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 interacions between several furnace operating parameters pay an important role in determining the performance of a cracking furnace. Changes in feedstock and fuel compositions, changes in the coke deposition in the furnace, co-s, and/or oxidation of furnace operating constants 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 conditions. The advanced control strategy presented in this application guide accommodates these interactions and...
effect ve y superv ses base regu latory f ow and temperature contro lers to stab ize convers on ma nta n y e d se ect v ty max m ze throughput, and avo d v o at on of furnace cc n stra ts The comb ned econ om c benef t from app y ng th s advanced strategy can be as much as $3 00/ton of ethy ene product on

Summary of Benefits

The advanced contro l strate gy for ethy ene crack ng furnaces out ned n th s app cat on gu de prov des the fo ow ng benef ts

- Stab ized and max m zed convers on of hydrocarbon feedstock to ethy ene
- Ba nced crack ng sever ty between furnace co s
- Im proved y e d se ect v ty to produce more of the gases read products and ess unread by products
- Max m zed furnace throughput to mprove ant produ ct v ty
- A vor ded unsafe operat ng cond t ons and equ p ment stress wh ch decrease the equ p ment operat ona fe
- M n m zed cok ng n furnace co s and max m z ed co fe through m n m z ng temperature

Process Description

A s mp f ed process f ow d agram for a typ ca ethy ene p ant s shown n FIGURE 1 Operat on a y the p ant cons sts of two ma n areas, a ‘ hot ’ s de and ‘ co d ’ s de The hot s de cons sts of the crack ng waste heat recovery, steam product on, gas fract on on, and quench areas The co d s de cons sts of the cracked gas compression gas cry ng, hydorgen separ at on and product recovery areas

A typical ethylene plant inc udes s x (6) to tve ve (12) crack ng furnaces wh ch are genera y fired w th natura gas These furnaces operat e n para e and are gene ra y des gn ed for one of severa d ff erent feedstocks (e g naphtha or gas o)

A more deta led schem at c of a crack ng fur nace s shown n FIGURE 2 The crack ng furnace cons sts of severa para e tube passes (co s) which have ind vid ual feed rate fuel and dilut on steam systems w th common supp y headers

In the crack ng furnace the feedstock hydrocar bon mo ecu es are pyro zed (therma y cracked) to y e d a m xture of saturated and unsaturated hydrocar bons conta ng arge y ethy ene and pro py ene. The typ ca pyro ys s y e d for a heav er feedstock (e g naphtha) s 60% C s and q ughter hydrocarbons, of wh ch 65% s ethy ene and propy ene

The feedstock s preheated by waste heat and d uted w th steam before be ng fed nto the crack ng furnace. The steam reduces the hydrocarbon part a pressure to increase y e d se ect v ty n the furnace co s, the feedstock s heated rap dy to a temperature of 1500°F Th s rap d heat ng at h gh ve oc t es causes therma crack ng of the feedstock mo ecu es

The h gh temperature eff uent gases from the crack ng furnace are coo ed rap d y be ow 850°F n the transfer ne exchangers (TLE s) both to quench the react on and to recover heat Th s recovered heat s used to generate h gh pressure steam which s then superheated and used to run arge turb ne dr ven compressors

The high tube wall temperatures in the furnace cause depos t on of carbon so ds (coke) on the inner surfaces of the co s. Over a per od of t me the coke bu d up impedes heat transfer and restr cts f ow Consequent y, the crack ng furnace must be shutdown per od ca y for decok ng Excess ve tube wall temperatures accelerate cok ng and reduce the length of the furnace run

The performance of the crack ng furnaces s very mport ant to overa econ om c performance of the p ant be cause the furnaces estab lsh the mater a ba ance for the entire p ant Two mpor tant parameters that determ ne the performance of the crack ng furnace are cracking sever ty and y e d se ect v ty
Cracking Severity

Cracking severity is a measure of the overall conversion of feedstock to \( C_4 \) and lighter products relative to the amount of energy input to the feedstock molecules for pyrolysis. Higher than optimum severity results in lower than desired molecular weight components in the furnace effluent gas, and increased coking in the furnace tubes. Lower than optimum severity results in more recycle associated costs and less product on.

The process variables that affect cracking severity are hydrocarbon feedrate and composition, steam feedrate, operating pressure, and outlet temperature. For a given feedstock composition, outlet temperature has the most pronounced effect on severity. Because cracking severity is not directly determinable for heavier feedstocks, the weight percentage of \( C_4 \) and lighter hydrocarbons in the furnace effluent gas is considered to be a reliable indication of cracking severity.

Yield Selectivity

Yield selectivity refers to the percentage of cracked feedstock which is a valuable product. High yield selectivity for ethylene is favored by short residence time and low hydrocarbon part a pressure.

A s tuat on where the cracking severity of feedstock can be significantly affected by, by man pul ng hydrocarbon feedrate and steam/hydrocarbon ratio. The hydrocarbon feedrate affects residence time on y. The steam/hydrocarbon ratio directly affects both residence time and hydrocarbon part a pressure.

Selectivity gradually decreases throughout a furnace run. As coke is deposited on the furnace tubes, the impeded heat transfer increases the residence time required to maintain selectivity. Since a reduction in feedstock flowrate increases the residence time, selectivity generally not acceptable. The selectivity deteriorates until 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 co's has a feedstock flow controller (FRC 1 N) and a d ut o s steam flow controller (FRC 2 N). On the ana yzers are genera y provided for hydrocarbon feed composi tions (AR 1) cracked effluent gas (AR 4 and AR 5), and fuel gas oxygen concentration (AR 6).

The furnace firing system is divided into one zone for each co. The 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 co's is monitored (TR 3 N), but the operator manually selects one of the co's temperatures to control. The fuel control valves (TC 3) if any coil out temperature s are g n f cant y different from the others, the operator adjusts the manual fuel valve as (H C 3 N) for the co.

With the conventional control strategy, the operator cannot effect very control severly and set each temperature. The operator sets the setpoints for co's output temperature, feedstock flow rate, and steam flow rate based on furnace operation history. When disturbances occur in feedstock composition or flow rate, the controller becomes very difficult for the operator to determine the correct adjustments. A change in the crack ng process further once the co's output temperature is set to achieve the required crack ng severly, changes in fuel heat value and pressure. The operator can compensate for these variables and set the temperature before the conventional output temperature controller. The advanced operator adjustment of the furnace setpoints can be compensated by selecting the correct gas and adjusting the setpoints.

Advanced Control Strategy

The advanced control strategy for ethylene cracking furnaces is summarized in Figure 3. A mathematical model of the cracking furnace process describes the relationship between co's, feedstock, steam, and fuel control parameters. The advanced control strategy requires the use of dual co's output temperature and pressure transmitters (PT 3 N) and dual co's fuel ow rate transmitters (FT 3 N), and a heat value analysis system for the fuel gas (AT 7).

The crack ng furnace model computes crack ng severly and y e d se ect v ty from s mp e process measurements (temperatures, pressures, ow rates) and furnace geometry data. The model is used to control the co's output temperature and steam/hydrocarbon ratios. The setpoint for the current feedstock composition and flow rate is achieved via targets for the current feedstock composition and flow rate. A so co's are ates the feedstock flow rate setpoint to meet the crack ng severly target for each co. The advanced control mode is automatic and is brated to actual crack ng furnace performance using on line ana yzer measurements and/or input laboratory test results.
Severity Control

The advanced controller adjusts the remote setpoint to each fuel controller (F C 3 N) for the outlet temperature necessary to achieve the operator set severity target. Th d remote setpoint includes feedforward compensation for fuel heat value temperature and pressure, so that the total energy input to the controllers is reduced rather than just the volume of fuel. The remote setpoints for the fuel controllers are coordinated to accommodate the impact of an nd the fuel controllers on adjacent co output temperatures. The features maximize the dynamc requirements for feedback from online process analyzers and/or laboratory test procedures.

The advanced controller aims to minimize variances on crack ng severity between the co s of the furnance. As a co becomes coked during extended crack ng furnance operation, the heat transfer to the feedstock restricted and the co outlet temperature decreases. To minimize the var on outlet temperature between the co s, the correspond variance on crack ng severity the owrate through each controller must be adjusted. To determine the required adjustments, the advanced a gor is used to adjust the feedstock owrate set points for the furnance co s. Based on s continuous measurement of energy balances for the co s, The adjustments are implemented as changes to the remote setpoint for each feedstock ow 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 measurement. The remote setpoints are feedforward compensated for steam pressure, steam temperature, and feedstock composition to that the actual mass ratio of the m, n, m, z, e, d, e, s, et, v, t, y These remote setpoints are used to control the dynamic requirements for feedback from process analyzers and/or laboratory test procedures.

Feedrate Maximization

The advanced crackng furnace controller also controls the maximum feedstock flowrate based on the previous variables and the current severity target and maximum measurement. The controller operates on the control system's maximum feedrate. A separate function is added to the advanced controller for operator action and is not acted upon by the advanced controller.

Constraint Avoidance

The advanced controller monitors the important physical and operational constraints of the crackng furnace and automates the constraints to prevent the constraints from being violated. The constraints enforced by the advanced controller describe the maximum severity, maximum tube wall temperature, maximum outlet temperature, and maximum coking rate. These constraints ensure safe and prolonged operation of the crackng furnace. When the advanced controller operates the crackng furnace at one or more constraints, the operator is alerted to the condition.

Fault Tolerance

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

To make the impact of an unavailable measurement signal on crackng furnace operation speciﬁc, interlocks have been designed into the advanced controller. These interlocks prevent inappropriate actuation of control valves under abnormal conditions.

The loss of any measurement signal causes an interlock actuation. If the signal is normal, the control valve is opened to operate on the furnace temperature (e.g., fuel gas temperature), the control valve is closed, and the signal is used. If the signal becomes unavailable, the base controller is held in the previous state. When the base controller is operated in the case of a fault, the interlock actuates and the affected controller function is bypassed, except that the operator must manually return the base controller to CASCADE mode.

Performance Monitoring

The Bayley advanced crackng furnace controller uses a performance monitor package to he p document the benefit ts resu ts from ts use. The following parameters are calculated for each product on shift by the advanced controller and are available forogg:

- Totalized Ethylene Product
- Average Crack ng Ef f cency (BTU/ton ethylene)
- Average Mode Crack ng Severity
- Standard Dev at at on o f Mode Crack ng Severity
- Average Tested Crack ng Severity
- Standard Dev at at on of Tested Crack ng Severity
- Percent Ut zat on o f Advanced Steam/Hydrocarbon Rat o Contro
- Percent Ut zat on of Advanced Fue Contro
- Totales Cracking Furnace Downtime
The advanced cracking furnace controller saves a significant portion of the total cost savings achieved. The cost savings are based on the following user entered data:

- **Heat Storage Furnace Efficiency Cost** ($/ton)
- **Heat Storage Average Ethylene Selection (v%)**
- **Heat Storage Ethylene Product on by Furnace (ton/year)**
- **Heat Storage Average Gross Profit for Ethylene Product on ($/ton)**
- **Heat Storage Average Cost for Maintenance Shutdown ($/day)**
- **Heat Storage Average Furnace Shutdown (days/year)**

The total cost savings are available foroggng

### Economic Analysis

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

### $1.2 Million / Year Savings and Profit

A 20% decrease in plant energy costs from improved cracking furnace energy utilization and reduced by product handling would result in savings of $380,000/year. These savings are based on energy costs of $38.80/ton of ethylene produced.

A 1.25 day/year reduction in downtime for each cracking furnace would generate an additional $179,000/year profit. These profits are due to increased product output due to increased furnace throughput.

The costs at on of these economic benefits is summarized in Figure 4.

### Implementation

Bayley Control System's TWORK 90 dstr buted microprocessor-based control system offers cost effectiveness and flexibility on the advanced control strategy for ethylene cracking furnaces. The advanced control functions for one cracking furnace can be implemented in two Module Functions on Control monitors (NMFC03).

The control can be integrated into a complete NETWORK 90 cracking furnace control system, containing a number of distributed control units within the NETWORK 90 module bus, or renovated in a stand-alone MNI 90™ cabinet. The control is non-Bayley control systems through hardware and software aspects are not already nput to NETWORK 90 control systems, and/or remote setpoints are output to equipment from other control systems 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 Bayley CRT-based operator consoles. The capabilities and features of the referenced NETWORK 90 equipment are fully described in the various Bayley Product Specifications.

The NETWORK 90 module configuration may be purchased from Bayley Control Systems subject to a software license and use agreement. For systems configured by Bayley the system's details and documentation will include the configuration options. For systems not configured by Bayley, a detailed configuration guide is available.
**BENEFIT**  
Energy cost savings from reduced cracking furnace energy consumption.

- 500,000 [metric TON ethylene] / YEAR
- 9.7 [metric TON ethylene] / [metric TON ethylene]
- $3.00 / [metric TON ethylene] / [metric TON ethylene]
- 75 [% furnace efficiency improvement]
- 2 [% energy efficiency improvement]

$388,000 savings / YEAR

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

- 500,000 [metric TON ethylene] / YEAR
- $100 [glossy profit] / [metric TON ethylene]
- 1.25 [% increase in ethylene production]
- 100 [% product on]

$625,000 [glossy profit] / YEAR

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

- 300,000 [metric TON ethylene] / YEAR
- 350 [operating DAYs] / YEAR
- $100 [incremental profit] / [metric TON ethylene]
- 1.25 [DAY/YEAR decrease in furnace downtime for decoking]

$179,000 [incremental profit] / 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 savings / YEAR
- $625,000 [glossy profit] / YEAR
- $179,000 [incremental profit] / YEAR

$1,190,000 [savings and profit] / YEAR

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**FIGURE 4  Economic Benefit Calculations**