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Implementation of a Dynamic Material Flow for a Pyroprocess

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1. Introduction

A pyroprocess contains over ten unit processes and nuclear materials in various forms that flow in and out of those unit processes. To understand a material flow at a glance in a pyroprocess is very difficult since several material elements take different routes as the process proceeds. Static or steady-state mass balance is the conventional approach for understanding the material flow of a process, which, however, does not provide precise results at any time but provides only averaged results. Therefore, a dynamic material flow according to the time and the event is needed for a correct analysis. This study applies a discrete event dynamic system based modeling and simulation methodology to the analysis of a dynamic material flow in a pyroprocess.

2. Pyroprocess

A pyroprocess is composed of the following principal unit processes[1]; (1) chopping, (2) decladding and high temperature voloxidation, (3) electrolytic reduction, (4) electro-refining, (5) cathode processing, (6) electro-winning, (7) Cd distillation, (8) residual actinide recovery, (9) salt purification. A conceptually designed material flow of the pyroprocess is shown in Fig. 1.

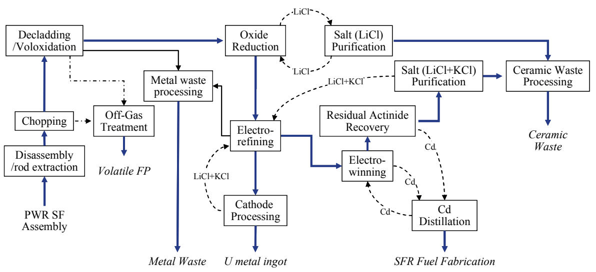


Fig. 1. Conceptual diagram of the Pyroprocess flow.

3. Model for Dynamic Material Flow

3.1. Model Requirements

Our purpose is to develop a discrete event dynamic system model for a pyroprocess not only to implement a dynamic material flow but also to perform a what-if scenario analysis. In order to recommend the important process design variables, a what-if scenario analysis is important. Most discrete event dynamic system modeling and simulation tools provide what-if scenario analysis functions. In this study, a commercial software, ExtendSim[2] is utilized to develop a dynamic material flow model named PyroFlow. The framework of PyroFlow is structured by functional and analytical requirements as follows:

Functional requirements
- Dynamic material flow analysis
- Discrete event system simulation
- Database management
- Parameterization of process design variables

Analytical requirements
- Bottleneck analysis
- Buffer capacity analysis
- Operational status analysis
- Statistical process operation simulation

3.2. Configuration of PyroFlow

Figure 2 shows three principal windows of PyroFlow. A model window on the top of Fig. 2 includes the process models which are described in square boxes (hierarchical blocks) and they are all connected with lines according to the possible material flow routes.

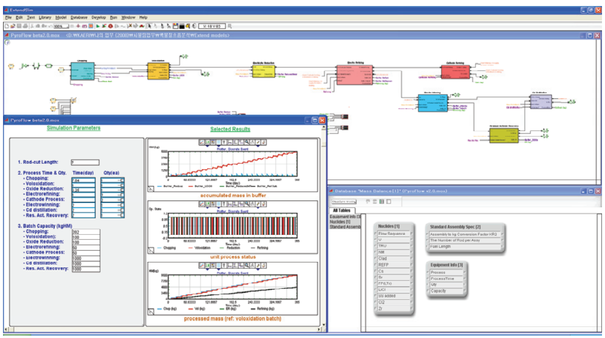


Fig. 2. Structure of the PyroFlow beta version.

Currently, the PyroFlow includes eight unit process models (chopping, vol-oxidation, electrolytic reduction, electro-refining, cathode process, electro-winning, Cd distillation, residual actinide recovery) as shown in Fig 3.

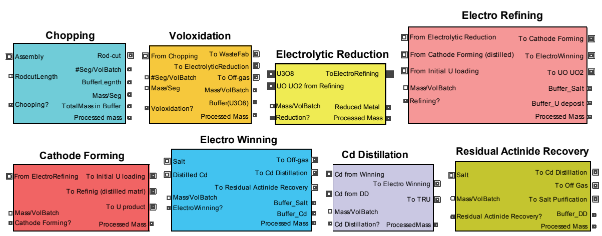


Fig. 3. Structure of the unit process models.

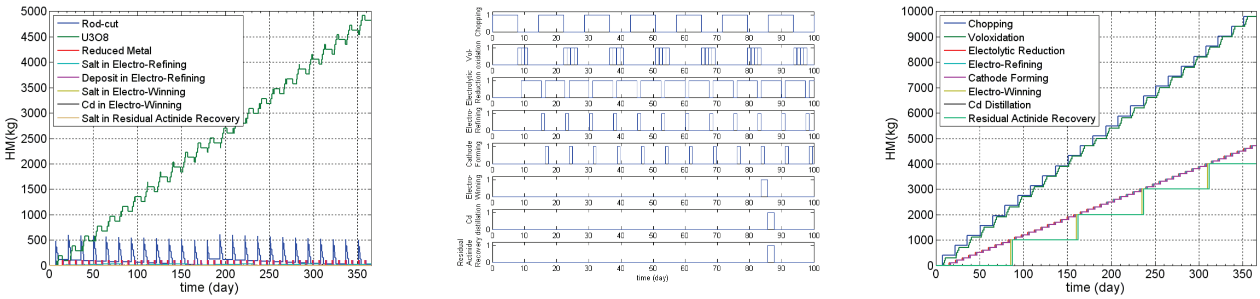
If the boxes are double clicked, detailed model windows will be open. This hierarchical modeling helps simplify and clarify models so that it lets users create hierarchical blocks that group several blocks together into one block while still allowing users to drill down into the lower levels to access the individual blocks. The database window on the right side includes a database about the static mass balance, the process design variables and the standard assembly specification. The static mass balance in reference to 10 ton, a burn-up of 55GWD/tU, a U-235 enrichment of 4.5 wt% and a 10 years spent fuel cooling is embedded in the database. For a dynamic analysis, the static mass balance is also needed as a reference. The process design variables are the process time, the number of equipments and the batch capacity of the equipments. The process design variables can be easily replaced by means of a database management function as well as a notebook window. The standard assembly specification includes the number of rod pins per assembly and the fuel length. The notebook window includes some selected results which are copied and pasted from the model window and process design variables which are able to be replaced by users.

4. Preliminary Simulation

Before carrying out simulations of a dynamic material flow, PyroFlow requires the process design variables affecting the dynamic material flow, which are the rod-cut length, the processing time, the equipments quantity and the batch capacity. Some of the following variables were estimated by taking into account the current level of the technology and the experimental results. The others were assumed or design requirements.

Table I: Simulation Parameters

Process	Capacity (kgU/batch)	Time (day)	Quantity (ea)	Remark
Chopping	392	7.84	1	200 days/10tU, 7cm rod-cut
Voloxidation	100	Approx. 1	1	estimated by experiment
Electrolytic Reduction	100	Approx. 6.25	1	estimated by current technology
Electro Refining	50	1	2	design requirement
Cathode Forming	50	1	2	design requirement
Electro Winning	1000	2	1	capacity: design requirement, time: assumption
Residual Actinide Recovery	1000	2	1	assumption
Cd distillation	1000	2	1	assumption



(a) mass in buffer (b) operation state (c) processed mass

Fig. 4. Simulation results for bottleneck analysis.

Preliminary simulation results shows where a bottleneck happens as shown in Fig. 4. Mass of accumulated materials in the buffers between the processes, the operation state of 8 unit processes, the processed mass are illustrated in Fig. 4. Due to the long time for processing the electrolytic reduction, a bottleneck happens. This bottleneck can be removed by reducing the process time.

5. Conclusions

A discrete event dynamic system based model for implementing a dynamic material flow was developed by using ExtendSim, which was named PyroFlow. Compared to a conventional static material flow, PyroFlow could provide various dynamic results according to the time and the event. Current version of PyroFlow has 8 unit process models and a static mass balance database as a reference. Some preliminary simulations were performed with estimated process design variables and the results showed that a bottleneck analysis was easy to carry out on the basis of a dynamic material flow. PyroFlow is expected to be a promising tool for various operational analyses such as a process parameter design, an operational scheduling, and a conceptual facility design.

REFERENCES

[1] J. H. Yoo, C. S. Seo, E. H. Kim and H. S. Lee, "A conceptual study of pyroprocessing for recovering actinides from spent oxide fuels," Nuclear Engineering and Technology, Vol. 40, No. 7, pp. 581-592, 2008.
[2] http://www.extendsim.com