Tinting – from gut feeling to process control

A software-based approach to improve process control in a tinting lab

Automation and digitalization are omnipresent. Their benefits on the shop floor in terms of costs, quality and throughput are well acknowledged. Now there exists a promising approach to introduce a new level of control and predictability to the process of tinting plastic ophthalmic lenses. A software may soon supply the missing quantitative link between the in-process parameters and the outcome, i.e. the color of the tinted glass. *By Peter Weber*

For this approach, Dr. Klaus Dahmen has merged his years of experience in ophthalmic's R&D with his background in surface physics to set up a new model of diffusion processes in ophthalmic lenses. In close cooperation with tec5, manufacturer of the well-established TFM spectrometer, he now presents a software, that directly communicates with the TFM. It yields a new intuitive representation of the pigments' effect in the lens and the results of the tinting process.

Finally, it links spectra (= colors) to process parameters (= recipes) and vice versa. That opens completely new opportunities to make the output of the tinting labs more predictable. In parallel this will stimulate equipment suppliers to keep up with the emerging opportunities of automation and provide a new generation of tinting hardware.

Recent developments on the shop floor are governed by automation and digitalization. While the second half of the last century saw the rise of information technology, nowadays we are still far from tapping its full potential. Algorithms, machine learning and artificial intelligence provide great opportunities to better control our production processes and subsequently improve quality, increase throughput and reduce costs. However, progress can only be achieved step by step. Implementation within existing processes needs the courage to invest in new ideas.

Beacon of automation – surfacing

Prime example in ophthalmic industries for a consistent implementation of new concepts is the lens surfacing process. Within the last ten years automation and in-process data acquisition were implemented on many shop floors. Other parts of the ophthalmic process chain lag behind.
Implementation of the coaters into a fully automated process chain is an unsolved task. And, most remarkable, the whole tinting procedure of prescription lenses is still a fully manual procedure with only a minimum of automation, data acquisition and systematic process control.

Mostly manual – tinting

One must pay maximum tribute to the operators in the tinting labs. With years of experience, combined with a perfect gut feeling and a lot of patience they manage to create impressive outputs during tinting season year by year.
But the other side of the coin: each tinting season is an ordeal, a test to the nerves of operators, process engineers and management. With only a minimum of process control, setbacks in terms of output are more the rule than the exception. Keeping up with delivery schedules puts an enormous amount of stress onto the operators. And whenever setbacks cannot be absorbed, unsatisfied customers are the result.
Uncontrolled rework loops create an equally uncontrolled rise of effort and costs. And eventually the planning of manpower in a tinting lab comes close to squaring the circle. Training new operators may take months, and only operators with years of experience and frequent practice can manage the job to its full extent. This severely conflicts with the highly volatile demand for sunglasses over the year, which requires quick and flexible allocation of personnel.
With a small portfolio of just a few standard colors, a tinting lab may be well manageable in the “classic” way. But if you wish to exploit the opportunities of the sunglasses’ market to its full extend, you need to quickly adapt to fashion and offer a wide range of colors to be in vogue.

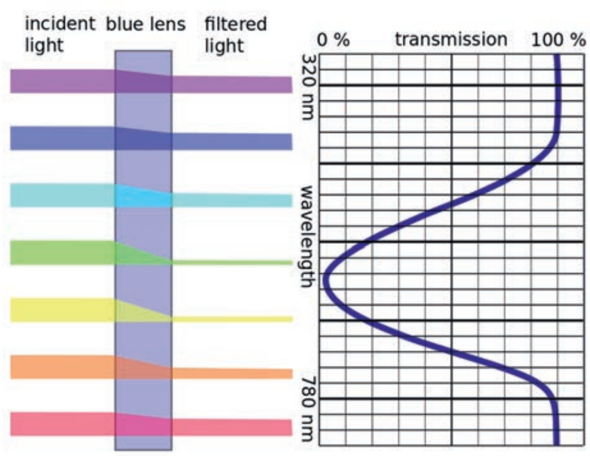
TFM spectrometer

Make tinting predictable

The potential for improvement in terms of stable, reliable, and predictable tinting processes was well known to Dr. Klaus Dahmen, when in mid-2020 he established his own business in the Rhine-Main area (Germany). Based on his years of R&D experience with a global player in ophthalmic industries, he committed himself to the vision of a software, that would establish a sound basis for well-controlled processes in any tinting lab.
To accomplish that the gap between process result (i.e. the tinted glass) and process parameters (e.g. pigment concentration, temperature, time) had to be closed. After half a year of theoretical work and programming, and reality-checks with hard-ware expert Jürgen Krall (IPS), in January 2021 the software was ready to be calibrated on practical tests.
The approach is based on the characterization of glasses by their transmission spectrum. It embraces the TFM, the ophthalmic standard spectrometer of metrology specialist tec5. Since September Dahmen and tec5 are closely cooperating in aligning interfaces. Shortly the software will be available with direct access to the TFM and respective data.

Merging process and metrology

At tec5 Dahmen’s activities were received very positive. Steffen Piecha, head of Sales, was involved in the TFM’s development (with Rodenstock) from the very beginning. As tec5 is specialized on process analysis by means of optical methods, in his eyes Dahmen provides the crucial missing link to process control, while up to now the TFM was mainly used to ensure compliance with legal regulations or to do sample quality control.
Nikolaus Petzold, Managing Director of tec5, points out that the TFM is a very alive product, getting regular overhauls of the hardware and continuous updates of the software. And thus, the additional customer value of the TFM by means of the new software fits perfectly well into the product strategy. The benefit



Visualization of the effect of tinted glasses on sunlight. Source: K. Dahmen of the cooperation is mutual, as the TFM is one of the few spectrometers, which measure valid spectra independent of the lens' refractive power.

About colors and wavelengths

Light is an electromagnetic wave and can be characterized by its wavelength. Our eye is, technically spoken, a sensor for light. And the color we see depends on the wavelength of the light. The detection limits of this bio-sensor, called eye, define the visible range of light, reaching from roughly 380 nm to 780 nm wavelength.

In theory each wavelength is related to a certain color. For example, light of a wavelength of 520 nm would be seen as green by the eye. In nature no single-wavelength light exists, all light is a mixture of wavelengths.

Most prominent example is the sunlight. It consists of all colors of the rainbow, each contributing with a different amount. Our eyes recognize this mixture as white light. If you measure the amount (intensity), by which each color (i.e. each wavelength) contributes, you determine the spectrum, in this case, of sunlight.

If you manage to remove a particular range of colors out of the sunlight's spectrum, the remaining light appears colored. This is what you actually do with sunglasses.

Tinting – a highly complex process

The tinting process is generally based on tree pigments: red, yellow, and blue. The concept is to disperse a certain amount of each pigment in water, put the glasses into the water, and let the pigments diffuse into the surface of the glass. Higher concentration of pigment in the water means higher amount in the glass afterwards. Within the glass certain pigments then absorb certain parts of the sunlight, the amount of each pigment in the glass finally determining its overall color.

As simple as the basic concept may sound, as complex the implementation may become. The pigments are large molecules thus one needs to accelerate the diffusion process into the glass by increasing the temperature of the bath. One may also add chemicals to the water to enhance the diffusion process. Already now you see quite a bunch of process parameters, that finally influence the result, i.e. the color of the lens.

Next, different speeds of diffusion within the lens for different pigments need to be considered. And the fact that diffusion is bidirectional comes into play, meaning that depending on the conditions, pigments may also diffuse back out of the lens into the water. To add further complexity, each different refractive-index of a lens has its own diffusion parameters. Even different suppliers or different batches may make a difference.

For the final impression of the lenses' color, the depth distribution of the pigments is not of much importance. Only the overall quantity counts for that. But to predict process parameters and the outcome of a certain process chain in terms of color, the depth distribution actually is very important, particularly when talking about rework steps or mixing of light colors on the lens in different baths.

With years of experience operators in a tinting lab get to know their tinting parameters by heart. But nevertheless, for the before-mentioned reasons an industrial process needs a certain level of systematic backup. Dahmen is convinced that his new software approach will not make the experienced operator obsolete but will support him. It will increase and stabilize the output in terms of quality and quantity. Positive side effect: this will improve the working conditions in the tinting lab by reducing stress and taking off unreasonable responsibilities from the shoulders of operators.

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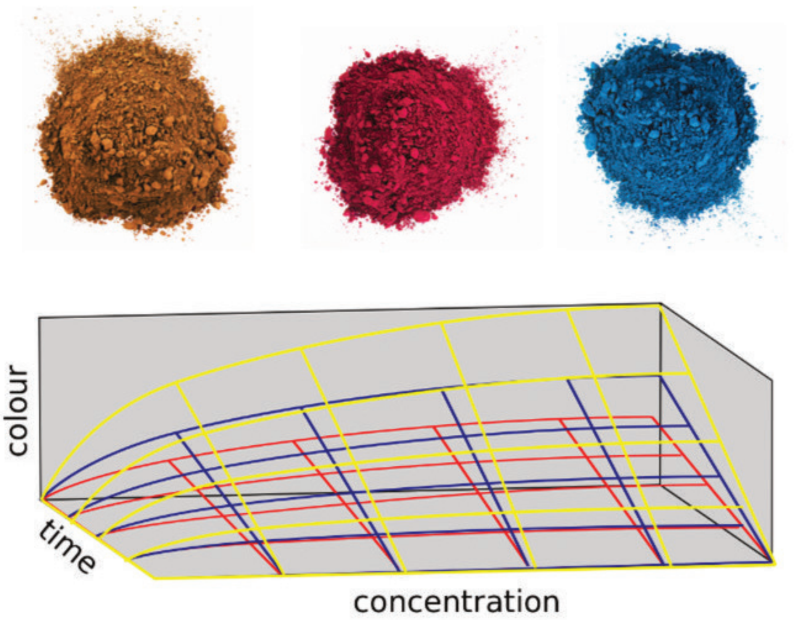
The software

As Dahmen illustrates, the basic scope of the new software is to link process parameters to the spectra of tinted lenses and vice versa. As tinting is based on a dynamic diffusion process, his simulations do not only predict the amount of the three different pigments in the lens. One step further, he integrated a model of the time-dependent diffusion process within the lens to heed the distribution in depth.

The whole simulation finally consists of three sub-models: one sub-model describes the state of the bath and the respective diffusion process into the lens surface. The second sub-model describes the diffusion process of the pigments within the lens. And finally, the third sub-model describes the resulting absorption spectrum in dependence of the before-mentioned pigments' distribution in the lens.

One basic paradigm shift in Dahmen's approach is to leave the established path of the 3-dimensional CIE- L*, a*, b* representation, as found in the DIN ISO Norm. As he states, for certain



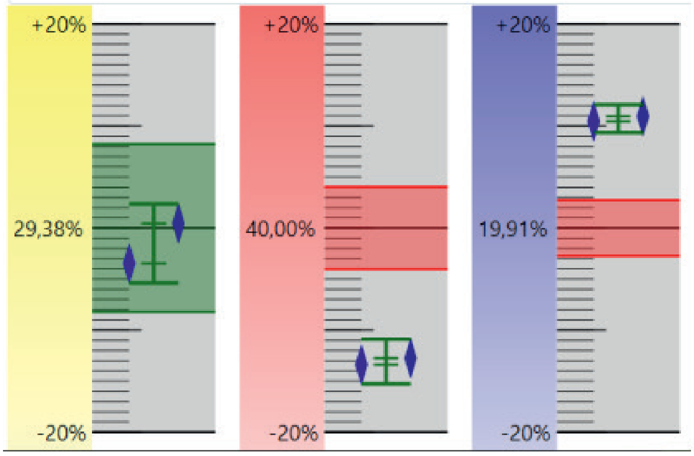
The software calculates color contributions for given tinting times and pigment concentrations to predict the outcome of the process. Source: K. Dahmen

topics the color space is an important model, but it is by far too abstract, to deduce parameters for the shop floor. Instead, he chose a completely new way of describing the "coloring power" of the pigments in a glass in terms of a relative number in percent for each of the three colors.
Baseline for these relative values is a set of reference-tinted lenses, where each of the three pigments is applied separately under given standard conditions. These relative values then completely characterize a lens in terms of color with respect to the used set of pigments. Core feature of the software is to calculate these three relative values (for red, yellow, and blue) from a given spectrum or vice versa. Then, with the tree relative values for a spectrum being known, the software can deduce the necessary process parameters, to reproduce exactly this spectrum.

Benefits

According to Dahmen the software will support and considerably accelerate development of new processes by automatically suggesting recipes for given colors (i.e. spectra). Additionally, the software will be able to reconstruct the necessary tinting process for existing lenses, e.g. for old reference samples.
Furthermore, the software can be used for quality control: continuous sample measurements can be evaluated, and statistical envelopes can be generated in the spectrum graphs to represent a wavelength-dependent spread of the process. This leads to production cards which will indicate upcoming instabilities of the process.
The software can even quantify the respective amounts of pigments within a measured sample and track them in the same way. In case of color deviations, the software will make suggestions on how to adjust the process to bring it back into specification (i.e. adjustment of pigment concentration, temperature, tinting time).
Another prominent application could be the scenario of switching to another supplier of pigments. Based on sample measurements with the new set of pigments the software could calculate new recipes for the future set of pigments from the old recipes.

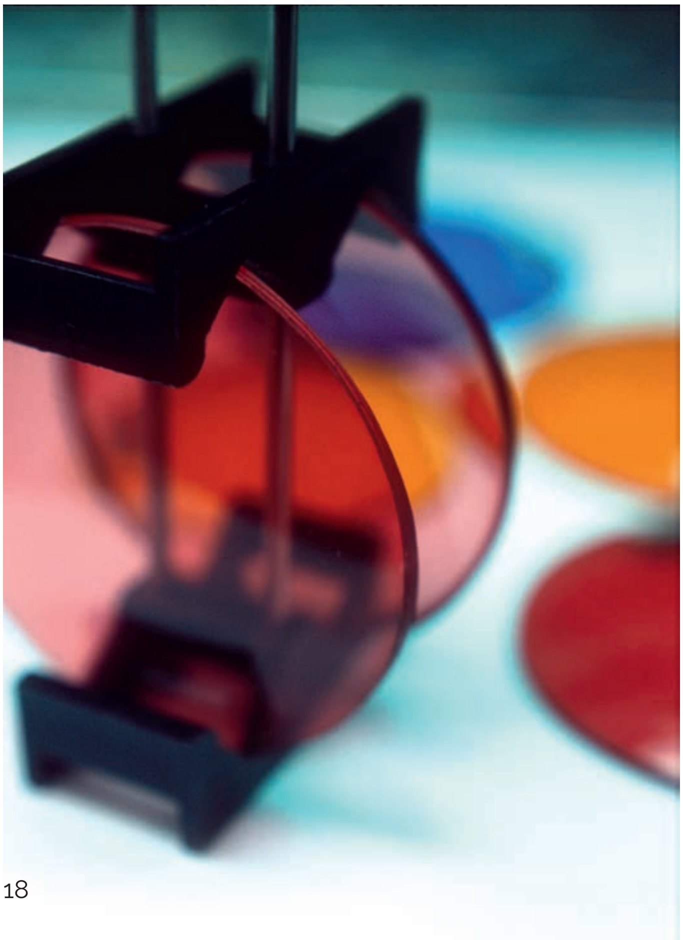
Or another application of the software: it is well known that the suppliers of pigments suffer from certain batch-to-batch variations. It may be possible to qualify a new batch by tinting standard samples and evaluating the results in comparison to earlier batches.
It may even be possible to automatically create suggestions, how to compensate these variations in the process. The systematics of the software may also give the means to align different production sites and make sure that the same sunglasses from different sites actually look the same.
Last but not least, the software will provide support for teaching new operators and will assist experienced operators by comparison of target to actual parameters of the tinted lenses in an intuitive graphical representation.



Intuitive visualization of measurement results for the operators: relative contribution of each pigment and its respective specifications for each of the two lenses. Deviations between the two lenses are depicted as well. Source: K. Dahmen

Status and outlook

Just recently, as Dahmen reports, compatibility testing and validation with the TFM spectrometer was finished successfully in cooperation with tec5. The user can now take control of the TFM, carry out measurements directly out of the software and get full access to recent measurement results and data. This means, that as of now the software with the above-mentioned features is available and utilizable for any owner of a TFM spectrometer.
At the bottom line this is a very promising approach to introduce a new level of process control in the tinting labs. Key innovation is the establishment of a link between measured outcomes of tinting, i.e. spectra of the lenses, and the initial process parameters, which actually determine this outcome.
The software has high potential to reduce efforts in the development of new recipes, to reduce rework, and, on the whole, to stabilize the processes in terms of cost, quality and output. As Dahmen points out, it will not provide 100% automation of the tinting processes but give support to developers and operators by supplying them with measurable, quantified data, that were never available up to now.
Of course, this new approach also opens new opportunities for the manufacturing equipment. Making process results measurable and feeding them back into control parameters will demand for a next generation of hardware with enhanced in-process data acquisition as well as improved means to control the process. ◆



Interview Partners

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2. Nikolaus Petzold, Managing Director, tec5 AG: years of experience as head of sales in the sensor business with strong scientific background in optical metrology. www.tec5.com
3. Steffen Piecha, Head of Sales, tec5 AG: 20 years of experience with tec5. www.tec5.com

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