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Feasibility of utilizing waste heat in drying of plant-based food materials

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Abstract

Food waste is an alarming issue for the modern world. Numerous researches are going on to reduce food waste and as a consequence, several drying techniques have been established. However, all of the systems require a significant amount of external energy. In this study, a system has been proposed that can utilize waste heat to dry the food materials, where the waste heat was used to heat the natural air for drying. The parameters associated with the system was optimized by doing the numerical studies in FLUENT environment of ANSYS 15 software. It has been found that the proposed system is capable of reducing about 1.2535 tons of CO_2 every year, whereas the installation cost and payback period is also low, which is $79 and 163 days respectively. Therefore, by implementing this technique we may think to have an energy efficient low-cost system that can gift us a green environment.

Keywords: Food dryer, ANSYS 15, Waste Heat, Feasibility analysis

1. Introduction

Food waste and hunger are two common and complementary phenomena in the world. Statistics show that 795 million among 7.3 billion people of the world, or one in nine, are suffering from starvation [1]–[4]. Meanwhile, nearly 1.3 billion tons of foods including fresh vegetables, fruits, and meat, bakery and dairy products are wastage [5].Among the total number of food-deprived people 780 million people live in developing countries, representing 12.9% or one in eight of the people of developing countries. So reducing the food waste to fight against hunger has become a liability for the world. Preserving the food by drying is a significant process for reducing food waste. Drying is one of the oldest even ancient food preservation technique. Therefore, it is still one of the dominating food preservation techniques that are practiced in developing countries across the globe. Accessible water is essential for the growth of microorganisms in food materials. Most of the raw food materials are high in water content and make it susceptible to the growth of microorganisms[6]. Drying is basically water removing process. Simultaneous heat and mass transfer take place during the drying process. In addition to prevention of microorganisms, drying offers ease in handling, packaging, shipping, and consumption. There are many types of drying process available which are basically classified on the basis of the strategy of heat supply. The most widely used drying methods in developing countries are solar drying, sun drying, and convection drying, and spray drying. However, in this study convection drying is the main point of discussion. Low-cost convective dryers have great potential in small farming areas of less than 1ha, where electricity can be made available. Even in remote places where electricity is not available, the diesel generator is a viable alternative. But, for all the cases external energy input is required[7]. In this study, especially for the developing countries of the world, a drying system using waste heat is proposed that can works as a substantial option to reduce food waste. Waste heat losses arise both from equipment inefficiencies and from thermodynamic limitations on equipment and processes. For instance, the need for many systems to reject heat as a by-product of their operation is fundamental to the laws of thermodynamics[8].Therefore, by utilizing this waste heat a low-cost efficient drying system is proposed and designed for this study. Moreover, the design optimization and feasibility study have been also accomplished.

2. Materials & Method

2.1 Required Condition for Drying

Different food has dissimilar structure that leading to a requirement of varying drying conditions for foodstuffs. Mainly these conditions depend on the existence of moisture in the food. Therefore, several amounts of heat are essential to remove the moisture content, so that it cannot affect the food. The required temperature to dry some major foods by vaporizing the liquid in them are shown in Figure 1[9]–[18].

Fig. 1. Required temperature to dry different types of food

2.2 Available sources of waste heat

Waste heat losses arise both from equipment inefficiencies and from thermodynamic limitations on equipment and processes. For instance, the need for many systems to reject heat as a by-product of their operation is fundamental to the laws of thermodynamics. However, there is a dire lack of information on the source of the largest waste heat losses in different sectors and processes and the nature of different waste heat sources (e.g., the waste heat quality and chemical composition) knowledge of these factors is critical in determining the feasibility and extent of opportunity for waste heat recovery[8]. Nevertheless, the different sources of waste heat with its exhaust temperature is shown in Table 1[19]–[21].

Table 1. Several sources of waste heat

Sources Of Waste Heat	Exhaust Temperature (℃)
Diesel Engine	300-500
Gas Turbine	370-540
Ceramic Kiln	200-300
Cement Kiln	200-350/300-450
Container glass melting	160-200/140-160
Boiler	230
Food Industry	164
Conventional Incinerator	760

2.3 System Description

The experimental setup is revealed in Figure 2.The setup is comprised of a number of devices including a drying chamber, heat exchanger, fan, motor, control unit, battery and Photovoltaic cell (PV cell). The Photovoltaic cell converts solar light photons into electricity, which is stored in a battery[22]. The stored electricity is used to run the motor which in turns run the fan to supply the required amount of working fluid i.e., air into the heat exchanger system. The mass flow rate of air is controlled by a control unit as shown in Figure 2. The heat exchanger is working on the principle of counterflow heat exchanger, where from the other side of the pipe hot exhaust (flue) gas is flown that transfer heat to the air. Finally, the hot air is distributed over the trays by the air distribution unit and exit of the air is provided such that the hot air then passes through the material to be dried. This ensures uniform mixing of the air and material being dried.

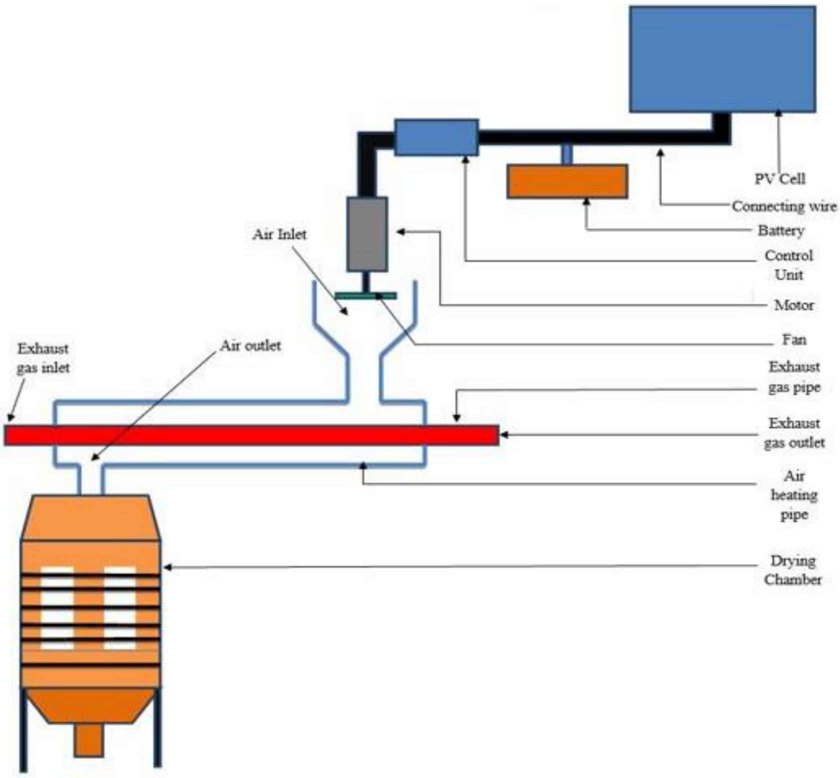

Fig. 2: Proposed drying system

2.4 Optimized Parameters

The numerical solution for the system was carried out using ANSYS 15 software in the FLUENT environment. The solution process is consist of pre-processing, solution and post-processing. The inlet velocity of external air at the inlet was kept 1.5 m/s and temperature of the air was 25 degree Celsius. The inlet turbulent viscosity ratio and turbulent intensity were set as 10 and 5% respectively since the geometry is not so complex [23].The temperature of the exhaust pipe was taken as 87 degree Celsius. For insulating the external pipe, its surface was kept as an adiabatic wall. For each analysis, the 3-D geometry created using Solid works was first imported in ANSYS FLUENT environment. The computation time for flow in the pipe was about 2 hours. The processor of the computer was Intel (R) Core ™ i7-4790 CPU @ 3.6 GHz and the RAM was 24 GB. All the required parameters to run the system in ANSYS FLUENT environment is represented in Table 2:

Table 2. Required parameters to run the system in ANSYS FLUENT environment

Parameter	**Value**
Air inlet velocity	1.5 m/s
Exhaust gas pipe diameter	49.44 mm
Air inlet pipe diameter	70 mm
Mass flow rate	0.0032 kg/s
Length of Heat Exchanger	250, 400, 500, 600, 700 and 800 mm
Material of Gas exhaust pipe	Aluminum
Material of air flow pipe	PVC

3. Result and Discussion

3.1 Required Length of the Heat Exchanger

Figure 3 illustrates the Effect of the heat exchanger length on the Outlet temperature and velocity, which is drawn based on the outcomes of simulation done in the ANSYS FLUENT environment. Overall, the output temperature of the air experienced an upward trend, whereas the outlet velocity of the air is experienced a decline in the increase of the length of the heat exchanger. The maximum output temperature was found 81.47℃ for the 800mm length pipe, where the output velocity was 0.73 m/s. However, the minimum output temperature was found 61.68℃ for the 250mm length pipe, where the output velocity was 1.47 m/s. But as for drying different food materials 70℃ temperature and 1 m/s velocity of air are optimum, which can be obtained by both 400 and 500mm heat exchanger[24]. Therefore, 400mm heat exchanger is selected to do the subsequent study.

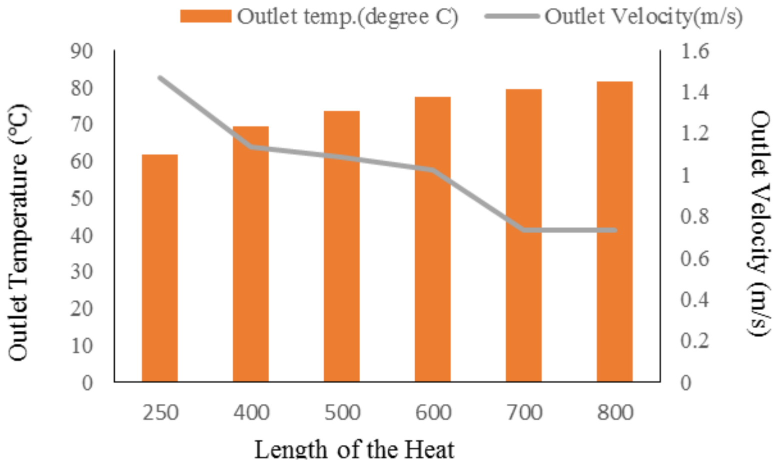

Fig. 3. Effect of the heat exchanger length on the Outlet temperature and velocity

3.2 Feasibility analysis

3.2.1 **Cost**

The cost of the system was estimated based on the design of the proposed system. The information about the price of the components was collected from the local market and an approximate total cost was predicted. Required components, their specifications, quantity, and prices are given in Table 3.

Table 3. Cost with different equipment's used in the construction:

Name of the components	Specifications	Quantity	Price in BDT
Exhaust gas pipe	600 mm Aluminum Pipe	1	90
Inlet Air pipe	600 mm PVC Pipe	1	70
Fan	3 in Diameter	1	20
Battery	12 volts/7.5 Ah	2	2400
Photovoltaic cell	40 watts	1	2080
Motor	12 watt	1	240
ARDUINO UNO Board	Controlling unit	1	495
IRF 3205	Mosfet Transistor	1	35
Jumper wire		10	20
Variable resistor	10 kilo Ohms	1	5
Food Storage Compartment	3×3 feet wooden box	1	800
		Total Cost	6255≈ USD ($79)

So in this cost analysis, it is seen that our proposed food dryer is economical than other conventional dryer.

3.2.2 **Emission Reduction**

Though power comes in many forms, Electricity is used worldwide now as a common form of secondary useable energy. To generate electricity, several types of feed materials are used among them Fossil fuel is a viable option which generates a significant amount of flue gas that effects the environment and finally prohibits to make a green environment which is the prime demand of the modern society [25]. It is estimated that about 0.0016 barrels or 0.0504 gallons of Petroleum or 1,000 cubic feet of natural gas are required to produce 1KWh electricity [26].This fossil fuel burning leads to serious CO2 emission. It is calculated that almost 8,887 grams of CO2are produced when 1 gallon of gasoline is burnt [27].This means 447.905 grams ofCO2 is produced while generating 1 kilowatt-hour electricity. As the literature suggests, 2798.6375 kW power is needed every year to run a convective dryer for drying mushroom, it technically produces about 1.2535 tons of CO2 every year. By applying the proposed technique, this substantial amount of CO2 emission can be reduced without affecting the performance. Figure 4 represents the summary of the positive effect on the environment of using the proposed drying technology utilizing waste heat instead of conventional convection drying.

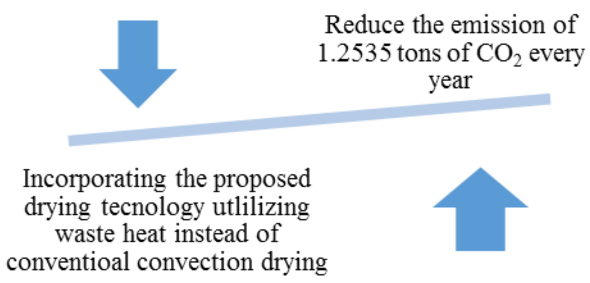

Fig. 4. Effect of Using proposed drying technology utilizing waste heat

3.2.3 **Payback period**

It was found from the literature that, slices of a mushroom are dried by hot air convective dryer within 184 minutes in 60°C temperature and for this operation, 2.5 kWh energy is consumed [28].The main power consumption is required for heating the air. For This purpose 2798.6375 kW power is required every year. In Bangladesh, the average cost of per unit electricity is on average BDT 5[29]. On the basis of these data, it's found that the cost of running the considered system per year is 13990 BDT. The predicted installation cost of the proposed system is only 6255 BDT as estimated in Table 1. Thus the payback period of the proposed system compared with the existing convection drying system is calculated as follows[30].

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Cash inflow per Period}}$$

$$\text{In this study, Payback Period} = \frac{\text{Installation cost of the proposed system}}{\text{Running cost for existing system per year}}$$

$$= \frac{6255}{13990}$$

$$= 0.447 \text{ year} = 163 \text{ days.}$$

The significance of this result is that it necessitates only 163 days to regain the money that was used to install. Therefore, this system is very efficient as well as cost-effective compared to the existing system.

4. Conclusion

The study illustrates the superiority of the proposed food drying system over conventional drying mechanism in terms of cost and emission reduction. The system is not only easy to construct but also cost-effective. Moreover, its running cost is technically zero since solar power is being used to run the motor and to external energy is required to dry the food materials. As a result, by implementing this technique we may think to have an energy efficient low-cost system that can gift us a green environment.

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