Ammonia Process

**INTRODUCTION**

The purpose of this document is to provide information regarding turbomachinery upgrade and retrofit opportunities in the process of producing ammonia. First, we’ll discuss ammonia as a product, how it’s produced, and what support systems this requires. Then we’ll describe three areas of opportunity for Triconex: safety, turbine controls and compressor controls. We’ll go into detail regarding what elements we can install, upgrade, or retrofit within those three categories. To conclude, we’ll discuss implications and strategies, special considerations, and other important information. You’ll find a number of diagrams following the text that describe relevant processes and organization.

**AMMONIA AS A PRODUCT**

Ammonia is primarily used in the production of fertilizers, such as ammonium sulfate, ammonium nitrate, ammonium phosphate. It is also used as a refrigerant and as an intermediate for some petrochemicals. Most ammonia plants are part of a larger fertilizer manufacturing facility that work with nitric acid, phosphoric acid, sulfuric acid, urea and/or co-gen. In its pure form, ammonia exists at ambient conditions as a gas. When compressed to between 200 and 300 psig, it can be condensed against air or cooling water. In order to apply it to the soil, ammonia must be combined with other substances. These substances are chosen for their additional benefits to the soil.

**PRODUCING AMMONIA**

The basic feedstocks for ammonia are natural gas (methane) and air. Natural gas provides hydrogen, and air provides nitrogen to the NH3 ammonia molecule. A conventional ammonia plant has these basic components: a primary reformer, a secondary reformer, a carbon dioxide removal and a synthesis loop. Most ammonia plants also have support and utility sections, steam system integration, storage facilities, etc.

In the primary reformer, high-pressure methane feed gas is heated and combined with high-pressure steam. In the presence of the heat and a catalyst, the methane and steam react to form carbon dioxide and hydrogen.
In the secondary reformer, the hot effluent of the primary reformer is combined with air, causing the oxygen in the air to combine with hydrogen. This process results in hot carbon dioxide, nitrogen, hydrogen and water vapor. These gases are cooled by generating steam.

Next, the process gas is passed through the carbon dioxide removal section and the dryers to remove all but the hydrogen and nitrogen gases (please see Figure 1 on page 6 for greater detail). This mixture is called the synthesis gas.

The synthesis gas is compressed by the syn gas compressor to more than 2500 psig. Then it is circulated through the synthesis loop where a catalyst induces the nitrogen and hydrogen to react to form ammonia. A direct contact cooler scrubs out the ammonia that forms in the syn loop. Unreacted gases are returned to a recycle stage in the syn gas compressor, and to the syn loop. Liquid ammonia from the ammonia refrigeration compressor condenser is sprayed into the reacted syn gas stream to cool it as it passes through the contact cooler.

Because this process poses significant hazards to both turbomachinery and safety, Invensys Triconex offers products and services to improve performance and increase user safety.

**Developments in Ammonia Production**

Prior to the late 1960s, first generation ammonia plants used reciprocating compressors because the required pressures were very high (over 5000 psig) and the flows were low. A large plant produced 200 tons per day.

Through the development of low-pressure catalysts and larger furnaces in the mid-1960s, M. W. Kellogg achieved pressures and flows that allowed the use of centrifugal compressors. Other ammonia developers soon began using similar designs. These second generation plants were capable of producing 1000-1250 tons per day.

A third generation plant is now being built by a few designers, including Kellogg and KTI/Fish. These plants are characterized by even lower syn loop pressures and modular process designs.

**SUPPORT SYSTEMS**

A number of support systems are associated with the production of ammonia. Some of these systems exist in almost every ammonia plant, while others are provided according to specific needs. This section discusses three specific support systems: feed gas compression, feed gas treating, and steam systems.

- **Feed Gas Compression.** When the natural gas supply to the plant is lower than the process requires, a compressor boosts the feed to the pressure required by the primary reformer. This compressor is usually a small, single-section centrifugal model driven by a steam turbine or an electric motor.

- **Feed Gas Treating.** If the feed gas contains sulfur or mercaptans, a desulfurization unit eliminates these contaminants prior to the gas’s entry in the primary reformer.

- **Steam Systems.** As the secondary reformer burns the oxygen (with hydrogen), a tremendous amount of heat becomes available and is used to generate steam. While older ammonia plants produced 600 psig steam, secondary reformers in post-1970s plants produced 1500-1800 psig steam. This high-pressure steam production became practical with the development of high-speed steam turbines suitable for such pressures.

To start the ammonia process, an auxiliary boiler provides the 600 psig steam required in the primary reformer. This steam drives the process air compressor and the ammonia refrigeration compressor.
Ammonia plants usually pass 1500 psig steam from the secondary reformer through the high-pressure section of the syn gas compressor turbine. This is sometimes called “topping the turbine.” The steam extracted from the high-pressure section is used to supply the process and the turbines operating at 600 psig. The condensing section of the syn gas compressor turbine provides any extra horsepower required by the compressor that is not already produced in the high-pressure section of the turbine.

Other steam pressure levels—such as 250, 150 and 50 psig—are used for heating and for small steam turbines in the plant. The syn gas compressor turbine inlet valve (V1) controls the 1500 psig steam pressure. The auxiliary boiler, let down and vent valves control the 600 psig header pressure.

**WHAT’S IN IT FOR TRICONEX**

When the Soviet Union dissolved, most of their inefficient ammonia plants were decommissioned because of excessive auto-consumption costs. Since that time, the profit margin in western-style plants has improved—especially because modern ammonia plants eliminate equipment redundancy. They now depend on sophisticated, un-spared furnaces and compressors, which deliver high profit margins. This environment is the perfect setting for the Invensys Triconex controllers.

Ammonia is an important component of the HPI market. To produce ammonia, manufacturing and fertilizer companies require robust control systems for their unique turbomachinery and safety needs. Invensys’ goal is to support these systems with our portfolio of solutions and services.

- **Safety.** Although ammonia plants now generate a high profit margin, they also face significant safety issues. In fact, their end product (NH3) is lethal if aspirated.

  One major safety concern relates to high pressures and temperatures. For example, the primary reformer is a fired heater that raises the methane temperature to over 1000°F. The secondary reformer adds high-pressure air to the effluent of the primary reformer. Both of these pieces of equipment represent very significant explosion risks if they are not properly protected. Another safety concern involves the synthesis loop, which contains hydrogen at up to 3000 psig. This high-pressure hydrogen can cause extensive damage if it is not precisely controlled.

  All of these safety hazards require the use of a very robust Emergency Shutdown System (ESD) platform. Invensys’ TMR safety systems are designed to protect equipment and people, minimizing risks by implementing proper safety routines and reliable hardware.

- **Turbine Controls.** Because steam is required in the production process, and because the secondary reformer has a significant exotherm, ammonia plants generally utilize steam turbines for driving pumps and compressors. In some ammonia plants (C. F. Braun design), gas turbines are used for driving the syn gas and/or process air compressors. The current Braun design still uses a Frame 5 to drive the air compressor. In this case, the exhaust is ducted into the primary reformer for use as heated combustion air.

  These turbines require reliable and efficient turbomachinery controls. Invensys Triconex has significant experience in the retrofit, upgrade and commissioning of TMC equipment involved in ammonia production. We provide turbine services for the following elements:

    - **Process Air Compressor.** This compressor is usually driven by a single-valve condensing turbine with 600 psig inlet steam. As mentioned above, this compressor is sometimes driven by a gas turbine or an electric motor.
**Syn Gas Compressor.** These compressors routinely operate at over 12,000 rpm. Their most common driver is a steam turbine, as this eliminates the need for a gear box. Gas turbines in this compressor’s horsepower range operate at 5000 rpm or less. In the mid-1960s, M. W. Kellogg pioneered the use of a very high pressure extraction-condensing steam turbine for this service. Today, virtually all designs incorporate this arrangement.

**Ammonia Refrigeration Compressor.** A 600 psig inlet single-valve extraction turbine is the most common driver for this service.

**Feed Gas Compressor.** Sometimes called the Natural Gas Compressor, this machine boosts feed gas to the pressure required by the primary reformer. Usually, it is a small barrel compressor driven by a single-valve steam turbine or an electric motor. Some ammonia plants do not have a fuel gas compressor if their pipeline pressure is adequate.

**Combustion Air Fans.** Large fans are used for the primary reformer combustion air. The induced draft (ID) fan is usually three times the size and power of the forced draft (FD) fan.

**Boiler Feed Pumps.** To protect the steam system against an electrical power failure, at least one of the boiler feed water pumps is driven by a steam turbine.

**CO₂ Removal Circulating Pumps.** These pumps are usually large—similar in power to the boiler feed, but spared by a motor-driven pump. Considering the large condenser loads in an ammonia plant, cooling water flows are significant. There is usually at least one cooling water pump, which is driven by a condensing steam turbine.

**Compressor Controls.** Each of the process compressors mentioned above is unspared and critical to the process. If any one of these machines stops producing forward flow, the process is interrupted. Each of the following machines also has special control requirements:

**Feed Gas Compressor.** The compressor is operated on discharge pressure control. Whether this machine is driven by motor or turbine, it usually includes a suction throttle valve that handles any uncertainty in suction pressure. For example, if the load drops such that the turbine reaches minimum governor and the discharge pressure continues to rise, the suction throttle valve dissipates this additional pressure energy.

Using an integrated controller cures a number of problems. For instance, the discharge pressure control is split-ranged between the speed controller and the suction throttle valve controller. The integrated controller is also useful in operating the compressor bypass valve (which differs from the kickback valve) for start-up and shutdown of the train.

**Process Air Compressor.** The 600 psig discharge from this machine enters the secondary reformer. To generate a pressure ratio higher than 40 requires up to six intercooled stages of compression. Plants built prior to the 1990s used two compressor bodies, and the high-pressure body sometimes used a gearbox.

Most modern ammonia plants use a single, integrally-geared six-stage compressor. The two-body compressors use a modulated vent valve on the discharge to prevent surge during operation above the minimum governor speed. Below minimum governor speed, a solenoid-operated vent valve opens on the low-pressure body discharge to protect the low-pressure body.

**Syn Gas Compressor.** In a second generation plant, this two-body machine has three intercooled stages and a recycle stage. It is common for the turbine to have a compressor body on each end. The second generation Braun plants use a three-body machine (three stages plus recycle) driven by a gas turbine—usually a Pratt and Whitney or Rolls-Royce aeroderivative. Third generation plants have reduced the syn loop pressure such that the syn gas compressor fits into a single body.
CONCLUSION

Now that we have discussed the process involved in ammonia production, it’s easy to see how crucial the related turbomachinery equipment is. It’s also easy to see the importance of reliable controls in minimizing safety hazards and increasing efficiency. With extensive, field-proven experience, Invensys Triconex provides control systems guaranteed to improve ammonia plant performance.

DIAGRAMS

The following diagrams explain the process of ammonia production for Kellogg, Linde, and KTI/Fish Processes:

- Ammonia Process (Figure 1)
- Fuel Gas Compressor (Figure 2)
- Air Compressor–Modern Kellogg Process, Third Generation (Figure 3)
- Syn Gas and Ammonia Train–Modern Kellogg Process, Third Generation (Figure 4)
- Process Air Compressor–Modern Linde Process (Figure 5)
- Nitrogen Booster Compressor–Modern Linde Process (Figure 6)
- Syn Gas Compressor–Modern Linde Process (Figure 7)
- Turbo Generator Set–Modern Linde Process (Figure 8)
- Syn Gas/Ammonia Train–Modern KTI/Fish Process (Figure 9)
- Process Air Compressor–Modern KTI/Fish Process (Figure 10)
- Process Air Compressor–Kellogg Traditional Process (Figure 11)
- Ammonia Refrigeration Compressor Train–Kellogg Traditional Process (Figure 12)
- Synthesis Gas Compressor Train–Kellogg Traditional Process (Figure 13)
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\text{Methane (CH}_4\text{) + 2H}_2\text{O} \rightleftharpoons \text{CO}_2 + 4\text{H}_2
\]

**Primary Reformer**

- Methane (CH\(_4\))
- Fuel Gas
- Steam
- \(\text{CO}_2 + 4\text{H}_2\)
- Air

**Secondary Reformer**

- \(\text{CO}_2 + 4\text{H}_2 + \text{N}_2 + \text{O}_2 \rightleftharpoons \text{CO}_2 + \text{N}_2 + 2\text{H}_2\text{O} + 2\text{H}_2\)

**CO\(_2\) Removal**

**Synthesis Gas Compressor**

**Dryers**

**Ammonia Refrigeration Compressor**

**Synthesis Loop**

*Figure 1: Ammonia Process*
Figure 2: Fuel Gas Compressor

Figure 3: Air Compressor—Modern Kellogg Process, Third Generation
Figure 4: Syn Gas and Ammonia Train—Modern Kellogg Process, Third Generation
Figure 5: Process Air Compressor—Modern Linde Process
Figure 6: Nitrogen Booster Compressor—Modern Linde Process

Figure 7: Syn Gas Compressor—Modern Linde Process
Figure 8: Turbo Generator Set—Modern Linde Process

Figure 9: Syn Gas/Ammonia Train—Modern KTI/Fish Process
Figure 10: Process Air Compressor—Modern KTI/Fish Process
Figure 11: Process Air Compressor–Kellogg Traditional Process
Figure 12: Ammonia Refrigeration Compressor Train—Kellogg Traditional Process
Figure 13: Synthesis Gas Compressor Train—Kellogg Traditional Process