A Code Development Framework for Material Flow in a Nuclear Reprocessing Facility

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1. Introduction

Modeling and simulation for electrochemical process mainly focuses on unit process reactions. However, modeling and simulation in the plant level could cope with operation and system engineering issues besides unit process reaction. In order to build a plant level code, framework appropriate for a pyroprocessing plant should be first studied. Three tiered architecture for code development was suggested consisting of unit process model in the first tier, operation model in the second tier and plant level code in the third tier. Material flow in that framework was firstly tested. For different level analyses, hybrid system modeling, i.e., the combination of continuous and discrete event system modeling is needed. In the suggested code framework, user could have two choices regarding the selection of unit process model: electrochemical model; dynamic mass balance calculation model. The plant level framework is also including the following functional modules: analysis module; visualization module; database module. This study addresses the framework for the plant level code development and preliminary analysis of material flow in pyroprocess.

2. Basic Framework

2.1 Multi-tiered modeling architecture

In order to build plant-level-model, 3-tiered code development architecture was suggested as shown in Fig. 1. The bottom tier is unit process modeling which includes electro-chemical model influencing output chemical composition. The middle tier includes unit and integrated operation model which describes operation behavior such as feeding, transporting and other mechanical operations from unit or integrated process aspect, respectively. The top tier is the plant-level-model, which could have various analysis modules and DB module for SNF and isotope inventory. It could also have to show the results, intuitively through well designed visualization module in Fig. 2.

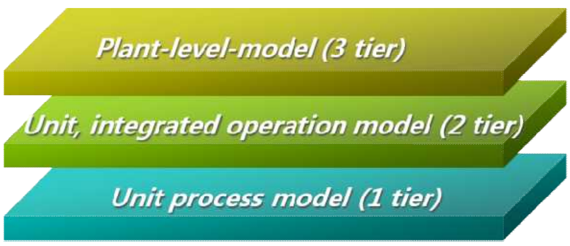

Fig. 1. Plant-level code development architecture: Three tiered model.

2.2 Development strategy

Without reliable unit process model, it is too difficult to build upper tier model. Currently electrochemical process is not well described by model and must be enhanced further. It is alike wasting time to wait until the reliable unit process model is built. Furthermore, most part of the middle and top tier model can be built without the unit process model. Given feeding material composition and its amount, unit process model presents generally output composition of element after electrochemical reaction. Noticing that expected values of output composition could be set by target values in an equilibrium mass balance sheet, the calculation of dynamic mass balance per batch operation in unit process might be alternative of unit process model. Even though equilibrium mass balance means total input and output mass balance in each unit process at a certain time, it can be broken down by unit of each batch operation capacity of unit process according to each batch time and it can be made to present dynamic mass balance. The current version of plant level framework was tested by using dynamic mass balance calculation algorithm without unit process model. However, the framework could selectively include the unit process model or dynamic mass balance calculation algorithm when the reliable unit process model is prepared.

2.3 Dynamic material flow

Pyroprocess consists of a dozen of unit process and various material streams among them. Material streams in pyroprocess are classified into two categories: nuclear spent fuels and two kinds of salt (LiCl and LiCl-KCl). First feeding material of pyroprocess is spent nuclear fuel from nuclear reactor in the form of assembly and final product is volatile FP (fission product), metal waste, ceramic waste, uranium metal ingot and TRU (transuranium) for fast reactor fuel fabrication. Every time process proceeds to next step,

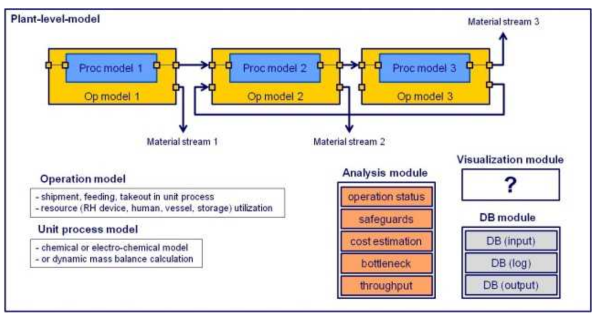

Fig. 2. Configuration of plant level framework.

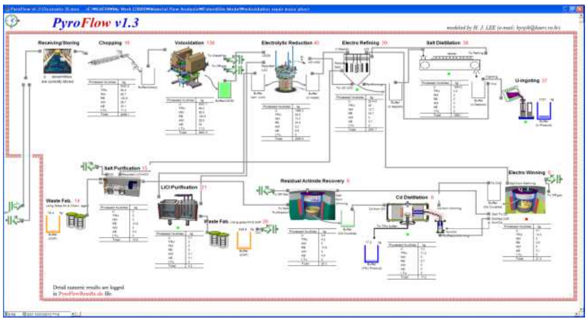

Fig. 3. Top window of pyroprocessing plant model.

many things (processed mass, buffer accumulation, the number of batch operation, etc.) are changed according to time. In order to capture such dynamic characteristic related to material flow, discrete event based dynamic mass balance calculation [1] is needed in case where a target mass balance is set by equilibrium state at a specific instance in time.

2.4 Model design

Fig. 3 presents the top model just embracing operation model and dynamic mass balance calculation algorithm. It shows basic information of material flow by means of visualization through animation which indicates text and picture information changing according to time. Multi-tiered model architecture might be simply represented on the model by hierarchy. Complex details corresponding to lower tiers could be hidden and on top window only a little information might be displayed. For example, electrolytic reduction process wants U3O8 powder and recycled or fresh LiCl salt as feeding material, and pushes output material into temporary buffers every batch operation. Basic information that unit process block includes is input connectors, output connectors, buffer accumulation, processed quantity, the number of batch operation and operation status as shown in Fig. 4.

2.5 Functions of current version

In the current version of framework, results are exported to EXCEL and displayed on charts in real time since it is fast enough to treat such limited data.

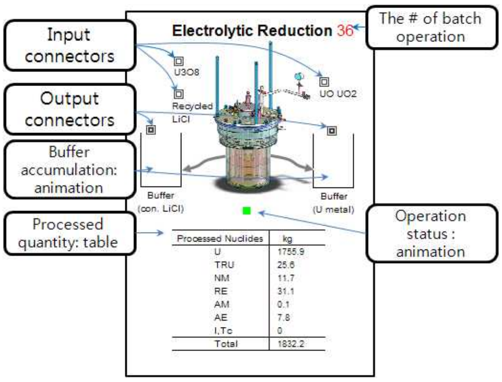

Fig. 4. Configuration of unit process block on the plant level top window.

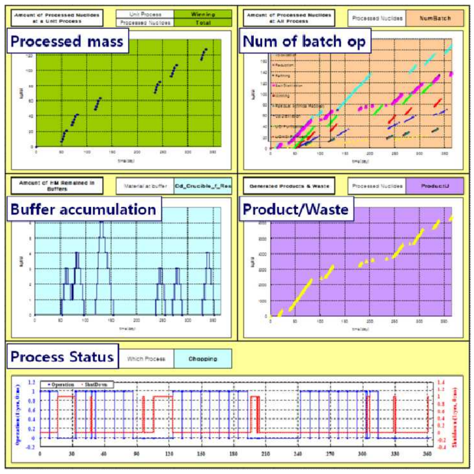

Fig. 5. Analysis results able to be obtained from current version of plant level model.

However, the more data might require more efficient DB management SW other than EXCEL. Fig. 5 shows results able to be displayed in the current version. The processed mass of grouped element or total heavy metal of spent fuel is displayed being classified by unit process. The number of batch operations tells us which process is late determining process or bottleneck process during simulation time. The buffer accumulation indicates that the facility has a minimum size of buffer storage to temporarily accommodate product to be sent to the next process. Also, product and waste mean final output in the pyroprocess, which will be sent to metal fuel fabrication facility for recycling and to an interim storage facility for disposal.

3. Conclusions

A plant-level framework consisting of 3-tiered model with some functional modules was suggested for pyroprocessing facility. Current version of framework includes basic function for material flow analysis. One of important characteristic in the current version is that dynamic mass balance calculation is possible even without unit process model. It can make us estimate integrated material flow in the pyroprocessing facility. The plant model framework will be improved to satisfy facility code requirement and to provide various analysis linked with nuclear related codes. Modelling and simulation for pyroprocessing facility is expected to save construction cost and reduce design error, finally devote generation of design requirement for engineering scale or commercialized scale facility.

REFERENCES

[1] H. J. Lee, K. Kim, H. D. Kim and H. S. Lee, Discrete event dynamic system (DES)-based modeling for dynamic material flow in the pyroprocess, Annals of nuclear energy, Vol.38, pp. 860-875. 2011.