Safe operation: Using online corrosion measurement, Elisabeth Schmitz monitors pipes in a plant for production of a chemical intermediate. X-rays (small photo) are also used to help prevent corrosion.

New technology for reliable corrosion protection

Rust is not just a matter of chance

Not only can corrosion damage have dramatic consequences for man and the environment, it can also entail considerable costs for industry. A Bayer research team has developed new methods to make inspection less expensive and improve corrosion protection for technical plants and equipment.

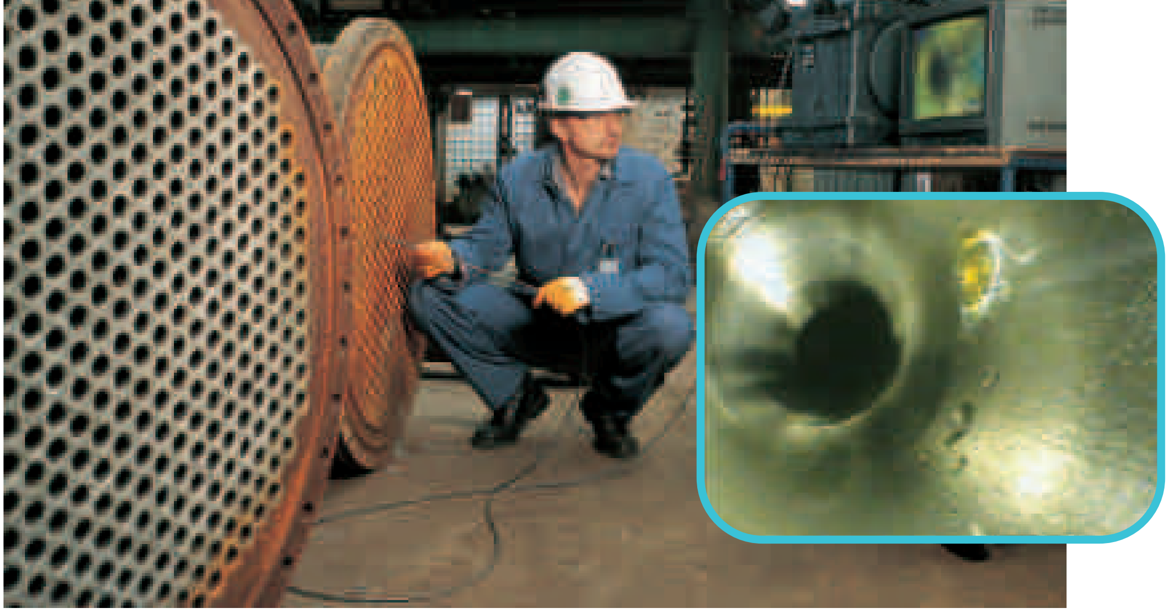
The disaster happened quietly, without warning. For years, nobody had the slightest inkling that a time-bomb was ticking away above the swimming pool in the Swiss town of Uster. Then, on the evening of May 9, 1985, the unthinkable occurred. The concrete ceiling suspended under the roof of the hall came free of its stays and crashed down onto the swimming pool. Twelve people died, 19 were injured. The reason for the accident was that a large number of the 200 or so stainless steel ceiling anchors had become corroded over a period of just 13 years and had yielded to the weight of the 800 m^2

concrete ceiling. Experts describe material-induced damage of this kind as stress corrosion cracking, and stainless steel is particularly at risk. Normally, such steel structures are covered with a wafer-thin oxide layer to protect them from further corrosion. Under certain conditions, especially in a chlorine or chloride environment, this layer can become perforated. In the warm, moist atmosphere beneath the concrete ceiling in Uster, hypochlorous acid formed on the steel anchors. Hidden from view, it nibbled away at the metal. "At the end of the day, every material has its Achilles heel," says Dr. Michael Renner. "Any material can corrode." Dr. Renner is an engineer and Head of Materials Engineering at Bayer Technology Services (BTS) in Leverkusen. He is also a proven corrosion expert who knows only too well what can make a material brittle: "The key to the whole affair is the combination of environmental conditions – for example temperature, pressure and the substances surrounding the material."
Corrosion is omnipresent and of vast economic importance. A recent study by the National Association of Corrosion Engineers (NACE) came to the conclusion that in the United States,

Biological iron corrosion

Iron should really remain corrosion-resistant for a very long time in closed, oxygen-free areas like pipelines and tanks, but there are some bacteria that have a taste for iron even under such harmless conditions. Instead of "breathing in" free oxygen from the air, these bacteria take in bound oxygen, for example from sulfate ions that occur naturally in many types of water. When they "exhale", these special bacteria release hydrogen sulfide, which is highly corrosive and can eat holes into ferrous materials.

An inside picture: Thomas Kowalski uses an endoscope to check a heat exchanger, and thus gains an insight into the pipes (small photo).



Corrosion expert: Dr. Michael Renner is Head of Materials Engineering at Bayer Technology Services.

corrosion causes economic damage every year amounting to about three percent of the gross domestic product (GDP), or around US$ 276 billion. In Germany, the renowned corrosion expert Professor Günter Schmitt, Head of the Laboratory for Anticorrosion Technology at the University of Iserlohn, puts the cost of corrosion damage every year at about four percent of GDP, which is equivalent to an annual loss of €64 billion. In addition to this, there are other high indirect costs, caused for example by environmental damage when contaminants enter the environment.

Corrosion has dramatic consequences for the environment

It's very seldom that catastrophes occur like the one in Uster. However, in industrial plants, corrosion often has considerable consequences without a major accident actually occurring. Bayer takes this subject very seriously, with anti-corrosion measures playing an important part in its safety concept. Significant economic losses can arise if a burst pipe or a leaking boiler results in a machine breakdown. In severe cases, production can come to a complete standstill.

"However, we are now able to significantly reduce corrosion damage and avoid problems in industrial plants with the aid of some quite ingenious methods," says Renner.

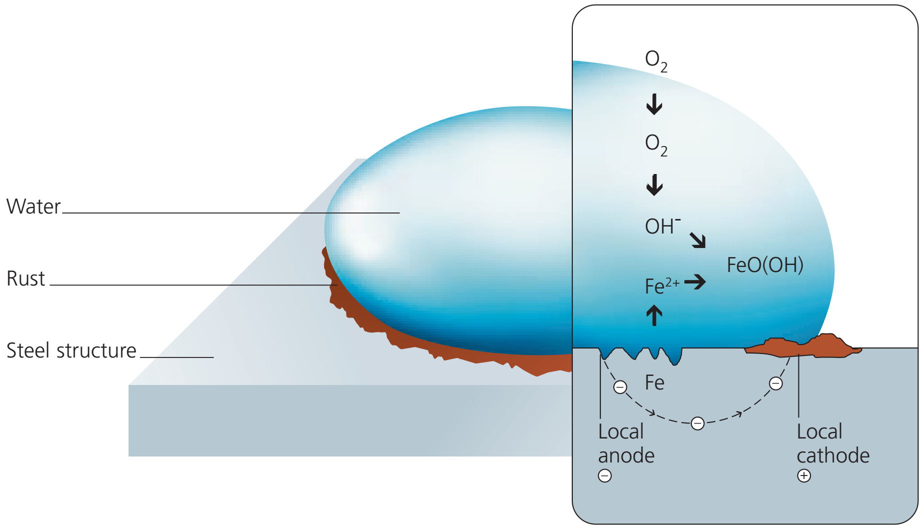
Over the last few years, BTS has come up with several such methods to ensure the stability of the relevant components. This has resulted in a unique database with thousands of corrosion parameters. The information pool contains details about the resistance of hundreds of different types of steel. How does a chemical act on different substances? At what temperature does sulfuric acid nibble at a pipeline? For decades, Bayer researchers have gathered material data and experience from chemical processes and added them to the analysis system. Other data have come from field trials and practical tests. The gigantic volume of information can be put to use with the aid of neuronal networks. "This means we are able, for example, to establish very effectively which material has the lowest tendency to corrode and is best suited for storing a particular chemical, and where necessary, we can even develop new materials," explains Renner.

However, corrosion starts causing costs even before a pipe or valve begins to leak. One fairly costly process in the fight against corrosion is what is known as "condition monitoring", which basically means carrying out an inspection of the production facilities to discover any corrosion damage before anything happens. The authorities stipulate that such inspections have to be carried out, and in many cases it means that the plants have to be switched off or tanks emptied, resulting in production coming to a tempo-

One type of rust is not the same as the next

Corrosion has many facets and causes. It occurs at all kinds of different places.

Type of corrosion	Occurs, for example,
General attack	on unprotected structural steel
Pitting	on stainless steel in contact with chloride-containing substances
Contact corrosion	on screws connected to other kinds of materials
Crevice corrosion	between the hole and the screw
Stress corrosion cracking	when electrochemical attack coincides with high mechanical stress



Rust – drop by drop
In electrochemical corrosion, the corrosion processes on the surface of the metal take place in an electrically conductive solution called the electrolyte. A thin film of moisture, a drop of water left in a gap or just hand perspiration is enough to trigger such a reaction. The atmospheric oxygen interacts with the water on the steel. At the center of the droplet, iron becomes dissolved as Fe^{2+} ions. This area now acts like a local anode. In the outer regions of the droplet, OH ions from the dissolved atmospheric oxygen react with the dissolved ferrous Fe^{2+} ions to form $Fe(OH)_2$ and in turn rust, FeO(OH). This is deposited in circular form at the edge of the droplet. Subsequently, the whole surface of the steel – starting from these points – becomes corroded.

rary standstill. To avoid this, staff in Leverkusen use new maintenance strategies, including non-destructive test methods that allow columns to be examined while still in operation, saving a considerable amount of money. The team from Bayer's Materials Engineering Department uses a mobile X-ray facility to carry out the tests. "We run over the column from top to bottom and establish the extent to which the X-ray signal becomes weaker," says Dr. Markus Finke from BTS.
Pipes and weld seams are also examined in the test laboratory using X-rays. Thanks to a new digital X-ray film, the image can be easily processed on the computer and then sent to the customer. In many cases, the effects of corrosion are measured by the erosion of the wall of the tank or pipe. Over the course of time, material becomes detached from the wall through mechanical stress due to flowing liquid or chemical reactions. Says Finke: "Using the digital X-ray picture, we can determine the wall thickness at the click of a mouse and check whether it is below a critical value."
One relatively new process is "online corrosion measurement". With the aid of sensors, it recognizes damage processes in real time before they actually become a corrosion problem.

Targeted monitoring brings higher safety and lower costs

Renner expects the Risk-Based-Inspection (RBI) system, which is basically targeted monitoring of industrial plants according to various safety aspects, to bring further optimization in the field of corrosion monitoring. Over the last five years, he has been working on RBI projects at Bayer's Baytown, Texas, site. "The most important aspects here are the probability of a defect and the consequences it could have in terms of safety and the environment." A process with highly toxic substances and highly corrosive ingredients would have maximum inspection priority. In cooperation with a software producer, a system has been developed that takes into account above all the material and corrosion aspects. In the meantime, BTS has concluded the inspection planning according to the RBI principle for several projects in the United States, and is currently involved in the E.U.'s RIMAP project, which paves the way for the introduction of Risk-Based Management processes.

www.nace.org/nace/index.asp
Website of the National Association of Corrosion Engineers (NACE).

Materials testing: Ralf Knuppertz (l.) and Friedhelm Müller prepare a pipeline for X-ray examination. The photos help to locate corrosion damage (small photo).