Reformer balancing for optimization of a primary reformer

Hugo S. Roberts – Johnson Matthey
Lawrence M. Sandy – PCS Nitrogen Trinidad Limited

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This study demonstrates that balancing tube wall temperatures can produce material improvements in overall energy efficiency, primary reformer methane slip and plant production. In 2014, an evaluation of the PCS 02 reformer suggested that there was an opportunity to improve its overall efficiency by balancing its tube wall temperatures. Using an agreed to methodology, adjustments were made tofuel header pressures on individual rows, reducing and increasing the temperature as necessary. Overall, fuel usage decreased and methane slip was reduced.

As a result of the adjustments made to the individual fuel header pressures, the average tube wall temperatures were effectively reduced in warmer rows or increased in cooler rows. A more detailed statistical analysis of the temperatures in specified rows reveals a marked improvement in the frequency distribution in the rows where adjustments were made. The subsequent redistribution of heat within the furnace resulted in a reduction in methane slip, an increase in production and a reduction in gas usage. Hypothetically, if these findings are applied to a 1,500 STPD ammonia plant, operating at 32.0 mmBTUIST, 98% reliability, consuming natural gas at US$3.00IMMBtu, with an ammonia price at US$420/ MT, an annualised saving of US$450,000 is achievable. Therefore, although it is subject to the influence of pricing variables, plant operators can expect significant annualised cost savings from such an exercise.

Introduction

The primary reformer is commonly described as the heart of a syngas plant because it is the single largest consumer of energy. Therefore, its efficiency and reliability are critical to plant performance. As a result, it has become best practice to continuously monitor and optimize its operation.

There are a number of parameters that can be monitored to assess the operation of the primary reformer, these include:

- operating pressure and pressure drop
- feedstock composition,
- operating temperature,
- steam to carbon ratio,
- excess combustion air,
- process outlet composition, and
- tube wall temperature profile and spread

Of these, the tube wall temperature (TWT) profile, and the spread of tube wall temperatures are parameters that are often overlooked until a tube is believed to be operating in excess of its maximum operating temperature. A wider temperature spread can result in higher than expected methane slip, leading to reduced plant efficiency and ultimately lower than desired production.

The most common method of monitoring tube wall temperatures is the optical pyrometer. Optical pyrometers have been used and proven for decades and can be convenient for identifying hot zones. However, measurement of individual tube wall temperatures for an entire reformer can be time consuming. Another technology that can be used is the gold cup contact thermocouples which can provide greater accuracy. However, its use is limited to tubes within reach of the peep holes. A recent alternative to both of these methods is the Reform,er Imager, which allows the operator to quickly capture high resolution images and perfonn analyses not easily possible with either of the previous two methods.

The Reformer Imager operates at a suitable wavelength for the reformer radjant section and takes video images of the inside of the reformer. This new technique captures very high resolution images coupled with a wide viewing angle. Temperature readings are available for every pixel in the image. A further advantage is that it provides the operator with the ability to view sections of the tube that are normally not accessible, including the top and bottom of the tubes. The videos are recorded directly to a laptop which provides for subsequent detailed analysis and trending, as illustrated in the snapshot of figure 1. The software allows for manipulation of the images so that issues such as hot spots can be identified long before they are observable with the naked eye. These are unique advantages over any other temperature measurement technique.

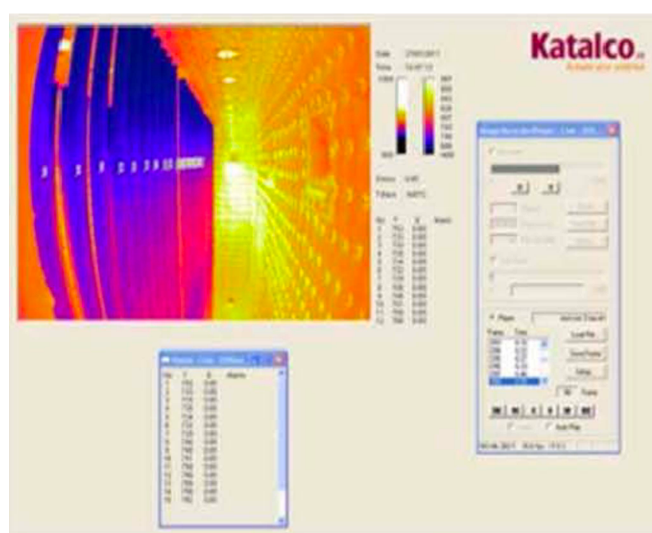

Figure 1. Snapshot of video from Reformer Imager

A reformer survey using the Reformer Imager was conducted at the PCS Nitrogen, Trinidad 02 Ammonia plant on March 13th 2014. This reformer is a 10 row design, each having 42 tubes. The reformer was resharped in 2006 and at the time of the balancing exercise had been using **KATALCO**™ catalyst for approximately 6 years. The purpose of the survey was to evaluate the performance of the reformer and catalyst. The general condition of the reformer was satisfactory, but there was a wide tube wall temperature spread.

Johnson Matthey and PCS Nitrogen Trinidad decided that there may be an opportunity for optimization of reformer performance by making iterative adjustments to the firing within the reformer to balance the tube wall temperatures - a procedure referred to as reformer balancing.

This paper presents actual plant data, demonstrating improvement in primary reformer operation. It also presents the financial benefit reformer balancing can deliver to the plant operator.

Method

Baseline conditions

On the 14th March 2014, a preliminary primary reformer survey was conducted on the PCS 02 plant in order to establish a baseline before balancing the reformer. The survey involved:

I. The use of a Reformer Imager to capture images which were used to determine the temperatures of the reformer tubes
2. Visual observation of the condition of the tubes, refractory and burners
3. Recording of burner valve positions
4. Collection of process data to model the performance of the primary reformer.

The initial reformer conditions were as shown in Table 1.

Parameter	Value
Reformer exit temperature °C (°F)	800.6 (1,473)
Average TWT °C (°F)	854.4 (1,570)
Maximum TWT °C (°F)	910.6 (1,671)
Minimum TWT °C (°F)	775.6 (1,428)
Process gas flow kg/hr (lb/hr)	31,047 (68,448)
Natural gas flow (lb/hr)	2,869 (6,324)
Process steam (lb/hr)	111,166 (246,178)
Primary reformer methane slip (%)	11.12

Table I. As-found condition on reformer

At the time the initial reformer survey was conducted there were ix burners out of service and seven burners throttled. This is summarized in Table 2 below (Key: R = row, B = burner).

Burners out of servuce	Burners throttled
R1/B16	R3/B3
R3/B11	R3/B4
R6/B18	R4/B4
R7/B8	R6/B17
R7/B18	R7/B10
R8/B9	R7/B11
	R8/B15

Table 2. Throttled closed burners on reformer

It was important to note the positions of the burners prior to commencing adjustments, as closed or throttled burners would contribute to the presence of cold zones.

Adjustments and optimized conditions

Both the survey on the 13th March and the preliminary survey conducted on the 14th March indicated that the outer rows were hotter than the inner rows. The fuel header pressures were reduced on the outer rows in an effort to lower those temperatures; the fuel header pressures on the two inner rows were increas,ed in an effort to raise the temperatures as that area was cooler.

Following these adjustments, a survey was done 6 hours later on 14th March 2014 and the 'as-left' process conditions were as shown in Table 3.

Parameter	Value
Reformer exit temperature °C (°F)	798.9 (1,470)
Average TWT °C (°F)	851.1 (1,564)
Maximum TWT °C (°F)	895.0 (1,643)
Minimum TWT °C (°F)	775.6 (1,428)

Table 3. Conditions 6 hours after adjustments

With steady plant conditions maintained, another survey was conducted 12 hours after the initial adjustments to assess the conditions of the reformer.

Parameter	Value
Reformer exit temperature °C (°F)	800.0 (1,472)
Average TWT °C (°F)	852.8 (1,567)
Maximum TWT °C (°F)	905.0 (1,661)
Minimum TWT °C (°F)	772.2 (1,422)

Table 4. Conditions 12 hours after adjustments

Final data collection was performed 48 hours after the initial adjustment and these are the conditions under which the reformer was left.

Parameter	Value
Reformer exit temperature °C (°F)	800.6 (1,473)
Average TWT °C (°F)	854.4 (1,570)
Process steam (lb/hr)	111,166 (246,178)
Primary reformer methane slip (%)	11.12

Table 5. As left conditions - 48 hours after adjustment

Results

While reformer balancing exercises have been performed at this unit previously, this is a comprehensive approach to quantify its impact to plant efficiency and production. The results can be summarized in terms of:

1. Reliability

Reliability was improved as a result of lower peak temperatures within the reformer. The average tube wall temperatures of the hotter outer rows were reduced by 5.6-8.3°C (10-15°F) on average.

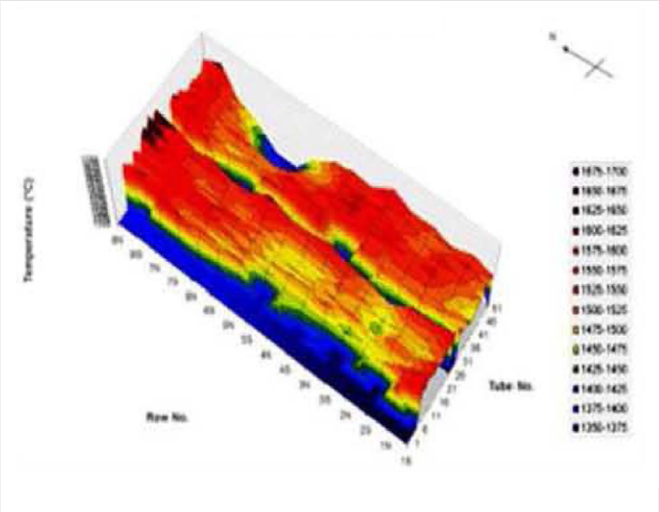

Figure 2. initial temperature map of reformer

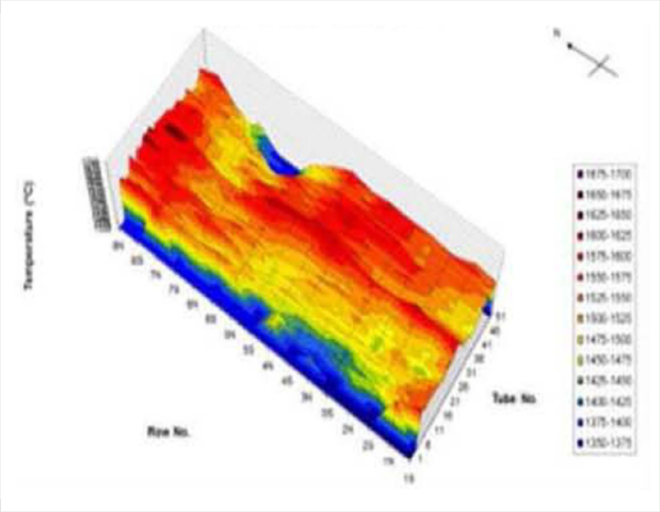

Figure 3. Final temperature map of reformer

2. Process performance

A summary of the process changes effected by the adjustments is shown below:

Parameter	Initial	Final
Reformer exit temperature °C (°F)	800.6 (1,473)	798.9 (1,470)
Average TWT °C (°F)	854.4 (1,570)	852.8 (1,567)
Maximum TWT °C (°F)	910.6 (1,671)	905.0 (1,661)
Minimum TWT °C (°F)	775.6 (1,428)	772.2 (1422)
Measured TWT spread °C (°F)	135 (243)	132.8 (239)
Corrected TWT spread °C (°F)	168.3 (303)	165 (297)
Process gas flow kg/hr (lb/hr)	31,047 (68,448)	31,059 (68,474)
Natural gas fuel flow (lb/hr)	2868 (68,448)	2850 (6,283)
Process steam (lb/hr)	111,664 (246,178)	111,765 (246,401)
Primary reformer methane slip (%)	11.12	11.03

Table 6. Summary of changes on reformer

It should be noted that the reformer imager measures the total radiation from the target and the surrounding hotter surfaces. These instruments cannot differentiate between radiation emitted by or reflected from the target. They must therefore be corrected accordingly and this

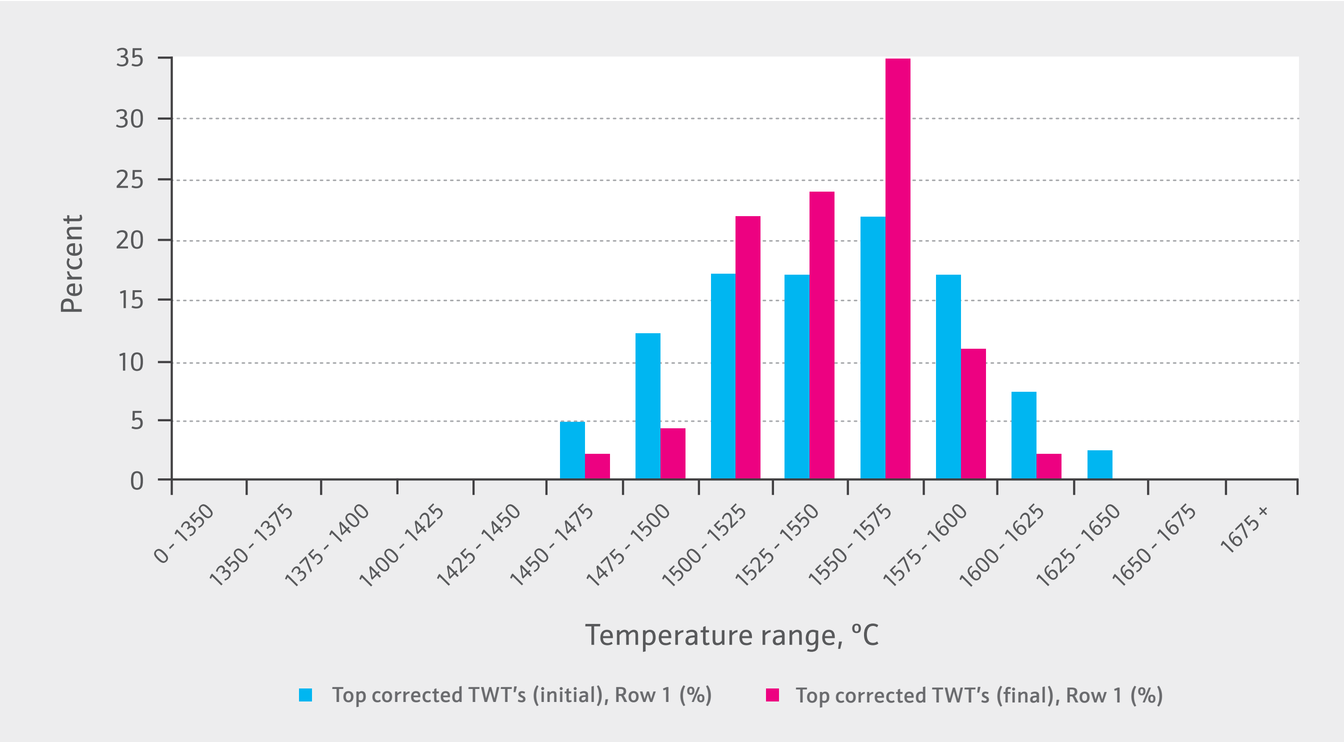

Figure 4. TWT frequency distribution, Row 1

is done by collecting background temperatures as well and backing out background radiation. Raw measured temperatures can be used as a guide, but corrected temperatures are a more accurate indication of tube wall temperature.

An examination of the frequency distribution of temperatures in the rows where adjustments were made illustrates the redistribution of heat within the rows. The data for row 1 is shown in Figure 4.

In the cases of Rows 1 and 8, the number of tubes at temperatures above 885°C (1625°F) was reduced while increasing the number of tubes within the range 801.7-857.2°C (1475-1575°F). In the case of Rows 5 and 6, the number of tubes with temperatures below 787.8°C (1450°F) was reduced while increasing the number of tubes within the range 801.7-857.2°C (1475-1575°F).

The resulting redistribution of heat within the furnace resulted in more efficient use of fuel to the reformer. Methane slip was reduced even with a lower reformer outlet temperature, resulting in improved reforming efficiency. The lower methane slip resulted in a lower inert content in the synthesis loop, which allowed for reduced purge rates and thus higher ammonia production. Table 6 demonstrates the changes in ammonia production and fuel gas usage observed as a result of the balancing exercise.

Parameter	Initial	Final
Reformer exit temperature °C (°F)	800.6 (1,473)	800.6 (1,473)
Primary methane slip (%)	11.12	11.03
Production tpd (STPD)	1633 (1,800)	1637 (1,805)
Process gas flow kg/hr (lb/hr)	31,047 (68,448)	31,059 (68,474)
Natural gas fuel flow (lb/hr)	2869 (68,448)	2850 (6,283)

Table 7. Summary of production increase

3. Financial performance

The efficiency benefit of approximately 0.037GJ/t (0.032MMBtu/ST) and 0.3% improvement in production can produce significant annualised savings. Hypothetically, for a 1,500 STPD ammonia plant, operating at 32.0 mmBTU/ST, 98% reliability, consuming natural gas at US$3.00/MMBtu, with an ammonia price at US$420/MT, an annualised saving of US$450,000 is achievable.

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Conclusion

In March 2014, a reformer balancing exercise was conducted on the PCS 02 primary reformer. The measured temperature spread was 135 °C (243°F) (corrected to 168.3°C or 303°F).

Adjustments made during our reformer balancing exercise reduced the measured temperature spread to 132.8°C (239°F) - an improvement of approximately 2.2°C {4°F) (corrected to 165°C or 297°F). The furnace is now much better balanced and further improvement is difficult to achieve at this point in time.

As a result of improving the temperature distribution within the reformer, fuel usage and methane slip at the exit of the primary reformer were both reduced, leading to improved energy efficiency and a modest increase in ammonia production.

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Billingham, UK
Tel +44 (0) 1642 553601
www.matthey.com

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