Implementation of a Feed Gas Saturation System to a 1970s Foster Wheeler Steam Methane Reformer

For ammonia plants wanting to improve the efficiency of their steam methane reformers, the installation of a feed gas saturator system provides a cost effective alternative to combustion air preheat and other upgrade options. By utilization of cold process condensate, additional heat is absorbed from cooler flue gas, steam demand is reduced, and condensate treatment is reduced. Completed in 2014, such a system was successfully implemented on a 1970s Foster Wheeler reformer at the Yara Trinidad Tringen 1 plant.

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Introduction

In an environment that requires continuous improvements to ensure sustainability and productivity, safe innovative methods for energy reduction is a key success factor towards competitiveness. Innovative methods utilizing waste heat to improve energy efficiency show great potential for energy reduction and improved productivity.

Commissioned in 1977, the Tringen 1 Ammonia Plant is located in Point Lisas Trinidad and is operated by Yara Trinidad Limited. The plant is a 1970’s Flour Daniel design that was revamped in 1996. In 2014, another revamp followed with the intent of reducing plant specific energy consumption by 12% while increasing the maximum achievable production rate by 5.5%. Though numerous modifications were made to the plant, the focus of this paper will be the benefits achieved from a Feed Gas Saturator System

Through reduction of process steam demand through cold process condensate utilization, implementation of a feed gas saturation system proved to be an effective method for reducing flue gas temperature and improving thermal efficiency, without modification to the existing combustion system.

Description of process

Background

The Tringen 1 plant original design production capacity was 1160 MT/day. The first revamp in 1996 focused on increasing production capacity and as such, the production rate was increased to 1365MT/day. The plant uses natural gas feedstock in a methane steam reforming side fired Foster Wheeler furnace with auxiliary convection burners. Furnace draft is created by three (3) induced draft fans. Prior to the 2014 revamp, process steam for reforming was supplied from the medium pressure (MP) 600psig (4140 kPag) header directly.

Unique features in this plant include the following:

1. The plant has an aqueous ammonia refrigeration system which is
supplemented by motor driven refrigeration screw compressors.

2. There are two syngas compressors. The first (LP Syngas Compressor) is located on the inlet to the CO2 system and compresses to approximately 1800psig. The second (HP Syngas Compressor) compresses to the synloop operating pressure of 3300psig (22800 kPag).

3. The CO2 removal is done by physical absorption using Propylene Carbonate, which requires a high pressure, thus the location of the LP Syngas Compressor.

2014 Energy Revamp

In 2011 a revamp concept was launched with an energy reduction focus. The resulting revamp concept indicated the possibility of a reduction in specific energy consumption from 43.5 MMBtu/MT (HHV) to 38.3 MMBtu/MT (HHV) while also increasing maximum production capability from 1440 MT/dy to 1520 MT/dy.

The principal strategy for energy reduction was a change in the medium pressure steam balance on the plant. It was identified that the plant was operating in a mode where the medium pressure steam demand exceeded the HP steam generation capability. As a result, additional MP steam was imported from natural gas fired auxiliary boilers. The revamp focused on areas where MP steam demand could be reduced. Several opportunities were identified. These included:

- Steam generation via waste heat recovery (Feed Gas Saturation)
- Reducing synloop pressure by the installation of a once through Make Up gas (MUG) converter leading to reduced power consumption of the synthesis gas compressor turbine.
- Change from selected turbine drivers to motor drivers or dual drivers.

In 2014, the revamp was executed and the main changes to process included:

1. Primary Reformer Convection Coil Changes to improve thermal efficiency of the furnace.
   - The convection coils were redesigned to maximize use of reformer convection duty. The chosen approach to improve reformer thermal efficiency was the full replacement of the convection section coils. This included hip coils, while using the existing structure, and a simplified coil configuration with the addition of a feed gas saturation system.

2. Installation of a once through Make Up Gas (MUG) converter with an associated high pressure steam boiler and boiler feed water preheat.

3. Conversion of the main synthesis loop from a wet gas loop to a dry gas loop using an Ammonia Wash countercurrent column for Syngas drying.

4. Modification of selected turbines to dual driver (motor/ turbine capability):
   - Two out of four Boiler Circulating Water Pump Drivers
   - Two out of three Induced Draft Fans on the Primary Reformer

5. Upgrade of the process condensate stripper from LP steam (to vent) to MP steam being recovered.

6. Installation of a booster process air compressor for production increase.

7. Installation of a supplemental ammonia bypass refrigeration compressor.

8. Modification of selected turbines to motor drivers.

After implementation of the above changes, the plant has been capable of achieving production volumes up to 1524 MT/dy at an energy consumption of 39.1 MMBtu/MT (HHV). The modifications implemented have been operationally stable and has not reduced plant reliability.

The main contributor in the overall energy reduction was the use of the reformer flue gas waste heat for feed gas saturation. In the case of the Tringen 1 furnace, this waste heat generated
33% of the required process steam from condensate. This steam would have otherwise been produced via auxiliary boilers. The use of feed gas saturation solely contributed to a reduction in plant specific energy by 2.0 MMBtu/MT (HHV).

**What is a Feed Gas Saturator Coil?**
A saturator coil is a reformer convection coil bank that uses available flue gas heat that would otherwise be vented, to vaporize a water stream directly injected into the feed gas stream. This water stream is usually process condensate or Boiler Feed Water (BFW).

In a typical ammonia plant, unreacted process steam is condensed for reuse. As this process condensate can contain impurities (e.g. dissolved gases and trace amounts of methanol and ammonia), from upstream in the reforming process and shift converters, reuse of this condensate as BFW normally requires treatment. A feed gas saturator coil system allows utilization of this condensate – without pretreatment – by injection into the natural gas feed. This process reduces the amount of “live” steam needed for mixing with the hydrocarbon feed upstream of the radiant catalyst tubes. There is also the benefit of extracting additional heat from cooler reformer flue gas.

![Flow diagram of a saturator coil / feed gas saturation system.](image-url)
Inclusion of a feed gas saturator coil alters the feed gas flow path from a typical steam methane reformer. As shown in Figure 1, the Natural Gas feed is first preheated in an interchanger before being further heated in a convection section preheat coil to elevate the temperature for the purpose of desulfurization.

Following desulfurization, the feed is then cooled by the interchanger before a water stream is injected (typically process condensate and/or BFW). Lowering the feed temperature after desulfurization is necessary to achieve a lower saturator coil inlet temperature thereby potentially increasing efficiency. The hydrocarbon feed and condensate mix passes through the feed gas saturator coil. The stream then passes through a separator (knockout) drum to remove any remaining liquid condensate. Generally, the saturator coil fully vaporizes the injected water with some superheating; however, where solid impurities are a concern, the coil may be designed for less than 100% vaporization. Following the separator drum, additional process steam is added to achieve the desired steam to hydrocarbon ratio before being further preheated for the reforming reaction.

Due to the replacement of a portion of “live” process steam by condensate, the combined mixed feed temperature is lower than if “live” steam only was used. To accommodate this, additional design changes are made, such as increased surface area to the mixed feed preheat coil, rearrangement of coils, increased arch or auxiliary firing, etc.

The colder saturator coil inlet temperature allows for cooler flue gas stack temperatures and higher reformer efficiency. Energy savings are seen in the form of reduced steam generation, reduced steam superheat, reduced condensate treatment, and more efficient induced draft (ID) fan operation due to decreased flue gas volume.

Saturator Coil Control and Operation

Feed gas saturation is achieved on the Tringen 1 plant by direct injection of water into the inlet manifold of the saturator convection coil. The water source can be process condensate, boiler feed water (BFW) or a combination of both. Process condensate is the primary source of water to the saturator coil with BFW as a back-up supply.
Process condensate from the primary process condensate knockout drum is pumped from the drum to the saturator coil and is controlled through a flow control loop. The flow control loop works in conjunction with the primary reformer steam to gas ratio controls and sets a remote set point for the total water flow required to the saturator coil. The exit temperature of mixed gas from the saturator coil is monitored via the DCS. A temperature differential indication is set up between the actual outlet temperature and the process stream dew point. If the actual temperature out of the saturator coil approaches 50F of the dew point temperature, a deviation alarm activates to alert the operator that the saturation temperature is being approached.

In the event that process condensate (primary water source) cannot supply the saturator coil water requirements, the controls will automatically begin injection of BFW to ensure that the required total water flow to the coil is maintained as well as the required steam to carbon ratio.

In the event that the temperature of the gas leaving the saturator coil reaches the dew point and liquid exits the coil, there is a separator on the outlet of the coil to prevent liquid from reaching the mixed feed coil. This vessel is equipped with a high level 2oo3 trip.

The control strategy has been tested in normal operation, startup –up, shutdown and plant upset conditions and has proven to be reliable.

**Primary Reformer Configuration**

**Original Design**
Built in 1977, the primary reformer is a Foster Wheeler design, with twin radiant cells. The convection section was design with six (6) streams – natural gas fuel, demineralized water, process air, natural gas feed, mixed feed (hydrocarbon and steam), and high pressure superheated steam – heated in a total of 15 coil banks – 7 in the vertical section and 4 in each hip section.

Prior to the revamp, the furnace was also experiencing multiple operational issues. Coils were operating above their design metal temperatures. Substantial air leaks were also discovered.
Figure 4. Pre 2014 Revamp Primary Reformer Configuration

Figure 5. Post 2014 Revamp Primary Reformer Configuration
Primary Reformer Configuration

Revamp Design
To address the issues of air leakage, coils operating outside of their design and mechanical integrity, it was decided to redesign the entire convection section. In spite of the redesigning of the convection section, the existing convection height and structure was maintained. Whereas the original convection section was design to avoid pinch points by dividing the process into numerous coil sections, the addition of the feed gas saturator was modular.

The revamped design introduced the saturator coil while reducing the number of streams to five – feed preheat, high pressure superheated steam, feed with condensate, mixed feed, and process air – across a total of only nine coil banks – five in the vertical section and two in each hip section, although the total surface area has increased. As the number of coil banks has decreased, so too has the number of jumpovers. Modifications also included conversion of the ID fan to dual drive operation (motor or turbine) instead of strictly turbine driven in order to further reduce plant steam demand.

Existing convection structural steel was reused. To improve installation time, coil modules were designed with straight walls for sliding into the existing structure (see Figure 6).

To provide room for the saturator coil in the existing structure, the fuel preheat and demineralized water coils were removed. As the saturator coil provides all the necessary cold flue gas heat sink, efficiency is not lost by removal of the fuel preheat; rather, a small reduction in adiabatic flame temperature, and thus thermal NOx formation, may be a tangential benefit to this design choice.

Figure 6. Coil module frame for improved installation time

Figure 7. Process condensate injection

To ensure proper mixing of the process condensate and desulfurized feed, process condensate is injected into the feed stream directly following the manifold as in Figure 7.
Performance

Performance prior to 2014 Revamp
Before the revamp, the reformer stack temperature was in the range of 690°F-710°F (366°C-377°C), with thermal efficiencies of approximately 80% (3 vol% O2, dry basis) and 81% (2 vol% O2, dry basis). The maximum demonstrated capacity was 1440 MTPD. The maximum reformer firing rate was 684 MMBtu/hr (722 GJ/hr), and the “live” process steam added to the feed stream was 227,000 lb/hr (102,900 kg/hr).

Predicted Performance
Due to the full revamp design scope, the production capacity was increased to 1520 MTPD. The reformer was predicted to operate with a firing rate of 722.7 MMBtu/hr (762.4 GJ/hr) and a stack temperature of only 330°F (166°C), having a fired efficiency of 91% based on 10% excess air (~2 vol% O2 dry in the flue gas).

With the new design, predicted use of process condensate for normal operation was 73,400 lb/hr (33,300 kg/hr) at 168°F (76°C). Due to this, MP process steam could be reduced to 157,000 lb/hr (71,200 kg/hr), with condensate providing the remaining 31.8% of the total steam requirement.

Under pre-revamp conditions, the HP Boiler produced 176,000 lb/hr of HP steam. The change of the ID fan from turbine to motor driven operation saves an additional 30,000 lb/hr of Steam. Together with the steam savings from the saturator coil, it was predicted the HP Boiler could have been shutdown.

Actual Performance
From actual operating data taken on August 24, 2015 following the revamp, the plant was running at 1500 MTPD, at 109% plant load. The average condensate to feed ratio was 0.947 lbmol/lbmol, resulting in a 66,000 lb/hr (30,000 kg/hr) process condensate utilization at 147°F (63.9°C). At an average flue gas temperature of 285°F (140°C), the actual revamp efficiency was 93.2% based on an O2% of 2 vol%, dry.

Due to the desire for operational stability should additional steam be needed, the HP boiler was not shut down but remains at minimum firing when the plant is at full load.

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Table 1. Performance comparison

Conclusion

Utilization of waste heat from the primary reformer flue gas can provide significant opportunity for energy reduction especially in older vintage plant designs. Though many potential opportunities exist for both energy and production improvements, a feed gas saturation system, by itself, can be an attractive option for energy reduction. The design, control strategy and operation have been proven to be reliable and stable with the potential to improve thermal efficiency by 12% while reducing the need for MP steam generation. In addition to the benefits of improved efficiency, the modification also results in the offloading of the ID fans and reuse of process condensate without pre-treatment.

Overall, though the benefits should be assessed on a case by case basis, the potential of this method for energy reduction should not be under-estimated.