THE DEVELOPMENT OF REAL TIME SIMULATIONS FOR OPERATOR TRAINING AT NABALCO

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Abstract

Nabalco has developed two real time dynamic simulations for operator training and control system verification. These comprise a Circulating Fluidized Bed Calciner (CFBC) simulation and a simulation of the Evaporation plant. The former was developed to aid in commissioning of the plant and control system. The latter was designed to train operators in startup and shutdown procedures and minimize the risk of carryover and subsequent environmental contamination.

Both systems rely on a high fidelity dynamic model to emulate the physical plant. In the case of the CFBC simulator, this was developed in MATLAB/SIMULINK and compiled using the Real Time Workshop. For the evaporation model, the dynamic version of SysCAD was used. Connection to the ABB/Bailey DCS was, in the case of the CFBC, via Hunter Control's Rapid Advanced Control Application development system (UNAC). In the case of the evaporation simulation it was via Matrikons OPC (OLE for Process Control) server. Minor modifications were made to the DCS logic to replace the IO (Input/Output) with model inputs.

To date all Calcination operators have been taken through the CFBC simulator training modules. Following the training sessions, an improvement in operator confidence and knowledge was noted by commissioning engineers. The CFBC simulation has also enabled the testing of safety interlocks and on one occasion managed to identify a conflict, which was subsequently rectified before it could contribute to a dangerous situation.

The evaporation simulation has been used to improve system architecture. It has been successfully connected to the DCS and validated against plant trial data.

1. Introduction

It is well accepted that having well trained operators is of vital importance to the efficient and safe operation of any plant. Not only does training raise the process understanding of the operator but it is also a vital component of any risk management strategy. As part of Nabalco's due diligence policy there has been considerable emphasis placed on operator training especially in light of events at Longford and Gramercy, investigations into which highlighted insufficient competency based training as a root cause of the failures.

Traditionally, operator training involves a period of instruction and supervised practice. Although this period is beneficial, the majority of the operator's skill is gained from experience built up over time. Invariably this learning curve involves a period of trial and error. It is clearly beneficial for the trainee to make errors on a simulation of the plant rather than the actual plant itself. For this reason Nabalco is pursuing the use of dynamic simulation in the training of operators.

The requirements of a successful simulation system are that the operator be

a) Presented with the same user interface utilised in daily plant control
b) Supported by an underlying model that faithfully represents plant behaviour to the required degree of fidelity

This generally requires that an offline copy of the control system (DCS) be connected to a high fidelity plant simulation. In this configuration the plant information required by the DCS, the values of the process variables, are supplied by the model. In return the DCS issues its PID outputs and control valve settings to the model, effectively controlling the simulated plant.

While modern Control systems are starting to introduce simulation capability, the development of such systems has, in the past, been costly and has often required development by the specialists. This made them difficult to reconfigure when plant modifications were made. The large amount of legacy equipment in current service also means that simulation systems generally need to be retrofitted. In recent times commercial software has become reliable and cheap enough for such systems to be developed in house. Thus at Nabalco it was decided to develop a training simulation system that could be configured and maintained by onsite personnel. The work at Nabalco had two goals: firstly, proving the benefits of simulation and, secondly, providing operator training modules in a cost effective manor and a platform for trialling advanced control options under simulation.

This paper will detail the two dynamic simulation projects undertaken at Nabalco to date:

- Fluidised Bed Calciner
- Evaporation Plant

2. Fluidised Bed Calciner

In 1999 Gove installed a Lurgi (now known as Outokumpu) Circulating Fluidised Bed Calciner (CFBC) for the calcination of Alumina Trihydrate. The CDBC was a new process unit for Nabalco of which there was little direct operational expertise. Added to this, as part of this process, a control room upgrade was undertaken, replacing old Fisher porter control indicators with ABB Conductor consoles. Consequently the operators in the area had to come to terms with both a new plant and a new control system.

It was hoped that the startup time of the system could be reduced by pre-commissioning the control system, pretuning the control loops and pre-training the operators. Consequently, both to satisfy the training requirement and

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meet the commissioning opportunity it was agreed to develop an operator training system based on a dynamic simulation of the CFBC.

Dynamic simulators had not been previously adopted at Nabalco for the purposes of operator training. Previous dynamic modeling work had focused on control system design and had only involved the development of stand alone simulations with no ability to connect to the control system. One of the outcomes of this project was to prove, at relatively low cost, the benefits of using dynamic simulation for the purpose of operator training.

The design of the CFBC simulation system is shown in Figure 1. The basic elements comprise a high fidelity model connected to an offline replica of the control system. The latter is identical down to the hardware level with the exception that the I/O termination racks have not been included. The two are linked via UNAC, a rapid prototyping tool developed by Hunter Control. UNAC connects via a serial cable to the DCS and adopts the ABB/Bailey monitor tune protocol to read and write to the DCS. Minor modifications were made to the DCS logic to accept input from UNAC. TCP/IP was used to interface UNAC to the model. Model I/O is mapped to control system I/O via a virtual wiring panel. This is stored as a database and code was written to traverse this database reading and writing the required values at the simulation update rate. A trainers interface was developed which allows simulation control and the addition of disturbances and instrument failure. The final element of the system is the control system interface used in the online system for the operator (ABB/Bailey Conductor).

On site expertise and onsite tools were deemed adequate to build the system. Specifically the model itself was developed in Matlab Simulink. Simulink itself is not a real time system but Nabalco purchased the Real Time Workshop specifically for this project. Using this system, flowsheets could be developed and simulations prototyped in a graphical environment. Once ready, the Simulink model could be converted to C code by the Real time Workshop. Code was then written to step the model in real time.

The user interface for the Trainer was developed in C++ using Microsofts Visual Studio integrated development environment and the MFC class library. The trainer interface, the wiring panel, the model, the real time code and code written to provide TCP\IP support were then compiled into one application "NABTrainer".

2.1 *The Model*

Simulink itself is a generic modeling system and has no process modeling elements. It is however highly customizable via user written 'S functions" and it is through these that the simulation system was developed. Three aspects needed to be catered for, Stream Vectors, Physical Properties and Unit Operation Models. The first two were already available as part of the general simulation environment, developed during previous control system studies. What was required for this project was the development of the necessary unit operation models.

A schematic of the plant is shown in Figure 2. The hydrate feed is dried by cooled furnace off gases and fed to an electrostatic precipitator. It is then pneumatically conveyed to a cyclone where it is heated by the direct furnace offgases. From there it reports to the furnace. Heat is recovered from the calcined alumina in a series of fluidized bed coolers. The first is used to preheat the combustion air and the second is fed by cooling water. The main unit operations in the system are:

- Furnace
- Cyclone
- Heat Exchangers
- Mixers and splitters
- Electrostatic precipitator

The simulation was not intended as a design tool and robustness was a more important consideration than accuracy. What is generally required in simulations like this is order of magnitude and trend accuracy. As such a number of simplifications could be made. Most process dynamics can be modeled as a series of lags (e.g mixed tank) and deadtimes (e.g. plug flow). Cyclones, mixers and splitters were therefore modeled as variations on a mixed tank. The furnace and the heat exchangers were modeled as combinations of mixed tanks. Specifically the furnace was modeled as three mixed reactors in series. Combustion of the fuel occurred instantaneously in the first reactor while hydrate calcination progressed throughout all. Variations in bed density were modeled by allowing solids holdup. A number of dead times were also introduced to the overall model, to represent transport delays (conveyors etc).

A flow driven simulation was chosen. This reduced the complexity of the system and eliminated the need for a pressure balance at each time step. Performance parameters and control system interlocks on this part of the process do not involve pressure measurements directly thus the fidelity of the system was not compromised by this choice.

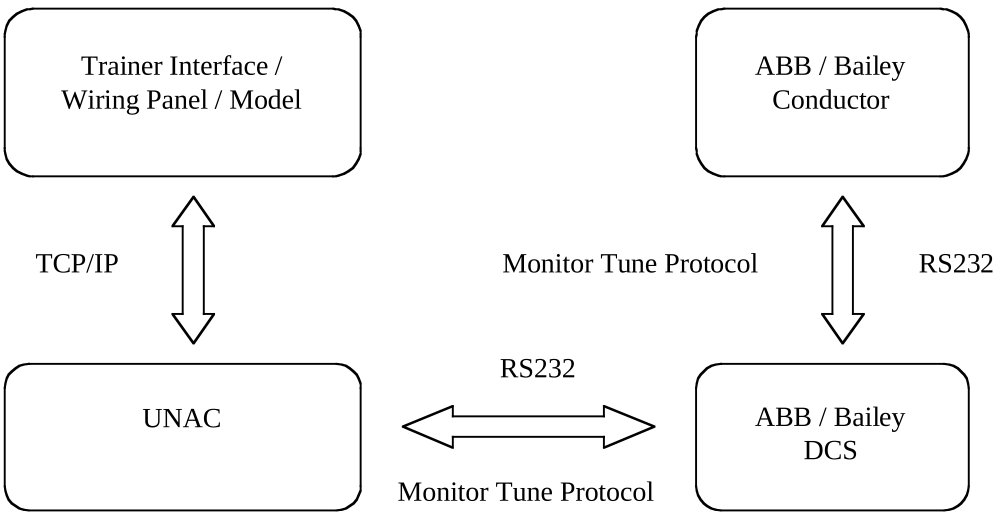

Figure 1 — Schematic of CFBC Simulation System.

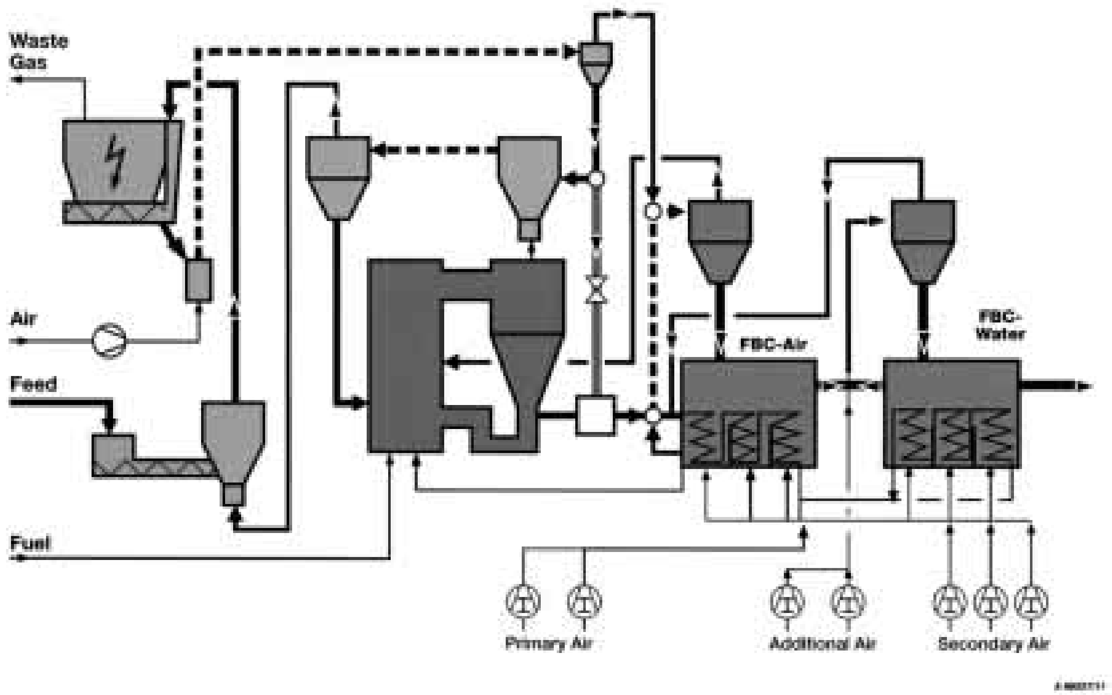

Figure 2 — Schematic of the Fluid Bed Calciner.

Any pressure drop measurements that were required were inferred from the solids mass flow through the system. The requirement to perform in real time resulted in the choice of a fixed step size explicit method (4th Order Runge Kutta).

2.2 *Model Validation*

During the development of the model the plant was not available to conduct tuning tests. Thus the model was tuned to a steady state model supplied by Outukompu and an inhouse model developed in Aspen Plus. The Hydrate reaction rate expression was modified to match the Loss on Ignition (LOI) against temperature curve supplied by Outukumpu. By validating at steady state we could ensure that the mass and energy balances were correct. During the commissioning of the plant further step tests were able to be performed on the physical plant. These tests included changes to the oil flow and feed rate to assess the temperature response.

2.3 *Training Modules*

Over the last 10 years Nabalco has been developing a competency based training system, recently aligning it to the Metalliferous Industry Mining package. The system has seen fruition in recent times with Nabalco winning the Australian National Training Authority's "Employer of the Year" award in 2000. A core aspect of this system is that a module exists for each job function. This module is a series of exercises designed to prove competency against a set of outcomes. These outcomes are defined by the package and are determined by industry experts. For the CFBC training system, a module was designed incorporating 40 exercises. The major aspects included

- Environment Recognition: Here the operator is introduced to all the elements of the user interface. Navigation through the various displays and normal values for all process tags are learnt here.
- Normal Startup: This runs from the preheat of the furnace to the introduction of feed. This is a problematic area. Air blowers must be introduced before the feed and the operator has very little time to adjust the fuel rate before the furnace temperature drops. If the furnace temperature drops too far, the system will trip.
- Interlock Recovery: This trains the operators in the correct response to trips. In some cases there was a significant difference between the CFBC and the rotary kilns the operators were used to. As an example a slug of product is interpreted as an ESP slide on the rotary kilns and the response to this is to stop the ESP blowers. With the FBC the correct response is to manage the increase in load by increasing the blowers and fuel rate.

2.4 *Training results*

One of the immediate benefits of the simulation system was the detection of an interlock conflict in the new control system. This problem was highlighted during the training when the plant was run in an extreme condition. These conditions have not yet occurred in practice but the problem has been able to be rectified before it could contribute to a dangerous situation.

The impact of the training the operators received was considered as successful by the Outukompu commissioning engineers. After initial commissioning the Outukompu engineers left site for a period of 6 weeks. During this time all operators were taken through the simulation modules. On return the Outukompu engineers noted that the skills of the operators had improved significantly.

3. Evaporation Plant

Nabalco operates an evaporation plant to re-constitute spent liquor (ex precipitation) for optimium strong feed liquor (feed to digestion). A schematic is shown in Figure 3. The system consists of 10 flash stages (5 positive pressure and 5 under vacuum) with 3 barometric condensers. Spent Liquor passes through 5 sets of heat exchangers and then a live steam heater before reporting to the flash vessels. It then passes through the flash vessels where water is driven off before returning through another 5 sets of heat exchangers. A portion of the concentrated liquor is recirculated to increase the evaporation rate and

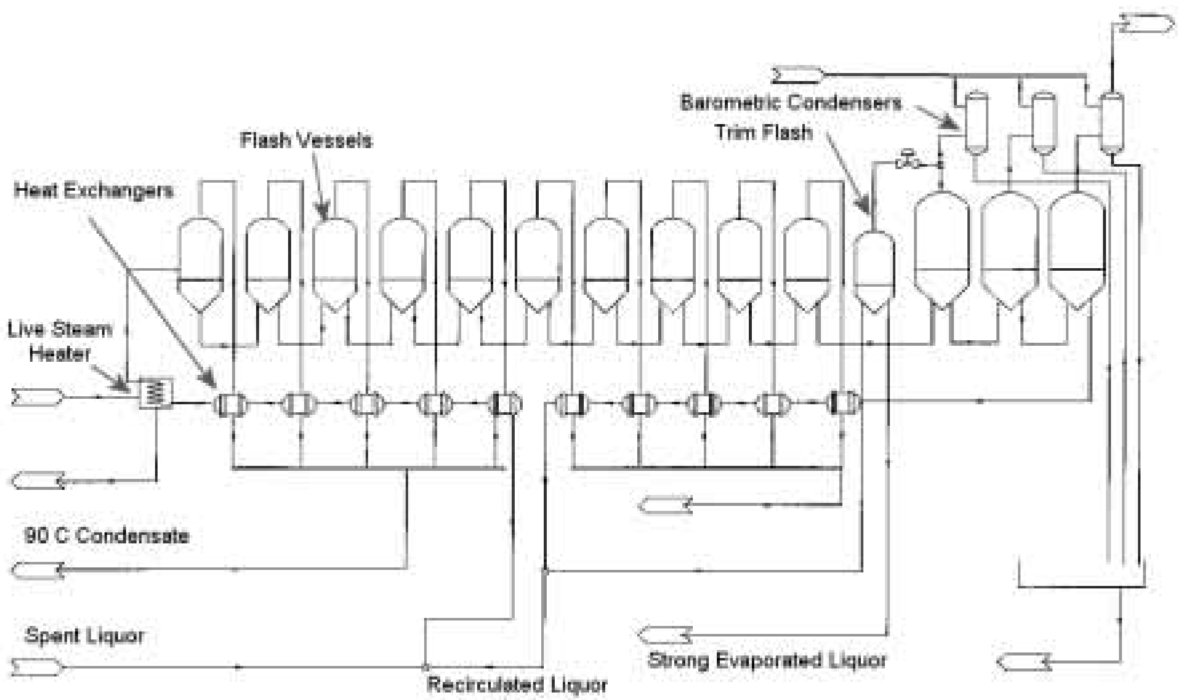

Figure 3 — Schematic of the Evaporation plant.

control the concentration. A trim flash unit is used for control of the discharge temperature. A constant flow of sea water is used to maintain the barometric leg in the barometrics and is discharged to the environment. Incorrect operation of the plant can result in carry over of process liquors into the sea water and thus the environment. The environmental risk exposure is increased during periods of startup and shutdown when the pressure profile changes significantly.

Following on from the success of the CFBC simulation and as part of Nabalco's due diligence policy it was decided that operators should be trained on a dynamic simulation of the evaporation plant before undergoing training on the plant itself. It was felt that this would minimize the risk of carryover to the environment and would form part of the competency based signing off process for operators.

3.1 *Nabalco's Real Time Dynamic Modelling Framework (RTDMS)*

In reviewing the development experience from the CFBC a number of potential improvements were identified.

1) The separation of the model/trainer interface/ wiring panel into separate components would allow easier reconfiguration of existing models (for plant and control system modifications) and allow easier configuration of new models.
2) The adoption of thin client technology would allow portability of the system. It would be possible to conduct training sessions anywhere on site.
3) The adoption of modeling system and trainer interface components that were flexible and easy to maintain would strengthen the configurability maintainability of the system.

It was also realized that the growing demand for simulation systems necessitated the establishment of a rapid development framework. Under this framework, all the major elements of the system; the model, the wiring panel, the trainer interface and the control system would be componentised and a set of standard interfaces developed for component interactions. The intention was that components could be configured and run independently and plugged together seamlessly. In this way, the system could run in the absence of one or more of the components or the components could reside on different machines. Configured correctly, components could be reused in future simulations. The system was also to be highly scalable. This would enable the simulation of multiple plant areas, possibly with different modeling platforms and control systems. With these factors in mind the following set of prerequisites were defined for the framework:

1. Support simultaneous connectivity to multiple modeling platforms and control systems.
2. Support the mapping of any control tag to any model tag via a virtual wiring panel.
3. Support manipulation of data flow between the control system and the model for an external trainer.
4. Support for start/stop/pause/continue of the modeling system.

In considering alternative development strategies including in house developed standards, it was determined that OPC (OLE for Process Control) supported the majority of the prerequisites. There was a concern that OPC would require an added development overhead to any in house models (they would need to support OPC as a server or client) however these were considered minimal compared to the advantage of working with an open system.

OPC effectively acts as the glue connecting the various components of the system together. In terms of the constituent components, a number of options were considered. On the control system side consideration was given to the use of UNAC. UNAC has the advantage of being both an OPC Client and Server and had the added feature of allowing a schematic to be developed which could serve as the trainers interface. Ultimately though it was decided to purchase Matrikon's OPC server for the Bailey SEM API. This had the advantage of using the later version of the ABB monitor tune protocol. The monitor tune protocol used by UNAC is an older version and is not currently supported and newer ABB/Bailey hardware would consequently be unable to be accessed by UNAC.

For the trainer interface a highly configurable graphical system supporting OPC was desired. Again UNAC was considered but ultimately Citect was adopted for its superior graphics. Citect also offered greater configuration flexibility through the use of Cicode.

The wiring panel was also managed by Citect. This, although somewhat counter to the philosophy of separation and encapsulation, avoided the duplication of tag databases and was the most practical solution. Mapped tags in the Citect tag database, had common names with read tags prefixed with an “r” and write tags with “w”. In a similar manner to the CFBC, Cicode was written to traverse the database searching for read tags. It would then search for the equivalent write tag and perform the transfer.

3.2 *The model*

One of the requirements of the simulation system is the ability to model the carry over of process liquor into the condensate and the seawater. It was considered that carry over is a function of the flash vessel level and the velocity of the flashed vapour. This, and the fact that a number of the evaporation plant trip points and interlocks are based on flash vessel level meant it was vitally important that the level in the flash vessels be modeled. For this a pressure balance was required and a pressure driven simulation was decided upon.

While all the model development for the FBC was carried out in house the requirement for a high fidelity pressure driven model lead to the sourcing of external expertise. Numerous alternatives were considered but eventually SysCAD was chosen as the platform for the model development, due to it’s low cost and focus on the mineral processing industries. Kenwalt (developers of SysCAD) have also had experience in developing pressure driven simulations for interfacing to control systems. Importantly SysCAD supports OPC as a client and a server.

3.3 *Model Development and Validation*

Since SysCAD supported the prerequisite unit operations, the modeling efforts could focus on flowsheet development and model tuning. The requirements for tuning were:

- The model satisfy the material and energy balances
- The model replicates the dynamics of the system
- Control valve and pump performance curves matched that expected by the control system.
- The model predict the flash vessel levels

The mass and energy balances were checked against existing models and plant design data. Model dynamics were checked against a plant trial. The trial was run over a period of 12 hours during which step changes were made to the feed flow, recycle flow, live steam heater temperature and barometric seawater flow. A comparison of model vs plant is shown in Figures 4 to 6. Here the temperature trends for several flash vessels are shown. As can be seen the requirement for order of magnitude and trend accuracy

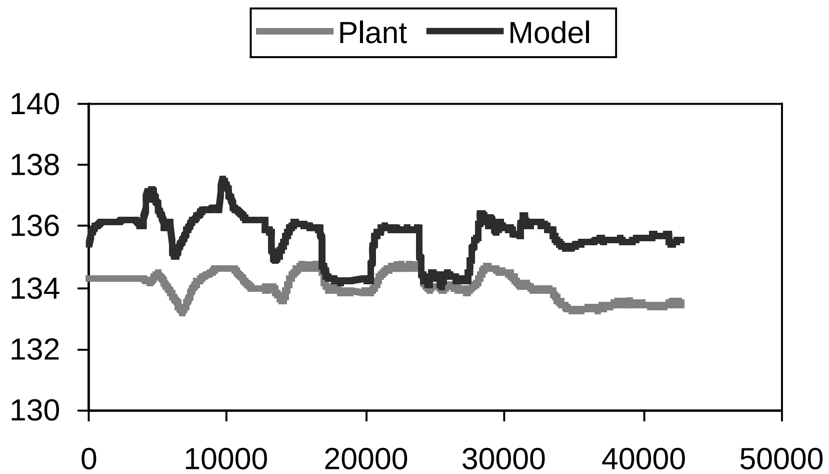

Figure 4 — 1st Flash vessel temperature trend; Model vs Plant.

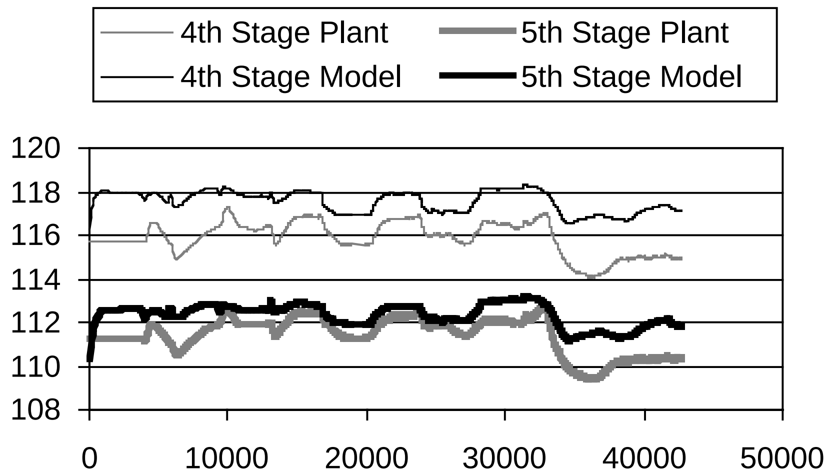

Figure 5 — 4th and 5th Flash vessel temperature trends; Model vs Plant.

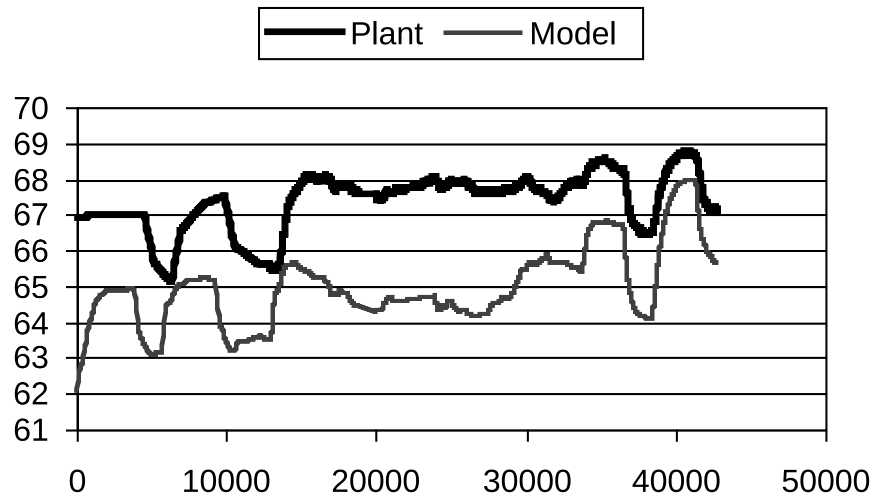

Figure 6 — 2nd Barometric flash vessel temperature trends; Model vs Plant.

has been met. It is also of note that the dynamics are reasonably well represented. This is important as the control loops on the DCS are expecting certain dynamics and if not met can result in an unstable control system.

One difficulty for the model was the prediction of carry over. This could not be validated via plant trials due to the obvious environmental issues. Instead reliance was placed on operator experience to indicate when a dangerous condition would arise and the model conditions at this point were used as a flag for the alarm. Effectively experienced operator personnel were asked what operating conditions were necessary to produce a carryover situation. These conditions were then input to the model to examine flash vessel level and vapour velocities. The values were then used as trip points for carryover in the simulation.

3.4 *Model/Control System Interaction*

A diagram of the Evaporation real time simulation system is shown in Figure 7. As can be seen the system was distributed across a number of PC's, affording portability of the training system. A conductor server and an OPC server connect directly to the ABB/Bailey DCS. These then connect to a trainer PC (housing the trainer interface and wiring panel), a trainee PC (Conductor client) and a model server via Ethernet. The conductor server and client communicate using an ABB/Bailey proprietary protocol while the remaining machines communicate via OPC. The underlying technology behind OPC is a Microsoft Technology called DCOM (Distributed COM), which requires careful configuration of security setting on all

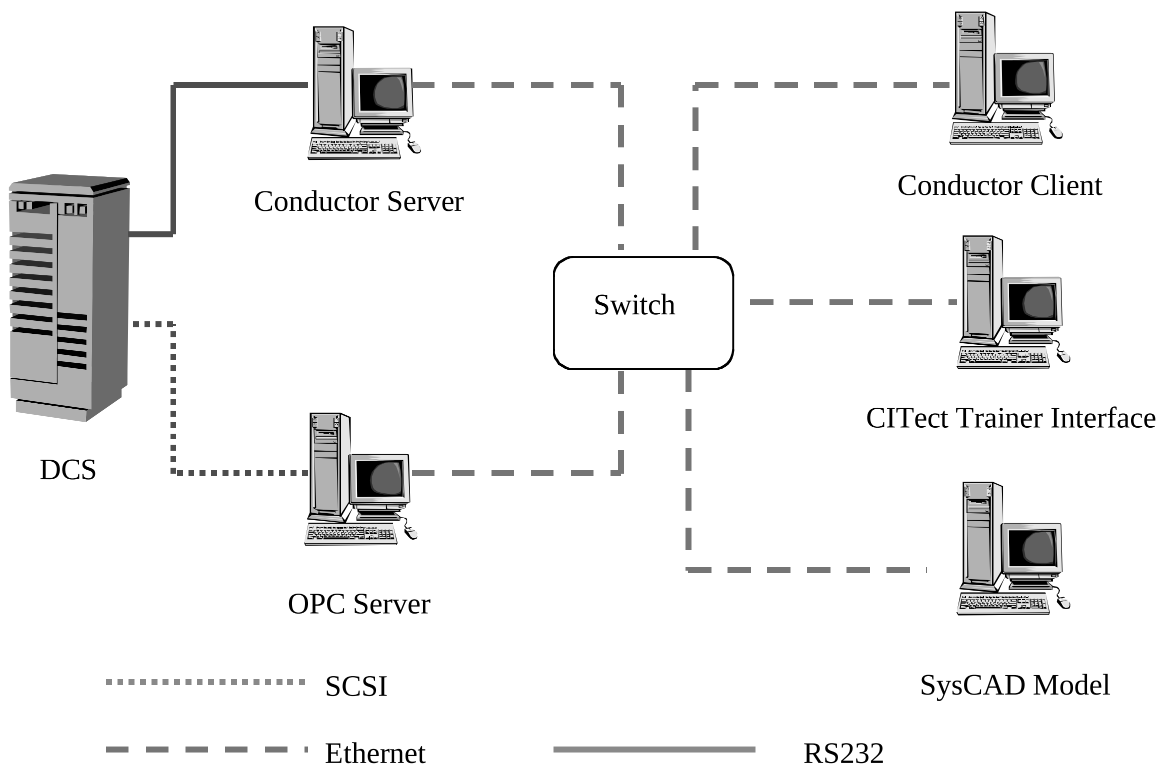

Figure 7 — Schematic of Evaporation Simulation system.

machines hosting DCOM servers. This proved problematic and ultimately required that every PC was on the same workgroup and logged in as the same user.

With OPC running, the interaction with the control system was seamless. The most difficult area was in the starting of the system. The evaporation simulation was a little more unstable that the FBC and as such the model could not be run on it's own without controllers. Fortunately SysCAD provides a scripting capability through its use of general controllers and code was able to be written to switch from local control to remote control (i.e from the control system).

One feature that was of great use was the ability to configure the model online. This enabled the sizing of control valves, pumps, and pipe resistances etc while the simulation was up and running. Since only minimal modifications to the control system were desired this was needed to stabilise some controllers. This can be likened to a kind of reverse of loop tuning.

Another beneficial feature of SysCAD was the ease with which the model could be reconfigured with unit operations added in a matter of minutes. Under the Simulink/RTW system, this required the generation of C code and recompilation of the system (Model/Wiring panel /Trainer interface). The graphical nature of SysCAD also made this reconfiguration easier to those unfamiliar with the model.

3.5 *Training Results*

At the time of writing model configuration was still underway and there have, as yet, been no actual training sessions conducted.

4. Conclusions

This paper detailed two projects that Nabalco has undertaken to produce dynamic simulation systems for operator training. This extended Nabalco’s previous dynamic modeling work by producing simulations that connect to the control system. The first project, a simulation of a fluidized bed calciner, was produced using in house expertise and tools. It was designed to prove the benefits of dynamic simulation at low cost. A number of training modules were produced and all in all the training proved valuable with improved operator knowledge and confidence noted by Outukumpu personnel. The simulation also highlighted an interlock problem that was corrected before plant commissioning.

The second project was the simulation of Nabalcos evaporation plant. The evaporation project was conducted to exploit the success of the CFBC project and was used to develop a dynamic simulation framework to facilitate the rapid development of future simulation systems. The componentisation of the system and the use of OPC for component connectivity was adopted. This and the use of a graphical modeling development tool made the system easier to configure and maintain.

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