DESIGN AND TRAINING IMPROVEMENTS THROUGH THE USE OF DYNAMIC SIMULATION

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ABSTRACT

Extensive use of dynamic process simulators is becoming the norm for many greenfield facilities in metals and mining, including alumina refineries. Many leading companies are benefiting from the use of dynamic simulation for greenfield projects and control upgrades because the inherent risk in new process plant design and the complexity of controls in the Bayer cycle. Interactive and accurate simulation provides the mechanism for enhanced operator training, and for validating and improving new process and control designs.

Dynamic simulation is used for operator training, and for validation of designs of process equipment and controls systems. By using dynamic simulation for operator training benefits can be attained by improving availability (minimization of lost production), safety, and operator competency certification for environmental and safety. In addition, dynamic simulation provides a means to validate process design to a greater degree than possible with typical process design tools that cannot provide the simulation fidelity and dynamics associated with alumina refineries and its interactions with operators and control systems. These improvements have proven to minimize design shortfalls that would negatively impact throughput, quality, and commissioning times. This paper discusses the current practices and benefits of dynamic simulation in alumina refining.

INTRODUCTION

Dynamic simulation is set of software applications used for many tasks, including operator training, control system logic and configuration validation, and even validation of process and equipment design. This simulation technology features high fidelity models that include process dynamics that provide the necessary realism to test process designs and train operators on new processes. In addition, good operator training requires control system simulation including interlocks and displays (or even connection to the actual control stations). Furthermore, the control system simulation can become a powerful tool to validate the design and configuration of Distributed Control Systems (DCS), Programmable Logic Controllers (PLC), and safety management systems.

The benefits of dynamic simulations include improved safety and reduce environmental incidents. Tangible financial benefits include better response to upsets that regain quality or production, identify malfunctions or design errors that minimize downtime and production losses. These benefits are illustrated in Figure 1.

THE NEED TO OPERATE MORE EFFECTIVELY

One the most important uses of dynamic simulation are for operator training. This is particularly true for new construction of refineries or major process additions like new units or trains. Indeed, this has become an accepted practice on many large capitol projects because of the enormous risk in starting and operating the refinery without operators experienced with the new equipment. Often the use of operator training applications on smaller endeavors is limited by the cost of the implementation and maintenance, and reduced benefits.

The benefits to dynamic simulation for improved operator effectiveness are often underestimated, ignoring the optimization benefits. In most the operating alumina refineries, the equipment is operated continuously and many operators are not well practiced in running under startup, shut down, or emergency conditions. Similarly, in new installations, operator may have even less skills in managing the process and the knowledge of the equipment limits, even under normal operating conditions. Fundamentally, the essential mechanism in learning is comprehension and repetition [1]. Dynamic simulation provides these essential learning mechanisms.

Many of the benefits of operator training using dynamic simulation are listed below and discussed in the sections that follow.

- Reduce incidents
- Operate refinery safely
- Maximize availability
- Operate closer to constraints
- Improve quality
- Minimize costs
**Operate Plant Safely**

Operator training using dynamic simulation is exemplary of good management practices regarding due diligence for health and environmental safety. The recent tragedies at the Gramercy alumina refinery was reported by MSA to be partially due to "...employees' lack of training in procedures to be followed in the event" [2]. In fact, the largest accident in US history, a $1.6B explosion in 1989 at a petrochemical plant, occurred in part to ineffective human intervention. A dynamic simulator can be the tool to provide not only the training of operator but also the means of certification, incident assessment, and peer benefit.

**Reduced Incidents**

Simulation is a proven tool to train operators how to respond to problems in a way that will not only improve safety of plant personnel, but also prevent excursions and thus reduce incidents that are unsafe to environment or equipment. Actual data of cost of incidents can be significantly depending upon the severity of the incidents. Refer to the estimated cost of incidents in alumina refineries in Table 1.

### Table 1. Estimated Costs of Incidents

<table>
<thead>
<tr>
<th>Incident</th>
<th>Lost hrs/yr</th>
<th>Annual Product</th>
<th>Gross Loss (or Profit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spills (Reduce Production) (4 times, 6 hrs each, 40%)</td>
<td>9.6</td>
<td>0.11%</td>
<td>$56,800</td>
</tr>
<tr>
<td>Equipment Break/Plugs (1 time, 12 hrs, 100%)</td>
<td>24.0</td>
<td>0.28%</td>
<td>142,000</td>
</tr>
<tr>
<td>Total</td>
<td>33.6</td>
<td>0.40%</td>
<td>198,800</td>
</tr>
</tbody>
</table>

Assumptions:
1. Based on 1,000,000 tonne per annum production,
   Value of alumina is $170/tonne,
   Cost of production $120/tonne.
2. Main Bayer circuit can process more bauxite, liquor, and hydrate.
3. Accumulative lost hours are in equivalent 100% production rate.

The actual costs of incidents have been extensively studied in other industrial processes. A detailed report of incidents in US petroleum and gas processing by the American Petroleum Institute reports that incidents can be costly, 20% of accidents cost $25-250K, 16% of accidents cost greater than $500K [3]. In addition, The Abnormal Situation Management Consortium (ASM), a group of large petrochemical companies dedicated to improved operations, has estimated the cost of incidents [1].

- North America process plants lose over $20 billion a year from abnormal situations.
- Human error accounts for 50% ($10 billion).
- Insufficient employee knowledge, and operator and maintenance worker errors are main causes.

The need for better operator training to reduce incidents is further exemplified by the Chemical Manufactures Association’s study of six sites regarding the causes of incidents and found that [4]:

### Causes of Incidents

- People & work context* 35-58%
- Equipment 30-45%
- Process 3-35%

*For People and Work Context causes, the chief explanations given were; inadequate or no procedure, and (refer to Figure 2).

**Figure 2. Causes of Incidents**

Nonetheless, for small to medium projects or for ongoing competency training, often the cost of operator training and the perceived reduced benefits usually prohibit its widespread use.

**Maximize availability**

In a fashion similar to reducing incidents discussed previously, good operator training using dynamic simulation can lead to better availability. Good operator action can maintain production, quality, and yield levels. In addition, operator actions have a direct impact on equipment life and on operational concerns like scaling, fouling, or plugging.

**Closer to constraints, Improve Quality, Minimize costs**

Better operator training is often looked at as a means to reduce the negative impact of abnormal situations. However, there are clearly advantages beyond preventing incidents. The operator has a huge impact on production throughput yield and quality. Today’s market pressures are placing more sophisticated equipment and controls under fewer operators [5]. Operators are the key to maintaining and improving throughput, yield, and cost reductions by pushing constraints, utilizing advanced controls, and operating the most efficient equipment. The estimate benefits to a typical alumina refinery are given in Table 2. These benefits are in addition to those by minimizing losses discussed in the previous section.
Tangible benefits from the use of dynamic simulators to improve process and control system design and validation.

The estimates that follow in Table 3 have been made for the typical uses of dynamic simulation for design and validation:

- Faster switch-overs (6 times, 6 hrs, 25%)
- Faster ramp-up (1 time, 5 days, 100%)
- Faster start-up (1 time, 352 days, 0.25%
- Improved tuning (1 time, 352 days, 0.1%)
- Improved control design (1 time, 352 days, 0.1%)
- Improved process design (1 time, 352 days, 0.2%

THE NEED FOR DESIGN AND VALIDATION TOOLS

The other important utilizations of dynamic simulation are for design and validation of processes and control systems. Many innovation leaders in alumina are using dynamic simulation for process design validation as well as control system design and validation. Comalco's Gladstone, the world's newest alumina refinery, is using dynamic simulation to improve the refinery process and control design, perform control configuration check-out and will be used to pre-tune many of the control loops. Typical uses of dynamic simulation for design and validation are listed below and discussed in the sections that follow:

- Optimize process, find bottlenecks before start-up.
- Control validation, improve control, pre-tune.
- Minimize errors, improve start-up.
- Prepare operating procedures, improve procedures.

The estimates that follow in Table 3 have been made for the tangible benefits from the use of dynamic simulators to improve process and control system design and validation.

### Table 2. Estimated Benefits of Better Operator Training

<table>
<thead>
<tr>
<th>Actions</th>
<th>Lost hrs/yr</th>
<th>Annual Product</th>
<th>Gross Profit</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faster Start-up (1 time, 12 hrs, 35%)</td>
<td>4.2</td>
<td>0.05%</td>
<td>$24,900</td>
<td></td>
</tr>
<tr>
<td>Faster Switch-overs (6 times, 6 hrs, 25%)</td>
<td>9.0</td>
<td>0.11</td>
<td>$53,300</td>
<td></td>
</tr>
<tr>
<td>Operator Skill/ Confidence (88 days, 0.25%)</td>
<td>5.3</td>
<td>0.06%</td>
<td>$31,200</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>18.5</td>
<td>0.22%</td>
<td>$109,400</td>
<td></td>
</tr>
</tbody>
</table>

Assumptions:
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   Value of alumina is $170/tonne,
   Cost of production $120/tonne.
2. Main Bayer circuit can process more bauxite, liquor, and hydrate.
3. Accumulative lost hours are in equivalent 100% production rate.

### Table 3. Benefits of Design & Validation Tool

<table>
<thead>
<tr>
<th>Incident/action</th>
<th>Lost hrs/yr</th>
<th>Annual Product</th>
<th>Gross Profit</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debottleneck (1 time, 180 days, 2%)</td>
<td>86.4</td>
<td>1.02%</td>
<td>511,400</td>
<td></td>
</tr>
<tr>
<td>Equipment Break/Pluggage (1 time, 1 day, 100%)</td>
<td>24.0</td>
<td>0.28%</td>
<td>142,000</td>
<td></td>
</tr>
<tr>
<td>Faster Schedule (construct.) (1 time, 5 days, 100%)</td>
<td>120</td>
<td>1.42%</td>
<td>710,200</td>
<td></td>
</tr>
<tr>
<td>Faster Ramp-up (1 time, 5 days, 20%)</td>
<td>24.0</td>
<td>0.28%</td>
<td>142,000</td>
<td></td>
</tr>
<tr>
<td>Improved Tuning (1 time, 352 days, 0.1%)</td>
<td>8.4</td>
<td>0.10%</td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>Improved Control Design (1 time, 352 days, 0.1%)</td>
<td>8.4</td>
<td>0.10%</td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>Improved Process Design (1 time, 352 days, 0.2%)</td>
<td>16.9</td>
<td>0.20%</td>
<td>100,000</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>288</td>
<td>3.41%</td>
<td>1,705,700</td>
<td></td>
</tr>
</tbody>
</table>

**Optimize Process, Find Bottlenecks Before Start-Up**

Dynamic simulation provides a means to validate new process designs that with many the typical process design software is difficult, if not impossible to achieve. Many design tools use steady state models with limited dynamic simulation capability. Even if these packages do have dynamic simulation features, they may not be amenable for modeling higher accuracies and complexities that include the dynamics of the system. Dynamic simulators for process design are high fidelity modeling systems that can expose the discrepancies, under/over design, and other shortcomings of steady state design tools. High fidelity dynamic simulators have been used to study operations in the following perspectives:

- Equipment capabilities at reduced and minimum flow conditions, improving turndown operations.
- Startup and shutdown operations, including heating requirements during startup.
- Abnormal operating modes and constrained flows.
- Process unit interactions, effecting sizing of equipment such as tankage.
- Design margins in pumps, bypass flows.

In alumina refineries and other metals processing plants, dynamic simulation has found significant deficiencies in digestion heating constraints and grinding throughput and sizing, and has been used to correct the designs of these systems.

**Control Validation and Improvements**

Another natural use of dynamic simulation is in testing and validating control design. Many of the features common to operator training and process design are well suited to control system design and validation. In most expansion projects or control system upgrades there is a need to test control strategies, logic, and operator graphics. A good simulation system can also be used to improve control strategies and even pre-tune the controls for a new process, particularly for those processes that have long time constants and delays, or multiple interactions. These situations make it difficult (time-consuming) to perform the rigorous testing need for tuning. Consider the following benefits of simulation for control system validation and optimization:

- Validate designs and configuration of controls:
  - regulatory controls (DCS),
  - logic systems (PLC, burner management, and emergency shutdown systems),
  - operator displays.
- Optimize operator displays for work flow (start-up & shutdown, switch-overs)
- Develop or validate complex control layers (regulatory cascades, start-up & shutdown routines)
- Pre-configure alarms, optimize for abnormal situations
- Validate or justify need for advanced controls
- Validate asset management applications (e.g., tuning or performance management packages)
- Validate configuration of process historian
- Validate business applications (e.g., web based reporting or data reconciliation)

In the case of alumina, these tools are being used to perform validation of operator displays on large control expansions and
have proven invaluable in the control design of a new mud washing line.

It should also be noted that there is a need for easy-to-use, low cost simulators for control system retrofits and ongoing operator training. In these situations, where the refinery dynamics are well understood and there is a core of experienced operators, the benefits of full simulation probably are not warranted. Even these lower fidelity simulations can achieve many of the objectives around validation of control systems.

Minimize Errors, Improve Start-Up
The use of dynamic simulation for design and operator training can streamline the initial start-up and operation of a new refinery or expansion project. This is because many of the key process designs, operations procedures, and controls will have been debugged and perhaps optimized for start-up conditions. Many industrial sites have benefited from a more aggressive start-up and ramp-up schedule due to:
- Better process designs (validated, re-designed).
- Better control and logic designs (validated, re-designed).
- Better operator displays and alarms.
- Difficult loops pre-tuned.
- Better operation (yield) at reduced flows (and better operator training).
- Capture real scenarios from process to improve training.

Prepare Operating Procedures, Improve Procedures
Until recently, the quality of operating procedures has relied heavily on the experience and transliterating skills of the operators, supervisors, and others involved. With dynamic simulation based operator training, it is possible to develop and test operating procedures in an interactive environment that closely mimics the controls and process. Dynamic simulation provides the tools to more easily develop and maintain operating procedures, such as:
- Optimization of procedures, so that operators and supervisors know what to do in a wide set of situations.
- Assess your procedures, perform and improve your initial operations virtually many times before using.
- Capture operator actions with simulator to document procedures or provide peer-based learning for many types of operations:
  - Normal startup/shutdown, acid/caustic wash, tank/vessel transfers.
  - Abnormal situation management (loss of power).
  - Recovery from upset conditions, (equipment trips, loss of steam, loss of agitation).

ESSENTIAL SIMULATOR FUNCTIONALITY
The utility of dynamic simulators is key to achieving success as simulators have a reputation of being expensive to implement and difficult to maintain. Tools that make the simulator easy-to-use, reduce the effort in both implementation and on-going maintenance, should be given consideration. However, essential functionality that insures the simulator achieves its goals must not be overlooked. There is no uniform set of standards for simulators in the process industries, including alumina refineries. Thus, the potential user of simulators has the burden to carefully specify the needs to meet their objectives.

Operator Trainer Simulators
To insure a successful implementation of simulator-based operator training system, the simulator should be specifically designed for operator training. The essential functions of operator trainer simulator should include:
- Instructor personality that includes setting operating conditions, fast time modes, running events (start-ups, trips).
- Skill competency features for benchmarking operator/supervisor competency that includes scoring of simulator scenarios and record keeping.
- Control system and logic interpretation (or builder) from the actual control system files. This allows for faster update to actual logic, reduces costs, and provides a more accurate simulation.
- Dynamic simulation for a more accurate training environment, which is particularly important for new refinery construction.
- Rich simulation model database that can substantial reduce effort and cost and improve model results. See discussion of Rich Model Database.
- Ability to convert steady state design models to the dynamic simulator. For example, the ability to use models developed from Metsim or Aspen Plus.
- Runtime displays that reflect actual operating displays.
- Capture operator actions, easily develop procedures or peer-share information. This requires interfacing to control systems.
- Synchronize simulator to existing conditions, thus minimizing set-up time and becoming more user friendly.
* For smaller projects or on-going training, there is a need for the option for using simpler tie-back model that eliminates need for complex models, thus simplifying synchronization to controls and reducing costs.

Control Validation Simulators
Control validation simulators are used to validate the control system configuration that includes the strategies, logic, displays, and alarms. Generally, an operator trainer simulator described previously would meet the requirements for control system validation. Comparatively, there is a lesser need to have an accurate dynamic simulation and operator trainer features such as fast time mode and event scenarios. A good control validation simulator should include the following features:
- Control system and logic interpretation (or builder) from the actual control system files. This allows for faster update to actual logic, reduces costs, and provides a more accurate simulation.
- Capability for simple tie-back model that uses control logic to provide process simulation (tie-back the output of controller to the controller input). This eliminates need for complex models, thus simplifying synchronization to controls and reducing costs.
- Option for dynamic simulation for a more accurate control environment, which is particularly important for new refinery construction. It should be compatible to operator training simulator (if needed) to reduce cost by not having to develop two sets of simulator models.
- Rich simulation model database that can substantially reduce effort and cost and improve model results. See discussion of Rich Model Database.
- Option for interfacing to actual operator displays, and thus allow for validation of operator displays.

**Process Validation Simulators**

Validation of the design and operating characteristic of process and its equipment is a good role for dynamic simulators. For this application, the dynamic simulator must provide many more of the process and equipment thermo-fluid and flow properties needing to be accounted for and visualized. The accepted practice in the industry is to use first principle models for reasons of flexibility and ease-of-use for new process designs. The essential functions of process validation simulator should include:

- Dynamic simulation, that more accurate models the process and equipment environment, particularly important for new refinery construction.
- Rich simulation model database that can substantially reduce effort and cost and improve model results. See discussion of Rich Model Database.
- Simple control system models to provide a more complete process environment or an option for interfacing to control system validation models for greater accuracy.
- Ability to integrate process units to analyze a more complete process and therefore review the interactions among units.

**Rich Model Database**

Essential to the implementation of a low cost and accurate dynamic simulation is the availability of predefined and tested equipment and process models. Development of new models is certainly more costly than using predefined models, but they run the risk of not accurately reflecting the intended process and equipment.

In addition, to further improve the usability of predefined models they should include externalized (parameterized) specifications of essential properties such that the models can be easily modified (e.g., ability to specify dimensions of vessels). For example, the models for a grinding mill (SAG or ball) would consider:

- Desired particle size distribution
- Ore grindability index and size
- Number of balls/rods, and their condition
- Mill Speed and flows, affecting mill retention.
- Integrated models with sump and cyclones or screens

Of course there should be a extensive collection of models for the complete Bayer cycle, including:

- Digestion
  -mills, heaters, digestion vessels, flash tanks).
- Clarification and mud washing
  -Thickeners, mud washers, deep thickeners, filters (sand, Kelly, ...).
- Precipitation
  -continuous or batch, hydrocones.
- Evaporation and heat interchange
  -heaters, flash tanks, effects, barometric condensers.

- Calciners
  -rotary kilns or fluidized beds, precipitators.
- Boilers
  -combustors, feedwater/drum, pulverizers.

**CONCLUSION**

The benefits of dynamic simulation are significant, able to produce large benefits on new alumina refinery and large expansion projects, as well as control retrofits. Newer technologies are available to provide simpler, lower cost simulations for smaller projects and on-going operations in order return suitable benefits. The value of dynamic simulation includes improve operational safety, decreasing lost production, improving project start-up schedules and ramp-up rates. These benefits are achieved using dynamic simulation applications for operator training, control system validation, and for process design validation. Best-in-class dynamic simulation packages have tools to reduce implementation and maintenance effort, and to provide functions that deliver value. These include features for training and certification, extensive alumina process equipment models, and control logic conversion tools.