Pyroprocessing Product and Waste Estimation with Storage Sizing

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1. Introduction

As one of promising spent nuclear fuel (SNF) reprocessing options, pyroprocessing is facing many issues to solve in terms of technical and economic feasibilities. More reasonable evaluation to support those feasibilities can come from estimation of product and waste generated in pyroprocessing. This study has a purpose to provide a rational basis to explain how much amount of product and waste in generated. Korea Atomic Energy Research Institute (KAERI) has developed a 10tHM/y pyroprocessing flowsheet [1], which is still used as an official flowsheet in KAERI. Process flow diagram suggested in the flowsheet may be changed as process technology improves with clearer identification of behavior of spent fuel species in the pyroprocessing.

2. Dynamic Material Flow

An integral material balance presents a cumulative material transported through each stream at a specific time, for example, a year, so it provides static information. Thus, dynamic changes according to the batch operation cannot be predicted in an integral material flow. Instead of using integral mass balance, a dynamic material balance model was used to estimate product and waste generation as well as work in process (WIP). The WIP, which means in-process inventory, is not like final product and waste that is accumulated at final storage without transportation out of facility. Integral mass balance cannot predict WIP changes but dynamic mass balance model can explain inventory changes according to time.

2.1 Simple Dynamic Mass Flow Model

A discrete event system (DES) based model has been developed [2] to simulate batch-wise material flow of integrated pyroprocessing. This model can simulate an integrated pyroprocessing according to event occurrence. Material flow associated with events such as WIP generation, storing, and transportation can be well described in the DES model. The unit process time controls a flow of WIP, on the other hand, separation factor known from experience and literature determines the composition of WIP. The dynamic mass flow model has such information as input control parameters to accommodate flexibility.

The model consists of 12 process groups divided by function and 31 kinds of unit process. The model has a total of 69 streams through which 3 and 17 kinds of product and waste are generated, respectively. Fig. 1 shows the material flow model built using ExtendSim [3].

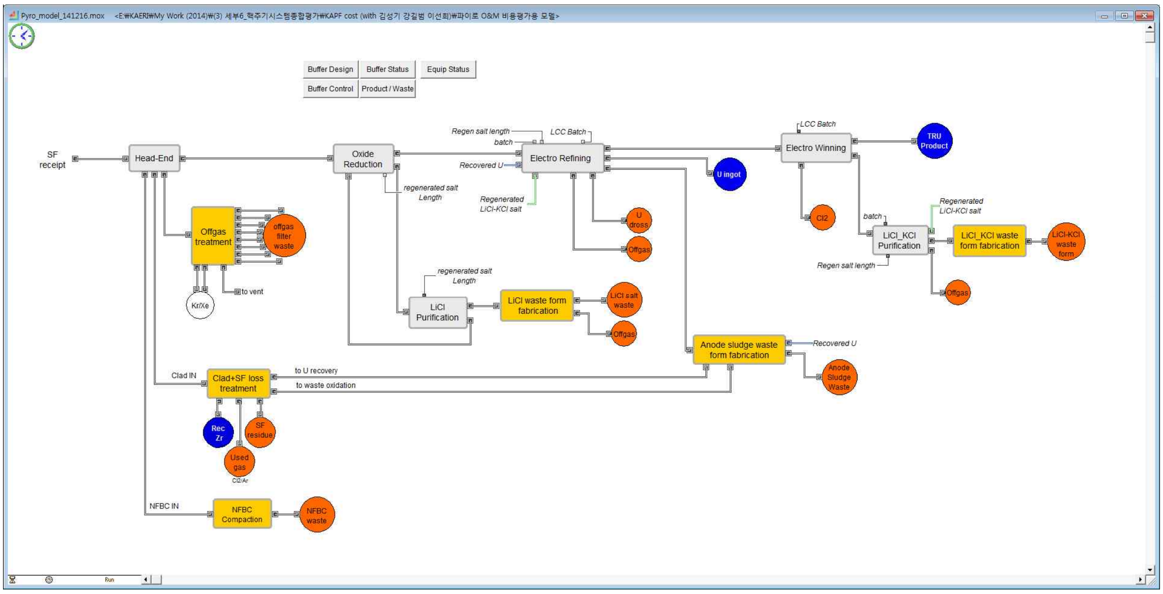

Fig. 1. ExtendSim model for dynamic material flow simulation of pyroprocessing, which comprises 6 major process groups, 6

waste form fabrication groups, and 12 kinds of final waste and 3 kinds of final product.

2.2 Capability and Limitation

The simple dynamic model generates a lot of simulation results because it uses database to track all of mass flow through every stream. Users can look for any WIP change, in other words, increase or decrease of WIP amount as corresponding process finishes operation and produces an item or one item is transported to the next process for feeding material, respectively. This is like an inventory to be able for user to track whenever any event associated with nuclear material occurs. It also deals with chemicals supplied for process. For example, this model can easily catch how much amount of LiCl salt must be needed and when for electrolytic reduction process in which LiCl is used as electrolyte.

The model can also have some limitation. It cannot distinguish spent nuclear fuel species. Therefore, waste classification by mass composition is not possible in the model. However, the total sum of SNF element is correctly calculated based on the flowsheet. Inherently, flowsheet deals with SF element independently according to elemental-basis separation factor but the model does not consider elemental behavior. Nevertheless, it distinguishes every chemical element to estimate consumed mass independently, which can contribute to cost estimation of chemical supplied.

2.3 Annual Product and Waste Generation

The reference SNF is 4.5wt% enrichment PLUS7 fuel after 55GWD/tU burn-up and 10 years cooling. The reference SNF assembly contains approximately 430.8 kgHM per assembly so the model is set to treat 24 assemblies annually to be slightly more than 10tHM/y. The simulation result is shown in Table I.

Table I: Final Product and Waste Forms Generated

Product or Waste Name	Type	annually generated item #	mass/item (kg/ea)	annually generated mass (kg)
NFBC	Waste	17	60.0	1,020
Recovered Zr	Product	171	12.6	2,159
Recovered SF Residue	Waste	97	17.3	1,675
fly-ash waste form with cement	Waste	41	20.0	820
Ca filter waste form with ceramic	Waste	10	19.9	199
Na2CO3 waste form with cement	Waste	7	0.9	6
AgX filter waste form with ceramic	Waste	10	20.0	200
Zeolite 5A waste form with ceramic	Waste	10	0.1	1
HZ waste	Waste	18	4.6	83
AgZ waste	Waste	18	1.5	27
LiCl salt waste form	Waste	12	56.1	673
Cl2 gas (LiCl waste dechlorination)	Waste	12	13.0	155
U ingot	Product	204	46.0	9,384
U dross	Waste	204	4.0	816
offgas(AnCl3)	Waste	204	0.9	177
Anode Sludge Waste form	Waste	42	50.0	2,100
Cl2 gas (LiClKCl waste purification)	Waste	144	0.05	7
LiClKCl salt waste form	Waste	9	69.5	625
TRU product (from LCC)	Product	123	0.9	116
TRU product (from RAR)	Product	141	0.3	41
Cl2 gas (LCC)	Waste	36	1.9	67
Cl2 gas (RAR)	Waste	36	3.0	107

2.4 Buffer Sizing

All WIP storages are optimized to have the minimum size to represent the same material flow as the unlimited storage. The unit size of any buffer can hold one item of WIP, product, or waste generated after one batch operation of its corresponding process. The optimum sized buffers do not adversely affect material flow but a buffer smaller than the optimum values can influence overall efficiency of integrated pyroprocessing. Therefore, actual buffer should be reasonably set to have more than 3 times or bigger than the optimized one. The Fig. 2 represents the number of items annually generated in two cases: optimized buffer and 50% of optimum buffer size for WIP of electrorefining. In the second case, the limited buffer blocks a fluent material flow and propagates the bottleneck to up-and down-streams. U ingot fabrication process close to electrorefining cannot produce the final product U ingot equivalent to approximately 10% of the optimal production.

3. Conclusions

A dynamic material flow model was built to estimate annual product and waste generation in the pyroprocessing. Dynamic material flow is analyzed for evaluation of buffer size to accommodate various kinds of WIP in the integrated pyroprocessing. The discrete event simulations contribute to find out the optimal buffer size enough to accommodate WIP generated. These results are needed to design pyroprocessing facility as well as to establish a management plan of final product and waste.

REFERENCES

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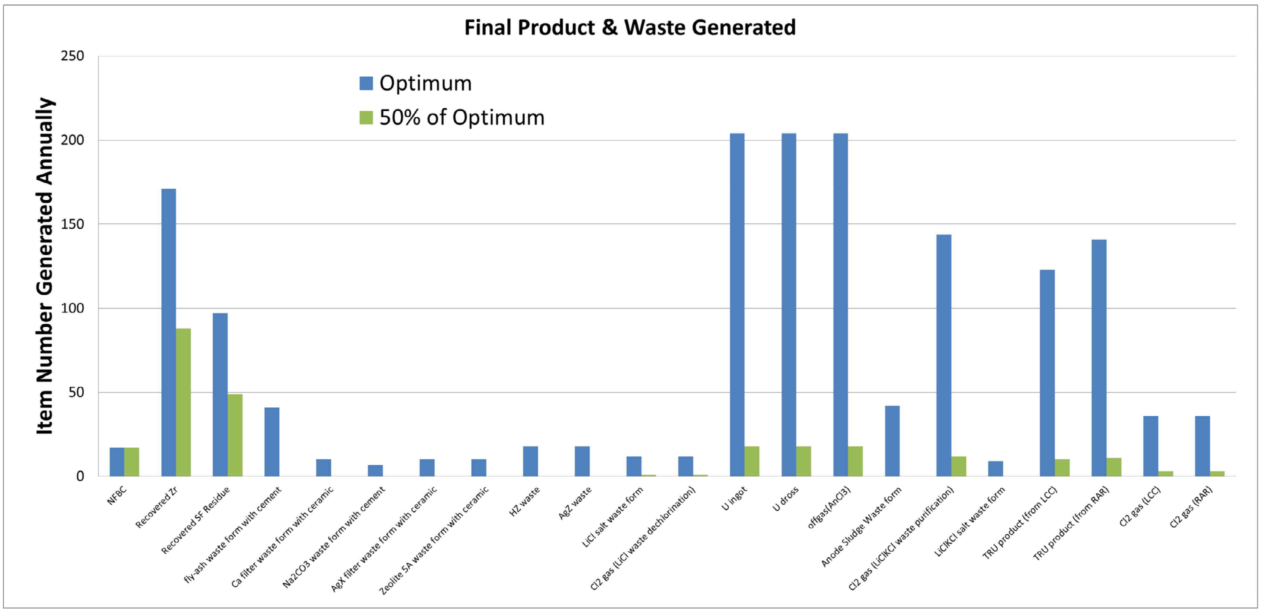

Fig. 1. Comparison between two cases: one of which is optimally sized and the other is 50% of the optimum case only for three buffers of electrorefining to accommodate cathode deposit, anode sludge, and LiCl-KCl salt with fission product.