Real-time analysis of ethylene production processes to optimize yield while maximizing uptime and maintaining safety and environmental compliance

Analyzer solutions to reduce environmental emissions, ensure safe operation, and optimize ethylene conversion and product quality.
Ethylene is the most produced organic compound globally and is an important building block for the petrochemical and chemical industry with over 150 million tons of ethylene produced yearly. The main commercial production of ethylene is by thermo/steam cracking of different hydrocarbon feed stocks, which is typically divided into a few main steps: cracking, quenching, compression and drying, and separation.

Ethylene plants can use a wide range of hydrocarbon feed stocks. One of the most common types is naphtha, a mixture of hydrocarbons that has a boiling range of 30°C to 200°C (86°F to 392°F). In some regions, including the United States and the Middle East, ethane and propane are the most commonly used feed stocks in ethylene production. The rapidly growing production of shale gas has resulted in construction on many new and expanded ethylene plants globally. Most of the ethylene produced is used in the production of polyethylene and ethylene oxide which is a feed stock for many more complex hydrocarbons and polymers. Process analytics ensures process control via online monitoring of the various process streams in olefin production.

Process control through compositional analysis by online analyzers results in maximized yields and ensures product quality.
ETHYLENE PLANT OVERVIEW

AT1: Cracker Furnace Combustion Control
AT2: Stack Gas
AT3: Furnace Decoking
AT4: Steam Boiler Combustion Control
AT5: Boiler Flue Gas
AT6: Transfer Line Exchanger Outlet
AT7: Inlet of Caustic Tower
AT8: Outlet of Dehydration Tower
AT9: Refrigeration Outlet
AT10: Demethanizer Off Gas
AT11 & AT12: Acetylene Converter Inlet and Outlet
AT13: Ethylene Product
AT14: Propylene Product

Processes not pictured in diagram:
AT15 – Thermal Oxidizer
AT16 – Tank Head Space Monitoring

Find the right solution for your ethylene plant
The first section of the ethylene plant is the pyrolysis furnace that "cracks" the feedstock into ethylene and other light hydrocarbons. The hydrocarbon feed stock is preheated and cracked in the presence of steam in tubular pyrolysis furnaces. The residence time in the cracking furnace (~871°C/~1600°F) is generally only a few seconds. The furnace temperature and residence time determine the distribution of hydrocarbon products.

The next step is the fractionation to separate the desired products. The diagram opposite refers to the main process units in a typical ethylene production plant. The analyzers and analytes measured are referenced using "AT" numbers. The analyte concentrations range from high percent to low parts per million (ppm) levels.

**AT1: CRACKER FURNACE COMBUSTION CONTROL**

**MEASURES:** O₂, Combustibles (CO+H₂), Methane/Hydrocarbons (CH₄+)

**PRODUCTS:** 5100HD, WDG-V

Within the cracker furnace, burners are used to generate the heat required for the cracking process. At the burner, fuel is combusted in the presence of air. Optimal combustion is typically at a setpoint of 1-2% excess oxygen (O₂). A flue gas analyzer is used to monitor the excess O₂ levels, and additional measurements can be made to detect incomplete combustion by measuring combustibles (CO+H₂) and to detect flame-out during start-up by measuring methane and hydrocarbons. The hydrocarbon measurement can also serve to detect potential process leaks from the tubes.

**AT2: STACK GAS**

**MEASURES:** SO₂, NOₓ, CO, CO₂, O₂

**PRODUCTS:** 9900, 914, 5100HD

In the United States, Environmental Protection Agency (EPA) regulations require continuous emissions monitoring of stack gas for sulfur dioxide (SO₂) and oxides of nitrogen (NOₓ).

**AT3: FURNACE DECOCKING**

**MEASURES:** CO, CO₂

**PRODUCTS:** 5100HD

In ethylene production, a hydrocarbon feed stream mixed with steam enters a tubular reactor where, under controlled conditions, the feed stock is cracked at 800 to 850°C (1472 to 1562°F) into smaller molecules within 0.1 to 0.5 seconds. This process takes place in the radiant coils of the furnace. To maximize conversion rates, the furnace needs to be periodically decoked and using a TDLAS analyzer is the preferred method of monitoring the decoking process.

Refer to Application Note A-0523 Monitoring the Furnace Decoking Process in Ethylene Production for more in-depth information about this process.
A knowledge of CO and CO₂ concentrations assists in optimizing the cracking process. The type of products produced depends on the tubular furnace’s temperature and pressure. The effluent coming off the reactor results in various products and regulations. Continuous emissions monitoring of carbon monoxide (CO), NOₓ, and O₂ in the flue gas is performed to meet emission regulations.

**AT4: STEAM BOILER COMBUSTION CONTROL**

**MEASURES:** O₂, Combustibles (CO+H₂), Methane/Hydrocarbons (CH₄+<sub>+</sub>)

**PRODUCTS:** WDG-V

A boiler is used to generate steam, which can be added to the feed to decrease coking and lower hydrocarbon pressure to increase olefin yield. A flue gas analyzer is used to measure oxygen (O₂) and control the burner of the boiler. The flue gas analyzer can also measure combustibles (CO+H₂) to optimize combustion, and it can measure methane/hydrocarbons to detect potential flame outs or fuel leaks during start-up.

**AT5: BOILER FLUE GAS**

**MEASURES:** NOₓ, CO, O₂

**PRODUCTS:** 9900, 914

Continuous emissions monitoring of carbon monoxide (CO), NOₓ, and O₂ in the flue gas is performed to meet emission regulation requirements.

**AT6: TRANSFER LINE EXCHANGER OUTLET**

**MEASURES:** CO, CO₂

**PRODUCTS:** 5100HD

Analysis of the furnace effluent gas provides valuable information on process control for the plant. The ratio of the types of products produced depends on the tubular furnace’s temperature and pressure. The effluent coming off the reactor results in various products. A knowledge of CO and CO₂ concentrations assists in optimizing the cracking process.

**PRODUCT SOLUTIONS**

**WDG-V**

Designed for safety and serviceability, the WDG-V provides accurate measurements of oxygen (O₂), combustibles (CO+H₂), and methane (CH₄) for combustion applications.

**9900**

Single or multi-component gas analyzer that can be used alone or as an integrated part of a continuous emissions monitoring (CEM) system.

**AT7: HYDROCARBON FEED STOCK**

**MEASURES:** O₂, Combustibles (CO+H₂), Methane/Hydrocarbons (CH₄+<sub>+</sub>)

**PRODUCTS:** WDG-V

A boiler is used to generate steam, which can be added to the feed to decrease coking and lower hydrocarbon pressure to increase olefin yield. A flue gas analyzer is used to measure oxygen (O₂) and control the burner of the boiler. The flue gas analyzer can also measure combustibles (CO+H₂) to optimize combustion, and it can measure methane/hydrocarbons to detect potential flame outs or fuel leaks during start-up.

**AT8: TRANSFER LINE EXCHANGER OUTLET**

**MEASURES:** CO, CO₂

**PRODUCTS:** 5100HD

Analysis of the furnace effluent gas provides valuable information on process control for the plant. The ratio of the types of products produced depends on the tubular furnace’s temperature and pressure. The effluent coming off the reactor results in various products. A knowledge of CO and CO₂ concentrations assists in optimizing the cracking process.

**PRODUCT SOLUTIONS**

**WDG-V**

Designed for safety and serviceability, the WDG-V provides accurate measurements of oxygen (O₂), combustibles (CO+H₂), and methane (CH₄) for combustion applications.

**9900**

Single or multi-component gas analyzer that can be used alone or as an integrated part of a continuous emissions monitoring (CEM) system.

**AT10: DEETHANIZER BOTTOM GAS**

**MEASURES:** O₂, Combustibles (CO+H₂), Methane/Hydrocarbons (CH₄+<sub>+</sub>)

**PRODUCTS:** WDG-V

A boiler is used to generate steam, which can be added to the feed to decrease coking and lower hydrocarbon pressure to increase olefin yield. A flue gas analyzer is used to measure oxygen (O₂) and control the burner of the boiler. The flue gas analyzer can also measure combustibles (CO+H₂) to optimize combustion, and it can measure methane/hydrocarbons to detect potential flame outs or fuel leaks during start-up.

**AT11: DEMETHANIZER BOTTOM GAS**

**MEASURES:** O₂, Combustibles (CO+H₂), Methane/Hydrocarbons (CH₄+<sub>+</sub>)

**PRODUCTS:** WDG-V

A boiler is used to generate steam, which can be added to the feed to decrease coking and lower hydrocarbon pressure to increase olefin yield. A flue gas analyzer is used to measure oxygen (O₂) and control the burner of the boiler. The flue gas analyzer can also measure combustibles (CO+H₂) to optimize combustion, and it can measure methane/hydrocarbons to detect potential flame outs or fuel leaks during start-up.

**AT12: DEPROPANIZER BOTTOM GAS**

**MEASURES:** O₂, Combustibles (CO+H₂), Methane/Hydrocarbons (CH₄+<sub>+</sub>)

**PRODUCTS:** WDG-V

A boiler is used to generate steam, which can be added to the feed to decrease coking and lower hydrocarbon pressure to increase olefin yield. A flue gas analyzer is used to measure oxygen (O₂) and control the burner of the boiler. The flue gas analyzer can also measure combustibles (CO+H₂) to optimize combustion, and it can measure methane/hydrocarbons to detect potential flame outs or fuel leaks during start-up.

**AT13: OVERHEAD GAS**

**MEASURES:** O₂, Combustibles (CO+H₂), Methane/Hydrocarbons (CH₄+<sub>+</sub>)

**PRODUCTS:** WDG-V

A boiler is used to generate steam, which can be added to the feed to decrease coking and lower hydrocarbon pressure to increase olefin yield. A flue gas analyzer is used to measure oxygen (O₂) and control the burner of the boiler. The flue gas analyzer can also measure combustibles (CO+H₂) to optimize combustion, and it can measure methane/hydrocarbons to detect potential flame outs or fuel leaks during start-up.

**AT14: METHANE RICH GAS STREAM**

**MEASURES:** O₂, Combustibles (CO+H₂), Methane/Hydrocarbons (CH₄+<sub>+</sub>)

**PRODUCTS:** WDG-V

A boiler is used to generate steam, which can be added to the feed to decrease coking and lower hydrocarbon pressure to increase olefin yield. A flue gas analyzer is used to measure oxygen (O₂) and control the burner of the boiler. The flue gas analyzer can also measure combustibles (CO+H₂) to optimize combustion, and it can measure methane/hydrocarbons to detect potential flame outs or fuel leaks during start-up.
Following the cracking process, the gas is quenched and compressed to remove any remaining heavy hydrocarbons, hydrogen sulfide (H₂S) and carbon dioxide (CO₂). The required quench stages are determined by the feed stock.

After water quenching, the gas is compressed to separate the hydrocarbons from the quench water. Then, a caustic solution is used to remove the acid gases H₂S and CO₂. The cracked gas undergoes further cooling and drying before separation begins.

The cracked hydrocarbons are rapidly quenched in several stages. The quench stages are determined by the feed stock. After the water quench step, the gases pass through a series of compressors where the hydrocarbons are separated from the quench water. Next, the gases are scrubbed of hydrogen sulfide (H₂S) and carbon dioxide (CO₂) using a caustic solution. The acid gases are stripped from the caustic solution and incinerated or sent to a sulfur recovery unit if high sulfur is present in the feed stock. H₂S and CO₂ in the cracked gas after caustic scrubber are analyzed using a 5100 TDLAS analyzer for process control.

Prior to entering the demethanizer the treated feedstock is analyzed for the amount of CO as a process control factor.

**AT7: INLET OF CAUSTIC TOWER**

**MEASURES:** H₂S, CO₂

**PRODUCTS:** 5100 HD

The cracked hydrocarbons are rapidly quenched in several stages. The quench stages are determined by the feed stock. After the water quench step, the gases pass through a series of compressors where the hydrocarbons are separated from the quench water. Next, the gases are scrubbed of hydrogen sulfide (H₂S) and carbon dioxide (CO₂) using a caustic solution. The acid gases are stripped from the caustic solution and incinerated or sent to a sulfur recovery unit if high sulfur is present in the feed stock. H₂S and CO₂ in the cracked gas after caustic scrubber are analyzed using a 5100 TDLAS analyzer for process control.

**AT8: OUTLET OF DEHYDRATION TOWER**

**MEASURES:** H₂O

**PRODUCTS:** 3050-D0, 5100 HD

Following the removal of the acid gases the cracked gas goes through a dehydration process using one or more absorption beds filled with molecular sieve to continuously remove water before the cracked gas reaches the refrigeration phase.

**AT9: REFRIGERATION OUTLET**

**MEASURES:** CO

**PRODUCTS:** 5100 HD

Prior to entering the demethanizer the treated feedstock is analyzed for the amount of CO as a process control factor.

**PRODUCT SOLUTIONS**

**5100 HD**

Uses tunable diode laser absorption spectroscopy (TDLAS) technology and can be configured with one or two absorption cells, providing dual stream analysis and/or the measurement of multiple analytes at the same time.

**3050-D0**

Proven, accurate quartz crystal microbalance (QCM) technology with built-in verification provides operators with increased measurement confidence. Available with the optional AMEVision display unit interface.
SEPARATION AND HYDROGENATION STAGES

The remainder of the processing plant operating units separate the olefins from the saturated hydrocarbons. If ethane is used as a feedstock, there will be little or no C3 or higher hydrocarbons and the depropanizer and debutanizer separation units will not be present.

PRODUCT SOLUTIONS

AT10: DEMETHANIZER OFF GAS
MEASURES: CH₄, C₂H₆, C₂H₄, CO, CO₂
PRODUCTS: 5100HD
After the removal of the hydrogen, the cracked gas passes into a demethanizer where the bulk of the methane is removed from the higher molecular weight compounds. The demethanizer overhead includes methane with some impurities such as hydrogen, CO, and trace amounts of ethylene. The methane rich stream is blended with natural gas and used to heat the cracking furnace.

AT11/12: ACETYLENE CONVERTER INLET AND OUTLET
MEASURES: Acetylene
PRODUCTS: 5100HD
Depending on the hydrocarbon feedstock used, the cracking furnace design, and operating conditions, the amount of acetylene byproduct can vary from 0.2 to 0.9% by weight. The most common method for acetylene removal is through selective vapor phase hydrogenation.

\[ C₂H₂ + H₂ \rightarrow C₂H₄ \]

It should be noted that during hydrogenation process other chemical reactions can occur and as a result ethylene could be converted to ethane if the reaction goes too far.

\[ C₂H₆ + H₂ \rightarrow C₂H₄ \]

To best control the reaction, continuous - no cycle time delay - measurement of the inlet and outlet of the first bed and acetylene converter outlet is achieved with a TDLAS analyzer. Although some processors choose to only measure the inlet or the outlet acetylene levels, measuring both optimizes catalyst life and conversion rates to ethylene, and reduces the amount of ethane created.

AT13: ETHYLENE PRODUCT
MEASURES: H₂O, NH₃, C₂H₂, C₂H₆
PRODUCTS: 3050-DO, 5100HD
The fractionated products from the C2 splitter overhead are the ethylene product, which is analyzed for process control purposes.

AT14: PROPYLENE PRODUCT
MEASURES: H₂O
PRODUCTS: 3050-DO
The fractionated products from C3 splitter are sent into the propylene product, which is analyzed for process control purposes.

3050-DO
Proven, accurate quartz crystal microbalance (QCM) technology with built-in verification provides operators with increased measurement confidence. Available with the optional AMEVision display unit interface.
Find the right solution for your ethylene plant

AT15: THERMAL OXIDIZER

MEASURES: \( O_2 \), Combustibles (CO+H\(_2\)\), Methane/Hydrocarbons (CH\(_x\)+)

PRODUCTS: WDG-V

For air pollution control, a thermal oxidizer is used to treat the waste gases and unwanted byproducts of the process. Thermal oxidizers typically use direct flame incineration of the waste streams and burner management systems are used for combustion control. A flue gas analyzer is used to measure oxygen to ensure proper operating setpoints. The flue gas analyzer can also measure combustibles (CO+H\(_2\)) to optimize combustion, and it can measure methane/hydrocarbons to detect potential flame outs or fuel leaks during start-up.

AT16: TANK HEAD SPACE MONITORING

MEASURES: \( O_2 \)

PRODUCTS: 5100HD

There are many organic vapor streams where it is critical to monitor the oxygen concentration to minimize the risk of explosion. For example, the tank head space contains volatile compound levels exceeding the Upper Explosive Limits (UEL) and therefore nitrogen blanketing is carried out to generate a non-combustible atmosphere with acceptably low levels of oxygen. To increase safety and minimize the use of nitrogen simultaneously, the nitrogen blanketing gas is controlled as a function of oxygen concentration in the headspace to ensure the oxygen concentration is below the lower explosive limit (LEL).

PRODUCT SOLUTIONS

WDG-V

Designed for safety and serviceability, the WDG-V provides accurate measurements of oxygen (O\(_2\)), combustibles (CO+H\(_2\)) and methane (CH\(_x\)) for combustion applications.

5100HD

Uses tunable diode laser absorption spectroscopy (TDLAS) technology, and can be configured with one or two absorption cells, providing dual stream analysis and/or the measurement of multiple analytes at the same time.

• Thermal Oxidizer

• Tank Head Space Monitoring

ametekpi.com
AMETEK Process Instruments delivers worldwide sales and service support through a network of direct and factory-trained global distribution channels.

AMETEK Service Assistance Program plans offer coverage up to 24 hours a day, 365 days of the year.

As worldwide experts in the manufacture of process analyzers and instrumentation, we have supplied solutions to industry since 1962, providing the widest range of analysis technology available.

Through process application consulting, we create custom-designed solutions that meet the needs of your specific application or process.

© 2021, by AMETEK, Inc. All rights reserved. Printed in the U.S.A. PI0003 Rev 2 (08/21)

One of a family of innovative process analyzer solutions from AMETEK Process Instruments. Specifications subject to change without notice.

Find the right solution for your ethylene plant ametekpi.com