A Kertészeti és Élelmiszeripari Egyetem KÖZLEMÉNYEI

ÉVFOLYAM
1996
(VOL. LV.)

PUBLICATIONES Universitatis Horticulturae Industriaeque Alimentariae

BUDAPEST, 1996

PUBL. UNIV. HORTICULTURAE INDUSTRIAEQUE ALIMENTARIAE VOL LV. 1996.

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Publ. Univ. Hortic. Industr. Aliment. ISSN 0238-6852

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ON THE SENSITIVITY INVESTIGATION OF A ROTATING FILM EVAPORATOR BY TAGUCHI'S EXPERIMENTAL DESIGN METHODOLOGY

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1. Introduction

The separation of a solvent from a solution of a solvent and a nonvolatile solute is commonly effected by use of the unit operation known as evaporation. Since energy is transferred in an evaporator from a condensing vapor to a boiling liquid, evaporation may be regarded as a special case of the unit operation called heat transfer [1,2,3,4]. Evaporators are commonly found in the inorganic, organic, paper, and sugar industries. Typical applications include the concentration of sodium hydroxide, brine, organic colloids, and fruit juices. Generally, the solvent is water.

Based on the previous investigations of the rotary film evaporator type UNIFILM with 0.3 m^2 heating surface designed and settled by CHEMIMAS for our department [5,6], we have critically investigated of the equipment to find optimal operational parameters (as factors) by experimental design [7,8].

2. The equipment

The experiments have been performed with a direct-flow falling, concurrent, underdriven rotating film evaporator with swinging blade (see Fig. 1).

3. Experimental design for optimization

For the first experiments, water was used as model material. We created a replicated 2^{5-1} fractional factorial design for 5 factors (steam pressure as z_1, vacuum as z_2, revolutions per minute as z_3, volume flow rate of cooling water as z_4, volume flow rate of feed as z_5), the optimisation parameter was chosen the mass flow rate of vapor in percent of the feed. The results can be seen in Table 1.

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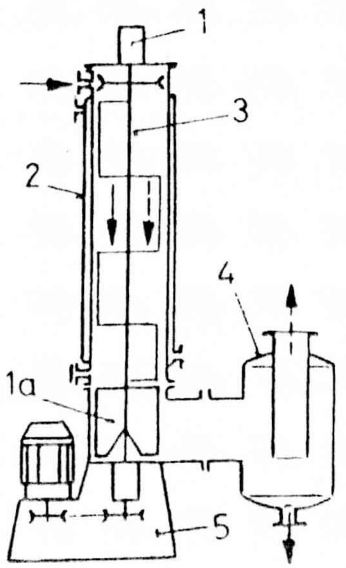

Figure 1 - UNIFILM-type rotating film evaporator
1-1a. bearing, *2.* case, *3.* rotor, *4.* vapor separator, *5.* holder and driving

Table 1. The results of the fractional factorial design

steam pressure z_1	vacuum z_2	revolutions per minute z_3	volume flow rate of cooling water z_4	volume flow rate of feed z_5	mass flow rate of vapor in percent of feed y	mass flow rate of liquid in percent of feed
kp/cm^2	kp/cm^2	1/min	litre/min	litre/h	%	%
2.8	0.6	3900	40	120	26.3±0.6	73.7±1.4
3.8	0.6	3900	40	80	51.3±1.1	48.7±3.7
2.8	0.8	3900	40	80	39.2±1.1	60.8±2.9
3.8	0.8	3900	40	120	36.5±0.7	63.5±1.5
2.8	0.6	4700	40	80	39.2±0.6	60.8±0.4
3.8	0.6	4700	40	120	27.5±0.6	72.5±0.8
2.8	0.8	4700	40	120	27.0±1.6	73.0±2.5
3.8	0.8	4700	40	80	54.5±0.3	45.5±0.6
2.8	0.6	3900	60	80	34.7±2.9	65.3±2.9
3.8	0.6	3900	60	120	25.1±0.5	74.9±0.6
2.8	0.8	3900	60	120	29.4±0.6	70.6±0.6
3.8	0.8	3900	60	80	51.7±0.7	48.3±1.2
2.8	0.6	4700	60	120	22.5±0.6	77.5±0.9
3.8	0.6	4700	60	80	46.1±1.2	53.9±0.5
2.8	0.8	4700	60	80	47.5±5.1	52.5±7.4
3.8	0.8	4700	60	120	34.3±0.7	65.7±2.2

The following linear function was fitted to the data:

$$y = 37.05 - 8.48\,z_1 - 0.64\,z_2 + 0.26\,z_3 + 2.98\,z_4 + 3.82\,z_5 \qquad (1)$$

The determination coefficient is 0.9246, and the F-value equals 24.53 and this value is significantly larger than $F(5,10)_{0.01} = 5.63$, even larger than $F(5,10)_{0.05} = 3.32$, so the linear function is adequate. According to Eq. 1, we have created the gradient design, the final step to find the optimum. See the results in Table 2 and Fig. 2.

Table 2. The results of the gradient design

	steam pressure z_1	vacuum z_2	revolutions per minute z_3	volume flow rate of cooling water, z_4	volume flow rate of feed z_5	mass flow rate of vapor in percent of feed, y	mass flow rate of liquid in percent of feed
	kp/cm^2	kp/cm^2	1/min	litre/min	litre/h	%	%
1	3.6	0.74	4300	50	77	45.9±0.6	54.1±1.4
2	3.6	0.75	4300	50	69	54.1±0.8	45.9±0.8
3	3.7	0.77	4300	50	61	61.5±0.6	38.5±1.3
4	3.8	0.78	4300	50	53	80.4±2.8	19.6±8.2
5	3.9	0.80	4300	50	46	86.3±2.1	13.7±4.0

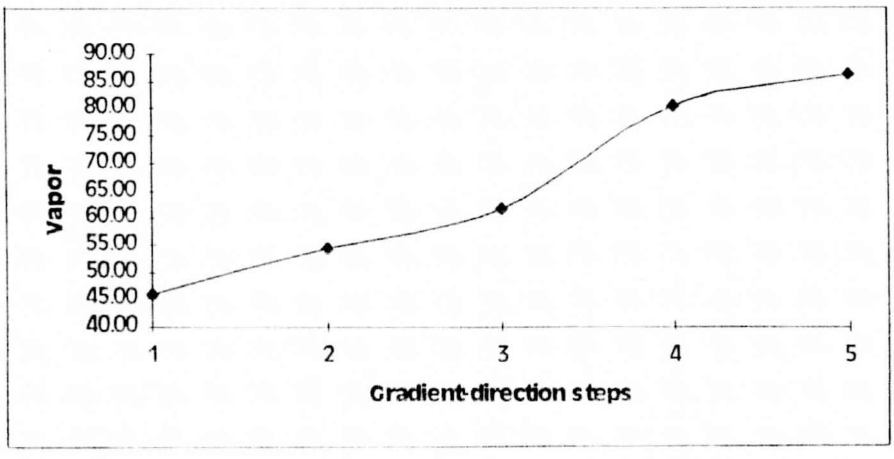

Figure 2 - The graph of the gradient design

4. Sensitivity investigation

In the second part of our investigation we try to obtain the sensitivity (9,10) of the evaporation to the factors. The model material was chosen as mixture of water, sugar and ascorbic acid as model material. Ascorbic acid was used for indicate whether the heat effect was harmful to the model materials. We did not find any changes in the amount of ascorbic acid after evaporation, so the evaporation was considerate enough.

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For our rotating film evaporator, the following factors can be considered:

Controllable factors
- **steam pressure**
- **vacuum**
- revolutions per minute of rotor
- volume flow rate of cooling water
- volume flow rate of feed
- **concentration of the sugar**

Noise Factors
- Internal
  - aging of the equipment materials
- External
  - quality of the steam
  - temperature and flow of the air as surroundings
  - temperature of the cooling water
  - steam-trap valve
- Individually fluctuation
  - equipment operator person

We chose only three controllable factors, i.e., the steam pressure, the vacuum and the concentration of the sugar. Fig. 3 shows the outline of the created 2^{3-1} fractional factorial design and the results can be seen in Table 3.

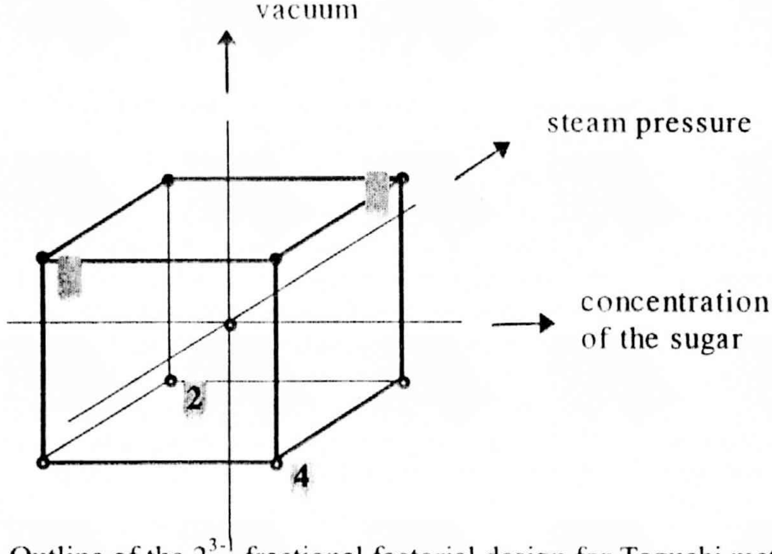

Figure 3. Outline of the 2^{3-1} fractional factorial design for Taguchi methodology

Table 3. Results of the 2^{3-1} fractional factorial design

steam pressure	vacuum	revolutions per minute	volume flow rate of cooling water	volume flow rate of feed	concen-tration of the sugar	mass flow rate of vapor in percent of feed
z_1	z_2	z_3	z_4	z_5	z_6	y
kp/cm^2	kp/cm^2	1/min	litre/min	litre/h	g/100g	%
3.8	0.785	4300	50	55	9.5	
0.05	0.005	0	0	0	0.5	
3.85	**0.79**	*4300*	*50*	*55*	**10**	74.20±0.64
3.85	**0.78**	*4300*	*50*	*55*	**9**	72.53±0.62
3.75	**0.79**	*4300*	*50*	*55*	**9**	74.34±1.0
3.75	**0.78**	*4300*	*50*	*55*	**10**	72.50±1.3
(+)73.36	**(+)74.27**				**(+)73.35**	
(-)73.42	**(-)72.51**				**(-)73.43**	
-0.06	**1.75**				**-0.08**	

Sensitivity calculations for:

steam pressure:

$$(74.20+72.53)/2 - (74.34+72.50)/2 = -0.06,$$

vacuum:

$$(74.20+74.34)/2 - (72.53+72.50)/2 = 1.75,$$

concentration of the sugar:

$$(74.20+72.50)/2 - (72.53+74.34)/2 = -0.08.$$

5. Conclusions

When water used as model material for optimization, the results coming from gradient design show us that there is no sharp optimal region of factor values, so we have to put these values depending on the technological purpose and materials used for it. The most influential factors are the steam pressure, vacuum, and the volume flow rate of feed.

We have also investigated the rotating film evaporator with Taguchi methodology, which is emphasized the use of fractional designs and other orthogonal arrays with objectives of making products robust to environmental conditions, making products insensitive to component variation, minimizing bias and mean square error about specification values, and reliability and life testing.

We have used mixture of water, sugar and ascorbic acid as model material and the results show us that the evaporation is the most sensitive to the vacuum. Since the evaporation is insensitive to the steam pressure, we can set it to the lower value to execute the operation more economically. The fact, that small change (about 1%) in the concentration of the sugar is not influential too, is reassuring.

Acknowledgement

R. Rajkó would like to thank the support of *MHB "A Magyar Tudományért" Alapitvány*.

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ROTÁCIÓS FILMBEPÁRLÓ BERENDEZÉS ÉRZÉKENYSÉGÉNEK VIZSGÁLATA TAGUCHI FÉLE KÍSÉRLRTTERVEZÉSI MÓDSZERREL

Összefoglalás

Rotációs filmbepárló berendezés optimalizálását végeztük el a kísérlettervezés módszertanát alkalmazva. Figyelembe vettük az előzőleg végzett kísérletek eredményeit, melyek alapján elsőfokú faktoriális tervet készítettünk és ennek eredményeit felhasználva alkottuk meg a gradiens tervet. Modell anyagként vizet használtunk, hiszen az élelmiszeriparban legtöbbször a víz eltávolítása a feladat a bepárlás során.

Az optimalizáció után a folyamatra legérzékenyebb műveletttani paraméterek felderítését végeztük el a Taguchi módszerrel. Modell anyagként aszkorbinsavtartalmú cukoroldatot alkalmaztunk. Eredményeinket számos grafikon és táblázat segítségével mutatjuk be az alkalmazott matematikai statisztikai módszerek megvilágítása céljából.