DIMENSIONING OF A SOLAR DRYER WITH APPLICATION OF AN EXPERIMENT PLANS METHOD FOR DRYING FOOD PRODUCTS

[1]B. TOUATI, [2]B. LIPS, [3]A. SAAD, [4]A. ABDENBI, [5]M. KARIMA

[1]Tahri Mohammed University of Bechar, Laboratory of Energetic in Arid Zone (ENERGARID), Team of Solar Resource and its Applications
[2]Thermal Center of Lyon (CETHIL, UMR 5008), INSA de Lyon, Lyon 1 University, France

Abstract—The purpose of this study is an application of experiment design method for dimensioning of a solar drying system. NIMROD software was used to build up the matrix of experiments and to analyze the results. The software has the advantages of being easy to use and consists of a forced way, with some choices about the number and range of variation of the parameters, and the desired polynomial shape. The first design of experiments performed concern the drying with constant input characteristics of the hot air in the dryer and a second design of experiments in which the drying chamber is coupled with a solar collector. The first design of experiments allows us to study the influence of various parameters and get the studied answers in a polynomial form. The correspondence between the polynomial thus determined, and the model results, was good. The results of the polynomials of the second design of experiments, and those of the model are worse than the results in the case of drying with constant input conditions. This is due to the strong link between all the input parameters, especially, the surface of the sensor and the drying chamber, and the mass of the product.

Keywords—Solar drying; Experiment design method; NIMROD; Mint leaves.

I. INTRODUCTION

In our previous study [1], a model was chosen from the modeling of an indirect solar dryer used to dry the leaves of mentha viridis. The model described is a tool which permit the dimensioning of the dryer as a function of the quantity of the product.

The figure 1 give an example of the succession of questions which conduct to the choice of the dryer type and its dimension.

If it is not recommended to ask the questions 3 or 6 before questions 1 and 2, in contrary, the answer to questions 4 or 5 let us to ask the questions 1 and 2 or 3 again, and answer them differently. This example does not consider the cost as constraint, in spite of its great influence in the choice to take in each stage.
The program named "SECHAGE" allows us to test by "numerical experiments" a drying material. The number of parameters to consider is important and require more much of numerical experiments; the use of a design of experiments permit to reduce the number of experiments, and to obtain the "answer "in the form of a polynomial function of parameters. This permit to visualize easily and to optimize the parameters [2.3].

II. STUDY OF THE DRYER USING OF DESIGN OF EXPERIMENTS

The first step of a design of experiments consists to choose the parameter to be studied and to define the range of variations.

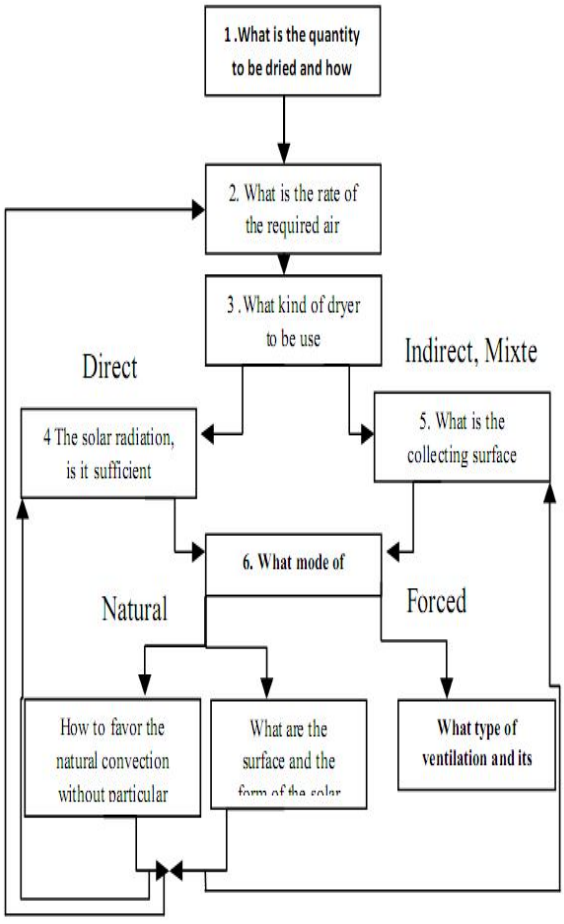


Fig. 1 Succession of questions in the dimensioning course.

The choice of the range of variation is important, and the result obtained is valid, only in the studied range of variation.
If this range of variation is narrow for a parameter, the predictable response will be that this parameter

has a negligible influence on the result. Inversely, if this range of variation is large, the possibility that the polynomial of response will badly represent the reality will be great.

The software NIMROD, written and distributed by Reactional Perspective and Information Analysis Laboratory, France, has been used to construct the matrix of experiments and analyze the results. The software has the advantages of being easy to use and consists of a forced way, with some choices about the number and range of variation of the parameters, and the desired polynomial shape.

A. Numerical experiences and results

The number of experiences to be realized depends on the form of the requested polynomial. after some essays, we have chosen a polynomial model with degree 2 using a composite matrix

The response will be

$$Y= b0+b1*X1+b2*X2+b3*X3+b4*X4+b11*(X1*X1) +b22*(X2*X2)+b33*(X3*X3)+b44*(X4*X4) +b12*(X1*X2)+b13*(X1*X3)+b23*(X2*X3) +b14*(X1*X4)+b24*(X2*X4)+b34*(X3*X4)$$

X_1 , X_2 , X_3 and X_4 represent the entry parameters of the design of experiments.

B. Study of a dryer with constant entry conditions of the air Selection of parameters and range of variations

We have chosen to study the whole parameters which may intervene in the solar dryer functioning.

The first design of experiments (model1) performed concern the drying with constant entry characteristics of the hot air in the dryer .

The studied parameters are:

- Temperature of the drying air Ts(from 30°C to 50°C)
- Volume flow rate of the drying air D_v (from 100 to 500 m^3/h) ;
- Surface of the drying chamber S_{enc} (from 0,3 to 1,0 m^2) ;
- The mass of mentha veridis leaves to be dried M_p (from 0,1 to 1,0 kg/tray).

As response, we have been interested by:

- Duration of drying of the tenth tray(D in hours)
- The required energy to evaporate the water contained in the mentha leaves (E in kwh/kg_{ms})
- The time interval between the trays 10 and 1 (Dd_tray in hours)
- The time interval between two water contents of mentha leaves(Dd_X_{pr} in hours)

This model need 25 experiences (for this problem) with 4 parameters .table.1 give the values of each parameter of the 25 experiences and the results obtained for the drying with constant characteristics of entry of the hot air in the dryer.

TABLE.1
THE VALUES OF THE ENTRY PARAMETERS AND RESULTS FOR THE FIRST EXPERIMENTAL DESIGN

N° Exp	Temp. T_s °C	Rate D_v m^3/h	Surface S_{enc} m^2	Mass product M_p kg	Drying duration D_X1C10 h	Energy E_X1C10 E kWh/kg_{ms}	Dif_interval X1C(10-1) Dd_tray h	Diff_inte (X1-X2) Dd_X_{pr} h
1	35	200	0,475	325	12,17	7,08	3,33	1,17
2	45	200	0,475	325	6,50	7,58	1,83	0,67
3	35	400	0,475	325	7,83	9,16	1,67	0,83
4	45	400	0,475	325	4,17	9,77	1,00	0,50
5(*)	35	200	0,825	325	17,50	10,13	8,17	1,33
6	45	200	0,825	325	9,50	11,02	4,50	0,67
7	35	400	0,825	325	10,50	12,19	4,17	1,00
8	45	400	0,825	325	5,67	13,20	2,33	0,50
9(*)	35	200	0,475	775	14,83	8,66	3,33	1,67
10	45	200	0,475	775	8,00	9,36	2,00	0,83
11	35	400	0,475	775	9,83	11,54	1,83	1,33
12	45	400	0,475	775	5,17	12,14	1,00	0,67
13(*)	35	200	0,825	775	20,00	11,58	8,00	1,67
14	45	200	0,825	775	10,83	12,57	4,50	0,83
15	35	400	0,825	775	12,22	14,34	4,00	1,17
16	45	400	0,825	775	6,67	15,55	2,33	0,67
17(*)	30	300	0,65	550	20,67	8,98	6,33	2,17
18	50	300	0,65	550	5,33	11,68	1,83	0,50
19(*)	40	100	0,65	550	18,83	8,19	8,17	1,50
20	40	500	0,65	550	6,17	13,50	1,67	0,67
21	40	300	0,3	550	6,17	8,21	0,50	0,83
22	40	300	1	550	11,17	14,56	5,00	0,83
23	40	300	0,65	100	6,83	8,93	2,83	0,50
24	40	300	0,65	1000	10,00	13,13	2,67	1,00
25	40	300	0,65	550	8,67	11,35	2,83	0,83

In the case of design of experiments (model 1), the output parameters of polynomials are written as follow:

$$D(hours)= 8.66667 - 3.29397*Ts -2.60881*Dv + 1.43286*Senc +0.83564*Mp + 0.99017*Ts^2 +0.86517 * Dv^2 + 0.68403* (Ts*Dv) - 0.42014*(Ts*S_{enc})- 0.51736*(Dv*S_{enc})- 0.25347*(Ts*Mp). \quad (1)$$

$$E(kW/kg_{ms}) = 11,35306 + 0,49625*T_s +1,27211*D_v + 1,58314*S_{enc} +1,00092*M_p – 0,24017*T_s^2 - 0,11169*D_v^2 -0,06506*M_p^2 + 0,10708*(T_s* S_{enc}) + 0,18011*(D_v* M_p) \quad (2)$$

$$Dd_tray(hours) = 2.83333 - 1.00000*Ts - 1.26389 * Dv +1.29167 * Senc+0.27083 * (Ts^2 + 0.47917 * Dv^2 + 0.31250 * (Ts * Dv) - 0.39583 * (Ts^2 + 0.47917 * Dv^2 +0.31250 * (Ts * Dv) \quad (3)$$

$$Dd_Xpr(hours) = 0.83333 - 0.34028 * Ts - 0.15972 * Dv + 0.13194 * Mp + 0.11981 * Ts^2 + 0.05731 * Dv^2 + 0.05208 *(Ts * Dv) - 0.05208 * Ts2 + 0.05731 * Dv^2 + 0.05208 * (Ts * Dv) \quad (4)$$

For the 25 experiences done by NIMROD software, and from table .1, giving the values of entry parameters and the results obtained for the first design of experiments of drying in constant entry conditions, we note that, drying duration of the tenth tray of the five experiments exceed one day. For the other experiments, we see that the temperature and drying air flow play an important role on the output parameters. The surface of the drying chamber and the amount of the product to be dried are less involved.

C. Study of a dryer with variable entry conditions of the air Selection of parameters and range of variations

A second design of experiments (Model 2) was treated, to study a complete system including, a dryer and a solar collector. In this case, the parameters are:

- The surface of the air solar collector S_{cap}(from 1 to 5 m^2) ;
- Volume flow rate of the drying air D_v (from 100 to 500 m^3/h) ;
- The surface of the drying chamber S_{enc} (from 0,3 to 1,0 m^2) ;
- The mass of mentha veridis leaves to be dried M_p (from 0,1 to 1,0 kg/tray).

For this design of experiments, the responses are:
- The drying time of the tenth (10) tray(D in hours) ;
- The difference of drying time, between the tenth and the first trays (Dd_tray in hours)

As before, this model requires 25 experiences, for a problem with four parameters. Table .2 gives the values of each parameter for the 25 experiments and the results obtained for drying or by coupling the dryer and the solar collector.

TABLE.2
THE VALUES OF THE ENTRY PARAMETERS AND THE RESULTS FOR THE SECOND DESIGN OF EXPERIMENTS "SOLAR DRYING"

N° Exp	surface of collector S_{cap} (m^2)	air flow rate D_v m^3/h	mass of the product M_p kg	chamber surface S_{enc} m^2	drying duration X1C10 D h	Dif- drying duration X1(C10-C1) Dd_claie h	Temp. wet air max K	Temp. drying air max K
1(a)	2	200	0,325	0,475	7,67	2,00	301,58	319,97
2(c)	4	200	0,325	0,475	4,50	1,00	305,43	338,44
3(a)	2	400	0,325	0,475	9,00	2,50	299,42	310,93
4(a)	4	400	0,325	0,475	5,17	0,83	301,58	320,17
5(b)	2	200	0,775	0,475	27,50	21,50	301,55	319,59
6(c)	4	200	0,775	0,475	6,00	2,33	305,43	338,51
7(b)	2	400	0,775	0,475	28,33	21,50	299,91	310,68
8(a)	4	400	0,775	0,475	6,67	2,17	301,57	320,10
9(b)	2	200	0,325	0,825	25,83	18,67	301,57	319,86
10(c)	4	200	0,325	0,825	5,17	1,00	305,43	338,38
11(b)	2	400	0,325	0,825	27,67	17,50	299,42	310,89
12(a)	4	400	0,325	0,825	7,00	0,67	301,94	321,83
13(b)	2	200	0,775	0,825	28,83	21,33	301,56	319,34
14(c)	4	200	0,775	0,825	6,83	2,50	305,42	338,25
15(b)	2	400	0,775	0,825	29,83	3,67	299,42	311,10
16(a)	4	400	0,775	0,825	7,83	2,50	301,56	319,95
17(b)	1	300	0,55	0,65	51,67	22,67	298,66	307,58
18(c)	5	300	0,55	0,65	5,17	1,33	304,20	332,30
19(c)	3	100	0,55	0,65	6,17	2,33	308,80	356,58
20(a)	3	500	0,55	0,65	8,67	2,50	299,86	312,72
21(a)	3	300	0,1	0,65	5,67	0,33	301,57	320,16
22(b)	3	300	1	0,65	26,50	20,83	301,56	319,71
23(a)	3	300	0,55	0,3	6,17	2,00	301,57	320,13
24(b)	3	300	0,55	1	25,33	19,00	301,56	319,84
25(a)	3	300	0,55	0,65	7,83	2,33	301 ,56	319,95

(a) the acceptable experiments
(b) experiments exceeding a day of drying.
(c) air temperatures exceeding the setpoint.

In this experimental design (model 2), the output parameters of polynomials are written as follow:

$$D(hours) = 7.83333 - 9.52083*S_{cap} + 3.81250*Mp + 3.43750*S_{enc} + 4.76217*S_{cap}^2 + 1.67883*Mp^2 +$$

$$Dt_tray(hours) = -5.76389*S_{cap} + 3.09722*Mp + 2.00000*S_{enc} + 2.20486*S_{cap}^2 + 1.85069 * Mp^2 + 1.82986*S_{enc}^2 - 1.33333*(S_{cap} * Mp) - 3.06250*(Mp*S_{enc}) \quad (6)$$

In this second design of experiments, we can define three categories of experiences, those with drying time less than a day sunshine duration, those that drying time is greater than a day, and those where the drying temperatures exceed the set point.

The last two categories of experiments are excluded because the results are inconsistent with the product quality(the temperature which exceed 50°C can affect the organoleptic characteristics of the plant. A drying exceeding one day is also prejudicial for the product quality caused by the adsorption phenomena of mentha leaves during nocturnal period, due to the brusque temperature change.

We have noted, also, that to dry 0.55 kg of mentha leaves in the first and tenth trays, with a collecting surface of solar energy 1m2, a flow rate of the air 300m3/h, in a drying chamber with surface 0.65m2, we need 30 to 52 hours of drying time, respectively. This implies that the product undergo the two phases desorption and adsorption, which may cause the deterioration of mentha leaves.

The results revealed, also the absence of air flow influence, and that the surface of solar collector dominates all the others parameters, such as the drying chamber surface and the mass of mentha leaves to be dried.

CONCLUSION

The purpose of this study is an application of a design of experiments method for dimensioning of a solar drying system. NIMROD software was used to build up the matrix of experiments and to analyze the results. The first design of experiments performed, concern the drying with constant entry characteristics of the hot air in the dryer, and a second design of experiments in which the drying chamber is coupled with a solar collector. The first design of experiments allows us to study the influence of various parameters and get the studied responses in a polynomial form. The correspondence between the polynomial thus determined, and the model results, was good. The results of the polynomials of the second design of experiments, and those of the model are worse than the results in the case of drying with constant entry conditions. This is due to the strong link between all the entry parameters, especially, the surface of the collector and the drying chamber, and the mass of the product.

REFERENCES

[1] B. Touati, B. Lips, B. Benyoucef, J. Virgone, A. Jamali, et al.. Experimental study and mathematical modeling of thin layer drying of mentha viridis by using indirect solar dryer.*International Symposium on Advances in Computational heat transfer (CHT'08)*, May 2008, MARRAKECH, Morocco.

[2] J. GOUPY, Plans d'expériences, Technique de l'ingénieur, Traité Analyse et Caractérisation, PE 230-1 - PE 230-26.

[3] B. LIPS, 2000, Utilisation des plans d'expériences pour l'étude d'un Sèche-linge à évacuation, Rapport final, Convention INSA-EDF n° E16/C59696/0.

★★★