Modeling Steam-Methane Reforming for Dynamic Risk Analysis

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Process simulations are used by chemical manufacturers to optimize the design of plants and their associated control systems, but little emphasis has been placed on using simulations to design and operate safety systems. Process simulations designed for safety purposes have the potential to inform operators and plant managers about accident scenarios likely to occur. The simulations can also be used to design and recommend safety systems that are most effective at mitigating the risks of postulated accident scenarios. A major difficulty lies in the development of process safety simulations; what attributes should a simulation designed for safety have? How should a simulation for process safety differ from a simulation for process design or control? How can a safety simulation be integrated into management of daily operations?

This presentation focuses on the development of a safety simulation for a steam-methane reforming (SMR) process. These processes often use pressure-swing adsorption (PSA) to recover H_2 product from off-gases. This inherently-transient unit is responsible for dynamic effects throughout the plant, which are crucial to understand when properly designing safety systems. Another attribute of the SMR process is the furnace box in the SMR-unit. Temperatures in this box are as high as 1,500K, but these are too high for thermocouple measurements. Consequently, in safety models, good temperature predictions are needed to avoid catalyst overheating and degeneration. Safety systems must respond by arresting rapid temperature rises resulting in accident scenarios.

This paper presents a robust method of using a plant dynamic model together with alarm and measurement data to conduct safety-system analysis. As all models contain process-model mismatch, the robust method will allow operators to comfortably make safety decisions for the plant. Issues concern the rigor of furnace models (e.g., in radiation heat transfer – view factor determination; the need for computational fluid dynamics; the need to model each of 400 tubes) and the PSA cycles involving each of 12 adsorption units. For safety purposes, given extensive alarm and process variable data, the need for high precision, involving high computational demands is shown to be relaxed.

Stated differently, this paper shows how simulations together with alarm and measurement data are used robustly to conduct safety-system analysis. Bayesian analysis fits this scheme well, with simulations providing informative prior distributions for the failure probabilities of the safety systems, and the alarm and process data providing the likelihood distributions, with which the posterior failure probabilities are updated. In this fashion, simulations describe the failure probabilities of safety systems using the traditional event-tree formulation. Also, they are used to set alarm threshold bands for the process in which the failure probabilities are the minimized objective function.