Development of a Domestic Fabric Dryer

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Abstract:- A fabric drying cabinet has been developed for domestic use. The concept came into been due to less available solar energy for fabric drying during prolong wet season between May and October every year in Nigeria. Many baby wears during this period need frequent wash and dried for use. Hence the design of a portable fabric cabinet dryer based on the principles of heat transfer and turbulent airflow. The drying chamber was designed to be 0.420 m^3, electric motor power of 1kW, volumetric air flow of 47.52m^3/s, fan's velocity pressure of 185.6N/m^2 with the system designed having total energy of 6.48 x 10^6 joules and useful energy of 5.6376 x 10^6 joules while the waste energy is 0.8424 x 10^6 joules. This gave the developed drying cabinet an estimated efficiency of 87%.

Keywords:- *Fabric, Drying Cabinet, Fabrication, Drying Chamber, Heat Transfer.*

I. INTRODUCTION

Fabrics are clothes used for coverings or garments intended to be worn on the human body. They help to protect the body from the environment such as cold and rain. It provides a mark of identity and covers human nakedness [1]. The soiling of fabrics is a universal problem which leads to a considerable expenditure on laundry. Fabrics are washed to remove the soils from contaminants and perspiration from the human body. The drying concept for this design was developed from all the types of drying of clothes. This include natural dryer, gas dryer, spin dryer, and heat pumps dryer [7]. These clothing are hung outside making use of natural energy from sunlight and the wind to remove moisture from them [4]. Drying is the process of removing moisture from damp materials with the aid of heat. Drying can also be defined as a mass transfer process resulting in the removal of moisture by evaporation from a solid material [13]. From the above definitions of drying, it could be inferred that drying is the combination of heat and mass transfer processes. It requires the application of hot ventilating air to the material being dried to evaporate the moisture by converting it into water vapour and mixing the water vapour with the drying air which eventually leads to its transportation outside the dryer [9].

In the past drying of clothes usually use natural way of drying using energy from the Sunlight and the wind, but with the evolution of technology, different ways of drying clothes within the peak of wet season has been developed. The clothes dryers that made use of electrical energy and other sources of energy has been developed, especially in the urban area where limited sunlight (cloudy days) and restricted air flow for house types such as high rise condominiums and apartments. In some urbanized areas natural drying of clothes on railings is prohibited for aesthetic reasons while the conventional domestic electric dryers are too expensive not affordable for the low income earners. The epileptic and inefficient power supply has become worrisome and at the same time forming a good research topics nowadays. Many cabinet dryers are widely use at the present time, especially by those who are in the working class [7].

It has been discovered that alternative means can be improvised to dry clothes instead of drying outside which takes a longer time to dry as a result of poor weather conditions [2]. Technology has made it possible for the people to make use of technology driven initiative in the drying of their cloths using dryers that make use of electric energy. [4].

The earliest clothes dryers were made in England in the late 18th century while France came in to the foray in the early 19th centuries. This inventions were known as "ventilators," they were large metal drums with ventilation holes, powered by hand cranks, and spinned over open fires. Their invention can't be traced to any one person, but perhaps no one would have wanted the credit, since the clothes always smelled of smoke, were often covered with soot and sometimes caught fire [7].

Equilibrium moisture content of fabrics as carried and determined by Perry is as shown in table 1.

Table 1: The Equilibrium Moisture Content of Fabrics [9]

Fabrics	Equilibrium Moisture Content (%)
Cotton	7-11
Wool	13-18
Silk	11
Linen	12

Pasty, 1977.

Investigation in to the process of cloth drying was carried out by Harizatul in the 2012 and it was discovered that the drying process followed an evaporation process in which the liquid water in the cloth turns to vapour and is getting rid of. Most of the water is spun out at high speed and drained away, but even the most efficient machine leaves a significant amount of wetness in the clothes [4]. The history of washing and drying machines dated back to centuries and the necessity to wash and dry clothing is almost as basic as the necessity of clothing itself [15].

The Huebsch Manufacturing Company patented an open-air dryer in 1931 and introduced the stacked dryer for commercial purpose in the year 1941 and continued their run up to 1954 when they introduced a coin-operated dryer for Laundromats.

The American Dryer Corporation came into the business of cloth drying in 1965 with two different coin-operated models designed for Laundromats. Fourteen years later they introduced the first computerized dryers [7].

The need for drying arises due to the following reasons: To reduce bulk or weight for economic consideration, handling or transport, reduce the material in the desired condition for further processing, handling or marketing, sterilize or preserve the product, and to recover by-products from slurries or solution [1]. Drying is often used in the agricultural sector to preserve agricultural product such as cocoa, cassava, fish etc. it is also used for the preservation of wood [13]. It is used in the food industries for processing food. Drying also is applicable to fabrics for removing moisture from them after laundry. Fabrics may be dried by hanging on the line outdoor or indoor, spread out flat on the floor or in an automatic dryer. Outdoor line drying, indoor line drying and spreading flat on the floor are all known as air drying [11]**.**

Drying of clothes in the dryer involves the use of stream of hot air which blows over the items to remove moisture from the material. The temperature difference between the air and the materials maintains a constant flow of heat to the material and simultaneously, evaporation takes place [1]. Drying clothes in the dryer saves time and effort, it makes items soft and smooth. It does not depend on weather [10].

For many years, clothes were hung on lines, spread on grasses or open surfaces for it to dry. Hot air blowing over them removes the moisture from them. This method of drying cloth is limited by weather conditions, such as rain, storm, pollution and dust.

The problem of having clothes dried in rainy season brought a method of drying clothes which made use of potbellied stove attached to a shed. This stove heats the room enough to keep the clothes from been wet. Clothes hanging close to the stove actually dried faster leaving clothes farther from the stove partially dried. This method was discovered to be inadequate in producing the desired drying [3]. Drying machine was later invented. The first drying machine to come to existence was the ventilator. This type of dryer is a barrel shaped metal drum with holes or slits in it and it is turned over fire by hand. The limitation in the use of the dryer is due to the fact that the clothes would dry but they might get burnt, clothes dried in the ventilator are characterized by strong smell of smoke, and known to pick up sooth from the smoke [9]. With the advent of electricity, the first electric dryer was introduced, it make use of electric current to fuel the heating coils and a fan to distribute the heat in the dryer. The walls of the dryer were lagged to prevent heat loss from the sides. Some common materials used in building fabric dryers are: stainless steel; galvanized sheet; coated mild steel. As technology improves, dryers that make use of timer to control the drying time for different fabric were introduced into the existing dryer [6]. Improvement in technology further gave birth to dryers that conserves energy and uses sensors rather than timer and shut the appliances off when the clothes are dried. In the course of time, the use of natural gas that uses gas burner to create heat was later introduced into drying machines. Dryers have survived the course of time with different types of dryer that uses different means of fuelling [14].

Compared to other forms of dryers namely combo washer dryer, tumbler dryer, microwave dryer, heat pump dryer and mechanical steam compression dryer, the present upright fabric designed dryer is expected to be more efficient because it will make use of hot air from the heating element [12]. The material to be used for its production is galvanized sheet due to its low cost and water resistant ability.

II. METHODOLOGY

The following engineering and design factors were considered for the design of this dryer: Rigidity and strength of the frame; lightness, weight for the dryer; availability of construction material; and sources of energy The following components were designed and analyzed for the dryer for ease of future production: Fan, heating element, Electric motor, Thermostat, Cabinet, Tray and Water collector.

A. Machine design analysis

Nomenclature:
A = Area of blade (m^2)
B = breadth of tray (m)
b = bottom width (m)
d = diameter (m)
g = acceleration due to gravity m/s^2
h = height (m)
H = fan head (Ns/kg)
L = length of tray (m)
ρ = material density (Kg/m^3)
P = power of electric motor (W)
Q = volumetric flow (m^3/s)
r = radius of motor shaft (mm)
T = Torque (Nm)
v = velocity of fan (m/s)
V = volume of blade (m^3)
t = thickness of blade (mm)

W = specific useful work (j/kg)
C_p = fan motor power consumption (W)
w = weight of each blade (N)
T_1 =Ambient temperature in dryer (°C)
T_2 = maximum working temperature (°C)

- *Design analysis of the electric motor*

Electric motor speed selected = 1400 rpm

- *Determination of the weight of the fan*

Assume blade shape is trapezoidal, no of blades = 6

Weight of each blade can be found from the relation
$w = \rho \, x \, g \, x \, V = 5.59N$ Per one

Number of blades = 6
Weight of blades = $6 \, x \, 5.59 = 33.54N$

Diameter of motor shaft $d = 0.42$

Radius of motor shaft = $\frac{d}{2} = 0.21m$

Torque = $\omega \, x \, r = 7.04 \, Nm$

Electric motor power $P = \frac{2\pi NT}{60}$

$= 1032 \, W \approx 1000 \, W$

- *Design analysis of the electric fan power*

Fan diameter $d = 0.24 \, m$

Motor speed = fan speed [direct drive]= $1400 \, rpm$

Air density $\rho = 1.2 \, Kg/m^3$

Fan velocity v = $\frac{\pi DN}{60} = 17\ 59 \, m/s$

Fan selection area $A = \frac{\pi d^2}{4} = 0.045m^2$

Volumetric air flow $Q = A \, x \, V = 47.52 \, {m^3}/{s}$

Fan velocity pressure = $0.5 \, x \, p \, x \, V^2 = 185.6 \, N/m^2$

Fan head $H = \frac{[fan \ velocity \ pressure]}{air \ density} = \frac{P}{\rho \, x \, g} = 15.77 \, Ns/Kg$

Specific useful work $W = H \, x \, g = 154.7 \, J/Kg$

Fan power consumption = $\rho \, x \, Q \, x \, W = 147W$

- *Design analysis of perforated tray*

Area of fan section $A = \frac{\pi d^2}{4}$

$= 0{,}038 \, m^2$

Length of tray $L = 0.7 \, m$
Width of tray $W = 0.5 \, m$

Area of tray= $L \, x \, B$

$= 0.7 \, x \, 0.5 = 0.35 \, m^2$
Area of tray for drilled holes = Area of fan section = $0.038 \, m^2$
(1)

Assuming a perfect square area for each hole, the dimension of each side
$= \sqrt{0.038} = 0.195 \, m$

Leaving a space of 1 mm between holes.
(2)
Area occupied by 1 hole = $0.01 \, x \, 0.01 \, m$
$= 0.0001 \, m^2$
(3)

For each side of 0.195 m length,
(4)
Number of holes per side = $\frac{0.195}{0.01}$

$= 19.5 \, holes \approx 20 \, holes$

Total number of holes = $20 \, x \, 20 = 400 \, holes$

Area of each hole = $\frac{\pi d^2}{4} = 0.000503 \, m^2$

Total area of air flow = $0.000503\pi \, x \, 40 \, x \, 0.7$
$= 0.0443 \, m^2$
(5)

- *Design analysis of electric heater*

Specific heat capacity of heater = $450 \, KJ/KgK$
(6)
Ambient temperature in the dryer T_1 = 27°C
Maximum working temperature T_2 = 100°C
(7)

Rate of heat flow $Q = m \, x \, C \, x \, (T_2 - T_1)$
(8)

Area of heating element $(Ag) = \pi dl = 0.0443 \, m^2$
(9)

Thickness of heating element $t = 0.0012 \, m$
Volume of heating = $A \, x \, t = 5.32 \, x \, 10^{-5} m^3$
(10)
Density of heating element $\rho = 8400 Kg/m^3$
(11)
Mass of heating element $(M) = \rho \, x \, v$

$= 0.044 Kg$
$Q = 0.044 \, x \, 450 \, x(100 - 27) = 1800 \, W$
$Q = 1.8 \, kW$

B. Determination of Dryer cabinet efficiency.

The quantity of heat produced (H_{ip}) is $1.8\ x\ 3.6\ x\ 10^6 = 6.480\ x\ 10^6$ Joules
The quantity of usable energy of Heat in steam (H_{is}) = $1.566\ x\ 3.6\ x\ 10^6$ Joules.

The quantity of heat loss by conduction and radiation (H_c) = $(6.480 - 5.6376) x\ 10^6$
$= 0.8424\ x 10^6\ J$.

The estimated thermal Efficiency of the cabinet dryer $\eta_{th} = \frac{Heat\ in\ steam\ (H_{is})}{Total\ Heat\ input\ (H_{ip})}\ x\ 100$

$$\eta_{th} = \frac{(H_{is})}{(H_{ip})}\ x\ 100$$

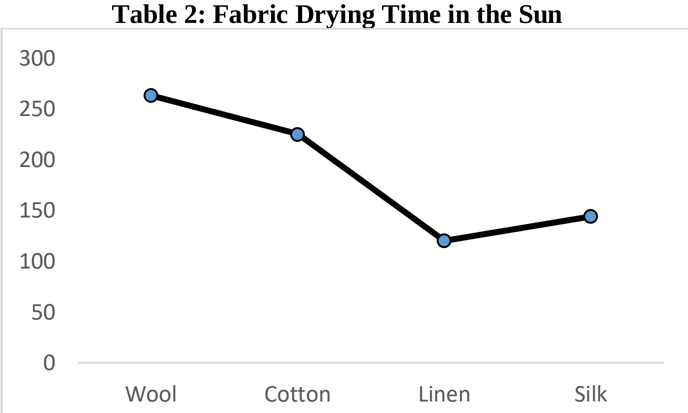
$$\frac{5.6376\ x\ 10^6}{6,480\ x\ 10^6}\ x\ 100 = 87\%.$$

C. Determination of fabric drying time in the sun

The fabrics of the same sizes were soaked in the same volume of water for 10 minutes in order to ensure maximum absorption of moisture. They were later thoroughly hand drained to remove the water in them.

The set of fabrics meant for sun drying was spread on the line at the same when the sun is at peak in the sky (12 noon). The following drying times were recorded for the different fabrics.

Table 2: Fabric Drying Time in the Sun



The longest time for drying these fabrics is that of the wool at 263 minutes. Therefore the estimated control timer of 300 minutes will be bought for the installation and use on the system. During performance evaluation after the construction, the timer will be set at various time less than its maximum for each fabric to be able to determine its optimal time for each fabric

D. Drawing of the Fabric Dryer: Below is the schematic diagram for the developed domestic drying machine.

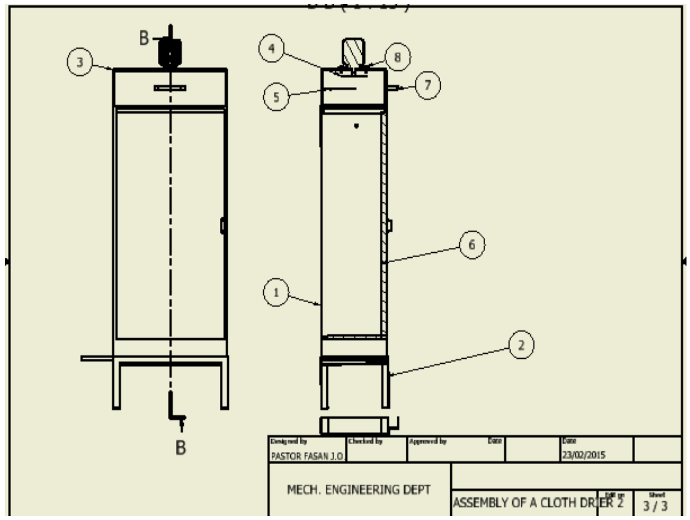


Fig 1: Section through BB of the developed dryer

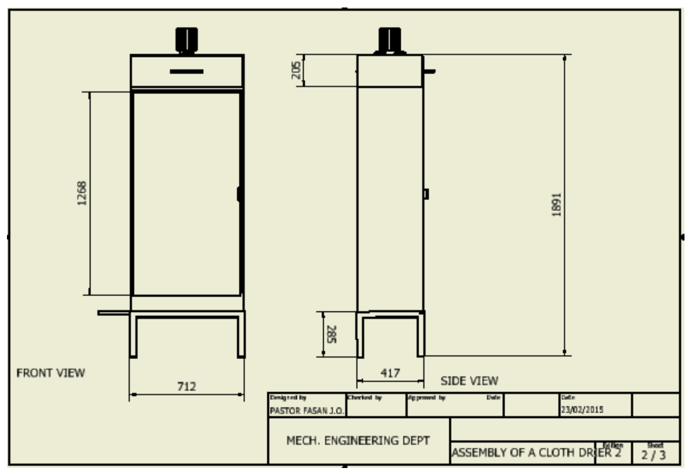


Fig 2: Front view of the dryer of the developed dryer

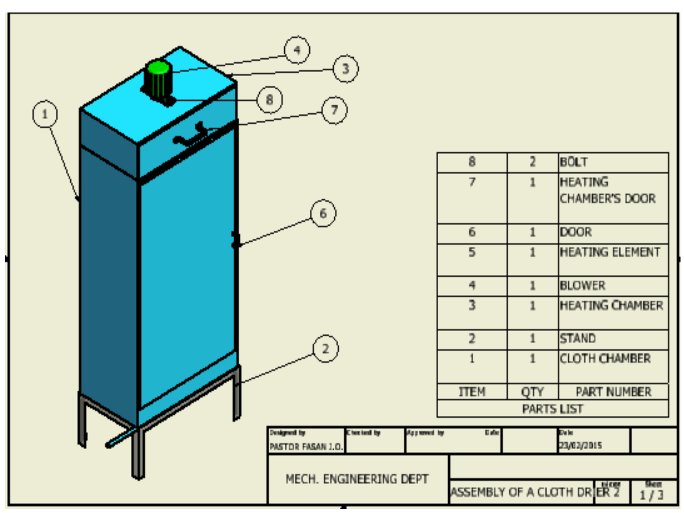


Fig 3: Assembly and part list of the developed fabric dryer

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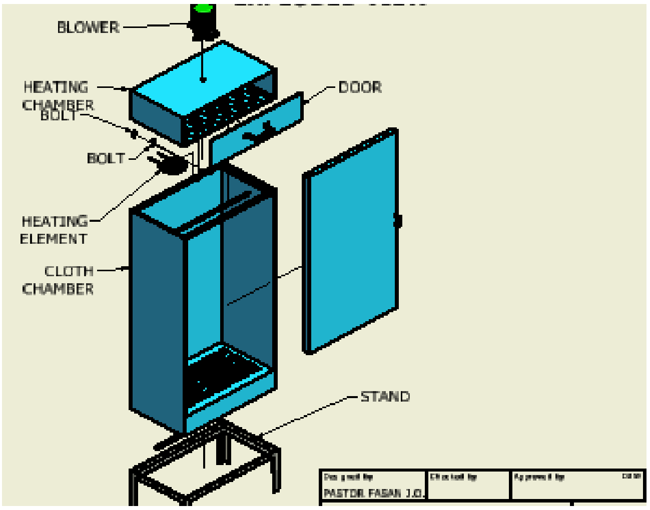

Fig 4: Exploded view of the developed dryer.

Table 3: Selected Material Used with reasons

S/N	Component	Possible Materials	Selected	Reason's
1	Angle iron	1. Stainless 2. Galvanized 3. Mild steel	Mild Steel	1. Strength 2. Low cost
2	Sheet Metal	1. Stainless 2. Galvanized 3. Mild steel	Galvanized	1. Corrosion resistance 2. Low cost
3.	Frame pipe	1. Stainless 2. Galvanized 3. Mild steel	Mild Steel	1. Strength 2. Low cost
4	Tray etc	1. Stainless 2. Galvanized 3. Mild steel	Galvanized	1. Corrosion resistance 2. Low cost

III. ESTIMATED COST OF PRODUCTION

The costs estimates are based on the length and quantity of materials required for the production of the domestic fabric dryer as shown.

Table 4: Cost estimate of materials used

Material	Unit Cost (₦)	Quantity	Total Cost(₦)
Galvanized sheet (2.44x1.22)	18,000	4	72,000
1inch Angle Iron	2,400	2	4,800
Frame Pipe	2,200	3	6,600
Electric Motor	5,500	1	5,500
Thermostat	1,500	1	1,500
Electrode	2,500	1	2,500
Heating Element	4,000	1	4,000
Fan	3,500	1	3,500
Hinges	250	4	1000
Handle	500	1	500
Cable	300	1	300
Plug	400	1	400
Paint	1,500	1	1,500
Miscellaneous			3,000
Total			**106,500**

IV. RESULTS AND DISCUSSION

The fabric dryer have been developed and its performance evaluated. The designed values for the important components are hereby stated: motor speed 1,400 rpm; volumetric air flow 47.52 m^3/s, fan velocity pressure 185.6 N/m^2; Total area of air flow0.0443 m^2, Quantity of heat 6.480 x 10^6 J while the usable energy is 5.64 x 10^6 J with an estimated efficiency of 87% and electric motor power is 1.0 kW. The perforated tray is 0.038 m^2, having 400 holes. Galvanized sheet metal was proposed for its production due to its low cost and water resistance against corrosion. The dryer shows the ability to dry wool in 263minutes, cotton in 225minutes, linen in 120 minutes and silk in 144minutes respectively.

Cost for the dryer production is $186.84 (N106,500) at an exchange rate of N570 to a dollar considering materials, labour, bought out, machining and non-machining cost.

Engineering drawings (isometric, orthogonal and exploded view) required for the dryer fabrication is now made available through the design concept in case of replicate.

V. CONCLUSION

This research made available a portable dryer capable of drying fabric particularly that of children during the wet season. The methodology adopted (design analysis, material selection and engineering drawing) were able to achieve the set goal (production of fabric dryer). Its performance proofed satisfactory when tested showing different time to different selected fabric. It is a very highly effective dryer.

VI. FUTURES SCOPE

The developed domestic drier is subject to modification in the future due to the unstable nature of power supply in the home country of production. A holistic approach must be taken to harness alternative sources of energy such as solar or wind energy which are in abundance. Though the cost implication may be higher at onset but the effort will definitely be justified once it is able to meet the need of the end users

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