the dishwasher for the economy cycle loaded case with the attachment of shell and tube heat exchanger.
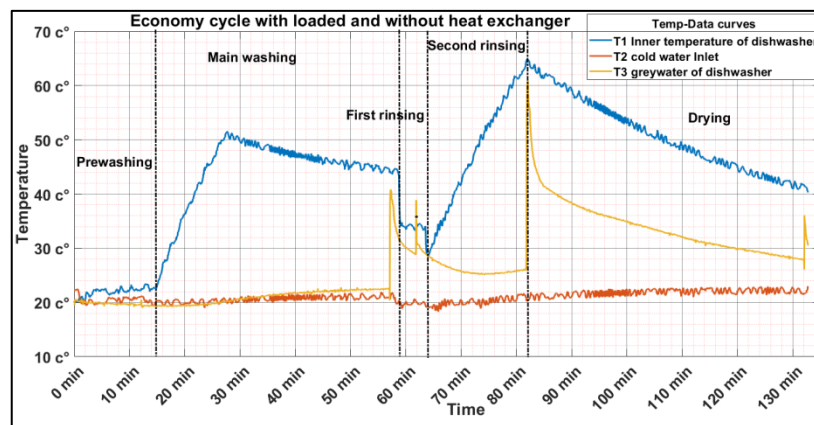

Figure 5. 17. Temperature variation during economy cycle in loaded case of dishwasher with shell and tube heat exchanger attachment.

The total cycle time is approximately about 132 minutes. The prewashing period occurs approximately at 22.5 °C and completes in 15 minutes. The discharge water of prewashing meets with the refilling water to main washing. The tap water heated to 21 °C. The main washing takes about 45 minutes at an average temperature of 43.5 °C. By the completion of the main washing the discharge water heats the refill water 24.7 °C in the heat exchanger during the refilling process. The first rinsing process takes about 4 minutes and with the average temperature of 34 °C. The discharge water of the first rinsing is also used to heat the refill water for second rinsing from tap water temperature to 22.5 °C the second rinsing starts and takes about 19 minutes. The average water temperature is approximately about 50 °C during the second rinsing process. The cycle completes with the drying process and it takes about 49 minutes.

The total energy consumption of the dishwasher was measured about 0.892 kWh. Energy consumption of dishwasher is decreased about 1.65% by recovering energy with shell and tube heat exchanger.

Figure 5.18 shows the measured temperature data of experimentation process of the dishwasher for the economy cycle loaded case with the attachment of shell and wire on tube heat exchanger.
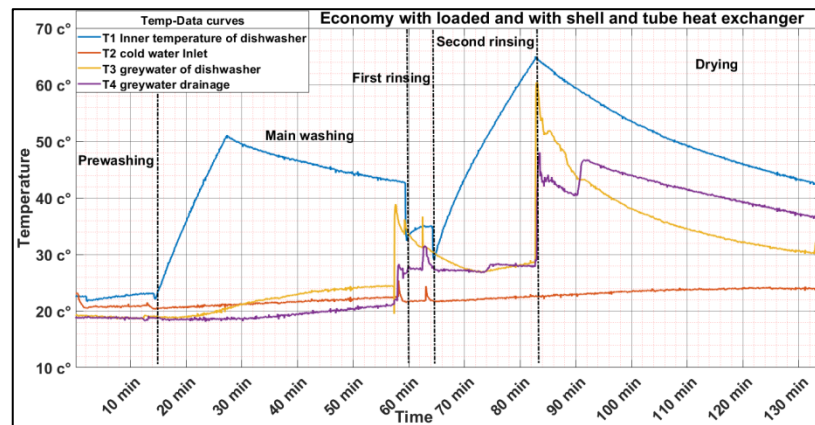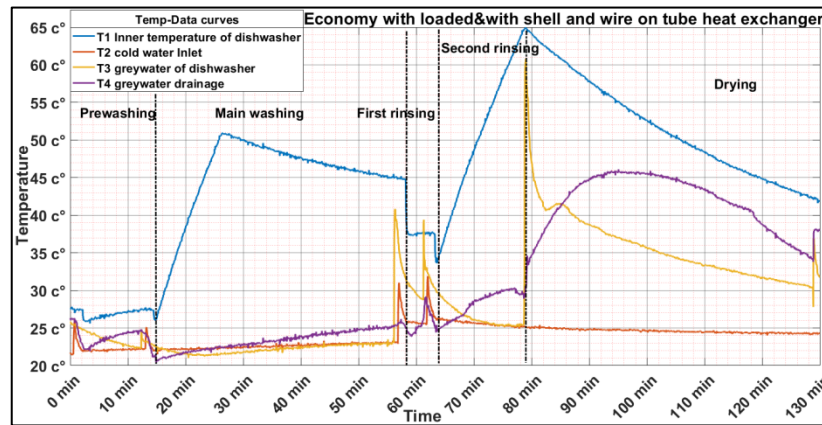

Figure 5.18. Temperature variation during economy cycle in loaded case of dishwasher with shell and wire on tube heat exchanger attachment.

The total cycle time is approximately about 130 minutes. The prewashing period occurs approximately at 22 °C and completes in 15 minutes. The discharge water flows through the heat exchanger and rejects some of the heat to tap refill water and heats it up to about 21.5 °C. The main washing takes about 43 minutes at an average temperature of 43 °C. By the completion of the main washing the discharge water come together with the refill water in the heat exchanger and some of the heat that is recovered to refill tap water. The refill water is preheated to 27 °C. The first rinsing process takes about 6 minutes and with the average temperature of 37.5 °C, the second rinsing starts and takes about 15 minutes. The first rinsing discharge water heats the refill water to 24 °C. The average water temperature is approximately about 53.5 °C during the second rinsing process. The cycle completes with the drying process and it takes about 51 minutes. Amount of electricity consumption in this cycle is 0.779 kWh. Energy consumption of dishwasher is decreased about 14.11% by recovering energy with shell and tube heat exchanger.

Preheated water temperatures by the recovery of heat from dishwasher greywater with the heat exchangers were compared to each other in Figure 5.19 for loaded case of economy program.
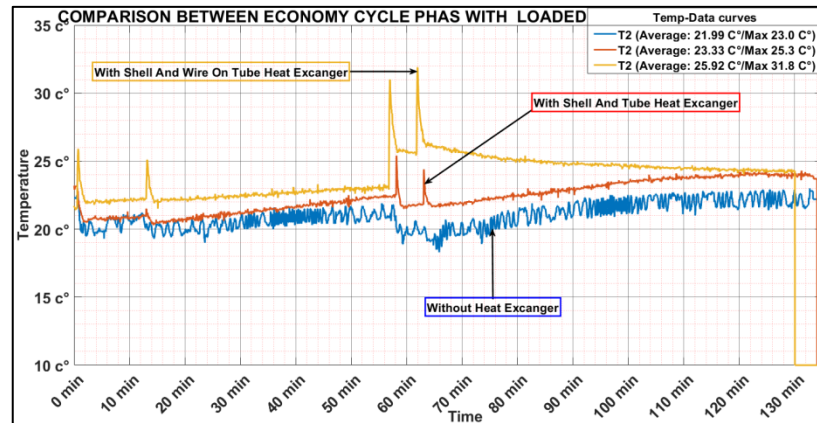
Figure 5.19. Comparison of the temperature of the water entering the dishwasher in the economy cycle with loaded.

We notice from the Figure 5.19 the followings: The blue curve, which represents the temperature of the tap water in the economy cycle without installing the heat exchanger, where the average temperature of water was approximately 20.99 ℃. The red curve after installing the shell and tube heat exchanger and the average temperature reached to 22.33 ℃ with rate of 6.38% increase. Yellow curve after installing the shell and wire on tube heat exchanger, the average heat reached approximately 24 ℃, with an increase of 14.34%.

Table 5.3 shows the energy consumption of the dishwasher in loaded case of dishwasher for the economy cycle.

Table 5.4. The energy consumption of the dishwasher in loaded case of dishwasher for the economy cycle.

Type of heat exchanger	Quantity of water (L)	Total time of cycle (min)	Temperature of tap water (ºC)	Environment temperature (°C)	Surface area heat exchanger (m²)	Energy consumption per dishwasher without heat exchanger (kWh)	Energy consumption per dishwasher with heat exchanger (kWh)	Percentage reduction in energy [%]
Without heat exchanger	16.468	135	20	19 - 20	-	0.907	-	
Shell and tube	15.993	134	20.5	19 - 20	0.065	-	0.892	1.65
Shell and wire on tube	15.474	130	20.5	19 - 20	0.271	-	0.779	14.11

Figure 5.20 shows the rate of reductions in energy, and time consumption by the attachment of heat exchangers in the loaded case of dishwasher in the economy program.
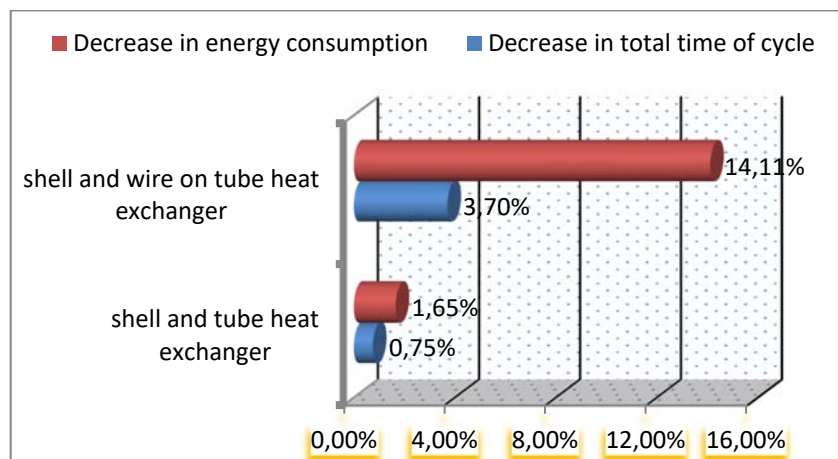
Figure 5.20. The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in loaded case and economy cycle.

The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in loaded case and economy cycle. The rate of energy

consumed without the heat exchanger installation is 0.907 kWh and attaching the shell and tube heat exchanger it declines to 0.892 kWh and the shell and wire on tube heat exchanger 0.779 kWh. Decrease rate of energy which is shown in the red column in the Figure 5.20 is 1.65% and 14.11% for two heat exchangers. The time of washing is 135 minutes, and it was reduced to 134 minutes by attaching shell and tube heat exchanger, for the shell and wire on tube heat exchanger is 130 minutes. The rate of decrease is shown by the blue column in the Figure 5.20 with a decrease rate of 0.75% to 3.70%.

5.5. EXAMINING THE QUICK PROGRAM FOR THE CASE THAT THE DISHWASHER IS LOADED

The following figure shows the quick cycle by loading the dishwasher and without installing a heat exchanger:
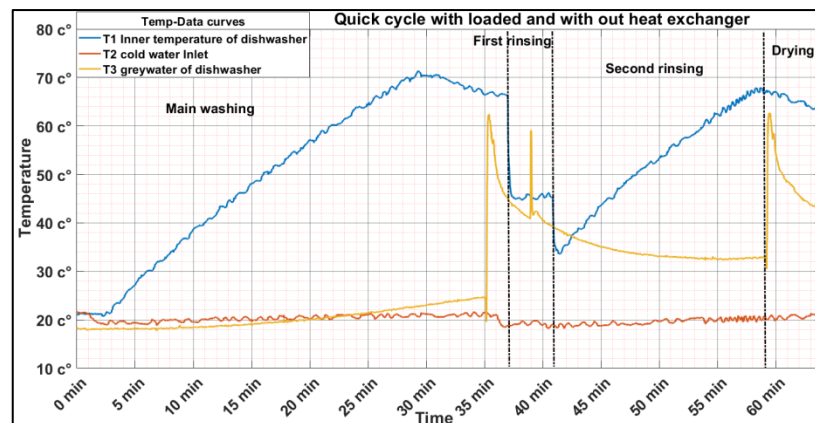
Figure 5.21. Temperature variation during quick cycle in loaded case of dishwasher without heat exchanger attachment.

The total time for the rapid cycle is 66 minutes, when the operation process of the cycle begins with a stage main washing where the average temperature is about 53 °C and the time is 38 minutes. And then the first rinsing stage, the average temperature is 47.5 °C and the time of the stage is 4 minutes. The second rinsing stage has a temperature of 56.5 °C and time 18 minutes, and finally the drainage stage with a time

of about 6 minutes. The total energy consumption of the dishwasher was measured about 1.182 kWh.

Figure 5.22 shows the quick cycle by loaded case of the dishwasher and attached the shell and tube heat exchanger:

Figure 5.22. Temperature ariation during quick cycle in loaded case of dishwasher with shell and tube heat exchanger attachment.

Figure 5.22 shows the measured temperature data of experimentation process of the dishwasher for the quick cycle loaded case with the attachment of shell and tube heat exchanger. The total time for the rapid cycle is 63 minutes, when the operation process of the cycle begins with a stage main washing where the average temperature is about 54.5 °C and the time is 34 minutes. At the end of main washing process, the water is discharged into the heat exchanger and heats the refill water to 29.4 °C. And then the first washing stage starts, the average temperature is 48 °C and the time of the stage is 5 minutes. The discharge water of the first rinsing process heats the refill tap water to 27.7 °C. The second washing stage has a temperature of 58 °C and time 15 minutes, and finally the drainage stage with a time of about 9 minutes. The total energy consumption of the dishwasher was measured about 1.167 kWh. Energy consumption of dishwasher is decreased about 1.27% by recovering energy with shell and tube heat exchanger.

Figure 5.23 shows the quick cycle by loaded case of the dishwasher and attached the shell and wire on tube heat exchanger:
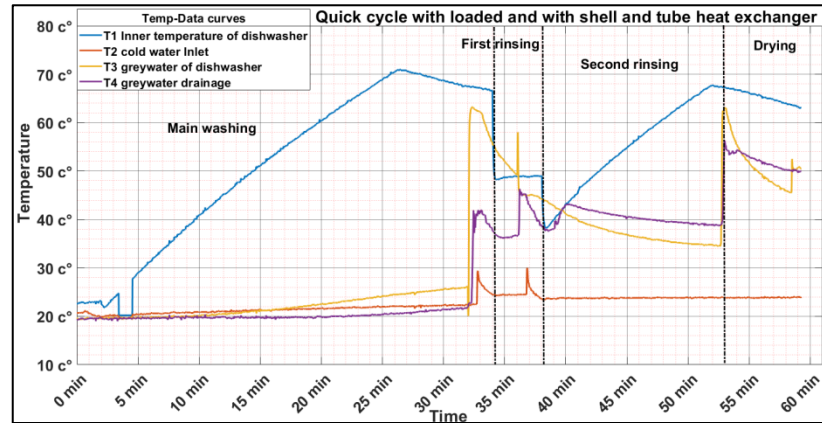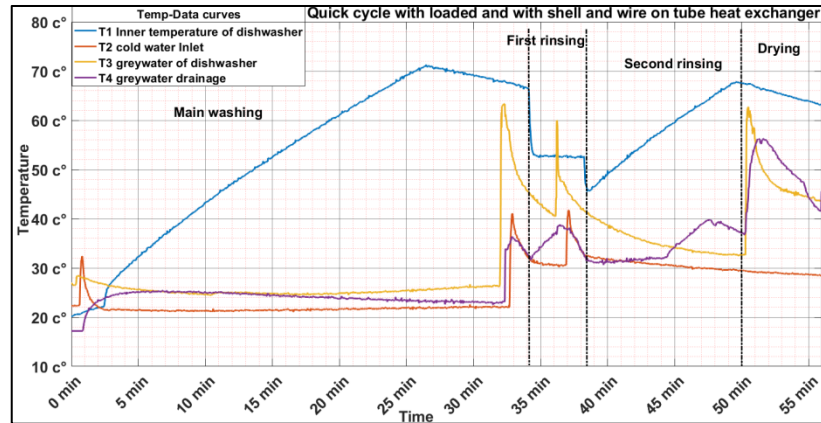
Figure 5.23. Temperature variation during quick cycle in loaded case of dishwasher with shell and wire on tube heat exchanger attachment.

Figure 5.23 shows the measured temperature data of experimentation process of the dishwasher for the quick cycle loaded case with the attachment of shell and wire on tube heat exchanger. The total time for the rapid cycle is 56 minutes, when the operation process of the cycle begins with a stage main washing where the average temperature is about 58 °C and the time is 34 minutes. The discharge water is directed into the heat exchanger at the end of the process and heats up the refill tap water to 36 °C. And then the first washing stage starts, the average temperature is 53 °C and the time of the stage is 4 minutes. The refill water of the second rinsing is heated by the discharge water of first rinsing from tap water temperature to approximately 32 °C The second washing stage has a temperature of 60 °C and time 12 minutes, and finally the drainage stage with a time of about 6 minutes. The total energy consumption of the dishwasher was measured about 0.999 kWh. Energy consumption of dishwasher is decreased about 15.48% by recovering energy with shell and wire on tube heat exchanger.

Preheated water temperatures by the recovery of heat from dishwasher greywater with the heat exchangers were compared to each other in Figure 5.24 for loaded case of quick program.

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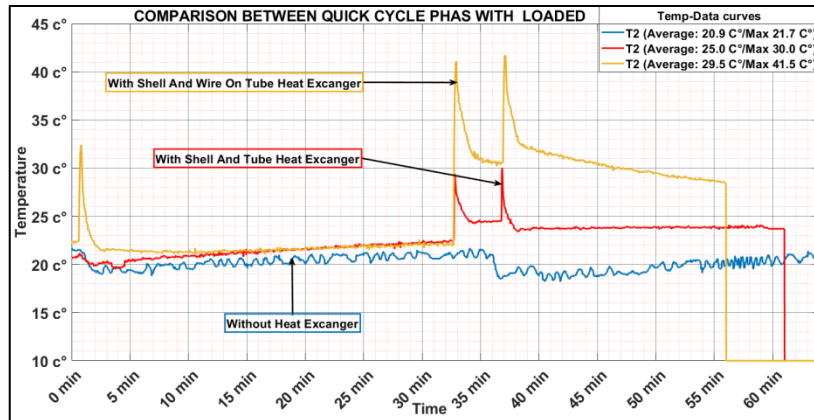
Figure 5.24. Comparison of the temperature of the water entering the dishwasher in the quick cycle with loaded.

We notice from the Figure 5.24 the followings: The blue curve, which represents the temperature of the tap water in the quick washing cycle without installing the heat exchanger, where the average temperature was approximately 20.11 ºC. The red curve after installing the shell and tube heat exchanger and the average temperature reached 22.54 ºC with a rate of 12.08% increase. Yellow curve after installing the shell and wire on tube heat exchanger, the average heat reached approximately 25.62 ºC, with a rate of increase is 27.40%.

Table 5.5 shows the energy consumption of the dishwasher with the heat exchanger by loading the dishwasher for the quick cycle.

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Table 5.5. The energy consumption of the dishwasher in loaded case of dishwasher for the quick cycle.

Type of heat exchanger	Quantity of water (L)	Total time of cycle (min)	Temperature of tap water (°C)	Environment temperature (°C)	Surface area of heat exchanger (m²)	Energy consumption per dishwasher without heat exchanger (kWh)	Energy consumption per dishwasher with heat exchanger (kWh)	Percentage reduction in energy per dishwasher [%]
Without heat exchanger	12.341	66	20	19 - 20	-	1.182	-	
shell and tube	12.334	61	20.5	19 - 20	0.065	-	1.167	1.27
shell and wire on tube	11.948	56	20.5	19 - 20	0.271	-	0.999	15.48

Figure 5.25 shows the rate of reductions in energy, and time consumption by the attachment of heat exchangers in the loaded case of dishwasher in the quick program.

Figure 5.25. The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in loaded case and quick cycle.

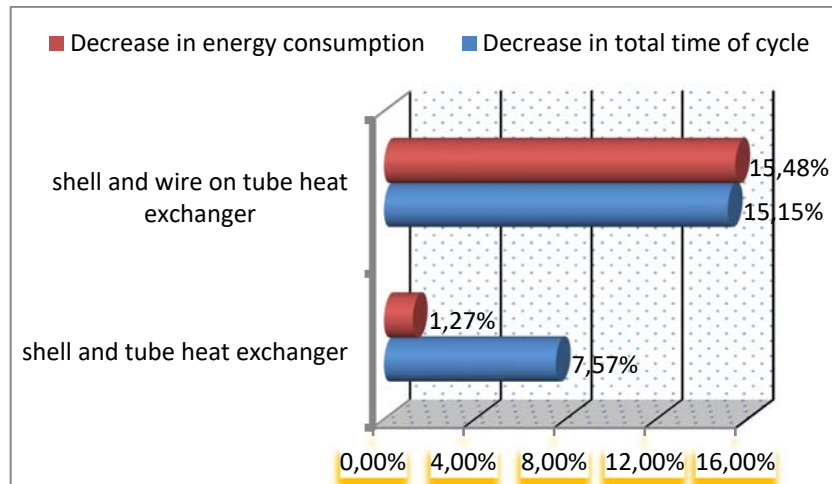The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in loaded case and quick cycle. The rate of energy consumed

without the heat exchanger installation is 1.182 kWh and attaching the shell and tube heat exchanger it declines to 1.167 kWh and the shell and wire on tube heat exchanger 0.999 kWh. Decrease rate of energy which is shown in the red column in the Figure 5.25 is 1.27% and 15.48% for two heat exchangers. The time of washing is 66 minutes, and it was reduced to 61 minutes by attaching shell and tube heat exchanger, for the shell and wire on tube heat exchanger is 56 minutes. The rate of decrease is shown by the blue column in the Figure 5.25 with a decrease rate of 7.57% to 15.15%.

5.6. EXAMINING THE INTENSE PROGRAM FOR THE CASE THAT THE DISHWASHER IS LOADED

Figure 5.26 shows the intense cycle by loaded case of the dishwasher and without installing a heat exchanger:

Figure 5.26. Temperature variation during intense cycle in loaded case of dishwasher without heat exchanger attachment.

Figure 5.26 shows the full time of cycle takes approximately about 113 minutes. The Intense cycle also composts of prewashing, main washing, first and second rinsing and lastly drying subprocess in the order. The average water temperature for prewash is approximately 38 ºC. The prewash process also takes about 24 minutes. At the end of prewash, the water is discharged and dishwasher refills from tap to do main washing. Then, the main washing process occurs with the average water temperature is approximately about 59 ºC and the process takes about 38 minutes. By the completion of main washing, the water discharged again, and the dishwasher refilled with tap

water. The first rinsing process completes about in 7 minutes and the water discharged from dishwasher at an average temperature about 44.5 °C. By the refilling of the dishwasher, the second rinsing starts and takes about 18 minutes. The average water temperature is approximately about 57.5 °C during the second rinsing process. The cycle completes with the drying process and it takes about 26 minutes. The total energy consumption of the dishwasher was measured about 1.484 kWh.

Figure 5.27 shows the intense cycle by loaded case of the dishwasher and attaching the shell and tube heat exchanger.
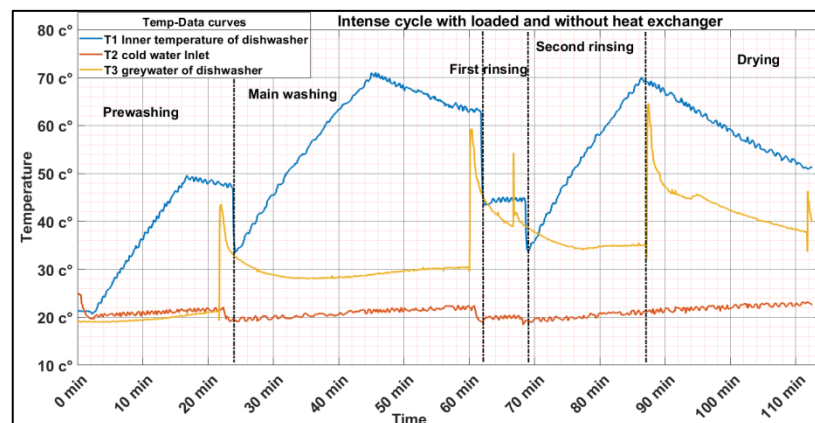

Figure 5.27. Temperature variation during intense cycle in loaded case of dishwasher with shell and tube heat exchanger attachment.

Figure 5.27 shows the measured temperature data of experimentation process of the dishwasher for the intense cycle loaded case with the attachment of shell and tube heat exchanger. The total cycle time is approximately about 113 minutes. The prewashing period occurs approximately at 41 °C and completes in 22 minutes. The prewashing completion requires the refreshing of water by discharging and refilling rom tap. The tap water comes together with the discharging water in the heat exchanger and heats up to 24.1 °C. The main washing takes about 37 minutes at an average temperature of 59 °C. The discharge water heats the refill water approximately about 30.2 °C during the discharge at the end of main washing and refilling to first rinsing. The first rinsing process takes about 12 minutes and with the average temperature of 46.5 °C. Then the first rinsing completes and discharge water of the first rinsing heats the refill water up to 28.2 °C the second rinsing starts and takes about 17 minutes. The average water

temperature is approximately about 57 ℃ during the second rinsing process. The cycle completes with the drying process and it takes about 25 minutes. The total energy consumption of the dishwasher was measured about 1.422 kWh. Energy consumption of dishwasher is decreased about 4.17% by recovering energy with shell and tube heat exchanger.

Figure 5.28 shows the intense cycle by loaded case of dishwasher and attaching the shell and wire on tube heat exchanger.
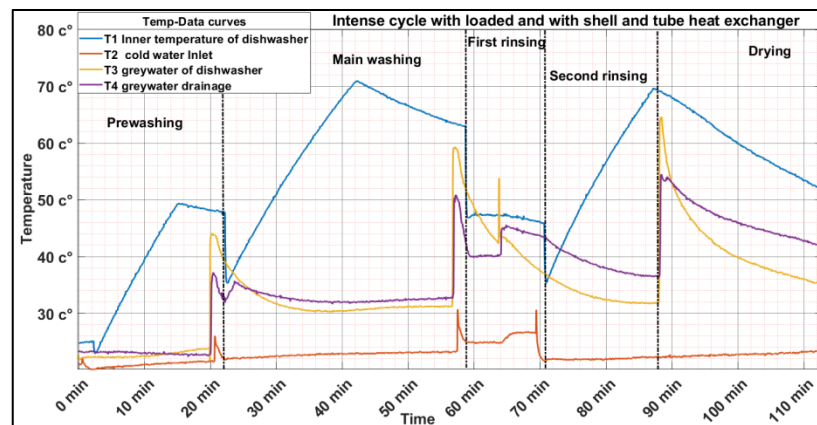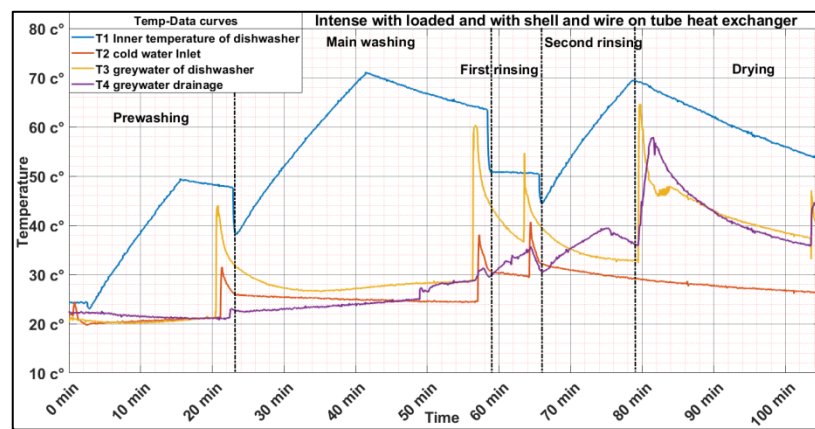

Figure 5.28. Temperature variation during intense cycle in loaded case of dishwasher with shell and wire on tube heat exchanger attachment.

Figure 5.28 shows the measured temperature data of experimentation process of the dishwasher for the intense cycle loaded case with the attachment of shell and wire on tube heat exchanger. The total cycle time is approximately about 105 minutes. The prewashing period occurs approximately at 40 ℃ and completes in 23 minutes. At the end of prewashing the water is discharged through the heat exchanger and meet with the refilling fresh tap water. It preheats the tap water to 29 ℃. The main washing takes about 36 minutes at an average temperature of 60.5 ℃. The discharge water energy recovered to preheat the refill water to 36 ℃. The first rinsing process takes about 7 minutes and with the average temperature of 50.5 ℃. Discharge water of the first rinsing is used to preheat the refill water of the second rinsing process up to 31 ℃. The second rinsing starts and takes about 13 minutes. The average water temperature is approximately about 60.5 ℃ during the second rinsing process. The cycle completes with the drying process and it takes about 26 minutes. The total energy consumption

of the dishwasher was measured about 1.251 kWh. Energy consumption of dishwasher is decreased about 15.7% by recovering energy with shell and wire on tube heat exchanger.

Preheated water temperatures by the recovery of heat from dishwasher greywater with the heat exchangers were compared to each other in Figure 5.29 for loaded case of intense program.
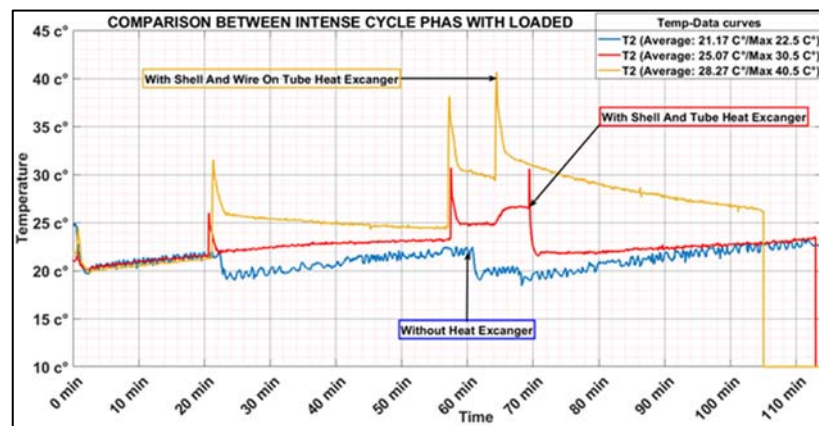
Figure 5.29. Comparison of the temperature of the water entering the dishwasher in the intense cycle with loaded.

We notice from the Figure 5.29 the followings: The blue curve, which represents the temperature of the tap water in the intense washing cycle without installing the heat exchanger, where the average heat was approximately 21.03 ℃. The red curve after installing the shell and tube heat exchanger and the average temperature reached 22.62 ℃ with a rate of 7.56% increase. Yellow curve after installing the shell and wire on tube heat exchanger, the average temperature reached approximately 26.07 ℃. With a rate of increase is 24%.

Table 5.6 shows the energy consumption of the dishwasher with the heat exchanger by loading the dishwasher for the intense cycle.

Table 5.6. The energy consumption of the dishwasher in loaded case of dishwasher for the intense cycle.

Type of heat exchanger	Quantity of water (L)	Total time of cycle (min)	Temperature of tap water (°C)	Environment temperature (°C)	Surface area of heat exchanger (m²)	Energy consumption per dishwasher without heat exchanger (kWh)	Energy consumption per dishwasher with heat exchanger (kWh)	Percentage reduction in energy per dishwasher [%]
Without heat exchanger	18.907	114	20	19 - 20	-	1.484	-	
Shell and tube	18.259	113	20.5	19 - 20	0.065	-	1.422	4.17
Shell and wire on tube	17.461	105	20.5	19 - 20	0.271	-	1.251	15.7

Figure 5.30 shows the rate of reductions in energy, and time consumption by the attachment of heat exchangers in the loaded case of dishwasher in the intense program.

Figure 5.30. The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in loaded case and intense cycle.

The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher in loaded case and intense cycle. The rate of energy

consumed without the heat exchanger installation is 1.484 kWh and attaching the shell and tube heat exchanger it declines to 1.422 kWh and the shell and wire on tube heat exchanger 1.251 kWh. Decrease rate of energy which is shown in the red column in the Figure 5.30 is 4.17% and 15.70% for two heat exchangers. The time of washing is 114 minutes, and it was reduced to 113 minutes by attaching shell and tube heat exchanger, for the shell and wire on tube heat exchanger is 105 minutes. The rate of decrease is shown by the blue column in the Figure 5.30 with a decrease rate of 0.88% to 7.90%.

PART 6

CONCLUSIONS

In this part, after completing the heat exchangers test in case of with loaded and unloaded condition of the dishwasher, we evaluated the values and results that we obtained through the experiments for each wash cycle in tables showing the efficiency of each heat exchanger. The extent of its ability to reduce energy consumption during the time washing period was assessed.

After the experimental data study of the information that we obtained and after drawing the curves, we found that the efficiency of the heat exchanger, when we evaluate in terms of the effectiveness of saving in consumption in both (electricity, water quantity, and cycle time) defined as shown in the tables 5.1, 5.2, 5.3, 5.4, 5.5, 5.6.

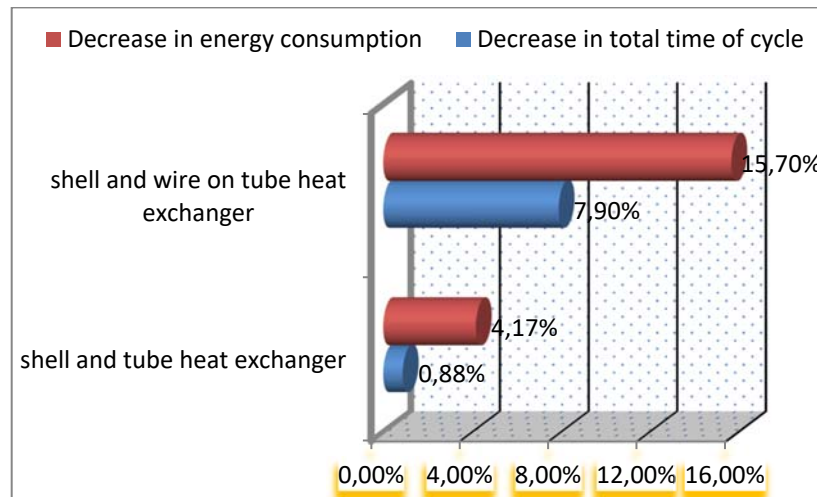It depends on several important factors, the most important of which are:

- The rate of reduction in energy, and time consumption by the attachment of the heat exchangers to dishwasher unloaded case to three cycle .and by increasing the surface area for the heat exchanger, the rate of heat transfer increases in shell and wire on tube heat exchanger if it compared to the tube and shell heat exchanger as shown in figures 5.5, 5.10, 5.15, 5.20, 5.25, 5.30 and results to energy (13.10% ,13% ,16,68%)(1.49% ,1.90% ,1,81%) and time (5.92% ,6.66% ,4.54%)(1.48% ,4.30% ,1.81%). and results loaded case to three cycle (14.11% ,15.48% ,15,70%)(1.65% ,1.27% ,4,17%) and time (3.70% ,15.15% ,7.90%)(0.75% ,7.57% ,0.88%).

- The time for water to remain inside the heat exchanger so that the slower the better the heat transfer between the two fluids is that it remains in the heat exchanger tank, which is expressed through the flow of the liquid (greywater and fresh water).

- The heat exchangers were tried on the dishwasher with the presence of loading inside the dishwasher and without loading the dishwasher there was no significant difference in performance to raise efficiency or it may be simple with regard to the efficiency of the exchanger better by loading the dishwasher as shown in the figures 5.4, 5.9, 5.14, 5.19, 5.24, 5.29.

- The longer and energy intensive cycle, the better the performance of the exchanger in terms of heat exchange and also the type of cycle The intense cycle gave the best result compared to the quick cycle as in the figures 5.7, 5.8, 5.21, 5.22, 5.12, 5.13, 5.27, 5.28.

- The design of the heat exchanger as in the experiment so that it is compact and applicable for the dishwasher body, which in turn transmits heat to it from the washer body to the exchanger body increases the efficiency of the exchanger.

- The cost of each one of the heat exchangers with rectangular tank, pipes and fitting connections are about $ 35.

- The amount of energy saved from each cycle using the large size heat exchanger, as follows:

First: (unloading the dishwasher) for the economic cycle 0.114 kWh, the quick cycle 0.132 kWh, the intense cycle 0.221 kWh.
Second: (by loading the dishwasher) for the economic cycle 0.128 kWh, the quick cycle 0.183 kWh, the intense cycle 0.233 kWh.
By taking the average of the economic cycle 0.128 kWh, the quick cycle 0.183 kWh, and the intense cycle 0.233 kWh. Annual average saving could be calculated about 0.181 kWh dependent on the user habits. Thus, the number of dishwasher used per year for a medium-sized family was assumed to be 280 washers, and that the use of a large family is 560 totals per year and 140 for a small family per year [51]. Any family can use different programs because of the different dirt on dishes and energy consumption, as well as providing capabilities that differ according to the programs and energy. To activate the idea of saving or educating the average consumer. We can

take the average savings potential for the three programs. The average energy saving of the program can be calculated and assumed around 0.181 kWh. The total savings can reach about 51 kWh for one year. Electricity price per unit $ 0.11/kWh. Average annual energy saving is about $ 5.61 per device. It is expected that it will emit 369.23 g CO_2 per kilowatt hour of electricity [52]. About 18.83 kg of CO_2 emissions can be avoided with the energy saved for each machine. And since the cost of the heat exchanger is about $ 35. It is estimated that the payback period is approximately 6.23 years. The following table shows how to classify the dishwasher according to energy efficiency:

Table 5.7. Energy efficiency classes [53].

Energy efficiency class	Energy efficiency index
A+++	EEI < 50
A++	$50 \leq$ EEI < 56
A+	$56 \leq$ EEI < 63
A	$63 \leq$ EEI < 71
B	$71 \leq$ EEI < 80
C	$80 \leq$ EEI < 90
D	EEI ≥ 90

The dishwasher category is determined according to the energy efficiency of the dishwasher specifications sticker from the manufacturer from A ++. The efficiency index was reached to 47.84 with the maximum heat recovery by using equation 3.10 and the class of the dishwasher moved to A +++ category after installing the heat exchanger due to the Table 5.7.

PART 7

SUMMARY

This study aims to restore the greywater temperature by connecting a built-in heat exchanger to a dishwasher. For this purpose, two different heat exchangers were created and integrated in the dishwasher. Types of heat exchangers are shell and tube, shell and wire on tube heat exchanger. The study was completed with experiments conducted in two different cases where the machine was not loaded and loaded, where maximum heat recovery was achieved by installing a heat exchanger with a household dishwasher where two different types of exchanges were connected and tried depending on the case filling the washing machine and emptying and experimenting the dishwasher three Drivers for the washing machine. The shell and tube heat exchanger was connected to the dishwasher and tried as the change in the heat consumption of the washing machine was small with a surface area 0.065 m², and after installing the shell and wire in tube heat exchanger with a surface area 0.271 m² Energy saving rate and reduced operating cycle time: Economic cycle: Energy ratio 13.10%, 14.11%, time 5.92%, 3.70%, and quick cycle energy ratio 13%, 15.48% time 6.66%, 15.15%, Intensive cycle energy ratio 16.68, 15.70%, time 4.54%, 7.90%. Dishwasher efficiency has been raised from A ++ to A +++, with an average annual energy savings of $ 5.61. It is expected that it will emit (369.23 grams of carbon dioxide per kilowatt hour) of electricity. About 18.83 kg of CO_2 emissions can be avoided by using the energy saved for each device. And since the cost of the heat exchanger is about $ 35. It is estimated that the payback period is approximately 6.23 years.

RECOMMENDATIONS

- This experiment was based on how to take advantage of the greywater heat for the dishwasher and recycle it through a heat exchanger to heat the tap water fed to the dishwasher to reduce energy consumption and also consider the design the compatibility of the heat exchanger with the dishwasher at the lowest possible price and effective heat transfer.

- Through the data and experience of the heat exchanger, the effectiveness of the heat exchanger with a large area is evidenced, and we recommend that researchers and companies adopt heat exchangers with a large and suitable surface area.

- Use materials that transfer heat quickly and excellently to make a heat exchanger tank.

- Adopting designs of heat exchangers for the same exchanger used for several types of devices and with the possibility of external installation at the same time.

- The possibility of developing the heat exchanger used to suit many devices and accessories within the dishwasher structure.

- Continuing research on developing heat exchanger models to suit many essential electrical appliances in our daily lives.

- Reducing as far as possible the external connections between the exchanger, dishwasher and the distance to the feeding tubes to avoid losing as much heat as possible.

- Choosing a suitable heat insulator suitable for the exchanger at a low price to be highly efficient.

- Size of the multi-panel heat exchanger a further study on the sizing of the heat exchanger could be carried out for a better performance of the heat exchanger, such as the number of the panels and the volume of the heat exchanger tank: An appropriate channel height between two parallel panels could sufficiently utilize the space of the tank and recover the heat from the waste water to the utmost. Besides, a compact tank would be more economical when hot wastewater

- discharge is not large. However, the number of the panels and the heat exchanger size are greatly dependent on the hot water usage.

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RESUME

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