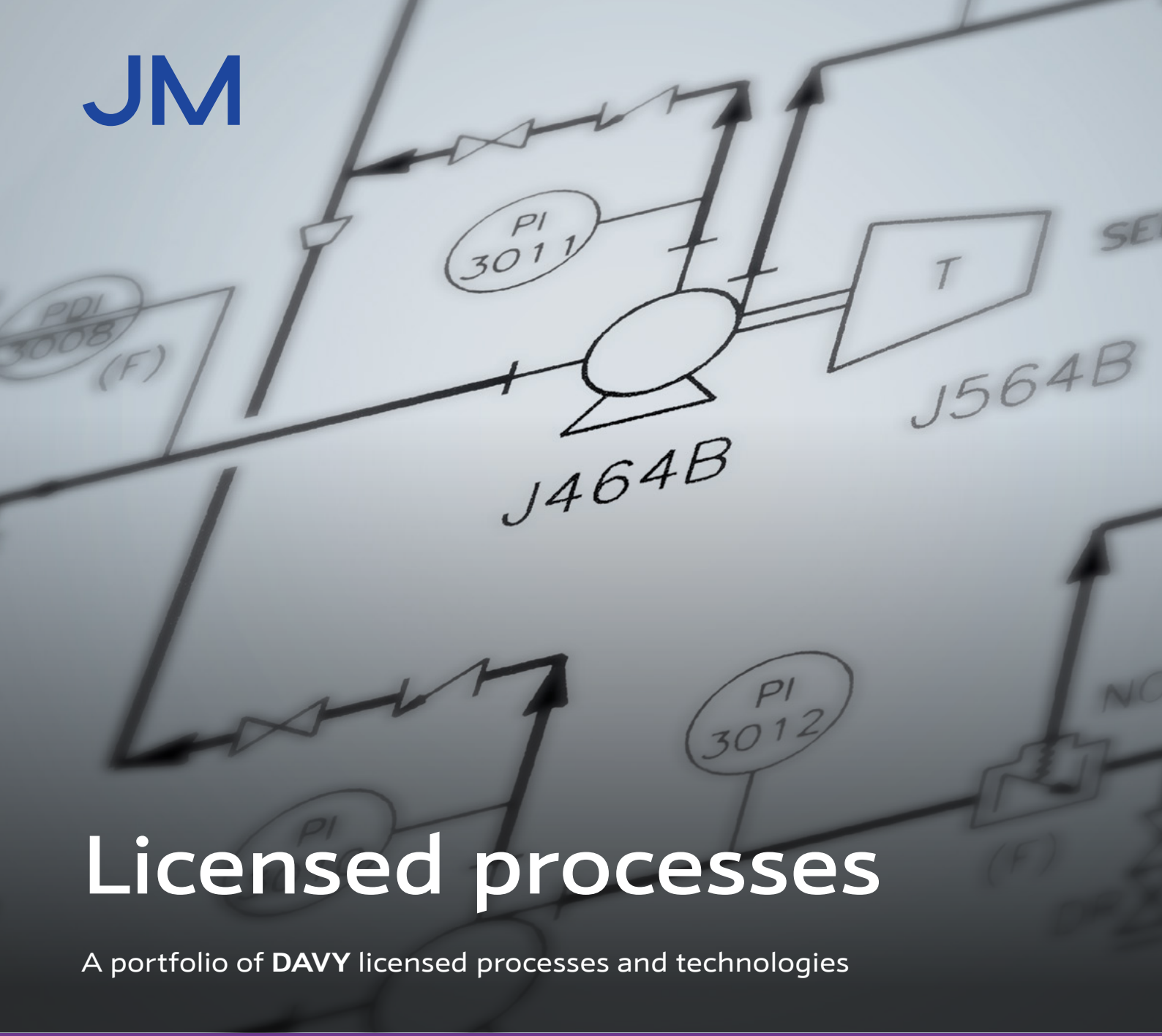


Licensed processes

A portfolio of **DAVY** licensed processes and technologies

Johnson Matthey
Inspiring science, enhancing life

A portfolio of advanced process technologies for global markets

Johnson Matthey (JM) develops and licenses proprietary process technologies. We also offer collaborating companies an extensive range of technology development, process design and engineering skills.

For over thirty years JM has been engaged in innovative DAVY™ licensing development. Our comprehensive expertise of catalysis and reaction engineering has been tailored to the production of a wide range of chemicals and we continue to develop novel processes using this experience.

In the following pages we describe some of the award winning process technologies which are available for license. These cost-effective process technologies have gained us a global reputation as one of the best licensing companies in the world.

Our licensing business is fully supported by technology transfer services including conceptual process design, feasibility studies, basic engineering, supply of critical equipment and catalysts, client training, plant commissioning, plant start-up and performance testing. We have full process engineering capabilities to deliver process licences with guarantees and to supply complete front-end design and commissioning services.

We also collaborate with partner companies to create intellectual property and to exploit innovative developments which may result.

DAVY processes

Biodiesel

Biodiesel, being derived from plant-based natural oils, offers great environmental benefits as a renewable alternative to conventional diesel made from fossil fuels.

However, a potential drawback of this product is its requirement for high-quality virgin oil feedstocks, which are available only from vegetation used as food. Consequently, the environmental demand for renewables competes with the imperative to feed the world's growing population and causes high-quality virgin oil prices to increase.

JM's **DAVY**™ biodiesel process offers a solution to this problem. Our flow sheet can employ inexpensive, low-quality, non-edible feeds, in addition to virgin and higher-quality oils.

The **DAVY** biodiesel flow sheet is evolved from our natural detergent alcohol (NDA) and butanediol (BDO) processes.

Our technology converts fatty acids from upstream hydrolysis to biodiesel-grade fatty acid methyl esters (FAME). This process also yields a high-value clean glycerol coproduct.

In summary, the biodiesel production route offers extensive environmental and economic benefits by converting a high-acid-content, low-value feed into a high-value renewable fuel.

This process was awarded the prestigious IChemE Sustainable Technology Award in 2014.

Butanediol (BDO) & Co-Products

JM are the leading DAVY technology provider for butanediol (BDO) plants worldwide.

We offer a more economical process by using low-cost raw materials, producing BDO from butane via maleic anhydride (MAH), or from sugar via succinic acid (SAC), with the latter process making bio-based BDO possible.

JM's **DAVY** process is also designed with an esterification step prior to hydrogenolysis. This achieves greater efficiency, and a higher-quality product. In addition, our process can make BDO's derivatives, tetrahydrofuran (THF) and gamma-butyrolactone (GBL), in variable ratios which are adjustable according to market need.

This flexible product output enables our licensees to respond quickly to changing market conditions by manufacturing the right product at the right time for the polymers and solvents industries.

Ethyl Acetate

This flow sheet is a breakthrough in ethyl acetate (EA) production.

We have developed a process that is ideally suited to bio-based ethanol feeds and so offers an EA production route that is almost 100% carbon neutral.

JM's **DAVY** EA process is also compatible with petrochemical ethanol feeds where necessary.

Our novel technology has received a number of industry awards, including the Kirkpatrick Chemical Engineering Achievement Award, the Institution of Chemical Engineers Crystal Faraday Award and the Royal Academy of Engineering MacRobert Award.

Gas-to-Liquids (GTL)

This world-leading GTL technology is the culmination of a continuing long-term collaboration between JM and BP.

Our novel GTL process centres on proprietary Fischer Tropsch (FT) technology, which produces high-purity paraffins using fixed-bed catalysis. The feed for the FT conversion is synthesis gas (syngas – CO, CO_2 & H_2), which can be derived from natural gas, or from gasified coal, biomass, MSW or petcoke.

A proprietary hydrocracking process delivers quality synthetic liquid crude products for the production of high-grade transport fuels, naphtha and base oils.

Methanol

JM is one of the world's leading methanol technology providers, with over half of the world's licensed methanol plants based on JM's DAVY technology.

We offer a wide range of technologies for methanol production. Synthesis gas (syngas – CO, CO_2 & H_2) can be generated by any of our reforming technologies or by gasification of coal, biomass, petcoke or municipal waste. Steam and gas-cooled reactors are available for methanol synthesis and two- or three-column distillation is used to produce the purified product.

The breadth of our technology solutions allows us to custom design a flow sheet for any particular project situation, be it large or small, onshore or offshore, for chemical or for fuel/MTO.

We also offer a fixed-bed dimethyl ether (DME) process, which uses methanol feed, as an extension to our methanol flow sheet for clients wishing to further enhance their licence.

Methylamines

JM has a class-leading methylamines flow sheet that offers superior product quality, low emissions and a highly efficient process in our plant design.

A JM **DAVY** methylamines plant can co-produce three products: monomethylamine (MMA), dimethylamine (DMA) and trimethylamine (TMA).

The product split is based on downstream demand. As DMA has the largest downstream market, mainly for dimethylformamide (DMF) production, it tends to constitute >50% of the product split, with MMA and TMA typically splitting the remaining production equally.

JM also offers **DAVY** technologies for the production of choline chloride (ChCl) using TMA, ethyl oxide and hydrochloric acid feeds; and DMF, which is produced from DMA and carbon monoxide.

Monoethylene Glycol (MEG)

JM, with its partner the Eastman Chemical Company, offers a unique process to manufacture MEG from methanol and syngas (CO, CO_2 & H_2).

In combination with our well-proven and reliable syngas-to-methanol technology, our new syngas-based process can compete favourably with conventional ethylene routes, particularly in regions with cost-advantaged coal and natural gas feedstocks.

Our flow sheet produces MEG in a two-step process via an intermediate chemical and employs proprietary and patented technology, delivering a proven fibre-grade product.

Natural Detergent Alcohols (NDA)

The use of methyl esters is the most widely practiced route to convert fatty acids to alcohols. JM's DAVY reactive distillation technology eliminates many problems associated with traditional esterification processes and minimises recycle of high-value fatty alcohol.

Our process involves no reaction by-products and requires no catalyst removal or neutralisation, so esters can be fed directly to hydrogenation without a processing loss. Due to its relatively mild vapour-phase hydrogenation conditions with a highly selective and active non-chromium catalyst, and a proprietary design of the reaction system, our process is highly efficient with very little by-product formation.

In addition, the **DAVY** NDA process has virtually no effluents. Small by-product streams are recycled and consumed within the plant using catalysts that are reprocessed, thereby protecting the local environment.

Oxo alcohols

In conjunction with our partners, The Dow Chemical Company, we are the world's leading technology supplier for plants to produce oxo alcohols from olefins.

Our low pressure hydroformylation, or LP Oxo℠, process is used throughout the world to convert propylene to the plasticiser alcohol 2-ethylhexanol (2EH) and/or butanols for use in solvent-related applications.

The LP Oxo℠ process has set a world standard for technical excellence. Plants using this process are highly feedstock and energy-efficient with low environmental impact. They are also easy to operate and maintain.

More than half of the world's production of these oxo alcohols is based on our LP Oxo℠ process. We have extended our technology to include higher molecular weight alcohols in a world-scale facility for the production of detergent alcohols from Fischer Tropsch-based olefins and Isononyl Alcohol (INA) from butenes (via a C8 intermediate).

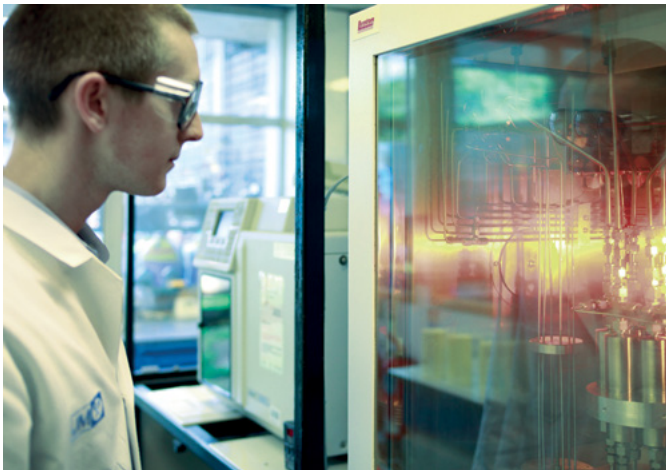
Apart from its wide use with propylene, this technology has been developed for converting cheaper normal butenes to the new plasticiser alcohol 2-propylheptanol (2PH). Similarities between this process and the process for converting Propylene to 2EH mean it is possible to retrofit existing 2EH designs for 2PH production, or design multi-product plants from the outset.

Propylene Glycol

Traditional propylene glycol (PG) production routes involve complex conversions of oil-derived feedstocks via propylene and propylene oxide intermediates.

By contrast, JM's simple PG **DAVY** process employs glycerol – a by-product of our biodiesel process – as its primary feedstock. In this way, our flow sheet offers PG production based on a 100% renewable feed while simultaneously adding value to an otherwise low-value biodiesel by product.

Our PG flow sheet can also accommodate alternatively sourced glycerol feeds.



Substitute Natural Gas (SNG)

Substitute natural gas (SNG) is a manufactured fuel gas designed to contain high levels of methane (CH_4) and therefore act as a natural gas substitute.

JM is the world's leading supplier of SNG technology, with our licensed plants providing more than half of global SNG production

Our process cleanly and efficiently upgrades the energy stored in solid hydrocarbons, such as gasified coal or petroleum coke, to a useful and easily transportable form. The final SNG product is also high-quality, being suitable for injection into gas distribution networks or, alternatively, conversion to LNG.

The key step in SNG production is methanation, which converts synthesis gas (syngas, CO, CO_2 and H_2) into methane.

Vinyl Chloride Monomer (VCM)

JM have recently acquired a well established VCM technology recognised by industry as the most advanced acetylene-to-VCM process worldwide.

Our acetylene-to-VCM flow sheet combines the best of JM's **DAVY** process design with JM's catalyst technologies, to offer major advantages over similar process routes used elsewhere, including:

- A lower equipment count
- Higher VCM quality
- Higher raw material efficiency
- A mercury-free process
- Anhydrous operation

These advantages will provide our licensees with reduced capital and operating costs and deliver an environmentally responsible process. In addition, **DAVY** VCM technology will produce higher-quality PVC downstream.

DAVY VCM technology is the only mercury-free process currently offered for licence. Indeed, ours is the only process that is ready for the expected complete ban on mercury catalysts for new plants started up after 2016 (as per the 2013 Minamata convention between 150 countries including China).

Technical service

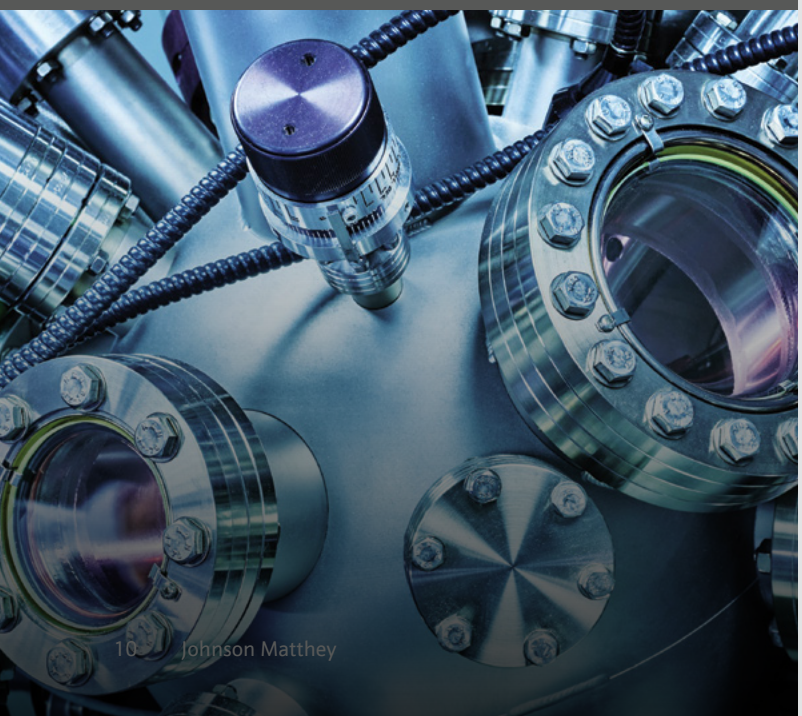
Our technical services help support effective and efficient running of your plant.
Use of JM catalysts and the technical support available helps ensure success, efficiency and profitability for our customers.

JM offers technical services including:

- catalysts selection
- process optimisation
- technical information on use of catalysts/ hydrogenation
- technical seminars for all levels of users of catalysts - process/plant operators, engineers and plant managers
- troubleshooting

JM technical services will help optimise:

- efficiency
- throughput
- reliability
- safety



Quality and consistency

Detailed laboratory analysis and testing of manufactured catalysts under real reaction conditions ensure that we consistently supply catalysts of the highest quality.

From selecting and using high quality raw materials right through to our finished products, quality is assessed and checked ensuring it is at the heart of our manufacturing. Use of sophisticated tools and methods, such as statistical process control, ensure we supply the most consistent and technically robust catalyst on the market today.

In addition to this, our catalysts are safe and simple to handle and our range of products carry appropriate certifications including suitability for Kosher and Halal applications and are free from genetically modified ingredients.

Our customers are our priority

JM actively engage with customers to understand their needs and work with them to achieve success. We supply a range of catalysts manufactured to the highest quality and world class technical support to ensure our customers have no problems and no surprises in use of our products. Our goal is to enhance your process efficiency by supplying catalysts that consistently deliver outstanding performance. We accomplish this using a combination of extensive research and development, state-of-the-art manufacturing technology and expert customer support. We deliver a range of catalysts that delight our customers time and time again.

Technology centre

Our world-class Technology Centre in Stockton-on-Tees was opened in 1998. Research and innovation have always been high in JM's priorities. We are convinced that these activities are essential to secure the future of our company.

Our creative chemists devise novel catalytic process routes to performance chemicals. Working with entrepreneurial chemical engineers, they have built up a portfolio of novel process technologies. These are rigorously tested in our unique mini-plants so that significant aspects of plant operation are extensively and rapidly analysed. This gives us the confidence to directly design global-sized plants, employing scale-up factors in excess of 250,000:1.

Our leading position in the licensing of process technologies for global markets is underpinned by a wide range of development activities which are market-focussed and driven by multi-disciplinary teams who carry out investigative chemistry at micro and bench scale.

Organic synthesis

Our group of professional chemists is well-versed in organic synthesis from small-scale research through to commercial levels. This capability is based on 'creative' chemists who have individual areas of expertise within the broad field of synthesis and apply modern techniques to achieve regio or enantio-selectivity. They work alongside technologists with a fundamental understanding of thermodynamics and kinetics in our laboratories. These laboratories meet all current standards and they are highly adaptable so that equipment that is specific to a particular investigation can be designed and included.

Mini-plant

Our personnel have gained considerable experience in the conception, design, engineering, procurement, fabrication, construction and operation of an extensive range of experimental rigs and small pilot plants or mini-plants. We have pioneered the use of such plants to deliver fast and inexpensive process development programmes.

Our multidisciplinary engineering capability is augmented with highly skilled electricians, welders, pipe fitters, metal fabricators, mechanics and instrument fitters. Expertise is also available in glass fabrication in a well fitted-out glass-blowing shop.

JM pilot plants are extremely flexible and can be used to develop new process routes or to produce small-scale quantities of chemicals. Our engineers can rapidly modify equipment for special tasks. Batch reactors can generate typically 20 litres per batch and our continuous mini-plants can deliver up to 2 litres or 2 kilos of product per hour.

Our policy is to achieve successful commercialisation of novel processes by thorough validation and simulation of the developed process. This procedure forms the basis of producing product samples for market testing and also provides guarantees for the performance of catalytic and non-catalytic processes.

We are able to quickly assemble bench-scale systems for rapid process analysis and the assessment of the feasibility of novel chemical routes.

Commercial exploitation of process technology

JM has a sound reputation for the development of generic technology arising from the solution of specific technical problems. We also have a wide **DAVY** technology portfolio with many years experience of selling licences to operating companies. These techno-commercial skills are available to collaborating companies for the exploitation of jointly-developed process technologies.

Reactor design, development and scale-up

Our experience and skills have enabled us to provide innovative solutions in the development of a wide range of processes for the oil and gas, petrochemical and fine chemical industries. In doing so, a very considerable proficiency and experience has been gained with respect to the following:

- Development and commercialisation of new chemical processes
- Reactor scale-up and design
- Conceptual flow sheeting and process simulation
- Reaction kinetic modelling
- Physical property and phase equilibria data
- Organic synthesis
- Commercial exploitation of process technology

Commercialisation of new chemical processes

JM has a well-established record of developing novel process technologies and providing them under licence to operate at global scale. As an essential feature of this activity we have extensive access to many types of homogeneous and heterogeneous catalysts and this has enabled us to accelerate our development programmes.

As part of our customised research and development service, clients and partners may benefit from collaborative agreements. We provide practical solutions using our mini- plants that can be tailored to business needs. Mini-plants are operated with a wide selection of process development, design and analysis features so that key design parameters are evaluated and process conditions are optimised.

Reactor scale-up and design

Reactors are one of the key elements of safe and economic process development. JM has extensive experience of the process and mechanical design of many types of reactor. These include adiabatic, isothermal and fired reactors operating in vapour phase, liquid phase or mixed phase with heterogeneous or homogeneous catalysts or without catalyst. Selection of the appropriate reactor configuration together with a fundamental understanding of process optimisation leads to correct appreciation of the scale-up problems involved and this is critical to minimising development costs and achieving plant performance.

A new process recently commercialised by JM involved successful scale-up by a factor of 270,000 from a laboratory catalyst life test unit to full plant capacity.

Conceptual flow sheeting and process simulation

JM has considerable experience and expertise in developing flow sheets. Optimum flow sheet configurations can be quickly developed using steady-state and dynamic process simulation software and heat exchanger 'pinch' techniques. We anticipate potential problems that can occur in commercialising new processes and develop robust economical processes by careful selection of design margins so that the correct operating flexibility is provided. Our broad practical experience of technology development, process design, detailed engineering, project management and commissioning ensures that operability, safety and maintenance considerations are always included from the early stages of design.

Reaction kinetic modelling

The performance of a reaction system is a complex function of its operating conditions. It is valuable to be able to interpret reaction data by fitting an appropriate reaction model to experimental data that predicts reaction equilibria and reaction rates for the system components.

The reaction model can be used to predict the performance of different reactor designs and to determine alternative operating conditions. We have much experience in fitting and then testing reaction models to experimental data. These models have been used successfully to predict reactor performance and provide optimum reactor design.

Physical property and phase equilibrium data

Accurate physical property data is fundamental to a successful plant design. We make a considerable commitment to developing and validating physical property databases for emerging technologies. A combination of literature sources, established computer databases and experimental determinations are used to compile the physical property data needed for a plant design.

A key element in most plant designs is accurate prediction of phase equilibria. This is necessary for design of equipment involving phase and composition changes and it is particularly important in designing fractionation equipment. It is well known that much of the VLE data in the public domain is not sufficiently accurate for plant design. Literature sources of data must therefore be used with caution.

Our considerable experience in developing Vapour-Liquid Equilibrium (VLE) databases for computer simulation packages is applied in our state-of-the-art laboratories which have the facilities to generate high-purity components and analyse component mixtures. Specially designed proprietary equipment has been developed for conducting VLE analysis in reactive systems.

We have a wide range of distillation equipment including a variety of tray designs with random or structured packings. We are familiar with specifying all types of distillation equipment for vacuum through to high-pressure service and optimising performance to minimise utility consumption and to meet product specifications.

Designed and produced by www.houseoftype.co.uk

For further information on Johnson Matthey, please contact your local sales representative or visit our website.
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