Study on In-Drum Drying Technology of Waste Concentrates

Liang Dong

Abstract The aim was to achieve the radioactive waste minimization in nuclear power plants by the treatment technology that can decrease the volume of waste concentrates, and the technological process of in-drum drying and the in-drum drying prototype device have been developed based on the investigation and survey, bench tests, and pilot experiments. Performances of in-drum drying of simulated waste concentrates are studied by the prototype device, in which boron concentrations are around 44,000 ppm and 30,000 ppm. The performances evaporated velocity of moisture, humidity and character of drying product, volume reduction ratio, and efficiency of decontaminate. The control parameters are optimized, and the prototype device is improved. The device has been improved, which is constituted with storage tank that maintains temperature by hot water, pneumatic diaphragm pump that transmits concentration, metering tank that can control the concentration volume of adding, infrared heater that controls temperature by adjusting power, jet pump that produces negative pressure, and pipe bundle condenser that condensates steam. The results show that average evaporated velocity of moisture can be attained as 5.94 kg/h, humidity of drying product is under 1.6% that meets anticipated target, character of drying product is contented demand, and the volume reduction ratio is around 5.25; treatment simulated waste concentrates whose boron concentration is around 44,000 ppm at the condition of heat temperature of 170 °C, small negative pressure in drum, adding 170 L concentration at first time, and maintaining high liquid level. It can be seen that the simulated concentrates can be disposed by the in-drum drying prototype device, and the technological targets can be met. Furthermore, the achievements of this study have been appraised in leading domestic level by China National Nuclear Corporation.

L. Dong (✉)
China Institute for Radiation Protection, Taiyuan 030006, Shanxi, China
e-mail: jianghong@cnpe.cc

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Radioactive concentrate of nuclear power plants refers to the produces of evaporator during treatment of radioactive liquid waste. Generally, it was solidified by cement solidification technology in most of the nuclear power plants [1–3], but the volume of solidification product increased, which is not in conformity with the principle of radioactive waste minimization, also increased the subsequent expenses. The volume reduction treatment technology, such as in-drum drying technology, has been carried out in many countries [4–19].

The concentrate in-drum drying equipment had been designed and constituted by China Institute for Radiation Protection (CIRP) in 2013 depending on the literature review and a series of test and test conditions [20]. The simulation concentrate in-drum drying treatment experiments by this equipment had been done, and reasonable control parameters were researched. Then, the step for the improvement of equipment was carried on.

1 Introduction of In-Drum Drying Process

There are many workshops that research in-drum drying equipment in various countries, including Germany, USA, and France.

Though the heating mode of in-drum drying equipment that were studied is not identical, its principle is consistent. The liquid waste that was filled in drum is heated by heat energy, then the water of liquid waste becomes steam; the solid waste stayed in drum as waste sent repositories, or further development [11]. Concentrate in-drum drying process is as shown in Fig. 1.

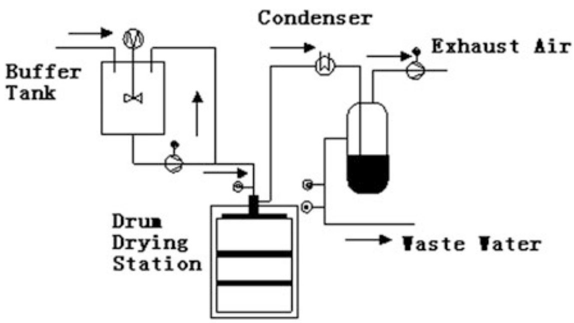

Fig. 1 Scheme of concentrate in-drum drying process

Table 1 Compositions of the simulated concentrates

Simulated concentrate (ppm)	H_3BO_3 (g/L)	NaOH (g/L)	$NaNO_3$ (g/L)	Na_3PO_4 (g/L)	$CoCl_2$ (μg/L)	$SrCl_2$ (μg/L)	CsCl (μg/L)	H_2O (g/L)
44,000	307.2	45.7	100.0	33.3	131.0	79.0	106.0	732.1
30,000	200.0	30.0	66.0	22.0	131.0	79.0	106.0	833.0

2 Pre-study on Concentrate In-Drum Drying Treatment

2.1 *Bench Test Research [21]*

On the basis of the research, in order to understand the change of concentrate properties during the in-drum drying process, bench test that treats simulation concentrate (see Table 1) had been done as shown in Fig. 2.

Research results show that the in-drum drying technology can treat simulation concentrate, with the liquid volume reduction of the dry product as shown in Fig. 3; volume reduction ratio is about 4.25 after drying the simulated concentrate whose moisture content is 70.7%; and the drying rate can be improved by the increase of the heating temperature and vacuum degree.

2.2 *Middle Test Research [22]*

On the basis of bench test, the in-drum drying pilot equipment was established (Fig. 4), the middle test research for simulation concentrate (see Table 1) has been done, and the product is shown in Fig. 5.

The results showed that the in-drum drying pilot equipment treat the simulating concentrate, the process of concentrate in-drum drying is feasible, volume reduction

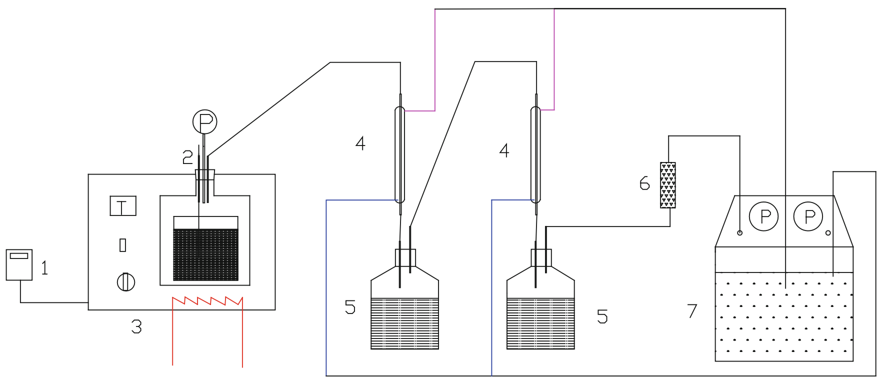

Fig. 2 Sketch of bench test unit

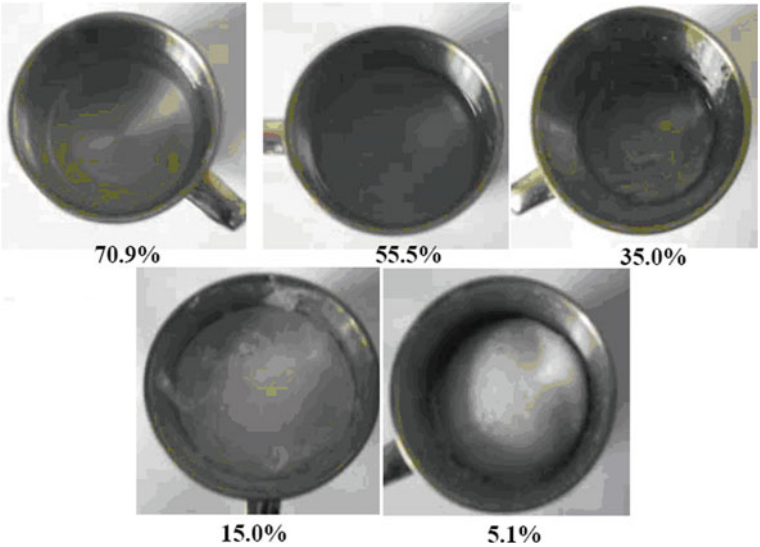

Fig. 3 Products of bench test

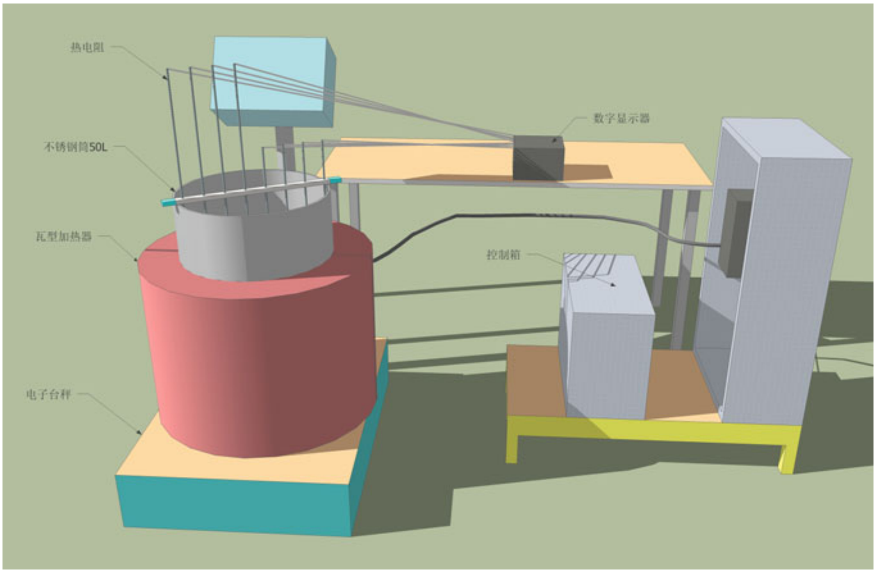

Fig. 4 Sketch of pilot equipment

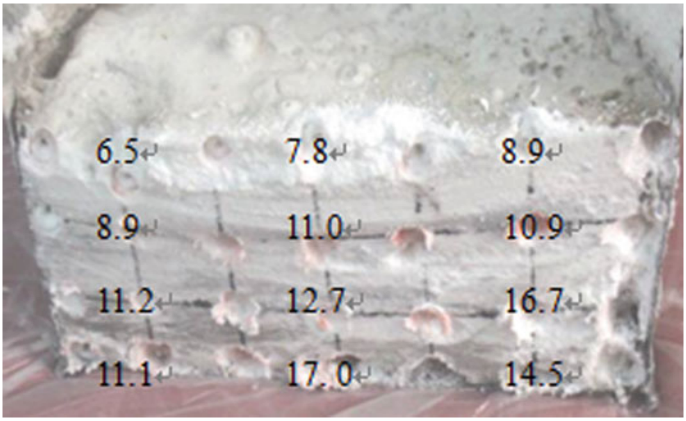

Fig. 5 Products of pilot experiment

ratio of dry product can reach 4.0, and the average moisture content of dry product is less than 15%.

3 The Establishment and Debugging of the Prototype Device [20]

The in-drum drying prototype device (200 L) of concentrate as shown in Fig. 6 was designed and constructed based on the above research. The details are described in the literature [20].

Device for the single machine debugging, the unit testing, and the whole process debugging of prototype device were completed times without number, the results show that the operation of In-drum drying prototype device (200 L) of concentrate is stable and the interrelated parameters meet the design requirements. Thereby, the experiment condition is contented.

4 Experimental Study on the Prototype Device

The object of experimental study on the prototype device is simulation concentrate that is shown in Table 1.

Fig. 6 The in-drum drying prototype device of concentrates

4.1 Procedure of Experimental

Process of simulated concentrate in-drum drying is shown in Fig. 7. A number of simulated concentrates were injected in the drum after the device is ready. The experiments were performed under the different operation parameters. During the trial, the level of concentrate in drum was kept in a high value, the quality of condensate was measured and sampled interval is 1 h; 15 L simulated concentrate was filled in drum when the volume of collected condensate has reached around 15 L, when the moisture content of production in theory or the rate for condensate collection was achieved the requirements the heating was stopped, the production was treated and analyzed after cooling.

4.2 The Determination and Calculation of Relevant Indicators

(1) Rate of evaporation
Drying stage rate of evaporation was characterized as the quality of condensed water collected per hour.

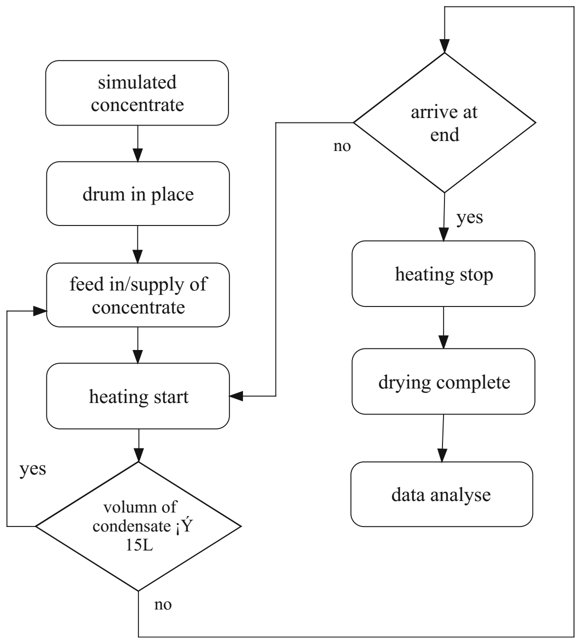

Fig. 7 Process of concentrate in-drum drying experiment

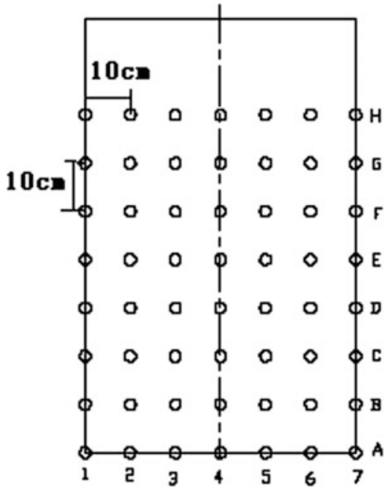

Fig. 8 The sampling point distribution for humidity analysis

(2) Moisture content of production
The products were slit along the axial direction, then sampling and moisture content testing are shown in Fig. 8.

(3) Volume reduction ratio
Volume reduction ratio = volume of concentrates treated (L)/volume of product (L).

4.3 The Conditions of Experiments

The experiment of simulated concentrate in-drum drying was conducted nine times, its control parameters are shown in Table 2, and the experimental results are shown in Table 3.

Table 2 The conditions of each experiment

Condition	Temperature of heater (°C)	Control mode of heating	Control mode of level	Total of drying (L)
No. 1	175/175/175	On–off	Initially 170 L, then 15 L supply while level falls 70 mm	680 (44,000 ppm)
No. 2	160/140/110	On–off		650 (44,000 ppm)
No. 3	150/160/160	On–off		730 (44,000 ppm)
No. 4	250/250/250	On–off		1000 (30,000 ppm)
No. 5	250/250/500	On–off		1000 (30,000 ppm)
No. 6	250/250/450	On–off	Initially 170 L, then XL supply while XL condensates have been collected ($X \geq 15$)	960 (30,000 ppm)
No. 7	250/250/250	On–off		700 (44,000 ppm)
No. 8	170/170/170	Power regulation		700 (44,000 ppm)
No. 9	170/170/170	Power regulation		700 (44,000 ppm)

Table 3 The results of each experiment

Serial number	Rate of evaporation (mix/min/average) (kg/h)	Average humidity of product (%)	Volume reduction ratio
No. 1	3.00/0.50/1.40	17.6	~4.0
No. 2	1.85/0.01/0.80	13.9	~4.0
No. 3	2.59/0.10/1.15	7.5	~4.0
No. 4	5.85/0.03/3.10	2.6	~7.0
No. 5	10.85/0.50/6.08	2.5	~7.0
No. 6	9.42/0.81/4.92	1.7	~7.0
No. 7	5.35/0.78/3.23	3.0	~4.0
No. 8	11.30/0.75/4.62	1.1	~5.0
No. 9	10.10/0.80/5.94	1.6	~5.0

Table 4 The relationship between water evaporation rate and conditions

Temperature of heater (°C)	Control mode of heating	Concentrate (B ppm)	Rate of evaporation (mix/min/average) (kg/h)
150/160/160	On–off	44,000	2.59/0.10/1.15
160/140/110	On–off	44,000	1.85/0.01/0.80
175/175/175	On–off	44,000	3.00/0.50/1.40
250/250/250	On–off	44,000	5.35/0.78/3.23
250/250/250	On–off	30,000	5.85/0.03/3.10
250/250/450	On–off	30,000	9.42/0.81/4.92
250/250/500	On–off	30,000	10.85/0.50/6.08
170/170/170	Power regulation	44,000	11.30/0.75/4.62
170/170/170	Power regulation	44,000	10.10/0.80/5.94

4.4 Results and Discussion

4.4.1 Rate of Evaporation

The following can be seen from the review of control parameters and rate of evaporation of all experiments (see Table 4):

1. The maximum and average rate of evaporation increases with the increase of heating temperature. This is because the improvement of heating temperature increased the difference in temperature between inside and outside of drum, and the energy that passed to the material per unit time is increased, thereby increasing the rate of evaporation;
2. Under the same conditions, the rate of evaporation that deals with simulated concentrate with 30,000 ppm boron is higher than the one that deals with simulated concentrate with 44,000 ppm boron, and this is because there is more water in the simulated concentrate with 30,000 ppm boron; and
3. The rate of evaporation through power regulation control heating temperature is higher than on–off control, and the main reason is power regulation control heating temperature fluctuations are small and energy transfer per unit time is relatively more.

4.4.2 Moisture Content of Production

In addition to the first trial, the humidity of other product is below 15%, that meets the requirements of indicators; distribution of product humidity is that the humidity around the center is higher than in other position. All in all, while the humidity of product is not uniform, the humidity of product on the whole is in accord with the technical indicators.

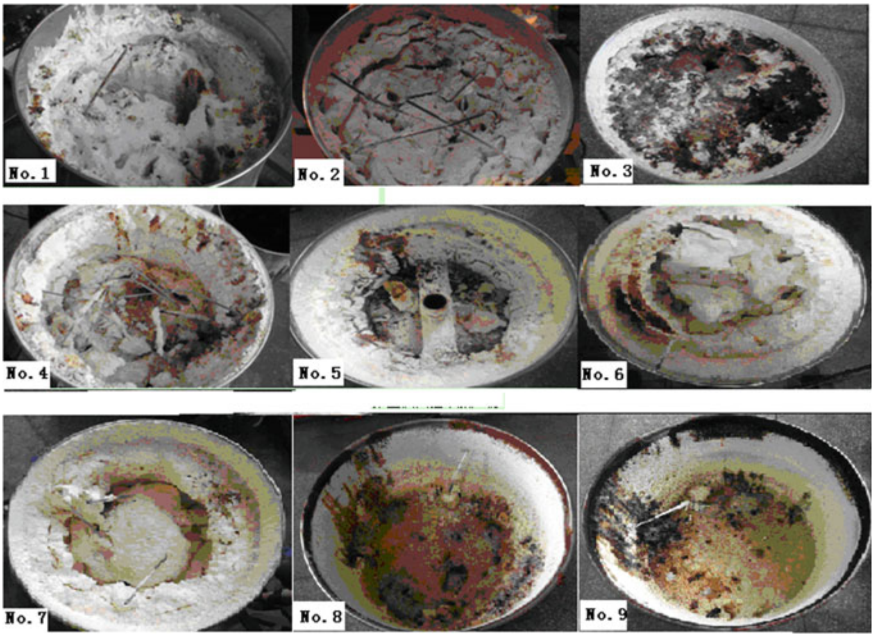

Fig. 9 Products of experiments

4.4.3 Properties of Product

The products of experiments are shown in Fig. 9. They are solid products, the humidity of which meets the requirements. But the product of first-time experiment includes three holes; the product of second experiment is cracked. There is a cavity and a through hole on the third trial product. The eighth and ninth products are solid with no holes and crack. In view of the eighth and ninth test and other seven times, the biggest different is the power regulation of the temperature control method; it can be continuous heating and maintain water evaporation drying process relatively stable so as to avoid the holes and cracks.

4.4.4 Volume Reduction Ratio

In view of the experiments of two kinds of simulated concentrate, its volume reduction ratio is from 4.0 to 7.0 (see Table 5). The volume reduction ratio of simulated concentrate with 30,000 ppm boron is 7.0, and the volume reduction ratio of simulated concentrate with 30,000 ppm boron is 4.0–5.0, mainly because of the different initial humidity of two kinds of simulated concentrate.

Table 5 The relationship between volume reduction ratio and conditions

Temperature of heater (°C)	Control mode of heating	Concentrate (B ppm)	Volume reduction ratio
150/160/160	On–off	44,000	~4.0
160/140/110	On–off	44,000	~4.0
175/175/175	On–off	44,000	~4.0
250/250/250	On–off	44,000	~4.0
170/170/170	Power regulation	44,000	~5.0
170/170/170	Power regulation	44,000	~5.0
250/250/250	On–off	30,000	~7.0
250/250/450	On–off	30,000	~7.0
250/250/500	On–off	30,000	~7.0

5 Conclusion

The radioactive concentrate in-drum drying process and the prototype device have been researched and developed, then the feasible debugging and the simulated concentrate experiment study were done. The results have shown that the simulated concentrate can be treated by in-drum drying prototype device; the average rate of evaporation can be up to 5.94 kg/h, the average humidity of product is 1.6%, and the volume reduction ratio is 5.25 when treating simulated concentrate with 44,000 ppm boron under the condition of heater temperature of 170 °C and adjusting temperature control power. It can satisfy the target whose rate of evaporation is 5–6 kg/h, the average humidity of product is less than 15%, and the volume reduction ratio is 2–6.

It is concluded from the investigative work that it is safety and feasible that treatment simulated concentrate by concentrate in-drum drying prototype device. It is necessary that study of treatment of radioactivity concentrates from nuclear power plant uses concentrate in-drum drying device.

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