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ADVANCED LOW PRESSURE DROP

SECONDARY REFORMER BURNER DESIGN

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Abstract

Due to the increasing demand of higher plant capacity and energetic consumption reduction of existing ammonia production plants, Ammonia Casale started developing of a new generation of secondary reformer burners to increase the efficiency of the secondary reformer stage of the synthesis loop.

With advanced fluid dynamic techniques, an extensive study of the existing burner technologies was carried out in order to address all the problems related to the existing design. The most significant results of this simulation are reported here after.

A new design for the burner tip was developed to reduce the air stream pressure drop while reaching a uniform temperature and composition distribution of the gas at the catalyst inlet, thus reducing the flame length.
The main features of the Casale Advance Secondary Reformer design are described together with the results of our fluid dynamic simulations.

Introduction

From the increasing demand of higher plant capacity and energetic consumption reduction of the existing ammonia production plant Ammonia Casale started developing new technologies for the revamping of ammonia synthesis loop front end.
Special attention was posed on the design of a new generation of secondary reformer burners in order to increase the efficiency of the secondary reformer stage of the synthesis loop.

The usual configuration for secondary reformer in a typical ammonia plant comprises a burner placed at the top of a combustion chamber inside a refractory lined vessel and an axial type catalytic bed following the combustion chamber (see Figure 1).

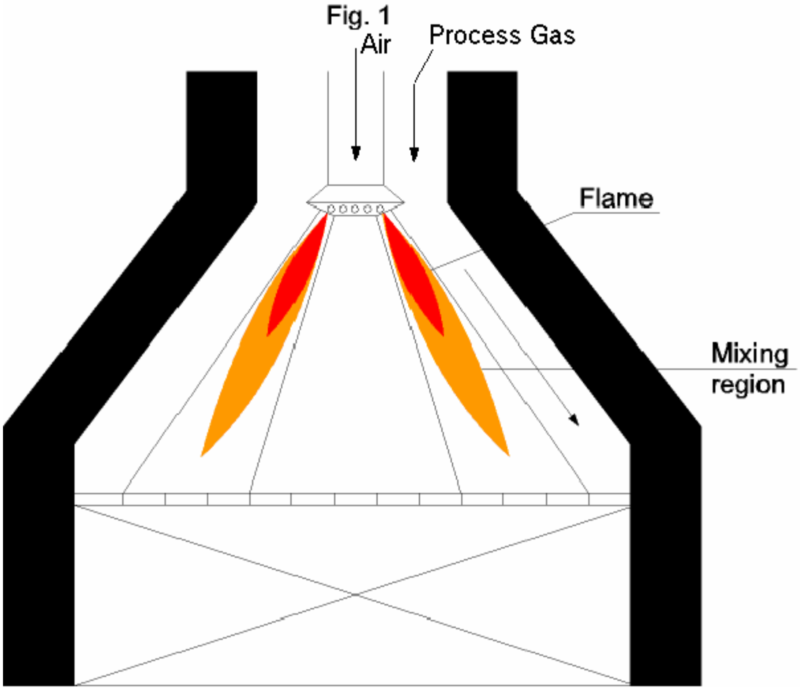
A uniform temperature and composition distribution of the reformed gas after the combustion chamber before the catalytic bed inlet is essential in order to reduce the equilibrium approach of the shift reaction ensuring a better conversion of the hydrocarbon to hydrogen. The burner must be designed in order to avoid the flame impingement on the catalyst surface preventing catalyst damage and allowing the use of more catalyst volume.

It is worth underlining that CASALE CHEMICALS is already experienced in similar and even more difficult burners, such as the partial oxidation burner of hydrocarbon and heavy residuals with oxygen.
In fact, CASALE CHEMICALS has recently designed and in December 1998 successfully commissioned a burner for the partial oxidation of natural gas with oxygen in a plant to produce CO. This plant is owned by ENICHEM and is located in Brindisi, Italy.

CASALE CHEMICALS is a sister company of AMMONIA CASALE and was established in 1996 with the goal of developing new technologies for the production of methanol derivatives (formaldehyde and related chemicals), hydrogen (water electrolysis) and for special combustion technologies.
This Company, therefore, shares the same experience, personnel and know how of AMMONIA CASALE and of the other CASALE companies, such as UREA CASALE S.A. and METHANOL CASALE S.A..
AMMONIA CASALE S.A., the company heading the group, has a very long tradition as designer of special equipment for chemical plants, particularly for ammonia methanol and urea production, its activity having started in 1921. For example, the latest CASALE technologies include the designs for ammonia converters, successfully used in more than 100 converters and the revamping of shift converters, both at high and low temperatures, the revamping of urea reactors with high efficiency internal trays, the revamping of methanol reactors with internals designed with special fluid dynamic devices for perfect mixing between hot and cold gas in very narrow spaces with low pressure drop, etc.
The operating results achieved in all above new technologies are excellent, and all the products receive worldwide acceptance.

Burner Design: The State of the Art

Historically, ammonia plant Secondary Reformers' conventional design was based on a multiple-nozzle burner for injecting pre-heated air into the primary reformer effluent gas. In the common design the burner is placed at the end of the air feed pipe at the top of a conical combustion chamber. The burner is usually designed as a shower sprinkler with a series of big holes in order to mix the air with the primary reformer gas that flows through an annular conduit concentric to the tube that fed the air to the burner tip. Mixing and combustion take place in the conical combustion zone and the combustion product flows down into the catalytic bed (Figure 1).



The refractory lining and the catalyst surfaces pose great problems of mechanical resistance to the burner metallic surfaces, due to the high temperatures of surfaces exposed to the flame caused by convection and high radiation heat fluxes from the flame.
With the introduction of preheated air (up to 600°C), used to reduce ammonia plant energy consumption, the burner surface cooling has become one of the major issues in the secondary reformer design.

In the last 25 year of conventional design to maintain the burner temperatures within reasonable values, the air was forced to flow in complex paths inside the burner head with important pressure losses. Non-even temperature and composition distribution of the gas also characterized some old burner designs with temperature hot spots on the catalyst surface and uneven composition of the reformed gas at the catalyst inlet.

In the early '70s the flow field and the gas mixing inside the conical combustion chamber were not well understood and the computational fluid dynamics technique, used today for the combustion simulation, were at an early stage of development and not applicable for industrial design.
The Casale fluid dynamic team carried out an extensive study of the existing secondary reformer burner technologies in order to address the problems of the most diffused secondary reformer design, using, as base case, the data of a typical 1570 MTD ammonia synthesis plant and a typical cone shaped secondary reformer vessel. As the worst condition for the gas temperature and composition spread at catalyst bed inlet, the catalyst surface was placed at 50mm below the vessel cone lower edge.

This investigation was carried out using advanced Computational Fluid Dynamic (CFD) techniques simulating the velocity, temperature and composition fields inside and outside the burner and in the combustion chamber. These simulations were performed with "Fluent", a commercial CFD software, and with in-house developed combustion subroutines.
Fluent is a general-purpose tool for real fluid dynamic engineering analysis. Developed by Fluent Inc. (USA), Fluent has been adopted by thousands of users worldwide because of its proven ability to solve the most complex flow problems and because it is one of the most tested and reliable CFD codes available today.

The typical problems affecting the conventional design can be seen from the temperature and gas velocity distribution on a radial symmetry plane, on the refractory inner surface of the vessel cone and on the catalyst surface as shown in following figures.
In Figure 2 and 3 two types of recirculation are clearly visible; the main between the burner and the vessel refractory lining and the secondary placed directly under the burner. The effect of the excessive flame length, due to poor mixing, on the vessel refractory lining and the catalyst surface are pointed out in Figures 2, 3 and 4. The general arrangement of the old burner design witnesses a lack of information regarding the deflection of a gas jets in cross-flow and of the jets entrainment.

In order to verify the possibility of reducing the pressure drops of the existing burners types (up to 1.5-2.0bar), using the same concepts and design philosophy we increased the number of air jets reducing the air velocity and subsequently the pressure drops.
Two arrangements were possible for the added jets on the burner tip. The results of the best configuration are reported in Figures 4, 5, 6 and 7.
Both the primary and secondary recirculations, present in the original configuration, are still present, but the secondary recirculation now is cold and rich of oxygen due to a reduction of mixing between the process gas and the air with oxygen present at the catalyst inlet (see Figures 4 and 5). The temperature spread on the catalyst surface is increased (see Figure 7).

Burner Design: Advanced Design.

Under the leadership of a very experienced combustion engineer, a group of Casale aeronautical engineers, using advanced fluid dynamic technique, was able to develop a new design for Secondary Reformer Burners.

The burner is a key element in the secondary reformer design, because it mixes the air and primary reformer effluent gases in a diffusion flame. The flame core temperature is very high, about 2000°C; consequently heat transfer to the burner from the flame, and the other hot surfaces as well, by radiation and by convection from the recirculating gases must be minimized while the exchange coefficient between the air, flowing inside the burner, and the burner surfaces must be increased with minimum pressure losses.
Hence, burner design must combine fluid dynamic principles of mixing and combustion processes to maintain a safe operation and a long equipment lifetime.

The goal was to develop a simple design capable of withstanding this severe operating condition in a safe, reliable and cost effective manner.

During the design of the Advanced Secondary Reformer Burner, Casale tried to obtain the following goal:

- Low-pressure losses of both air (much lower then the existing design) and primary reformer stream;
- Low temperature of the burner surfaces exposed to the flames;
- An almost perfect mixing in the diffusion flame (see Figure 8);
- Reduced flame length in order to increase the catalyst volume for high load operations;
- Homogeneous gas composition and temperature distribution at catalyst bed entrance:
- Protection of the refractory lining from the flame hot core (see Figure 10).

The flame is short and the recirculation of the reacted gases protects the refractory and the burner from the flame hot core and also ensures a homogeneous gas and temperature distribution at the catalyst bed entrance (Figure 9).

The air flow inside the burner was simplified and optimized, the internal shape of the burner was redesigned, to improve the heat transfer in order to reach the necessary level of cooling of the burner surfaces exposed to the flame, and at the same time, to reduce the pressure losses.

The expected performances of the Casale Advanced Secondary Reformer, for a typical 1570MTD ammonia synthesis plant in a typical cone shaped vessel are:

- Maximum pressure loss for the air stream: 0.5 bar
- Burner wall temperatures: 700-800 ºC.
- Temperature on the catalyst surface: Uniform within a decine of
- Celsius degree (see Figure 8)
- Gas composition on the catalyst surface: Almost Homogeneous

Casale has already developed advanced technology for the production of synthesis gas through partial combustion of natural gas with pure oxygen, for Enichem S.p.A. The burner operates with an average temperature of the main recirculating gases at about 1300°C, 200 to 400°C over the mean temperature of the secondary reformer recirculation. It has to be underlined that the Brindisi burner is operating with pure oxygen, therefore, in much more severe conditions in terms of temperature. The burner is operating properly and no signs of overheating are appearing even after more than one year of operation.

Conclusions

From an extensive analysis of the current burner technology, it seems clear that is necessary to conceive a new design for the burner tip in order to reduce the air stream pressure drop while reaching a uniform temperature and composition distribution of the gas at the catalyst inlet.
Casale reached this goal in the new Advanced Low Pressure Drop Secondary Reformer Burner with an accurate design of the fluid dynamic flow field both inside (air stream) and outside (combustion chamber) the burner.
The CFD simulation of the combustion chamber with chemical reactions, and of the airflow inside the burner with conduction through the burner solid surfaces, were useful to understand and optimize the burner design addressing most of the common problems of this type of burner.