

## A sharp profile

Optical determination of temperature gradients within the smallest space enables optimized reaction

Inline measurements of temperature profiles in spatially confined applications place special demands on the measurement technology. This especially applies for determination of the temperature changes in tube and tube bundle reactors. An innovative measuring system for fiber-optic temperature measurement has been developed for this purpose. It allows a greater number of measuring points while simultaneously reducing the protective tube in the reactor. This system has been successfully implemented in an application at Evonik in Marl, Germany.

Reliable determination of the temperature profile within the catalyst filling has far-reaching significance for the catalytic conversion of gases and liquids in tube / tube bundle reactors. They significantly influence the course of the reaction, the quality of the material conversion as well as the aging of the catalyst. The identification of hotspots – areas with excessive temperatures that can occur in the filling – plays an important role.

Matthias Hüning of Evonik Industries in Marl, Germany, specialist in electrical measurement and control technology in the High Performance Polymers business sector, describes the problem in his plant as follows. "We use tube bundle reactors in our production plant for Lauro lactam, a starting material for Vestamid® L. The challenge is to install a sufficient number of temperature measurement points in a small space within a single tube reactor in order to quickly detect high temperatures and undertake countermeasures. In this way, we can prevent destruction or the accelerated aging of the catalyst due to overheating. This avoids a plant shutdown, which would otherwise be required due to the complicated procedure for replacing a catalyst."

Due to the small diameter of the reactor tubes, the necessary number of measurement points and the demands on the speed of data acquisition, it was not possible to use a conventional measuring system (RTDs or thermocouples). Together with Siemens, Evonik therefore employed fiber-optic temperature sensing based on Fiber Bragg Grating technology.



The multipoint measurement system SITRANS TO500 transmits temperatures and temperature profiles reliably and fast. By indicating the spatial temperature distribution, the system improves visibility into operating conditions to optimize quality, yield and life cycle.

## Fundamentals of optical temperature detection

Fiber Bragg Gratings (FBG) are optical periodic structures inscribed in optical fibers. Since a particular wavelength of incident light is reflected while all others are passed, each grating acts as a narrow-band filter. Fiber Bragg Gratings (FBG) are optical periodic structures inscribed in optical fibers. Since a particular wavelength of incident light is reflected while all others are passed, each grating acts as a narrow-band filter.

If a light beam with a broad spectrum is sent through an FBG, the reflections of each section of the changing refractive index only affect a specific wavelength of light to any substantial degree. This is called Bragg wavelength and calculated by formula1:

$$\lambda_b = 2n\Lambda$$

Whereby  $\lambda_b$  = Bragg wavelength

$n$  = Effective refractive index of the fiber core

$\Lambda$  = Distance between the gratings, also referred to as the grating period

The Bragg wavelength depends on the distance of the reflectors within the grating ( $\Lambda$ ). Multiple gratings may therefore be placed on a fiber. Changes in length of the fiber by force or heat deform the grating and result in a shift of the reflected wavelength. This is mainly due to change to the refractive index of the quartz glass by the thermo-optic effect [2], [3], [4].

$$\frac{\Delta\lambda}{\lambda_0} = (1 - p_e) * \epsilon + (\alpha_\lambda + \alpha_n) * \Delta T$$

$\Delta\lambda$  here represents the change of the wavelength and  $\lambda_0$  the original incident wavelength. The first part of the expression describes the effect of strain on the change in wavelength, which is demonstrated with  $p_e$  for the photoelastic coefficient and  $\epsilon$  for the strain on the grating. The second part takes into account the effect of temperature on the change of the wavelength, which is represented with  $\alpha_\lambda$  for the coefficient of thermal expansion and  $\alpha_n$  for the thermo-optic coefficient, i.e. the temperature dependence of the refractive index [3].

### Effect of strain and temperature

As formula 2 shows, both temperature and strain cause a change in the wavelength. To eliminate the influence of the strain, the FBG may not be subjected to mechanical stress when used as a temperature sensor. Siemens uses the characteristic of the wavelength change as a function of temperature in its measurement system, SITRANS TO500. The system consists of a transmitter to which up to four fiber optic measuring probes with up to 48 FBG can be connected. This makes it possible to synchronously measure the temperature at up to 192 locations per measuring system. In the present application, FBGs are inscribed every 20 cm. Siemens offers its customers measuring probes precisely tailored to the application in regard to length, number of sensors and the sensor positions.



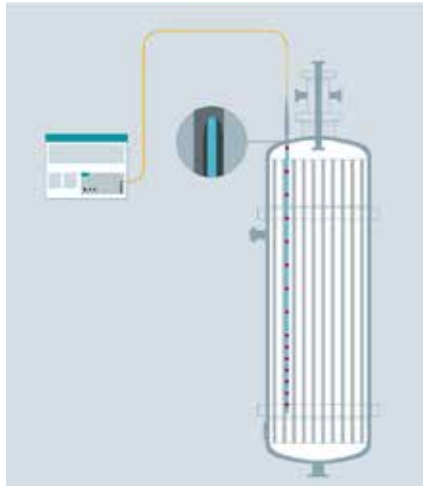
Matthias Hüning of Evonik Industries in Marl, Germany, specialist in electrical measurement and control technology in the High Performance Polymers business sector.

### Detailed profile provides knowledge

In this application, each measuring probe with a diameter of approximately 1 mm records temperatures in a measurement range of 32 °F to 752F (0 °C to 400 °C) with a measuring error of < 0.5 K. It is also characterized by a very fast response time; the T90 time is under four seconds [6].

Due to the measured value transmission (reflection of light), which takes place in the same fiber, no additional cables are necessary. This means the required diameter of the protective tubes for the measurement setup is substantially reduced. On the one hand, a larger cross-section and hence volume is available for the reaction in the reactor, which has a positive effect on the throughput. On the other hand, the response times of the sensors are reduced because the damping effect of the air gap between the fiber with its inscribed gratings and the tube walls is kept low.

"Our plant personnel can detect the development of hotspots or the effectiveness of the catalyst in good time with the detailed recording and visualization of the complete temperature profile in the reactor," Matthias Hüning continues. "We use this information to initiate measures to reduce the temperature, for example, in the first scenario. In the second scenario, we can perform maintenance procedures, such as replacing the catalyst when necessary due to its age." Both applications extend the life of the catalyst in the reactor, which means cost-effective, preventative maintenance procedures are performed based on need.



Schematic diagram of the tube bundle reactor with SITRANS TO500 and built-in measuring probe.

### Advantages for installation and maintenance

The applications of contactless measuring procedures with fiber-optic sensors are becoming increasingly common in the chemical industry. The sensors are not sensitive to electromagnetic interference and are also chemically resistant. Another advantage is the possibility to couple the optical signals. Joachim Kölsch, product manager at Siemens Process Industries and Drives, explains this. "For the installation at Evonik we use a glass fiber coupler to connect the sensing fiber in the reactor and the transmission line to the transmitter. This coupler can simply be disconnected for maintenance purposes, for example, when the reactor cover needs to be opened. The measuring probe can be easily pulled out before revision of the reactor or before replacing the catalyst and rolled onto a spindle. The latter also enables it to be easily and safely transported."

The SITRANS TO500 transmitter provides the determined values for analysis in control systems via a Profibus DP interface and make them available for management of the assets and optimization of the process.

Precise and rapid detection of temperature profiles for gas phase reactions in fixed bed reactors, for example, effectively helps to detect the thermal load of the catalyst filling and maintain efficiency by introducing countermeasures. With the innovative implementation of optical measured value acquisition using Bragg gratings along fiber-optic media, Siemens provides its customers with an elegant way to simultaneously record and process a wide range of temperatures for monitoring and optimization measures. Customers can efficiently detect faults and optimize the reaction processes, thereby achieving higher product throughput in the plant. Evonik has now implemented the application described in the first production plant after a thorough testing phase.



Matthias Hüning talking with the Siemens Product Manager Joachim Kölsch, who is working in the field of the temperature measurement.

## References:

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Grundlagen der optischen Sensormessung mit Faser-Bragg-Gittern (Fundamentals of optical sensor measurement with Fiber Bragg Gratings)

[4] Optical fiber temperature measurement  
German Patent DE102014018825

[5] Fundamentals of Fiber Bragg Grating (FBG) Optical Sensing  
<http://www.ni.com/white-paper/11821/en/>

[6] Optical Fiber Temperature Measurement for Process Industry S. von Dosky, W. Ens, H. Grieb, M. Hilsendegen, H. Schorb - Siemens AG, Karlsruhe AMA Conferences 2013

The tube bundle reactor is a reactor type in which the reactions are performed in the gas phase. In this case, the gas mixture in tubes, around which a coolant flows, is converted using a catalyst. The typical assembly consists of a coolant tank holding 1,000 to 30,000 catalyst filled tubes, depending on the design, with a diameter of 2 cm to 5 cm and a length of 1 to 5 m. To ensure uniform distribution of heat, the coolant is constantly circulated and can consist of thermal oils, molten salt or water.

Source: Wikipedia

Evonik uses the name Vestamid® to summarize a group of high-quality polyamides including polyamide 12, 612, 610, 1010, polyamide 12 elastomers, polyphthalamide and bio-based polyamides.

Due to their mechanical properties, chemical resistance and the high melting point of the final products, Polyamide 12 powders are particularly useful in powder-based 3D printing processes such as selective laser sintering (SLS) and the high-speed sintering (HSS). Fiber composites represent another area of growth, since polyamide 12 fine powder is suitable as a matrix of thermoplastic composites made of glass, carbon, aramid or steel fibers. Applications can be found, for example, in the automotive and oil industries, the sports sector and orthopedics.

Source: Evonik - [www.vestamid.com/product/vestamid/de/produkte-dienstleistungen/](http://www.vestamid.com/product/vestamid/de/produkte-dienstleistungen/)

and <https://www.kunststoffe.de/news/unternehmen/artikel/evonik-baut-produktionsstrasse-fuer-polyamid-12-pulver-1315358.html>



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