THE CASALE PLATE-COOLED DESIGN, REDEFINING CHEMICAL REACTORS

by

E. Filippi, F. Di Muzio, and E. Strepparola

AMMONIA CASALE S.A.

Lugano, Switzerland

For presentation at
DEFINING THE FUTURE
Munich, Germany, 24-26 September 2007
organized by Süd-Chemie

Via G. Pocobelli 6
6900 Lugano
Switzerland
Tel +41.91.960.72.00
Fax +41.91.960.72.91
www.casale.ch
ammonia@casale.ch

AmmoniaCasale

THE CASALE PLATE-COOLED DESIGN, REDEFINING CHEMICAL REACTORS

by

E. Filippi, F. Di Muzio, and E. Strepparola

AMMONIA CASALE S.A.

Lugano, Switzerland

ABSTRACT

Fixed beds chemical reactors have been designed for decades to perform heterogeneous catalytic reactions, either using single or multiple adiabatic beds or beds with tube cooling.

CASALE has always played an important role in the development of these reactors in the last 85 years, having introduced and used many different designs for various processes, such as ammonia, methanol, shift processes, etc.

In the first 60 years of their existence, these reactors were axial tube-cooled, while, more recently, they were based on axial-radial adiabatic bed designs. The latter design was very successful and is now used in almost 200 reactors for various applications.

The need to improve the efficiency of reactors and to reach very large production capacities in a single vessel, has been a great incentive to CASALE to introduce new reactor design, the latest one is its Plate-Cooled Design. This new design has already been successfully applied in ammonia and methanol synthesis reactors, in axial or axial-radial, gas-cooled or steam-raising configurations. Its application can potentially be extended to several new fields, enabling a simplification in many processes with advantages in efficiency and maximum production rates in single vessel units.

INTRODUCTION

In the history of industrial chemistry fixed bed catalytic reactors have been workhorses used in many production processes.

The applications ranged from exothermic to endothermic reactions, from low to high pressure.

The layouts of these converters range from simple adiabatic single-bed converters to multiple-bed adiabatic with intermediate cooling and to isothermal, i.e. with direct heat exchange of the catalyst beds with cooling or heating surfaces.

The fixed bed reactors are relatively simple, but have a number of intrinsic limitations. Some of these are relevant to their maximum size and to their ability of exchanging large amounts of heat generated or absorbed by the reactions, or to continuously extract a part of the catalyst for regeneration.

To overcome these limitations, several design variations have been introduced, like the radial or axial-radial flow to eliminate the size limitations (Figure 1), but to increase the capability of heat exchange it have been necessary, in some cases, to adopt more complicated designs, like the slurry converters.

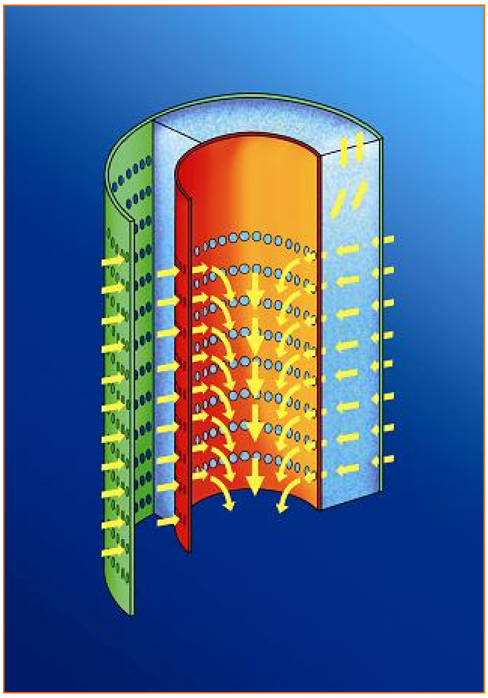

Figure 1 – *Fluid path followed in a classical CASALE axial-radial catalyst basket.*

THE NEW DESIGN

The typical temperature profile resulting from an adiabatic-layers converter in a reaction limited by equilibrium, like ammonia or methanol synthesis, is of the saw-tooth type (Figure 2). This implies a not-optimised use of the catalyst mass that can be overcome by introducing cooling or heating devices directly into the catalyst. Traditionally, these devices have been tubes, but with the increasing demand for efficiency, flexibility and production rate in single vessel, the tube designs are becoming obsolete.

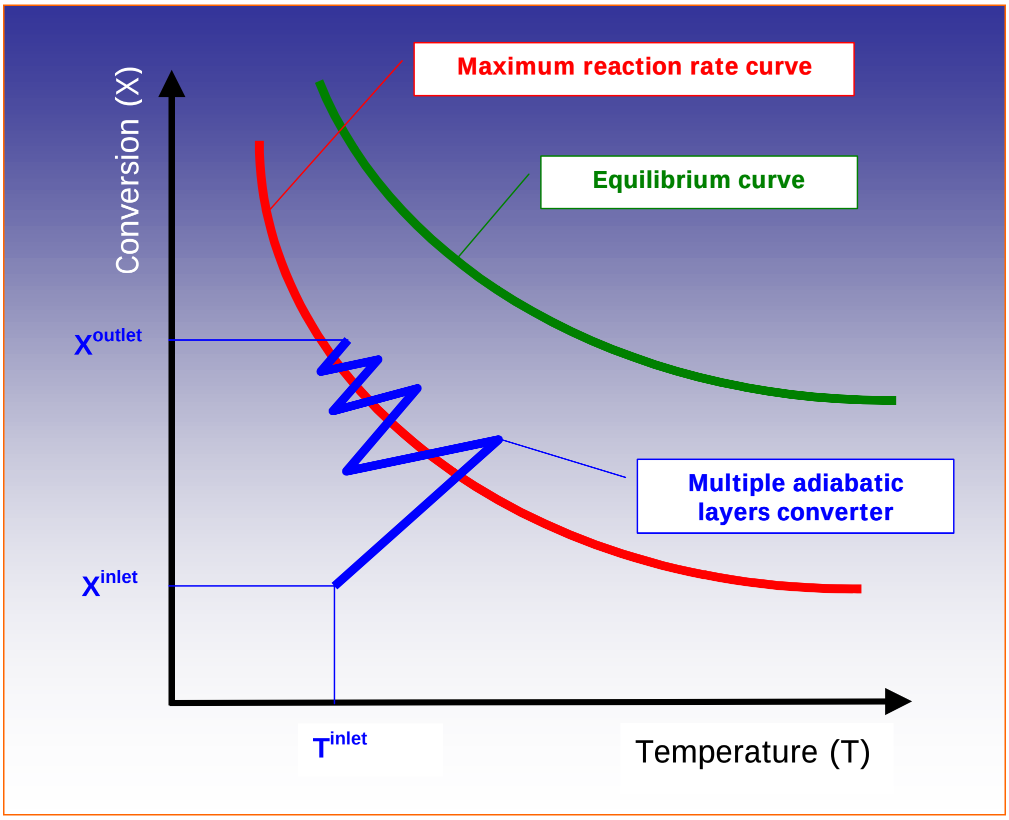

Figure 2 – *Path followed by multiple adiabatic layers converter in Conversion-Temperature graph.*

In this framework, the approach followed by CASALE to improve converter efficiency and, at the same time, to increase the maximum production rate achievable and the heat transfer capability of fixed bed reactors, has been to utilize a different type of heat transfer surface immersed in the catalyst beds, abandoning the traditional tubes for the plate type surfaces (Figure 3).

The use of plates to cool the fixed beds has a number of advantages over the use of tubes, for both the process and the mechanical aspects.

The most important advantages achievable from the process side are:

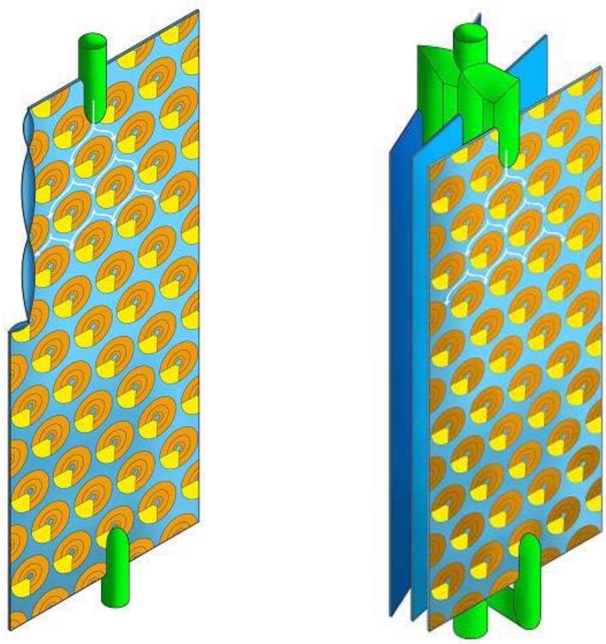

Figure 3 – *Sketch of a single element and of a bundle of plates.*

- It is possible to control the temperature profile along the catalyst bed, modifying it during the operation, like in a traditional quench-cooled converter with multiple adiabatic beds. This temperature control is obtained, for example in an exothermic reaction system, injecting part of the cooling gas, or liquid, in different points of the cooling plate (Figure 4).

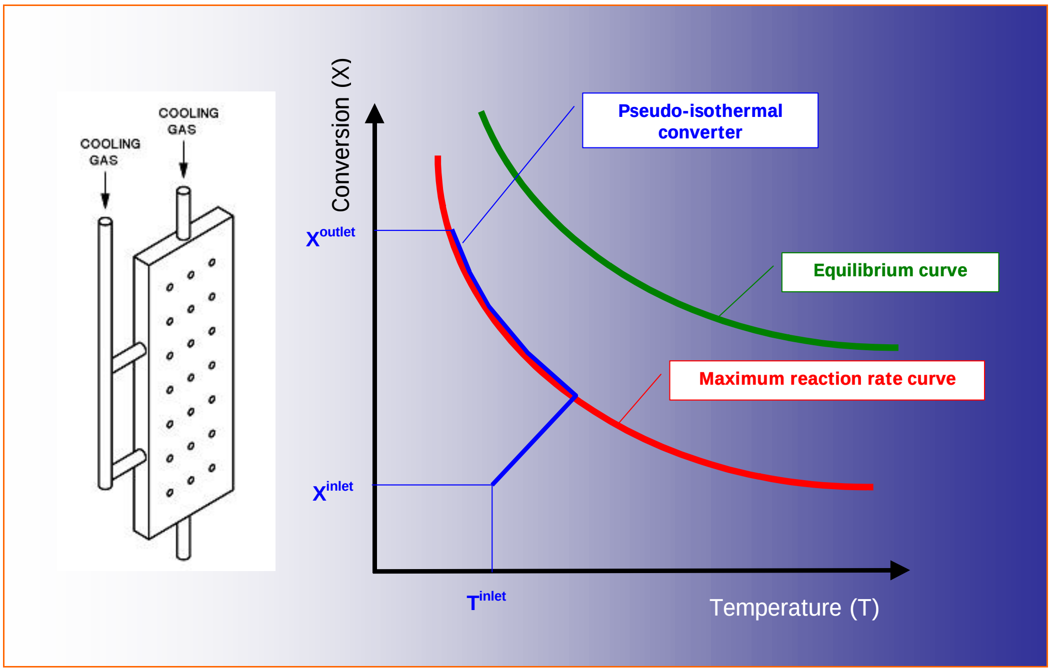

Figure 4 – *Injections of coolant fluid in plate cooling device and converter behaviour.*

The quantity of injected gas can be controlled from external control valve, allowing the modification of the heat transfer capability in different parts of the reactor “on line”.

This feature is important, as it makes it possible to optimise the operation of the converter, according to any specific situation, that may be quite different from the original design ones, like different catalyst activities, different feed compositions, different loads, etc.
The possibility of injecting this cooling media along the surface is made easy by the use of plates, in both the axial and axial-radial bed design, as demonstrated by the CASALE converters already in operation (Figure 5).

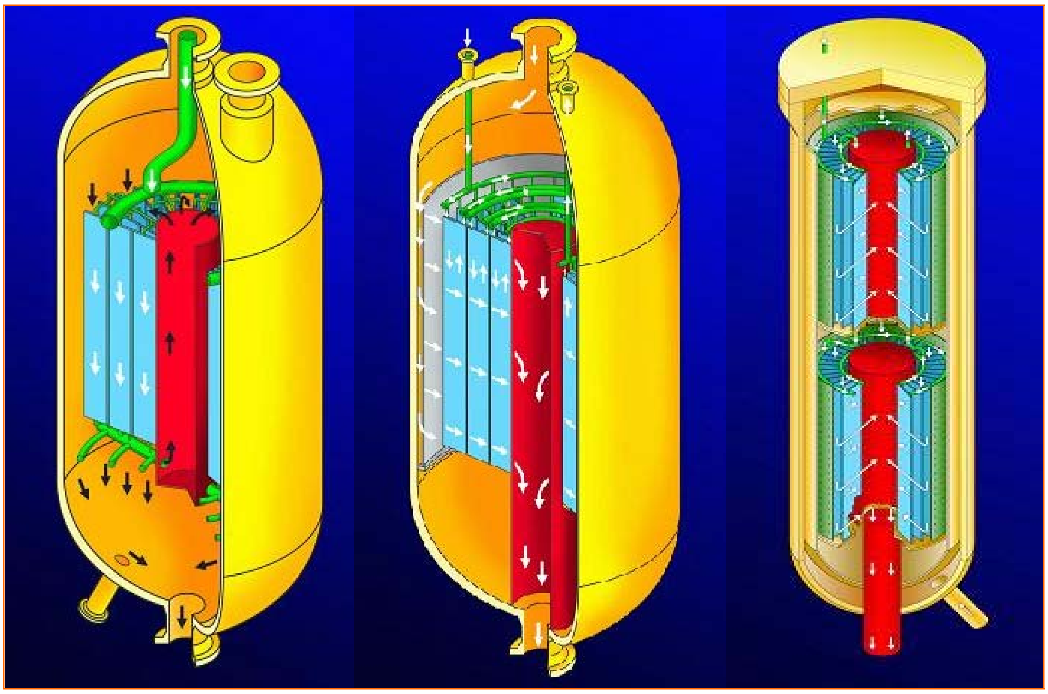

Figure 5 – *Examples of pure axial and axial-radial plate-cooled single converter and multiple-bed converters, e.g., a typical arrangement used in an ammonia converter.*

- It is possible to design axial-radial catalyst beds with direct heat transfer with any type of cooling, or heating, media.
  This means that axial-radial beds can be designed not only with an isothermal heat transfer fluid, such as boiling water, but also when this media has to be gas or liquid, with no change of phase. This application of axial-radial beds is not possible with tubes, and this specific feature, using axial-radial catalyst beds with gas or liquid as heat transfer fluids, is very important, because it allows to reach single vessel capacities that are several times larger than those reachable with tubes. The reason is that with an axial-radial bed, it is possible to obtain throughput several times higher than with an axial bed of the same diameter, as the axial-radial bed can be much longer and has an almost negligible pressure drop.
  This fact is well known for decades, and has been applied in hundreds of adiabatic beds reactors, for example in ammonia plants. What is new is the application with direct heat transfer. In fact, the use of

gas cooling in processes like ammonia or methanol synthesis brings significant efficiency improvements in terms of conversion per pass, achievable thanks to the more favourable temperature profile, with respect to the use of adiabatic beds. Unfortunately, the use of gas cooling with tubular geometries is possible only in axial configurations. In fact, an axial-radial flow with gas cooling in vertical tubes would result in a cross flow with an irregular temperature field in the bed, negatively affecting the bed efficiency.

By using plates as cooling elements, it is possible to have parallel flow between the cooling gas and the reacting gas, finally obtaining an efficient bed with a very high productivity (Figure 6).

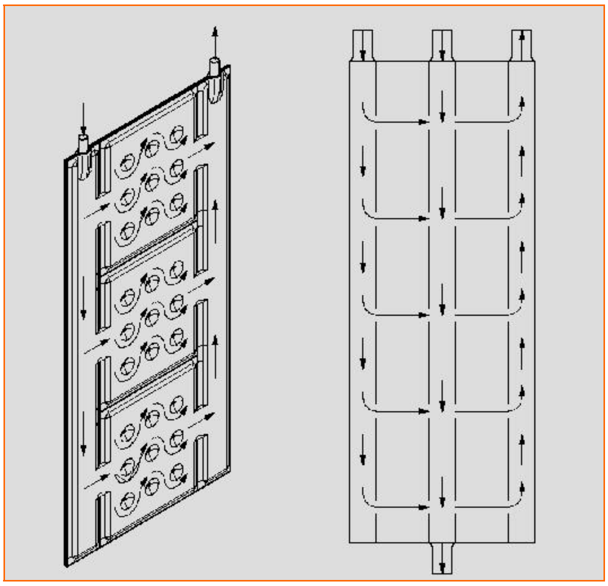

Figure 6 – *Example of plate arrangements for axial-radial beds.*

With reference to the mechanical aspects, the most important advantages achievable are:

- A very high reliability of the system, thanks to the production process of the plates. The plate's production process is, in fact, automatic, with welding machines operating on the plates, obtaining the required geometry with essentially no manual input. In this way, once the plate production process is tuned, all the plates are identical and reach the highest reliability (Figure 7).
- The plates' geometry can be adapted to the process needs, allowing the designer to optimise the system to the various requirements, like axial or axial-radial beds, small or large, with boiling fluid or gas or liquid, with temperature control in any part of the bed, etc.
- Plates can be built by using various materials, according with the application type, e.g., corrosive coolants, high temperature, hydrogen and nitrogen attack. During the ammonia converter design, several metallurgical problems must be solved and plates have demonstrated their versatility also in these critical conditions.

Figure 7 – *Example of welding-machine working on a plate.*

- The plates do not need a tube-sheet, allowing their application to the largest units, and also the introduction of the plates in the reactors in prefabricated groups through manholes (Figure 8). This last features means that it is possible to transform existing converters to the new, more efficient design, and that, in new or revamped applications, it is always possible to access any part of the converter, such as the internal vessel walls, for control or repairs.

Figure 8 – *"In situ" Installation of new internals.*

- Catalyst loading and unloading is simple and fast, as the plate-cooled catalyst beds are continuous single layers, where the catalyst is loaded from the top with a sparger, and unloaded from the bottom through dropouts. The absence of tube-sheets allows an easy access to the bed from the top, and plenty of room in which to move, ensuring high quality results.

PRESENT APPLICATIONS

All the features that have been presented in the previous chapter are well-proven in industrial applications. At present CASALE has in operation eight plate cooled reactors. Out of these three are ammonia synthesis converters, gas-cooled and axial-radial flow, five are methanol synthesis converters, three are gas-cooled axial flow converters, one is a boiling water axial flow and one is a gas-cooled axial radial. The production rate of these units varies from 400 MTD to 3'400 MTD. Eight more converters are under design, all for methanol synthesis, having capacities ranging from 1'350 MTD to 7'000 MTD.

The first application that went on stream in 2002 (Figure 9) was a methanol converter. The process performances obtained were better than expected, and the ability of the new internals to ensure the desired temperature profile and even distribution was confirmed. This converter was already existing, so the new internals had to be installed through an "in situ" installation through the top manhole.

Figure 9 – *The first plate-cooled methanol converter.*

All the mechanical features were then successfully tested, and could then be applied in the following projects.
Initially. in this first converter the operations of catalyst loading were tested, and more recently, also the catalyst unloading. During loading the catalyst was introduced from the top with a suitable sparger, and it did not suffer any kind of damage and a satisfying loading density was reached.

This converter recently underwent the first catalyst replacement, after five years of operation. It was an important test, to verify the catalyst unloading in this type of reactor for the first time. Also this exercise was positive: all the catalyst flowed out of the converter through bottom down loader nozzles in few hours and no catalyst remained in the converter (Figure 10).

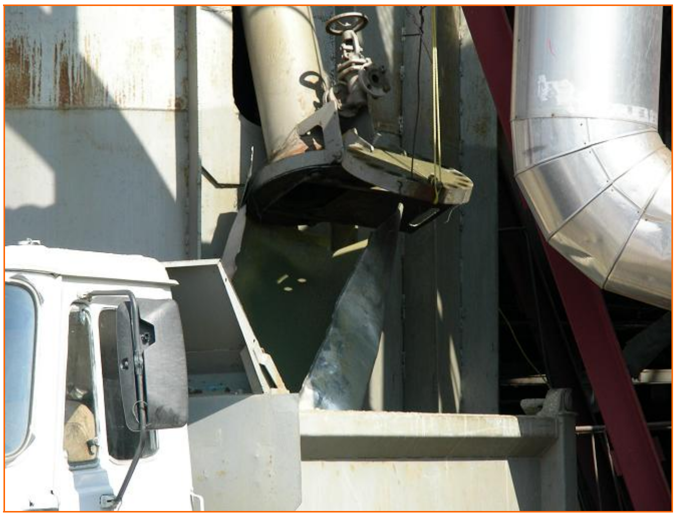

Figure 10 – *Catalyst unloading in axial gas-cooled plate converter.*

In the following figure, two other industrial applications regarding methanol are depicted: the first is referred to a steam-raising converter with boiling water as coolant (Figure 11a), while the second one to a gas-cooled converter (Figure 11b). In both cases, the actual converter performances match the expected performances.

In 2004, plate technology was fruitfully applied also in ammonia converters and Figure 12 presents the operating conditions of this first one. By modifying various sections of the plant and revamping the internals of the converter with a double axial-radial gas-cooled bed configuration, the capacity of the plant was incremented of 30%.

These applications have now created a large amount of experience, in the hands of CASALE, demonstrating the validity of the process and mechanical concepts adopted, and the high efficiency of this design, thanks to the performances achieved.

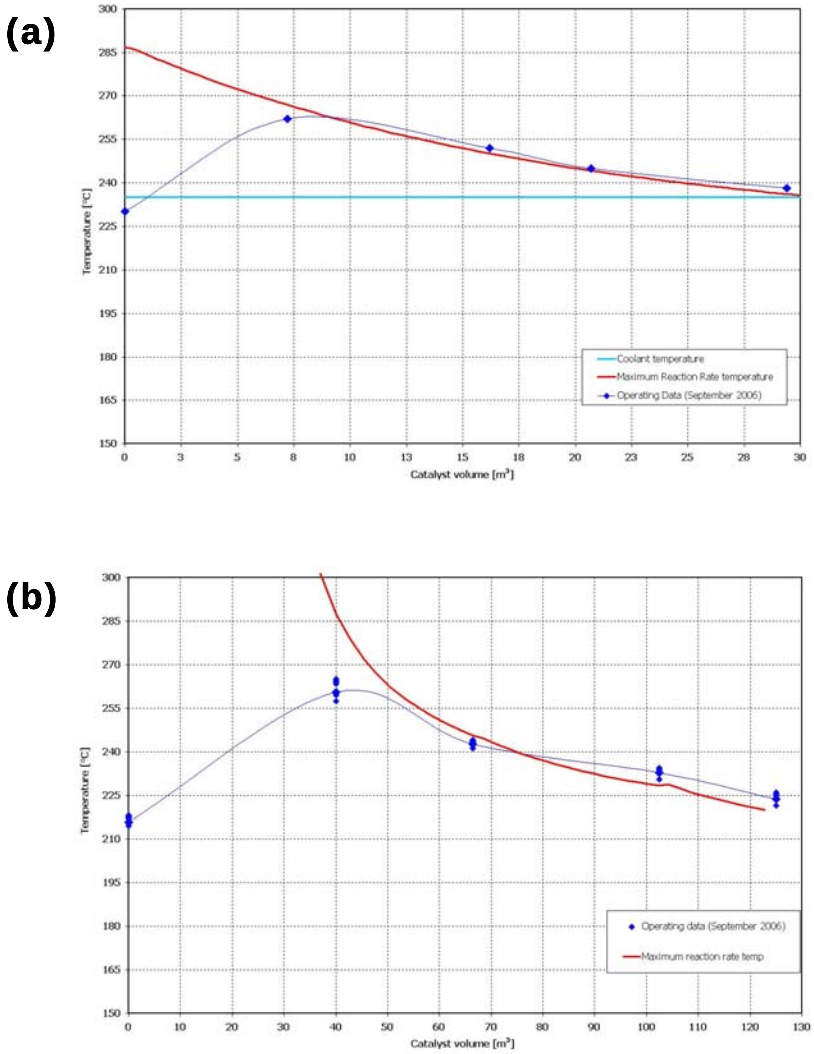

Figure 11 – *Example of methanol converter operating conditions.*

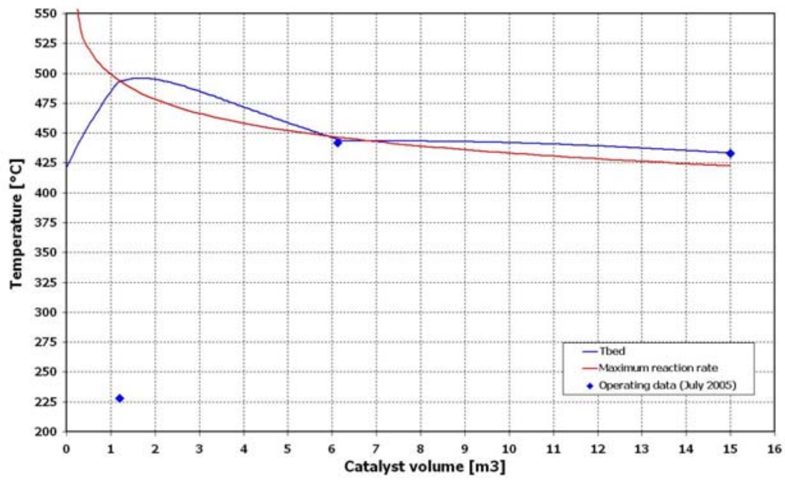

Figure 12 – *Example of ammonia converter operating conditions.*

POSSIBLE FUTURE DEVELOPMENTS

CASALE converter technology, where cooling elements are immersed directly into the catalyst, can be usefully adopted especially in those cases, one in which the reaction has a significant heat generation or the other where it has a consumption rate per unit of catalyst volume, not just limited to ammonia and methanol conversion. For instance, in recent years, a relevant number of methanol-derived products have been brought to industrial attention. In some cases, the potential application of internal cooling design seems to be very promising.

Furthermore, as previously underlined, CASALE technology allows pushing the loaded catalyst performing to its best. In fact, by using the pseudo-isothermal design, avoiding inter-stage cooling with injection of fresh make-up gas or with an internal heat exchanger, is possible to target the optimal operating region for the converter (Figure 13).

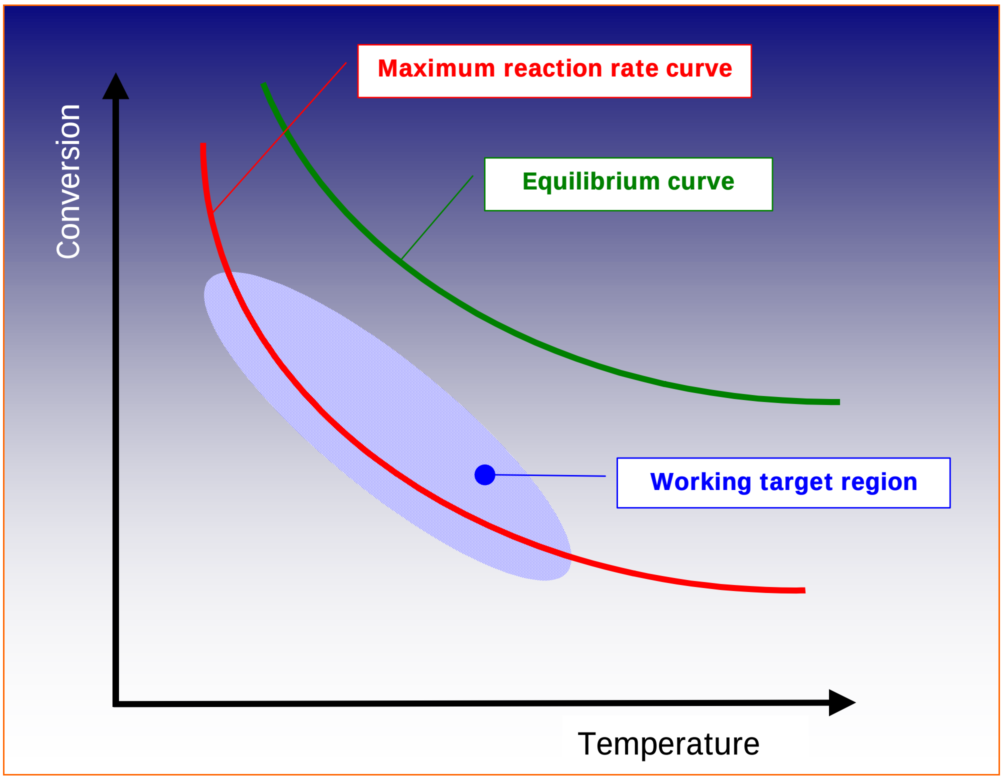

Figure 13 – *Guidelines sketch for applying CASALE technology.*

This aspect has important consequences, as the actual trend followed in building new plants is to increase the total production and efficiency. Looking at what is happening in methanol area, the plant capacity is now two times greater than those of the largest plant actually on stream, and CASALE was already able to design a 7’000 MTPD converter in a single vessel for a new plant. Combining all the experiences matured in last years, i.e., the axial-radial technology and the isothermal design, it will be possible to further extend the converter capability up to 15’000 MTPD in a single vessel.

Furthermore, this philosophy can be usefully applied also to chemical productions that in general require more than one single vessel: by using plate-cooled internals, it is possible to significantly reduce the number of production units, and increase their operating efficiency.

CONCLUSIONS

Casale has introduced a new design, based on several different and innovative concepts, e.g., the use of cooling plates and temperature control along the catalyst bed, the converter internals made by detachable modular components, and the axial-radial gas distribution in the catalyst.

It is remarkable that this new design approach is now successfully proven in the industry in a few plants in different applications.

Furthermore, this new generation converter has interesting advantages, which allow a further increase in efficiency and in the maximum capacity achievable in new or revamped plants.