Techno-Science
Scientific Journal of Mehmet Akif Ersoy University
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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 0.4m³ 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

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

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

$$\dot{Q}_{co} + \dot{Q}_{bl} + \dot{Q}_{ai} = \dot{Q}_{ud} + \dot{Q}_{losses} \quad (3)$$

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

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

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

$$\dot{Q}_{ai} = \dot{m}_{ai} h_i \quad (5)$$

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

$$\dot{Q}_{losses} = \dot{m}_{ai} h_o \quad (6)$$

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

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

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

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

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

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

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.

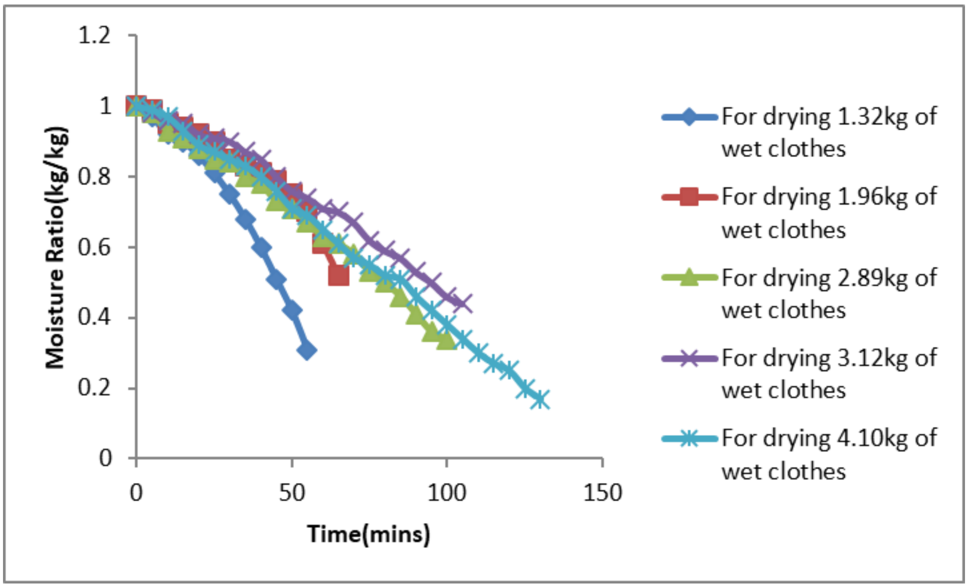

Fig. 2. The variation of the moisture ratio with time

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.

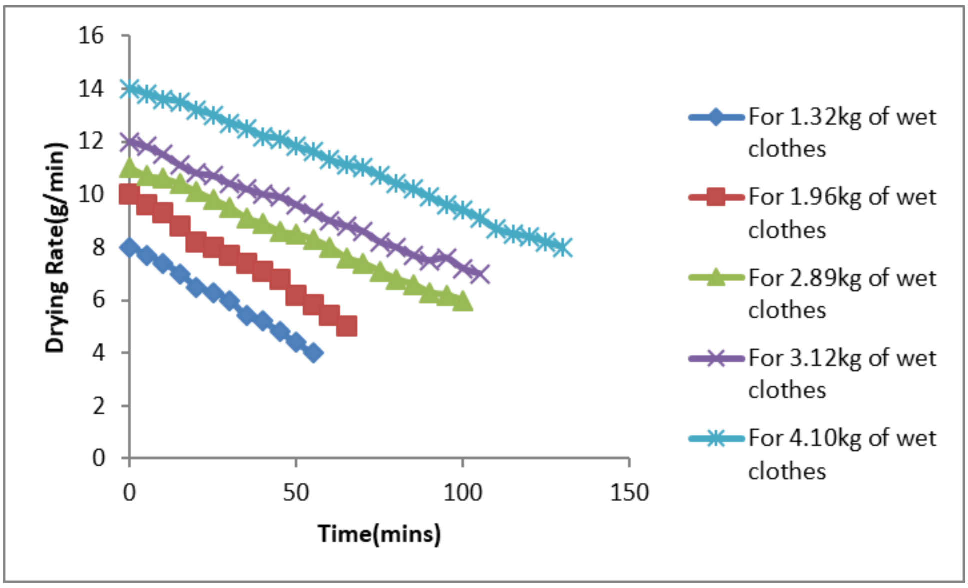

Fig. 3. The variation of drying rate with time

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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Techno-Science *Paper ID: 519272*