

# PROCESS INTEGRATION IN THE CHEMICAL AND PETROCHEMICAL INDUSTRIES

## CONTEXT

Chemical and petrochemical manufacture accounts for approximately 30% of industrial energy usage<sup>1</sup>, mainly using hydrocarbons as the energy source. In the petrochemical sector, these hydrocarbons have a dual role as both the feedstock which comprises the final product and the energy required to make the conversion. This paper focuses only on energy consumed in conversion.

Unlike oil refining, where a relatively small number of different processes are employed in hundreds of refineries around the world, the chemical and petrochemical industries use an enormous range of different process technologies with different energy requirements and heat integration challenges. Chemical and petrochemical processes also operate at a scale which is at least one order of magnitude smaller than oil refining, so it is usually more difficult to justify as much additional process complexity. This paper seeks to focus on common features of petrochemical and chemical complexes, rather than individual processes, identifying the extent to which processes are currently heat integrated, and the main barriers to achieving improved process integration.

## NATURE OF PETROCHEMICAL COMPLEXES

The majority of petrochemical production is conducted on integrated manufacturing sites. Such sites typically contain one of two very large scale and high temperature (over 850°C) primary conversion processes: steam cracking and steam reforming. In both of these processes, a relatively stable hydrocarbon feedstock (ethane or naphtha in the case of steam cracking, methane in the case of steam reforming) is reacted endothermically to yield more reactive intermediates (olefins in the case of steam cracking, synthesis gas in the case of steam reforming).

In many cases, these reactive intermediates are purified using cryogenic distillation processes, and then further reacted in a plethora of different downstream processes to create the products needed by society, namely plastics and industrial chemicals. The majority of these downstream reaction processes operate at much more moderate temperatures (300°C or less) and are exothermic. In many cases, purification of the products consumes some heat at similar or lower temperatures.

Thus in a typical petrochemical complex, the main process streams experience immense swings in temperature from as high as 1000°C to -100°C or below, and then back up to perhaps 200-300°C. Consequently a substantial amount of hydrocarbon is combusted to generate very high grade heat to supply the high temperature endothermic processes, while a substantial amount of much lower grade heat is rejected from the low temperature exothermic processes, and power is consumed to operate the cryogenic sections. A major feature of petrochemical complex design and operation is therefore the recovery of heat from high temperature processes and its effective use in the downstream processes.

## HIGH TEMPERATURE PROCESS CHALLENGES

The two most common high temperature processes are carried out in similar processes. The feedstock, mixed with steam, is reacted in tubes contained within the radiant section of a furnace. The flue gases from the furnace pass up a stack containing tubes to recover heat: this is typically used to pre-heat the reaction feeds, and to generate superheated steam (usually at least 100 bar). This is typically used in extracting turbines to drive process

compressors, while generating lower process steam suitable for separation processes. The flue gas typically leaves at between 100 and 200°C, since an excessive amount of heat transfer area would be needed to recover further heat from this large but slow-moving gas stream.

Heat recovery from the process streams is constrained by other issues. In steam cracking, it is essential to stop the reaction very quickly, so it is usual for the hot gas to be fed directly to a “quench column” in which it is contacted with oil or water to cool it. This means that the sensible heat in the gas stream is degraded from reaction temperature to the quench column temperature. In steam reforming, the concern is more metallurgical: between about 300 and 850°C, a phenomenon known as “metal dusting” can lead to remarkably rapid disintegration of steels<sup>ii</sup>, and so again, rapid cooling is used resulting in the sensible heat of the process gas being sharply downgraded.

## CRYOGENIC PROCESS CHALLENGES

The most common cryogenic process in the petrochemical industry is the separation of olefins from the reaction mixture in steam cracking. This typically requires chilling to -100°C to separate the products from the methane byproduct, and further chilling to -145°C if hydrogen is to be separated from methane. Cryogenic sections of olefins plants have been heavily studied and are generally highly integrated with extensive use of multi-stream plate-fin heat exchangers.

A less widely used case is the recovery of pure carbon monoxide and hydrogen from synthesis gas, as is required for production of acetic acid. This requires lower temperatures, but is less complex than the olefins case, and is also generally very highly integrated.

## MODERATE TEMPERATURE PROCESS CHALLENGES

Downstream processes fall into several groups, each with their own distinct challenges.

The majority of olefins are converted into polymers, of which polyethylene and polypropylene are the largest in terms of volume. These reactions are very exothermic and mainly take place at less than 120°C, making effective use of the heat evolved very difficult. In general, the heat is rejected to cooling water.

A second group of reactions are selective oxidations, of which the reactions to make terephthalic acid, ethylene oxide, propylene oxide, adipic acid, acrylonitrile, vinyl acetate, and maleic anhydride are the most common. Again these reactions are very exothermic but take place at higher temperatures (typically between 180 and 350°C). In most of these processes, heat is recovered effectively from the reaction step and used for preheat and purification processes, and, in some cases, heat or power can be exported<sup>iii</sup>.

A third group are syngas conversions, of which reaction to methanol, acetic acid, and ammonia are the most significant. These have broadly similar characteristics to the oxidations, but are less exothermic.

## OVERALL CONCLUSIONS

The chemical and petrochemical industries contain a very diverse range of different processes. There are many mature and well-integrated technologies, but opportunities still exist for technology vendors and operators to make improvements in energy efficiency by process integration. In addition, very large exergy losses remain, requiring different technological breakthroughs, as well as process integration analysis, to address. Chemical and petrochemical processes will continue to be very large producers of lower grade heat.

## REFERENCES

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<sup>i</sup> International Energy Agency information paper “Chemical and Petrochemical Sector. Potential of best practice technology and other measures for improving energy efficiency”, September 2009.

<sup>ii</sup> See, for example, [https://en.wikipedia.org/wiki/Metal\\_dusting](https://en.wikipedia.org/wiki/Metal_dusting).

<sup>iii</sup> <http://www.bp.com/en/global/corporate/technology/technology-now/petrochemicals-technology.html> is an example.