KOREAN J FOOD SCI. TECHNOL.
Vol. 17, No. 3(1985)

Effect of Reverse Screw Elements on the Residence Time Distribution in Twin-Screw Extruder

J. K. Lim, S. Wakamiya*, A. Noguchi* and C. H. Lee

Department of Food Technology, Korea University, Seoul
**Food Engineering Lab., National Food Research Institute, Japan*

이륜형 압출기의 체류시간 분포에대한 역피치 스크류의 효과

임재각, 若宮祐喜*, 野口明徳*, 이철호

고려대학교 식품공학과 · *일본 농림성 식품총합연구소 식품제조공학실

Abstract

The residence time distributions were measured experimentally to determine the effect of reverse screw elements at various screw configurations in twin screw extruder. A simple model was used to estimate the number of filled C-chamber on the forwarding screw. The inclusion of reverse-screw elements resulted in the increase of median residence time and the broadening of color distribution. True residence time was affected by using the reverse screw elements just before the die. The number of filled C-chamber was decreased with the increase of screw revolution speed at the same screw configuration.

Introduction

The residence time distribution is a measure of average process time for a material spending in the extruder. The time required for a material to advance along the scews depends, apart from the screws' speed, on the configuration of the screws themselves, that is how many and what kind of sections are composed in the extrusion channel. Furthermore, it depends also on the degree of filling of these sections and the actual output of the machine. It can be measured experimentally using a tracer and stimulus-responce techniques as outlined by Levenspiel.[1]

Various mathematical and experimental approaches have been applied to discover the residence time distribution of the particles inside the extruder. Most of the previous work have been carried out with a single-screw extruder.[2~4] Very little work has been published about the residence time distribution in twin-screw extruder. Linko and his coworkers[5,6] first reported the residence time distribution of the feed mass in a Creusot-Loire BC-45 twin-screw cooking extruder. They used $^{56}Mnso_4 \cdot H_2o$ as a radioactive tracer. Their results showed residence time along the barrel was greatest either in front of the die or in front of the reverse screw element, depending on the screw configuration.

Mosso *et al.*[7] used a synthetic dye to measure the residence time distribution in a twin screw extruder. Their investigation showed that increasing the screw rotation resulted in a marked reduction of the minimum residence time, but no changes in the dispersion of residence times. Increasing the feed rate caused in a reduction of the residence time, but the water content of the food mixture had little effect on the residence time distribution.

Simple estimation study of residence time in twin screw extruder was done with a color dye technique.[9] In a study of flour mixture extruded at varying screw speed and feed rate, Noguchi *et al.* used a simple equation to express the true residence time(the period while the melted material remains in the extruder).

The purpose of the present work is to estimate the true residence time and the effect of the reverse screw elements on the residence time distribution at various screw configuration in twin-screw extruder.

Materials and Methods

Materials and Equipments

Wheat flour obtained from Nisshin Milling Co. Ltd. was used as a raw material. All experimental work was done with a French Creusot-Loire BC-45 twin screw extruder. The profile of two intermeshing and corotating screws can be represented by the characteristics of five successive pairs of segments, as shown in Fig. 1. The corotating screws with intermeshing flights were constructed of elements that could be assembled in different compositions. Five different screw compositions were employed as shown in Fig. 2.

Screw speeds were set at 60, 80, 100 and 120 rpm, respectively. The feed rate and the water content of wheat flour were kept constant (20kg/hr, 25% H_2O). Temperature was monitored with an electromagnetic induction heater and three band-heater. Pressure measurements were made with a Dynisco TPT-432A pressure transducer.

Material density in molten zone was estimated by using Methyl Alcohol and Shimazu Flow Tester Model CFT-500 was used to measure the material density in compressed zone.

Extruder Operation

The extruder was operated at steady state for each set of conditions. Attainment of steady state was judged by a constant pressure recored on Toyoseiki Pen Recorder Type 3056.

The color indicator, 0.5g of erythrosine, was injected through the feed opening. The time for the first observation of color dye in the extrudate was recorded as the minimum residence time, and then the extrudate was cut at five seconds intervals. Samples of extrudate were ground with laboratory coffee mill and measured its color value by the color meter(SM-3, Suga Co. Ltd.). The median residence time was expressed at the time when the maximum color intensity was observed in the ground extrudate.

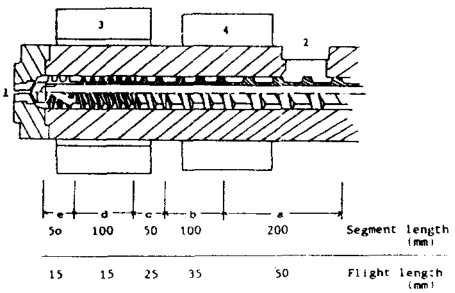

Fig. 1 Schematic Picture of Creusot-Loire BC-45 twin Screw Extruder

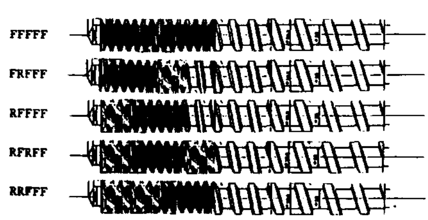

Fig. 2 Screw Configuration which could be done in Creusot-Loire BC-45 Twin screw extruder

Results and Discussion

The characteristic residence time distributions at different screw speed were plotted in Fig. 3 and Fig. 4 for the cases FFFFF and RFRFF. The inclusion of reverse screw elements brought about a remarkable broadening of the color distribution curve and

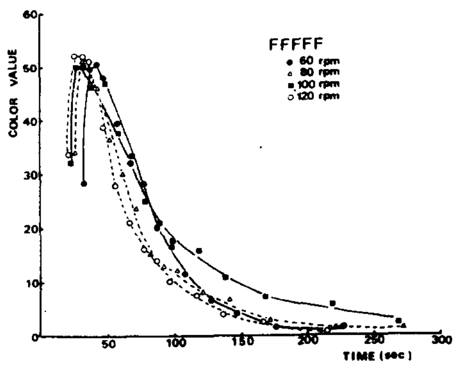

Fig. 3 residence time distribution in FFFFF screw configuration

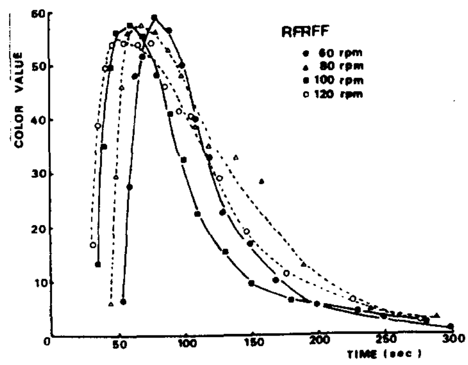

Fig. 4 Residence time distribution in RFRFF screw configuration

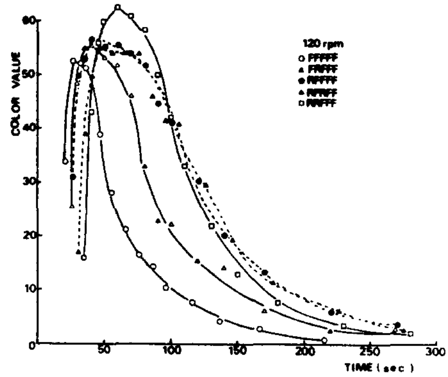

Fig. 5 Distribution of color die in the extrudate at 120rpm screw speed

increasing the median residence time, as shown in Fig. 5, which compare the residence time distribution of 5 different screw configurations.

A change in the screw speed shifted the minimum and median residence time but little affected to the residence time distribution. This was not surprising and consistent with the results of Noguchi *et al.*[8] and mosso *et al.*[7] *Noguchi et al.* suggested a simple equation for residence time distribution as follow;

$$T = T_x + \frac{1}{x}\Sigma\frac{l}{a} \quad \cdots\cdots(1)$$

where, l = length of each screw element (*mm*)
a = screw pitch (*mm*)
x = screw speed (rps)

It was assumed that the true residence time T_x was a constant at fixed feed rete F, and then the observed median residence time T was the total of two periods; the transport zone and the melt and pump zones.

But generally, 3 zones exist in the extruder; melting zone, compressed zone, i.e. pump zone, and transport zone. If the material will be filled and compressed in the last channel of coveying screw as compressed zone, the transporting volume of material to the melting zone will be depend on the conveying volume of material per one screw rotation. So, the length of compressed zone will be varied according to the screw speed even if feed rate was fixed. The equation (1) was slightly modified as followed.

$$T = T_x + T_c + T_f \quad \cdots\cdots(2)$$

where, T_c = the residence time on the compressed zone, depending on the volume and the feed rate
T_f = the residence time on the transport zone, depending on the screw speed and configuration

So, equation (2) become;

$$T = T_x + \frac{1}{x}(\Sigma\frac{l}{a} + \frac{V.\rho}{F/x}) \quad \cdots\cdots(3)$$

where, V = void volume of compressed zone (cm^3)
F = feed rate (g/s)
ρ = material density on the compressed zone (g/cm^3)

When all observed median residence time was plotted at the reciprocal of screw speed, each data gave almost straight line, of which correlation coefficient, γ, was over 0.96 as shown in Fig. 6. These results indicate the true residence time is independent on the screw speed, which is consistent with the observation by Noguchi *et al.* But, true residence time was varied at different screw configuration, especially, when reverse screw element was used just before the die. When other reverse screw element was inserted in the middle of screw, it showed different slope but same true residence time. Equation (3) was used in order to estimate the length of compressed zone, number of filled channel on the conveying screw using the observed median residence time and the true residence time which was obtained from Fig. 6.

Calculated melting zone length and the number of

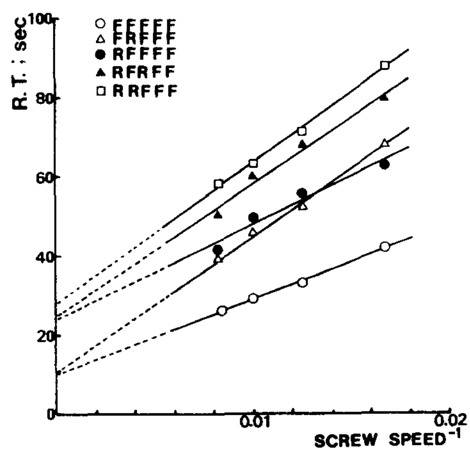

Fig. 6 Relationship between observed median residence time T and reciprocal of screw speed

filling channel was shown in Table 1. Melting zone length was drastically increased when reverse screw element was used before the die. It caused the broadening of the color distribution curve. Reverse screw element between the forwarding screws did not affect the melting zone. This is not surprising because the material exists in this zone as a solid state. The number of filled C-chamber was depend on the screw speed. This is consistent with the assumption that the transporting volume of material to the melting zone will be depend on the conveying volume of material per one screw revolution as mentioned before.

There was no filled C-chamber on forwarding screw at RRFFF screw configuration at 120 rpm. Calculated melting zone and compressed zone was shorter than two reverse screw elements. Therefore, this result indicates the poor filling in the reverse screw element zone, which means less bulk density compared to other screw speeds.

Table 2 shows the residence time and the bulk density of wheat flour in the region of supplemented reverse screw element between forward screw elements. Residence time in this zone was estimated from Fig. 6 as the difference of residence time between FRFFF and FFFFF arrangements and between RFRFF and RFFFF screw arrangements. Bulk density was calculated employing the following equation;

Table 1. Materal melting zone length from the die and the number of filling channel in last forward screw element

Screw configuration	Melting zone(*mm*)	The number of filling C-chamber 60rpm	80rpm	100rpm	120rpm
FFFFF	25	11.4	8.4	6.5	5.1
FRFFF	25	11.4	8.4	6.5	5.1
RFFFF	25	10.7	6.9	4.6	3.1
RFRFF	52	10.7	6.9	4.6	3.1
RRFFF	56.5	11.3	5.3	2.1	–

Table 2. Residence time and bulk density of wheat flour in supplemented reverse screw element

Screw configuration \ rpm	residence time(sec) 60	80	100	120	bulk density(g/cm^3) 60	80	100	120
FRFFF	26	19	16	13	1.4	1.02	0.86	0.7
RFRFF	16	12	10	8.5	0.86	0.65	0.54	0.46

$$T = \frac{V_r \cdot \rho}{F} \quad \cdots\cdots (4)$$

where. V_r = void volume of one reverse element

Increasing the screw speed resulted in the decrease of residence time and bulk density in this zone. The pitch of forwarding screw element just before the supplemented reverse element was different at two screw configuration. It caused in different residence time. Calculated bulk density at 60 rpm on FRFFF screw arrangement was larger than measured one from the Flow Tester. It indicates that forward screw element just before the reverse one is partially filled with wheat flour.

The inclusion of reverse screw elements caused the increase of median residence time and the broadening of residence time distribution. But the residence time was shorter than expected when two reverse screw elements were employed. The number of filled C-chamber was also a little larger than expected at low screw revolution rate, which probably was resulted from the inaccurate estimation of the density of wheat flour in the extruder. True residence time was affected by using the reverse screw elements just before the die. Therefore, the number and the position of reverse screw elements are very important to control the time of heat treatment and the product quality.

요 약

이륜형 식품 압출기에서 체류시간의 분포에 대한 reverse screw element 의 효과를 보기 위하여 여러가지 screw 조합에 따른 체류시간의 분포를 실험적으로 평가하였다. Forwarding screw 에서 형성된 C-chamber의 수를 평가하기 위해 아래와 같은 model equation 을 도출 하였다.

$$T = T_x + \frac{1}{x}\left(\Sigma \frac{l}{a} + \frac{V \cdot \rho}{F/x}\right)$$

Reverse screw element 를 사용함으로써 체류시간 분포 곡선은 넓게 펴지는 경향이 있었고 최대 peak에 도달하는 시간이 증가 하였다. True residence time 은 die 바로 앞에 있는 reverse screw element 에 의해 주로 영향을 받았다. Filled C-chamber의 수는 같은 형태의 screw조합에서는 screw 회전수가 증가함에 따라 감소 하였다.

References

1. Levenspiel, O. : *Chemical Reaction Engineering*, 2nd ed., John Wiley and Sons, Inc., New York, NY.(1972)
2. Bruin, S., van Zuilichem, D. J. and Stolp, W. : *J. Food proc. Eng.*, **2**,1 (1978)
3. van Zuilichem, D. J., de Swart, J. G. and Buisman, G. : *Technol.*, **6**, 184 (1973)
4. Davidson, V. J., Paton, D., Diosady, L. L. and Spratt, W. A. : *J. Food Sci.*, **48**, 1157 (1983)
5. Linko, P., Olkku, J., Antila, J. and Heikkinen, J. : *Food Process Engineering*, Appl. Sci. Publ., London., Vol. 1, 791, (1980a)
6. Linko, P., Olkku, J. Antila, J. and Rosenberg, K. : *Getreide Mehl Brot.*, **34**(3), 78 (1980b)
7. Mosso, K., Jeunink, J. and Cheftel, J. C. : *Agric.*, **99**, 1 (1982)
8. Noguchi, A., Mosso, K., Aymard, C., Jeunink, J. and Cheftel, J. : *Technol.*, **15**,105 (1982)
9. Noguchi, A. and Cheftel, J. C. : *J. Japanese Soc. Food Sci. Technol.*, **30**(2), 114 (1983)

(Received march 30, 1985)