FLEXIBLE PREDICTIVE CONTROL FOR CHANGING OPERATING MODES ON TWO DISTILLATION UNITS

This article shows how complex control objectives were satisfied using powerful features attached to the regular multivariable predictive controller. The control objectives and results are described.

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These applications were done on a crude distillation unit designed to process 66 TBSD of crude oil per day and on a vacuum distillation unit (27 TBSD) at the Mobil Oil refinery in Normandy-France.

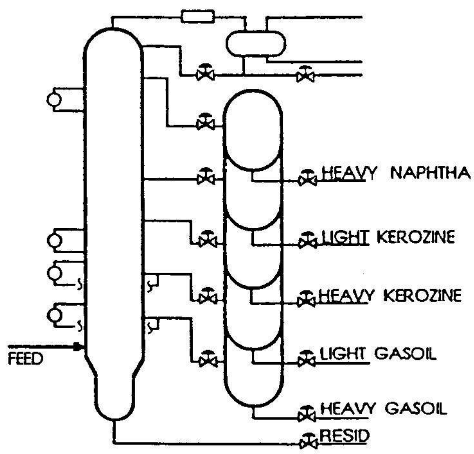
The control tool that has been selected in June 1988 to achieve the project is the IDCOM-HIECON (*) control algorithm because of its interesting functionalities and capabilities. A previous application of the same IDCOM- HIECON had been applied to the recovery section of a solvent dewaxing unit the year before with success and bad shown some of its possibilities. Both applications started after a feasibility study. In June 1989, the refinery got a detailed design for the atmospheric distillation project describing the operating modes to be taken into account and all the corresponding control strategies.

The following parts present the processes, the control objectives and strategies, the main steps of the project and some results and benefits.

DESCRIPTION OF THE UNITS

Atmospheric Unit

The topping unit in the Notre Dame de Gravenchon refinery (France) is a 50 trays, 2 beds column with 4 pumparounds and 4 side draws. This refinery is mainly lubes oriented and the atmospheric resid is then processed by a vacuum unit The products qualities which are measured and that were selected for the control application are the heavy naphtha 95 % point, the 90 % and flash points of the light kerosene and the gas oil pour point. Among the input variables which can be manipulated, the draw off flow rates were considered to be used by the controller; others like pumparound duties, stripping and furnace outlet temperature are to be adjusted for other purposes than dynamic control.
Three disturbances have shown a significant effect on the qualities (the top temperature, one stripping steam ratio and the top pressure) and are to be taken into account by the controller as feed forward variables.



(*) This algorithm had been developed by Adersa in 1986 from the simpler IDCOM (identification and control of multivariable processes). Introducing hierarchical control, this methodology is licensed to engineering companies.

Control strategies and requirements: Three main operating modes are to be considered: maximization of the kerosene or Naphtha cut yield and an intermediate strategy between these two. In case of yield maximization, the qualities specifications are given in terms of constraints. The objective is then to draw as much kerosene or Naphtha as possible with respect to the quality constraints. A secondary objective is to maximize also the yield of the next product as far as the main objective is satisfied.

In case of intermediate mode, the draw offs yields are not to be maximized and the qualities have set points values fixed.

Regarding operating conditions, other situations have also to be considered such as keeping the light and heavy kerosene side streams segregated or mixing them after being drawn ; the kerosene qualities (90 % and flash points) are specified on the light kerosene in the "segregated" case and on the mixed kerosenes in the other case. Because of these operating modes changes, the controller is required:

- to automatically change the control strategy depending on the mode
- to allow bumpless switch from a mode to another.

Since the quality analysers are not 100 % available, the controller should be able to go on working through back-up control substructures in case of some analyser failure. The same procedure should work also if one of the manipulated variables is switched to manual by operators.

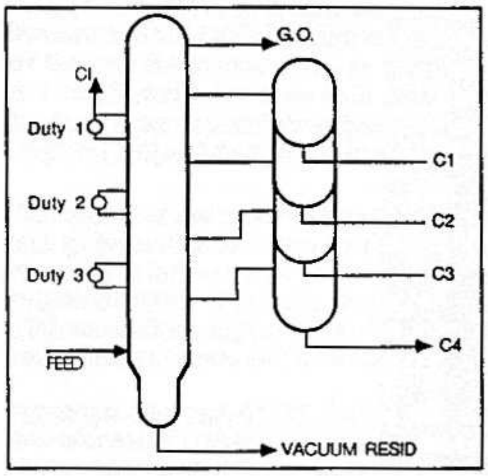
vacuum unit

The vacuum distillation column processes the atmospheric resid to produce four distillates whose viscosities to be controlled increase from the top to the bottom of the tower.

The duties of the three pumparounds are adjusted from time to time for the global optimisation of the unit.

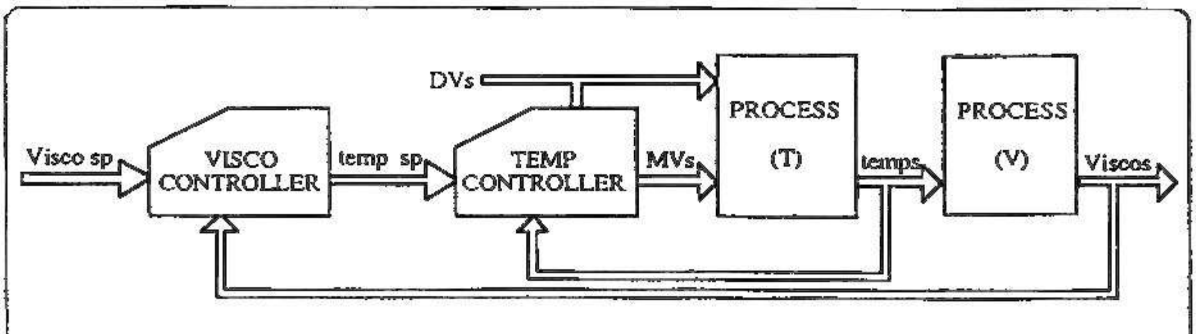
Four variables (the distillates draw off flow rates and the top reflux) can be manipulated for viscosity control purposes.

Five disturbances variables have been selected after plant tests, including the feed cutpoint which reflects the composition and the flow rate of the last distillate (C3) that is not available for control and can be modified manually for other reasons than viscosity control.



Control structure and requirements: three viscosities (Cl, C2, C3) must satisfy their set points with some given tolerance. The controller must take into account the main disturbances as feed forward variables. The vacuum unit may run mainly through three operating modes, corresponding to different flow rates of the intermediate cut Ci and then corresponding to different set points values specified to the viscosities.

It is well known (and verified during the plant tests) that the draw box temperatures are strongly correlated to the viscosities. The idea is then to build a cascaded control structure, considering that a first control level is concerned by the temperatures and the second one controls the viscosities.



The viscosity controller computes a set of temperatures set points to satisfy the viscosities set points. The temperature controller satisfies these set points by acting on the manipulated variables.

Such a control structure has several advantages:

- *Disturbances:* when non measured disturbance variables affect both temperatures and viscosities, then the effect is visible first on the temperatures. Controlling the temperatures makes easier to "erase" this effect than waiting for the effect to be seen on the viscosities,

- *Dynamics*: the time response between the manipulated variables and the temperatures (from one ta three hours) is shorter than between these same manipulated variables and the viscosities (from two hours to four hours and half, including the lime delay). The control can take advantage of using a faster feedback.

- *Sensors:* the thermocouples are more reliable than the viscosity meters; so if the viscosity controller cannot go on working because of viscosity-meter failure, then the temperature controller keeps on working. In this situation, the real viscosities may not be right at their set points but the unit is at least stabilized thanks to the controlled temperatures.

IDCOM-HIECON CONTROLLER CAPABILITIES

Model

Regarding the temperature controller, the internal model has been identified between the nine selected inputs and the temperatures. This model is strongly multivariable: only two gains were considered as negligible. Concerning the viscosity controller, experiments have been applied once the temperature controller has been implemented. This had been done to make simpler the temperatures moves which are needed to identify the temperatures -viscosities relationships. In practice, the constraints limiting the actions of the temperature controller made difficult to apply all the planned plant tests. Anyway a rough model has been built from the collected data and implemented into the viscosities control structure. One temperature-viscosity model is needed per operating mode because of significant differences coming from the influence of the intermediate cut Ci operation rate.

Control algorithm

As a result of the 20 years Adersa's experience in process control, IDCOM-HIECON is a powerful model based predictive controller designed for multivariable processes. The "black-box" model is represented by step responses corresponding to each input -output relationship. Such a representation is very convenient for multivariable processes and for dynamics which are not simple analytical transfer functions. This model is used to predict the behaviour of the outputs to be controlled and to compute the corrective actions to be applied to the manipulated variables. The control algorithm gets its advantages from all the embedded features and takes easily into account the user's control strategies.

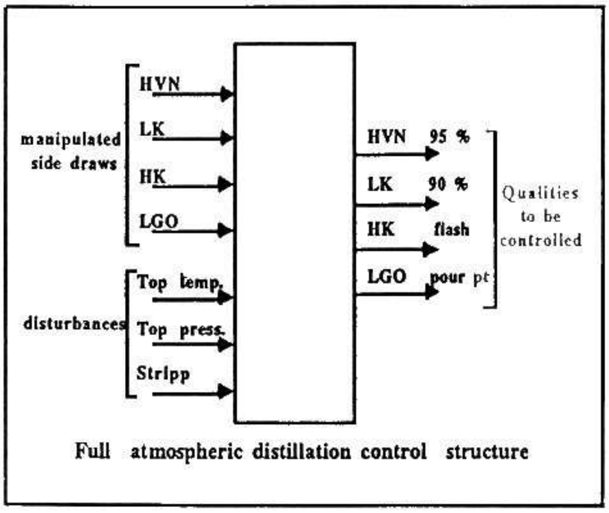
Some of these features were very useful for this application, such as:

- each output variable to be controlled can have its own closed loop time response (to a set point change) specified by the user at a constant value or at a value depending on the set point-measurement deviation ;

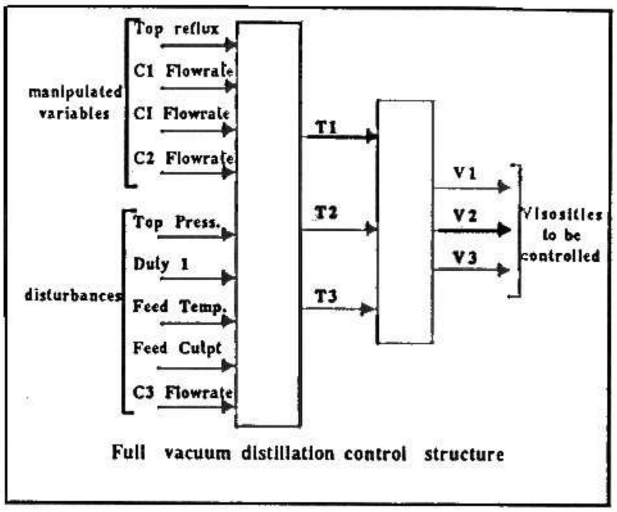
- constraints may be specified and changed in real time on the manipulated variables and on the controlled qualities as well (absolute and speed limits) ;

- an ideal resting value (IRV) may be given to some manipulated input variables: these inputs tend to their IRV as long as the other manipulated inputs can satisfy all the outputs specifications. The maximization of a given product yield is done through this feature.

The control structure is designed through a table describing the set of inputs with their attributes (manipulable / feedforward, constraints, IRV) and the set of outputs to be controlled with their own ones (set point, zone, constraints, closed loop time response). As many control structures are defined this way as needed by the different operating modes.



Full atmospheric distillation control structure



Full vacuum distillation control structure

Table 1 gives an example of such a control structure on the atmospheric unit for three different operating modes in case of segregated kerosenes.

MODES OUTPUTS and INPUTS ATTRIBUTES	MAXI NAPTHTHA	MINI NAPHTHA	INTERMEDIATE
Heavy Naphthal 95 %	* < max	< max	set point
Light Kero 90 %	min < * < max	min < * < max	set point
Light Kero Flash	> min	* > min	set point
Gas oil pour point	set point	set point	set point
HVN rate	MAXI 1	MIN 1	free
Light Kero rate	MAXI 2	MAXI 2	free
Heavy Kero rate	IRV	IRV	free
Gas oil rate	free	free	free

Table 1 : Atmospheric distillation control structures corresponding to three different operating modes. Depending on the mode. the symbol (*) shows which constraints are active.

The IDCOM-HIECON capability to make dynamic control and real time optimisation has been appreciated because it makes possible to define the control strategy exactly in the terms the problem is addressed.

In case of some detected (or declared) problem about a sensor or about an actuator, the control supervisor module switches to a back-up control substructure when such a substructure has been defined. If no substructure has been defined, then the algorithm does it utmost to find a trade off (lack of manipulated input) or to minimize the inputs moves (missing analyser). About 50 structures have been designed for the topping unit application to manage each potential situation through a specific control strategy: for instance, if such analyser fails, then keep the sum of two given sidestreams constant.

OPERATOR INTERFACE

The operators need to understand the way the controller is working and need to make sure that the applied inputs moves are the right answer to a given situation. It is rather difficult to understand what is going on when a multivariable controller is working:

- all the manipulated variables move simultaneously and the future effect on the controlled variables is quite impossible to estimate ;

- the feedforwarding produces unexpected actions for someone familiar only with regular PI controllers ;

- introducing objectives like yield maximization in the control strategy makes the behaviour harder to analyze.

Added to the control performances, the degree of process control acceptance by the operators depends on the way the interface is designed. Three different screens had to be developed for each unit to display information about the measured values, the control strategy and specifications, the status of the sensors, and so on.

From the "control screen", the operator can change the displayed values of the specifications and constraints. The system checks the measurements and the links between the actuators, the DCS and the process computer: the analysers and the actuators status is set off and displayed in case of problem. The operator can set them to "out of order" whatever the reason is. Through this screen, the operator can also fix the control strategy like "mixed keros and mini-naphtha mode".

A second screen: "help screen" explains in full sentences what the objectives are, like:

> "minimize the naphtha yield with flash constraint, maximize the keros yields with the 90 % constraint, keep the heavy kero yield around its ideal resting value and satisfy the gas oil pour point set point"

The "help screen" presents the performances regarding the products qualities and, using the control internal model, it gives their predicted behaviours. This screen shows also which manipulated variables are on their constraints to help the user analyse a situation.

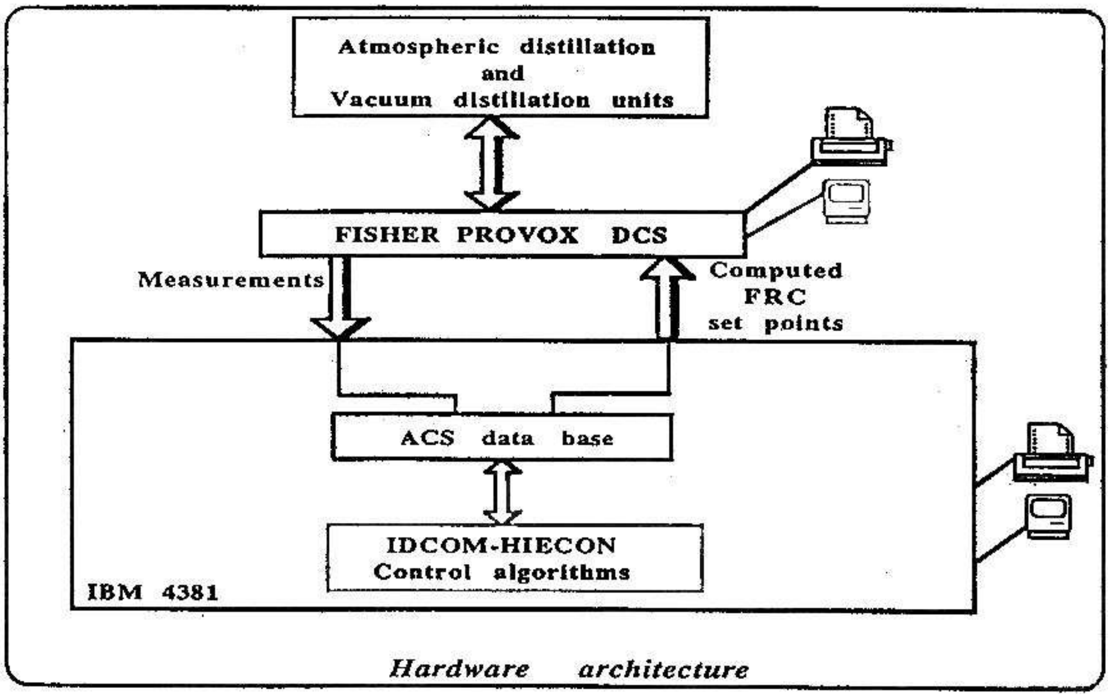
The third screen mainly displays the other variables which are not part of the control structure but which correspond to the working conditions of the unit, like duties and top pressure.

HARDWARE AND SOFTWARE ARCHITECTURES

A DCS is connected to the distillation columns as well as to several other units. This DCS is a FISHER PROVOX system which gets the measurements from the sensors and sends the computed control actions to the actuators. It manages level zero control, alarms, historical data, data logging and it displays trends and process pictures on colour CRTs to the operators.

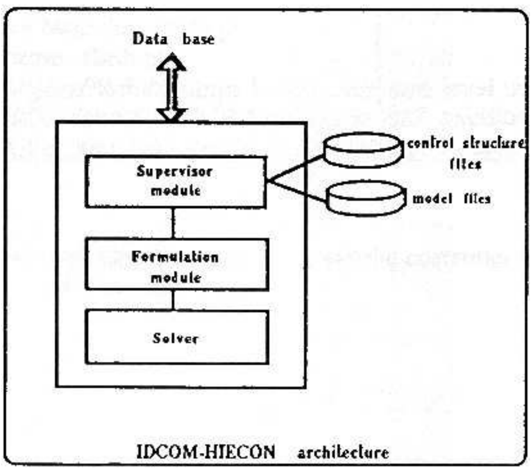
A process computer has been installed to manage upper level controls. Global optimisation using physical models and other programs needing some computation facilities. This computer (IBM 4381 with ACS) has its own industrial data base and allows the user to implement specific real time routines accessing this real time data base.

The IDCOM-HIECON control software is implemented in this computer and the three corresponding user's screens are displayed through the ACS facilities on colour CRTs in the control room and in other departments in the refinery.



The control algorithm gets the measurements (inputs and outputs) and the user's specifications (set points, constraints, operating mode) from the ACS data base and sends back the computed values of the manipulated variables and some messages to be displayed.
Another routine is in charge of the communication between the ACS real time data base and the DCS.

Software architecture: the IDCOM-HIECON software consists of three main parts:



- a supervisor module which communicates with the environment, selects and reads a new control structure and internal model if needed,

- a module which builds the control equations and prepares the formulation of the problem in the suitable form for the solver,

- a solver which computes the control inputs moves to satisfy the specified objectives.

The first module is the only one to be adapted for any specific application: it is mainly a set of I/O statements to access the data base and the control structures disk files and some logics to select the suitable control structure depending on the operating conditions.

Main steps of the project

A first set of input and output variables was defined during thy functional design including the description of the main control objectives. These variables are the variables to be manipulated by the controller, the products qualities to be controlled and the disturbance variables that may affect these qualities. A quite large number of input variables was considered at the beginning to avoid forgetting any significant effect. Experiments were prepared and applied to these inputs (step changes) to evaluate their dynamic effect on the products qualities.
The collected data were then used to identify the internal model required for the IDCOM-HIECON predictive controller. At this stage the disturbances were finally selected to be taken into account by the controller as feed forward variables:

- top pressure, top temperature and one stripping steam ratio on the atmospheric unit,

- top pressure, duty of the first pumparound, feed temperature and cut point, draw off of the heaviest distillate on the vacuum unit.

The identification algorithm provided the model in terms of step responses to be used by the controller. The identified model was then implemented into the PC work station with the control algorithm for control structures designing and testing on simulation. Some adaptations were made in the software to transfer it from the work station to the IBM 4381 host process computer: communication with the ACS real time data base.

In the same period, the user's interface was designed and implemented. During the sustained performance tests, the controller has been operated continuously, considering most of the defined control structures and substructures.

All the project partners were involved in these different phases, mixing knowledge and experience on process, operations and control aspects.

Results

The performances can be considered in terms of control, local optimisation and operation rate. Regarding the control objectives (satisfaction of set points or constraints) two figures have been estimated from collected data: the deviation between the mean value of the measured qualities and their objectives and the corresponding standard deviation.

Atmospheric unit

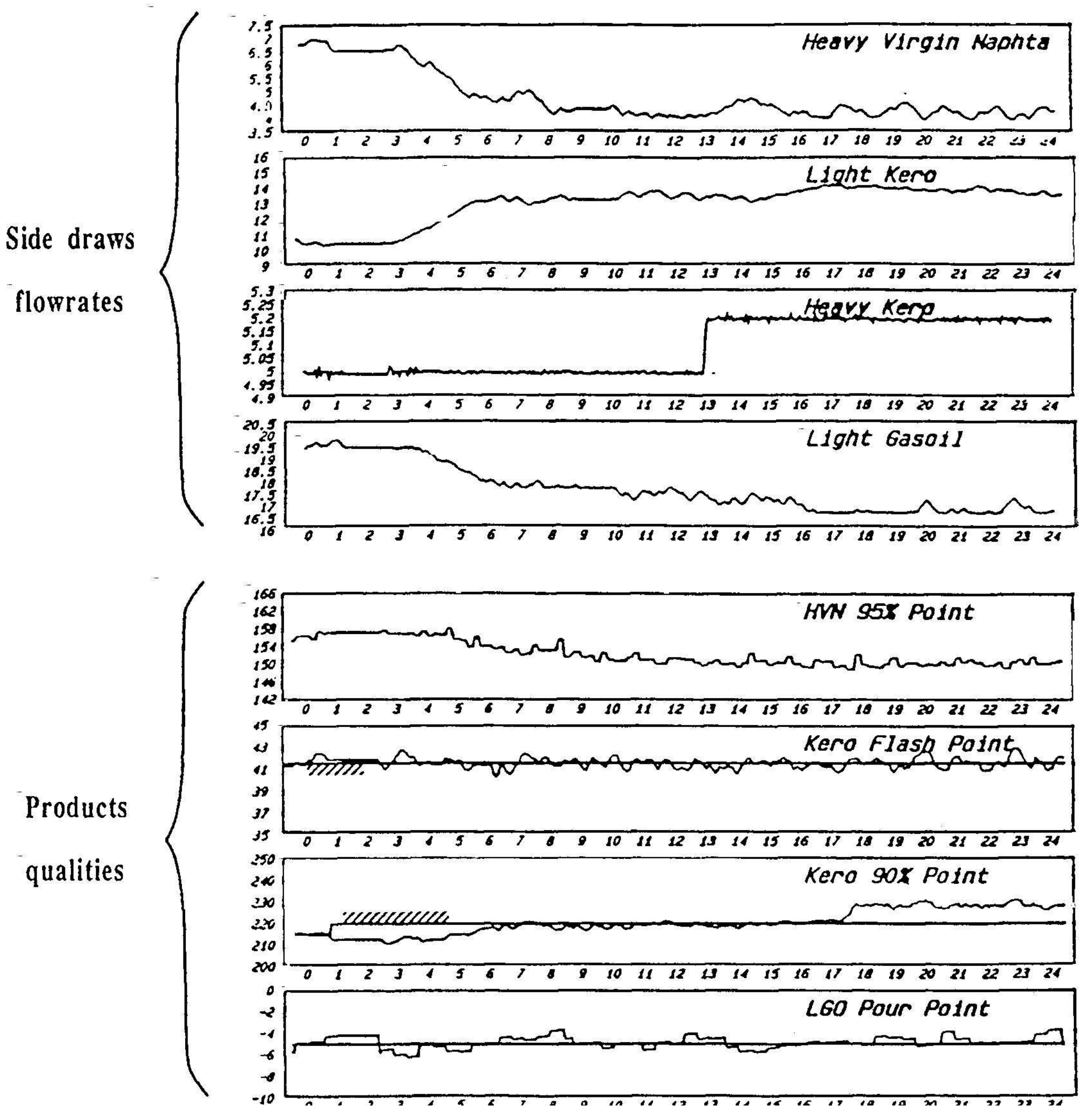
Qualities (°C)	Meas-objective deviation	Standard deviation σ
Heavy Naphtha : 95 % pt	0.1	1.6
Kerozine : flash pt	0.1	0.8
Kerozine : 90 % pt	0.5	1.8
Gas oil : Pour pt	0.1	0.75

The second aspect concerns the way the controller manages the dynamical yields maximization white respecting the qualities constraints.

The following trends show the behaviour of the main variables over 24 hours. The control structure being used during this period corresponds to a maximization of the light kerosene yield, which makes the heavy naphtha yield decrease. In this control structure the objectives and means are:

- three manipulated variables: heavy naphtha, light kerosene and light gas oil with their own minimum, maximum and speed constraints. The heavy kerosene drawn is not manipulated in this configuration.

- three qualities must respect constraints :
  - .the heavy naphtha 95 % point constraint is far above the operating point,
  - .the kerosene flash point is against its low limit,
  - .the kerosene 90 % point is against its high limit
- the light gas oil pour point satisfies its set point.



During the last third of the plotted period the control structure is switched to a back-up structure because of some problem on the kerosene 90% point analyser.

Vacuum unit

The width of the variation range of the viscosities (± 2 σ around the set point) is smaller or equal to the range specified by the refinery .The handling of the unit is improved when switching from an operating mode to another and in case of viscosity meters problems. Thanks to the reduction of the viscosity fluctuations, the severity of the Furfurol processing is also reduced.

Cuts	V1	V2	V3
Standard deviation σ	0.15 cst (40 °C)	0.15 cst (100 °C)	0.23 cst (100 °C)

Depending on the operation mode, the yield increase varies between 0.26 % and 1.24% thanks to the control improvement.

The last aspect of the results to be considered is the controller operation rate: thanks to the flexibility of the control structures, IDCOM-HIECON runs more than 98 % of the time.

Conclusion

The system was operational at the end of 1989 on the atmospheric unit and on June 1990 on the vacuum unit and has been running ever since with a very good acceptance of operating people.

The tight collaboration between ADERSA and the refinery during the project makes possible the design of other control strategies and structures by the refinery on its own.

The reduction of the qualities moves around their specifications allowed the benefit of the automatic yield maximization. The significant increase of the yield, translated into financial terms, corresponds to a pay out time shorter than a year.

References

J. Richalet, A. Rault, J.L. Testud and J. Papon, Model predictive heuristic control: applications to Industrial processes. *Automatica,* 14 (1978) 413 -428.
P. Grosdidier, J.B. Froisy and M.D. Hamann, The IDCOM-M controller, *IFAC Workrhop on Model Based Process Control, Atlanta, GA. lune* 13- 14, (1988).
P. Grosdidier, M. Morari and B.R. Holt, Closed-loop properties from steady-state gain information. *Ind. Eng. Chem., Fundam.,* 24 (1985) 221- 235.
A.R.M. Soeterbock. A.J. Koster. An Application of the Unified Predictive Controller to a Distillation Column. *Computer IntegraJed Desjgn of ControUed Industrjal Systentr. Proc. CIM -Europe Workshop.*
S.S. Sofer. R.J. Mulholland and W.H. Bare. From simple regulatory control to computer optimization. *Hydrocarbon Processjng. January* (1988).
G.D. Martin. L.D. Van Horn and K.M. Cassaday, Experience with hydrotreater computer control, *Hydrocarbon Processing, March* (1984).
L.H. Veland, *I.* Hoyland, C.R. Aronson and D.C. White, Unique features improved crude unit advanced contro1, *Hydrocarbon Processing. September* (1987).
J. Richalet and J. Papon, Industrial Applications of Internal Model Control, *Proceeding 7th lFAC-1MACS Conference on digital computer applications to process control,* (1985).
R.M.C. De Keyser, Model Based Predictive Control Toolbox, *Proceedings CIM-Europe Workshop on Computer Integrated Design of Controlled Industrial Systems,* (1990), 35 -56