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**TECHNICAL NOTE**

**Validation of inline  
photometers for improved  
measurement confidence**

Kemtrak manufactures a range of industrial photometric analyzers  
for real-time concentration, color & turbidity control.

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# VALIDATION OF INLINE PHOTOMETERS FOR IMPROVED MEASUREMENT CONFIDENCE

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## KEYWORDS

Photometer, Spectrophotometer, Absorbance, Neutral Density, Optical Filter, Reference Material, Spectrophotometry, Traceability, NIST

## ABSTRACT

One of the primary concerns when using an inline process analyzer for real-time liquid or gas analysis is validating that the instrument is working to specification. Process photometers are often calibrated using liquid or gas calibration standards or using process data from the laboratory. These calibration methods can require considerable resources, so the preferred maintenance approach is to regularly validate performance, as opposed to full recalibration of the instrument. The most typical validation method is verification of instantaneous reported instrument reading against process sample measured offline. This method is limited to only one sample concentration at a time and may not provide a true indication of how the instrument will perform under changing process conditions. This paper will discuss the pros and cons of various photometer validation and verification methods and the impact photometer instrument design has on these methods.

## INTRODUCTION

A photometer is an optical instrument designed to measure the absorption of light at a given wavelength after it passes through a fixed distance of sample. Different chemicals absorb light at different wavelengths, and through the application of Beer's law, the concentration of a chemical in solution can be accurately determined. Photometers are highly applicable to a wide range of applications in process analytical chemistry.

Filter photometers are instruments designed to operate at one or more fixed wavelengths *e.g.* 280, 300, 330, 400 nm, while spectrophotometers allow monitoring of a range of wavelengths within the specifications of the instrument *e.g.* 400 – 800 nm.

Spectrophotometers are commonly used in chemical laboratories as they provide flexibility when working with a wide range of different samples. They are, however, precision instruments designed to be manually configured and operated by a trained technician in the relative comfort of a laboratory. Spectrophotometers measure individual samples that are prepared and typically placed in a standard size 12.5 mm square glass cuvette before being inserted into the measurement path of the instrument. Laboratory spectrophotometers are, in nearly all cases, operated with an offline sample based measurement methodology. Feedback from measurements taken cannot be considered real-time.

Filter photometers are commonly used as an online, real-time process instrument to continuously monitor a fixed process stream as part of an overall plant control system. The expectation is that they will operate unattended over long periods of time without operator intervention or the need for maintenance and servicing. Process photometers use specialized industrial in-line measurement cells or immersion probes which are designed to withstand harsh process conditions *e.g.* extreme pressures and temperatures, hazardous/explosive and radioactive environments.

The expectation of a filter photometer in a process, is that it will reproduce measurements made on the same process samples using a laboratory spectrophotometer, however continuously and in real time.

### PHOTOMETER DESIGN

A photometer requires a light source to generate light that is introduced to one side of a fixed path length occupied completely by the sample to be measured. The light passes through the sample where some is absorbed at the measuring wavelength. The remaining light emerges at the opposite side where it is converted to an electrical signal using a suitable photodetector. In order to obtain a signal that is proportional to concentration, the light reaching the photodetector must be monochromatic (single wavelength), and Beer's law is applied as follows:

$$A = \log \frac{I_0}{I} = \epsilon l c \quad (1)$$

where:

- $A$  = Absorbance (AU)
- $I$  = Photodiode signal with sample
- $I_0$  = Photodiode signal with no sample (zero)
- $\epsilon$  = Molar absorption coefficient ( $L \cdot mol^{-1} \cdot cm^{-1}$ )
- $l$  = Optical path length (cm)
- $c$  = Concentration of absorbing substance (mol)

Process photometers are typically used to measure the concentration of one component in a sample stream. The molar absorption coefficient ( $\epsilon$ ) and the optical path length ( $l$ ) are therefore constant and Beer's law can be simplified as follows:

$$c = a \cdot A \quad (2)$$

where:

- $a$  = Constant consisting of  $\epsilon$  and  $l$

Laboratory spectrophotometers almost exclusively use broad band light sources such as halogen for visible (VIS, 400 – 700 nm) and near-infrared (NIR, 700 – 2000 nm) and deuterium for ultra violet (UV, 200 – 400 nm). Monochromatic light is obtained by splitting the broad spectrum light into a spectrum using a diffraction grating or prism and using either a single photodetector with mechanically moving grating or prism, or on more modern instruments, a diode array detector (hundreds of photodetectors arranged side by side on a monolithic component). *Figure 1* simplifies and contrasts the optical bench arrangement of these two methods. Single photodetector spectrophotometers are more sensitive than diode array spectrophotometers and have a photometric range >4 AU. However, they are slow in operation as they contain moving mechanical components. A diode array spectrophotometer has no moving parts and takes an instantaneous spectrum snapshot however due to detector "pixel" size and light leakage issues, range is typically limited to approximately 2 AU.

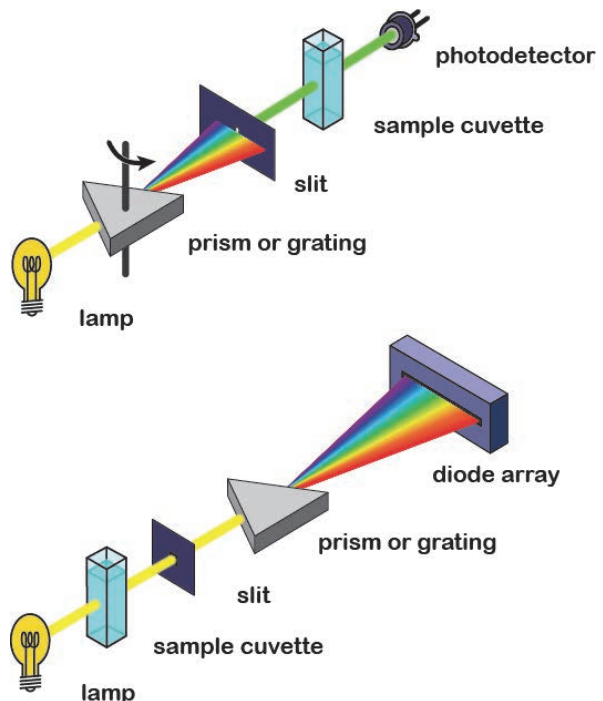
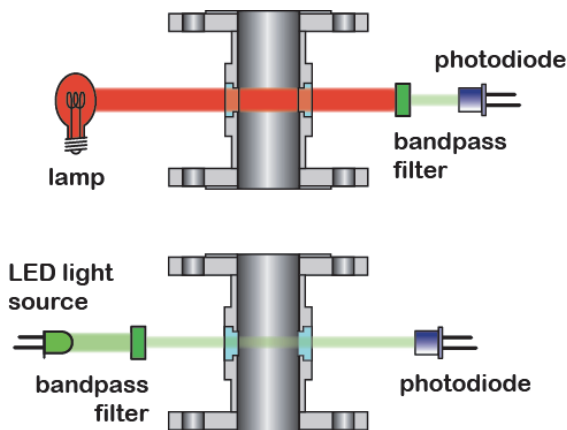


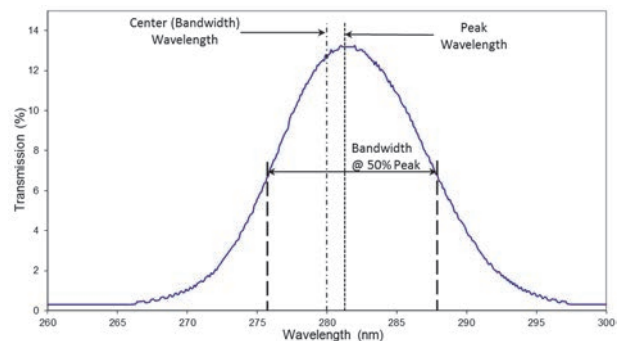
Figure 1) Simplified optical path arrangements  
 Top: Mechanical spectrophotometer/variable wavelength photometer  
 Bottom: Diode array spectrophotometer.

Traditional process filter photometers use narrow bandpass optical filters in conjunction with broad spectrum incandescent, halogen (VIS, NIR) and mercury vapor (UV) light sources to generate a facsimile of monochromatic light. Modern filter photometer designs utilize high performance specific peak wavelength light emitting diodes (LEDs) instead of broadband light sources. *Figure 2* illustrates traditional and modern filter photometer optical bench designs; the top figure depicts a traditional process photometer where broad spectrum light is passed through the sample followed by an optical bandpass filter to obtain monochromatic light at the detector; the bottom figure depicts a modern design where the optical filter is placed before the sample with a specific wavelength LED light source. The primary difference in the two arrangements is the positioning of the optical filter; in traditional designs, the light source is hot and a filter in close proximity to it is subject to potential damage over a relatively short period of time whereas in the modern design the LED source is cold and non-damaging. A further advantage of the modern design is that the process itself is no longer exposed to broadband light outside of the wavelength of interest that can be potentially damaging to the process medium. This is particularly true for applications such as protein detection in bioprocessing that utilize UV light for the measurement.



*Figure 2) Top: Traditional lamp type industrial photometer  
Bottom: Modern low power LED type industrial photometer*

A problem with process filter photometers is the issue of stray light. It is the effects of stray light that often lead to dissatisfaction with photometer performance when deployed in a process environment. Narrow bandpass filters are constructed to allow light to pass through a very small region, typically 10 nm wide, around a specific peak wavelength (the wavelength of interest), while blocking light from passing at all other wavelengths. Typical narrow bandpass filters block light outside the wavelength of interest to approximately 3 AU (0.1% of the total transmitted light) outside of the pass band. Light below this level passes through the filter and, unless absorbed by the process, will reach the photometer photodiode and be included in the measurement result. A typical narrow band pass filter specification is shown in *Figure 3*.



**Example Narrow Band Pass Filter Specification**  
Peak Transmission: 280nm +/-2nm, >13% transmission  
Center (Bandwidth) Wavelength: to be at peak transmission +/- 2nm  
Bandwidth: 10nm +/-2nm at 50% of peak  
Blocking: 5 OD average, >3OD from peak transmission, at 300nm point

*Figure 3) Example of narrow band pass filter specification*

Process filter photometers that utilize LED light sources combined with narrow bandpass filters operate with virtually no stray light outside of the pass band region around the wavelength of interest. Due to this, LED light source photometers adhere closely to Beer's law and providing a linear response to changing absorbance across their operating range. This means that any engineering unit can be correlated to absorbance, while leaving a possibility for confident validation of the instruments performance.

Where broad spectrum light sources are used, the amount of stray light passing through a narrow band pass filter can be significant and will affect the linearity of the instruments measurement response to concentration change. *Figure 4* shows the effect of stray light from a broad spectrum light source on photometer performance at higher absorption values. While engineering units can be correlated to instrument response, validating the measurement once in field can be quite complicated.

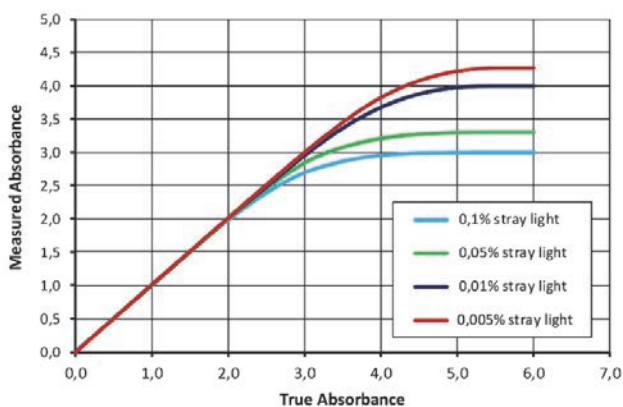


Figure 4) Influence of stray light on absorbance linearity

In general terms, LED filter photometers with low stray light characteristics will operate linearly under high absorbance conditions, perhaps as high as 5 AU while traditional filter photometers with broad band light sources will exhibit increasing non-linearity with increasing absorbance and have a reduced measurement range upon “flat-lining”. The overall range of measurement of a traditional photometer will depend upon the quality/depth of the narrow band pass filter blocking.

*Figure 5* highlights the significant difference between a typical broad spectrum phosphor coated mercury vapor lamp and a narrow band LED light source. As can be seen, the mercury vapor lamp emits multiple light peaks that can be a source of stray light in a photometer.

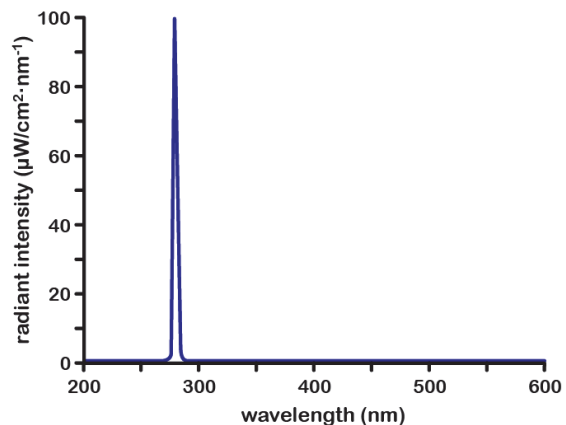
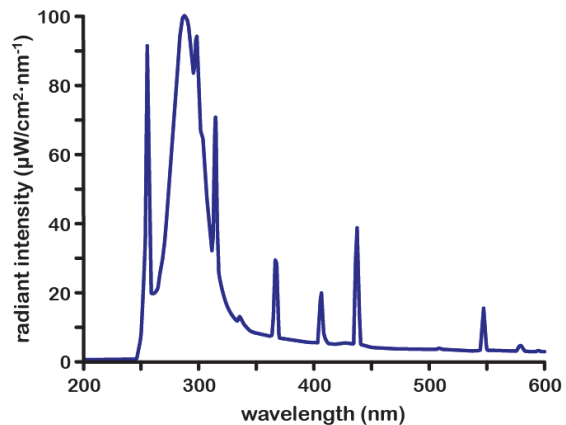


Figure 5) Top: Phosphor coated mercury vapor lamp;  
Bottom: 280nm LED light source.

In the field, a process photometer is commonly calibrated directly towards a sample or reference color standard using a fixed wavelength and optical path length (OPL) in the desired concentration or engineering unit of the calibration sample (*e.g. ppm, g/L, Saybolt color units*).

The selection of measurement wavelength and OPL depends upon the substance being measured and the desired concentration range of the measurement. Concentrated samples are normally diluted in a laboratory to ensure absorption is within the operating performance of the instrument, when a 1 cm OPL cuvette is typically used (although longer and shorter OPL cuvettes are available from some manufacturers). Sample dilution is not possible on process photometers analyzing the sample in-line, however for such cases, industrial measurement cells with a longer or shorter OPL can be used. Further strategies of selecting an “off-peak”



wavelength can be employed when the process fluid is highly absorbing. *Figure 6* shows the absorbance of acetone in water at two different concentrations. For 100 ppm acetone, a 200 mm OPL and measurement wavelength ( $\lambda_1$ ) of ca. 265 nm is recommended. For 100% acetone, a 1 mm OPL and measurement wavelength ( $\lambda_2$ ) of 300 nm is suitable.

Industrial photometers can also use a second non-absorbing reference wavelength to compensate for baseline shifts due to turbidity, air bubbles or optical window fouling and therefore ensure a continuous measurement of high reliability. For both samples in *Figure 6*, a reference wavelength ( $\lambda_{ref}$ ) of 400nm is suitable as there is no influence from acetone at this wavelength.

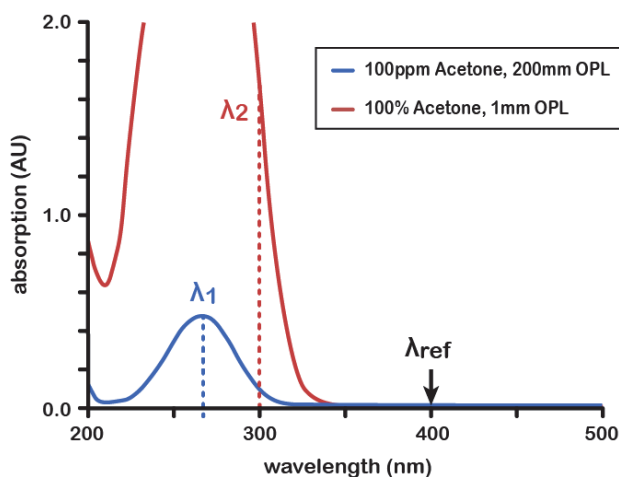


Figure 6) Absorption of acetone in water.

For the majority of applications where absorbance characteristics obey Beer's law, a simple zero plus one sample point will be sufficient to calibrate an online photometer. It should be noted, however, that Beer's law does not describe the behavior of concentrated solutions (greater than  $10^{-2}$  M) due to interactions between the absorbing molecules or when measurement is made at a wavelength where the slope of the sample absorption curve is very steep. In such cases a non-linear calibration should be used. Industrial photometers typically include non-linear and piece-wise linear calibration models.

## VALIDATION

One of the primary concerns of an operator is to be sure an instrument is working to specification and therefore providing a correct measurement to an overall control scheme. The best way to validate a process photometer is to vary the process concentration itself between certain maxima and minima, taking samples at critical points and comparing the process photometer reading to laboratory data. However, this may not be practical for a continuously running production system. An alternative method would be to remove the in-line process photometer measurement cell from the process line and introduce a series of verified samples or standard solutions in a controlled manner to confirm agreement. However, this method is not always desirable as the process must be interrupted and it may not be possible where line fluids are potentially hazardous to health or present disposal and other challenges. Both of these methods require process disruption and a considerable labor overhead.

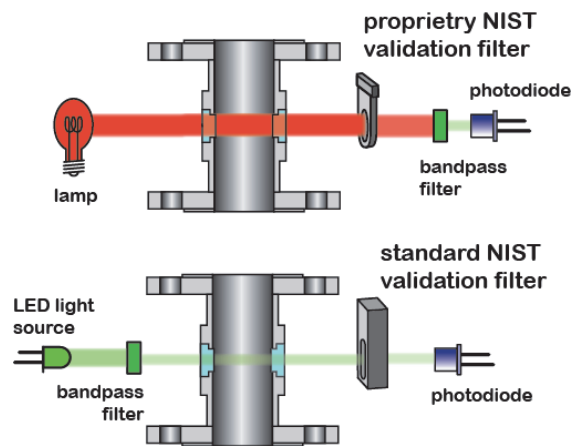


Figure 7) Insertion of traceable filters.

Left: traditional hot lamp type photometer

Bottom: Modern LED cold light type photometer

A process photometer can be validated using standard non-intrusive traceable reference standards that will verify photometric accuracy and linearity, both of which are critical to measurement result quality. *Figure 7* depicts typical optical bench designs for a traditional lamp type filter photometer and a modern LED type filter photometer,

indicating where proprietary or standard 12.5 mm cuvette style filters might be inserted in the circuit. Note that in the traditional lamp circuit, the validation filter is inserted before the band pass filter and is therefore exposed to all wavelengths coming from the lamp, whilst in the LED design, the validation filter is inserted after the band pass filter and is only exposed to the wavelengths in the pass band.

As process photometers can be verified without the need to interfere with the process line, confidence as a result from regular trouble free validation is assured while saving valuable time and resources. Internationally recognized quality systems such as GLP, ISO9000, ISO/IEC Standard 17025 and US Pharmacopeia chapter <857> require that systems are certified using traceable reference materials. The US National Institute of Standards and Technology (NIST) and the United Kingdom National Physical Laboratory (NPL) have developed a number of convenient traceable reference standard materials for verifying the accuracy of the absorbance (or transmittance) and wavelength of a photometer. These materials are certified for absorbance at a number of wavelengths in the ultraviolet (UV), visible (VIS) and near infra-red (NIR) spectral regions, using national reference spectrophotometers built and maintained by NIST and NPL.

#### VALIDATION OF WAVELENGTH AND BLOCKING

Bandpass filters essentially define the operating wavelength and performance of a process photometer so it is important to ensure they meet or exceed the original specification from the manufacturer. Bandpass filters, while generally stable, can exhibit signs of decay over time with changes in peak transmission and stray light blocking capability caused by environmental factors *e.g.* moisture or erosion from the light source itself. *Figure 8* shows an example of the type of damage that can occur to a bandpass filter over time when installed in close proximity to a hot mercury vapor gas discharge light source.



*Figure 8) Bandpass filter damage. New filter is shown on the left, eroded optical filter due to prolonged exposure to a hot mercury type UV lamp on the right.*

Validation of the wavelength accuracy of a spectrophotometer is undertaken using a liquid sample containing a number of distinct peaks such as a solution of holmium perchlorate or a holmium oxide and/or didymium doped glass filter. If the spectrophotometer is equipped with a deuterium or mercury lamp then the emission of the lamp itself can be measured due to distinct emission lines that will not change with time.

For example, a deuterium lamp has a distinct emission at 656.1nm and a weaker emission at 486.0nm. Mercury vapor lamps have a number of principal emission lines at 253.7nm, 313.25nm, 365.48nm, 404.66nm, 435.83nm and 547.07nm, all clearly visible on *Figure 5*, which can be used for wavelength validation. A number of spectrophotometers use such emission peaks to automatically calibrate the instrument and offer methods to validate the wavelength and automatically generate a validation report.

Liquid photometer wavelength reference standards include a solution of holmium oxide in perchloric acid (holmium perchlorate), didymium in perchloric acid (a mixture of praseodymium and neodymium) which is recommended by the U.S. Pharmacopoeia (USP 24), samarium perchlorate and rare earth sulphate which all have distinct wavelength peaks in different ranges of operation. Liquid reference materials are normally permanently sealed into standard 12.5 mm UV quartz cuvettes to prevent contamination. The most common glass type reference filter used for wavelength validation is holmium oxide as this filter provides a range of distinct absorption peaks in the visible region. Solid glass type validation filters provide a convenient

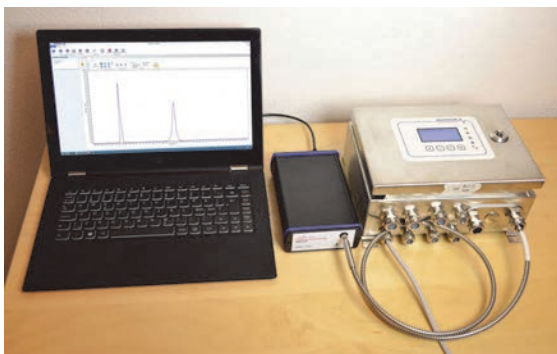




and safe method to quickly validate wavelength accuracy.

It is not possible to validate wavelength accuracy of a filter photometer using wavelength calibration standards because most filter photometers operate at one or two fixed wavelengths and are therefore not able to resolve the distinct peaks provided by the wavelength validation standard.

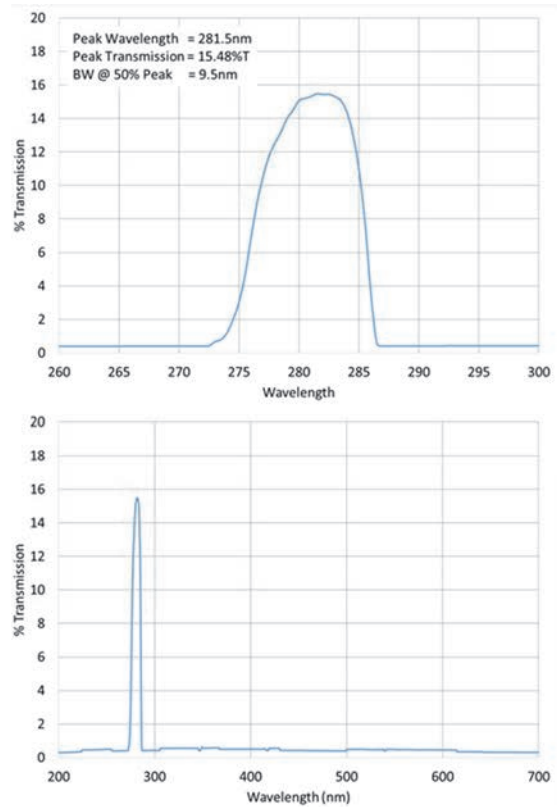
For filter photometer designs that utilize fiber optic connections to the inline measurement cell, wavelength accuracy can be validated using a portable fiber optic type spectrophotometer. As shown in *Figure 9*, a fiber optic based industrial photometer is connected directly to a portable spectrophotometer using standard SMA 905 type fiber optic connectors, making the task of wavelength validation straightforward. The portable fiber optic based spectrophotometer is validated using nationally recognized and certified wavelength standards and used as a transfer standard. Stray light issues, should they exist, can also be assessed. The entire fiber optic circuit can be checked and tested in this way and a high degree of confidence obtained on the measurement circuit integrity.



*Figure 9) Wavelength validation of a Kemtrak industrial fixed wavelength photometer (right) using a portable USB based fiber optic spectrophotometer (middle)*

Lamp based filter photometers have their photodetectors and filters installed in housings directly on the measurement flow cell so it is not possible to verify wavelength accuracy in the field. In this case, the band pass filters should be removed from the assembly and scanned in a traceable

spectrophotometer to determine whether their passband characteristics are within specification and whether there is any stray light in the out-of-band areas. *Figure 10* shows two scans of a bandpass filter. The first measures the actual dimensions of the passband itself. The peak wavelength and bandwidth at 50% of peak transmission can be measured and checked against specifications. The second scan is a wider scan that looks for potential stray light breakthrough points in the filter. Any filter measured out of specification is an indicator that a lower degree of confidence in the performance of the photometer is warranted and the bandpass filter should be replaced.



*Figure 10) Validation of 280nm bandpass filter using a laboratory spectrophotometer  
Top: pass band characteristic at the wavelength of interest  
Bottom: stray light search in out-of-band areas*

## VALIDATION OF PHOTOMETRIC (ABSORBANCE) PERFORMANCE

Photometric performance or absorption accuracy testing is a measure of how accurately the instrument will measure absorption and is critical for correct operation due to the fact absorption is directly proportional to concentration in accordance with Beer's law.

Absorption accuracy is determined by measuring a range of different known absorption value samples spanning the desired operating range of instrument e.g. 0 – 2 AU. At least three different absorption values ranging up to the maximum desired absorption value should be measured and compared.

There are a number of methods for validating photometric performance:

- Process samples
- Certified optical filters
- Certified liquid or gas standards

### Process samples

This is probably the most typical validation method employed in the field. A sample of the process stream is taken along with a simultaneous reading of the photometer output on the instrument display. The process sample is analyzed offline and the photometer reading is compared to the result of the analysis. If the readings are in accord, the instrument is deemed to be operating within established acceptance criteria and no further action is required. If there is a deviation, the action often taken is to adjust the zero offset of the photometer to bring the readings into alignment. This method is, however, often limited to only one sample concentration and may not provide a true indication of how the instrument will perform under changing process conditions. To fully validate the performance of the photometer, the process itself should be adjusted so the color or concentration of the sample stream changes sufficiently to provide a multiple of sample points over the desired operating range of the process. In most cases, this is not possible or desirable in a production environment, making validation a waiting game –

taking advantage of a process upset to produce additional validation points to determine the performance of the instrument.

### Certified optical filters

The National Institute of Standards and Technology (NIST) have specified a range of robust glass type validation filters that are suitable for use with both laboratory spectrophotometers and field process photometers that use a standard 12.5 mm type square cuvette filter holder. A NIST traceable reference material is defined as "a reference material produced by a commercial supplier with a well-defined traceability to the National Institute of Standards and Technology (NIST). The traceability is established via criteria and protocols defined by NIST" [1]. The glass type validation filters specified by NIST exhibit long term stability and are simple and convenient to use. A set of certified glass type photometric validation filters is shown in *Figure 11*.



*Figure 11) NIST traceable metal on fused silica glass absorption filter set for 12.5 mm standard cuvette holder*

NIST specifies the use of two different types of glass reference filter, namely neutral density [2] and metal on fused silica glass filters [3]. Neutral density type reference filters are made from a type of glass which blocks a known percentage of the light passing through it. The amount of absorption at a

given wavelength is determined by the type and thickness of the filter glass. Metal on fused silica glass filters differ in that a layer of reflecting metal is deposited on the glass surface of the filter, reflecting rather than absorbing a percentage of the total light passing through the filter.

A benefit of using metal on fused silica glass filters is that these filters exhibit a relatively flat transmission profile over a wide wavelength range of 250 nm – 2200 nm, compared to the neutral density type filters that are limited to 360 – 1100 nm. As metal on fused silica glass filters reflect light it is important to confirm these filters are suitable for use with the instrument under test and that the positioning of these filters in the sample holder is consistent. It is recommended to validate an instrument using a set of a least three certified glass type validation filters plus a blank for measurement of background absorption. Typical certified filter nominal absorption values include a blank, a filter in the range 0.01 – 0.30 AU (low), 0.50 AU (medium) and 1.0 AU (high) however higher filter values up to 2.0 AU are recommended for most filter photometers.

The range of the validation should also represent the range of the instrument operation. It is a further recommendation by NIST that traceable filters should be recertified on a two year cycle.

Certified filters are used to validate that a filter photometer is working to its absorbance specification. Inserting a certified filter into the light path of a filter photometer should cause the instrument to read the absorbance of that filter at the configured wavelength of the photometer within the specified uncertainty of the instrument.

In the case of industrial photometers with broad band light sources, proprietary filters supplied by the instrument manufacturer are often used to calibrate the instrument to correct for deviations from Beer's law rather than validate the instrument. When calibrating a photometer using such filters, great care must be taken as any correlation of engineering units to absorbance may no longer be valid after such adjustments, especially if single point linear or piece-wise linear curve-fit methods

(essentially joining the calibration points with straight lines) are employed.

Where possible, traceable filter standards such as those in a 12.5 mm cuvette form factor that can be used to validate both offline devices such as laboratory spectrophotometers and online devices such as filter photometers should be employed. This greatly simplifies the expectation that offline and online measurements should be essentially similar and thus improve confidence in the online measurement. A typical implementation of standard 12.5 mm square certified filters for validation of a process photometer is shown in *Figure 12*. The non-intrusive cuvette filter holder allows a traceable validation filter to be placed directly in light path without interruption of the process line.



*Figure 12) Kemtrak 3/4" Tri-Clamp type in-line measurement cell with validation accessory using certified filters in a standard 12.5 mm size cuvette format*

### **Certified liquid or gas standards**

Liquid standards are commercially available to calibrate and validate a wide variety of optical instrument measurement units. Typical examples include ASTM color (ASTM D 1500), Saybolt color (ASTM D 156), APHA/Hazen/Platinum cobalt color (ASTM D 1209 and ISO 6271-1:2004), Gardner color (ASTM D 1544) and Rosin color (ASTM D 509). There are also a wide range of certified standards for gas measurement instrument calibration and validation.

For chemical concentration or absorption measurements, standards can be prepared in a laboratory and used with online photometer instruments. For example, a commonly used liquid

photometer absorption reference standard is potassium dichromate because it has distinct peaks in the UV and VIS spectrum. Instruments measuring alcohol content might use a series of different alcohol/water concentration samples. Whatever the standard used, the absorption of a set of different liquid concentrations are measured and then applied to the instrument to check for linearity and absorption accuracy.

Liquid standards can be introduced into a photometer light path in one of two ways:

1. Directly into the sample cell
2. Using standard cuvettes or proprietary insertable liquid holding devices

Some process photometers are installed in a side stream/fast loop sample line where they can be isolated and standard fluids introduced into the sample cell for validation purposes. Aside from the problems of hazardous material handling, flushing the cell between one sample and the next is key to obtaining good results. The practice of flushing with a zero solution between standards should be avoided as the potential of diluting effects of a zero solution to any one standard solution are greater than the effects of one standard solution to the next. This method may require the consumption of a significant volume of standard which can be costly. Standard solutions should be discarded once used and not reused. Some standard solutions may have a shelf life and should not be used if they have expired.

An alternative to inline side stream validation is to remove the flow-cell from the line, blank one end and introduce standard fluids directly into the optical flow cell. This is a perfectly valid method of validating a photometer, notwithstanding any issue surrounding materials handling. Care should be taken to ensure that ambient light is prevented from entering the cell while measurements are being taken and that the fluid completely fills the cell and is free of bubbles (and “microbubbles”), particularly on the surfaces on and around the optical windows.

For process photometer measurement cells fitted with validation filter holders, standard fluids can be used to validate the instrument without the need to

remove the cell from the process line. It is important to take into consideration the optical path length of the measurement cell compared to the optical path length of the cell used for the liquid validation sample. *For example*, if the optical path length of the measurement cell is 10 cm and the liquid sample cuvette is 1cm, then the reading of standard in the 1 cm cuvette will be 10x lower than if measured by the longer path length of the measurement cell. In accordance with Beer’s law, it is also possible to use a 10x more concentrated sample in the 1cm cuvette to provide the same reading as a 10cm path length. *Figure 13* shows how liquid filled cuvettes can be used for validation purposes.



Figure 13) Kemtrak industrial 2" ASME/ANSI flange wafer type in-line measurement cell with validation accessory using 12.5 mm liquid sample cuvettes

## OPTICAL PATHLENGTH AND ERROR ASSESSMENT

Industrial process measurement cells are typically assemblies of robust metal bodies e.g. stainless steel, nickel alloy, titanium etc., scratch resistant sapphire optical windows and elastomer seals. All the mechanical parts have general tolerances related to the limitations of the CNC lathes and milling machines used to manufacture them. Normal engineering tolerances for such operations are typically  $\pm 0.1 - 0.05$  mm ( $\pm 0.004 - 0.002$  in).

When using short path length measurement cells the error due to manufacturing tolerances can be



significant and must be taken into consideration. If the measurement cell is calibrated using a liquid calibration solution directly in the measurement cell then any inaccuracies in the optical path length will be automatically taken into consideration and compensated for in accordance with Beer's law.

Certified validation filters only validate the performance of the photometer and cannot be used to compensate for inaccuracies in the measurement path length. For that reason it is always recommend to validate the measurement cell using liquid solutions before installing in the process. If necessary, an optical path length correction factor should be applied to the process photometer after installation. As the optical path length is fixed and will never change, this correction factor need only be measured once and will be unique to the specific measurement cell.

## CONCLUSIONS

Filter type photometers can provide valuable real time measurements into an overall control scheme and assist in reducing production costs by improving product consistency and quality. The practice of validating performance at one point in the field may not necessarily guarantee that the instrument is performing to specification.

An understanding of the stray light issues surrounding filter based photometers can greatly improve the approach to field validation and can enhance measurement accuracy. Using photometric standards certified by third parties to nationally maintained standards allows a greater correlation between offline and online measurements and therefore provides a greater confidence in the results provided by in line photometers.

Validation of a photometer is necessary at more than one measurement point. Bandpass filters used to generate a single (monochromatic) wavelength can decay over time, particularly in the presence of high power hot light sources and can create non-linearity of measurement at higher concentrations that can lead to product quality problems. Using

multiple validation points can help describe non-linearity exhibited by a photometer and allow action to be taken to correct it.

The use of filters and absorbance standards to validate photometers removes the need to take photometers offline and handle potentially hazardous materials as test samples. Provided stray light impact is understood and any error in optical path length is assessed, highly reliable validation measurements can be obtained with a resulting high confidence in the measurement results of the instrument itself.

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