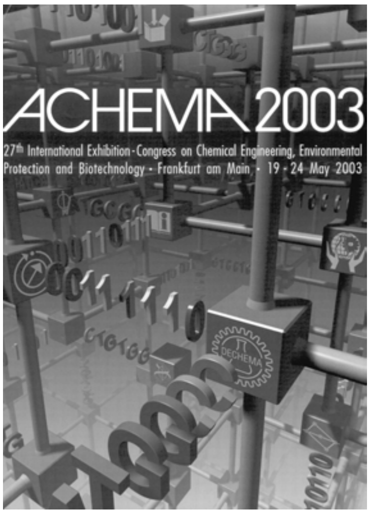

ACHEMA 2003
19–24 May 2003
Frankfurt am Main/Germany

The opening ceremony of the 27th ACHEMA was performed in the Congress Center at the Frankfurt Exhibitions Grounds. From Monday, May 19 2003 the gates to the world's biggest chemical engineering Exhibition/Congress and International Meeting on Chemical Engineering Environmental Protection and Biotechnology were opened to the public for 6 days.
The special technical and trend reports of ACHEMA 2003 exhibition were prepared for publication and realesed by internet as press informationby authorities from DECHEMA. Trend reports covering present and future state of Bulk Solids Management, as well as on the Microreactors and Heat Transfer in the CPI are present in this issue.

BULK SOLIDS MANAGEMENT

The effective handling of bulk solids is a difficult and costly challenge for most chemical process operators. Erratic or nonexistent flow of materials, product segregation based on particle size, density or other material characteristics, or flooding of fine powders all impact system performance. The many facets of bulk–handling equipment and solids–related processes was presented at ACHEMA 2003 from 19–24 May 2003 in Frankfurt/Main by numerous exhibitors and in special congress sessions.

Flow–related problems can cause delays in the startup of a new plant, and they can contribute to excessive downtime in an existing plant, both of which can impact production schedules and productivity, depress product conversion rates and yields, and lead to poor product quality and the production of off–specification products. Any unreliability in the performance of the bulk–handling equipment and solids–related processes will undermine efficiency and diminish net profis.

Increasing effort is directed toward developing equipment and processes that can promote better, more–predictable behavior of bulk solids during processing. Improved analytical tools are being developed to increase measurement accuracy during bulk–solids flow and metering operations, and new bulk solids are being developed that have improved flow properties.

The past decade has gratifyingly seen renewed interest in this field by professional societies, governmental agencies, and accademia. Among the many groups that are active in improving the halding of bulk solids is the Working Party on the Mechanics of Particulate Solids, which is part of the European Federation of Chemical Engineering. Others include ASTM Subcommittee D18.24, whose efforts focus on the characterization and handling of powders and bulk solids, and the American Institute of Chemical Engineers'(AIChE) Particle Technology Forum. AIChE's efforts bring together numerous engineering groups and professionals, which are involved with all aspects of particle technology – from fluidization and agglomeration, to drying, particle characterization, and silo design.

Meanwhile, within the past two years, a new group has formed within the American Society of Mechanical Engineers, named the Structures for Bulk Solids Standards Committee. Its charter is to develop and maintain standards related to the design and construction of silos used for the storage and distribution of bulk solids.

The U.S. government and academia also have once again become interested in this field, and many universities have launched research projects and introduced courses related to powder mechanics. Today, there are several particle technology centers in the U.S., funded primarily by the National Science Foundation. Similar projects are launched in Europe, they are supported by the European Commission. Such renewed interest in identifying ways to improve the understanding of particle behavior, and efforts to design better systems for handling and processing bulk powdered materials represents a dramatic change within the last decade.

Advances in silos

A key focal point for bulk–solids technology is the storage silo. The bulk–solids storage silo can come in many shapes and sizes, including bins, bunkers, hoppers, moving–bed reactors and other structures that are used to store, feed, and, in some cases, process powders and other bulk solids. Since the early 1960s, this field has been dominated by the pioneering work of Dr. Andrew Jenike, whose name is nearly synonymous with the field. Jenike has developed many now widely used design techniques to achieve mass flow, a flow pattern in which all material is moving whenever any is discharged (thereby eliminating the formation of "dead zones", where materials collect and flow is impeded within the storage bin or piping). This is an essential requirement for the reliable handling of most powders and bulk solids.

In addition to Jenike's mass–flow design techniques, which are well known and proven through thousands of installations, unique designs continue to be developed, involving either internal or external changes to the silo geometry. Such technical advances include the following:

Silo inserts

An insert is a device placed within a silo, usually within its hopper section, either to expand the size of the active flow channel in a funnel–flow silo (thereby producing mass flow), or to relieve pressure at the outlet region. Inverted cones and pyramids have been used for years, but with limited success.

A better approach is to use a hopper–within–a–hopper design. Material flows through the annulus between the inner and outer hoppers, and through the inner hopper, unless it is covered at the top. With the right proportions of both geometries, a completely uniform velocity profile can be achieved, thereby minimizing particle segregation and the formation of dead zones. The use of this device can also improve blending of materials within the bin or silo.

Liners and coating

In principle, flow can often be improved by building a taller bin or silo. But process plants typically have a practical limit to how tall a bulk–solids bin or silo can be built.

In order to achieve mass flow while still meeting headroom constraints, the hopper walls must be smooth, and they must retain their smoothness with use (even if the materials being handled are corrosive or erosive). One popular way to improve the surface smoothness of widely used light–gage stainless steel bins and hoppers is to add a ultrahigh–molecular–weight (UHMW) polyethylene liner.

Sometimes, the addition of a thin coat of epoxy paint can also improve wall smoothness and durability. And an alternative, a plasma coating can be considered. This involves flame–spraying a porous substrate onto a prepared base metal, then impregnating that porous substrate with a low–friction polymer.

Hopper shapes

Design engineers are always searching for ways to improve upon bin and hopper geometries, to improve their functionality and reduce solids–flow–related problems. The common denominator in most improved bin and hopper geometries is the use of flat, sloping surfaces (often with vertical end–walls), rather than geometries that employ conical cross–sections.

Gravity–flow process vessels

Compared to mechanically agitated or fluid–bed processing vessels, gravity–flow devices provide numerous benefits, including relatively gentle handling of particles, significant surge capacity during processing, and lower capital and operating costs than agitated or fluid–bed systems. Such vessels are useful for applications ranging from polyolefin handling to ore reduction to drying.

However, despite the many benefits of gravity–flow processing vessels, problems with improper design have limited their effectiveness. Localized fluidization, non–uniform gas distribution, non–uniform velocity profiles of the solid particles, and poor handling characteristics of the bulk solid often lead to incomplete purging or non–uniform conditioning of the materials being handled in the vessel. Any of these can result in the formation of off–grade product, can increase the risk of fire or explosion, and can lead to environmental compliance issues, downstream handling problems, and cross–contamination of materials during the grade changeovers.

Today, many solids–flow–related problems can be prevented or minimized by selecting a combination of hopper design (using, for instance, very steep hopper walls), and low–friction materials of construction or liners, to promote mass flow of bulk solids.

Blending, sampling, segregation

Research is ongoing to better understand the blending and mixing of bulk solids, and to find ways design a blender that will maintain the material mixture during discharge. Even so, a properly blended mix of solid materials can be undone by downstream segregation. Thus, proper sampling techniques, used throughout the process, are essential to guaranteeing product quality and to identify processing problems.

Feeding, conveying and transferring materials

An effective, state–of–the–art way to feed materials from an elongated–outlet, mass–flow silo is to use a tapered interface that discharges onto a belt feeder. Another common alternative is a specially designed screw. Mass–flow design and fabrication techniques have improved over the years, so such screws are finding wide application today.

New bulk–solids feeder designs include rotary–disk devices that provide low wear and reliable sealing capabilities. A moving–hole feeder is often used for biomass and for difficult–to–flow bulk solids.

Conveying equipment is generally classified as either mechanical or pneumatic. Dense–phase pneumatic systems, while more limited in application than dilute–phase pneumatic conveyors, are often used when particle attrition or abrasive wear is a concern. Meanwhile, stepped–diameter piping is useful if there is a need to keep particle velocities within a low range.

High–pressure rotary valves, used in conjunction with pneumatic conveyros, allow for continuous feed, which is not possible with blow tanks. Ongoing improvements in instrumentation allows for better overall control and troubleshooting during pneumatic conveying.

Transfer chutes are often used to direct bulk solids from one conveyor to another. Through proper testing and application of established design techniques, common problems of buildup, limited capacity, dusting, excessive wear and particle attrition can be avoided.

Modeling and analysis

With today's high–speed computers, it is possible to quickly calculate velocity and displacement profiles in many standard (and even some non–standard) silo geometries, using continuum–mechanics models. These relatively new analytical capabilities can considerably reduce the time needed to run physical models, and provides greater insight into flow behavior.

Well–established numerical methods, such as the finite element method, allow engineers to analyze stress and flow behavior of particulate solids in many bulk–solids applications, including silos, blenders and conveyors. Such techniques can also be used to investigate the macroscopic behavior of bulk granular materials. However, some engineers have difficulty using these numerical methods, because the models are based on certain assumptions related to material homogeneity and flow behavior, and because it is often difficult to establish robust to represent the behavior of granular bulk solids.

A promising alternative is the discrete element method (DEM), which models mechanical behavior of the material at the individual–particle level. Technical professionals investigating the use of DEM hope that this newer approach can help to clarify the relationships between the bulk properties of a material, and the underlying interactions among its constituent particles. So far, however, specific methods and algorithms to do so are still under development.

Test equipment

The direct shear tester, as pioneered by Dr. Jenike, has become the international standard for measuring the flow properties (cohesive strength, internal and wall friction angles, bulk density values) of bulk solids. It is the only tester that has received official recognition by being integrated into standards now in place Europe and the U.S.

Other shear testers are also used. The ring shear tester provides unlimited rotational shear displacement, which is useful when testing difficult materials. It is also more easily automated than a direct shear tester.

However, conventional shear–testing equipment may not be suitable for many quality–control applications, because of the associated costs, the level of training and skill required to operate the equipment, and the time required to get results. Thus, various newer testers, in addition to the direct shear and ring shear devices, have been developed over the last 20 years to measure the relative flowability of powders and other bulk solids.

Meanwhile, specialized testers have been developed to measure particle–segregation characteristics, attrition tendencies, abrasive wear and other useful properties. Ongoing work is underway to develop better tools and methods to predict "ratholing" tendencies (this is the tendency for materials to build up as a cake on the walls of a silo, leaving a relatively restricted opening in the center for loose materials to flow through), caking behavior, silo loads, and impact of transmission of pressure waves through bulk solids.

MICROREACTORS

No one disputes that economies of scale favor construction of mega–size petroleum refineries and petrochemical plants. But as economies are achieved and investment returns are diminished, chemical process operators may also be able to apply the principles and tools of microengineering to make their operations not only smaller, but smarter, as well. ACHEMA 2003 from 19–24 May 2003 in Frankfurt/Main showed these perspectives and trends in the exhibition and the congress.

Tiny devices – reactors, heat exchangers, static mixers, pumps and other components – can be fabricated in configurations measured in millimeters, and embedded with micrometer–sized pores or channels. Thanks, in part to larger relative surface areas, devices with these small dimensions are more efficient for mass and heat transfer. This results in greater selectivity and higher yield for chemical reactions.

Continued development of these devices is expected to drive construction of miniature chemical plants that are inherently safe, and can operate in an explosive or hazardous regime that may be off–limits to a conventional plant and equipment. Miniature plants may even perform processes that could not be carried out or were not even known before, says Wolfgang Ehrfeld, former CEO of the Institute for Microtechnology Mainz GmbH, and now head of Ehrfeld Mikrotechnik. Ehrfeld Mikrotechnik is working with Lurgi GmbH to find applications where microreactors can be used.

The Institute for Microtechnology Mainz GmbH is the micro technology partner of the Innovation Group steered by the reputable process developer UOP LLC. This consortium of world–wide partners acts as development and business platform to join expertise and hereby to bring new technology into the market. In this partnership, UOP and IMM recently have tested concrete applications of chemical micro processing and currently are accomplishing first steps to industrial exploitation thereof.

In petroleum refineries and petrochemical plants, for example, microreactors can be used to boost utilization of distributed feedstocks and products, as well as to increase process integration across markets, says Anil Oroskar, senior manager and center leader at the engineering science skill center of UOP. He believes microreactors could facilitate the utilization of stranded natural gas for liquefied–natural–gas (LNG) or gas–to–liquids (GTL) technologies. The potential for intensified liquefaction of natural gas exists, he says, because 95% of oil wells do not contain enough natural gas to employ conventional LNG technology economically.

Not just smaller, but smarter, too

Miniaturization of components has seen the biggest advance, particularly in areas where being small is the key objective, says Michael Matlosz, chemical engineering professor at LSGC–ENSIC. Small devices are used in high–throughput screening and combinatorial chemistry, lab–on–a–chip and other tiny analytical systems, as well as portable energy systems and artificial organs. While the push has been to make microreactors better via process intensification, he believes the next phase will be to make microreactors "smart" enough to enable advanced process control.

Smart microreactors have created new synthesis paths for performing reactions. For example, processing and reactor concepts for the direct fluorination of aromatic compounds have been developed at IMM and the Massachusetts Institute of Technology. The safe operation with elemental fluorine giving the favourable electrophilic substitution pattern was demonstrated at the MIT as well as at the Institut für Angewandte Chemie. In the latter case, monofluorination of toluene at high selectivity and conversion was achieved both, with the IMM falling film microreactor and micro bubble column. These reactors meanwhile became off–the–shelf products in IMMs microreactor catalogue, which comprises 26 chemical micro processing devices and 2 plants. Volker Hessel, head of IMM's Chemical Process Engineering Department, says, these products are accepted by a more and more increasing number of customers, not only in Europe but meanwhile world–wide and especially in the Far East. This is demonstrated by the enormously rising sales rates in the past two years.

Controlled periodic processing is another task that microreactors can do that conventional technology cannot. For the electrochemical partial oxidation of ethanol to acetaldehyde, for example, an electrochemical cell achieves 98% selectivity for 10 s, after which the CO inhibits the catalyst. Matlosz's group is developing a technique, called raster–pulse electrolysis, that enables this reaction to be performed continuously. The process achieves "not a 10% increase in yield," he says, "but 100%".

Instead of a traditional electrochemical cell with macroscopic electrodes, the researchers made a cell composed of a large number of thinly sliced porous anodes separated by thin insulators. By imposition of a non–uniform voltage, a windshield–wiper effect is achieved in the reactor, alternating between catalyst cleaning (desorption) and catalyst deactivation (adsorption). The next step will be to monitor the catalyst, to decide when to administer the pulse.

Besides electrochemical reactions, thermal and photochemical reactions can be made smarter by controlled periodic processing, says Matlosz. With this in mind, a new microreactor for rapid temperature cycling has been developed by the Karlsruhe Research Center and the University of Erlangen (Germany). The device is able to change the temperature of a gas flow by 100K within 2 seconds versus several minutes for a fluidized bed, says researcher Jürgen Brandner of the Karlsruhe Research Center. The group plans to integrate a catalyst into the device and perform heterogeneously catalyzed gas–phase reactions.

A non–uniform flow distribution for the cooling fluid provides optimal performance in a microreactor for platinum–catalyzed oxidation of ammonia to nitrous oxide, in research conducted at Eindhoven University of Technology. For this highly exothermic reaction, cooling is necessary to avoid hot spots and to reduce temperature gradients across the catalyst, both effects that decrease selectivity for N_2O.

Not just for process development

In the seven years since microreactor technology was formally established as a discipline, there has been a steady increase in the number of chemical reactions and physical changes performed in miniature. Although many of these have been done at universities, some companies, including BASF AG, Merck KGaA, and Du Pont are already using microreactors in process development and even in production. In another example, Siemens Axiva GmbH has developed a new process for continuous radical polymerization of acrylates in seven years since microreactor technology was formally established as a discipline, there has been a steady increase in the number of chemical reactions and physical changes performed in miniature. Although many of these have been done at universities, some companies, including BASF AG, Merck KGaA, and Du Pont are already using microreactors in process development and even in production. In another example, Siemens Axiva GmbH has developed a new process for continuous radical polymerization of acrylates in seven years since microreactor technology was formally established as a discipline, there has been a steady increase in the number of chemical reactions and physical changes performed in miniature. Although many of these have been done at universities, some companies, including BASF AG, Merck KGaA, and Du Pont are already using microreactors in process development and even in production. In another example, Siemens Axiva GmbH has developed a new process for continuous radical polymerization of acryladictable; even bulk commodity production up to several hundred thousands tons of product per year is not out of reach.

Methods and materials

In addition to traditional techniques such as chemical and plasma etching, and LIGA, researchers can now make microdevices using mechanical and laser–micromachining, photoablation, photopolymerization and optical deep lithography. "Devices are already available for R&D," says Ehrfeld. "Now we have to implement a cost–effective basis for mass production."

Microfabrication developments are also making it possible to fabricate devices in a wide range of materials, from glass, silicon and engineered polymers to stainless steel, Hastelloys, copper, gold, silver and other metals. The Karlsruhe Research Center combines microstereolithography by rapid product development (RMPD) with low–pressure injection molding (hot–molding), to make microreactors in ceramics that withstand high temperatures and corrosive media. Designs are first generated as a 3D model via CAD, then transferred to polymer molds by microstereolithography. These are then copied into silicone molds that are used as tools for the hot molding process. The final ceramic component is then obtained after dewaxing and sintering.

The Karlsruhe Research Center has modular microreactor systems available in Al_2O_3 for heterogeneously catalyzed, gas–phase reactions operating continuously at temperatures up to 1,000°C. Exchangeable catalyst carriers can be quickly changed for catalyst screening. Other materials available include ZrO_2, $BaTiO_3$, Al_2O_3/TiN, and hydroxapatite.

An easy mix

Besides improving chemical reactions, microreactor technology is also showing potential for improving physical processes. In Japan, for example, an alternative to energy–intensive mixers for making emulsions has been developed by researchers at the National Food Research Institute, the University of Tsukuba and the University of Tokyo.

The researchers have been able to form monodispersed oil–in–water dispersions by simply forcing soybean oil through a silicon microchannel array – a 4–in. dia. wafer with 10,000 channels 200 um long and 20 µm dia. – into a continuous flowing aqueous phase. Microspheres (32.5 µm ±1.5%) of oil emerged from the channels for pressures above 1.8 kPa to form the emulsion. A single device can produce 6.5 mL/h of stable emulsion.

Whether the process is physical or chemical, microreactor technology will revolutionize the chemical process industries in much the same way that microelectronics transformed information processing, says Ehrfeld. And just as innovations have doubled computer speeds almost annually, a similarly fast pace of change will characterize chemical processing.

A microreactor that cannot clog

Although the benefits of performing chemical reactions in microreactors (efficient mixing, heat and mass transfer) have been demonstrated, clogging of the narrow channels remains a problem to be solved, says Bernd Penth, managing director at Synthesechemie GmbH. Clogging is not possible in the company's MicroJetReactor, because the reactants and product are never confined together in a microchannel. The system can be used to make micro and nano particles of metallic oxides, various inorganic salts, ceramics, pigments and other powders, or oil–in–water emulsions.

In the MicroJetReactor, the reactants are pumped at high pressure (up to 4,000 bars) through diametrically opposed sapphire nozzles (60–350 µm widths). The fluid jets, with velocities up to 1 km/s, collide in a free area where intensive mixing and hydrodynamic cavitation causes physical and chemical reactions. The product "fog" is then blown through a heat exchange with cold inert gas, which also serves to prevent side reactions.

The reactor utilizes nozzles and pressure lances developed and optimized for conventional water–jet–cutting technology, says Penth. The capacity of the system depends on concentrations, nozzle diameters and operating pressure. For precipitation reactions, a feed rate of 500 L/h will produce about 1–20 kg/h of product, says Penth. Laboratory units, with 50 L/h throughputs were made available last year for customer trials. A 500 L/h system, complete with triplex pumps and flow monitors on both feeds costs about $75,000. The first such unit was sold at the end of last year to an undisclosed German chemical company, which is now using the system in production.

Already at ACHEMA 2000, CPC Cellular Process Chemistry introduced the world's first commercially available, fully integrated microreactor system. More than 60 reactions from different classes have been performed successfully in the company's standard reactor system. In most cases, improvements in yield and/or selectivity have been found. A process for which a patent has been filed adapts the microreactor system to synthesize the pharmaceutical Ciprofloxazine.

Mgt mikroglas technik AG also offers a commercialised, fully integrated microreactor system, which comprises diverse glass micro devices. Organic reactions, for example, can be performed in integrated flow configurations composed of a micromixer, a reaction zone and a heat exchanger. Apart from much other functionality this system, by using glass as a construction material, provides the striking opportunity to monitor optically or to literally watch the processes and reactions. In particular, detailed information on flow pattern analysis and the course of mixing can easily be derived.

This advantage has extensively been used and demonstrated by IMM by exploiting such information as data base for rational design of microreactors. For instance, the commercially available flow focusing micromixer SuperFocus is capable of mixing liquids within a few milliseconds as confirmed by rhodanide imaging of colour changes at the interstaces of the 128 lamellae. Another application area of micromixers is the generation of emulsions with a uniform droplet size distribution. Under certain conditions droplet formation occurs via the decay of liquid cylinders on a time scale of milliseconds, the dynamics of which is governed by a hydrodynamic instability (known as the Rayleigh–Plateau instability). Microfluidics can rely on first–principle modeling approaches rather than models with effective degrees of freedom which usually induce a high degree of arbitrariness, such as turbulence models, says Steffen Hardt, head of the Fluidics and Simulation Department at IMM. Thereby, rational reactor design is facilitated enormously.

The market and german R&D push

In order to evaluate the economic potential of microreactor technology, IMM and the French consulting company YOLE Développment joined forces under a partial grant by the European Commission's GROWTH program to prepare the PAMIR study. IMM estimates that for 2002, the sales volume for microreactor technology is estimated to reach 36 million Euros, only for applications in R&D and process optimization. The growth rate follows the average growth of sales volume in the chemical industry. According to the PAMIR study, first applications in production are expected to be realized in pharmaceuticals and fine chemicals.

At least two major coordinated research programs have recently been established in Germany. Under the funding umbrella "Microreactor Systems in Chemical Engineering", the German Federal Ministry of Education and Research promotes the evaluation of microreactors systems in industrially relevant chemical production processes. Several projects under the control of DECHEMA e.V. have gained experience since 1998.

For example, DECHEMA's Karl Winnacker Institute has developed a computer program that predicts the potential of a microreactor application for a specific synthesis. The program consists of two parts. A consultative part uses process engineering parameters, algorithms and a simplified model of a microreactor to predict the feasibility of the reactor. A verification part then generates more detailed information of attainable performance data. The first part has been tested on two reactions: synthesis of phthalic anhydride from ortho–xylene and the direct oxidation of ethylene to form ethylene oxide.

Within the framework of the German Funding Program MST 2000+, a construction kit for "Modular Micro Process Engineering" is presently being funded. The strategic project aims at the standardization of interfaces and connectors of microstructured components, such as reactors, mixers and heat exchangers to enable and facilitate the coupling of devices from different manufacturers to complex microplants. An industrial network, initiated by DECHEMA and comprising about 40 companies and research institutes is participating in this process. A catalogue of micro–components for process engineering is already available.

A similar project "Microsystems in the Mechanical Industry – Match–X" has been funded within MST 2000+ before. In cooperation with the VDMA and the Fraunhofer Society a construction kit for modular microsystems has been developed. Harmonization of the construction kit for micro–process engineering and the microsystems construction kit is being pursued.

ACHEMA 2003 will be a thinktank and business platform for the future application of microreactor technologies.

HEAT TRANSFER IN THE CPI

Heat transfer describes the transfer of energy that occurs when two systems at different temperatures are in contact. In the chemical process industries (CPI), heat–transfer engineering involves the determination of cost, feasibility and size of equipment that is needed to transfer a specific amount of heat from one fluid to another in a given amount of time. Typical heat–transfer equipment includes boilers, heaters, refrigerators and heat exchangers. Since heat exchangers perform the majority of the heat–transfer work in CPI applications, they are the focus of this report. At ACHEMA 2003 in Frankfurt/Main thermal processes and equipment was one of the most important exhibition groups. Numerous exhibitors and the ACHEMA Congress presented new technologies and the outlook for their application.

Counter–current versus co–current flow

The relative flows of the two fluids in a heat exchanger can be co–current, counter–current, or a combination of the two. By design, co–current flow can never yield an outlet coolant temperature higher than that of the outlet hot fluid. However, this is not the case for counter–current flow. Using counter–current flow, it is possible to have outlet coolant temperatures approach the inlet temperature of the hot fluid. Thermodynamically, it can be shown that an exchanger arrangement using counter–current flow gives the most efficient heat transfer.

Fouling

Many process streams leave deposits on the heat–exchange surfaces, which impedes heat–transfer efficiency, and often leads engineers to specify heat exchangers that are larger than they actually need. Any fouling deposits must be eventually removed, which calls for periodic heat–exchanger shutdown. The main causes of fouling inside a heat exchanger are water streams that form hard crystalline deposits, and streams whose organic components can form sticky layers of deposits on the surfaces inside the exchanger.

Stream composition, flow velocity and wall temperature are the prime variables that impact fouling rates, and both industry and academia continue to invest considerable time and effort to develop more fouling–resistant materials, more–refined methods to estimate fouling rates, and improved techniques for removing fouling that has occurred.

Basic data required for heat exchanger design and selection

Most heat–exchanger problems ultimately result from faulty or inadequate information at the design stage. For each fluid, the designer needs to know the following:

Flowrate at design conditions. This should normally be the maximum flowsheet rate.

Heat duty. For heating or cooling a single–phase fluid, this may be expressed in terms of the temperature change to be accomplished.

Process requirements. These include inlet temperature and pressure and allowable pressure drop. If the heating medium is condensing steam, the available pressure at the control valve is needed, not the pressure generated at the powerhouse.

Fouling nature of the fluid. Using such data, the system designer can decide how much fouling allowance to provide for when sizing the exchanger, and what type of fouling–resistant materials to specify.

Process–fluid properties. These include the specific heat, viscosity, density and thermal conductivity associated with the anticipated range of operating temperatures and pressures, for both the tube–side and shell–side fluids.

Expected turndown. This information is required for designing proper control strategies, and should be known to avoid oversizing the exchanger.

Materials of construction. Some applications stipulate special materials to ensure compatibility with the fluids to be handled by the exchanger.

Special requirements. Occasionally, applications require special construction requirements, such as removable bundles or double tube sheets.

Selecting the right heat–exchanger type

The choice of heat exchanger type directly affects process performance and also influences plant size and layout, the length of pipe runs, and the strength and size of supporting structures.

Experts warn that too often, engineers either forego a through analysis of competing heat–exchanger options, or they postpone such an analysis until well into the detailed–design stage. Too often, engineers go immediately to the "workhorse" heat–exchanger design, the standard shell–and–tube exchanger. However, experts note that for many applications, the less–conventional but still well–established heat–exchanger designs, such as plate exchangers, finned–tube designs, and compact exchangers, for example, offer advantages. Even enhancing features within the shell–and–tube exchanger, such as the use of tube inserts, helical baffles, twisted tubes and rod baffles, are routinely ignored. Furthermore the prospects for micro–heat–exchangers are promising.

The first step in a thorough selection process is to eliminate those technologies that are clearly unsuitable for a given application. It is not necessary to exhaustively investigate all features of the alternative technologies that are available; in fact, a basic understanding of each one's benefits and weaknesses will quickly narrow the search. Discussed below are the general strengths of each of the major heat–exchanger types.

Shell–and–tube: This oldest type is still the most pervasive design in use in the CPI, because its rugged and versatile design can accommodate all extremes of process variables, such as pressure, pressure drop, temperature and fluid corrosivity, yet its design also makes it relatively easy to maintain and repair. If constructed in carbon steel, the cost for a basic shell–and–tube unit is relatively low. In the case of difficult or unique process conditions, shell–and–tube exchangers often require the placement of baffles inside the shell, to direct the flow of the shell–side fluid. For example, fluids with viscosity over 5 centipoise (cP) will require helical baffles to be added. The choice of baffle designs, include single–, double– and triple–segmental, and rod and "egg–crate" non–segmental. Recently, a spiral–type baffle has become available, to minimize pressure drop that arises from changes in flow direction.

Other types of tube enhancements are also available to improve heat–transfer efficiency. Among these enhancements are: internal and external fins; wavy or otherwise altered tube profiles; and wire inserts, which also reduce fouling. Turbulence promoters have also become popular.

One downside of shell–and–tube exchangers is that most of the time, it is not practical to use counter–current flow in a shell–and–tube exchanger. If the flowrate of the tube side fluid is not extremely high, the resulting tube–side velocity will probably be too low to give an acceptable film coefficient or adequate protection against fouling. In this case, it is necessary to employ multiple tube passes (to create changes in flow direction). Most heat–exchanger designs have an even number or tubes, so that both tube–side inlet and outlet piping connections can be made at the same head (elevation).

Plate exchangers: These are predominantly used in the food industry, because they are extremely easy to clean. For applications with sufficient allowable pressure drop, plate exchangers will remain strong competitors to shell–and–tube designs. Specific designs include plate–and frame, plate–in–shell and plate–fin types. Plate–fin units are most easily suited for multi–streaming – that is, the contacting of more than one hot stream and one cold stream in a single unit. Such a design can effectively contain a whole heat–exchanger network within the body of a single exchanger. And, the use of welded compartments allows the use of plate exchangers at higher pressures, although this will reduce the unit's ease of cleaning.

Compact heat exchangers: Predominant in cryogenic applications, compact heat exchangers offer a high area–to–volume ratio and often combine several streams in one unit. A major limitation is the relative difficulty of cleaning. With air as the coolant stream, they are widely as automotive coolers and condensers. A key attraction is that they offer extremely small liquid passages (down to 1–mm dia.).

When assessing heat–exchanger options for a given application, the following steps should be carried out, to eliminate designs that are not suitable for a given application:

1. Compare temperature and pressure limitations of the exchanger type against required duty
2. Check the required material of construction against the range of materials that can be used for the type of exchanger
3. Evaluate the suitability of the exchanger type for hazards associated with the fluids being processed (such as toxicity, flammability or mixing hazard)
4. Determine if the exchanger is likely to be subject to fouling. If so, decide what cleaning mechanism is to be typically used, and check the suitability of the exchanger candidate for this type of cleaning
5. Verify the availability of maintenance personnel at the proposed location. If specially skilled or trained workers are not readily available, eliminate any technologies that require special attention

Thermal design

Sizing a heat exchanger for a specific process application is often referred to as thermal design. This is an inherently trial–and–error process and must be accurate before the unit's mechanical design can begin. First, an exchanger configuration is proposed and then rated – meaning that its estimated performance is computed and the results are compared to the process requirements. If calculations indicate that the trial configuration is inadequate, the specifications must be modified, and the rating must be repeated. Assuming that the basic data has already been assembled, the analysis generally follows these four steps:

1. Compute heat duty: The required heat duty expresses the amount of heat that must be transferred through the exchanger. It depends on the fluid that needs to be heated or cooled and is calculated from its flowrate, specific heat, and the inlet and desired–outlet temperatures.
2. Compute mean temperature difference: The mean temperature difference is the driving force for heat transfer and directly affects the required heat transfer surface area. In practice, it is estimated through a logarithmic relationship that depends on the flow arrangement and is referred to as the log–mean temperature difference (LMTD).
3. Design a trial exchanger configuration: This step involves a number of decisions. In the case of a shell–and–tube exchanger, for example, a designer must decide: which fluid to put in the tubes; whether to use fixed tubes or a removable bundle; what tube size, thickness and materials to specify; the number of tubes and tube passes (changes in direction) to specify; and what baffle considerations will be necessary.
4. Compute heat–transfer coefficients and pressure drop: These calculations must be determined for all fluids in question, and must take anticipated fouling into consideration.

If the final step does not satisfy the process requirements, the designer must return to Steps 3 and 4 before moving on to the setting the mechanical specifications for the exchanger.

Process simulations

The greatest impact of the today's advanced computer technology has been the widespread availability of complex process–simulation programs, which, in principle, can be used to simulate entire plant designs. This ability has allowed engineers to study, in detail, numerous process alternatives without capital expenditures. Simulations are particularly valuable during heat–exchanger assessment, design and specification. However, complex designs such as that of a shell–and–tube exchanger will require a close interaction with a knowledgeable engineer, who usually must assess many proposed changes of variables using during the simulation modeling, before obtaining a valid design.

Heat–exchanger networks

A typical CPI plant has a number of streams that must be heated and a number of streams that must be cooled. Economy of production requires that heat be interchanged (or recovered) between the process streams, with minimal heat supplied from outside sources, and minimal heat lost irretrievably to sinks, such as rivers. In recent years, design engineers have focused their efforts on exploring many design variations that will allow for the most advantageous pairing of streams, respecting temperatures and flow quantities, to arrive at the optimal design.