A review on possibilities for the development of heat pump cocoa drying in Ikom (Cross River State), Nigeria

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Abstract: *Recent research has shown that heat pump drying is an efficient method of drying for drying industries. Applications of heat pump dryers provide high energy efficiency with controllable air flow, air humidity, temperature, and have significant energy-saving potential. They deliver more heat energy during the drying process than the work input to the compressor. There are many traditional methods of drying agricultural produce such as direct or indirect sunlight, wood burning, electrical heating, fossil fuel burning, and diesel engine heating. The heat pump drying method is more advanced than the traditional Nigeria's industrial and agricultural drying methods. As a result of high increases in fossil fuel prices, failed electricity projects, in Nigeria resulting from the political problems associated with crude oil production, as well as the problem of environmental pollution due to* CO_2 *emissions, green energy, energy saving and energy efficiency are imperative.*

Key Words: *Heat pump, drying, energy-saving, efficiency*

Introduction

Heat pump drying (HPD) is a new and better technology in which materials can be dried at low temperature and in an oxygen-free atmosphere, using less energy than common drying methods. This method is therefore more advantageous for drying biological materials which are thermally sensitive and oxygen sensitive [Chou SK, Chua KJ, 2001]. Drying is one of key processes in many food industries and in many agricultural countries; large quantities of food products are dried to improve shelf life, reduce packaging cost, lower shipping weights, enhance appearance, encapsulate original flavour and maintain nutritional value. The primary objective of drying any agricultural product is to remove moisture from the food so that bacteria, yeast and mould cannot grow and spoil the food. Other important factors are the economic consideration, environmental concerns and product quality aspects. These are the three main goals of drying process research in the food industry [Chua KJ, Chou SK, Yang WM, 2010]. In many cases, the drying process is applicable to seasonal biological materials such as fruits and vegetables, so that they can be stored for as long as possible and be available out of season [Patel K, Kar A., 2012].

Traditional methods of drying biological materials such as fruits, grains, nuts and vegetables have been widely employed in Nigeria. The general and well-known drying methods employed are the direct and indirect sunlight, wood and fossil fuel burning, electrical heating and diesel engine heating. However, most of these methods result in smoke and other emissions which have adverse effects on human health and contribute to the problem of climate change. A review of the literature reveals that commercial dryers are highly inefficient. It is seen that the reason for this inefficiency of commercial dryers is that they are generally not equipped with heat recovery facilities, whereas heat pumps can provide a very efficient means of recovering both sensible as well as latent heat. A heat pump also delivers more heat than the work input to the compressor. Heat pump assisted dryers are approximately 10 times more efficient than traditional drying systems [Chua KJ, Chou SK, Yang WM, 2010]. Limited number of studies focused on the benefits of HPDs for industrial and agricultural applications in different countries as is shown in Table 1. Therefore, it becomes pertinent for the application of HPD systems in Ikom in particular and Nigeria in general [Meyer JP, Greyvenstein GP., 1992].

Most of these researches in HPD have been concentrated around Europe and Asia as shown in Table 1. With differences in environmental and climatic conditions, we can therefore, not simply apply these results which are based on European and Asian environmental and climatic conditions, directly to another different region with different conditions, like Nigeria. An economic analysis of drying grain using heat pumps and other methods such as direct electrical heating and diesel engine burning was carried out by Meyer and Greyvenstein [Meyer JP, Greyvenstein GP., 1992].

They discovered that using heat pumps was more economical than using direct electrical heaters, provided that the apparatus was used for 3 months or longer. In Ikom, Nigeria, about 90% of farmers use direct heat of the sun to dry biological materials such as grains [Meyer JP, Greyvenstein GP., 1992]. Only a few use wood. It is important to develop the market for HPD systems in Nigeria, as the technology is still in its infancy. This will go a long way to improve the quality of their products especially cocoa which is harvested in large quantities. This is necessary because of the quantity of cocoa produce per annum and the stress the farmers undergo to get the products dried to the required moisture content. Often the quality of the cocoa is compromised due to poor drying methods. Usually, the period of high yield of cocoa coincides with high rainfall which will invariably affect drying of the beans long after fermentation. The reduction in quality of the dried product translates to reduction in economic value of the product.

The objective of this review was to provide an overview of heat pump dryers and a comparison with traditional drying methods in Nigeria in general and Ikom in particular.

Table 1: Summary of Studies in Heat Pump Drying (HPD)

Reference	Location	Application(s)	Conclusion
19,20	Singapore	Green beans	A coefficient of performance (COP) value of above 6 was observed and a specific moisture extraction rate (SMER) above 0.65 was obtained for a material load of 20 kg and a compressor speed of 1200 rpm
2	Turkey	Apples	A system which is composed of the combination of both dryers is considered to be more efficient
2,6-8,19	Singapore	Agricultural and marine products	With scheduled drying conditions, the quality of products can be improved
44	Australia	Grains	An open-cycle HPD performed better during the initial stage when the product drying rate was high
29	South Africa	Grains	HPD is more economical than other dryers
25	Brazil	Vegetables (onion)	Better product quality and energy saving of the order of 30% was obtained with HPD
28	Australia	Macadamia nuts	A high quality of dried nuts was observed
41	Norway	Marine products (fish)	The high quality of the dried products was highlighted as the major advantage of HPD
36	Thailand	Agricultural food drying (bananas)	HPD is economically feasible and particularly appropriate for drying materials with a high moisture content
32	New Zealand	Apple	A modified atmosphere heat produces products with a high level of open pore structure, contributing to the unique physical properties
35	Thailand	Garlic and white mulberry	Computer simulation model of the heat pump dehumidified drying was shown to be in good agreement with experimental results
5	Iran	Plums	The optimum temperature of drying for plums is about 70-80 °C; the SMER of the designed dryer was notably more than conventional types of dryers with respect to saving energy
21	Singapore	Apple, guava and potato	A modified atmosphere heat pump dryer produced better physical properties
26	Brazil	Mango	The energy efficiency was better compared with an electrical resistance dryer
43	Thailand	Fruits (papaya and mango glace)	Mathematical models of fruits drying using HPD were developed and validated experimentally. The optimum criterion is minimum annual total cost per unit of evaporating water. The effects of initial moisture content, cubic size and effective diffusion coefficient of products on the optimum conditions of HPD were also investigated. Exergy and energy analyses were performed.
31	Turkey	Wool	The SMER was 0.65-1.75 kg/kWh. The COP was 2.47-3.95.
37	New Zealand	Peas	The thin layer drying kinetics model of peas was developed. The model can be used to accurately predict the drying time in a heat pump, thus bringing about energy and cost savings.
4	Turkey	Tropical fruits (kiwi, avocado and banana)	Mathematical models of the drying characteristics of tropical fruits were developed. The results were in good agreement with experimental results.
27	Indonesia	Red chilies	The high quality of the dried chili was highlighted as the major advantage of HPD compared to sun drying

Source: [Thomas Kivevele and Zhongjie Huan, 2014].

I Historical Development of Heat Pump Drying (HPD)

The traditional methods for drying agricultural products have been widely employed around the world. The most common methods employ are the direct or indirect sunlight and wood burning. Although these methods are cheap, there are problems associated with these methods, such as poor-quality of dried products, little or no control over the drying process, possible contamination of the product by dirt, and interference by rodents and other animals, infestation by insects or mould and exposure of the product to rain and wind, which causes repeated wetting and re-drying. HPD has been found to be more economical than the traditional drying methods [Chua KJ, Chou SK, Ho JC, Hawlader MNA., 2002]. Figures (1 and 2) show the different traditional methods of cocoa drying in Ikom, Nigeria.

Figure 1: (a) Traditional Sun Drying of Cocoa at Home

Figure 1: (b) Traditional Sun Drying of Cocoa in the Farm

Figure 2: Combined Sun with Wood Drying

Heat pumps generally work through vapor-compression cycles or absorption-compression cycles. They are heat-generating devices that transfer heat in the opposite direction of natural heat flow by absorbing heat from an area of low temperature and releasing it to a warmer area much the same way as a water pump takes water from a depth to a higher head. Heat pumps are widely used in water and space heating applications. Heat pumps were first commercially produced in the USA in the 1930s, but only became popular in the 1970s following reduced operating costs. Approximately one-third of all single-family homes built in the USA were heated by heat pumps in 1984 [Calm JM., 1997]. Progress has been made in alternative industrial applications of heat pumps, especially in the dehumidification and drying of agricultural products [Meyer JP, Greyvenstein GP., 1992],[Perera CO, Rahman MS., 1997], [Wongsuwan W, Kumar S, Neveu P Meunier F ., 2001].

Work on heat pump dehumidifier was first in 1976 [Hodgett DL., 1976,]. Hodgett reported that the energy consumption of HPDs was lower than that of conventional steam-heated dryers, and the results agreed with those of Geeraert [Geeraert B., 1976] whose application of HPD was in timber drying. A report on the advantages of heat pump dryers such as high energy savings and a wide range of drying conditions with respect to temperature and humidity was made in 1982 [Tai KW, Devotta S, Watson RA, Holland FA., 1982]. The conclusion that the SMER increases as the relative humidity of the dryer outlet air increases was reported by [Zylla et al]. It was further reported that a well-designed engine-driven heat pump could achieve a reduction of about 30-50% in drying energy cost [Cunney MB, Williams P., 1984]. Energy consumption could be reduced by 40% when drying malt with a coupled gas engine heat pump dryer [Erbay Z, Icier F., 2009].

The classification and current state of the art of heat pumps are represented in figures 3 and 4 below.

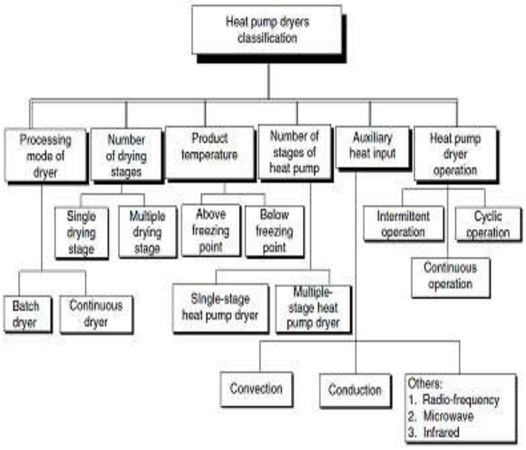

Figure 3: Classification of heat pumpsSource: [Mujumdar, A.S., 2007]

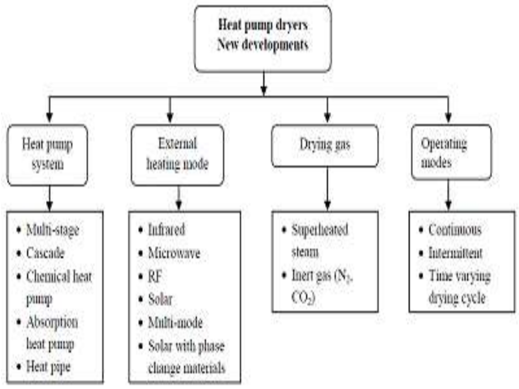

Figure 4: Current state of the art of heat pumps

Source: Mujumdar & Jangam Some Innovative Drying Technologies for Dehydration of Foods

II Working Principles of HPD

An HPD system consists of two subsystems: a heat pump (refrigeration system) and a drying chamber. Heat pumps can transfer heat from natural heat sources in the surroundings (such as the air, ground or water), or from industrial or domestic waste, or from a chemical reaction or dryer exhaust air. The drying chamber may be made of a tray, fluid bed, rotary or band conveyor. The heat pump dryer consists of a heat pump (including a compressor, a condenser, an expansion valve and an evaporator), a dryer and air cycling circuits, to connect the heat pump and the dryer (Figure 3). The working principle of closed HPDs (as shown in Figure 3) is that the exhausted air from the dryer enters the evaporator of the heat pump, where it is cooled and the moisture in the air is condensed and removed. The cool and dry air from the evaporator then enters into the condenser of the heat pump and is heated. The hot dry air then enters the dryer to absorb the moisture of the products being dried in the dryer. The air becomes exhausted air at the outlet of the dryer, and the cycle repeats. Because the heat pump retrieves the heat in the exhausted air to heat the air entering the dryer while it removes the moisture in the exhausted air, it achieves high energy efficiency in the drying of biological materials. In an open cycle, exhausted air is not re-circulated and the HPD uses ambient air as the heating source.

Like a refrigerator, a heat pump may be a vapor compression system; but it rather takes energy from a cold source unlike the refrigerator and transfers it to a hot region in order to raising the temperature of the region or compensating for heat losses from the region. Some commercial heat pumps do combine both cooling and heating actions in a single package.

Their energy efficiency is strongly influenced by the exhausted air relative humidity from the dryer in the closed cycle. The system is shown in figures 3. With low relative humidity of the exhausted air, there requires low evaporating temperature in the heat pump evaporator to remove the moisture from the exhausted air, which leads to a large temperature difference between the evaporator and the condenser, invariably resulting in low energy efficiency in the heat pump and the heat pump dryer. This could be remedied by letting some of the exhaust air flow through the evaporator and condenser, and the leftover air bypass the evaporator, and the two portions to mix before the dryer. This process is to raise the relative humidity of the exhausted air and reduces the energy consumption of the heat pump dryer. The capacity of the heat pump will require careful control. One can as well solve the low relative humidity problem of the exhausted air by introducing a desiccant unit which should be placed parallel with the evaporator to share in the moisture removal. A closed-cycle heat pump dryer [Xanthopoulos G, Oikonomou N, Lambrinos G.,2007] is shown in Figure 5 below.

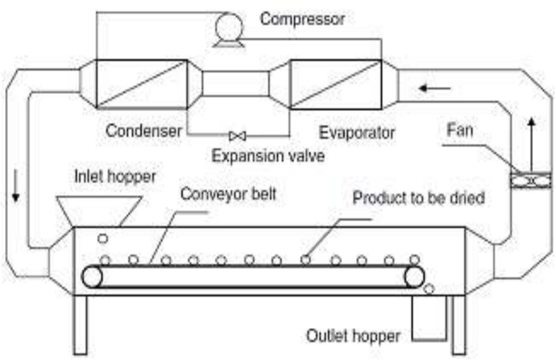

Figure 5: A Closed-cycle Heat Pump Dryer

The evaporator heat transferred Q_L is commonly referred to as the refrigeration effect, *RE*. The product of the refrigerant mass flow rate and RE, the rate of cooling produced by the unit, is called the refrigeration capacity [kW].

Applying the First Law to the refrigerant in the system as a whole, we find that the work and heat transfer, [kJ/kg] terms are related by

$$Q_L + Q_H = W \quad (1)$$

where Q_H and *W* are negative for both refrigerators and heat pumps. Hence

$$Q_L + |W| = |Q_H| \quad (2)$$

Equation (2) is written here with absolute values to show that the sum of the compressor work and the heat from the low-temperature source is the energy transferred by the condenser to the high-temperature region.

The useful effect or desired energy transfer of the heat pump is the passage of energy from the condenser to the high temperature region at T_H. Thus the coefficient of performance *COP* which is a measure of the efficiency of a refrigerator or heat pump is

$$COP_{HP} = \frac{Q_H}{W_C} \quad (3)$$

where Q_H is the rejected heat at the condenser and W_C is the input work to the compressor and

$$Q_H = Q_{subcooling} + Q_{condensation} \quad (4)$$

High values of COP, which is the energy characteristic of the HPD are desired and may be achieved by minimizing the compressor work input for given values of heat transfer. This may be particularly advantageous to apply a vapor compression system in cases and applications in which simultaneous heating and cooling functions are required to cool a computer office with the evaporator while heating rooms on the cold side of the building or the dryer with the condenser.

Combining equations (1) and (2) yields

$$COP_{HP} = \frac{Q_H}{W_C} = \frac{|W_C| + Q_L}{W_C}$$

$$= 1 + \frac{Q_L}{W_C} = 1 + COP_r \quad (5)$$

Since $Q_L > 0$ and $COP_r > 0$, the heat pump COP must always exceed 1. This is also evident directly from the definition Equation (3) because the First Law Equation (2) requires that $|Q_H| > |W|$. Note the relationship of refrigerator and heat pump COPs for the same cycle.

For a more efficient functioning of the heat pump dryer, a blower is incorporated with additional load W_f to the system. We now have that

$$COP_{HPD} = \frac{Q_H}{W_C + W_f} \quad (6)$$

where W_f is the work input to the blower [kJ]. The performance of the dryer is determined by its exergy efficiency (ψ) [Erbay Z, Icier F., 1985]. The driving force behind heat losses during drying processes is the temperature gradient between the drying chamber and the environment [Dincer I, Sahin AZ., 2004]. The major cause or loss of Exergic efficiency is irreversibility. The exergetic efficiency of the drying chamber (ψ) is the ratio of the total exergy gained by the air stream to the total exergy that enters the system. Thus, the general form of exergy efficiency is written as [Dincer I, Sahin AZ., 2004, Akpinar EK., 2004].

$$\psi = \frac{\text{Exergy input for evaporation of moisture in product}}{\text{Exergy of drying air supplied}}$$

$$\psi = \frac{\dot{E}X_{out}}{\dot{E}X_{in}} \text{ X } 100 \quad (7)$$

Therefore, the exergy ($\dot{E}x$) values (J/s) at the dryer can be calculated using the general form of the exergy equation applicable for steady- flow systems as reported by [Midilli and Kucuk [Midilli A, Kucuk H., 2003].

$$\dot{E}x = \dot{m}_a C_{pa}\left[(T - T_a) - \ln\frac{T}{T_a}\right] \quad (8)$$

where $\dot{m}_a$ is the air mass flow rate (kg/s), C_{pa} is the thermal capacity of air (J/kg.K), T is the temperature (K) and T_a is the ambient (air) temperature (K).

The specific moisture extraction rate (SMER) is one of the main factors that describes the efficiency of the heat pumps when compared to direct electrical dryers [Patel K, Kar A., 1992]. It is the only performance characteristic that considers both the dryer and heat pump system. It is defined as the ratio of the mass of water removed from the product (condensed water in the evaporator in (kg) to the required energy for this (kWh).

$$\text{SMER} = \frac{\text{Water removed from product}}{\text{Energy required for water removal}}$$

$$\text{SMER} = \frac{\Delta X}{\Delta h} \quad (9)$$

where Δx is the amount of water removed (kg) and Δh is the amount of energy consumed (kJ).

III Types of heat pump dryers

Different types of HPD systems could be found in the market. The product to be dried informs the user the choice of selection. They are the air, chemical, ground source, hybrid systems etc. only the air type is discussed in details here. This is mostly used by famers to dry biological materials such as grains in which cocoa beans produced in large quantity in my locality, Ikom Nigeria falls.

Air Source Heat Pump Drying Systems

They are the most widely used heat pumps [Colak N, Hepbasli A., 2007]. An air source heat pump (ASHP) shown schematically in Figure 4 consists of heating and cooling system which engages the ambient air as its heat source and heat sink. It uses a refrigerant system consisting of a compressor and a condenser to absorb heat at one place and release it at another. They are usually known as reverse cycle air conditioners when used as space heaters. Domestically, an ASHP absorbs heat from the outside air and releases it inside during winter, and reverses the process in summer. It can offer a full central heating solution and domestic hot water when properly set up with an efficiency of up to 80% [Daghigh et al., 2004, Daghigh R, Ruslan MH, Sulaiman MY, Sopian K., 2010]. Of recent, air source heat pumps have increasingly become applicable for the drying of biological materials. Xanthopoulos designed a closed-cycle ASHP for drying whole figs [Xanthopoulos G, Oikonomou N, Lambrinos G., 2009]. They were able to present a mathematical single-layer drying model to predict the drying rate of whole figs. They concluded that, among the models tested, the best model in terms of fit was the logarithmic model.

IIV Types of dryers

Most of the commonly used dryers in the market are batch and conveyor dryers. However, many other dryers used are also reported on in literature, such as rotary dryers and fluidized beds [Xanthopoulos G, Oikonomou N, Lambrinos G., 2009].

Batch dryers

These are more widely reported on literature than other dryers. Batch drying systems allow for total recirculation with a very low air leakage rate; improving high thermal efficiencies [Xanthopoulos G, Oikonomou N, Lambrinos G., 2009]. Batch dryers are also reported to be good for low capacity applications, such as laboratory experiments [Perera CO, Rahman MS., 1997].

Conveyor dryers

Other promising results are from conveyor dryers. They are often referred to as continuous bed drying and can be compared with batch dryers. Batch dryers are potentially better option for drying specialized crops. Possibly because of their suitability for capacity needs [Xanthopoulos et al.,2009, Hawlader MNA, Uddin MS, Ho AB, Teng ABW., 1991], but very few studies have been done on them.

Drying heat pump technology: R&D needs and future challenges [Minea, V., 2012].

- Provide drying-schedules in terms of set dry- and wet-bulb temperatures, temperature depression in relation with the air relative and absolute humidity, and flow rate.

- Provide drying curves of the dried products, specifying whether their moisture content was measured and how (oven, continuously or intermittently)

- Install pre-heating and supplementary (back-up) heating (if necessary)

-Essential data:

 Input/output quantities and initial/final moisture contents or dried materials

 Heat pump dehumidification capacity and/or compressor rated input power

 Condenser heating and heat rejection capacity

 Heat pump pressures and temperatures throughout the drying cycles

IIIV Major Advantages and limitations of heat pump dryers

The major advantages of HPD found in literature [Ong, S.P. & Law, C.L.,]:

- Heat pump dryers are cost-effective for drying solid food products and other labile substances
- Relatively low drying temperatures (25-45°C)
- Systems operate independently of ambient conditions as totally enclosed systems
- Higher rehydration capacity
- Better color retention with less browning effect
- Higher retention of vitamin C
- Better preservation of volatile compounds

• They have high energy efficiency of up to 60% reduction in energy costs when compared with traditional drying technologies.

• They are temperature profiled controlled, a requirement that meets the specific product to be dried. They are fitted with temperature sensors and advanced controllers to regulate the temperatures of both the condenser and evaporator to arrive at suitable drying temperatures. This is not feasible with traditional drying methods. Optimal air flow of the blower or fan is also achieved by controlling their speeds.

• They are more environmental friendly. There could be 80-100% of chemical emissions resulting from drying some products and up to 60% reduction in CO_2 emissions.

• Heat pumps can operate 24 hours per day thereby resulting in consistent output of products. This consistent drying boosts the production potential when compared with the traditional drying methods.

• Heat pumps can operate in ambient conditions- (from -20 °C to 80 °C) - because of the moderate climatic conditions in Nigeria, this will saves energy compared to Asian and European countries.

• They create business opportunities for both famers and industry.

• Time saving – more products are dried within a shorter time when compared with the traditional methods.

One of the researchers [Minea, V., 2011] points at the following bottlenecks:

• Uncertainty by potential users as to heat pump reliability

• Lack of good hardware in some types of potential applications

• Lack of experimental and demonstration installations in different types of industries

• Lack of required knowledge of chemical engineering and heat pump technology in target industries

• Relative cost of electricity and fossil fuels affecting the commercial viability of drying heat pumps

• Higher initial cost – there is higher initial installation cost when compare with those for traditional drying methods. This initial cost comes from equipment such as the controllers, compressors, heat exchangers. However, in the long run if the period of use is more than a year, the return on investment is worthwhile and obtained within a short period.

• Environmental pollution often results from refrigerant leakage from refrigerant system cracks in the pipes and valves. Pressure drops due to these leakages automatically lowers the dryer performance. To reduce gas emissions harmful to the environment, the use of green refrigerants such as carbon dioxide and nitrogen oxides is encouraged [Schmidtt EL, Kliicker K, Flacke N, Steimle F., 1998, Sarkar J, Bhattacharyya S, Gopal MR., 2006].

V Comparison of HPD with Nigerian Traditional Drying Methods

The demand for heat pump systems for water heating and space cooling and heating is still undeveloped in Nigeria. However, some developed and developing countries have of recent shown interest in applications of heat pumps for energy saving and are investing much money and time on HPD research. However, the development of heat pumps for industrial and agricultural drying in Nigeria is still in its infant stage, possibly due to:

• The concept of HPDs is not yet well known in Nigeria and is less understood by the famers than that of traditional drying methods;

• The instability of electricity and high cost of fossil fuels due to fuel bunkering and pipeline vandalization;

• Unwillingness of government to invest on HPD research or the embezzlement of funds meant for such researches by those saddled with this responsibility;

• The lack of interest or techno-economical information regarding HPDs;

• Preference for cars and other products to those of HPDs in Nigeria.

A comparison of HPD with common traditional drying methods for biological materials was carried out in South African [Meyer et al., 1992, Perera CO, Rahman MS., 1997]. Table 3 shows the details. From these results in South Africa, it is clear that the advantages of HPD far outweigh those of the traditional methods for drying biological materials. Unlike in Nigeria, South Africa is currently experiencing an increased need for drying processes for various industrial, commercial and residential applications. Therefore, development of HPD systems in Ikom (in Southern Nigeria) in particular for drying cocoa and other biological materials and Nigeria in general is imperative. The development of HPD systems will go a long way to not only reduce energy consumption if effectively utilized but to be more environmentally friendly and create more business opportunities for both farmers and industrialists [Meyer JP, Greyvenstein GP., 1992].

Table 3: Comparison of heat pump drying with traditional South African drying methods

Item	Direct/indirect sunlight	Wood burning	Electrical heating	Diesel engine heating	Heat pump dryers
Efficiency	Very low	Low	Low	Low	High
Temperature range (°C)	<40	10-100	0-100	10-100	10-65
Operation time	During the day	Anytime	Anytime	Anytime	Anytime
Drying air flow	Depends on wind	N/A	Controlled by fan speed	N/A	Controlled by fan speed
Moisture extraction	Depends on weather	Low	Accurate	Low	Accurate
Temperature control	N/A	Fair	Accurate	OK	Accurate
Product quality	Depends on weather	Bad, because of smoke	Good	Bad, because of smoke	Very good
Environmentally friendly	Yes	No	Yes	No, because of CO_2 emissions	Yes
Weather effect	Yes	No, if operation is indoors	No, if operation is indoors	No, if operation is indoors	No, if operation is indoors
Initial capital cost	Low	High	High	High	Very high
Payback period	N/A	N/A	Long	Long	Short
Maintenance costs	Very low	Low	High	High	High
Application range	Limited	Limited	Wide	Limited	Wide
Operational control	N/A	Limited	Available	Available	Available
Noise level	None	Low	Moderate	High	Moderate
Energy-waste level	N/A	High	High	High	Low

N/A: Not applicable

Source: [Thomas Kivevele and Zhongjie Huan, 2014].

VI Comparison of different drying methods

The efficiencies of heat pump dryers and others are compared as shown in Table 4 bellow to see the most advantageous [Perera CO, Rahman MS., 1997]. HPDs have a higher SMER range (1.0-4.0 kg H_20/kWh) than other drying methods. The heat pump dryer is therefore an efficient and energy-saving alternative for drying industries.

I will highly recommend that the government of the Cross River State of Southern Nigeria in particular install the HPD in Ikom Local Government, which is rich in cocoa production and other agricultural products.

Table 4: Comparison of heat pump drying with vacuum and hot air drying

Item	Hot air drying	Vacuum drying	Heat pump drying
Specific moisture extraction rate (kg H_20/kWh)	0.12-1.28	0.72-1.2	1.0-4.0
Drying efficiency (%)	35-40	≤70	95

Operating temperature range (°C)	40-90	30-60	10-65
Operating % relative humidity range	Variable	Low	10-65
Capital cost	Low	High	Moderate
Running cost	High	Very High	Low

Source: [Thomas Kivevele and Zhongjie Huan, 2014].

VII Economic analysis

The economics of heat pump dryers has been in limited study, comparing with other convection electrical dryers [Chua *et al*., 2010, Soylemez MS., 2005, Hepbasli A, Colak N, Hancioglu E, Icier F, Erbay Z., 2010]. A techno-economic analysis of grain drying using heat pump dryers in South Africa by Meyer and Greyvenstein [Ceylan I, Akta § M, Dogan H., 1992]. Their result show that the life-cycle cost of an electrical heater and diesel engine were three and four times higher, respectively, than that of heat pump dryer systems. The optimization of heat pump fruit dryers and analyses of the annual total cost per unit of evaporating water and the result that the cost was linearly proportional to both interest rate and electricity price and decreased with increasing lifetime is reported [Teeboonma *et al.*]. Heat pumps generally have great potentials for saving energy because they are the only heat-recovery systems that enable the temperature of the waste heat to be raised to a more useful level [Soylemez MS., 2005].

Conclusion

Different types of heat pump drying systems are appropriate for the drying of heat-sensitive products and many other products. The conclusion of many researchers is that heat pump dryers are more energy efficient than electrical dryers. The quality of HPD products is quite better than those dried by conventional drying systems. The SMER and COP are the widely reported measures for determining HPD efficiency systems. It is reported widely that the desiccant-assisted heat pump dryer has a greater energy-saving potential than basic heat pump dryers for batch drying of thermally sensitive biological materials. In comparison with different Nigerian traditional drying methods, the advantages of a heat pump dryer are quite outstanding. It is therefore, the right time to invest in the development and expansion of HPD systems applications in Nigeria, especially in industrial and agricultural product, like cocoa drying. The market for heat pump dryers will be of great assistance to Nigerians in many sectors and will help to reduce the high energy consumption.

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