Bailey®
network 90®

Advanced Control of Ethylene Cracking Furnaces

(Chemical)

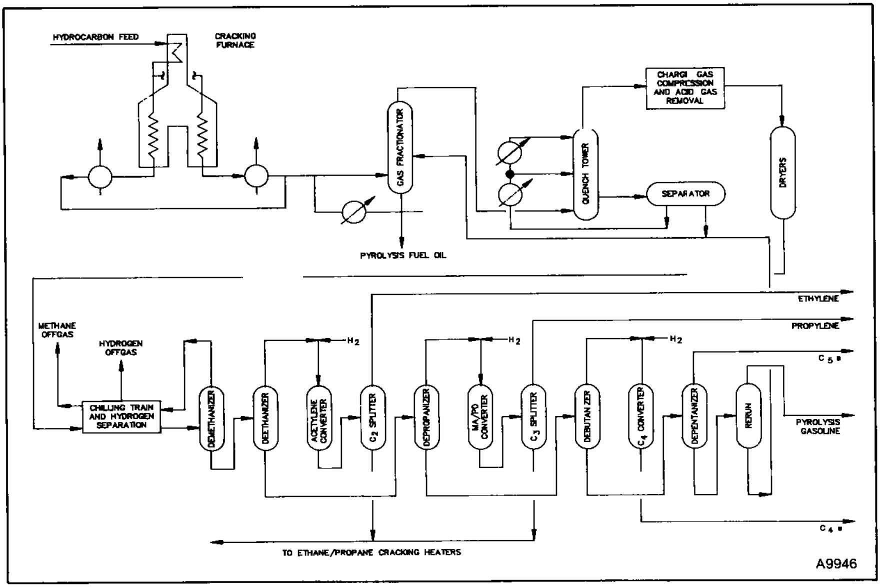

FIGURE 1   Typical Ethylene Production Process

Introduction

Significant economic benefits can be realized from effective control of the cracking furnaces in ethylene plants. These furnaces thermally crack hydrocarbon feedstock to ethylene and propylene. The performance of the cracking furnaces has a major impact on the economics of the entire plant. Complex interactions between several furnace operating parameters play an important role in determining the performance of a cracking furnace. Changes in feedstock and fuel compositions, changes in the coking deposits in the furnace coils, and/or violation of furnace operating constraints make continuous adjustment of furnace operation necessary to maintain optimum performance.

Conventional control strategies do not provide the operator with an effective tool to deal with these operating complexities. The advanced control strategy presented in this application guide accommodates these interactions and

Application Guide

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Bailey Controls
Babcock & Wilcox a McDermott company

effectively supervises base regulatory flow and temperature controllers to stabilize conversion, maintain yield selectivity, maximize throughput, and avoid violation of furnace constraints. The combined economic benefit from applying this advanced strategy can be as much as $3.00/ton of ethylene production.

Summary of Benefits

The advanced control strategy for ethylene cracking furnaces outlined in this application guide provides the following benefits:

- Stabilized and maximized conversion of hydrocarbon feedstock to ethylene.
- Balanced cracking severity between furnace coils.
- Improved yield selectivity to produce more of the desired products and less undesired by-products.
- Maximized furnace throughput to improve plant productivity.
- Avoided unsafe operating conditions and equipment stress which decrease the equipment operational life.
- Minimized coking in furnace coils and maximized coil life through minimizing temperature fluctuations.

Process Description

A simplified process flow diagram for a typical ethylene plant is shown in **FIGURE 1**. Operationally, the plant consists of two main areas, a "hot" side and "cold" side. The hot side consists of the cracking, waste heat recovery, steam production, gas fractionation, and quench areas. The cold side consists of the cracked gas compression, gas drying, hydrogen separation and product recovery areas.

A typical ethylene plant includes six (6) to twelve (12) cracking furnaces which are generally fired with natural gas. These furnaces operate in parallel and are generally designed for one of several different feedstocks (e.g. naphtha or gas oil).

A more detailed schematic of a cracking furnace is shown in **FIGURE 2**. The cracking furnace consists of several parallel tube passes (coils) which have individual feedrate, fuel and dilution steam systems with common supply headers.

In the cracking furnace the feedstock hydrocarbon molecules are pyrolyzed (thermally cracked) to yield a mixture of saturated and unsaturated hydrocarbons containing largely ethylene and propylene. The typical pyrolysis yield for a heavier feedstock (e.g. naphtha) is 60% C_3 and lighter hydrocarbons, of which 65% is ethylene and propylene.

The feedstock is preheated by waste heat and diluted with steam before being fed into the cracking furnace. The steam reduces the hydrocarbon partial pressure to increase yield selectivity. In the furnace coils, the feedstock is heated rapidly to a temperature of 1500°F. This rapid heating at high velocities causes thermal cracking of the feedstock molecules.

The high temperature effluent gases from the cracking furnace are cooled rapidly below 850°F in the transfer line exchangers (TLE's) both to quench the reaction and to recover heat. This recovered heat is used to generate high pressure steam which is then superheated and used to run large turbine driven compressors.

The high tube wall temperatures in the furnace cause deposition of carbon solids (coke) on the inner surfaces of the coils. Over a period of time the coke build up impedes heat transfer and restricts flow. Consequently, the cracking furnace must be shutdown periodically for decoking. Excessive tube wall temperatures accelerate coking and reduce the length of the furnace run.

The performance of the cracking furnaces is very important to overall economic performance of the plant because the furnaces establish the material balance for the entire plant. Two important parameters that determine the performance of the cracking furnace are cracking severity and yield selectivity.

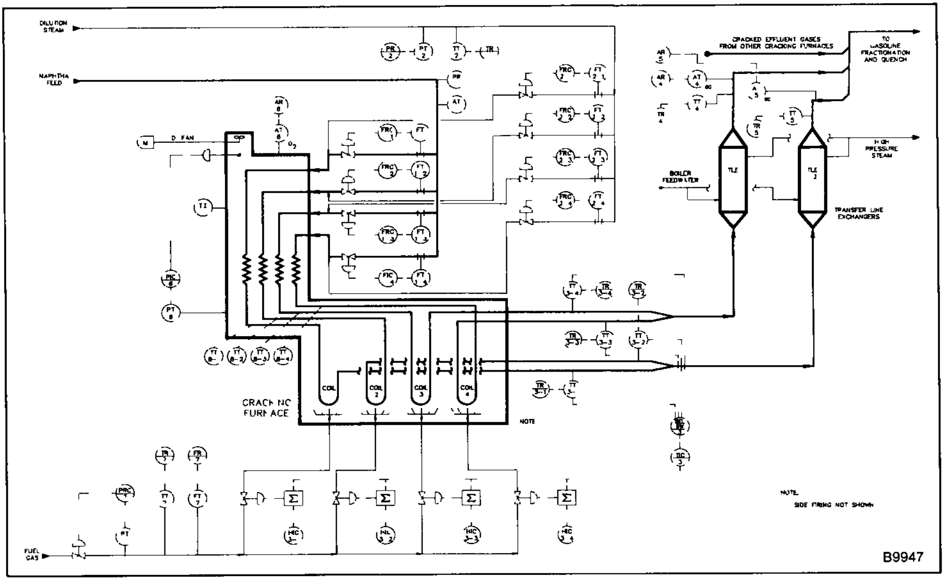

FIGURE 2 Conventional Control Strategy Ethylene Plant Cracking Section

Cracking Severity

Crack ng sever ty s a measure of the overa con vers on of feedstock to C_3 and ghter products t is re ated to the amount of energy nput to the feedstock mo ecules for pyro ysis H gher than opt mum sever ty resu ts n ower than des red molecu ar we ght components in the furnace eff uent gas, and ncreased cok ng in the furnace tubes Lower than opt mum severity resu ts n more recycle assoc ated costs and ess product on

The process var ab es that affect crack ng sever ty are hydrocarbon feedrate and compos t on steam feedrate co operat ng pressure and co outlet temperature For a g ven feedstock co outlet temperature has the most pronounced effect on sever ty Because crack ng sever ty s not d rect y determ nab e for heav er feedstocks, the we ght percentage of C_3 and ighter hydrocarbons n the furnace eff uent gas s considered to be a re ab e indication of crack ng sever ty

Yield Selectivity

Y e d se ect v ty refers to the percentage of cracked feedstock wh ch is a va uable product H gh se ect v ty for ethy ene s favored by short residence t me and ow hydrocarbon part a pressure

n a s tuat on where the crack ng sever ty s f xed se ect v ty can be s gn f cantly affected on y by man pu at ng hydrocarbon feedrate and steam/hydrocarbon rat o The hydrocarbon feedrate affects res dence t me on y The steam/hydrocarbon rat o directly affects both res dence t me and hydrocarbon part a pressure

Select v ty gradua y decreases throughout a furnace run As coke s depos ted n the furnace tubes, the impeded heat transfer ncreases the res dence t me requ red to mainta n se ect v ty S nce a reduction in feedstock flowrate to ncrease the res dence t me s genera y not acceptable the se ectivity deter orates unt the furnace tubes are decoked

Conventional Control Strategy

The conventional control strategy for an ethylene cracking furnace is shown in **FIGURE 2**. Each of the furnace coils has a feedstock flow controller (FRC 1 N) and a dilution steam flow controller (FRC 2 N). On line analyzers are generally provided for hydrocarbon feed composition (AR 1), cracked effluent gas (AR 4 and AR 5), and flue gas oxygen concentration (AR 6).

The furnace firing system is divided into one zone for each coil. Fuel is fed to burners in the bottom and up the sides of the furnace for each zone. The temperature of the effluent gas from each coil is monitored (TR 3 N) but the operator manually selects one of these coil temperatures to control all of the coil fuel control valves (TIC 3). If any coil outlet temperature is significantly different from the others, the operator adjusts the manual fuel valve bias (HIC 3 N) for the coil.

With the conventional control strategy, the operator cannot effectively control severity and selectivity. The operator sets the setpoints for coil outlet temperature, feedstock flowrate and steam flowrate based on furnace operating history. When disturbances in feedstock composition or flowrate occur, it becomes very difficult for the operator to determine the correct adjustments which will stabilize the cracking process. Further, once the coil outlet temperature is set to achieve the required cracking severity, changes in fuel heating value and pressure will produce significant variations in severity and selectivity before the conventional outlet temperature controller can compensate. Appropriate operator adjustment of the furnace setpoints is further complicated by significant lags in both process and analyzer response and coking of the furnace coils.

Balancing of the coil outlet temperatures is also difficult for the operator with a conventional cracking furnace control system. When the extent of coking through all of the furnace coils is the same, the heat transfer characteristics allow effective balancing of outlet temperatures by adjusting the manual bias for each coil fuel valve (HIC 3 N). However, as the extent of coking in each coil becomes different, it is necessary to readjust the feedstock flowrate for each coil to balance the coil outlet temperatures. It is difficult for the operator to determine the correct adjustment without several iterations, after which a new adjustment must be made to compensate for further changes in coking.

With conventional cracking furnace controls, control of steam/hydrocarbon ratio is also quite difficult. Since the hydrocarbon and steam feedrates are controlled separately, the steam/hydrocarbon ratio cannot be effectively adjusted by the operator during feedstock flowrate disturbances. Also, depending on the extent of coking in a particular furnace coil, a change in the steam/hydrocarbon ratio may become necessary to maintain optimum selectivity for that coil.

To accommodate these difficulties without exceeding critical operational constraints for the cracking furnace (e.g. maximum tube wall temperature, maximum heating rate), the operator uses wide safety margins. This generally has the effect of limiting the throughput of the cracking furnace.

Advanced Control Strategy

The Bailey advanced control strategy for ethylene cracking furnaces is summarized in **FIGURE 3**. A mathematical model of the cracking furnace provides the basis for adjusting the remote setpoints of furnace coil feedstock, steam and fuel controllers. In addition to the process instrumentation utilized by the conventional control strategy, the advanced strategy requires individual coil outlet pressure transmitters (PT 3 N), individual coil fuel flow transmitters (FT 3 N), and a heating value analyzer for the fuel gas (AT 7).

The cracking furnace model computes cracking severity and yield selectivity from simple process measurements (temperatures, pressures, flows) and furnace geometry data. The model calculates the coil outlet temperature and steam/hydrocarbon ratio setpoints required to achieve severity and selectivity targets for the current feedstock composition and flowrate. It also calculates the feedstock flowrate setpoint required to meet the cracking severity target for each coil. The furnace model is automatically calibrated to actual cracking furnace performance using on line analyzer measurements and/or operator input laboratory test results.

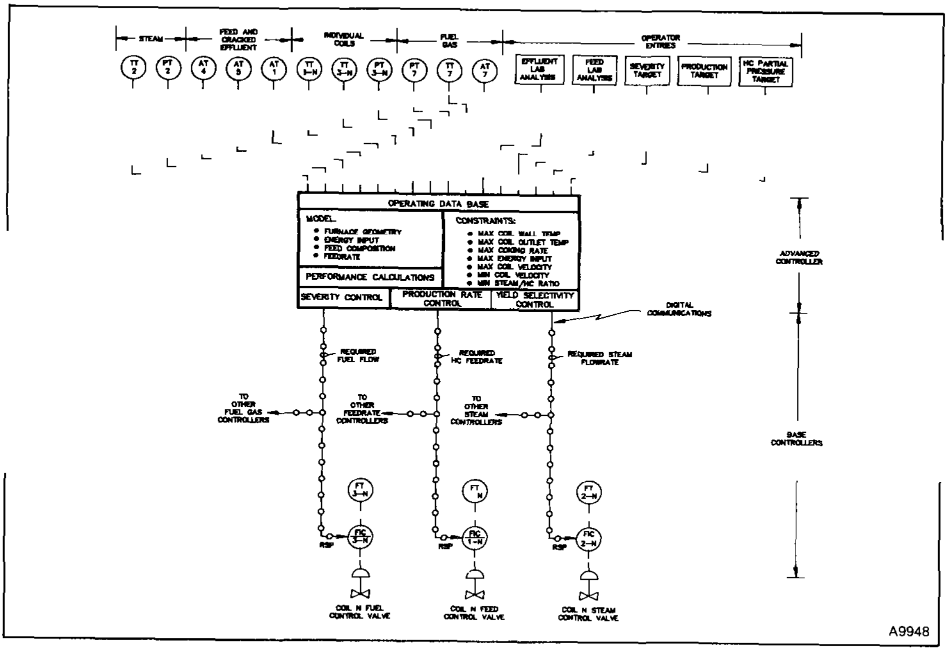

FIGURE 3   Advanced Ethylene Cracking Furnace Controls

Severity Control

The advanced controller adjusts the remote setpoint to each coil fuel controller (FIC 3-N) for the coil outlet temperature necessary to achieve the operator set severity target. This remote setpoint includes feedforward compensation for fuel heating value, temperature and pressure, so that the total energy input to the coils is controlled rather than just the volumetric flow of fuel. The remote setpoints for the fuel controllers are coordinated to accommodate the impact of an individual coil fuel controller on adjacent coil outlet temperatures. These features minimize the dynamic requirements for feedback from on-line process analyzers and/or laboratory test procedures.

The advanced controller also minimizes variation in cracking severity between the coils of the furnace. As a coil becomes coked during extended cracking furnace operation, heat transfer to the feedstock is restricted and the coil outlet temperature decreases. To minimize the variation in outlet temperature between the coils and the corresponding variation in cracking severity, the flowrate through each coil must be adjusted. To determine the required adjustments, the advanced algorithm recalculates the feedstock flowrate setpoints for the furnace coils based on simultaneous mass and energy balances for the coils. The adjustments are implemented as changes to the remote setpoint for each feedstock flow controller.

Selectivity Control

The advanced controller adjusts the remote setpoint to each coil steam controller (FIC 2 N) for the steam/hydrocarbon ratio necessary to maximize yield selectivity. These remote setpoints include feedforward compensation for steam pressure, steam temperature, and feedstock composition so that the actual mass ratio is controlled, rather than the volumetric ratio. This minimizes the dynamic requirements for feedback from process analyzers and/or laboratory test procedures.

Feedrate Maximization

The advanced cracking furnace controller also calculates the maximum feedstock flowrate possible for the furnace. This calculation is based on achieving the current severity target and maximizing selectivity with the current feedstock composition, and without violating furnace operating constraints. The maximum feedrate is displayed for operator action, and is not acted upon automatically by the advanced controller.

Constraint Avoidance

The advanced controller monitors the important physical and operating constraints of the cracking furnace and automatically prevents the constraint from being violated. The constraints enforced by the advanced controller describe the limits of pyrolysis reaction with regard to maximum severity, maximum tube wall temperature, maximum coil outlet temperature, and maximum coking rate. These constraints ensure safe and prolonged operation of the cracking furnace. When the advanced controller is operating the cracking furnace at one or more constraints, the operator is alerted to the condition.

Fault Tolerance

There is extensive interaction between the various control functions within the advanced controller. Several process measurement signals may be used for one or several of these control functions. The loss of any one measurement signal may have a major impact on some control functions and a minor impact on others.

To minimize the impact of an unavailable measurement signal on cracking furnace operation, special interlocks have been designed into the advanced controller. These interlocks prevent inappropriate control action upon loss of a measurement signal, and maintain the highest level of control system functionality possible under abnormal circumstances.

The loss of any one measurement signal causes an interlock action. If the lost signal is not dynamically critical to operation of the furnace (e.g. flue gas temperature), the controller will use a previously valid value of the signal. If the lost signal is dynamically critical (e.g. fuel flow), the remote setpoint for the base controller will be held at a previously valid value. When the base control loops are implemented in NETWORK 90, if the primary measurement signal for the loop *becomes unavailable, the base controller is* automatically and bumplessly switched to MANUAL mode. In all cases, the interlock action is alarmed, and when the lost signal becomes available again, the affected control functions will be automatically and bumplessly reinstated (except that the operator must manually return the base controllers to CASCADE mode).

Performance Monitoring

The Bailey advanced cracking furnace controller includes a performance monitoring package to help document the benefits resulting from its use. The following parameters are calculated for each product on shift by the advanced controller and are available for logging:

- Totalized Ethylene Production
- Average Cracking Efficiency (BTU/ton ethylene)
- Average Model Cracking Severity
- Standard Deviation of Model Cracking Severity
- Adverage Tested Cracking Severity
- Standard Deviation of Tested Cracking Severity
- Percent Utilization of Advanced Steam/Hydrocarbon Ratio Control
- Percent Utilization of Advanced Hydrocarbon Feedrate Control
- Percent Utilization of Advanced Fuel Control
- Totalized Cracking Furnace Downtime

The advanced cracking furnace controller also calculates and totalizes the cost savings achieved. The calculation is based on the following user entered data:

- Historical furnace effluent recycle cost ($/ton)
- Historical average ethylene selectivity (%)
- Historical ethylene production by furnace (ton/year)
- Historical average gross profit for ethylene production ($/ton)
- Historical average cost for maintenance shutdowns ($/day)
- Historical average furnace shutdown (days/year)

This total cost savings is also available for logging.

Economic Analysis

The most tangible economic benefits of this advanced control strategy are associated with increased ethylene production due to stabilized and increased yield selectivity and decreased furnace downtime. For a 500,000 metric ton / year ethylene plant with ten (10) cracking furnaces annual cost savings and incremental profits could total $1.2 million.

$1.2 Million / Year Savings and Profit

A 2.0% decrease in plant energy costs from improved cracking furnace energy utilization and reduced by product handling would result in savings of $388,000 / year. This savings is based on energy costs of $38.80 / ton of ethylene produced.

A 1.25 day / year reduction in decoking downtime for each cracking furnace will generate an additional $179,000 / year profit. This profit is in addition to the profit resulting from production increases due to maximizing the throughput of each cracking furnace.

The calculation of these economic benefits is summarized in **FIGURE 4.**

Implementation

Bailey Controls NETWORK 90 distributed microprocessor based control system offers cost effective and flexible implementation of the advanced control strategy for ethylene cracking furnaces. The advanced control functions for one cracking furnace can be implemented in two Multi Function Controller modules (NMFC03).

This controller can be integrated into a complete NETWORK 90 cracking furnace control system, communicating digitally with the base controllers through the NETWORK 90 module bus, or implemented in a standalone Mini 90™ cabinet, communicating with non Bailey control systems through hardwired analog signals. Input/output modules are required if measurement signals are not already input to NETWORK 90 controllers, and/or if remote setpoints are output to equipment from other control system manufacturers, the exact number and type depend on the specific cracking furnace design and existing control system equipment.

Operator interface can be provided by any of the Bailey CRT based operator consoles. The capabilities and features of the referenced NETWORK 90 equipment are fully described in the various Bailey Product Specifications.

The NETWORK 90 module configurations required to implement this advanced cracking control strategy may be purchased from Bailey Controls subject to a software license and use agreement. For systems configured by Bailey the system diskettes and documentation will include the configurations. For systems not configured by Bailey, a detailed Implementation Guide is available.

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BENEFIT Energy cost savings from reduced cracking furnace energy consumption.

500 000 [metr c TON ethy ene] / YEAR
* 9 7 [m on BTU requ red] / [metr c TON ethy ene]
* $3 00 / [m on BTU]
/ 75 [% furnace eff c ency]
* 2 [% mprovement n energy eff c ency]

$388,000 sav ngs / YEAR

BENEFIT. Incremental profit due to increased ethylene production from stabilized conversion and maximized throughput.

500 000 [metr c TON ethy ene] / YEAR
* $100 [gross prof t] / [metr c TON ethy ene]
* 1 25 [% ncrease n ethy ene product on]
/ 100 [% product on]

$625 000 [gross prof t] / YEAR

BENEFIT: Incremental profit from reduced cracking furnace downtime due to avoiding coking rate constraints.

500 000 [metr c TON ethy ene] / YEAR
/ 350 [operat ng DAYs] / YEAR
* $100 [ncrementa prof t] / [metr c TON ethy ene]
* 1 25 [DAY/YEAR decrease n furnace downt me for decok ng]

$179 000 [ncrementa prof t] / YEAR

BENEFIT: A 2% decrease in plant energy costs combines directly with a 1.25% increase in ethylene production and a 1.25 DAY/YEAR increase in cracking furnace operation to form the total economic benefit

$388,000 sav ngs / YEAR
+ $625,000 [gross prof t] / YEAR
+ $179,000 [ncrementa prof t] / YEAR

$1 190,000 [sav ngs and prof t] / YEAR

FIGURE 4 Economic Benefit Calculations

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