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CONFERENCE PAPER

FABRICATION AND OPTIMIZATION OF FISH DRYING: COMPARATIVE STUDY OF SUN AND SOLAR DRYING TECHNIQUES USING REGRESSION MODELS

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Abstract

Post-harvest deterioration of fish due to high moisture content remains a significant challenge in coastal and rural regions. This study presents a comparative investigation of traditional open sun drying and a developed solar drying system for Grey Mullet (Mugil cephalus). Drying experiments were conducted under controlled and natural conditions, and moisture loss was recorded over time. Thin-layer drying models, namely the Lewis and Page models, were applied to evaluate drying kinetics.Statistical analysis showed that the Page model exhibited superior performance with a coefficient of determination (R^2) close to 0.99 and minimal error values. The solar drying system demonstrated faster drying rates, reduced final moisture content, and improved product quality compared to sun drying. The results confirm that solar drying is an efficient and sustainable alternative for fish preservation.

Introduction:-

Fish is a highly perishable food product due to its high moisture content and biological composition, which accelerates microbial spoilage [1]. Drying is one of the oldest and most widely used preservation techniques, particularly in developing regions. Traditional open sun drying is commonly practiced due to its simplicity and low cost; however, it is associated with several drawbacks such as contamination, dependence on weather conditions, and non-uniform drying [2]. Solar drying offers a controlled and hygienic alternative by utilizing renewable solar energy to enhance drying efficiency and product quality [3]. The integration of solar dryers improves temperature control, reduces drying time, and minimizes environmental contamination. Mathematical modeling plays a crucial role in understanding drying behavior and predicting moisture variation during the drying process [4]. Thin-layer drying models such as the Lewis and Page models are widely used due to their simplicity and effectiveness in representing drying kinetics [5].

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The objectives of this study are:
- To design and develop a solar drying system
- To analyze drying characteristics of Grey Mullet
- To compare solar drying with traditional sun drying
- To identify the most suitable drying model using regression analysis

Materials And Methods:-
Sample Preparation:-
Fresh Grey Mullet (Fig. 1) samples were collected and cleaned thoroughly. The fish were cut, washed, and subjected to brining to enhance preservation and drying efficiency. Excess moisture was removed prior to drying.

Fig. 1 Sample (Grey Mullet)

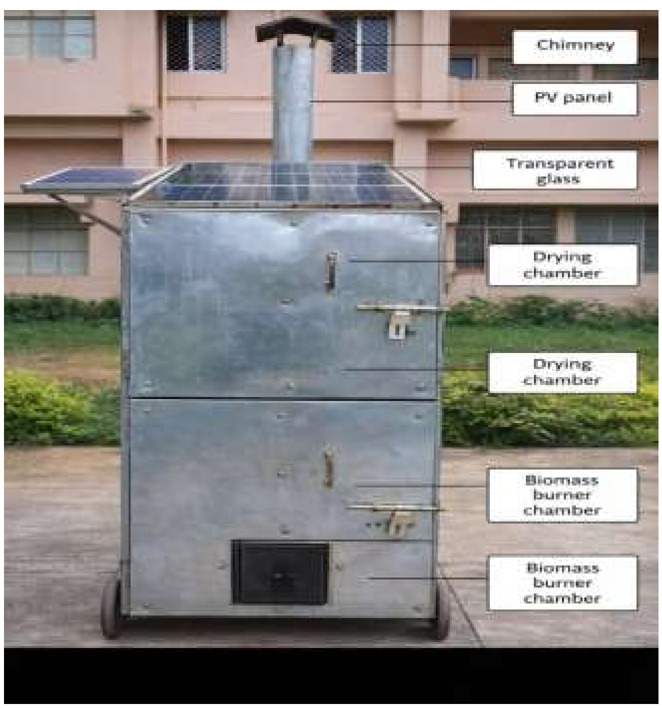

Fig. 2 Solar dyer

Experimental Setup:-
A hybrid solar dryer as shown in Fig. 2 was designed consisting of:
- Flat-plate solar collector
- Insulated drying chamber
- Photovoltaic-powered blowers
- Chimney for air circulation

The system was designed to maintain higher internal temperatures than ambient conditions, ensuring efficient drying.

Drying Procedure:-
Drying experiments were conducted under:
- Solar drying conditions (using the developed dryer)
- Open sun drying conditions

The weight of the samples was measured at regular intervals to determine moisture loss.

Mathematical Modeling:-
Moisture content (dry basis) was calculated as:
The sensorial quality, microbiological stability are depends on the moisture content $(M)$of the sea foods.The moisture content of sample is estimated on dry basis .The moisture content of a sample is expressed in percentage (%).The formula is depends on initial weight and oven dried of the sample. The sample is kept inside an electric oven, which is maintained at 105^0C for 24 hours to get oven dried weight (m_2) of the product.
Let
M = Moisture Content based on dry basis (gg^{-1})
It means it expressed in gram of wet mass to gram of dry mass.
m_1 = Initial mass of the sample (g)
m_2 = Oven dried mass of the sample (g)

$$M = \left(\frac{m_1 - m_2}{m_2} \right) \times 100$$

Moisture Ratio (MR) is an important parameter, which is required in regression analysis to get predicted moisture content and other drying parameters which are necessary for plot the drying curves and developed the mathematical model.

$$MR = \left(\frac{m_t - m_e}{m_1 - m_e} \right)$$

Where m_t = Moisture content at any instant of time
m_e = Equilibrium moisture content
m_1 = Initial moisture content
As the relative humidity of the drying air inside the solar dryer continuously fluctuates, the m_e value may be neglected as compared to m_t & m_1 hence, the above equation can be expressed as below

$$MR = \frac{m_t}{m_1}$$

Drying capacity means mass of moisture remove from the sample with respect to time during experiment. It can be measured by a term called "rate of drying". Rate of drying is expressed as $\frac{dm}{dt}$ .Drying rate is also another significant parameter in drying process

A number of mathematical models for drying kinetics have been developed by many scholars. In this research article, the mathematical model proposed by Lewis and Page have been taken as a reference models .Here the Experimental moisture contents obtained in the drying experiments arefitted to the selected drying models. In this investigation Microsoft excel data analysis statistical tool is used for regression to finding out the drying parameters and drying constants for developing the mathematical models .Drying parameters such as coefficient of determination (R^2), modeling efficiency (EF), reduced chi-square (χ^2), root mean square error (RMSE). The higher the R^2 value and lower the $\chi^2$and RMSE values, the better is the goodness of fit . R^2 is statistical parameters that show the variation around the mean explained by the mathematical model.χ^2 is the mean square of the deviations occurs between experimental and predicted result for the model. ($RMSE$) shows the deviation between predicted and experimental value for an experiment. The expression for above parameters is shown in below.

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{esp,i} - MR_{pre,i}\right)^2}{N - C}$$

$$RMSE = \sqrt{\frac{\sum \left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N}} \qquad EF = \frac{\left[\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{\exp,mean}\right)^2\right] - \left[\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,in}\right)^2\right]}{\left[\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{\exp,mean}\right)^2\right]}$$

Where,
$MR_{exp,i}$=i[th] experimental moisture ratio
$MR_{pre,i}$=i[th] Predicted moisture ratio
N=Number of observations
C=Number of constants in the model
Where,k = drying rate constant $\left(hr^{-1}\right)$
t = drying time at a particular instant $\left(hr\right)$
n=constant

Drying Models:-
Many investigators are proposed different drying models for drying characteristics; out of those we used two models such as Lewis model and Page model for reference to the experimental value.
The moisture ratio (MR) is given by;

$$MR = \exp\left(-k\,t\right) \text{(Lewis model)}$$

$$MR = \exp\left(-kt^n\right) \text{(Page model)}$$

Statistical Analysis:-
Model performance was evaluated using:
- Coefficient of determination (R^2)
- Root Mean Square Error (RMSE)
- Reduced Chi-square (χ^2)

Higher R^2 and lower error values indicate better model accuracy [6].

Results and Discussion:-
Regression analysis is carried out with the experimental database and drying curves are plotted to get the drying parameters for the mathematical model.The Fig. 3 &Fig.4 represents for Lewis model and Page model in sun drying respectively and Fig. 5 &Fig. 6 for Lewis model and Page model in solar drying. Fig. 7 provides the drying rate comparison between sun drying and solar drying methods. Table 1 provides the statistical drying parameters of fish drying.

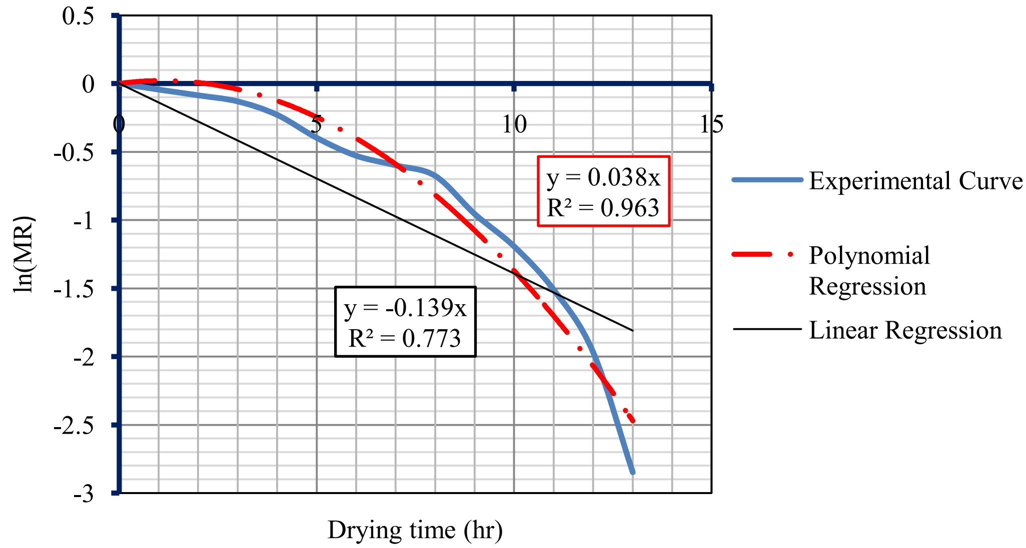

Fig. 3 Profile of ln (MR) with drying time (sun drying)

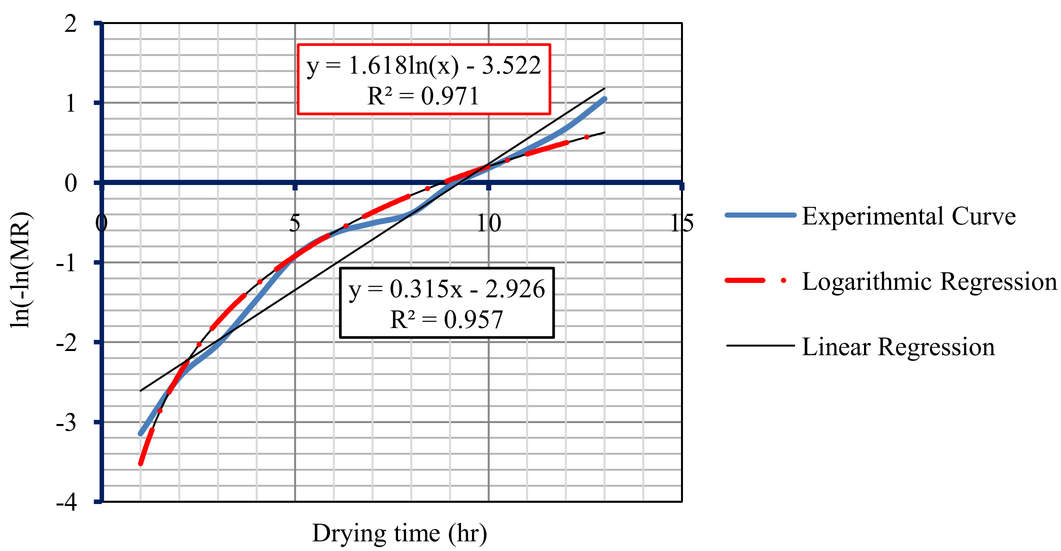

Fig. 4Profile of ln (-ln(MR)) with drying time (sun drying)

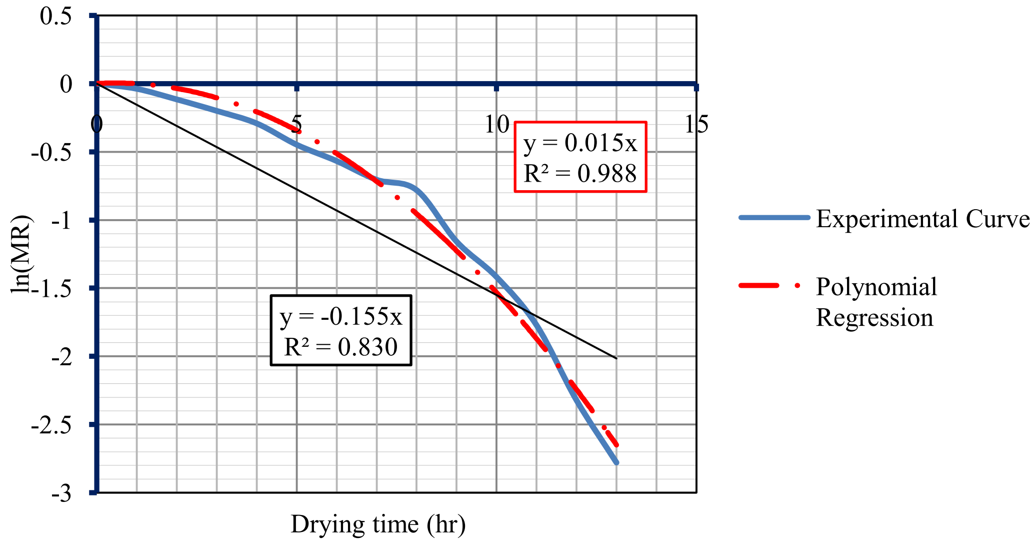

Fig. 5 Profile of ln (MR) with drying time (solar drying)

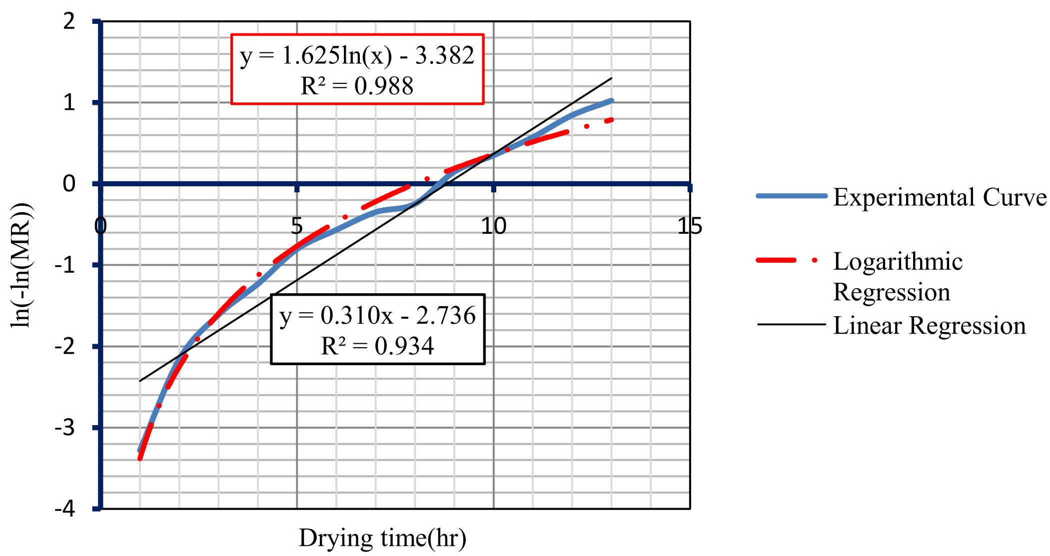

Fig.6 Profile of ln (-ln(MR)) with drying time (solar drying)

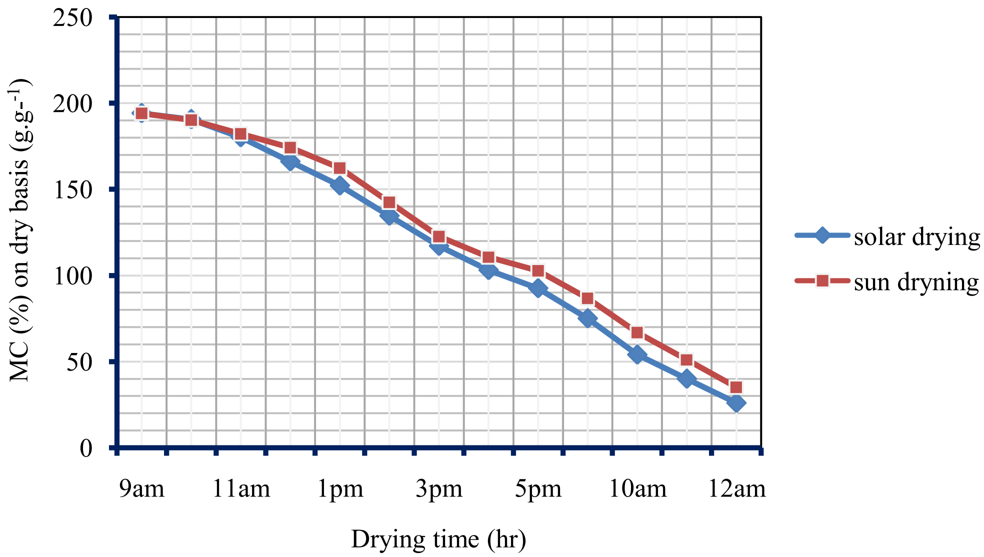

Fig.7Comparison of variation of moisture content

Fig.3 shows the moisture variation in sun drying as reference to Lewis drying equation ($MR = \exp(-k\,t)$) to find the drying constant. Its value found to be 0.139 hr^{-1} and the value of R^2 is 0.773 in linear regression, which is a far deviate from the experimental curve. In comparison to this, it is found that polynomial regression line (red dotted mark) is found to be best fit to the experimental curve.

Fig.4 shows the moisture variation in sun drying as reference to Page model equation ($MR = \exp(-kt^n)$) to find the two drying constants associated with the equation. The value of k and n are found to be 0.029 hr^{-1} and 1.618 in linear regression respectively. The value of R^2 is 0.957.The linear regression line of Page mathematical model is deviates from the experimental curve where as logarithmic regression (red dotted mark) seems to be better fit to the experimental curve.

Fig.5 shows the moisture variation in solar drying as reference to Lewis drying equation ($MR = \exp(-k\,t)$) to find the drying constant. Its value found to be 0.155 hr^{-1}.The value of R^2 is 0.830.The linear regression line is deviates from the experimental result and seems to be not good fit for the curve, where as polynomial regression tends to better fit.

Fig.6 shows the moisture variation in solar drying as reference to Page model equation ($MR = \exp(-kt^n)$) to find the value of drying constants (k,n).These value of k is 0.033 hr^{-1} and n is 1.625.Logarithmic regression (red dotted mark) is better fit to the experimental curve rather than the linear regression.

Fig.7 compares the variation of moisture content on dry basis of the product throughout the experimental period. It observed that the moisture content of the product is always decreases faster rate in solar drying as compared to the sun drying. The experiments of the products have been carried out almost for 13 hours of drying where initial moisture content (dry basis) of the sample varies from 194.12% to 19.23% and 15.55% in sun drying and solar drying respectively. In the first, few hours of starting of the experiment the variation of moisture contents are almost same in sun and solar drying after that it is more in solar drying because of maintaining higher temperature inside the dryer as compared to atmospheric temperature, which causes lower relative humidity and more affinity to moisture removal.

Table 1. Summarise of drying parameters

Parameter	Sun Drying (Lewis)	Sun Drying (Page)	Solar Drying (Lewis)	Solar Drying (Page)
n	–	1.618	–	1.625
k	0.139	0.029	0.155	0.033
MBE	0.02854	0.0023	0.0268	0.00254
RMSE	0.16895	0.0486	0.1637	0.05047
χ^2	0.03074	0.00302	0.02888	0.00301
EF (%)	96.42	67.19	99.54	97.04
R^2	0.773	0.957	0.83	0.988

Drying Characteristics:-

The drying process showed a rapid reduction in moisture content during the initial stage due to surface evaporation, followed by a slower drying rate governed by internal moisture diffusion.
Solar drying demonstrated significantly faster moisture removal compared to open sun drying.

This is attributed to:

- Higher internal temperature
- Controlled airflow
- Reduced humidity

Model Evaluation:-

The Lewis model showed moderate agreement with experimental data, whereas the Page model provided an excellent fit.

- Page model $R^2 \approx 0.99$
- Lower RMSE and χ^2 values

This indicates that the Page model more accurately represents the nonlinear drying behavior of fish [7].

Performance Comparison

Parameter	Sun Drying	Solar Drying
Drying Time	Higher	Lower
Final Moisture	Higher	Lower
Hygiene	Poor	Better
Efficiency	Low	High

Solar drying clearly outperformed traditional sun drying in all aspects.

Technological Advancements:-

Recent advancements in solar drying include:

- Integration of thermal energy storage systems
- IoT-based monitoring and control
- Hybrid drying systems with auxiliary heating

These innovations improve system efficiency and reliability [8].

Conclusion:-

This study confirms that solar drying is a superior method for fish preservation compared to traditional sun drying. The developed solar dryer achieved faster drying rates and better product quality. Among the models tested, the Page model was found to be the most suitable for describing drying kinetics.The results highlight the potential of solar drying as a sustainable and energy-efficient solution for small-scale and commercial applications.

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