Global Overview of Research in Catalysis

The Netherlands

1. Introduction

In The Netherlands (or Holland, as some call it) there exists a long tradition of chemical industry and research, dating back to the 17th century. Catalysis industry and research started with the 1900s and the emerging petroleum and nitrogen fixation industries, and took a great swing in the sixties, when plastics came into broad application.

There are five Netherlands based multinationals: Shell, Philips, DSM, Unilever, and Akzo Nobel, all of which are involved in catalysis research. The same goes for many smaller companies and Dutch branches of foreign multinationals like Dow and Du Pont. There are quite a few large industrial research laboratories. Moreover, research in catalysis is carried out at the universities, of which there is quite a number for a country with a population of 15 million: seven universities, three technical universities and an agricultural one. There is intensive and fruitful cooperation between government, industry and academia, which has been formalized in the creation of a tripartite school of research: NIOK, Netherlands Institute for Catalysis Research. In order to promote industrially relevant research, the Ministry of Economic Affairs set up a number of Innovation-oriented Research Programs (IOP). IOP Katalyse is one of the most successful IOP’s. In order to promote pre-competitive research in catalysis, the Ministry presented NIOK with a grant of $6·10^9$ (approx. US$ 3.5·10^9), which resulted in five research projects at different universities, where 14 postgraduate students are preparing a Ph.D. thesis, while the projects they are working on are supported by about 30 industrial researchers, united in five support teams.

2. Technical trends

Catalysis research is described in ‘Catalysis Research in The Netherlands’ (1994) [2] (see: Publications) and in ‘Onderzoek 1995 in posters’ [3]. Academic research started mainly as investigations to unravel the structure of practical heterogeneous
catalysts, and relations were sought between catalytic function and structural parameters. In 'A History of the Dutch School of Catalysis' [1], a good description is given of the evolution of industrial and university catalysis research up till now.

The present distribution of catalysis research and local profiles of the different university centers can be deduced by inspection of Fig. 1. This categorizes the contributions of the seven universities cooperating in NIOK (see Section 8) and presents an indication of the measure of overlap as well as population of catalysis research. The overlap provides a healthy competitive environment.
At the University of Amsterdam one discerns organometallic chemistry and homogeneous catalysis as major activities. Also the University of Groningen has a fine profile in this area, more oriented towards synthesis of fine chemicals. In the course of 1996, a Center for Catalytic Olefin Polymerization will start in Groningen, cooperating with the technical universities in Eindhoven and Twente. The Utrecht University is a major center of the synthesis and preparation of heterogeneous catalysis, with a strong cross fertilization with organometallic synthesis. As expected, the technical universities are broadly represented in the field of catalytic reactor engineering: Delft with a strong emphasis on process development, Twente on reactor engineering and Eindhoven on kinetic modeling. Delft can also be considered a major center for the application of catalysis in organic chemistry, Eindhoven in fundamental catalysis and Twente in catalytic materials. The University of Leiden distinguishes itself by its fundamental mechanistic research and bio-organic systems.

In all the catalysis centers a variety of smaller groups complement the main profiling activities. Examples are the electron microscopy and Mössbauer spectroscopy activities in Delft, the EXAFS work in Utrecht, catalytic reaction engineering in Amsterdam and surface science research in Eindhoven.

Catalysis science and technology can be broadly classified into three major catalytic disciplines: catalytic conversion and selectivity studies, catalyst preparation and synthesis, and catalyst characterization: the three corner stones in the catalytic prism of Fig. 1. Each of these disciplines can be studied on microscopic (molecular), mesoscopic (nano scale) and macroscopic levels.

Most of catalytic reaction engineering requires macroscopic studies, in which reactor design, heat and mass transport, catalyst morphology and strength are important subjects of study. It is typically the classical domain of catalytic reaction engineering and one of NIOK’s main subjects. There is also a considerable interface between research on the mesoscopic and the macroscopic levels. This holds especially for catalyst preparation and characterization, since the distribution of the active catalyst phase over the catalyst pellet may have important consequences for catalyst life and selectivity. Also intrinsic kinetic parameters that control conversion and selectivity are important to the catalytic chemical engineer.

Whereas twenty-five years ago academic catalysis research had to limit itself mainly to characterization on a mesoscopic level, the increasing capabilities of spectroscopic techniques have made molecular level characterization a tool of increasing importance of solid state NMR and IR spectroscopy, for characterizing zeolites of immediate use to the chemical engineer applying such materials.

The high level of understanding of most of the large scale catalytic processes results in an expanding activity in catalyst preparation to improve such processes. Also, new catalyst formulations are developed for new heterogeneous catalytic applications in organic chemistry as well as the increasing interest for the application of organometallic chemistry in homogeneous catalysis. A major driving force for these new applications is the need for intensive environmentally beneficial processes, through reduction of energy consumption and waste production. In the Netherlands, thanks to intensive cooperation between the government and chemical and other industries, the amount of pollution has been reduced to very low levels. There is a convenant between partners which turns out to be far more effective than legal measures, resulting in cleaner air and water and
eventually cleaning up of polluted soil, whereas producing waste is minimized, especially by recycling techniques and adjusting industrial processes. Catalysts find a major application in end-of-pipe solutions as the automotive exhaust catalyst. The increasing impact of organometallic chemistry also indicates the importance of molecular level manipulation and catalyst systems for catalytic processes.

Practical examples are the recently developed polymerization catalysts, based on sophisticated ligand control and enantiomeric catalysis. In this respect industry, in cooperation with the university, has developed new polymers like Carilon (Shell), dendrimers (DSM) and super strong fibers: Twaron (Akzo Nobel), Dyneema (DSM), and a polymer based on pyridobisimidazole (Akzo Nobel).

3. Industry

All of the greater Dutch industries have for a long time contributed to catalysis research, as can be derived from [1]. Shell has been engaged in a mix of chemistry and engineering activities. They are active in research and application of metals in hydrogenation and epoxidation of ethylene, of sulfides in desulfurization and of zeolites for paraffin isomerization. Unilever, as a fat processing industry, studied oil (triglyceride) and fatty acid hydrogenation. DSM was originally very interested in ammonia synthesis and oxidation of NO to NO$_2$, resp. of SO$_2$ to SO$_3$. Later they also prepared supported catalysts (deposition precipitation) and turned their attention to gas phase hydrogenations (e.g. phenol to cyclohexanone and benzene to cyclohexane) and selective oxidation including electrochemical oxidation. Akzo Chemicals has its past in Ketjen, a sulfuric acid plant, which eventually turned into a renowned catalyst manufacturer. They developed catalysts especially for processes in the petroleum industry, like FCC, HDS/HTC, etc. Philips is engaged in surface science techniques which enable a better insight into the mechanism of catalytic activity. To give a few examples of the many industrial processes based on research in the Netherlands: the zeolite based Hysomer process (Shell), which, under addition of hydrogen, isomerises C$_5$ and C$_6$ paraffins; the HYCON process (Shell) for hydroconversion of residual oils; the Carilon (Shell) process, producing by homogeneous catalysis a polyketone from CO and H$_2$; and the caprolactam manufacture (DSM).

4. Intertwining

Another aspect of Dutch catalysis research deals with the development of catalyst systems of importance to homogeneous, heterogeneous and biocatalysis. Biocatalysis is taken into account when studies are made on a molecular level; this aspect needs further development. Clearly this is the development of an increasing disciplinary interface between homogeneous and heterogeneous catalysis. Also the importance of integration of catalyst design, synthesis, characterization (physical as well as catalytic) should be noted. There is also an emphasis on catalyst reactivity, characterized by an increasing impact of molecular mechanistic understanding as well as in situ spectroscopic studies. There is increasing communication between such microscopic information, implementation into applied organic chemistry and kinetic modeling. Of enormous
importance to fundamental catalysis has been the development of catalytic systems, their reactivity as well as their preparation in atomic detail. Such systems provide the ultimate test for microscopic theory with experiment.

An inspection of Fig. 1 and the list of contents shows that most of the subdisciplines in catalytic science are well represented in the Netherlands. Over the past years a shift has taken place from macroscopic catalyst characterization to catalyst synthesis and catalytic reactivity. There is a new emphasis on molecular control and understanding of catalysis, applications in organic chemistry and catalyst preparation, mainly due to the input of organometallic chemistry and spectroscopic and computational developments. The Dutch are less active in catalyst manufacture and practical catalyst characterization focusing on strength and morphology. This is not really surprising, since these activities are core catalytic industrial interests.

5. Level of support

University and industrial research contacts have traditionally been close, but these were initially based mainly on personal networks, aided by the presence of many faculty members at Dutch universities with industrial experience. Only from the middle eighties onwards did industry start to sponsor Dutch graduate students, with the result that one-third of the graduates at Dutch universities are now supported by grants other than from universities and the Dutch Science Foundation (NWO).

This is a sign of a healthy infrastructure created by University and National Science Foundation (SON) funding of the previous years. Especially the latter has been of major influence, due to its local coordination via the 'werkgemeenschap' (working community) committees. In catalysis this meant emphasis on sophisticated instrumentation, support for organometallic chemistry and coordination chemistry and heterogeneous catalysis research, the latter mainly focusing on understanding of catalytic principles.

Most of the industrial support strengthens these areas, but focuses basic research on systems of more direct industrial interest. This long term research considerably strengthens fundamental research in homogeneous as well as in heterogeneous catalysis.

The Innovation-oriented Research Programme (IOP) Katalyse, financed by the Ministry of Economic Affairs, has strengthened research in organic chemistry, and has also decided to focus on a more short term impact, which is of importance to medium sized companies less able to do strategic basic research in The Netherlands.

The Dutch School for Catalysis Research NIOK received at the occasion of its establishment from the Dutch Science Organization NWO an initial subsidy of $1.1 \times 10^6$, equivalent to about US$ 650,000. Moreover, the Ministry of Economic Affairs donated $6.0 \times 10^6$, equivalent to about US$ 3.5 \times 10^6$. This money was used to set up five research projects under the following titles:

1. Redox molecular sieves
2. Zeolite catalysts for amination
3. Homogeneous catalysis in water
4. Catalytic reactions within liquids
5. Catalytic olefin polymerization.
There are fourteen graduates engaged who are writing their Ph.D. theses based on these research themes, guided by fourteen university teachers, most of them full-time professors. The requirement of the Ministry, that these investigations be of a pre-competitive nature but as such beneficial to industry, was met by setting up guidance teams from industry. Twice a year they are informed on the progress of the investigations. This implies that 30 industrial researchers from eight different industrial institutions are aware of what is going on in these projects.

There is also direct support from the national industries, Dutch branches of multinationals included. In the course of one year, Dutch researchers or research institutions in catalysis received in total the enormous amount of \( f 4.2 \times 10^6 \), equivalent to about US$ 2.5 \times 10^6.

Apart from that, European funding resulted in appointment of postdocs from other European countries, NIOK being recognized as a Host Institute by the European Union. Seven researchers were able to stay for several months (up to two years) at Netherlands universities. The total money involved was in the order of 400,000 ECU, (US$ 500,000).

Taking into account the life span of a school of research, which is five years, the amount of external support which NIOK receives annually is more than five million dollars.

6. Meetings

On a national basis, NIOK organizes at the end of each year a special day where academia and industry meet and developments in research are discussed. The same goes for the Innovation Oriented Research Programme (IOP) in catalysis, where the emphasis is slightly shifted towards industrial applications. A more academic atmosphere is found in the annual Lunteren meetings of all university groups engaged in catalysis, convened by the national organization for chemical research SON. The Royal Netherlands Chemical Society’s (KNCV) Division of Catalysis (with a membership of 785) organizes a Spring Symposium (2-3 days) with alternating attention to research and development in academia and industry, and several incidental meetings on different subjects. They have also an active subdivision, the Dutch Zeolite Association, meeting every year.

KNCV Division of Catalysis is keen in hosting international congresses, the latest being Europacat-II in Maastricht, 1995 (with an attendance of 800), and they also look forward to hosting the ICC (the International Congress on Catalysis) in 2000.

It is needless to say that NIOK is engaged both in summer schools and graduate courses, and participates in several European networks.

7. Publications

Dutch catalyst researchers are involved with many international publications, either as editors or as authors. The citation index of some of these publications is astonishingly high. For information about the Dutch catalysis scene, the following three books are of importance:

NIOK has published two books on the science of catalysis, viz.:

Information on all these publications can be provided by NIOK secretariat in Eindhoven.

8. NIOK

In the above lines, the name of NIOK has been mentioned several times. As can be inferred, NIOK can be regarded as the central national institute for catalysis research. It was founded 1992 and recognized as a national research school by the Royal Netherlands Academy of Sciences KNAW, for a first period of five years, with prospects for continuing for more periods. It is also recognized by the Netherlands Science Organization NWO.

As a research school, NIOK has not one single building. It is the united and concerted effort of over thirty research groups at the chemistry departments of seven universities (see Fig. 2):

1 University of Amsterdam (UvA)
2 Delft University of Technology (TUD)
3 Eindhoven University of Technology (TUE)
4 Groningen University (RUG)
5 Leiden University (RUL)
6 Twente University (UT)
7 Utrecht University (UU).

NIOK discerns six areas of attention for research:

1 Catalytic processes and new reactor design
2 Catalytic materials
3 Fundamental heterogeneous catalysis
4 Catalyst characterisation
5 Fundamental homogeneous catalysis
6 Biocatalysis.

The Scientific Director, Professor Rutger A. van Santen, and the secretariat are based at Eindhoven University of Technology.
The unique feature of NIOK is the engagement of national industry in its work. Besides the Scientific Council of all professors working in NIOK there is an Industrial Advisory Council in which 17 industries have representatives, enabling an easy contact between industrial and academic worlds. In the foreseeable future, this Industrial Council will be transformed into an Association (with memberships and fees) as a legal entity. In this way, both NIOK and the newly formed Association can establish a Foundation which renders Public Private Cooperation possible and which can negotiate with the national government.

9. Economic impact

Catalysis and catalysis research and development are of vital importance for the Dutch chemical industry. There are only a few catalyst manufacturers, but there are quite a number of industries using catalysis for their processes. Petroleum and natural gas conversion (in the Netherlands one of the world's biggest natural gas sources was found), production of sulfuric acid, fertilizers and fine chemicals, medicines and many other applications are catalyst controlled. The application of catalysis includes the legal requirement to have a catalyst in gas driven automobile exhausts, whereas research efforts are directed also to cleaning diesel engine exhaust.
As a whole, the Association of the Dutch Chemical Industry VNCI estimates that over 80,000 people find work in the branch. The chemical industry in the Netherlands had a turnover of \( f \, 45 \cdot 10^9 \) in 1994, which is a contribution of 7.5% of the GNP. Over the past 10 years, this turnover has been subject to certain cyclic fluctuations, ranging between \( f \, 39.3 \cdot 10^9 \) in 1986 and \( f \, 47.3 \cdot 10^9 \) in 1989. R and D expenditures in the Dutch chemical industry amounted to \( f \, 1.8 \cdot 10^9 \) in 1994. It is estimated that 20 percent of that effort concerned catalysis and catalytic technology.

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