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USING REAL TIME DATA WITH RIGOROUS MODELS TO OPTIMIZE PLANT PERFORMANCE

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ABSTRACT

On-Line optimization of process units has heretofore been restricted to the individual equipment level using linear approximate models. The advent of the low cost, high speed micro-computer coupled with the speed and robustness of an equation based exact simulator is making real-time optimization of entire process units a reality. The resultant implications for a decision system applied to day-to-day operations, point to a significant change in the way process plants will be managed in the future.

INTRODUCTION

In the past, the application of exact or rigorous models has been limited to the design and off-line operations analysis of process plants. It is now within our reach to integrate this same level of precision into a decision system for real time on-line analysis and optimization of individual processes. The value of this decision system based on exact models extends far beyond optimization. It is the beginning of a whole new way of managing process plants.

ChemShare's ProCAM^{sm} is a new technology employing rigorous models for process computer aided manufacturing. It is a management decision system for process plants, aimed at maximizing the return on existing assets.

Effective decisions require timely, reliable information of economic value for people to make profit making decisions.

Unfortunately business today is faced with an overload of information which is neither timely nor reliable.

Our task is to filter out the dependent information and identify independent variables available for action. Once identified an analysis technique must be engaged to guide decisions.

ProCAM serves this function by combining process data with market place economics to provide the accurate analysis needed for profit making decisions.

PROCESS PLANT DECISION SYSTEM

At the heart of this system is an equation based exact process model developed through over 20 years of process modeling experience. The uniqueness of this model is its computational speed - 100 to 1000 times faster than previous exact models.

This speed has been complemented by the evolution of the mini-super computer and the distributed control system, DCS. Computers have decreased in cost while increasing in both memory and calculation speed. Previous limitations to on-line work. Distributed Control Systems continuously monitor and electronically log mounds of process data heretofore unattainable.

At the same time another computer system evolution, management information systems, has been accumulating economic data for after-the-fact accounting purposes.

The objective of ProCAM is to combine the accounting perspective of the information system with the engineering perspective of the process data system through an exact on-line model to control profits from a real-time perspective. The goal being to manage by way of profits instead of just controlling cost.

OPTIMIZATION OF PROCESS OPERATIONS

There are basically three levels of optimization in the process industry: long range, day-to-day and actual operation control.

Long range planning is normally performed off-line using linear programs (LP's) based upon narrow ranged linearized correlations and are often global in nature.

Optimization of actual operations are being implemented through advanced control techniques using linear approximate models. These systems are intended to optimize individual equipment performance.

The gap until now has been accurate day-to-day planning and optimization. ProCAM fills this gap with a real-time optimization system that can also be addressed off-line for "What if?" studies. ProCAM considers the overall process using a non-linear rigorous model.

ProCAM can be used to update LP performance gradients for long range global studies while at the same time receiving economic information on inter unit pricing.

Actual operations provide ProCAM real-time process data to calculate the optimum target set points. ProCAM can also provide undated gradients for linear approximate models controlling individual equipment.

DATA RECONCILIATION AGAINST EXACT MODELS

We begin an on-line analysis by first reconciling the measured process data and calibrating the model to the plant. Process measurements are subject to two types of errors: random errors, which are inherent measuring inaccuracies, and gross errors, which are caused by miscalibrations or malfunctions. These measurement errors produce inconsistent sets of data which violate material balance, energy balance, and equilibrium equations and cause numerous problems for engineers trying to evaluate process unit performance.

Data reconciliation is a statistical procedure which enables the adjustment of data so that weighted differences between calculated and measured values are minimized subject to the modeling equations.

Selected measurements are used as input to the model. Differences are compared between the calculated values based on the model inputs and the measured values. Variables are statistically manipulated until the error between the measured and calculated values is minimized. The total amount of adjustments are also minimized. Gross errors are detected, eliminated from the measurements and reported for maintenance of the instrument.

The objective is to determine the best set of adjusted process data which satisfies the energy and material balances for the process in conjunction with the laws of nature. The model must match the plant at the current operating point before any analysis or optimization can be performed. Heat exchanger ratings are calibrated to match the actual observed fouling factors. Distillation stage efficiencies are calculated and adjusted for actual conditions. Other equipment models are calibrated to determine their current operating efficiency.

The result is a statistically consistent set of data not only useful for further modeling analysis but also for accounting and statistical quality control (SQC) programs.

CRUDE UNIT EXAMPLE

Let us look at how ProCAM can be applied to a refinery process unit. We have chosen a crude unit for simplicity but the same method can be applied equally to other units.

We have a 100,000 BPD crude unit consisting of an atmospheric tower, vacuum tower and heat exchanger network. The heat exchanger network is modern with a total of 35 heat exchangers designed with pinch technology that takes full advantage of flow splits and multiple exchanges of products and pumparounds against crude. The objective of on-line analysis will be to improve the profitability of the current operation by manipulating the operating variables.

The first step in performing the optimization is to consider the mechanical constraints to be imposed upon the process. Each potential limit must be identified and a method of analysis determined. All equipment will be rigorously rated during optimization. Exact modeling allows for the detailed rating methods necessary for true optimization to be employed.

Next, the economic objective function must be defined. We have chosen a very elementary function for this example. The objective is equal to the sum of all product values less the sum of variable utility costs. to maximize "pre-tax profit". The objective function is The cost of crude, was omitted because the rate was constant for this example.

TABLE 1

MECHANICAL CONSTRAINTS

Limiting Elements	**Analysis Method**
Design Pressure of Equipment	Max/Min Press. Limit
Preheat Train Surface Area	Heat Exchanger Rating
Fired Heater Capacity	Heater Rating
Overhead Condenser Capacity	Heat Exchanger Rating
Tower Loading - Max. & Min.	Hydraulic Tray Rating

There are 28 independent variables that can be manipulated, including 6 product specifications. All of the variables are available for optimization. For purposes of this example, we are going to hold the product specifications constant throughout the optimization.

TABLE 2

ECONOMIC OBJECTIVE FUNCTION

Component Elements	**Values Assigned***	
Light Naphtha (LN)	19.85	$/BBL
Heavy Naphtha (HN)	20.10	
Kerosine (KER)	20.70	
Diesel (DIE)	19.60	
Light AGO (LAGO)	19.40	
Heavy AGO (HAGO)	18.10	
Vacuum Ovhd (VOHD)	18.00	
Lube Cut (Lube)	19.80	
Heavy VGO (HVGO)	18.00	
Deep Cut VGO (DCVGO)	18.00	
Vacuum Resid (VR)	17.00	
Fuel Gas	2.25	$/MMBTU
Stripping Steam	1.00	$/MLB

Objective Function = Product Values - Fuel Costs - Steam Cost

*Basis Spring, 1987

TABLE 3

AVAILABLE PROCESS VARIABLES (28)

Atmospheric Tower	Vacuum Tower
Feed Rate	Vacuum Tower Pressure
Atmospheric Tower Pressure	Temperature of Top Tray
Temperature of Top Tray	Temperature of Pumparound Return
Upper Pumparound Rate	Lower Pumparound Rate
Lower Pumparound Rate	DCVGO Product Rate
Overflash Rate	Overflash Rate
Stripping Steam Rates (6)	Stripping Steam Rates (2)
Bottoms Rate	Bottoms Rate
Product Specifications (4)	Product Specifications (2)

Numerous different sets of the remaining 23 variables could be selected. This technology has been applied to processes much more complex that this and could easily handle all 23 variables, but to simplify presentation we used only 6 variables for this example.

Tower pressures, pumparound rates and overflash are important in crude oil distillation. Increasing tower pressure increases vapor handling capacity but decreases separation. Pumparound rates control the amount of internal reflux which effects both separation and tower capacity. Overflash is directly related to the amount of feed vaporized. Increased steam provides better separation but increases vapor traffic.

Table 4 shows the movement of the optimized variables from initial to optimum. Note how much the optimized variables changed. In multivariable optimization, as in this example, large changes in variables are common and lead to significant improvement even though the response surfaces are relatively flat.

TABLE 4

SELECTED OPTIMIZATION VARIABLES (6)

Atmospheric Tower	Initial	Optimum	%
Top Pressure, PSIA	28	23.9	-14.6
Upper Pumparound Rate, MOL/HR	800	300	-62.5
Lower Pumparound Rate, MOL/HR	2,000	2,240	+12.0
Kero Stripping Steam, LB/BBL	5.5	7.1	+29.1
Overflash, % on crude	5%	8%	+60.0
Btm Stripping Steam, LB/BBL	2.4	4.0	+80.0
Vacuum Tower			
None			

Of the six optimization variables, top pumparound rate reached its lower limit and overflash reached its upper limit. Both of the arbitrarily specified limits could be relaxed to obtain further improvement in profit.

Of the mechanical constraints, only one, tray loading below the upper pumparound, was active at the optimum. Optimization almost always drives some constraints to their limit. Knowing what limits constrain operations is important in studying how to improve unit or plant performance.

Table 5 presents the technical results of the optimization. The bold numbers represent the fixed product specifications that were held constant throughout the optimization. The 5 - 95% gaps show a significant improvement in product separations in the atmospheric tower resulting in a shift in yield structure. Particularly the 36° improvement in the bottoms.

TABLE 5

TECHNICAL RESULTS

	INITIAL				**OPTIMUM**			
Products	**Flash PT °F**	**TBP EP °F**	**TBP 5-95 °F**	**Yield Vol %**	**Flash PT °F**	**TBP EP °F**	**TBP 5-95 °F**	**Yield Vol %**
LN		312		15.3		320		16.5
HN		390	-46	6.5		380	-42	4.6
KER	**130**	**530**	-41	13.8	**130**	**530**	-34	15.6
DIE	178	**615**	-103	14.2	184	**615**	-92	13.7
LAGO	242	**710**	-91	11.8	247	**710**	-82	12.9
HAGO	297	829	-110	4.6	308	818	-91	2.9
ARC	274		-190	33.8	298		-154	33.8
VOHD	268	779		5.4	276	781		4.4
Lube	**350**	**925**	-71	8.9	**350**	**925**	-73	10.1
HVGO	406	1067	-128	6.7	409	1067	-130	6.5
DCVGO	444	1200	-220	6.4	446	1200	-224	6.4
VR	540		-209	6.4	540		-209	6.4

The bottoms rate from the atmospheric tower is a potential optimization variable, but it was fixed for this example. Thus the atmospheric tower produced more of the more valuable products at the expense of the less valuable.

The lube draw from the vacuum tower is confined by specifications at both light end (Flash point = 350°F) and heavy-end (TBP (EP) = 925°). Better separation in the atmospheric tower permits more of this valuable product to be made in the vacuum tower without increasing the feed rate to the vacuum tower.

The overall economic result of the optimization, presented in Table 6, is to use more energy to give better separation to produce more of the higher value products. The combined results show a "pre-tax profit" improvement of over $5,000 per day or over $1.8 million annually. The optimization actually increased operating costs (fuel and steam) but more than compensated by producing more of the higher "value-added" products. Under a strict cost-centered management approach this solution might not be implemented -- it increases operating costs over $200,000 per year. Only when the entire business picture is evaluated can true bottom line impact be determined.

ON-LINE ANALYSIS STEPS

We have just described an example of how ProCAM can manipulate operating variables to improve operations, but how does ProCAM perform on-line the steps necessary to produce the results?

A ProCAM run begins by monitoring key process variables as a function of time to determine steady state. Once steady state is determined, a time average

TABLE 6

OVERALL ECONOMIC RESULT

Component Elements	Values Assigned $/BBL	OPTIMUM - INITIAL % Yield	$/Day
LN	19.85	+1.2	+25,266
HN	20.10	-1.9	-38,753
KER	20.70	+1.8	+36,680
DIE	19.60	-0.5	- 9,976
LAGO	19.40	+1.1	+21,010
HAGO	18.10	-1.7	-30,535
VOHD	18.00	-1.0	-17,607
Lube	19.80	+1.2	+22,275
HVGO	18.00	-0.2	- 2,664
DCVGO	18.00	0	0
VR	17.00	0	0
	Subtotal Products		**+ 5,696**
	Fuel	+ 4.5%	+ 560
	Steam	+10.5%	+ 26
	Subtotal Utilities		**+ 586**
	Products - Utilities		**+ 5,110**

Annual Improvement = $1,865,000

set of process measurements is taken from the process. These initial values are screened for obvious gross errors and suspect measurements are identified and set aside. The screened data is then reconciled against the rigorous model of the process. Additional suspect measurements are identified and combined with the original list and reported as Bad Instruments. Data reconciliation also provides a list of equipment information pertaining to fouling factors, catalyst activities and others.

Once the data are reconciled they can be combined with current economic data to perform multi-variable optimization as in our previous example. Optimum conditions are reported to management for implementation by the control system.

Once a new steady state is reached the system is ready to begin again.

EXPERIENCE OF A LEADER

We have recently installed ProCAM for an oil and gas production company at its 240 million standard cubic foot per day (MM scfd) Natural Gas Liquids (NGL) - Nitrogen Recovery Unit (NRU).

The plant consists of two identical fractionation trains, requiring modeling a total of over 100 pieces of equipment. The heat pump and refrigeration fluids are common to both trains requiring the simultaneous solution of both trains to determine system interactions. Over 450 process measurements are reconciled to the rigorous model.

Each train consists of an NRU column, expander/compressor, demethanizer column and cold boxes.

The cold units consisting of brazed aluminum plate-fin heat exchangers. All operations are rigorously modeled in ProCAM including thermal rating of the cold box exchangers.

The hardware configuration, Figure 1, for this installation consists of two process computers. A MicroVAX II operating in VMS and an Apollo DN 10000 operating in UNIX. Communication is accomplished through an ethernet system by Excelan.

Data is obtained from the DCS by a plant information package which resides on the MicroVAX. The ProCAM executive program communicates with the plant information package monitors for steady state and manipulates input and output files is also on the MicroVAX.

The Apollo DN 10000 is a 30 MIP machine which handles the actual ProCAM calculations. All ProCAM models reside on the Apollo. Access is also provided via modem for headquarters and remote locations to check plant status and do off-line "What if?" studies. Results are displayed in summary tables on the CRT's with detailed hard copy printouts available for trouble shooting and analysis.

While the system has only been on-line a few months it is clear that the payout will be less than one year. Data reconciliation alone has uncovered several operational inefficiencies that only rigorous modeling could detect.

VALUE OF ON-LINE ANALYSIS

The company most experienced in on-line optimization, based on published information, is Shell Oil. Their experience shows that process optimization conservatively increases the "value-added" by the process by 3% to 5%.

The additional benefit of data reconciliation is evaluated case-by-case. It is the fastest way to detect errors in instrumentation and can have great value in monitoring equipment performance factors. It is also a source of consistent, filtered data for accounting and statistical quality control (SQC) programs.

Reports on calculated performances of instruments and equipment are maintained to improve plant safety by identifying potential hazards before they occur.

An additional benefit of on-line exact models is the capability to do off-line "What if" studies using real-time data. The same tool which analyzes current operations can be used to analyze a feed stock change before it is purchased or the effect of anticipated product pricing changes.

Supply optimization always is important when feedstock alternatives are available. In such cases, supply optimization can be of more value than process optimization.

Classically much engineering has been required to locate bottlenecks in processes. On-line analysis constantly identifies all bottlenecks and thereby, significantly reduces the time required to engineer retrofits.

CONCLUSION

The value of ProCAM exact models extend far beyond optimization. ProCAM is leading the transition from cost-centered operations to true profit-centered management. Process plants which apply this technology will gain a significant advantage. ProCAM truly is changing the way process plants are managed.

FIGURE 1

HARDWARE CONFIGURATION