Profitable catalyst solutions

Bettina Munsch, Evonik, Germany, and Christoph Kins, AMC, Germany, explore how active nickel foam catalysts can help to optimise hydrogenation processes.

The global economy has been defined by its tumultuous nature in recent years. Like most sectors, the chemical and advanced materials industry has been impacted by a multitude of challenges – inconsistent economic growth, geopolitical tensions, climate-related crises – with sluggish demand witnessed globally.

In the first eight months of 2023, chemical output grew less than 1% y/y; as such, many companies turned their focus to reducing costs and improving efficiencies to help offset reductions in output.

However, there is cause for optimism. The American Chemistry Council expects global chemical production volumes to go up by 3.5% into 2025. As the landscape evolves, players within the industry will need to adapt, and continue shifting their portfolios as demand and industry fluctuations require.

Given 80% of chemical products are manufactured using catalytic processes, businesses can stand to take advantage of new opportunities – capitalising on innovations, new materials and solutions that can assist in reducing waste, optimising costs and improving operational efficiencies.

Catalytic hydrogenation is a fundamental procedure for a range of processes that contribute towards the manufacture of products that consumers rely on daily, including food, petrochemicals and pharmaceuticals. Consequently, selecting the right hydrogenation catalyst is critical for optimal performance – and profitability.

For businesses requiring these specific catalysts, an attractive option for achieving hydrogenation takes form in activated nickel foam. In various hydrogenation reactions, it offers high catalytic activity and selectivity, offering an alternative to noble metal catalysts, such as palladium or platinum on carbon, but avoiding the investment in the precious metal.

Conventional activated nickel catalysts

Activated nickel is derived from leaching out the aluminium from a nickel-aluminium alloy, leaving high-surface nickel where the aluminium was before; it is the most effective way to achieve slurry type reactions. The more traditional and prevalent form of activated nickel catalysts is powder, which is particularly suitable for applications using a batch reactor.

This type of powder catalyst consists solely of metal – up to 95% nickel and a small amount of residual aluminium. It does not include an inert support, such as alumina, silica or carbon, allowing for a complete material reclamation after use, supporting a circular economy.

The most suitable type of activated nickel catalyst depends on the application and the reactor that a plant uses. For example, for the pharmaceutical industry, it is generally true that a batch reactor is more typical for smaller plants; it is what has traditionally been used for the well-known powder catalysts. This kind of multi-purpose reactor involves a process where the starting material is inserted into a secure reactor before the reaction, and removed afterwards, allowing for frequent application changes and catalyst exchanges. The manual efforts are tolerable due to relatively small campaigns and high value products.

Fixed bed reactors are more commonly used in large high-throughput plants and require a material that does not move inside the reactor, making it possible to insert the starting material in a continuous way. This removes the need to open and close the reactor to insert and remove the educts and products, minimising the handling time. However, this method reduces product change flexibility and requires a catalytic material with a high lifetime and low pressure drop.

Until now, it has not been possible to use activated nickel for fixed bed applications, unless the application is suited to activated nickel granules. However, these have a very limited commercial usage and are almost exclusively used for the hydrogenation of butynediol to butanediol. Due to the lack of a fixed bed – only in selected industrial and petrochemical applications such as hexamethylene diamine and toluene diamine – activated nickel powder catalysts can be applied in a continuous process; despite the challenges and efforts required to continuously separate the catalyst from the product and recycle it into the reactor.

Now, conventional supported nickel catalysts are used widely for fixed bed applications, but demonstrate challenges associated with oxidic support and oxidic nickel, such as high pressure drop, safety concerns during handling, and support degradation.

The evolution of an innovative foam

The industrial interest in metal foams began at the start of the 21st century, and has only grown since. Well known for its application in batteries (electrodes), heat exchangers, filters, energy absorbers, flame arrestors and biomedical implants, the low surface area of the non-activated nickel has acted as a limitation, with use only outside the field of hydrogenation processes.

When it comes to the application of metal foam as chemical catalysts on an industrial scale, so far only few examples exist. These include steam methane reforming (SMR), partial oxidation of methanol to formaldehyde and biogas desulfurisation.

Evonik has transferred tried-and-tested activated nickel technology from powder form catalysts and applied it to fixed bed applications in the form of activated nickel foam. The foam, which is manufactured under a licence from Alantum Europe GmbH, is a new generation of lightweight fixed bed catalysts made from almost pure nickel and with no supporting element (i.e., carrier). This makes for a low weight solution, without the large portion of wasted aluminium that comes with the granules.

The high surface area, combined with its unique geometry, increases the amount of contact between the material and the catalyst, which has been proven to increase the reaction rate by orders of magnitudes attainable with traditional fixed bed catalysts. With its conceptionally high flexibility in material design, it allows for the structuring of the internal reaction space of existing plants, without necessarily having to touch outer reactor geometries, downstreaming or infrastructure, to achieve at the same time efficiency improvements.

Table 1. Physical property differences of Ni foams and Ni granules

	Ni - foams	Ni - granules **
Dimension	4 x 4 x 2 mm	2 - 3 mm or 4 - 8 mm
Filling density	ca. 0.35 kg/l	ca. 1.7 kg/l
Ni	ca. 85%	45 - 55%
Al	<15%	45 - 55%

** Ni granules are usually activated in situ

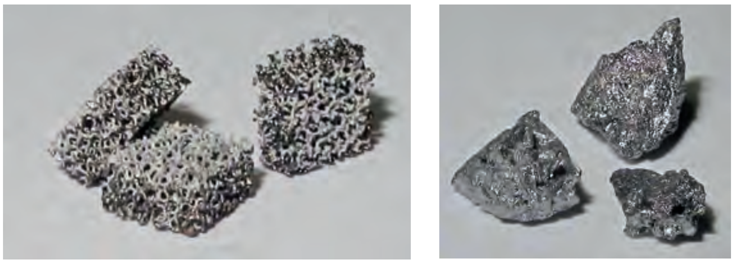

Figure 1. Ni foams (left) and Ni granules (right).

Moreover, the vast reactive surface to weight ratio means considerably less quantities of catalyst are needed to maintain the same product output. Despite the porous geometry, mechanical stability and abrasion resistance is outstanding.

Unlike powder and granule form catalysts, the activated nickel foam can, in principle, be customised to the desired shape and size. This reduces undesired by-products while prolonging the lifetime of the catalyst and broadening its application. It has been found to be suitable for manifold applications like the hydrogenation of butynediol to butanediol, the transformation of aldehydes into oxo alcohols, and the hydrogenation of sugars to polyols. In hydrogenation tests of butynediol to butanediol, Metalyst® MC 911 resulted in higher conversion and selectivity in comparison to the incumbent granule catalyst at the same reactor bed volume.

Benefits of nickel foam catalysts

Although typical fixed bed catalysts allow for material reclamation, nickel foam catalysts allow for faster and simpler refining and reclamation because of the absence of any oxidic carrier (support). Additionally, the extremely low pressure drop over the reactor bed and reduced abrasion makes them conducive to shrinking the environmental footprint of the plant and reducing maintenance costs in downstream equipment. For production personnel, the fact that the foam is ready to use means there is no plant down-time, and the absence of dust makes for easier and faster handling compared to more traditional activated nickel catalysts.

Moreover, this development enables the future possibility of being able to build and adapt processes around this new technology, in order to open up opportunities for plants to improve sustainability, and profitability further. For example, this could be done if process conditions and reactor geometries are tailored to nickel foam, as this kind of catalyst delivers higher activity, while requiring a catalyst bed of less volume. That being so, the lower requirement for power or pressure means that processes could be carried out in a reactor that is much smaller, ultimately saving costs if a plant were to build a reactor on this premise.

Experimental investigations were performed in a two-stage-reactor setup comprising an upstream recycle reactor containing a Metalyst® MC 981 foam catalyst fixed bed and a downstream finishing reactor filled with a state-of-the-art continuous process catalyst. Stress tests were run over more than 3000 h of operations, inclusive of varying operation conditions, i.e., variations in temperature and feed load. Results showed there was no significant degradation of system performance.

Conclusion

As the chemical industry navigates through a challenging and volatile global landscape, the need for cost-effective and efficient solutions is crucial. Nickel foam catalysts, such as Evonik's Metalyst® MC 9 series, are an innovative offering for those looking to optimise their hydrogenation processes.

Presenting a variety of benefits, businesses that utilise these catalysts can experience faster handling times and enhanced safety, due to their unique physical composition. Nickel foam catalysts can also assist in achieving sustainability goals; due to the absence of an inert support, these catalysts facilitate easy reclamation – reinforcing a circular economy. Additionally, they are ready-to-use and effective at a lower pressure, offering energy savings and improved environmental impact – important to end consumers, and also providing businesses with a potential competitive edge.

As chemical companies continue to shift their portfolios, long-term strategies are re-evaluated and re-adjusted. Activated nickel foam catalysts can support these objectives, presenting opportunities to streamline processes through developing purpose-built reactors – resulting in enhanced cost savings in terms of both time and energy.

The continued demand for activated nickel powder metal catalysts underscores their importance in a vast variety of processes, particularly in the pharmaceutical, agrochemical, and sugar substitutes industries. Evonik has responded to this demand by expanding its production capacities by 25% at its sites in Hanau, Germany, and Dombivli, India.