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Exergy and Energy Analyses and Evaluate Drying Parameters to develop a Stastistical model for a Solar Dryer in Fish Drying

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Abstract - This research paper presents a theoretical and practical aspect of energy and exergy analyses of a solar dryer by using the concept of first law and second law of thermodynamics in association with regression analysis to evaluate drying parameters to develop a statistical model. Energy and Exergy analyses may be considered as prime tool for design, analysis, and optimization of thermal systems. The solar dryer energies itself with the use of solar radiation that received from the collector attached with the dryer. This research investigation was carried out in the city of Bhubaneswar, Odisha (India) between the month of January to March 2016 at the campus of CAET, OUAT, Odisha. Experiments were conducted by drying grey mullet (fish) in the dryer. Grey Mullet was taken for investigation which is abundantly available in the costal belt of Odisha. Experimental parameters like weight of the sample, temperature of the sample aswell as atmosphere and relative humidity were recorded each one hour interval during the experimental period. Regression analysis has been focused on these drying parameters and developed Page statistical model whose model efficiency and coefficient of determination were found be 97.04 % and 0.934.It also found that the exergetic efficiency touches the maximum in between 1:00 p.m. to 3:00 pm.

Keywords — Coefficient of determination exergy, grey Mullet, model efficiency, regression, solar dryer

I. INTRODUCTION

Drying of marine products particularly fish had been of great importance for preservation due to their longer shelf life and availability throughout the year. Traditional sun drying method had been used since ancient time to dry different marine and agricultural products.However; the traditional drying has number of limitations like uncontrolled drying, more drying time, and lack of hygienic condition. Conventional drying technology though provides though overcome the unhygienic condition but due to too expensive it cannot be adopted. Solar drying technology overcome all these difficulties and found suitable for drying the products. The design of solar dryer is quite simple, low cost technology and dries the product in hygienic condition. Various solar dryer have been developed which can be categorized indirect, direct and specialized dryer. [1]-[4].Energy and Exergy analysis were carried out to evaluate the performance of the solar dryer. The following equations for exergy and energy were found out from literature review [5]-[9]. Drying means the removal of water from the any product. In the present investigation we are dealing with drying of a fish. Normally the term 'drying' implies the removal of water by evaporation but water can be removed by other methods: for example, the action of salt and the application of pressure will remove water from fish. Since water is essential for the activity of all living organisms its removal will slow down, or stop, microbiological activity and can thus be used as a method of preservation. Drying is as a traditional method of preserving fish, the action of the sun and wind is used to effect evaporative drying. In recent times, the controlled artificial dehydration of fish has been developed in some industrialised countries so that fish drying can be carried out regardless of weather condition. During air drying, water is removed from the surface of the fish and water moves from the deeper layers to the surface. Drying takes place in two distinct phases. In the first phase, whilst the surface of the fish is wet, the rate of drying depends on the condition (velocity, relative humidity etc.) of the air around the fish. If the surrounding air conditions remain constant, the rate of drying will remain constant; this phase is called the 'constant rate period'. Once all the moisture from the surface has been carried away, the second phase of drying initiates and this depends on the rate at which moisture can be brought to the surface of the fish. As the concentration of moisture in the fish falls, the rate of movement of moisture to the surface is reduced and the drying rate becomes slower; this phase is called the “falling rate period”[10]. Moisture Content of a product are expressed in percentage (%).There are two methods with which moisture content can be determined one is on the basis of wet and other is on the basis of dry. Rate of drying provides the capacity of drying; it means mass of moisture

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remove from the product with respect to time during experiment. In the mechanism of drying, heat is transfer from outside to the product (specimen here is fish) to evaporate moisture from the product and circulation of air is responsible for carry away the evaporated moisture in a effective process.

A. Energy analysis

The energy analysis is based on the first law of thermodynamics, which incorporates the principle of conservation of energy and is the traditional method to assess the performance of energy systems and processes.

$$Q = AI$$

$$Q_U = AI(\alpha\tau)$$

$$Qa = \dot{m}(C_P)_a \Delta T$$

$$\eta_C = \frac{\dot{m}(C_P)_a \Delta T}{AI} \qquad \text{(i)}$$

B. Exergy Analysis

Exergy is a tool, which indicates how far a system departs from equilibrium state. The part of low grade of energy which is available for conversion is termed as "exergy".Exergy determines the type, location and magnitude of heat loss as well as reduces loses to make the system more efficient. It based on the second law of thermodynamics. Exergy development is due to potential kinetic and physical exergies, out of these potential and kinetic exergies can be neglected, hence exergy can be determined by considering only physical exergy.The physical exergy means development of maximum work when a system changes from initial state point to another state point which is in thermal and mechanical equilibrium with the surrounding (dead state point) occurring in a reversible process. The dead state coordinates are 1 atmospheric pressure, 298 K and absolute humidity of 0.009 kg/kg of dry air [11]-[13].

$$(E_x)_C = Q_U\left(1 - \frac{T_{atm}}{T_S}\right) \qquad \text{(ii)}$$

Where T_S =Solar Temperature which is 75% of solar black body temperature (5800K).In current topic this temperature is assumed to be constant and negligible variation. T_S is estimated to be about 4350K.[14].

$$(E_X)_F = \dot{m}(E_{in} - E_{out}) = \dot{m}[(h_{in} - h_{out}) - T_a(s_{in} - s_{out})] \qquad \text{(iii)}$$

$$h_0 = (C_P)_0 T_0$$

$$h_i = (C_P)_i T_i$$

$$(C_P)_i = a + KT_i$$

$$(C_p)_o = a + KT_0$$

$$dS = \frac{dQ}{T} = \frac{C_P DT}{T} = \left(\frac{a+KT}{T}\right)(dT) = \frac{a.dT}{T} + K(dT)$$

$$\Delta S = a\ln\left(\frac{T}{T_{atm}}\right) + K(T - T_{atm}) \qquad \text{(iv)}$$

$$(\eta_{EX})_D = \left(\frac{E_F}{E_C}\right) \qquad \text{(v)}$$

$$EUR = \frac{h_{in} - h_{out}}{h_{in} - h_{atm}} \qquad \text{(vi)}$$

Mathematical equation for Page model is given below in equation "(vii)"

$$MR = \exp(-kt^n) \qquad \text{(vii)}$$

Microsoft excel software was used for regression analysis to find out the drying parameters and developed the Page mathematical model.

II. RESEARCH METHODOLOGY

i. Research Location

College of Agricultural Engineering & Technology Bhubaneswar (CAET)
University: Orissa University of Agriculture and Technology (OUAT)
Latitude: $20^0$15'N
Longitude: $85^0$52'E
State: Odisha
Country: India

The fresh products (Grey Mullet fish) were purchased from "Chilika fresh shop"in the early morning and undergone required technical process to prepare samples for drying experiment.

ii. Material and Method

The drying of the sample was carried out in the solar dryer as shown in figure 1 (a) & 1 (b) inside the OUAT premises for this research investigation. A collector having area 1.54x 0.85 m^2 is mounted on the top of the dryer. It collects the solar radiation; hence temperature of the air inside the dryer increases and moisture was removed from the products to be dried.

Fig. 1(a) Front side of the Solar dryer

Fig. 1(b) Back side of the Solar dryer

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iii. Brief description of the dryer:

The dryer has following basic components

- Solar flat Collector
- Drying Chamber
- Absorber plate and Insulator
- Photo voltaic panel (12V)
- Blowers (2 nos)
- Chimney

The drying chamber was painted with special black chrome coating for better absorption of the solar radiation and minimized heat loss from the chamber. A twelve volt photo-voltaic solar panel is provided to receive the solar energy and converts to dc current for energize the blowers provided in the back side of the dryer. Two number of 12 volt blowers are provided which get the energy from the PV panel. The function of the blower is to develop forced convection for easy removal of moisture that extracts from the wet product during conducting the drying experiment.Hence, maintaining low humidity inside the drying chamber. The moisture escapes to the atmosphere through the chimney which is provided at the back side of the dryer. Heat energy lost through the walls of the dryer was assumed negligible as the amount is very very less as compared to the heat lost in moisture removal. Thermocouples are use for measure the temperature of the drying air inside the dryer.

iv. Sample Preparation:

The susceptible organs of the fish were removed carefully and then allowed to soak in salt solution of strength 35% concentration for 20 to 25 minutes for uniform absorption of salt. Wash the fish thoroughly with tap water so that excess salt which was adhering to outer surface of the fish would properly remove which renders in drying. Kept the fishes on the screen for few minutes to drip out the excess water. Sample was prepared as shown in figure 2.Sample was taken and kept in an oven maintained at a temperature 105^0c for 24 hours to got oven dried weight which was required for estimating the moisture content of the sample.

Fig. 2(Sample Grey Mullet)

III. STATISTICAL MODELS

In the present investigation some important models were found during literature review and Summarized in the table 1[15]-[18].In this study developed the Page model parameters. The literature review revealed that there is no single mathematical model is suitable for for drying kinetics of the product; however, models listed in the table 1 are found to describe drying parameters of the product. Therefore, models are necessary to predict the drying curves. The statistical models are classified into three different categories such as theoretical, semi-theoretical, and empirical. Semi-theoretical models are derived based on Fick's second law but are simplified and added with empirical constants most cases to improve curve fitting. In the empirical model a direct relationship is obtained between moisture content and drying time. The model we have developed in this research study is under semi-theoretical category. This type of models offer a compromise between theory and ease of application (Akpinar, 2006).

Model No	Model Equations	Name	References
1	$MR = \exp(-k.t)$	Lewis	Liu and Bakker – Arkema (1997) and O'Callaghan, Menzies and Bailey (1971)
2	$MR = \exp(-k.t^n)$	Page	Agrawal and Singh (1977) and Zhang and Litchfield (1991)
3	$MR = a.\exp(-k.t)$	Henderson & Pabies	Chhninman (1984) and Westerman, White and Ross (1973)
4	$MR = a.\exp(-k.t)+c$	Logarithmic	Yagctoglu, Degir Mencioglu and Cagaty (1999)
5	$MR = a.\exp(-k.t)+(1-a).\exp(-k.b.t)$	Diffusion	Kassem (1998)
6	$MR = a.\exp(-k_0.t)+b.\exp(-k_1.t)$	Two term model	Henderson (1974)
7	$MR = \exp\left\{-c\left(\frac{t}{L^2}\right)^n\right\}$	Modified Page Equation-II	Diamante & Munro (1991)
8	$MR = a.\exp\left\{-c\left(\frac{t}{L^2}\right)\right\}$	Simplified Fick's diffusion	Diamante & Munro (1991)
9	$MR = 1+a.t+b.t^2$	Wang & Singh	Wang & Singh (1978)

Table 01

IV. RESULT & DISCUSSION

During the observation period, it was found that the highest temperature attainted in open atmospheric condition was near about 315 k where as inside the dryer it was more than 320 k and throughout the drying period the inside temperature was always more than the outside temperature, which indicates, the drying rate must be faster than open atmospheric condition that shown in fig.3. In the afternoon session when solar radiation is comparatively less but still the dryer maintain a good temperature, hence the solar drying provides the uniform drying of the product.Exergy means the available energy utilize for heating the object during the drying process. The hot air used for heating the object inside the dryer and that hot air generates due to more heat absorbed in collector, which receives the solar radiation in the form of heat energy. The air is circulating inside the dryer and there may be loss of exergy in the form of heat through walls, roof as well as due to manufacturing defects. The exergy loss is termed as "exergy destruction". The exergy profile is shown in fig.4.The exergy of circulating fluid

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(air) is gradually increases and reaches the maximum at around 1:00 p.m. and then decreases.The efficiency of the dryer attains its maximum value in between 1:00 p.m. to 3:00 p.m. and decreases drastically towards the end of the day as the solar radiation fall down in the afternoon session, which reported in fig.5.Coefficient of determination (R^2) is the output of regression analysis. It measures how close the data is to be fitted regression line statistically. It value was found 0.934 after plotting the graph as shown in fig.6.Same result also got in regression.

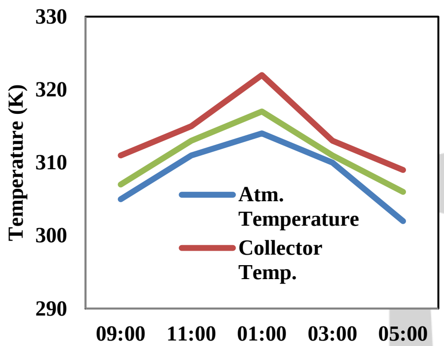


Fig. 3 . Profile for temperature variation

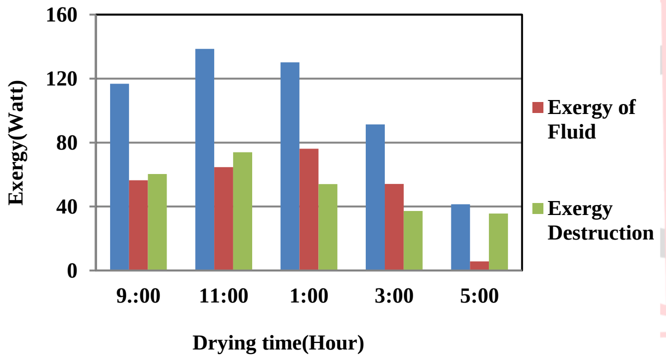


Fig. 4 Exegy profile

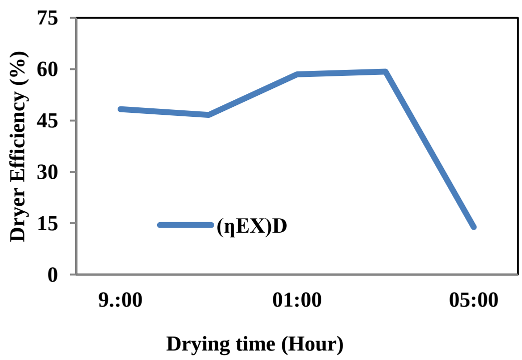
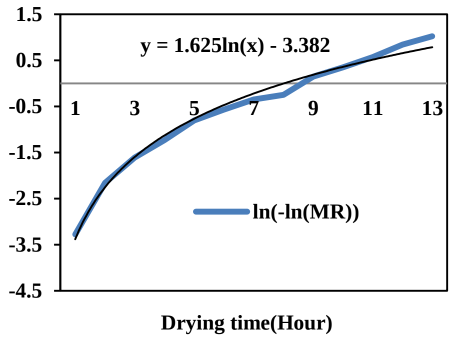


Fig. 5 . Profile for dryer efficiecny



7 . Variation of ln(-ln(MR)) with drying time(Hour)

Table 2

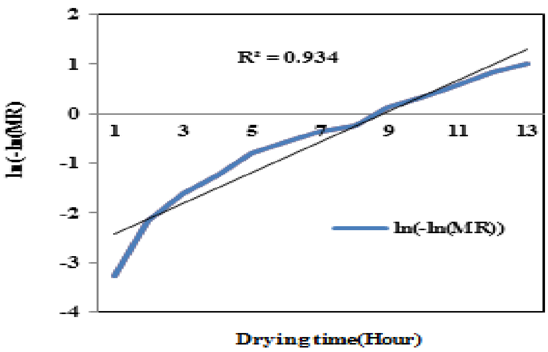


Fig. 6 . Variation of ln(-ln(MR)) with drying time(Hour)

Drying Parameters for Page Model (Grey Mullet)						
R^2	EF	χ2	MBE	RMSE	n	k
0.934	97.04	.003011	0.0025478	0.050476	1.625	0.333

V. CONCLUSION

Small fishermen of coastal area of Odisha are generally drying the fish in traditional open sun drying process which is very unhygienic, more time consuming as well as nutritional value decreases, ultimately their financial status affected. So we choose a product (Grey Mullet fish) for research study which is one of the main sources of their income. The benefits of solar drying technology must be aware to them so they will adopt and get benefitted. In the research study the exergy destruction is found slightly more in the dryer. So care must be taken to improve the design of the dryer so as to increase the dryer efficiency further in future. The solar dryer can be installed in any location with proper inclination of the collector and drying can be done efficiently.

The R^2 is one of the primary drying parameters for selecting the best mathematical model to explain drying curves of product. There are also some other drying parameters such as EF, MBE, RMSE to evaluate to goodness of fit of the selected models.The lower χ2 and RMSE values and the higher R^2 and EF values are the criteria for the goodness of the fit (Torgul and

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Pelivan,2002;Demir.*et al*.,2004).The drying parameters of selected specimen for Page mathematical model is shown in Table 2.This mathematical model can be compared with other mathematical models as shown in Table 1 for further study.

NOMENCLATURE

Q = Incident solar energy on the collector

Q_U = Useful solar energy

α = Absorptivity of the collector

τ = Transmissivity of the collector

$\dot{m}$ = Mass flow rate

$(C_P)_a$ = Specific heat of air

ΔT = Change in temperature

A = Area of the collector

I = Solar Insolation

η_C = Efficiency of the collector

$(E_X)_C$ = Exergy received by the collector

T_{atm} = Ambient Temperature

T_S = Solar Temperature

$(E_X)_F$ = Exergy received by the fluid

E_{in} = Inlet energy

E_{out} = Outlet energy

h_{in} = Specific enthalpy of air at inlet

h_{out} = Specific enthalpy of air at outlet

s_{in} = Specific entropy of air ai inlet

s_{out} = Specific entropy of air at outlet

$(\eta_{EX})_D$ = Efficiency of the dryer

$(C_P)_0$ = Specific heat of air at outlet

$(C_P)_i$ = Specific heat of air at inlet

EUR = Energy Utilization Ratio

MR = Moisture Ratio

R^2=Coefficient of Determination

MBE =Mean Bias Error

RMSE=Root Mean Square Error

$\chi 2$=Reduced-Chi square

EF=Model efficiency

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