# ACHEMA 2006
# 28. međunarodni sajam i kongres za hemijsko inženjerstvo, zaštitu okoline i biotehnologiju

U Frankfurtu je u periodu od 15. do 19. maj 2006, održan 28. međunarodni sajam i kongres za hemijsko inženjerstvo, zaštitu okoline i biotehnologiju, ACHEMA 2006. Sa 3880 izlagača iz 50 zemalja, ovogodišnja ACHEMA 2006 je u poređenju sa prethodnim bila do sada najveća. Na 135514 $m^2$ izložbenog prostora bila je izložena oprema, sistemska i tehnološka rešenja za hemijsku, petrohemijsku, farmaceutsku i prehrambenu industriju kao i srodne industrije obrade materijala. Približno 180000 stručnjaka iz 98 zemalja je posetilo ovogodišnji sajam u potrazi za najnovijim razvojnim rešenjima i trendovima i uspostavljanju novih poslovnih kontakata. Ovaj skup je, takođe, odražavao i trenutno stanje svetske ekonomije.

Po prvi put, više od 30% posetilaca je došlo iz inostranstva, sa velikom delegacijama iz Japana, Indije, Kine i Srednjeg Istoka. Inostranih izlagača je bilo više od 44%, sa upadljivim porastom iz Kine, Južne Koreje i Indije.

Paralelno sa sajmom, održan je i prateći međunarodni ACHEMA kongres sa 925 predavanja koja su ukazala na brojne nove pristupe u procesnom inženjerstvu i biotehnologiji. Među najzapaženijim su bila ona iz mikroprocesne tehnologije, nanotehnologije, automatizacije procesa, novih goriva baziranih na bio masi, tehnologije voda, novih materijala za gorivne ćelije, i novih procesnih tehnologija sa "zelenim rastvaračima".

Nemačko društvo za hemijsko inženjerstvo i biotehnologiju, DECHEMA (www.dechema.de) prati ovaj sajam i kongres, objavljivanjem izvešaja o trendovima o novim proizvodima i tehnologijama. Kao i ranijih godina, počev od ovog broja, u cilju upoznavanja naših čitalaca sa novim smernicama, ovi izveštaji u nešto skraćem obliku biće dati i u našem časopisu.

DECHEMA je istakla 20 glavnih trendova i to: 1. Pumpe i fitinzi, 2. Inženjering, 3. Compresori, 4. Budući izvori energije, 5. Separacione tehnologije, 6. Laboratorijske i analitičke tehnologije, 7. Farmaceutska tehnologija, 8. Intenzifikacija precesa, 9. Automatizacija procesa, 10. Menadžment (Upravljanje), 11. Tehnologija pakovanja, 12. Tehnologije vode, 13. Inženjerstvo postrojenja, 14. Energetski koncepti, 15. Bioprocesiranje, 16. Industrijska biotehnologija, 17. Mikrotehnologija, 18. Sigurnosni sistemi, 19. Logistika u hemiji, 20. Nanotehnologija.

**PUMPS AND FITTINGS: EFFICIENCY AND AVAILABILITY DEPEND ON THE QUALITY OF DESIGN DATA**

As always, the one thing that visitors want to know is how plants can pump media and control the flow of material safely and reliably with zero emissions and above all, how this can be done in the most cost–effective manner.

In what is admittedly an extreme case, pump manufacturer KSB is supplying the biggest cooling water pumps it has ever made to a new coal–fired power station in Yuhuan, China. Each of the eight 130 ton units can pump up to 16,000 liters of cooling water per second, drawing 4.6 MW of power from the grid. But even small industrial pumps consume a lot of energy. Operators who were not aware of this in the past or simply didn't want to know are now in for a shock when they look at their spiraling utility bills. Electricity prices have been rising steadily at double–digit rates in Germany since 2002 (despite deregulation). Electricity continues to become more expensive throughout Europe. In light of these developments, pump system operators are looking even more closely at the overall efficiency of their pumps and motors.

Even with older pumps, it is worth looking at the pump and the operating environment to find ways of counteracting the increased cost of electricity. The Pumps + Systems Association at the German Engineering Federation (VDMA) believes that energy savings in the region of 20–30% are realistic. The Group has now joined forces with the German Energy Agency (dena) to launch the "System Efficiency"campaign.

A framework is being put in place to help industrial and commercial operators analyze and reduce the amount of energy used by their pump systems. Industrial partners are contributing to the project, including pump manufacturers Grundfos, KSB, Sulzer and Wilo. The goal is to define ways to save energy and demonstrate the economic payback of energy saving measures, provide information, analyze lifecycle costs and generate a wide range of fact sheets.

**Ensuring availability**

Saving energy is important. However, pumps and other "auxiliary" equipment must do one thing above all in an industrial process, namely they have to run and run and run. From the process engineering point of view, availability is crucial and it overshadows other considerations.

So what can equipment producers and operators do to prevent downtime? Redundancy is one possible answer, for example a reserve pump. More elegant solutions are now available which make increasing use of electronics and sensors. Moving mechanical parts will also be subject to wear no matter how good and durable the components are. This makes it all the more important to detect wear as early as possible.

It is also important that operators sit down with suppliers at a very early stage to discuss the operating requirements to ensure that the supplier is aware of the load and stress factors. It is always better to avoid critical operating conditions by conducting good up–front planning for the entire system than to simply find a reliable way of detecting a "bad" system.

Again and again, practical experience has shown that bad actors are usually pumps that are too big for the job. Nobody denies this in principle, but everyone knows that "good planning" presents a very significant challenge when basic information on the media and the process is not available when pump specifications are drawn up.

Energy conservation is not the only reason why a centrifugal pump should run at or near the operating point. Mechanical stress is also an important consideration. When pumps are not operating near the operating point, radial forces begin to put stress on the bearings and mechanical seals, and cavitation increasingly becomes a problem. This makes it important to avoid adding in a safety factor in the pump specification.

If a pump is designed correctly, failure will only occur due to early or random failure or as a result of out–of–spec operating conditions. Normal wear is another possible cause of failure (end of life).

**Monitoring and early fault detection**

The wish of every process engineer and maintenance technician is to have a way of detecting equipment faults before downtime occurs. Action rather than reaction is the goal. A range of vibration, pressure, temperature and structure–borne sensors along with the associated analysis equipment is now available on the market. There are also diagnostic systems for mechanical seals and bearings, and self–monitoring functions are built into in control systems.

Traditional sensors capture a value and then trigger something that no operator wants to see, namely a fault warning. Early warning systems kick in earlier, signaling a problem before the pump fails or is damaged.

Sophisticated monitoring systems make sense on large pumps. By monitoring vibration levels, current and voltage fluctuations and changes in process parameters (temperature, pressure and flow rate), these systems are capable of providing dependable early warning about potential problems caused by out–of–spec operation or wear.

However, nobody winds up in the emergency room just because they catch a minor cold. The cost and effort invested in monitoring must be commensurate with the risk and the value of the pump. Not all pumps are equally important. It is not always a big problem if a secondary piece of equipment fails unexpectedly. The next level down is component monitoring, which means keeping an eye on diaphragms, valves, cans and bearings. Experts only recommend the use of intelligent early warning systems when this level of sophistication is actually warranted.

It is generally accepted that structure–borne noise is a reliable indicator of faults on rotating parts. The only problem with sensors is the financial aspect. The crucial issue is criteria extraction. How and when does the operator recognize that there is a problem?

The goal is to associate a unique frequency with each fault. This approach already works for functional components in the oscillating pump head of diaphragm pumps. These condition monitoring systems detect the majority of possible faults, for example a leaky fluid valve (these highly sensitive systems monitor the timing between the structure–based noise signal and the intake and pressure stroke). It is now possible to reliably detect leakage greater than 1%. The combined analysis of structure–based noise and pressure signals leads to a detection of 90% of possible failures according to the provider.

When you are weighing up the pros and cons of intelligent early warning systems from the cost point of view, you should keep in mind that when you use these systems, service intervals always increase and the payback period is usually relatively short. You frequently hear that the cost of a monitoring system should not exceed 10% of the value of the pump, but you should keep an open mind on this. How critical the system is to the customer is more important than the cost ratio between the monitoring solution and the pump.

**Redundancy: the pros and cons of backup pumps**

Redundant pumps are often used in the chemical industry to guarantee system availability (A and B pumps). The added cost inevitably leads people to ask where and under what conditions redundant pumps can be eliminated. Actually, there is no simple solution to this dilemma. When an operator is considering doing without a backup for a pump which runs continuously, the cost of starting up and shutting down the system and the cost of lost production resulting from a fault has to be compared to the additional cost of a backup pump.

The operator and the supplier take on a lot of responsibility if the decision is made not to use a backup. The product will have to meet very high quality standards, and the pump specification will have to be much more precise. Monitoring and early warning systems are essential in these applications. Experts advise operators to run the pump in the process which will be used later on to ensure that the specifications are correct. Verifying the process suitability of the pump during the commissioning phase gives the operator the opportunity to up-

grade the pump, and the supplier has the chance to make improvements.

Quality assurance is particularly important when the pump is expensive and the lead time is very long. When you look at quality, you have to look at the quality of the pump itself, the quality of the process data and the quality of machine diagnostic/early warning systems. Process and specification data must be reliable and reproducible in order to make sure that the pump operates faultlessly.

Careful attention must be paid to the pump housing production process at the foundry or forge. It is not uncommon for operators to complain about substandard casting quality. Outsourcing of castings in low–cost countries was not and is not always accompanied by a suitable supplier qualification process. Is this the price we have to pay for globalization? Pump producers who have a problem need to act quickly.

**Sealless pumps with no shaft seals: a 200 million euro market**

Operators have to use pumps which have elaborate mechanical seals or pumps without shaft seals (magdrive or canned motor pumps) to safely handle dangerous or environmentally hazardous media and avoid the release of emissions.

Operators have the following options to eliminate the risk of leakage:

- hermetically–sealed pumps with canned motor drive (absolutely leakproof primary and secondary fluid containment, no buffer medium required)
- magdrive pumps (single casing, secondary mechanical seal needs to be monitored; buffer fluid must be reprocessed)
- multiple mechanical seal pumps with buffer fluid (buffer fluid must be reprocessed)
- multiple mechanical seal pumps with dry–running seal (buffer fluid must be reprocessed)

The crucial difference between canned motor drive and magdrive is the fact that the canned motor has secondary fluid containment. The terminal box and the cable glands have to be impermeable to gas and fluids, and they must be designed for the rated pressure of the subsystem. In case the can is destroyed as a result of bearing damage or corrosion, no hazardous substances can be released into the atmosphere. Magdrive pumps can be a safety hazard if a fault occurs. A double–wall can minimizes the risk to a large extent, but the space between the walls must be constantly monitored.

How large is the market for sealless pumps (canned motor drive and magdrive pumps)? The industry assumes that worldwide demand is in the region of € 200 million. The European market is estimated at € 60 million, and € 20 million of that is in Germany. The ratio of magdrive to canned motor drive is about 2:1.

Following the introduction of ATEX 100a which also applies to non–electric pumps, the ratio is expected to shift in favor of canned motor pumps. To comply with the new regulations, standard pumps (including magdrive pumps) require more monitoring to detect dry running and excessive temperature. Canned motor drives are electrical devices which already have appropriate safety features which make them inherently ATEX 100 compliant.

**Metering pumps: migrating to system solutions**

There are very few industrial applications where a centrifugal pump is inherently a bad choice. However, metering pumps are one example where this is in fact the case. Positive displacement pumps are the most popular solution in these applications. Manufacturers are obviously now paying more attention to the peripherals. A look at current products on the market reveals a move towards system solutions. The main advantages are one–stop shopping with a single point of contact, elimination of interfacing problems between the components and elimination of assembly work. The turn–key systems are supplied fully assembled. On request, the system can be installed and commissioned on site. This removes most potential sources of error.

The market seems to be ready to embrace individual modules. The reason for this is that the properties of the medium and the degree of precision needed for the process are important criteria in any given application. Even metering applications which appear to be simple always have a holistic aspect, making a system approach superior to installation of separate components.

**Fittings: driving down the cost of automation**

German producers of industrial fittings were able to increase turnover by 7% (+13% in the export sector) in the first half of 2005. There were significant differences between the various product segments. Turnover of shut–off valves showed the strongest growth at 10% (+4% in the domestic market and +18% in the export markets). Safety and monitoring equipment was up 5% (domestic: –5%; export: +16%). Domestic and foreign turnover in the control valve segment grew by a modest 2%.

Despite the fact that demand for control valves was down in the period, the percentage of automated valves and fittings continues to increase.

Two types of requirements profiles are common in automation applications. Some valves operate purely in on–off mode, and the valve is only moved to one of the end positions. In control mode, the flow rate in a pipe is monitored to detect deviations from a setpoint. When you are looking at automation costs, there is more involved than just the choice of the fittings themselves. The type of actuator (manual, electrical, pneumatic or hydraulic) also influences the cost of the automation project. Various combinations produce different mixes of investment, operating and energy costs.

Compared to linear controls (valves and sliders), it takes less force to operate 90° controls (flaps and stop–cocks), so the actuators can be small and cheaper.

Here is a practical example, which shows what "cheaper" can mean. In October 2005, a technical fault interrupted production in a steam cracker at a large chemical plant. The safety systems reacted as intended, and the raw gas was burned off at the flare. The cause of the problem was traced to "atypical mechanical damage to the actuator" on a special valve, and the resulting costs were enormous. For every hour that the flare burned at the steam cracker, the company lost tens of thousands of euros, and it took several hours before the flare went out. This is a typical example of how a relatively "cheap" component can cause enormous damage.

All industrial plants in Germany will have to comply with the European regulations (IPPC Directive 96/61/EC) and national legislation (air quality, etc.) by 2007. This affects valve spindle and housing seals. Successful implementation depends on the quality of the sealing components and on the state of existing valves (rework may be necessary). It is also important that the seals are properly installed. Additional measures, for example using disk springs on the gland, provide an additional margin of safety in difficult spindle sealing applications. The incremental cost associated with compliance to the regulations is not without its benefits, however. Correct planning and implementation increase service life and maintenance intervals.

The trend to unit–based solutions is also evident in the valve industry, for example pressure reducers and temperature control stations. For users and plant engineers, the number of components which need to be sourced is reduced substantially when subsystems are available. The supplier takes responsibility for detailed design of valves, fittings, pipes, etc. which are installed in the unit and which must comply with applicable regulations and standards. The supplier also takes care of certification and provides a complete set of documentation.

The potential advantages to operators, who take an in–depth look at life cycle costs when they evaluate pumps and fittings, go beyond a possible reduction in energy costs. Lower life cycle costs provide an indication that the pumps or fittings are compatible with the system and the process and that they are less likely to fail. Sometimes it is necessary to look at alternatives, and a recently published study claims that there are cases where a new solution can be a good investment. A life cycle analysis provides a good basis for comparing different pump designs, and there can be considerable differences. On the other hand, life cycle costs are unlikely to vary significantly on pumps with similar designs which are made by different manufacturers.

## PLANT ENGINEERING: ACCELERATED PRODUCTION AND SHORTER PLANNING CYCLES

Two ACHEMA economic forums sheded light on the opportunities and risks which are associated with the development of the process industries in the high–growth regions in China and the Arab world. The events were entitled "China on the verge to an innovation super power" and "The Middle East – upcoming hot spot for the world's process industry".

China is hungry for chemical products and energy. To meet the strong demand, foreign and domestic companies continue to build up massive production capacity. Four years after construction initially got underway, operations have commenced at the integrated BASF/Sinopec complex in Nanjing. Based on the Ludwigshafen model, the 220 hectare site with an annual capacity of 1.7 million tons has a steam cracker, a CPP (combined cycle power plant), its own port on the Yangtze and new chemical production facilities.

The BP/Sinopec and Shell Nanhai BV/CNOOC projects are similar in scale. DB Research expects that turnover of chemical products will grow annually by 10% to € 400 billion by 2015 compared to 3.5% growth in the USA and 3% in Germany. Production capacity for ethylene alone is expected to increase by about 6 million tons in 2005 and 2006 (compared to ethylene output of 5 million tons in Germany in 2004).

### Moving from world–scale format to more modest proportions

Big is not necessarily the future in the engineering world. Dr. Stefan–Robert Deibel, President of Corporate Engineering at BASF, is one of the industry experts who are convinced that the days of classic world–scale plants are numbered. "We need a paradigm change, and we are already working on new strategies. The dilemma posed by world–scale plants is readily apparent. If you do not build a plant until there is strong market demand for a product, then you are essentially already too late. If you build a plant at the same time as the competition, excess capacity will cause prices to collapse." What this means is that the chemical industry needs engineering strategies which are able to cope with rapid changes in market demand. Modular technology and strict standardization will both have a role to play. Elements of microprocess technology will also be part of the equation, more as a philosophy than a factor which determines absolute plant size.

Dr. Aldo Belloni, who is responsible for Engineering and Gas at Linde, made another important contribution to the world–scale debate. "We are starting to reach the limits of process equipment engineering. This poses a big risk, because on nearly every mega–project, we have to design a machine that has never been built before, the world's largest air compressor or the largest expansion turbine in the world. Logistics problems are also becoming more difficult to manage. Increasingly, apparatus, columns and other plant subsystems are be-

ing welded together on site because the elements are simply too large to be transported."

**The IMPULSE program**

So what will the chemical plant of the future look like? The IMPULSE program has been working on this issue (Integrated Multiscale Process Units with Locally Structured Elements). This project, which was initiated by the EU in the 6th Framework Programme, is looking primarily at the use of microtechnology. The companies and institutes which are involved in the project are convinced that this technology can lay the foundation for a new generation of production systems in the near future.

In order to achieve its goals, IMPULSE intends to install locally structured components on production systems. These components will be integrated directly into the process equipment. The following list outlines some of the program goals:

- Convert batch processes into continuous processes
- Modular, scalable processes
- Integration of a new generation of components into existing systems
- Subsystem miniaturization to facilitate distributed production
- Individual goals include minimization of the use of solvents or even deployment of solvent–free production systems, maximization of the space–time yield, increased selectivity, reduction in the cost of product separation and improved QC measurement technology.

One of the industrial partners in the IMPULSE program, Degussa, has demonstrated how this works in practice. In an effort to substantially increase process yield, the company is using the process intensification approach to significantly improve factors like the space–time yield by several orders of magnitude rather than by mere percentage points. The improvement could be based on highly–active catalysts or special micro–reactors which provide a more intensive exchange of heat and material according to Dr. Henrik Hahn, Process Intensification House Manager.

The concrete goals are to deploy new processes and systems which are based on new technology to take advantage of lower investment costs and shorter reaction timescales. The benefit of this approach is that capacity can be ramped up to meet increased demand. Not only that, the new technology will even make it possible to develop new types of products.

The chemical plant of tomorrow as envisaged by IMPULSE will probably not only be significantly smaller than today's facilities, it will also be more efficient and have a lower impact on the environment. Plants can also be located closer to the customer, and this adds a new dimension to "demand driven production". The strategy of distributing a larger number of smaller production facilities across Europe will reduce transportation costs, and it gives producers the opportunity to react quickly to changing market conditions.

20 partners from seven European countries are members of the IMPULSE consortium. In addition to CNRS (Centre National de la Recherche Scientifique) which coordinates the project, the consortium includes a number of leading European research centers and academic institutes which work in the fields of chemical engineering, microprocess technology and process innovation. These organizations are working with four leading industrial partners: GlaxoSmithKline, the world's second largest pharmaceutical company, Degussa, the world's largest producer of special chemicals, Procter and Gamble, a leading player in the world consumer goods market and Siemens, the world leader in automation technology.

The German Education and Research Ministry (BMBF) has provided € 15 million of funding for the microprocess technology program which go underway in January 2005. The program is focused on the use of microprocess technology for industrial production. Five projects are working on industrial photochemistry, process intensification, polycondensation and the production of pharmaceutical intermediates in micro reactors. The goal of the uVT–GUIDE is to develop guidelines for the industrial use of microprocess technology.

**When the market changes course: mono production instead of multi–product plants**

Sometimes the engineering strategy simply has to change. If a plant operator wants to retain flexibility, make smaller product quantities and/or use the plant for more than one product, the tendency is to opt for a multi–product plant. Later, economic pressure can force the transition to mono production, because practical experience shows that cost performance will improve by at least 25%. The explanation is simple. Multi–product plants use a large number of small systems, which makes handling more cumbersome. Fewer tanks are needed in mono production, making it easier to automate the plant and reduce staffing levels. Larger tanks and systems automatically drive down specific energy consumption per ton. Intelligent process management and optimized kinetics increase selectivity throughout the process including preliminary stages by around 10%.

This can play out as follows in a real world application. Following the conversion on the Irgafos line from batch to continuous operation, the team which is responsible for Ciba special chemicals at the Lampertheim plant were satisfied with the results of the new process. The innovative process enabled the company to double production capacity for this important phosphite–based process stabilizer to 10,000 tons per year. The productivity and ecological efficiency of the line also improved. Following the changeover, the increased capacity was accompanied by significant reductions in energy consumption, raw material usage and residuals.

**Construction of biofuel plants is booming**

Interest in production facilities for biodiesel and bioethanol and in strategies for using biomass is not limited to the experts. The general public also shares this interest. The reason for this focused attention is simple. Fuels prices only seem to move in one direction (up), and we need to find alternative source of raw materials, at least in the medium term.

There is therefore no question that demand for biofuels will continue to increase, making this a very lucrative growth market for the plant construction industry. This market has international sponsors. Both the US and Europe offer tax incentives and define additive levels to promote biodiesel and bioethanol production. Experts predict that about 100 new facilities will be built in Europe by 2010 and around 60 in the US. The required investment will be in the neighbourhood of ? 6 billion.

Renewable raw materials will be turned into important chemical products. Basic chemicals will have to be converted into bio intermediates, for example ethanol, glycerin, hydromethylfurfural, lactic acid, propylene glycol, and other high–quality intermediates in order to be competitive with basic petrochemical products (olefines, aromatics, etc.). The production of glycerin from oil, ethanol from starch and isomaltose from saccharose is already a reality, but other products such as glycerin–based acrolein or sugar–based propylene glycol and lactic acid are still at the R&D stage.

**White biotechnology continues to grow**

To an increasing extend, biotechnology is able to offer alternatives to traditional chemical processing methods. One example is Vitamin B2. The yield of a multi–stage chemical reaction starting with D–ribose is only 60%, whereas bioproduction produces far different results: 50% cost reduction, 36% less waste and a 25% reduction in energy usage. In many cases, the conversion from a chemical process to a biotechnology process can significantly reduce resource consumption as well as the impact on the environment without the need for elaborate, costly investment.

This example shows very clearly that lower cost and improved handling are the driving forces behind conversion to bioproduction. The elimination of the conventional synthesis stages during the production of vitamins and antibiotics reduces both production costs and the environmental impact, and this enhances the acceptance level of bioproduction

The DECHEMA technology forum, which was held in the summer of 2005, confirmed that the importance of white biotechnology has indeed increased in recent years. The forum left little doubt that white biotechnology has significant potential due to its ecological benefits and its promise of better economic performance.

Experts believe that white biotechnology will become a more significant factor in the production of bulk chemicals and that we will see increasing use of bio catalysts. Bioreactors with a volume of 500 $m^3$ (and more) are used worldwide to produce bulk products including flavor enhancers, L–glutamate and the feed additive L–lysine. They are also used in the production of antibiotics, vitamins, citric acid and lactic acid.

Bioproduction places specific demands on process engineering. Special aspects of the treatment process, handling of large volumes, problems related to sterile equipment and strict safety regulations are the defining factors of a biotechnology production system, and they have to be included as an integral part of the overall process.

**Trends that suppliers need to watch**

The results of a survey conducted by the German Engineering Federation (VDMA) entitled "Trends in Process Technology 2004–2008" shed light on emerging engineering strategies. University faculty members and manufacturers were asked to give their views on process machinery and equipment.

The survey revealed that the importance of automation technology will continue to increase. Manufacturers would be well advised to be prepared to supply more machines and devices that are automation ready. The diversity of fieldbus systems which manufacturers will have to cope with is expected to increase rather than decrease in the future.

Suppliers will also have to keep a watchful eye on nanotechnology, membranes, sensors and instrumentation. Producers and university faculty members expect that the major advances in process engineering will be based on these technologies.

The handling of solids could offer an opportunity for producers of process machinery and equipment. Now that oil prices have risen, development of renewable energy sources and secondary fuels has become more attractive. Fuel cell technology undoubtedly offers significant development and market potential. Possible changes to regulatory requirements relating to noise and dust protection, chemicals and improved energy efficiency must be kept in mind during the product development phase.

The product–related ("traditional") services such as spare parts, repair, maintenance and field service will not become less important. On the contrary, teleservice appears to be a sensible way forward, and it could help producers to drive down costs.

The study also showed that machine producers have identified a lack of sensors for moisture measurement and capture of various mechanical variables (e.g. pressure and vibration) in certain applications. There is room for improvement on existing sensors to improve self–monitoring, miniaturization, ruggedness and engineering design.

**Moving towards the digital factory**

Simulation means creating a model of the production process based on fundamental physical and chemical principles. Reactions, mixing operations as well as

material transition and heat transfer phenomena in a reactor and in upstream and downstream stages have to be described using mathematical models.

Simulation continues to improve. With modern simulation software, users can enter reaction formulas directly on a GUI just as if they were writing them down on paper. The software generates the kinetic equations and balances of mass, energy and momentum. The software can also calculate the thermodynamic and transport properties of mixtures which react with each other. The results can be used in the subsequent engineering process. The time factor is crucial on every engineering project to ensure a rapid return on investment. Engineering planning across a whole range of disciplines must take place in parallel. As state–of–the–art engineering planning tools continue to evolve, they are getting nearer to the goal of encompassing the entire engineering process.

The quality of the simulation software and 3D models which are now available gives impetus to the concept of the "digital factory". The idea is to reproduce the entire production process as a three–dimensional planning model. The advantages are obvious. Engineers can use the model to try out and optimize a range of options before construction gets underway. The plant can be built much more quickly than in the past, and the product can be on the market faster, which is a significant competitive advantage. The "digital factory" is more than just a concept. It is becoming an accepted solution as a universal tool in the automotive industry, which can be used in product development, design and production. To some extent, it also has a lot to offer in other industries. Computers can often be used to identify and eliminate weakness during the planning phase. Engineers can use these tools to analyze and sometimes even speed up the process. Users working on simulators can create a digital model of systems, machines, logistic operations, production steps and process flows and then make any necessary changes.

## COMPRESSORS: CENTRIFUGAL AIR COMPRESSORS CONTINUE TO EVOLVE

Air compressors are widely used in countless industrial, petroleum–refining and petrochemical applications. In recent years, manufacturers have moved toward modularized designs, improvements in other mechanical aspects, and the addition of increasingly advanced control strategies and diagnostic capabilities. For plant operators, these improvements ensure the reliable, cost–effective availability of dry, oil–free compressed air for numerous plant and process operations.

Compressed air is an essential requirement for combustion systems, air–separation processes, pneumatic–conveying systems, plant and instrument air, and other applications in such diverse locations as chemical plants, industrial gas facilities, fertilizer plants, steel mills, mining operations, automotive, electronics–fabrication, food–and–beverage and textiles facilities, and glassmaking operations. While the basic design of the centrifugal air compressor has remained unchanged for many years, vendors of these workhorse machines are well aware of the need to continuously advance their designs, in order to keep pushing the performance envelope.

Many of these continuous–improvement efforts have been aimed at reducing capital and operating costs. For instance, in recent years, advances in everything from the mechanical design of the entire package, to the seal and bearing design, to the broader diagnostic capabilities of today's advanced control systems, have resulted in demonstrable improvements in both the mechanical and aerodynamic performance, and the electrical efficiency of centrifugal air compressors, which have improved reliability and reduced costs.

While the air compressors that are used for oil–and–gas, petroleum–refining and petrochemical applications must meet the rigorous specifications of American Petroleum Institute (API) standards, such as API 672 and API 617 and their global equivalents, such specialized compressors tend to use the same basic air end – the heart of the compressor – as today's standard industrial units. The specialization of API–certified compressors comes from the additional specifications that are related to testing and inspection, and from upgrades to the basic design, custom engineering of the skid, the use of advanced materials of construction, and the addition of different enclosures, additional instrumentation, controls and piping, proximity probes, redundant lubrication system components, and welded stainless steel connections for the oil piping.

While all of these specialized upgrades can raise the cost of an API compressor considerably, the good news for industrial operators is that many of today's regular industrial air compressors now include – as standard – many of the same performance–enhancing add–ons that were once reserved for customized or highly engineered API compressors.

For example, advanced interstage coolers with low approach temperatures are now part of many standard packages. Such high–efficiency coolers typically employ compact, highly efficient shell–and–tube coolers, high–density–plate coolers, or plate–fin coolers to remove the heat buildup that occurs between air compression stages within the centrifugal compressor.

### Modular designs reduce costs

In recent years, nearly all of the major manufacturers have begun to offer centrifugal air compressor systems that are assembled from a number of standardized, pre–engineered modules. Today's, air compressors with modular designs are available from such vendors as AG Kühnle, Kopp & Kausch's Compressor Division, Cooper Compression, Man Turbo AG, FS–Elliott Co., Dresser–Rand Co., Siemens Power Generation Industrial Applications, and General Electric. The use of pre–engineered, pre–assembled modular components greatly re-

duces the number of overall components and parts compared to conventional designs. This reduction in parts lowers capital costs and shortens assembly times, and modular designs allow all internal parts to be pre–assembled in a shop environment, under more controlled working conditions than those found in a typical plant environment.

Meanwhile, for the user, modular designs make it easier for maintenance engineers to gain ready access to work on various compressor subsystems. For instance, individual control, intercooler or lubrication modules can be accessed for maintenance or repairs without disturbing or disassembling the whole unit.

Today's modular designs also give operators unprecedented flexibility when it comes to modifying the system parameters to meet changing facility needs with minor, module–specific adjustments or replacements. For instance, if the facility's compressed–air needs change over time, due to demand for higher or lower flow, the engineer only needs to exchange one or two individual modules to up grade and adapt the existing compressor.

Siemens' large–scale axial–radial flow centrifugal compressors (STC–SR) and axial flow compressors (STC–SX), which provide flowrates from 50,000 to 1,400,000 $m^3$/h primarily for world–class air separation plants, fluid catalytic cracking (FCC) systems, blast furnaces, propane dehydrogenation, and GTL installations, have been modularized to optimize the design, process engineering and reliability while reducing costs.

Meanwhile, the Polaris centrifugal air compressors from FS–Elliott have also been modularized. In late 2005, the Polaris P–300, which has a power rating of 224–336 kW and flow capacity of 32–59 $m^3$/min inlet, at discharge pressure of 3.1–10.3 bar, was introduced. Since then, the Polaris P–400 and P–500 (the naming convention corresponds to the basic power rating of the unit) have become available, and several additional models will follow in 2006.

Dresser–Rand's Datum centrifugal air compressors, available in 14 frame sizes, are also now manufactured using standardized modular designs.

In 2005, Cooper Compression reengineered its existing centrifugal air compressor family (the Turbo–Air 2000) and introduced the Turbo Air 2020 two–stage centrifugal air compressor, giving it a completely modularized design. The TA 2020 is now constructed from six standardized modules – one each for the drive train, gearbox, inlet air filter, control system, oil system, and cooling system. The TA 2020 compressor are available with a power rating of 185–300 kW, and a flow capacity of 19–55 $m^3$/min at a discharge pressure of 3–8.6 bar).

Like so many other modularized air compressors, the Cooper Compression TA 2020 has a greatly reduced number of parts, compared to traditional designs. For instance, the water manifold now requires just 30 parts, down from 130, while the number of parts in the rotor assembly has been reduced from 54 to just 17. This greatly reduces material costs, improves assembly time, and shortens the lead time for the customer, says the company.

Meanwhile, Cooper Compression's all–new TA 9000 plant air compressor – the largest frame in the company's standard plant–air line, introduced in late 2005 – has also been modularized. The three–stage Turbo Air 9000 has a power rating of 1,120–1,680 kW, and a flow capacity from 184–334 $m^3$/min at discharge pressure of 5.5–10.3 bar.

In addition to modularization, the performance and reliability of today's centrifugal air compressors are being improved thanks to ongoing improvements in other aspects of their mechanical designs. For instance, many manufacturers have improved compressor reliability by continuously improving the rotor shaft bearings, using such designs as hydrostatic bearings, non–contact magnetic bearings, self–adjusting bearings, and double–acting thrust bearings to minimize vibration over the full range of operating load.

And every vendor takes pride in its state–of–the–art impeller designs. Most of today's impellers are made from hardened steel to withstand the corrosive and erosive effect of atmospheric contaminants and water vapor, and incorporate state–of–the–art backward–leaning design, with intricate, proprietary three–dimensional configurations – which requires complex, five–axis milling during manufacturing – for optimal aerodynamic performance.

Man Turbo recently improved the design of its RIK, RIKT and RIO centrifugal compressors, which are designed mainly for large–scale air–separation plants, by replacing the first inline impeller with an overhung open impeller with no shroud. Compared to the previous design, such an impeller has a higher specific volumetric flow (dimensionless volume coefficient) at similar or better efficiencies, says the company.

**Advanced control systems and diagnostic capabilities**

Today's manufacturers continue to add control system capabilities to improve overall air compressor control, to improve system reliability and energy efficiency in the face of varying demand, and to assist with troubleshooting, and predictive and preventive maintenance efforts.

For instance, the Regulus control system on FS–Elliott's Polaris P–300 centrifugal air compressor is a programmable logic controller (PLC) with an intuitive touch–screen interface that allows the operator to view and control all operational parameters, including system status, history, mode selection, setpoint values, system data and diagnostics and testing.

While standalone control is important, most of today's centrifugal compressors also include a serial port that allows the unit to interface seamlessly to the facility's plantwide distributed control system (DCS). This allows the user to monitor and manage all of air

compressor needs either right at the unit, or from any remote location.

The control systems that come as standard on many of today's industrial centrifugal air compressors now routinely allow for greater process monitoring and diagnostics than ever before, letting operators track, for instance, the real–time status of such critical operational factors as pressure and temperature, surge detection, aerodynamic performance, rotor and bearing vibration, shaft displacement, rotor axial position, water temperature and flow in the cooling system, lube oil supply, and even the temperature inside an enclosed room to detect any heat buildup from the motor.

**Ensuring oil–free air**

Many compressed–air applications – such as combustion, food–and–beverage, pharmaceutical, semiconductor manufacturing and medical applications, among others – cannot tolerate even trace amounts of oil contamination in the air delivery from their compressors. To meet this challenge, today's centrifugal air compressors routinely incorporate elaborate shaft–sealing designs at the impeller shafts to isolate the air compression chamber and air passages from any lubrication oil in the gear casing.

The design of Cooper Compression's TA–2020 and TA–9000 compressors also include an isolated atmospheric space that keeps the air section and the gearbox completely separated.

Meanwhile, in Atlas Copco's ZB VSD centrifugal compressor, the impeller is mounted directly onto the motor shaft. This eliminates the need for a gearbox altogether – the source of traditional oil–air contamination – making the ZB VSD "totally oil free," according to the company.

**Coping with fluctuating demand**

Producing compressed air is an inherently costly and energy–intensive operation. As a result, compressor manufacturers are always seeking ways to improve the energy efficiency of their units.

While compressed air is an essential requirement for many chemical processes, and industrial and manufacturing operations, very few facilities have a constant demand for it – instead, the need for compressed air typically varies from day to day, and sometimes from hour to hour.

The conventional approach for coping with such fluctuating demand has been to run the compressor at a constant rate, and to simply vent the unneeded compressed air to the atmosphere. But this is an inherently costly and energy–inefficient approach.

In recent years, to reduce energy consumption and match the compressor operation more effectively with the application requirements, many positive–displacement compressors (such as screw and reciprocating–piston compressors) have been equipped with variable speed drive (VSD) capabilities, to modulate the speed of the motor, or variable frequency drive (VFD) capabilities, to modulate the frequency of the incoming power. Rather than allowing the compressor to simply run idle when demand for compressed air falls, these systems use pressure sensors, frequency converters and microprocessor–based controls to continuously adjust the motor speed, allowing the compressor to provide the required air supply at the required pressure while greatly reducing the electrical demand of the overall system.

However, while the use of VSD and VFD has become commonplace for positive–displacement compressors, except for rare exceptions, such systems are not appropriate for centrifugal air compressors. Because the output of air from a centrifugal compressor is a function of the motor speed, any reduction in speed would hinder the unit's ability to deliver a given volume of air at a given discharge pressure.

Instead, to maximize energy efficiency and minimize costly air bleed in the face of variable demand, today's centrifugal air compressors tend to rely on inlet guide vanes, with or without diffusers and throttling valves, to modulate the amount of inlet air coming into the unit, and this allows such designs to meet variations in product demand more energy efficiently compared to units that rely on blow–off valves.

One exception, however, is the ZB VSD centrifugal air compressor from Atlas Copco AB (www.atlascopco.com). Designed for low–pressure compressed air applications, this compact system (weighing just 1,200 kg) does include VSD capabilities as a standard feature. To achieve larger flow volumes, multiple ZB VSD units can be connected in parallel.

The ZB VSD is also directly driven by a permanent magnet synchronous, which reduces energy losses and cooling requirements and offering higher speeds in a more compact design than conventional designs, according to the firm. Atlas Copco also offers the heavy–duty GT Series centrifugal air compressors to serve large–scale cryogenic air–separation units producing oxygen and nitrogen, and the H–Series and ZH–Series centrifugal air compressors for a variety of industrial, refining and petrochemical applications.

Several years ago, a major redesign helped AG Kuhnle, Kopp & Kausch modularized SFO and SFOG centrifugal compressors to achieve stage efficiency of greater than 90% in most applications. According to the company, this represents "best–in–class" isentropic (stage) efficiency. This efficiency, combined with the use of inlet guide vanes and inlet diffuser guide vanes, and an advanced control system, allows the SFO and SFOG compressors to accommodate turndown ratios as great as 35% without the need to bleed off unwanted compressed air. Turndown ratios of 50–70% are more typical throughout the industry. These two product lines are designed for relatively low–pressure applications, and have a power rating to 10,000 kW, producing compressed air flows of 1–150 $m^3$/sec at discharge pressures up to 3 bars.