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REFRIGERATION LOOP DYNAMIC ANALYSIS USING PROTISS

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Abstract - Integrated steady state and dynamic simulators represent the next step in the development of process modeling and simulation. PROTISS™ is one such simulator developed by Simulation Sciences. This general purpose process simulation package provides users with an analysis tool through the design phases of a project as well as allowing users to design and test viable control and optimization systems. Operability issues involving optimal process design for the entire range of process operation can be addressed effectively. Furthermore, control and instrumentation issues such as variable pairing, observability, and model mismatch can be addressed earlier in the project. This paper describes the use of the dynamic simulation tool for the operational analysis of a multi-stage refrigeration loop. Particular attention is given to analysis of advanced control system check out and tuning. Studies discussing model validation and tuning are presented for varying cooling load and demand changes and compressor upsets. The ability of the dynamic simulator to solve complex process configurations in real time using high fidelity models is described. The user is able to describe the process configuration in engineering terms. Discussion is provided to highlight the program's ability to solve complex and advanced control configurations. Simulation studies show the utility of using dynamic simulation for the analysis of control strategies with respect to the units performance and robustness issues during events such as load changes and disturbances.

PROCESS DESCRIPTION

One of the prime quality variables of natural gas produced in oil company operations will be its hydrocarbon or water dewpoint. There are several means of achieving the dewpoint dependent upon circumstances, but one common method is to use mechanical refrigeration as a source of cooling to which the process gas is subjected. The process gas is cooled to a defined temperature, and when the working pressure is allowed for, this represents the dewpoint of the gas. The process under study in this paper is such a refrigeration circuit. The natural gas flow is not part of the simulation other than to provide a load for the refrigeration circuit.

The choice of refrigerant is dependent on the required amount of chilling and in this case the refrigerant is commercial propane. The refrigerant loop is based upon a centrifugal compressor with the propane being compressed to some 23 baras. The propane is condensed with an air cooled heat exchanger, and the condensed propane is admitted to the shell side of a kettle heat exchanger through which the process gas is flowing on the tubeside. The latent heat taken up by the vaporizing propane provides the required chilling of the process gas. The vaporized propane is returned to the suction of the compressor.

The shell side of the chiller operates at about 4 bars, and in order to increase the efficiency of the circuit, the high pressure propane is flashed to an intermediate pressure; the vapor evolved from this flash being routed to an intermediate stage of the compression process. The liquid from the flash is routed to the chiller.

There are two main inventories of liquid propane in the circuit, the first being the shell side of the chiller, but the main quantity is in the propane accumulator downstream of the condenser.

CONTROL DESCRIPTION

Control of the process gas temperature exiting the chiller is the prime objective of the process. This is determined bye the quantity of heat removed and hence the amount of propane vaporized in the chiller. The amount of propane vaporized is in turn determined by the surface area available and the temperature difference across the exchanger. This latter is in turn determined by the pressure of the vaporizing propane. The system as installed depended on a manual adjustment of the level of propane in the chiller to control the process temperature.

Levels in the flash vessel and the chiller are conventional and the remainder of the circuit can be largely self balancing. However, on the system as installed, a temperature controller on the discharge of the condenser is installed which manipulates the number of fans operating on the exchanger. A separate pressure controller bypassing an amount of gas around the condenser is also installed.

As with any centrifugal compressor system, protection of the compressor against surge is required. In the installed plant, this is accomplished by an integrated proprietary antisurge system which monitors the performance of the compressor stages and opens a recycle valve as the machine approaches surge. In the model, this proprietary system is replaced by two PI controllers operating on a generic surge parameter measurement. Unlike most compressor systems with recycle gas cooling by heat exchanger, this system uses a direct cold propane quench from the interstage liquid to provide the cooling. The liquid quench and suction temperature control are enabled when the recycle valve opens.

MODEL DESCRIPTION

The PFD (is an abbreviation for Process Flow Diagram. This is a term commonly used by process engineers for a summary representation of the process and is used within the PROTISS context to mean the steady state representation of the process) or steady-state simulation consists of 9 major unit operation models and 11 simple pipes models. Simple pipes are used in the PFD to account for piping pressure drops. These pressure drops are used by the simulation program automatically to calculate piping node volumes and equivalent piping CV's used for pressure drop calculations during dynamic simulation calculations. A steady-state single variable controller is used to manipulate the recirculation rate in the circuit to a desired refrigeration load. Following the successful matching of the PFD conditions, the simulation program automatically generates an open loop P&ID (is an abbreviation for Piping and Instrumentation Diagram. This is a term commonly used by process engineers for a detailed representation of the process including the details of instrumentation. It is used within the PROTISS context to mean the dynamic representation of the process.) or dynamic simulation from the results of the steady-state simulation. The automatic generation process of the P&ID is discussed in other references by the author.

The propane refrigeration circuit is represented by a multi-component mixture of Ethane, Propane, Butane, and Iso-Butane. Propane accounts for approximately 94% of the stream composition. The process load is represented by a mixture of Methane, Ethane, Propane, Butane, Nitrogen, and Carbon Dioxide. Methane accounts for approximately 77% of the stream composition.

Starting from the open loop P&ID, additional equipment and streams are added to complete the P&ID. The additional equipment includes drivers, process control, recycle lines and emergency shutdown logic. All process units are modeled rigorously using first principles dynamic models. Thermodynamic and physical properties are calculated using a local model approach to accelerate execution speed.

A single motor driver is used to drive both compressors. A flow controller is used to set the process load feeding the vaporizer (E2). Load changes are implemented by changing the setpoint of the controller. A flow controller is used to set the Air rate to a bank of fans that supply the necessary flow to the condenser (E1). The controller receives a setpoint signal from a calculation block that determines the strategy to turn on or off fans based on the exit temperature of the condenser. Level controllers are used for the vaporizer (E2) and propane flash drum (F2). A pressure controller is used to set the bypass rate of the condenser

(E1) back to the propane accumulator (F3). The surge control system sets the recycle rate from the discharge of compressor (C2) to the inlet of compressor (C1). In the event that the surge control system turns on, a calculation block is provided to turn on a temperature control valve. The temperature control valve bypasses propane from the feed of the vaporizer to the discharge of the vaporizer. Thus, providing direct quench with the result of cooling down the circuit.

The model consists of more than 200 unit operation models, 7000 unit operation variables, and 450 streams. Actual equipment performance data was used in the model such as compressor performance curves, heat exchanger details, vessel sizing and valve size CV's.

Heat and material balances are solved rigorously over the entire model at each integration time step. A combination of simultaneous and sequential modular solution techniques are employed within the model. Simultaneous techniques are used to solve the pressure-flow networks (mass balance), whereas control systems and logic functions are solved in a sequential modular basis. It has been found that a combination of such techniques provides high accuracy, model robustness, and fast computation.

STUDY

The objective of the study is to demonstrate that a simpler control of the compressor circuit which allows the self balancing nature will be as effective as the present scheme, and that control of the pressure in the chiller (hence temperature of the vaporizing propane) will be more effective at controlling the process gas dewpointing.

In order to make these changes, a TC on the process gas outlet of the chiller is cascaded onto a pressure controller which measures the pressure in the chiller propane side. This pressure controller acts on the vapor discharge line from the chiller to the compressor suction. Since the heat transfer is dependent on LMTD, controlling the pressure in the chiller vapor space will hence control the vaporizing temperature of the propane, hence the LMTD. The antisurge control will take care of any tendency for the compressor suction pressure to become too low.

The other change in the control is to modify the discharge system. Presently, the temperature of the propane is controlled by the fin-fans (step change in load through switching fans on and off). The liquid propane enters the accumulator through the bottom and the pressure is independently controlled by a bypass around the fin-fans to provide a vapor blanket. In the simplified system, the liquid propane exiting the condenser goes into the top of the vessel and the pressure is controlled by switching the fans. The bypass is eliminated and the temperature control becomes only a control to limit the minimum temperature (hence pressure) that the system can attain.

RESULTS

It will be appreciated that in even an apparently simple a process such as this, there are major differences in the time constants. The compressor represents a very fast acting system, with internal flow changes occurring in fractions of a second. However, the large volume of propane in the accumulator and large thermal masses of the high pressure containing equipment represent a set of altogether longer time constants. For a dynamic model to demonstrate good agreement with plant data, therefore is a not insignificant task. It is essential that this is achieved before the analysis of modification to the control system is undertaken. Figures 3&4 show the response of the compressor flows to a large reduction in load. The authors consider that these results do represent good agreement with plant data, especially given the limited numeric and temporal resolution of the field data available to the authors at the time of writing.

CONCLUSION

Dynamic simulation has traditionally been an area for specialist companies working with arcane tools to provide dynamic analysis of process designs. This is often carried out late in the design process such that limited opportunity for design optimization is possible. In the area of plant operational analysis, unless major problems are required to be solved, dynamic simulation often proves too costly and time consuming a methodology.

With the availability of this new generation of integrated tools, the use of dynamic simulation as an extension of the process flowsheeting work much earlier in the life cycle provides a significant opportunity for capital cost saving improved plant operability.

FURTHER WORK

The work so far has shown the ability of PROTISS to be used to match actual plant performance to a dynamic simulation in an easy way. Future work will look at the upgrade to the control schemes of the plant and this will be reported as a presentation to the conference.

REFERENCES

Goldfarb, S., D. Mills, A. Terroux, PROTISS, A Dynamics Modeling Environment, *Chemputers Europe*, October 1995.

Anderko, A, J.E. Coon, S.M. Goldfarb, Local Thermodynamic Models For Dynamic Process Simulation, *ADCHEM*, May 1994.

Figure 1: Process Flow Diagram

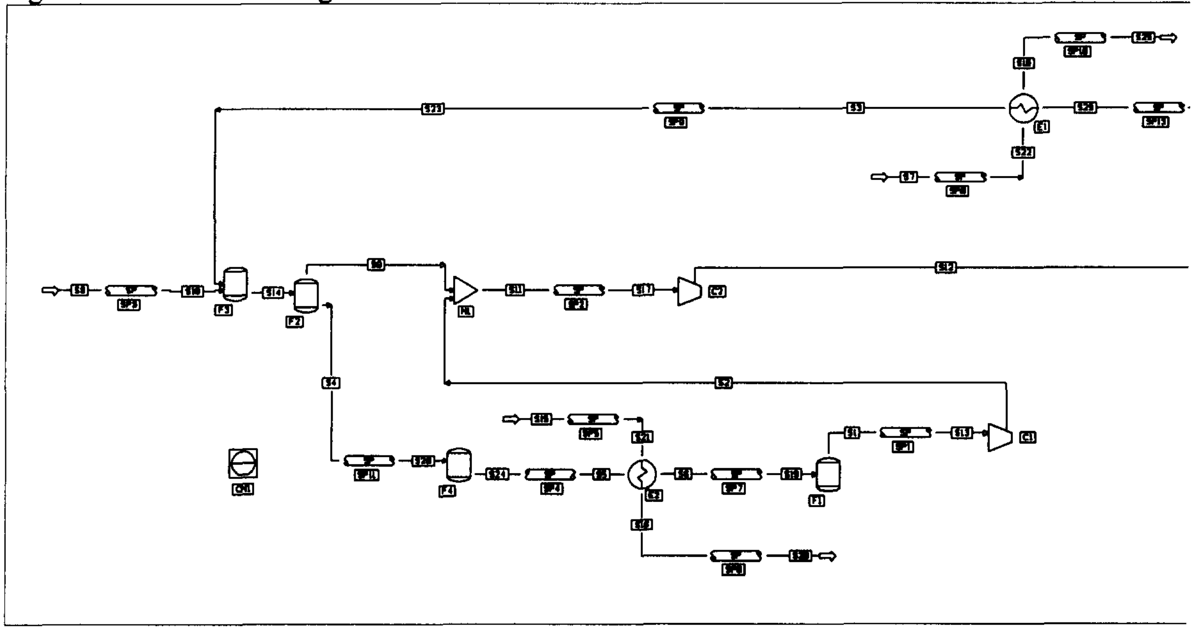

Figure 2: Piping & Instrument Diagram

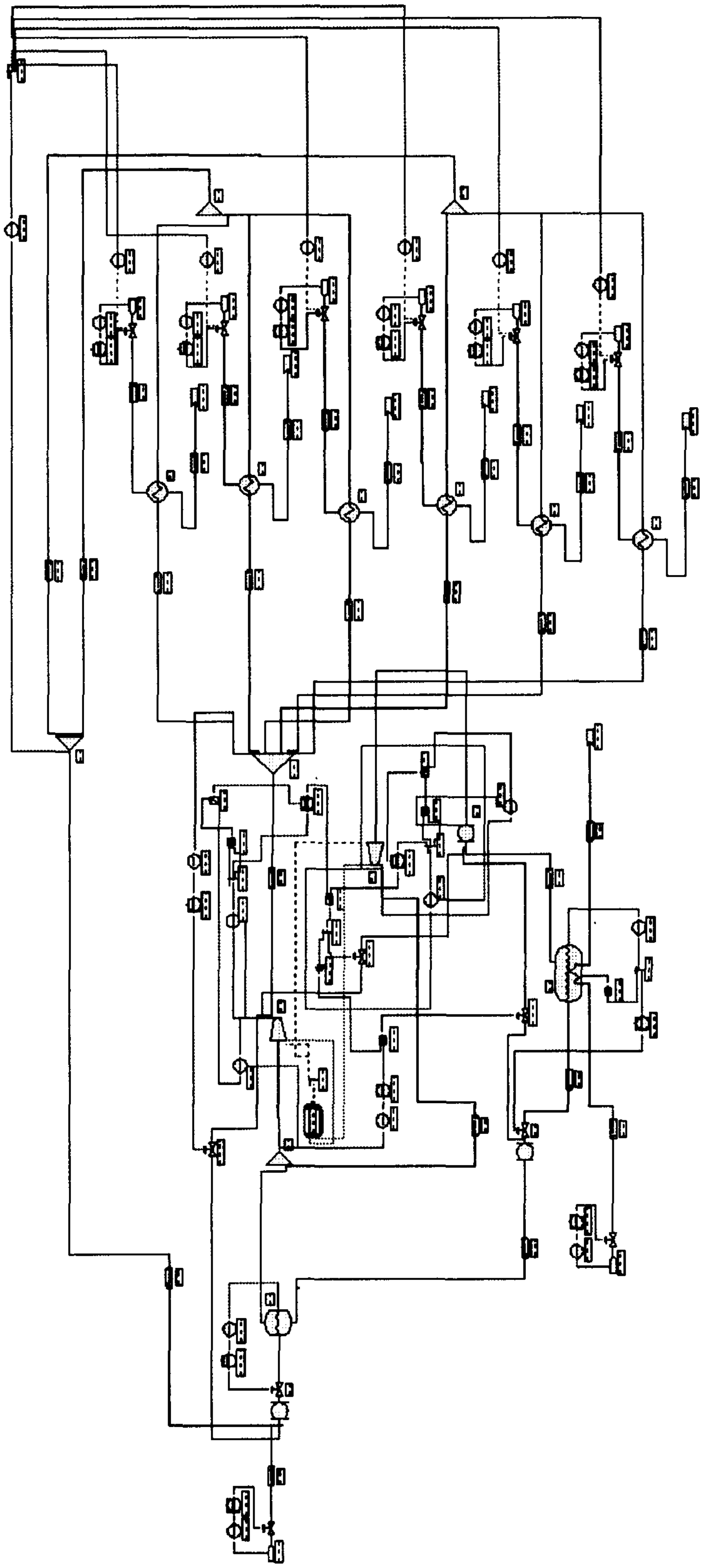

Figure 3: 1st Stage Flowrate

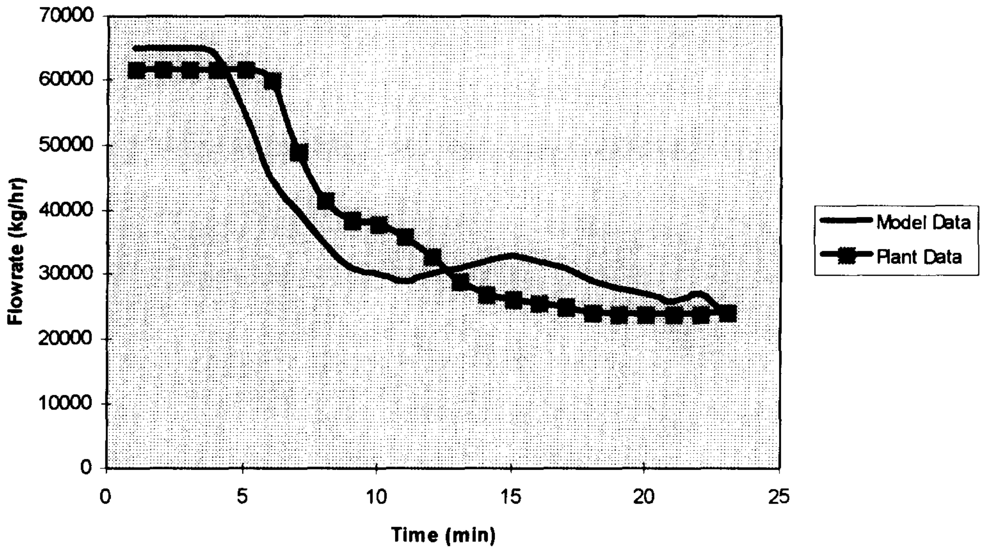

Figure 4: 2nd Stage Flowrate