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Ceramic coating application in a refinery steam methane reformer furnace

Increase an SMR's thermal efficiency by applying a high emissivity ceramic coating on the furnace box walls

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Ceramic nowadays is a very popular material, thanks to its heat and corrosion-resistant properties. Ceramic material is inorganic and in the form of non-metallic oxide, nitride, or carbide. In the 20th century, new ceramic materials were developed for usage in advanced ceramic engineering, such as in semiconductors and space technology. Ceramic coating has a well-known thickness, emissivity, and heat transfer coefficient. Ceramic coatings can be applied to both tubes (preventing oxidation and scale information) and refractory (maximising heat transfer to the process) surfaces.

I-Ceramic technology

By increasing the emissivity – a material's ability to absorb and reradiate energy – of a refractory lining in a furnace, these specialised ceramic coatings can provide energy savings depending on zthe fuel being used. High emissivity ceramic coatings in industrial furnaces are widely used for this purpose.[1]

Ceramic coating applications are one of the best ways to improve radiant and conductive heat transfer efficiency in high temperature industrial furnaces.

Benefits of the application can be listed as:

- Increased efficiency, leading to energy savings
- Reduced stack gas emissions of NOx and CO_2
- Preventing oxidation, carburisation, and various types of corrosion
- Extended equipment life

General information

In a refinery with a hydrogen production unit, most of the hydrogen production takes place on the nickel based catalyst in the steam methane reformer (SMR) furnace tubes. The reactions inside the 188 vertical catalytic tubes in two rows (94+94) in the SMR furnace are endothermic. Continuous and homogeneous heat flow is critical for the reaction kinetics.

The SMR heater is a terrace-wall type SMR furnace with two radiant chambers. The heat required for the endothermic reactions is provided by 144 burners on two floors (72 burners each) and on both sides of the tubes. The fuel sources in the furnace are the off-gas mixture from the pressure swing adsorption (PSA) system and the refinery fuel gas.

The hydrocarbon feed mixture (natural gas and/or LPG and/or light naphtha) combined with high pressure (HP) steam is separated into two and enters the SMR furnace tubes from the upper region.

During the downward flow, CxHy and H_2O react on the catalyst surface and turn into H_2, CO, and CO_2. The heat required for the reactions is transferred continuously from the combustion chamber to the catalytical tubes. The hydrogen-rich high temperature process gas leaves the tubes at the bottom through hairpins and is routed down to the transfer line to downstream equipment, a waste heat boiler.

The furnace operates with a natural draft, and the airflow in the combustion chamber is regulated by the stack damper opening. While the hot combustion gas in the radiant region transfers its heat to the catalytic tubes, some of the heat is absorbed by the refractory surface and reflected to the tubes. The combustion gas leaves some of its heat in the radiant zone and flows towards the convection zone. In the convection zone, it passes through the preheat and economiser coils, transferring its heat energy to the unit feed, boiler feed water, and steam streams.

The thermal efficiency of the furnace box can be increased by applying a high emissivity ceramic coating on the furnace walls, which enhances the radiative heat transfer contribution from the hot surface walls to the catalyst tubes.[2] Thanks to the high emissivity coating material to be applied to the refractory surface, it aims to increase the amount of heat absorbed in the radiant region and reflected to the tube surfaces. In this way, while the heat transferred from the combustion gas to the radiant zone increases, the heat transferred to the convection decreases, and therefore the steam production decreases. In this way, it aims to achieve the same production capacity with less fuel consumption values or to increase the production amount with the same fuel consumption values.

Application

The application was discussed with a company experienced in this field. In line with the information received about the application, it was decided to make the refractory coating during the unit planned turnaround. The application was conducted by company employees, with the chemicals provided by them.

Floor-to-ceiling scaffolding was installed in the two radiant chambers of the SMR furnace for the

Figure 1 Refractory surface before sandblasting

Figure 2 Catalytic tubes covered with paper before application

Figure 3 Refractory surface after application

application. Burner mouths are closed with planks, and it is ensured that no dust or chemicals get into them. The existing refractory surface has been sandblasted to obtain a smooth surface on which the coating will adhere.

All of the catalytic tubes are covered with paper and the ceramic coating solution is prevented from contaminating the tubes.

The application was made by spraying the prepared water based ceramic coating solution on the refractory surface with pressurised guns.

After the application was completed, the sawdust remaining after sandblasting on the floor was vacuumed and cleaned. Afterwards, the papers wrapped on the tubes were removed and the scaffold in the radiant region was taken out.

In the post-application period, with the unit start-up, it has been observed that the adsorbents loaded in the PSA unit were entrained by the off-gas flow and reached the burners of the SMR furnace. While a portion of the adsorbent reaching the burners has burned, the remaining part caused some damage to the ceramic coating application surface by spraying from the burners.

However, the adsorbent particles reached the convection zone, causing a decrease in the heat transfer and an increase in temperatures in this zone. This made it difficult to separately examine the positive effect of the newly made ceramic coating application.

Increasing PSA unit efficiency with adsorbent change during the turnaround and different operating conditions between the selected two days make it difficult to examine the effect of the ceramic coating. However, two days at the furnace exit temperature at the same H_2 production capacity from the pre- and post-start-up periods were selected for comparison purposes. While these days were selected, a peer based comparison was made with the operation values at the same H_2 production capacity, furnace exit temperature, and steam/carbon ratio.

When the temperature points in the upper part of the radiant zone are examined, it can be seen that the temperature in this zone has decreased by an average of 17°C compared to the pre-application. It is also noted that the bridge wall temperature has decreased by an average of 26°C. It is seen that the expected 40°C temperature drop in the company's forecast is partially achieved. These temperature drops indicate that the application gives positive results. Considering the temperature differences in the convection zone, it is seen that the temperatures of the parts close to the radiant zone decrease. However, no decrease in flue gas temperature was observed due to the decrease in the amount of steam production and increasing pollution in the economiser coils compared to the past.

The amount of fuel burned in the furnace and the thermal load of the furnace in these two periods were examined and relatively compared in **Table 1**.

When the off-gas/fuel gas consumptions before and after the application in the SMR furnace are examined, it can be seen that both fuel sources have decreased (the PSA adsorbent change and the increased H_2 recovery rate are also effective in the decrease of the off-gas amount and LHV value). By looking at the closest off-gas and fuel gas analyses to the selected dates, the calorific values were calculated and the released energy obtained from the fuel was found. However, the steam production amounts on the selected days for actual comparison are different. When these values and simulation results are examined, it is seen that the amount of heat transferred to the radiant area after the application increased from 49.8% to 52.7% in the simulation by 2.9%. While an increase of 2.23% is expected in the firm's forecast, further increase

SMR furnace fuel consumption relative values

	Before application, base situaton	After application
PSA off-gas, kg/h, relatively	1	-1.30%
Fuel gas consumed, kg/h, relatively	1	0.93
Off-gas LHV, kcal/kg, relatively	1	0.93
Fuel gas LHV, kcal/kg, relatively	1	1.06
Energy given by off-gas, Gcal/h, relatively	1	0.91
Energy given by fuel gas, Gcal/h, relatively	1	0.99
Reaction heat, relatively	1	0.97
Rate of heat transferred to the radiant zone, %, relatively	1	(+2.9%)
Total energy consumption, Gcal/h, relatively	1 released; 1 absorbed	0.93 released (-6,8%); 0.92 absorbed (-8,3%)

Table 1

despite the PSA drift experienced shows that the implementation was successful. Calculation of the increase as 2.9% as a result of the simulation indicates that the application would yield better results if PSA drift had not occurred. As a result of the simulation, if no normalisation is made for the operating conditions for different days, the heat released by the fuel decreases by 6.8%; the heat absorbed in the tubes decreases by 8.3%.

The selected two days were normalised according to all conditions (PSA efficiency, S/C ratio, boiler feed water temperature, coil cleaning) and the results were tabulated (see **Table 1**).

- A 9% reduction in extra fuel load (in Mkcal/h) is expected for the same H_2 production
- A 3.5% reduction in the released load of the furnace is expected for the same H_2 production
- For the same H_2 production, a 4.5% reduction in the absorption load of the furnace is expected
- An 8% decrease is expected in the amount of HP steam sent to the refinery for the same H_2 production

The economic return of the application was calculated over the natural gas equivalent of the amount of energy saved in the furnace. The decrease in total energy consumption corresponds to the natural gas amount of 588 t/y, which corresponds to 240 k$/y.

Despite the negativities experienced and the large number of variables, these returns are the minimum returns calculated, and it is estimated that higher returns can be obtained from the application under normal conditions. The economic return of the application cannot be calculated using the simulation results. In this case, it is seen that the application made with a cost of 286 k$ covers the investment cost within one to two years.

Conclusion and evaluation

High emissivity refractory coating application was applied by a well-known company in the hydrogen unit's planned turnaround. The ceramic coating applied to the radiant zone refractory surface aimed to absorb the heat more at the same combustion load in this zone The application of the coating was carried out successfully, but the positive effect of the application was limited due to PSA adsorbent entrainment after the unit start-up. Thanks to the application in the evaluation:

- It has been observed that the temperatures in the upper part of the radiant zone and the bridge zone of the SMR furnace are lower for the same production capacity and operating conditions. While 40°C was predicted according to the company's prediction, it was observed that this value was realised as 26°C after the application.
- Evaluating the thermal load of the furnace, it was observed that the heat used for H_2 production in the radiant zone increased by 2.9% compared to the pre-application simulation results (this value was predicted as 2.23% by the company before the application).
- It has been determined that when the operational conditions are equalised (such as PSA rec., shift T) as a result of the simulation for the same capacity as the application, it will consume 2.75 Gcal/h less additional fuel energy. There is an 8% decrease in HPS production.
- The economic return of this saving (additional fuel - HPS) was calculated as the reduction in natural gas consumption over actual values and was found to be 240 k$/y with actual values.
- As a result, it has been observed that the application has a positive effect on the temperature profile in the furnace and reduces fuel consumption by saving heat. Even though the effect of the PSA adsorbent entrainment on the possible earnings was negative, the application was realised in a situation where it pays itself back within one year, thanks to the total gain.

APP-1 H_2 simulation model outputs

The hydrogen unit simulation model was created to incorporate the hydrogen unit furnaces convection section, SMR reactor, shift reactor, and TEMA type heat exchangers into the unit. The model was checked against both the design condition and various field data.[3]

The model calculates the product H_2 and tail gas produced based on the natural gas, CCR gas or recycle gas entered. In the model, the radiant load rate was entered manually and the extra fuel and HP steam production needed in the unit were calculated. According to the field data (especially based on the extra fuel consumed in the field and the HPS produced), the radiant load rate for those days was found. After the application, it was observed that the radiant load ratio increased by approximately 2.9% compared to the past.

Comparing the field data alone is not enough, and the company's ceramic coating result can be seen by bringing the different operational parameters of the two days to the same base in the simulation model:

- PSA efficiency was around 87% before the application, while it was 89.7% after the application. This efficiency difference affects H_2 production, the residual gas quantity, and the residual gas LHV. As PSA yield increases, the amount of TG and LHV decrease. This creates an increase in extra fuel.
- While the gear input temperature is 359°C before the application, it is 320°C after the application. This affects both H_2 production and residual gas LHV. The residual gas LHV increases at high temperature. This reduces extra fuel consumption. Low temperature increases H_2 production and lowers residual gas LHV.
- Before the application, an increase in pollution was found in the convection coils compared to after the application date. This increases the extra fuel load and reduces steam production.
- Before the application, the SR working pressure was around 26 kg/cm^{2}g, while after the application it was around 24 kg/cm^{2}g. Low pressure increases both H_2 production and furnace load.
- Furnace excess O_2 is around 2% before the application and around 3% after the application. High excess O_2 increases fuel gas consumption and steam production.
- Before the application the unit BFW inlet temperature is higher.

There is no natural gas and CCR

gas composition analysis for the two selected days. There is FG analysis of those days. For this reason, analyses from three days ago were used and may cause a slight difference in these results. The methane contents of natural gas for the two days are also different (96.4% vs 92.6%), which can make a difference in the evaluation.

The two selected cases were normalised according to all the conditions listed above (except for the natural gas composition) and the results were tabulated:
- A 9% reduction in extra fuel load (in Mkcal/h) is expected for the same H_2 production.
- A 3.5% reduction in the released load of the furnace is expected for the same H_2 production.
- For the same H_2 production, a 4.5% reduction in the absorption load of the furnace is expected.
- An 8% decrease is expected in the HP steam sent to the refinery for the same H_2 production.
- A decrease of approximately 40°C is expected in the bridge wall temperature.
- 1.6% increase in H_2 production is expected for the same extra fuel load (increasing SR outlet temperature, same charge amount).
- A 4% increase in H_2 production is expected for the same SMR absorb furnace load (increasing SR outlet temperature, same charge amount).
- If no normalisation is made under the conditions described for two days, a 1% reduction in extra FG load is calculated.
- If no normalisation is made in the conditions described for two days, a 7% reduction in SMR furnace released furnace load is calculated.
- If no normalisation is made under the conditions described for two days, an 8% reduction in SMR absorption furnace load is calculated.

References

1 WIKIPEDIA, https://en.wikipedia.org/wiki/Ceramic

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3 Aspen Technology Inc., Aspen HYSYS Unit operations Guide, Version 10.

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