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Modeling, Simulation and Analysis of the Drying Process of "Paddy" Rice in a Mill in the Department of Huila, Colombia

[1]Nelson Corredor Sanchez, [1]Oscar Jaramillo Castano,
[1]Jorge Bernardo Ramirez Zarta and [2]Ruthber Rodriguez Serrezuela
Department of Industrial Engineering, Faculty of Engineering,
Corporacion Universitaria del Huila (CORHUILA), Neiva, Colombia
[2]Faculty of Electronic and Biomedical Engineering, University Antonio Narino,
Bogota, Colombia

Abstract: In this research, we performed the acquisition of the temperature generated in the rice drying process "paddy" to later carry out its identification, simulation and validation of the obtained model. The data generated by the model are compared with the data emanating from the process from which the analysis is performed. The drying process of paddy rice consists of generating a moisture loss of 12% rice and is done through a line towers system in which air is injected at a specific temperature and a constant flow of air over the rice which in each tower is developing a programmed movement. The drying of the rice in the tower No. 1 takes approximately 1 h and 20 min and is very important for the drying process because it must reach a moisture loss of at least 5% and the rice must be homogenized with moisture minimizing the dispersion of that moisture that is mainly caused by the diversity of paddy rice suppliers. This study presents results on the recommendations that the operator tower No. 1 must carry out in relation to the air temperature during the drying process to reach a greater loss of humidity without increasing the grain temperature above 32°C because you can try the quality of the rice. This study does not reach the controller calculation process simply remains in the collection and model validation.

Key words: Drying rice, modeling, simulation, drying towers, green rice paddy, model validation

INTRODUCTION

The Department of Huila is the third producer of white rice nationwide, producing an average of 348 tons of white rice per day. This process is done through a system of harvest and postharvest in the harvest the farmer defines his process of planting until cutting of the green rice "paddy" to take to the mills. When the rice is received in the mills, the post-harvest system starts.

At present, it is possible to simulate various physical or chemical processes as by Serrezuela *et al.* (2016a, b) using computer tools. In which the rice passes through the processes of drying, threshing, pre-cleaning, peeling, extraction of husk, separation of brown rice and paddy rice, cleaning, polishing, sorting and packaging (Rodriguez and Pinilla, 2015; Serrezuela *et al.*, 2016a, b Serrezuela and Chavarro, 2016ab).

Drying is a process of great importance in the food production chain because the moisture content is undoubtedly the most important feature in determining whether grain is likely to deteriorate during storage. The drying is done to inhibit the germination of the seeds, reduce the moisture content of the grains to a level that prevents the growth of the fungi and prevent deterioration reactions (Pedrera *et al.*, 2013).

This process is carried out by means of a system of 5 towers line. Each tower has a capacity of 45 tons of rice which remains circulating in each tower with about 1 h 20 min with temperature controlled air flow for each constant tower. The rice is gradually losing moisture in the following way; it loses about 3% moisture in the tower 1, 3% in tower 2, 2.5% in tower 3, 1.5% in tower 4 and 1.5% in tower 5. For a total humidity loss an average of 11.5%.

In tower 1, the rice has an average initial moisture of 24% with a standard deviation of 2.64% which is relatively high because the rice comes from different suppliers and the humidity levels of each have in most cases significant differences. For milling companies adopting the line towers system it is important to reduce the humidity of tower 1 by at least 5% with a standard deviation of 1.1%,

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Corresponding Author: Nelson Corredor Sanchez, Department of Industrial Engineering, Faculty of Engineering, Corporacion Universitaria del Huila (CORHUILA), Neiva, Colombia

Fig. 1: System of lines of towers

Table 1: Estimated drying process results

Tower No. 1	Moisture entry	Moisture output	Delta moisture
1	24.0	19.0	5.0
2	19.0	16.0	3.0
3	16.0	13.5	2.5
4	13.5	12.5	1.0

In order to reduce the use of 5-4 towers maintaining the same conditions of drying in the other towers (Cubillos and Mendoza, 2010) (Fig. 1 and Table 1).

In this way, the drying process is carried out in less time and less cost, since, the use of the tower 5 implies an increase in the duration of about 72 min and an estimated cost of 80 weights per kilogram related preparation tower, consumption of thermal and electrical energy, labor cost (among others).

The purpose of the present study is to establish optimal air temperature levels in tower 1 to maximize the moisture loss of rice taking into account that the temperature of the grain cannot exceed 32°C, since there is a risk of crystallizing the grain and the level of broken rice is significantly increased which causes a loss in rice quality and when the level of broken rice exceeds 15% is not accepted for human consumption and should be sold at less price as an ingredient of concentrate for animals or taken to other industries.

Problem statement and justification: The drying process of white rice in tower No. 1 is controlled empirically in relation to the air temperature in the tower. Because that process depends on the ability of the operator who carries out revisions of humidity and temperature of the grain more or less every 30 min and depending the partial results, take the decisions on increase, decrease or maintain the temperature of the air in the tower No. 1. By, Zeledon and Mata (1992) performing this process so intuitively, the final moisture loss results are on average 3.25% which is low in relation to the objectives of the company. These moisture loss results have a high dispersion so there are occasions where the moisture loss is more tham 5% but in 6 out of 8 drying processes this reduction is not achieved.

Another problem of carrying out the tower drying 1 in the mentioned way is that 6 out of 15 drying processes had a grain temperature >32°C in breach of the restriction established by the company to maintain the quality of the product. It is also important to minimize the dispersal of moisture and grain temperature in each drying process in order to obtain a more homogeneous drying that allows modeling of the process with high reliability and minimizes the risk of rice partition. With the accomplishment of this investigation, the operator of the tower 1 will have a reference on the level of temperature of has to maintain in different times of the process of drying in said tower. Is significantly reduced operator empirical practice, achieving loss maximize grain moisture with more homogeneous results in relation to humidity and temperature, minimizing the level of broken rice and in particular, reducing the processing times and costs (La Gra *et al*., 1982; Carvajal *et al*., 2016; Afzal and Abe, 1997).

MATERIALS AND METHODS

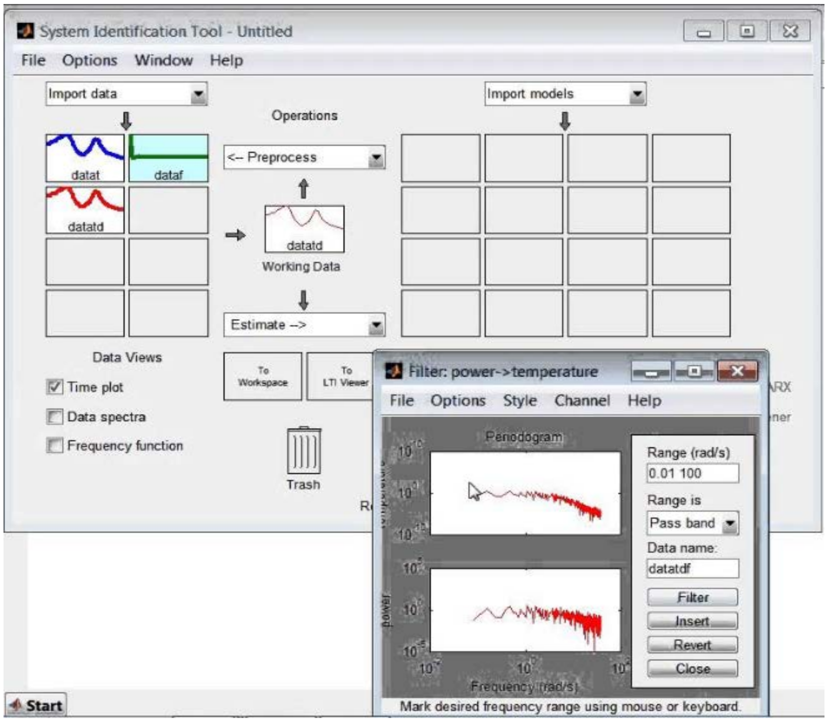
Methodology and development: The temperature was acquired in the tower where the Paddy rice is dried during several days. These curves were imported into Matlab Software and through the identification toolbox the model of the plant was obtained as can be in Fig. 2.

The identification of the experimental model is performed using the three parametric function models provided by Matlab these are OE, ARMAX and ARX. Finally, the cross-validation of each of the models and the comparative analysis of the results are performed for the respective selection of the mathematical model that best describes the dynamic behavior of the system.

Figure 3 shows the graph that compares the actual behavior of the system (simulated data) with the obtained ARX model. A fit of 91.19% is reached; this parameter measures the percentage of similarity between the two signals. The result delivered by MATLAB is as follows:

>>m=arx(z,[221])
Discrete-time IDPOLY model:
A(q)y(t) = B(q)u(t)+e(t)
$A(q) = 1\text{-}1.753q^{-1}+0.7535q^{-2}$
$B(q) = 3{,}244q^{-1}n\,2{,}523q^{-2}$

- Estimated using ARX from data set z
- Loss function 9,08695e-008 and FPE 9,13325e-008
  Sampling interval: 1



Range (rad/s): 0.01 100

Range is: Pass band

Data name: datatdf

Mark desired frequency range using mouse or keyboard.

Fig. 2: System toolbox identification of MATLAB

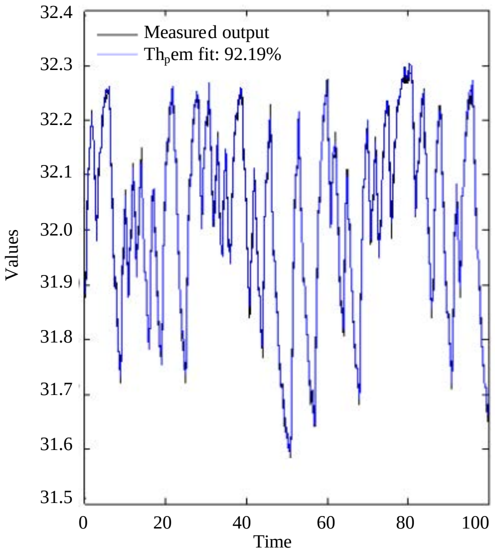


Fig. 3: System toolbox identification of MATLAB

The data-based adjustment derives all the information needed to generate the model directly from the data. The models that emerge from this technique are also known as "black box" models or non-parametric adjustments. Figure 4 shows the validation of the obtained model (Olmos *et al*., 2002; Rordprapat *et al*., 2015; De la Vargas, 2006).

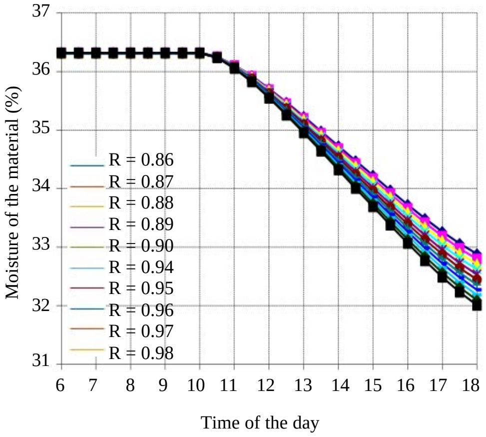


Fig. 4: Validation of the obtained model

The method for carrying out an optimization of the drying process of the tower No. 1 comprises two faces; the first phase has a non-experimental approach in which the procedure carried out by the tower operator is described and analyzed in aspects related to the regulation of the air temperature in the tower, the initial humidity, the dispersion of the initial and final moisture, relative humidity, ambient temperature which have been assumed by the company as variables that have an impact on the effectiveness of the process (Fig. 4) (Golmohammadi *et al*., 2012; Bustamante, 2010;

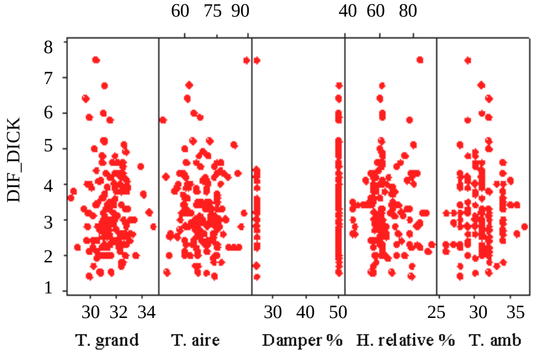


Fig. 5: Temperature and humidity ratio

Frias *et al*., 2002; Wang *et al*., 2007; Zarta and Serrezuela, 2017; Sharma *et al*., 2005; Menges and Eetekin, 2006; Midilli and Kucuk, 2003).

The objective of the first face is to identify the correct practices by the operator of tower 1 with which a moisture reduction of at least 5% was achieved without the temperature of the grain exceeding 32°C in addition, the procedures that lead to non-compliance with the humidity and temperature conditions will be analyzed to obtain more tools to validate the good practices of the operator and to be able to make inferences about the method that allows to generate the best results of drying in the tower No. 1.

Figure 5 a graph of the temperature of the grain with respect to the percentage difference outlined moisture. The process that is carried out for the drying of tower 1 is very empirical and presents great difficulties to control the temperature and the reduction of moisture of the grain, 38.3% of the drying solutions in tower 1 exceeded the temperature of the grain to more than 32°C which due to the requirements of the company is not recommendable for the quality of the product.

In addition, only 5 out of 37 processes of drying processes in tower 1 achieved a reduction of humidity ≥5% which is essential for total drying to be carried out in 4 towers and not in 5. On the other hand, in Fig. 6, four regions with solutions of drying in first tower are identified. Region No. 1, Fig. 5 contains the solutions expected by the company, since the grain temperature does not exceed 32°C and the humidity percentages are reduced by >5%. It is observed that >85% of the solutions are in region 2 where the temperature of the grain does not exceed 32°C but the moisture loss does not exceed 5%. Increasing the costs of drying by the use of 5 towers and risking the quality of the product because the increase of the percentage of broken rice increases in 1.8% for each degrees celsius that increases the grain when it surpasses the 32°C.

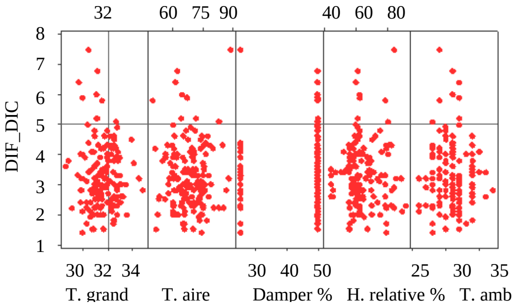


Fig. 6: Feasible region of tower No. 1 drying

Figure 6 shows the characteristics of the solutions of region 1 in relation to the air temperature in the tower, percentage of relative humidity, ambient temperature and percentage opening of the damper which is manipulated directly by the operator. The tower and only graduates to 50 or 25% by company specifications (Afzal and Abe, 1997; Akpinar *et al*., 2003).

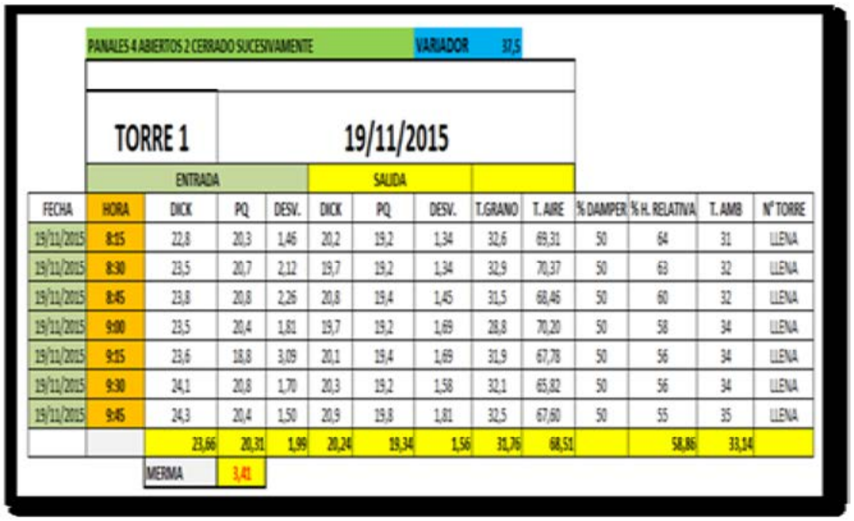
RESULTS AND DISCUSSION

The solutions of Region 1 are differentiated according to the incoming moisture from the grain to the tower which is measured after a mixing process that homogenizes the rice to obtain more uniform conditions of drying. Said measurement is made through the DICK John GAC 2100 and Kett PQ-510 which measure the level of humidity of the rice in the entrance as well as the salinity of the same in each tower.

The initial moisture of the grain in tower No. 1 has been ordered in three percentage intervals. In the first interval (19.2, 23.8) which is considered to have low initial humidity, the relative humidity was maintained at approximately 60% in 5 out of 8 drying processes or solutions. The ambient temperature ranges from 29-32°C, the temperature being maintained at the following initial moisture intervals.

The operator graduated the opening of the damper to 50% which is the maximum allowed opening of ambient air to tower 1, maintaining the temperature of the air in the tower with a mean of 68.35% and the difference of humidity are between 6.29 and 7.3% (Fig. 7). For the second initial moisture range of the grain (23.8, 28.4) the relative humidity has an average of 65.4% with a standard error of 1.34, the opening of the damper was also graduated to 50% and the air temperature in the tower had a average of 63.58°C, the humidity difference is around 5.93%.

The third initial moisture range (28.4, 33) is considered high humidity, the average relative humidity is 73.9% with maximum levels up to 84%. The opening of the damper



PANALES 4 ABIERTOS 2 CERRADO SUCESIVAMENTE VARIADOR 37,5

TORRE 1 19/11/2015

		ENTRADA			SALIDA								
FECHA	HORA	DICK	PQ	DESV.	DICK	PQ	DESV.	T.GRANO	T. AIRE	% DAMPER	% H. RELATIVA	T. AMB	N° TORRE
19/11/2015	8:15	22,8	20,3	1,46	20,2	19,2	1,34	32,6	69,31	50	64	31	LLENA
19/11/2015	8:30	23,5	20,7	2,12	19,7	19,2	1,34	32,9	70,37	50	63	32	LLENA
19/11/2015	8:45	23,8	20,8	2,26	20,8	19,4	1,45	31,5	68,46	50	60	32	LLENA
19/11/2015	9:00	23,5	20,4	1,81	19,7	19,2	1,69	28,8	70,20	50	58	34	LLENA
19/11/2015	9:15	23,6	18,8	3,09	20,1	19,4	1,69	31,9	67,78	50	56	34	LLENA
19/11/2015	9:30	24,1	20,8	1,70	20,3	19,2	1,58	32,1	65,82	50	56	34	LLENA
19/11/2015	9:45	24,3	20,4	1,50	20,9	19,8	1,81	32,5	67,60	50	55	35	LLENA
		23,66	20,31	1,99	20,24	19,34	1,56	31,76	68,51		58,86	33,14	
		MERMA	3,41										

Fig. 7: Summary of results dried in tower 1

was maintained at 25%, the air temperature in the tower exceeded 70°C in at least half of the cases. In addition, the greatest reductions in grain moisture were achieved with differences up to 7.4%.

By performing a similar analysis to that carried out on region 1, a comparative analysis is carried out on regions 2 and 3 where >90% of all the drying processes in tower No. 1 are found. This analysis was ordered according to the three initial moisture ranges of the grain identified for the analysis of region 1 (Valverde *et al*., 2007). For the initial low humidity range, the relative humidity has an average of 55.72% with minimum and maximum levels of 48.3 and 72.5% respectively. The ambient temperature is between 26 and 34°C, the opening of the damper was set at 50% by the operator when the relative humidity did not exceed 60% which was presented in approximately 8 out of 11 solutions. The moisture difference did not exceed 3% and the grain temperature, although not exceeding 32°C was between 30.84 and 31.92°C (Fig. 6).

When the damper graduated to 25%, the air temperature in the tower exceeded 65°C and the grain temperature averaged 32.81°C and exceeded 32°C in 75% of cases. The difference of humidity of the grain was around 4.05%. For the second initial moisture range of the grain, considered as the average moisture range, the relative humidity was between 55 and 62%, the ambient temperature was slightly lower than the previous range.

The damper graduated in 6 out of 10 cases at 50%. The difference in moisture was between 2 and 3%, only 3 out of 10 cases exceeded 3% without the grain having its temperature at more than 32°C. When the damper graduated to 25%, the air temperature in the tower oscillated between 61 and 72°C and the grain temperature was 32.4°C, surpassing 32°C in 45% of the cases.

For the interval where the initial moisture of the grain is considered high, the damper was graduated to 25% when relative humidity exceeds 60%. The difference in grain moisture remained around 4-5% but 40% of cases the grain temperature exceeded 32°C and when the operator graduated damper to 25%, the difference in grain moisture was The lowest, between 1.3 and 2.2%.

CONCLUSION

Using the tools provided by the Matlab Software, it is easy to obtain the different models and to validate them. The obtained results allow to affirm that these models are very close to the real behavior of the system being studied. The drying process of rice paddy in tower No. 1 efficiently, allows to reduce the number of towers used in the system of drying towers line of 5-4 towers. Minimizing the drying time and the costs of this process. But this drying in tower No. 1 is very subject to the decisions that the operator of the tower takes in relation to the injection of ambient air to the tower. Which depends on the humidity and temperature of the grain and the interior of the tower.

As an initial step, the drying solutions in tower No. 1, according to the empirical methods used by the tower operator have been experimentally determined. In this way, the correct practices are defined that the operator must take into account depending on the humidity and temperature conditions of the grain and the environment at certain moments of the process.

On the other hand, with the present study a reference is generated to compare the results of a process modeling in which it is possible to optimize the drying in the tower 1 and where the empirical techniques of the operator are contemplated as part of a heuristic algorithm that allows put into practice in the tower, the results of an optimized model.

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