e-ISSN 2651-3722

Techno-Science

Scientific Journal of Mehmet Akif Ersoy University

Year: 2019 Volume: 2 Issue: 2

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Scientific Journal of Mehmet Akif Ersoy University has been published three issues per year by Burdur Mehmet Akif Ersoy University.

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Scientific Journal of Mehmet Akif Ersoy University

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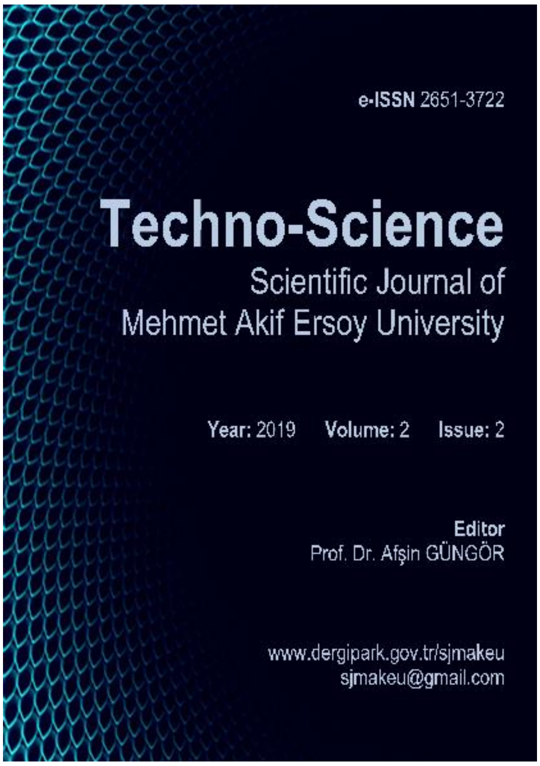

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Techno-Science
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We are happy to introduce the second issue of the second volume of our journal. I thank everyone who contributed to this issue. See you in the third issue.

May 31, 2019
Prof. Dr. Afşin GÜNGÖR
Executive Manager and Editor
On behalf of the Editorial Board

Techno-Science

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[5]. BS EN 14214:2012+A1:2014. *Liquid petroleum products - Fatty acid methyl esters (FAME) for use in diesel engines and heating applications - Requirements and test methods.* The British Standards Institution. London.

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Techno-Science
Scientific Journal of Mehmet Akif Ersoy University

Year: 2019 **Volume:** 2 **Issue:** 2

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Techno-Science *Issue ID: 45542*

Techno-Science 2:2 (2019) 27-31

Techno-Science
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Fabrication of low cost solar flat plate collector

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ARTICLE INFO

Article History

Received	:	20/05/2019
Revised	:	30/05/2019
Accepted	:	30/05/2019
Available online	:	31/05/2019

Keywords
Solar collector
Flat plate collector
Cost

ABSTRACT

Flat plate collector is a device which is used to collect the sun radiation and convert it into thermal energy. The main parts of the flat plate collector (solar geyser) are the glazing, pipes, heat collecting absorber flat and insulating body. In this research an effective flat plate collector has been fabricated for solar geyser, which is low cost, simple design, and easier installation for heating purposes. More focus has been given to the heating loss and collecting solar radiations. Controlling the heat loss, the fluid can absorb more thermal energy which increases the efficiency. A different technique has been employed to enhance the efficiency of solar geysers. Effect of using double glazing to control the heat losses, because the temperature between glass covers and the absorber is not equal to environment. Increasing the length and reducing the diameter of the pipe improved the heat harvesting and observes more heat from absorber sheet.

1. INTRODUCTION

The burning of fossil fuels increase air pollution, the level of CO2 has increased more than 30%, and surface temperature increased about 0.8 °C, causing climate change [1-2]. On the other side much energy is required to industries due to increase in population. The renewable energy concept can solve this problem. It is the energy obtain from natural processes which refilled constantly. The energy is collected from renewable resources are naturally refilled by wind, rain, tides, sunlight (sun irradiation) and geo heat. This energy cannot be collected without proper systems such as wind turbine, photovoltaic (PV) panel and solar thermal collector, which may provide the best way to get energy without air pollution, low cost and with high yield [3].

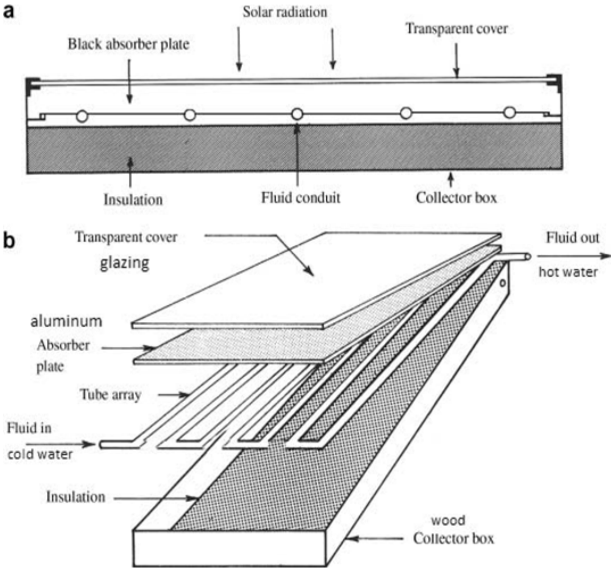

Fig. 1. *Schematic of flat plate collector*

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To cite this article: Ullah, S., Kasi, J.K. (2019). Fabrication of low cost solar flat plate collector. *Techno-Science* vol. 2, no. 2, p. 27-31.

The sun is the closest and a large energy source for the earth, a large amount of energy is received from the sun to the earth. The earth receives light and heat from the sun and receive enough energy in the form of heat. Solar energy has great potential and zero carbon emission [4]. In renewable energy solar energy is one of the most common and outstanding source of energy. This energy is low cost and environment friendly.

We can get solar energy in different ways. Here in this work solar thermal collecting method is represented. Solar collector can be classified in two types, concentrating and non-concentrating. Non-concentrating is further divided more in evacuated tube collector and flat plate collector. Flat plate collector plays a key role in solar energy. It is a type of heat exchanger between source and liquid flow in it [5]. When the sun radiations fall on it, it converts sun irradiation into thermal energy and transfer it to liquid by using the well-known greenhouse effect. Typically, Collector refer the device which collect sun radiation. This radiation is in the form of electromagnetic radiation (long and short wavelength).

Flat plate collector is more effective due to low cost, simple design, and easier installation compare to other form collecting solar radiation system. This controls the building owner's bill for energy to heat water.

Flat plate collector is an insulated box with glass cover (glazing) which does not absorb sun radiation and a large absorber sheet of metal typically aluminum or copper, because these metals are good heat conductor. Copper is best conductor but aluminum has low cost. This absorber sheet is made blackened which absorb more sun radiation and on absorber sheet the copper pipe is attached in zig zag arranged which contain the heat transfer liquid or fluid (specially water). When the sun radiation falls on absorber sheet and it increase the temperature of absorber surface and as the sheet get hooter it transfers it heat to copper pipe and the fluid absorb the heat from copper pipe, which is then used in heating application, such as room heating, water heating and many other industrial applications. If user need hot water day and night so an insulated tank is used to store hot water during the day and use as owner needed. This may be direct or indirect. 13% Use of hot water in home is the 2nd essence energy demand of Scotland [6]. The coper pipe and absorber are enclosed in a wood box and glazing on the top. To control heat losses a rigid foam is used on the sides and bottom by Hottel and woertz in 1942 and hollet and whiller in 1958 [7-8].

Many researchers reported different development and analysis technique to increase the performance of flat plate collector in USA [9-10]. They describe the way to increase the efficiency and can collect more radiation of the sun.

In the solar collector some of heat is lost into environment. These thermal losses include, (a) heat lost from glazing due to wind, (b) heat lost due to radiation back to sky, (c) heat lost due to air between absorber and glazing. The heat is lost through the glass cover (glazing) because the temperature in between glass covers and the absorber is not equal to environment, so the heat is lost though the glass cover. To minimize the heat losses by increasing the number of glazing, instead of single glassing by using double glassing which can improve the efficiency of the flat plate collector. In between these glassing there will be vacuum which help to control the heat losses. if once we control heat losses, it will increase the efficiency of the flat plate collector and get more heat on absorber which transfer these heat to fluid

In development of pipe designing which is zigzag shape and also by decreasing the width of the pipe and increasing the number of the pipe which gave better performance because it covers more area of the absorber and can get more heat from absorber plate.

2. METHODOLOGY

As we know that solar flat plate collector is a system for heating liquids, this system is commonly used in houses, offices and industries. This increase the temperature of liquids to several degrees by trapping the solar radiations coming from the sun. The system is designed in such a way in which the sun radiations are easily trapped and increase the temperature of liquid.

Flat Plate collector have some main parts such as Transparent Glazing, Absorber plate (Aluminum plate), the Riser (tubes for liquid passage), and a casing box for these parts.

2.1. Transparent Cover (Glazing)

The materials of glazing cover are transparent to solar short wavelength radiation. The water white glass which is purely transparent is more suitable material, instead of using any other plastic materials. As we know that a portion of heat is losses from the heated cover by a convection and reflection, so the heat loss is controlled by increasing the number of glazing. The space between first glazing and absorber is equal to 1.5 inch.

2.2. Black Absorber Plate

Absorber plate of a solar water geyser is a metal, usually the aluminum or copper, we use an aluminum plate. Aluminum has very low density therefor it is very lightweight. It is a very good conductor of heat and electricity, so due to best conductivity we use Aluminum or copper plate as an absorbing material. The liquid tube is attached on the top of the plate. The aluminum plate is coloured dark with black paint; the black paint should be thin. The coatings have high absorptivity to short wavelength radiations. The length of the plate is 4.5 ft, and its width is 3 ft.

2.3. Heat Transport system and fluid

Actually the liquid which is used here is mostly water because the water is very effective heat transport medium, but some un fever conditions are caused due to water. as the water may be get freeze in tubes under some conditions such that during cold nights or in winter weathers the atmospheric temperature decreases which may cause the water freeze, once the water is freeze in the tubes then it might be very difficult to be heated soon. another problem of passing water through tubes is of corrosion of metal by water, due to this situation the leakage may be happened. So instead of using water we can also use fluids (Ethylene glycol), Ethylene glycol is an organic compound with the formula $(CH_2OH)_2$. its boiling point is 197.3 ^{o}C and its density is 1.11 g/cm^3. For better heat transfer the tubes are arranged in such a way in which the liquid rotates in zig zag rotation to get the solar heating continuously. The length of the tube is 35ft long.

2.4. Heat Losses Control components

To the efficiency of solar geyser can be increased by controlling the heat losses. As discussed above that a way to control heat losing is by glazing, the glazing may be given single or double but the best way to control heat losing is to give double glazing. but some other components are also used to control heat loss, the foam with a thickness 1.5 inch is fixed in the casing (Frame), behind the absorber, and the double hardboards of wood are also fixed over the foam in the casing. There is a vacuum between the absorber and foam which may be a good way to control heat losing.

2.5. Casing (Frame)

The casing or frame is a nonfunctional component. Which control heat losing from the side and also give support to all other components of the flat plate collector and protection. The casing of the flat plate collector is a frame made of wood with a length equal to 4.9 ft and width equal 3.3 ft. the wooden frame is covered with an iron plate sheet.

Table 1. *Specifications of the flat-plate collector*

Specifications	flat collector	Unit
Dimensions of frame	135×99	cm
Absorber area	122×92	cm
Glazing thickness	4	mm
Absorber thickness	1.5	mm
Frame (aluminum)	-	-
Piping	D=6.2, t=1.1	mm
Piping length	35	ft
Weight	34	kg
Insulation (polystyrene and wood)	3.8	cm

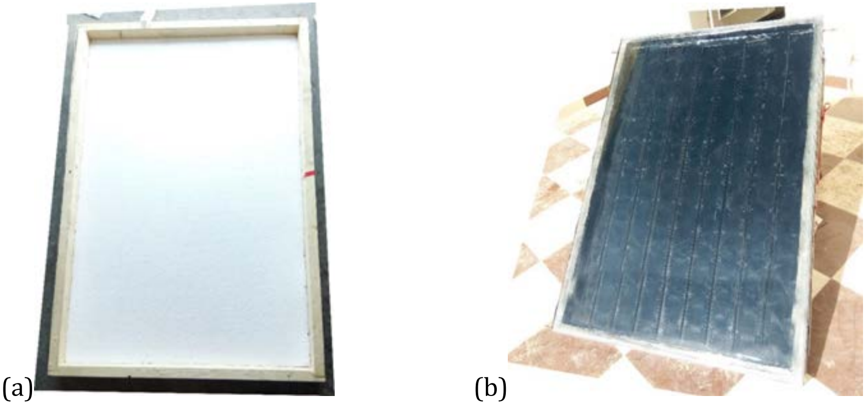
(a) (b)

Fig. 1. *Casing of the flat plat collector and assembled flat plate collector*

3. RESULTS AND DISCUSSIONS

The assembled flat plate collector was installed with the water supply take placed on the top of the roof and obtained the data as shown in the table 2. The data was taken between 10.30 am to 2.25pm with the initial ambient temperature 21^{o}C.

Table 2. *Observations and calculation between time and varying temperature of solar geyser*

S.No	Timing (t)	Ambient Temperature (T_1) ^{0}C	Temperature of water before observation (T_2)	Temperature of water after observation (T_3)	Water Flow rate (liter/30 sec)
1	10:30 am	21	17	22	0.5
2	10:40 am	23	17	31	0.5
3	10:50 am	24	17	33	0.5
4	11:03 am	24	17	41	0.5
5	11:13 am	24	17	43	0.5
6	11:24 am	25	17	44	0.5
7	11:34 am	27	17	44	0.5
8	12:30 pm	26	18	44	0.5
9	12:40 pm	26	18	43	0.5
10	12:50 pm	27	18	44	0.5
11	01:00 pm	28	18	44	0.5
12	01:55 pm	27	17	41	0.5
13	02:05 pm	26	17	39	0.5
14	02:15 pm	24	17	37	0.5
15	02:25 pm	23	17	35	0.5

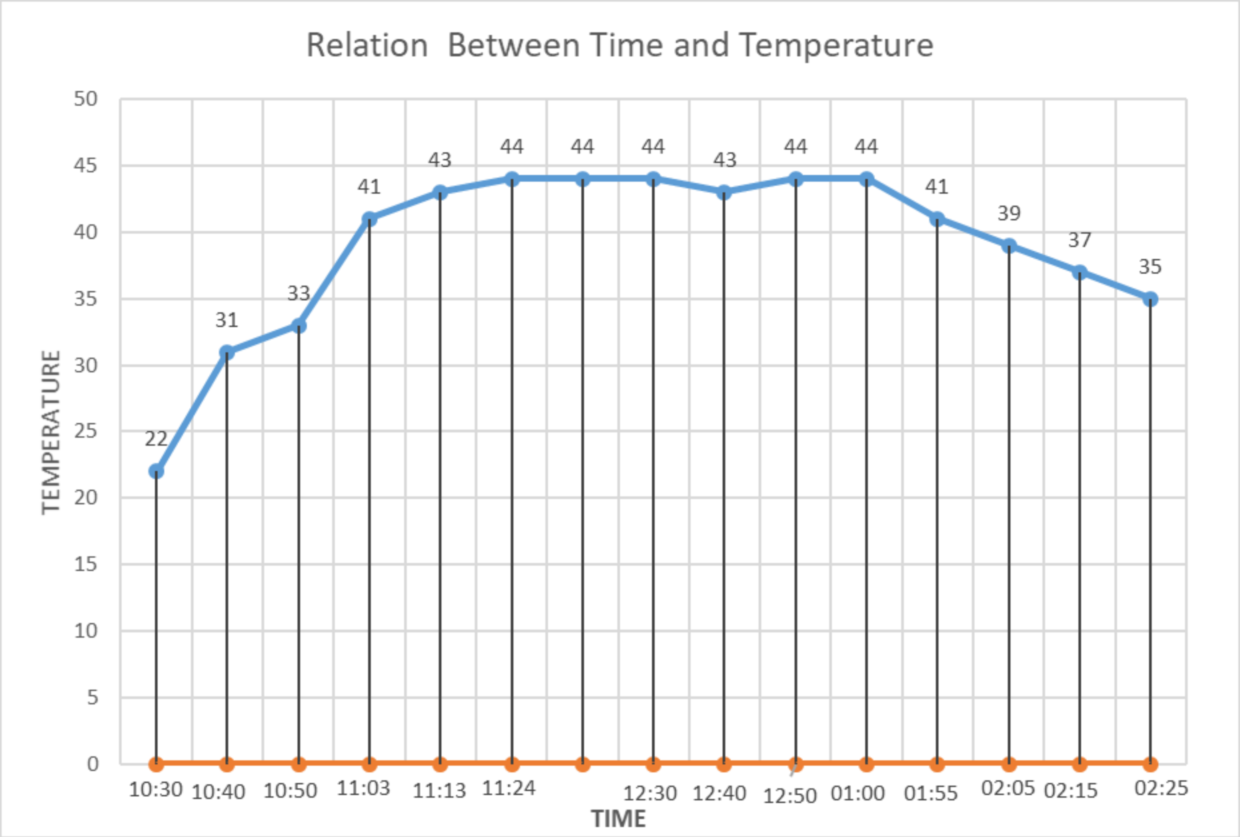

Fig. 3. *Temperature obtained by the flat plate collector in different timings*

Figure 3 shows the graphical results between time and temperature of ambient and flat plate collector. In the beginning on 10:30 am the result shown was 22 ^{o}C, after waiting for 10 minutes at 10:40 am the temperature of outlet water reached to 31 ^{o}C, from 11:13 am to 11:24 am the temperature of water raised to 44 ^{o}C. and remain constant as shown in the curve diagram till 12:30 pm, but then suddenly ambient temperature decreased due to which water's temperature also decreased at 12:40 pm for one degree, and reached to 43 ^{o}C. it is all because of blowing of air in the atmosphere. After 10 minutes at 12:50 pm the temperature again raised for one degree, and reached to 44 ^{o}C, and remain constant till 01:55 pm. And on 01:55 pm the temperature decreased and came down to 39 ^{o}C. Gradually after each 10 minutes it is observed that temperature becoming down as shown in the curve diagram.

4. RESULTS AND DISCUSSIONS

In this research a simple low cost solar thermal flat plate collector was fabricated which can be used as solar geyser. To control the heat losses double glasses glazing was used.

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Techno-Science *Paper ID: 571891*

Techno-Science 2:2 (2019) 33-39

Techno-Science
Scientific Journal of Mehmet Akif Ersoy University
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Original Research Article

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The effect of zeolite addition on the treatment performance of sequencing batch reactor under low temperature

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ARTICLE INFO

Article History
Received : 09/10/2018
Revised : 28/05/2019
Accepted : 30/05/2019
Available online : 31/05/2019

Keywords
SBR, zeolite
nitrogen removal
low temperature
sludge volume index

ABSTRACT

In this study, two lab-scale sequencing batch reactors (SBRs) were used for the treatment of municipal wastewater at low temperature (15^{o}C). These SBRs were a C-SBR (control SBR) and a Z-SBR (zeolite SBR). Both reactors were operated in similar conditions, except for addition of zeolite in the Z-SBR. The results showed that the average COD, TN, NH$_4^+$-N and TP removal were 90%, 53%, 88% and 93% in Z-SBR compared with 90%, 35%, 75% and 93%. The results of COD removal showed that there was no significant difference between two reactors. Z-SBR had better removal capability of nitrogen than C-SBR. Z-SBR exhibited same TP removal with the C-SBR. A higher MLVSS concentration and lower SVI values were observed in Z-SBR compared to that of the C-SBR. The average MLVSS concentration for Z-SBR and C-SBR is 2900 mg l^{-1} and 2120 mg l^{-1}, respectively. The SVI values were lower in Z-SBR (80-100 mL g^{-1}) than C-SBR (120-140 mL g^{-1}). The highest NH$_4^+$-N removal efficiency was observed at pH value of 8.0. It was found that zeolite addition into SBR lessened the negative influences of low temperature and positively affected the performance and sludge settling capability. This work showed that the Z-SBR is an efficient modification of the activated sludge process for co-removal of organic matter and nitrogen at low temperature.

1. INTRODUCTION

The discharge of ammonium nitrogen into surface water causes the adverse environmental impacts, such as toxicity to aquatic organisms, depletion of dissolved oxygen and promotion of eutophication [1]. Therefore, the removal of ammonium nitrogen from wastewater is extremely important. The physicochemical processes and biological nutrient removal have been used widely to remove ammonium nitrogen. Compared to the physicochemical methods, biological processes have been widely adopted in practice due to their more effective and relatively inexpensive [2].

Increasingly, the sequencing batch reactor has been demonstrated to be a viable alternative to continuous-flow activated sludge process for the biological treatment of both domestic and industrial wastewater [3]. The all major phases in SBR process occur in the same tank in sequential order namely, fill, react, settle, draw and idle [4]. The possibility to change the length of each phase individually provides considerable flexibility to the process [5].

Temperature is one of the most influential factors on the growth of nitrifying bacteria. It has been well accepted that a higher temperature enhances nitrification rate as bio-chemical driven bacterial processes accelerate as temperature increases [6]. Nitrifying bacteria are known to be very sensitive to low temperatures and nitrification can be strongly inhibited by low temperatures. Low temperatures are known to limit the activity of the microorganisms and very low temperatures can result in deactivation [7]. Many wastewater plants in Turkey are operated below around 20^{o}C for most the year; therefore, effective methods should be developed to protect the nitrifying bacteria from low temperature.

Zeolites are crystalline hydrated aluminosilicates whose crystalline structure is formed by channels and cavities of strictly regular dimensions called micropores that can be found naturally and synthetically [8]. Natural zeolites exist abundantly, low cost and an additional benefit of using natural zeolites is their regenerative properties [9]. Zeolite is a well-known

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To cite this article: Gurtekin, E., (2019). The effect of zeolite addition on the treatment performance of sequencing batch reactor under low temperature. *Techno-Science* vol. 2, no. 2, p. 33-39.

material for its ability to preferentially remove ammonium nitrogen from wastewater [10]. The addition of zeolite has been shown to effectively enhance nitrification rates in wastewater treatment systems [11-13]. Zeolite works as an ion exchanger material due to the ability to preferentially remove ammonium from wastewater [14]. However, it has not been found the reports on removing organic matter and ammonium nitrogen simultaneously from raw wastewater under the conditions of low temperature in a single reactor as sequencing batch reactor by using zeolite. The aim of study was to investigate the effect of zeolite powder addition on the performance of sequencing batch reactor in removing organic matter and ammonium nitrogen simultaneously under the conditions of low temperature.

2. MATERIALS AND METHODS

2.1. Reactor set-up and operation

Two similar-sized SBRs with working volume of 5 L were used in this study. These reactors were made of rigid plexiglas. The air was supplied by an air pump through a porous stone diffuser located at the bottom of each reactor. The complete cycle of the SBRs was 6 h, with four cycles performed per day. Each cycle consisted of five following phases: fill (15 min), aerobic phase (435 min) sludge settling (15 min) and effluent discharge (15 min). A certain amount of excess sludge was disposed at the end of the aerobic phase to maintain the SRT at approximately 20 days. The temperature of the mixed liquid was kept at 15 ^{o}C and the pH was maintained at around 7.5.

The natural zeolite was obtained from Bigadic (Turkey), then the zeolite was ground to powder form. Zeolite has a mean diameter of 0.1-0.2 mm. Batch zeolite powder addition was applied to composate for the loss of zeolite powder at 1.0 g l^{-1} throught the cycle and the addition of zeolite powder into Z-SBR was conducted between fill and aeration phase of every cycle.

2.2. Seed sludge and wastewater

The both reactors were seeded with activated sludge collected from a local municipal wastewater treatment plant. The reactors were acclimatized for about 40 days prior monitoring. The wastewater was collected from outlet of grit tank of the same plant and its characteristics are summarized in Table 1.

Table 1. Characteristics of municipal wastewater

Parameter	Concentration
pH	7.52
COD, (mg l^{-1})	360
NH_4^+-N, (mg l^{-1})	30
TN, (mg l^{-1})	48.6
TP, (mg l^{-1})	9
SS, (mg l^{-1})	120

2.3. Analytical Methods

The concentration of COD, TP and MLVSS were determined according to Standard Methods [15]. TN, NH_4^+-N, nitrite and nitrate were measured by Standard Kit (Merck Specquorant). The water samples were measured in duplicate.

3. RESULTS AND DISCUSSION

3.1. Pollutant Removal Performance

As shown Figure 1, the average COD removal efficiency in the C-SBR and Z-SBR were similar, around 90%. The results indicated that addition of zeolite into the reactor did not enhance the efficiency of organic matter removal, because heterotrophic bacteria which responsible of degrading the carbonaceous components in the both reactors were enriched at low temperature.

The greatest differences in treatment's effectiveness were for total nitrogen and for ammonium nitrogen. TN and NH_4^+-N removal efficiency for C-SBR are 35% and 75% respectively, while TN and NH_4^+-N removal efficiency for Z-SBR are 53% and 88% respectively. The lower TN and NH_4^+-N removal efficiency in C-SBR at the low temperature was probably due to several biomass washouts, not allowing a proper growth of nitrifying microorganisms as they have lower specific biomass growth rates. The addition of zeolite in Z-SBR was capable of enriching and retaining an active nitrifying biomass, that capable of promoting NH_4^+-N removal to NO_3^--N at low temperature.

Both reactors exhibited similar TP removal performance (about 93%). It was concluded that low temperature in two reactors did not affect the removal efficiencies of TP.

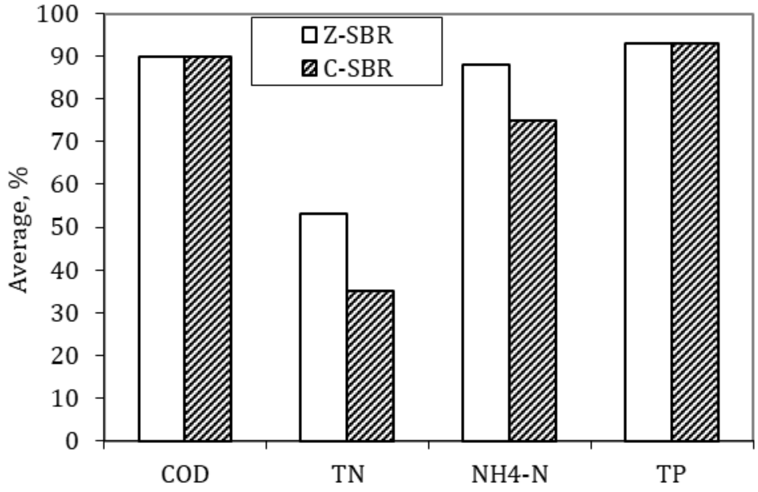

Fig. 1. Pollutant removal performance of C-SBR and Z-SBR.

3.2. Pollutant Removal Characteristics

The variation of COD removal with the function of the cycle period is depicted in Figure 2. The COD profiles for both SBRs have a general decreasing trend, however, it was observed for C-SBR, the COD decreased from 360 mg l^{-1} to 40 mg l^{-1} at a time period of 3.5 h, while it last 3h for Z-SBR. Due to the competitive advantage of heterotrophic microorganisms on ammonium oxidizing bacteria, COD removal was dominant reaction in the first three hours. After that, the COD concentration remained at a nearly constant level.

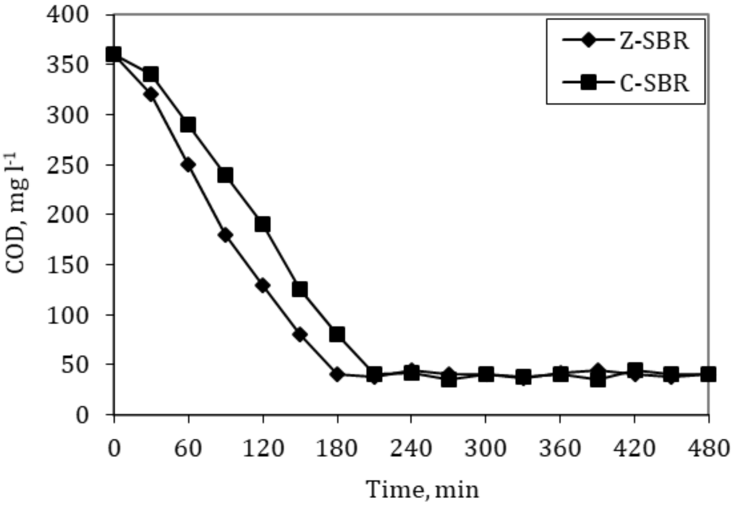

Fig. 2. Variation of COD profiles in C-SBR and Z-SBR.

It can be seen from Figure 3 that the NH_4^+-N concentration remained unchanged at first 180 min and then decreased to 7.8 mg l^{-1} at the next 150 min in C-SBR. For Z-SBR, NH_4^+-N fell faster from 30 mg l^{-1} to 22.8 mg l^{-1} at the first 180 min, while the content of nitrite and nitrate was negligible over this period. Therefore, the reduction of NH_4^+-N can be attributed to the adsorption and ion exchange of zeolite powder for NH_4^+-N. During the period of minute 180-330, NH_4^+-N decreased to 3.8 mg l^{-1} in Z-SBR. These results indicated that the presence of zeolite materials in the reactor could improve the removal of ammonium at low temperature.

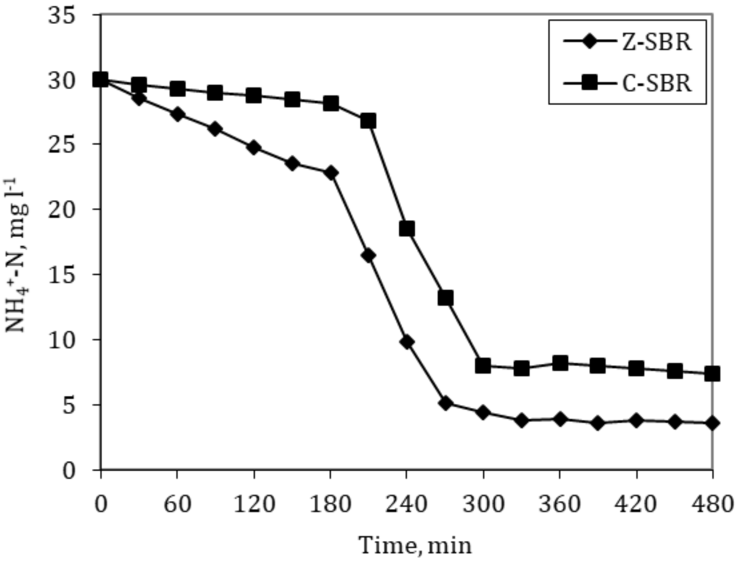

Fig. 3. Variation of NH_4^+-N profiles in C-SBR and Z-SBR.

Figure 4 shows that the amount of NO_x (nitrite+nitrate) increased significantly after 240 min. For Z-SBR, the amount of NO_x from 1.8 mg l^{-1} to 10.5 mg l^{-1} in the 60 min and then kept almost stable, while for C-SBR, the amount of NO_x from 1.5 mg l^{-1} to 9.6 mg l^{-1} during 240-300 and then increased 19.8 mg l^{-1} in the next 180 min. Compared to the Z-SBR, the C-SBR has a higher concentration of NO_x left after 480 min. During the period of minute 240-300, the amount of NH_4^+-N reduction (from 9.8 mg l^{-1} to 3.4 mg l^{-1}) in Z-SBR is lower than that (from 18.5 mg l^{-1} to 8 mg l^{-1}) in C-SBR, while the amount of NO_x increased in Z-SBR is more than that increased in C-SBR and this verified that nitrification rate is faster in the Z-SBR.

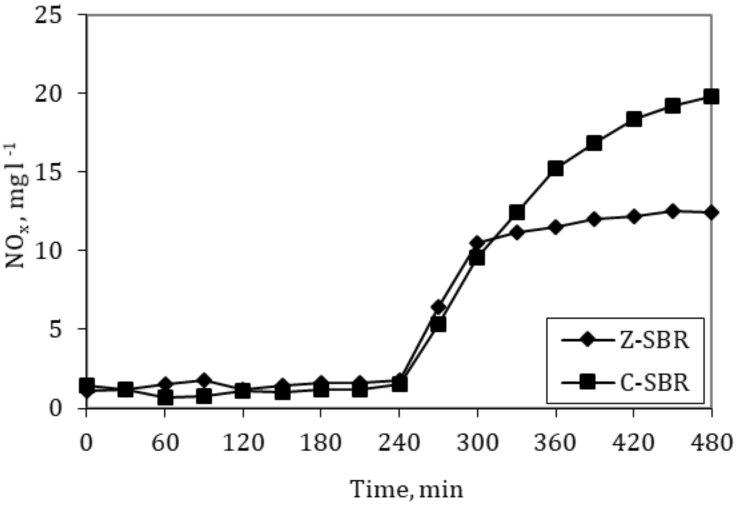

Fig. 4. Variation of NO_x profiles in C-SBR and Z-SBR.

It can be seen from Figure 5 that TN decreased from 48.6 mg l^{-1} to 31.6 mg l^{-1} in 480 min in C-SBR, while in Z-SBR TN decreased by 8.4 mg l^{-1} which is about equivalent to the amount of NH_4^+-N reduction in the first 30 min and then TN was reduced to 19.8 mg l^{-1} at the aeration time point 270 min. During the period of 270-480 min, it was found that the TN rose to 23.2 mg l^{-1} with the extension of aeration and the amount of NO_x was detected to have a rise (from 6.4 mg l^{-1} to 12.4 mg l^{-1}). The NH_4^+-N adsorbed by zeolite powder (about 7.2 mg l^{-1}) was nitrified by nitrobacteria. Compared to the C-SBR, there has a higher TN removal of 8.4 mg l^{-1} in Z-SBR which should be attributed to the enhanced simultaneous nitrification and denitrification (SND) took place in Z-SBR. The same effect of addition of zeolite was observed in submerged membrane bioreactor (SMBR) operating in continuous mode. It was found that a mean 25% higher total nitrogen (TN) removal took place in the test system compared to a control consisting of a SMBR without added zeolite [16].

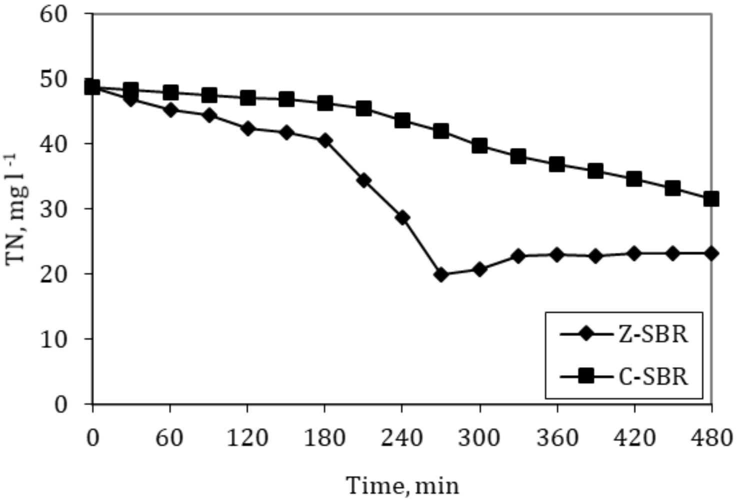

Fig. 5. Variation of TN profiles in C-SBR and Z-SBR.

The variation of TP concentration during a complete cycle is illustrated in Figure 6. In C-SBR and Z-SBR, TP concentration decreased to below 1 mg l^{-1} at the time point 210 min. These results indicated that the low temperature did not have a detrimental effect on phosphorus removal.

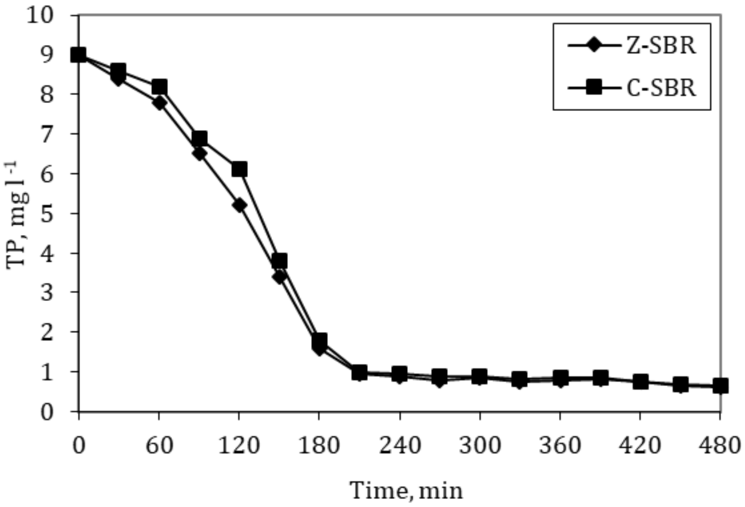

Fig. 6. Variation of TP profiles in C-SBR and Z-SBR

DO is an important parameter that significantly influences the organic and nitrogen removal processes in biological processes [17]. DO leaps could be directly related to COD and NH_4^+-N concentrations, with the depletion of COD and NH_4^+-N causing a sudden increase in the DO. With the extension of aeration time, DO rise continuously at one reaction cycle in these two reactors, as can be seen Figure 7. It was found that DO has a distinct leap at the time point of 190 min and then kept almost stable. In Z-SBR, another distinct DO leap was observed at time point 270 min while it took place at a late time point 330 min in C-SBR.

According to the experimental results illustrated in Figures 2-5, it was analyzed that time period 0-190 min was the stage of organics degradation. At this stage, supplied oxygen was slightly more than needed oxygen and DO in reactors rose slowly. The changes of DO in C-SBR and Z-SBR were similar during the organic degradation. After the biodegradable organics was degraded completely, DO leap happened and then reached a new balance at high level. At the following stage, supplied oxygen was consumed by nitrobacteria for nitrification. At time point minute 270, nitrification stage ended and a second DO leap took place, then DO reached now level 7.5-8.0 mg l^{-1}. In C-SBR, nitrification stage ended at time point minute 330 and DO jumped at around 7.0 mg l^{-1}. Therefore, combining the Z-SBR results shown in Figures 3-5, it could be seen that the addition of zeolite powder enhanced the nitrification ability from viewpoint of DO variation.

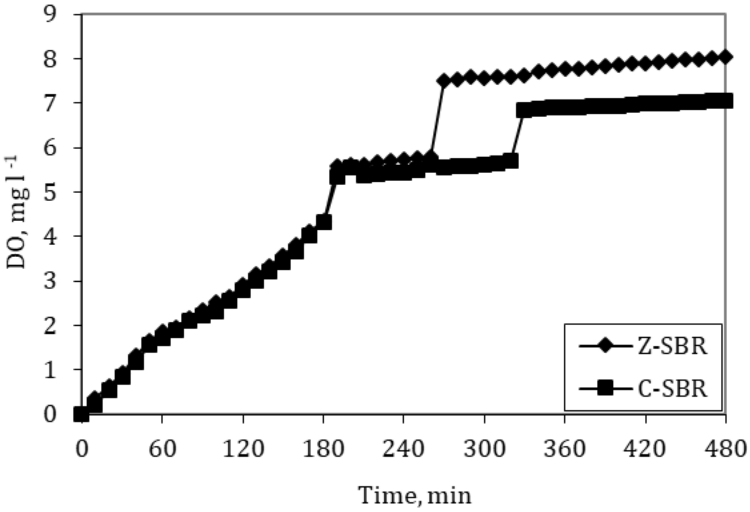

Fig. 7. Variation of DO profiles in C-SBR and Z-SBR.

3.3. Roles of Zeolite in the SBR

The ammonium is removed by zeolite through sorption and ion exchange. First, some portion of NH_4^+-N in the influent is adsorbed onto the surface of zeolite. Then, zeolite concentrated with NH_4^+-N and an aerated environment provides favorable conditions for autotrophic bacteria attachment. At the following stage, the adsorbed ammonium nitrogen was released into the liquid phase due to the chemical equilibrium and transformed to oxidized nitrogen by nitrifiers. In this stage, the zeolite was completely regenerated by nitrifiers. Therefore, zeolite can play an important role in ammonium removal as well as organic removal in the SBR.

3.4. Sludge Characteristics

Zeolite addition into reactor significantly increased the concentration of MLVSS. The average MLVSS concentration in Z-SBR was 2900 mg l^{-1}, although the C-SBR merely showed average biomass concentration of 2120 mg l^{-1}.

SVI is an important parameters affecting the performance of a wastewater treatment system. SVI was ranged from 120-140 mL g^{-1} for C-SBR, while SVI was ranged from 80-100 mL g^{-1} for Z-SBR. This shows that the addition of zeolite could have an apparent effect on the improvement of sludge compresibility and settleability.

3.5. pH

The average NH_4^+-N removal efficiency in two reactors with different influent pH values were also investigated (Figure 8). The average NH_4^+-N removal efficiency was improved with the increase of pH values (from 6.0 to 8.0). However, its removal efficiency was decreased when pH value was 9.0. Therefore, the optimal pH was 8.0 in two reactors. The activity of nitrifying microorganisms was restrained to some extent at pH value of 6 and 9, because they were sensitive to variety of pH. This was consistent with the results obtained by Guo et al. [18] that optimum NH_4^+-N removal detected at pH value of 8.0.

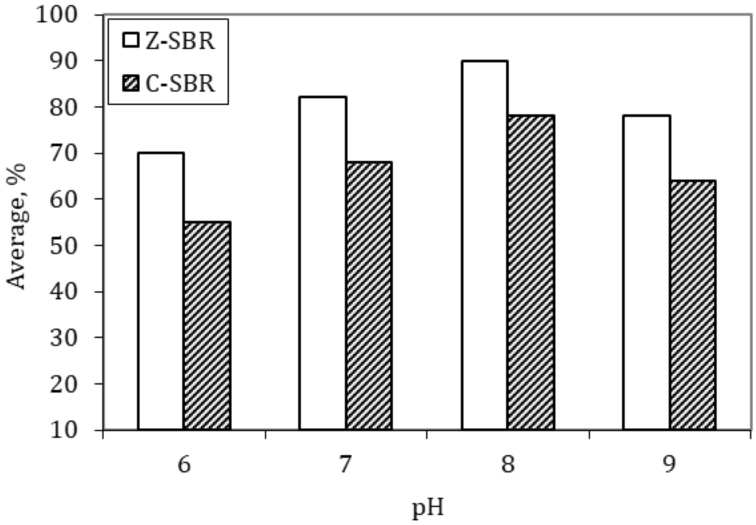

Fig. 8. Effect of influent pH values on NH_4^+-N removal in C-SBR and Z-SBR.

4. CONCLUSIONS

Low temperature had a little effect on COD removal efficiencies. Both reactors could efficiently remove organic matter from wastewater. However, the nitrogen removal rate in Z-SBR was higher than C-SBR. Z-SBR represented the same phosphorus removal as the C-SBR. A high of MLVSS concentration was observed in Z-SBR compared to that in C-SBR. Z-SBR had lower SVI values than C-SBR. The best NH_4^+-N removal performance of two reactors was obtained with pH values of 8. These results suggest that Z-SBR could be an alternative technology to treat municipal wastewater at low temperature.

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Techno-Science 2:2 (2019) 41-46

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Original Research Article

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The use of waste heat from domestic refrigerator for drying clothes

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ARTICLE INFO

Article History

Received	:	29/01/2019
Revised	:	29/05/2019
Accepted	:	30/05/2019
Available online	:	31/05/2019

Keywords

Waste heat
refrigerator, clothes
drying
drying closet.

ABSTRACT

This paper exhibits the experimental study of the use of waste heat from domestic refrigerator for drying clothes. A $0.4m^3$ *capacity drying closet with a 100W blower was fitted to the back side of an LG refrigerator which contains the condenser that emits waste heat. Wet clothes of weights 1.32kg, 1.96kg, 2.89kg, 3.12kg and 4.10kg were hung in the drying closet in succession to dry when the refrigerator was in operation. Air flow temperature, drying closet temperature, hot air velocity in the drying closet, relative humidity and drying time were measured. The drying characteristics and performance of the drying closet were evaluated. The results of the study revealed that wet clothes of weights 1.32kg, 1.96kg, 2.89kg, 3.12kg and 4.10kg were respectively dried in 55, 65, 100, 105 and 130 minutes. The drying rate is in the range of 6.02kg/min to 11.06kg/min. Specific moisture extraction rate varied between 0.752kg/kWh and 1.833kg/kWh and drying efficiency of the closet varied between 48.8 and 63.1%.*

1. INTRODUCTION

Clothes drying in a developing country like Nigeria is mainly achieved by natural drying process that is, utilizing solar energy directly. This involves spreading the clothes inside, around and outside the house and it is at the expense of the beauty of the house [1]. The drying period of clothes put to dry by natural process is very long and it is longer when the air is highly humid [2]. Household clothes dryer is among the most energy consuming devices in homes [3]. In European homes, clothes driers whose power sources are electricity are increasingly in use and this has led to high rate of electricity consumption [4]. The main energy sources for drying machines are electricity, fossil fuels such as kerosene, petrol, diesel and gas. These energy sources can be conserved by evaluating and using alternative energy sources for clothes drying.

In most homes in urban and some in rural communities of Nigeria are found refrigerators which is either vapour compression type that requires electricity for powering or vapour absorption type that utilizes heat from any source for its operation. In both types of the aforementioned refrigerators, the condensing unit releases heat to the surrounding which is wasted. This waste heat can be utilized for drying clothes. This is the focus of this study. Prior to this study, the dire need to look out for alternative energy source for clothes drying has been identified many researchers. On that note solar powered clothes dryers were developed by Ali and Mohammed [5] , Alam [6], Jain et al [7], Wu [8] and Amiebenomo et al. [9] to mention just a few. In the same vein, the technology of the use of waste heat from the condenser of air conditioners was evolved by Ambarita et al [1], Suntivarakorn, et al [2], Han and Deng [10], Mahlia et al. [11], Othman [12], Ambarita et al. [13], Jing-Wei et al. [14], Braun et al. [15], Martin et al [16], TeGrotenhuis et al. [17], Bengtsson et al. [18], Zhang [19], and Honma et al [20] still to mention just a few.

From the foregoing the use of heat pump drying process which entails the use of waste heat from the condenser of air conditioners besides others for clothes drying purposes have been studied by many researchers. But there is little or no significant study on the use of waste heat from the condenser of a domestic refrigerator for clothes drying. So this research

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To cite this article: Musa, N.A., (2019). The use of waste heat from domestic refrigerator for drying clothes. *Techno-Science* vol. 2, no. 2, p. 41-46.

work is concerned with the use of waste heat from a refrigerator to dry clothes in the developed 0.4m^3 capacity drying closet fitted with 100W blower that was developed by Okuo [21].

2. EXPERIMENTAL SETUP

The refrigerator employed for this study was an LG refrigerator made in China. The specifications of the LG refrigerator are shown in Table 1.

Table 1. Specifications of the LG Refrigerator made in China used for the experiment

S/N	Specifications	Values/Types
1	Model Number	GC -051SA
2	Size(Dimension)	443mm × 450mm × 501mm
3	Gross volume	50L
4	Refrigerant	55g, R134a
5	Rated power input	85W
6	Condenser	Air cooled

The drying closet was fitted with screws to the back side of the refrigerator which contains among others, the condenser as shown in Figure 1.

Fig. 1. The refrigerator fitted with the drying closet

2.1. Experimental Run

Five different set of clothes of cotton materials were weighed to know their dry weights which were 0.6 kg, 0.9 kg, 1.4 kg, 2.1 kg and 2.6 kg respectively .The clothes were put in bath filled with water and wrung out for the water content to reduce. The wet clothes were weighed with a hanging scale manufactured in China to obtain the initial weights of the set of wet clothes to be dried which were 1.32 kg, 1.96 kg, 2.89 kg, 3.12 kg and 4.10 kg respectively. Experiments were conducted using each set of the wet clothes in turn.

The drying closet was loaded with a set of the wet clothes. The refrigerator was filled with several food items for preservation so as to reflect its actual domestic usage . Thereafter the refrigerator as well as the blower were powered. After every five minutes, the clothes in the drying closet were weighed with the hanging scale. The temperature of airflow into and out of the drying closet were measured with K type thermocouples. The relative humidity and the temperature of inside the drying closet were measured with Relative humidity meter and velocity of the hot airflow in the drying closet were measured with anemometer. With the data obtained from the experiment, the drying characteristics and performance of the drying closet were evaluated.

The moisture ratio was evaluated by using the relation stated as

$$\theta_R = \frac{m_{fi} - m_{oi}}{m_{in} - m_{oi}} \tag{1}$$

Where, θ_R is the moisture ratio, m_{fi} is final mass of wet clothes after drying for a period of time, m_{oi} is the mass of the dry clothes prior to wetting and m_{in} is the initial mass of the wet clothes.

The drying rate was determined using the expression

$$\dot{m}_t = \frac{m_{in} - m_{fi}}{\Delta t} \tag{2}$$

Where $\dot{m}_t$ is the drying rate and Δt is the drying time interval.

The energy balance over the drying closet is given as

$$\dot{Q}_{co} + \dot{Q}_{bl} + \dot{Q}_{ai} = \dot{Q}_{ud} + \dot{Q}_{losses} \tag{3}$$

Where $\dot{Q}_{co}$ is the condenser heat, $\dot{Q}_{ai}$ is the energy of the inlet air, $\dot{Q}_{bl}$ is blower power, $\dot{Q}_{ud}$ is the energy used for drying clothes in the closet which is the energy required to remove moisture from the clothes and $\dot{Q}_{losses}$ is the energy loss through the hot air exhaust and the insulating walls of the drying closet

The available heat at the condenser from the thermodynamic cycle of operation of the refrigerator in line with Musa et al. [22] for drying clothes was evaluated by using the relation stated as

$$\dot{Q}_{co} = \dot{m}_r(h_3 - h_4) \tag{4}$$

Where $\dot{m}_r$ is the refrigerant mass flowrate, h_3 is the enthalpy`at point 3 in the thermodynamic cycle of operation where the vapour of refrigerant at low temperature and pressure is compressed and raised to a high temperature. h_4 is the enthalpy at point 4 in the same cycle of operation where the refrigerant condenses and releases heat and it is this heat that is now rejected to the drying closet.

The energy of the inlet air to the drying closet was estimated using the formula given as

$$\dot{Q}_{ai} = \dot{m}_{ai}h_i \tag{5}$$

Where a_1 is the mass flowrate of air into the drying closet, h_i is the enthalpy of air at the inlet of the closet.

It was assumed that the energy loss through the walls of the cabinet is negligible. So the energy loss through the drying closet is by convection that is through the outlet air. So it was determined by applying the equation stated as

$$\dot{Q}_{losses} = \dot{m}_{ai}h_o \tag{6}$$

Where h_o is the enthalpy of air at the outlet of the drying closet

The energy used for drying clothes was evaluated using the rearranged Eq. 3 as

$$\dot{Q}_{ud} = \dot{Q}_{co} + \dot{Q}_{bl} + \dot{Q}_{ai} - \dot{Q}_{losses} \tag{7}$$

The drying efficiency of the closet was obtained by using the relation given as

$$\eta_{closet} = \frac{\dot{Q}_{ud}}{\dot{Q}_{co} + \dot{Q}_{bl} + \dot{Q}_{ai}} \tag{8}$$

Besides the drying efficiency of the drying closet, specific moisture extraction rate(SMER) is one of the most frequently used performance indices for heat pump dryer. It is defined as the ratio of the quantity of moisture in terms of mass removed from wet clothes to the total energy used. That is

$$SMER = \frac{\Delta x}{\dot{\mathrm{Q}}_{\mathrm{ud}}\Delta t} \tag{8}$$

Where Δx is the total quantity of moisture removed from the wet clothes during the drying period and Δt is the drying time.

So the specific moisture extraction rate(SMER) was obtained by using Eq. 9.

3. RESULTS AND DISCUSSION

The result of the performance evaluation of the drying closet using waste heat from domestic refrigerator is shown in Table 2.

Table 2. Performance result of the clothes drying closet

S/N	Weight of wet clothes(kg)	Weight of dry clothes(kg)	Drying time(mins)	Average Drying rate(g/min)	Specific Moisture Extraction rate(kg/kWh)	Drying Efficiency (%)
1	1.32	0.6	55	6.02	0.757	63.1
2	1.96	0.9	65	7.52	1.674	54.4
3	2.89	1.4	100	8.45	1.768	49.6
4	3.12	2.1	105	9.41	0.896	57.7
5	4.10	2.6	130	11.06	1.833	48.8

It can be seen from Table 2 that the drying time as well as the average drying rate of the clothes increased with the weight of the wet clothes. This reason may be adduced to the fact that the higher weight wet clothes were closely packed together in the closet than the lesser weight clothes. So the hot air circulated more rapidly in the lesser weight clothes and remove the moisture than the higher ones in the drying closet. Moreso, the specific moisture extraction rate(SMER) which shows the degree to which energy is used in the drying process decreased as the efficiency increased as evident in Table 2. Wet clothes of 4.10kg has the highest SMER of 1.833kg/kWh and 1.32kg wet clothes has the least SMER of 0.757kg/kWh. The higher the amount of moisture in the clothes, the higher was the SMER. The efficiency varied between 48.8 and 63.1%. The variation of the moisture ratio of the wet clothes with time is shown in Figure 2.

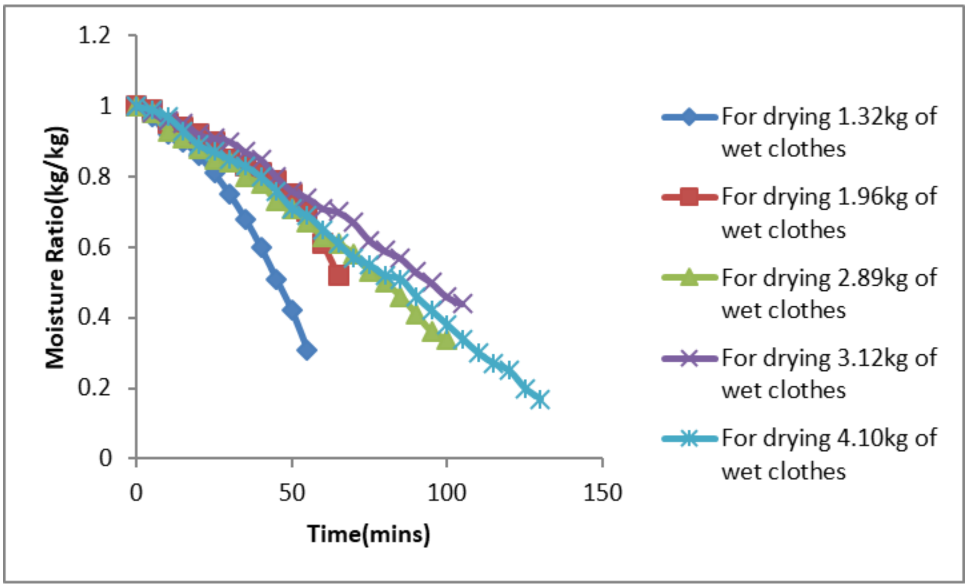

Fig. 2. The variation of the moisture ratio with time

It can be seen from Figure 2 that the moisture ratio of the wet clothes irrespective of the weight of clothes being dried with the drying closet decreased with time. The relationship between the moisture ratio and the time is approximately linear with the least weight of clothes of 1.32kg having the highest gradient. This is similar to the observation made by Ambarita et al[1] in their works. The variation of drying rates of the wet clothes with time is shown in Figure 3.

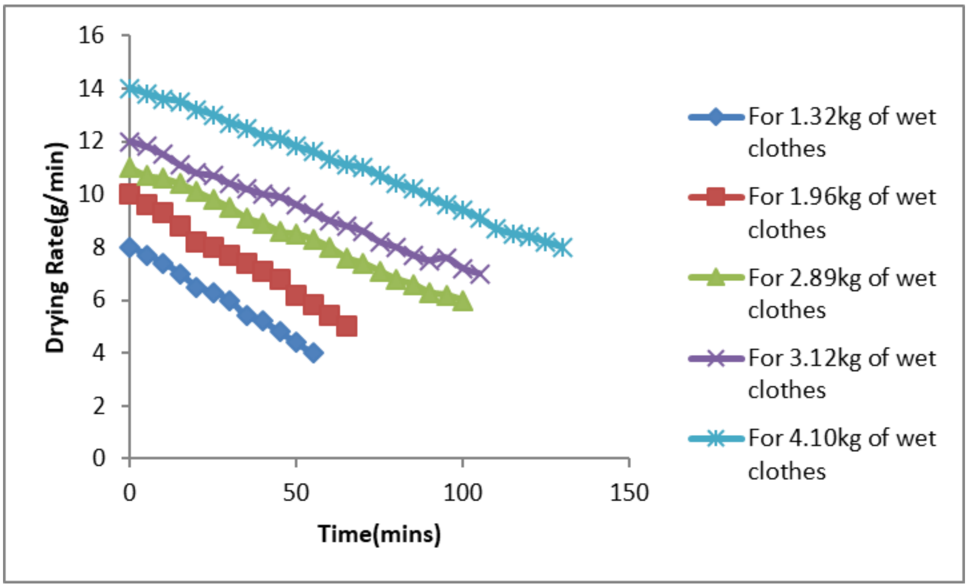

Fig. 3. The variation of drying rate with time

It is evident in Figure 3 that the drying rates increased with increase in the weight of wet clothes as earlier observed in Table 2 and decreased with time regardless of the weight of wet clothes. The drying rate may have been enhanced by increase in air flow that takes moisture away[3] and increase in the temperature. Wet clothes of 4.10 kg have the highest drying rate of 11.06 g/min and 1.32 kg of wet clothes has the least drying rate of 6.02g/min.

4. CONCLUSION

Artificial clothes drying method requires a lot of energy. In this era of energy crisis, conservation and reduction in the waste of any available energy is a welcome development. So using waste heat from domestic refrigerator for drying clothes in a closet was studied in this research work. Based on the outcome of the study, it can be concluded that the waste heat is a practicable heat source for drying clothes and this has made it to attract more value.

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e-ISSN: 2651-3722