STUDY ON THE REVERSAL TIMING FOR THE SRA REVERSIBLE DRYER [#]

Phan Hieu Hien, Nguyen Hung Tam, Nguyen Van Xuan [##]

INTRODUCTION

In Vietnam, over the past 20 years, the simple flat-bed dryer has been accepted and developed into the foremost dryer for reducing post-harvest paddy losses due to adverse rainy weather, with about 3000 units of capacities from 4 to 8 tons per batch. Good features of these dryers are: fairly high capacity, good grain quality, low drying cost, easy to install and operate. Nevertheless, as simplest dryers with a major drawback of non-uniformity in final grain moisture content, they have to be changed to meet the needs for more-mechanized dryers at rice milling centers.

The series of SRA dryers (RA is abbreviation for Reversible-Air, S is drying in Vietnamese) have been designed to serve the above change. The research began in 1999 at Nong-Lam University (**NLU**, formerly University of Agriculture and Forestry) with a laboratory model for basic information about drying characteristics of various crops with reversible airflow. Next, a pilot 1.5-ton/batch SRA dryer was designed and tested with paddy and coffee. Finally, the dryer was scaled up to different models, of 2; 4; 6; 8; 10; and 12 tons per batch. Twenty five SRA units have been applied successfully in various Provinces of Vietnam; of which 8 units have each dried 500- 1500 tons in the past 3 years. Features drawn from testing and using these dryers are: ***a***) Saving of land space; ***b***) More mechanized, meaning less use of manual labor; ***c***) Multi-crop use, including high-moisture products such as coffee, sliced cassava, longan... , and ***d***) The investment and drying cost are not higher compared to a flat-bed dryer of similar capacity. Successful applications of these SRA have been reported elsewhere (Nguyen Hung Tam et.al., 2002; Phan Hieu Hien, 2003)

The unique feature of these dryers, is that the drying is reversed only once, which makes the process different from other dryers reported in the literature with periodic air reversal, say, every 2 hours. Less air reversal means less intervention by manual labor, which in turn contributes to lower drying cost. But this once-only air reversal should ensure moisture uniformity for users' acceptance.

[#] *Paper for presentation at the Seminar on "Agricultural Engineering and Agro-products Processing towards Mechanization and Modernization in Rural Areas" at Nong-Lam University, HoChiMinh City, 11-12 December 2003.*

[##] *Lecturers, Faculty of Agricultural Engineering and Technology, Nong-Lam University HoChiMinh City, Vietnam. E-mail* phhien@hcm.vnn.vn

REVIEW OF LITERATURE

Reversible-air drying is not a new concept. In Taiwan (Din-Sue-Fon, 1981) designed a 1-ton/batch reversible-air dryer, with a rectangular drying bin and a central box for reversing the air from the fan... Treatments included air reversal every 1 hour and 2 hours; with good results and recommendation for 2-hr periodic air reversal.
Thus, the objective of this sub-study is to determine the appropriate timing for the air reversal as a function of initial moisture content. Experiments were conducted in 2002 at the NLU Center for Agricultural Energy and Machinery; results were verified with field testing of full-scale dryers. Results should be presented as a handy graph or table for the convenience of dryer operators.

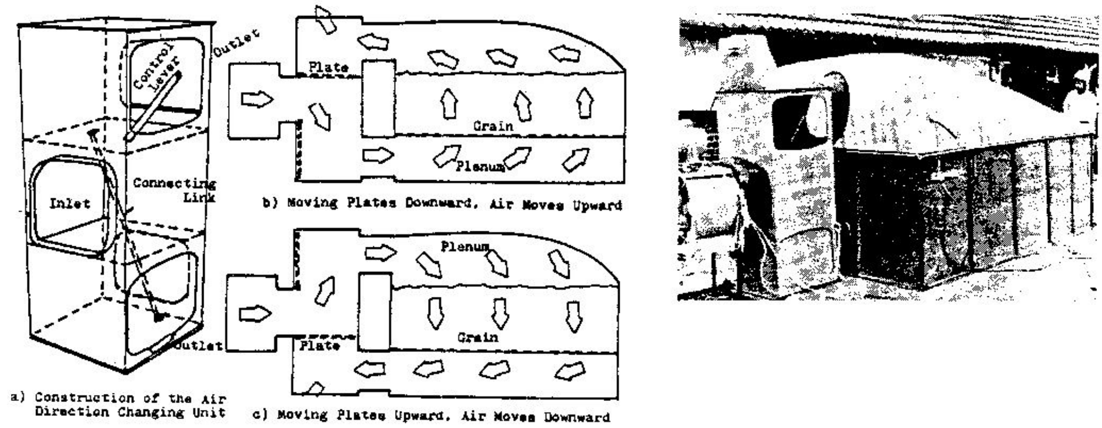


Figure 1: Reversible air dryer in Taiwan

In the Philippines (Kuizon, 1995) also built reversible-air dryers with similar configuration. In 1998, the American-based ADS Company installed the 6-ton reversible-air dryer in Vietnam; unlike the above two dryers, this drying bed is vertical while the airflow is horizontal.

In these dryers, as well as in other separate simulation studies (Sabbah et.al., 1977, 1979), air is reversed periodically every 3 hours. Scientifically it is fine, but practically with full-scale dryers, air reversal takes time and labor, which obviously increase the drying cost. The minimum number of air reversal time is one, provided the non-uniformity in final grain moisture content is below an acceptable level.

Our desk evaluation of the oversea dryers revealed some drawbacks. In the Taiwanese and Philippines designs, the air is blown at the center, thus increases the bed height level, making more difficult for manual loading. The American vertical-bed only fits granular drying materials like grains, thus could not accept other hi-moisture and sticky materials. Hence, a different air-reversal configuration (Figure 2) has been selected, which is briefly described below .

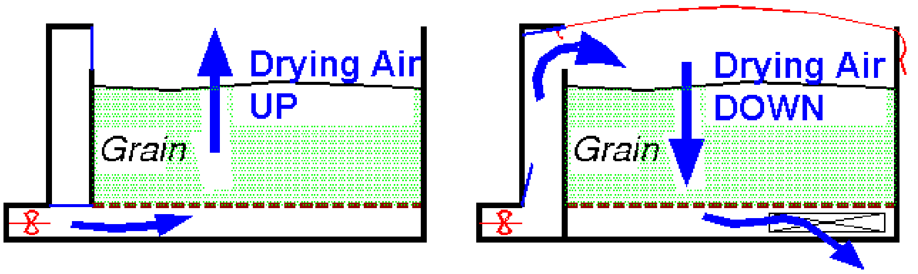


Figure 2: Principle of operation for the SRA reversible air dryer

Scaled-up reversible-air dryer

Different reversible-air dryers, of 2, 3, 4, 8, 10, 12 tons per batch have been installed at rice mills to determine the compatibility of the design with actual production conditions (Figures 3 and 4). All of the above dryers have three features in common: *(1)* A side-duct plenum chamber which is convenient in reversing drying air, and allows a low drying bed for convenience in loading/unloading. *(2)* A two-stage axial-flow fan, which provides airflow of 0.8- 1.0 $m^3 s^{-1} ton^{-1}$ at 500-pascal static pressure. The axial fan fits local fabrication skills, with comparatively low cost. *(3)* A "standard" drying bed of 0.6m has been based on the fan capability to push air through paddy as a high-resistance material to airflow. Still, the bin is designed to accommodate a bed up to 1 meter high, for materials with lesser resistance to airflow.

Figure 3: The SRA-1.5 reversible air dryer

Figure 4: Three-ton/batch mobile dryer SRA-3M

Thin-layer drying equations

For the prediction of the moisture reduction of the drying process, whether simple or sophisticated, a thin-layer drying equation is needed. Collection from published sources, drying curves of these equation vary widely, as much as 3 times (Figure 5). We selected two which most likely reflect long grain paddy properties in Vietnam. One is by Wang and Singh (1978), the other is by Doan P. Cuong and P.H. Hien, with experimental data conducted at IRRI. The equations are listed in the Appendix.

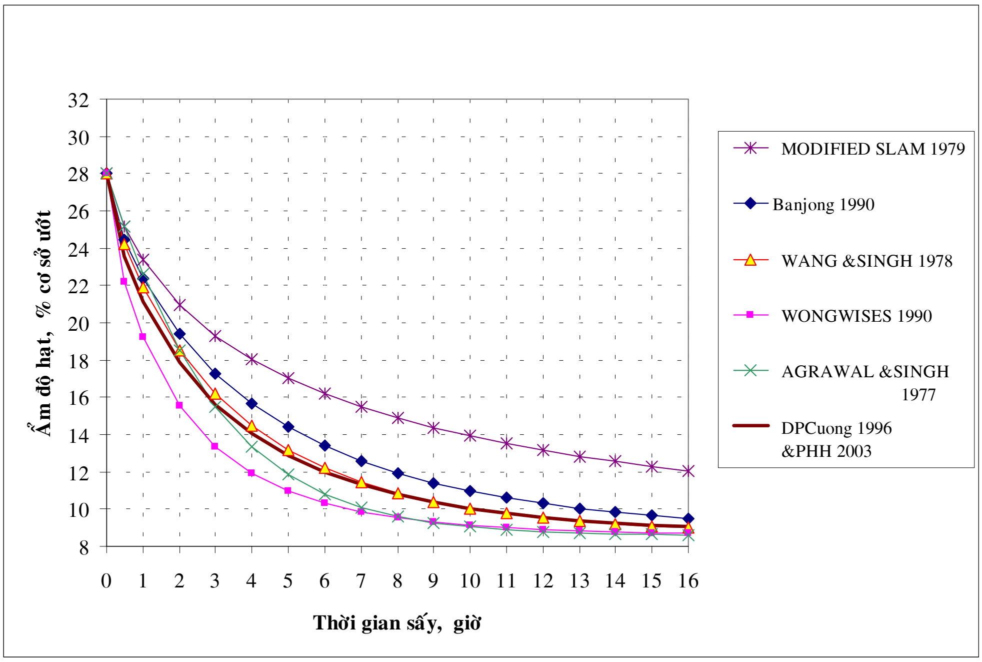


Figure 5: Comparison of different thin-layer drying equations for paddy

MATERIAL AND METHOD

Laboratory reversible-air dryer

A laboratory dryer, named SRA-TN (Figure 6), was built for studying the moisture reduction curves as influenced by the bed depth, the airflow rates, and the timing of air reversal. The construction includes: *(1)* a 3-m high, 0.39m-dia. cylindrical bin; *(2)* a 1-HP centrifugal fan, with ducting for blowing air either upward or downward through the bin; the airflow is measured and controlled by an orifice plate and valves; and *(3)* a furnace burning coal at 1 kg/hr.

Measuring equipment included: moisture meter, scales, temperature recorder, rotameter for superficial air velocity, airflow orifice plate (Ower, 1977)... Since the reversible air dryer is similar to flat-bed dryers, in which grain is in long contact with the drying air, the drying temperature for paddy was controlled below 45 ^{o}C. Thus, experiments did not take temperature as a variable under study, since it is verified worldwide.

RESULTS AND DISCUSSION

Experimental data with the SRA-TN laboratory dryer is summarized in Table 1.

Table 1: Summarized results of the drying experiments

	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5
Grain layer thickness, m	0.60	0.50	0.60	0.50	0.50
Initial moisture content, %wb	22.5	27.6	29	29	28.8
Superficial air velocity, m/minute	16	16	16	14	14
Unit airflow rate, m^3/s /ton	0.85	0.94	***0.85***	0.82	0.82
Drying temperature (average), ^oC	45	43	***45***	45	43
Results :					
Air reversal after (hours)	*4*	*6*	*7*	*5*	*7*
while the MC:					
of the Upper layer, %	20.8	22.1	17.6	19.8	17.9
of the Lower layer, %	14.0	10.7	12.3	13.3	13.3
Final moisture content (average), %	14.7	12.6	13.1	12.8	13.7
Final moisture differential, %	***2.3***	***1.4***	***1.0***	***0.7***	***0.4***
Drying time, hours	6	8	9	7	9

Although the data are not enough for a systematic analysis, some remarks can be drawn on the relationship between the air reversal timing and the moisture content.

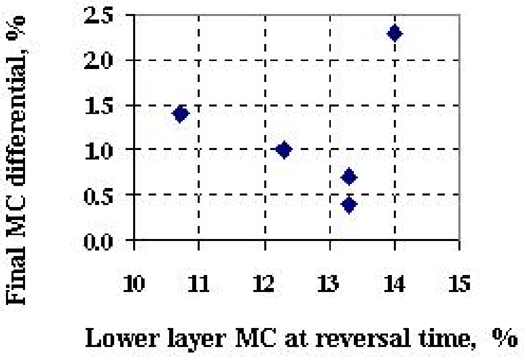
Batch 1: Due to early air reversal timing while the upper-layer MC was still high at 20.8%, and the lower-layer was still high at 14.0% MC, rewetting occurred leading to high moisture differential.

Batch 2: With the upper-layer MC at 22.8%, but the lower-layer MC was over-dried at 10.7%, the final moisture differential was unacceptable at 1.4%.

Batch 2,4, and 5: Conditions were similar to Batch 2, but the air reversal was done when the lower-layer MC was 12.3- 13.3 %. The final non-uniformity in MC was much improved.

Plotting the final non-uniformity in MC versus the lower-layer MC, and versus the upper-layer MC (Figure 7), just so few experimental points did not lead to any significant statistical regression (coefficient of determination R^2 = 0.007 for the lower layer , and R^2 = 0,383 for the upper layer). However, examining the graphs, coupled with judgement on the drying process, the following inferences could be roughly drawn on air reversal timing for the least final non-uniformity in MC :

- In the drying temperature range between 43- 45 ^oC, do not reverse the airflow when the upper-layer MC is still high, over 20%. Reverse the airflow when this MC is 18- 19%.
- Reverse the airflow when the lower-layer MC is about 12%.



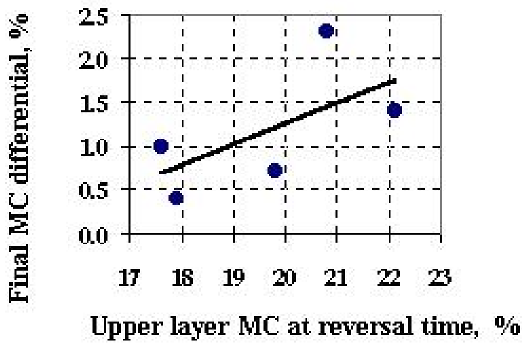


Figure 7: Effect of the lower-layer MC (a), and the upper-layer MC (b) at the time of air reversal on the final non-uniformity in MC

In practice, for full-scale dryers, it is not convenient for operators to monitor the MC of the lower layer due to the bulky mass of grain over. On the other hand, the sampling of grain moisture at the upper layer is too easy with bare hand. Thus it is necessary to predict the MC at the lower layer, as basis for the decision of reversing air.

Grain at the lower layer is always in contact with incoming hot air, thus can be considered as in thin-layer state. Hence, using the thin-layer drying equation (Appendix) and comparing with experimental results are shown in Figures 8 and 9.

The comparison showed that the equation by Wang & Singh and by Cuong & Hien are in good matches. On the other hand, equation by Agrawal &Singh predicted in the over-dried direction.

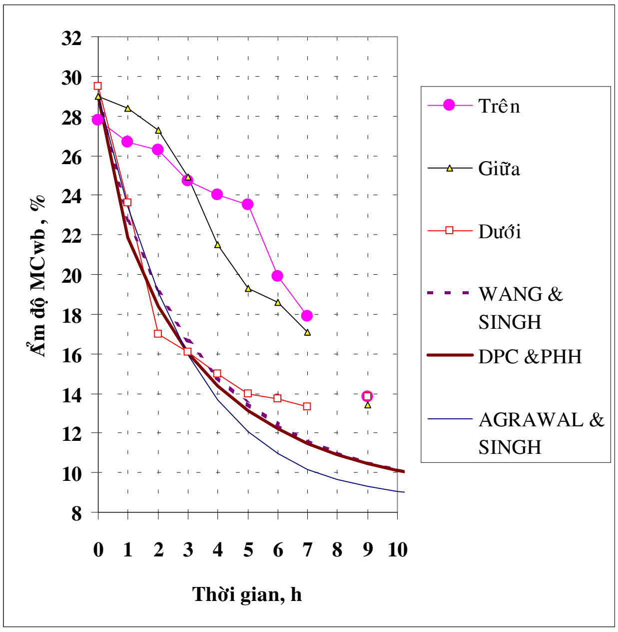


Figure 8: Moisture reduction: Comparison between experimental results and from thin-layer drying equations. (Batch 5). The arrow marks the air reversal time point.

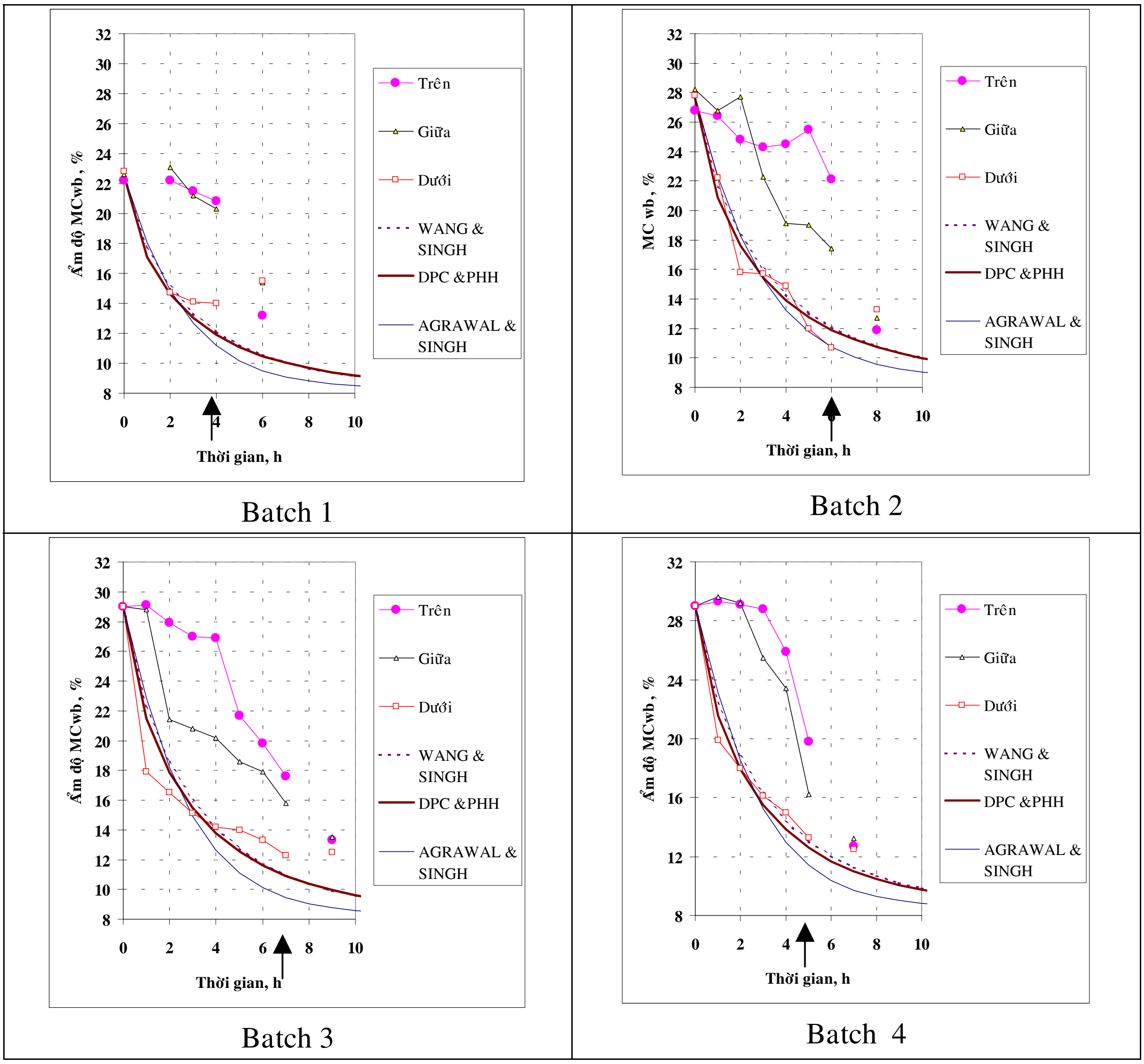


Figure 9: Moisture reduction: Comparison between experimental results and from thin-layer drying equations. (Batches 1, 2, 3, and 4).

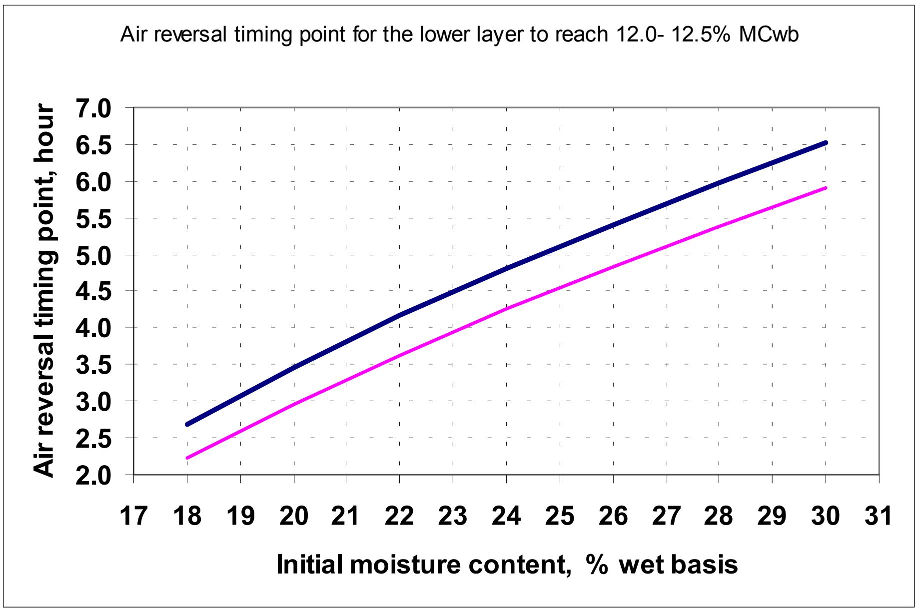


Figure 10: Air reversal timing point (area between two lines)

Thus based on the appropriate thin-layer equation, it was established that the drying time so that the lower-layer MC reaches 12- 13% is also the time point for reversing the airflow. Calculations with initial moisture content from 18 to 30 % result in a handy graph (Figure 11). The actual field tests for verification showed close agreement; Figure 10 is an example with the 10-ton-per-batch SRA dryer. Still, note that the graph is a simplifying estimate, since in practice, other factors might interfere, such as ambient temperature and humidity, unit airflow, amount of foreign impurities... Hence the graph should be used with due judgement.

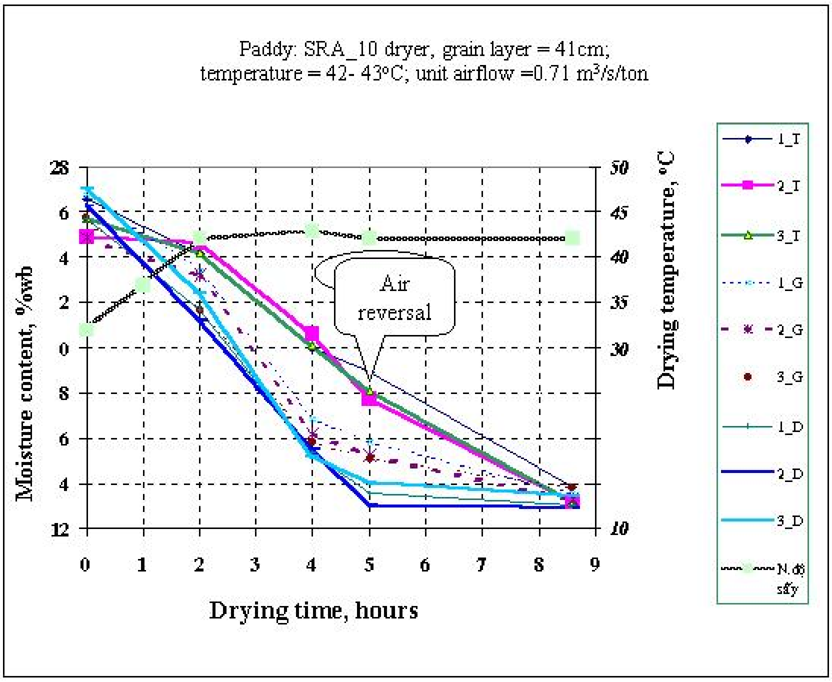


Figure11. Moisture reduction of the 10-ron-per-batch SRA dryer

CONCLUSION

A study with the laboratory reversible dryer, coupled with matching to an appropriate thin-layer drying equation, resulted in a graph which is handy for the dryer operators to use for estimating the time for reversing the airflow, depending on the initial moisture content.

REFERENCES

1. AIT Drying Simulation Help Files. 1992. Asian Institute of Technology, Bangkok.
2. ASAE (American Society of Agricultural Engineers). 1995. *Yearbook 1994.*
3. BROOKER D. B., F. W. BAKKER-ARKEMA, C. W. HALL. 1992. *Drying and storage of grains and oilseeds*, AVI Publ. Van Nostrand Reinhold, New York.
4. CHAMP B.R., E. HIGHLEY, G.I. JOHNSON (Eds). *Drying in Asia.* ACIAR Proceedings N° 71.
5. DOAN PHU CUONG. 1996. *Simulation of the drying process on the SRR-1 dryer.* Master's Thesis, University of Agriculture and Forestry HoChiMinh City.
6. DIN SUE FON. 1981. *Stationary flat-bed rice drier and two way airflow drying*

methods. In: Agricultural Mechanization in Asia, Africa &Latin America. Vol. N^o 2 Winter 1981, pp. 53-56.

7. KUIZON P. *Rice husk furnace and reversible airflow grain dryer.* In: Champ B.R., E. Highley, G.I. Johnson (Eds.). *Grain Drying in Asia.* ACIAR Proceedings N^o 71, pp.356-359.
8. NGUYEN HUNG TAM, .N.V. XUAN, and P. H. HIEN. 2002. *Results of reversible air drying research (in Vietnamese).*Journal of NLU Agricultural Science and Technology N^o 1 /2002, pp.81-90.
9. PHAN HIEU HIEN, N.H. TAM, AND N.V. XUAN. 2003. *The reversible air dryer SRA: One step to increase the mechanization of post-harvest operations*. Proceedings of the International Conference on Crop Harvesting and Processing held in Louisville, Kentucky, February 10-12, 2003
10. PHAN HIEU HIEN , N.V.XUAN, N.H.TAM, L.V.BAN, T.VINH. 2000. *Grain dryer in Vietnam (in Vietnamese)* . Agricultural Publishing House, Ho-Chi-Minh City, Vietnam.
11. SABBAH M.A., G.E. MEYER, H.M. KEENER, and W.L.ROLLER. 1979. Simulation studies of reversed-direction airflow drying method for soybean seed in a fixed bed. Transactions of the ASAE Vol.22 pp. 1162-1166
12. SABBAH M.A., G.E. MEYER, H.M. KEENER, and W.L.ROLLER. 1977. Reversed-direction airflow drying for soybean seed. Transactions of the ASAE Vol.20 pp. 562-570
13. SHARP J.R. 1982. *A review of low-temperature drying simulation models*. Journal of Agr. Engineering Research Vol.27, pp.169-190.

APPENDIX: THIN-LAYER DRYING EQUATIONS

1) WANG and SINGH (1978)

MR = EXP(-k * t ^n)

k = 0.01579 + 0.0001746 * Tc - 0.0001413 * Rh

n = 0.6545 + 0.002425 * Tc + 0.0007867 * Rh

2) DOAN PHU CUONG and PHAN HIEU HIEN (2003), from data by Doan Phu Cuong (1996)

MR = EXP(-k * t ^n)

k = 0.0405814 + 0.0000732708 * Tc - 0.000487217 *Rh

n = 0.2830962 + 0.0054218474 *Tc + 0.006062111 *Rh

with : t = drying time, minute

Tc = drying temperature, ^{o}C

Rh = relative humidity of the drying air

MR = moisture ratio = (M – Me) / (Mdb – Me)

Mdb = grain initial moisture content, decimal

Me = equilibrium moisture content, decimal