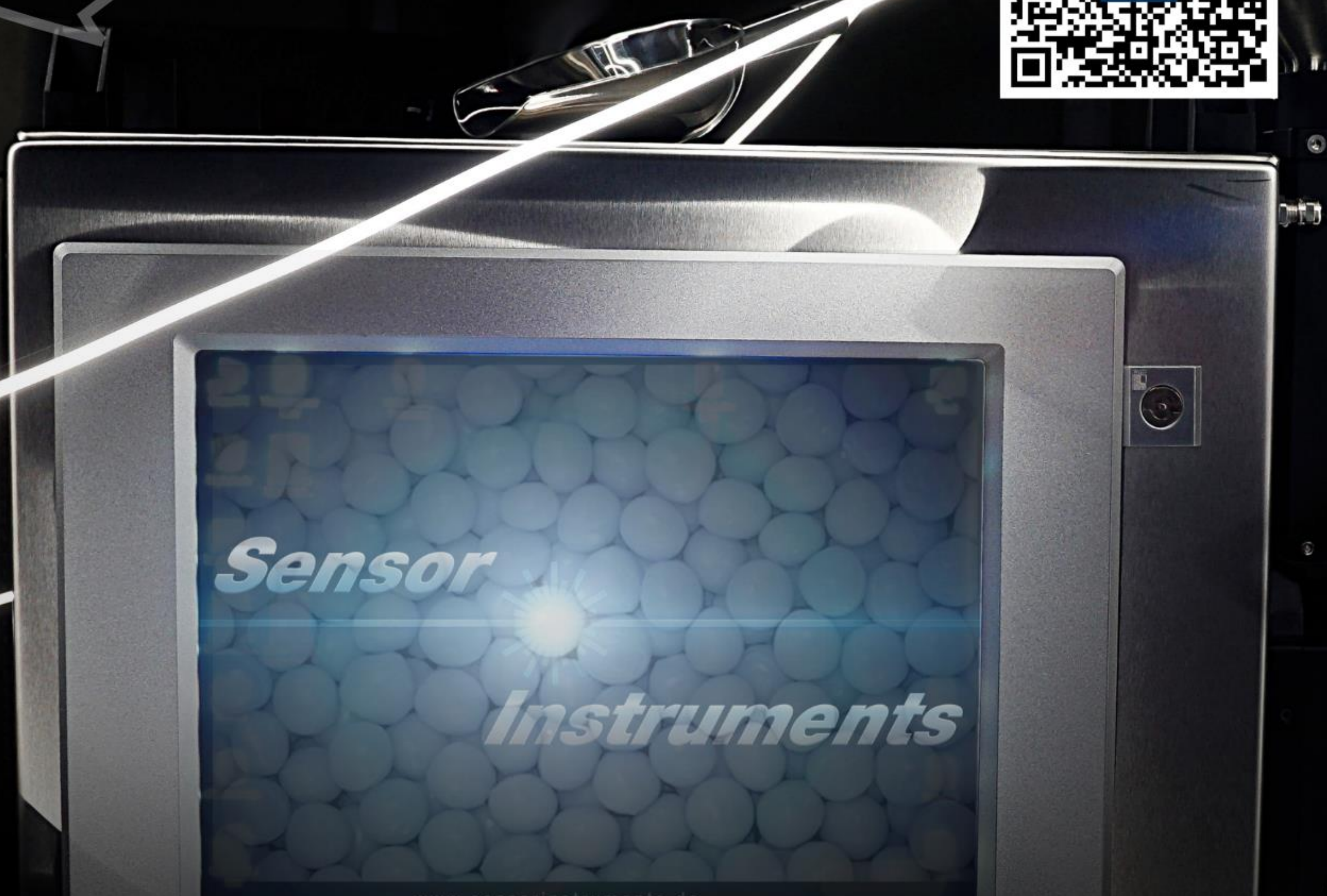
COLOR
PLASTIC TYPE
TAG TEC



Sensor systems

Lab & Inline
in the **Plastic recycling industry**

Sensor Instruments GmbH I Schlinding 15 I 94169 Thurmansbang

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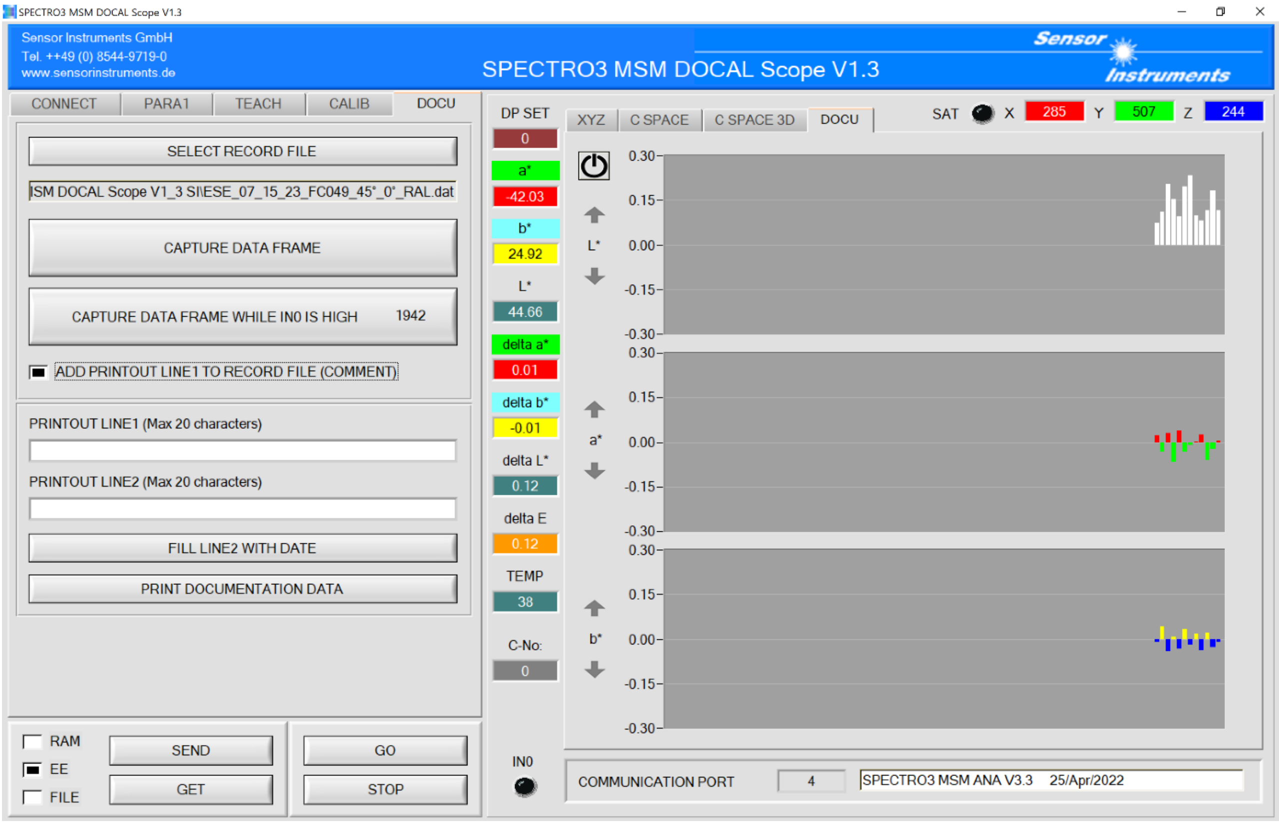
Sensor systems for recyclate control in the plastics industry for laboratory and inline use

While downcycling of plastic products still predominated in the past, the form of recycling in which the reused plastic is put to the same or a comparable use is now becoming increasingly important. This in turn means considerable additional technical effort in separating and sorting the items delivered to the recycling plant throughout the recycling process. After separation of as many non-plastics as possible, for example by means of metal separators and wind separation, sorting is currently primarily by color (color sorting systems) and type of plastic (NIR cameras). Despite pre-sorting, where mainly whole articles are checked, as well as post-sorting (after shredding the plastic articles and subsequent washing) of the plastic particles known as flakes, it is not possible to achieve 100% grade purity. Certain variations in color must also be expected. In order to allow unrestricted use of the recyclates produced in this way, they must be checked for purity before the next processing step, at the very latest immediately before extrusion. Typically, this could be done by a metering system equipped with appropriate sensors. The degree of purity of both the color and the type of plastic is monitored. If the purity falls below a certain level, less recycled material is added and more virgin material is added, so that the deviations in the final article in terms of color and plastic type are within the required tolerances. Furthermore, additional sensors can be used to detect a marker from the TAGTEC family contained in the recyclate (contained in the masterbatch from Gabriel Chemie). In the case of articles of the same color and plastic type, markers are used, for example, to distinguish between a clear PET ketchup bottle and a clear PET shampoo bottle. In addition to the actual sensor technology for testing the color, the type of plastic and the presence of any TAGTEC markers, the company Sensor Instruments also offers test systems for the laboratory, including the appropriate accessories for calibrating the devices, as well as inline devices, which will be explained in more detail below.

1. The Sensor Instruments DOCAL – Software

Although the individual sensors for determining the color, the type of plastic and the detection of markers differ greatly for physical reasons, an attempt was made to give the respective PC software a uniform appearance for the monitoring and calibration software. The available features are identical, only the physical measurement variables differ. DOCAL stands for DOcumentation and CALibration. The Windows® -based PC software enables monitoring with simultaneous recording of the measurement data as well as calibration of the sensor systems. The DOCAL PC software can be used for both laboratory and inline systems. The DOCAL software can be operated by means of software wizards, the user is guided as far as possible through the calibration by means of calibration standards (for example RAL plastic cards for the calibration of the color or different types of plastic, defined plastic plates are also used for this purpose and of course the plastic plates with different TAGTEC markers and also different concentrations). But also with the recording and the representation of the measured values the greatest possible value was attached to a simple handling.



The example shown here is the DOCU page of the DOCAL PC software for the color sensor systems. The current L*a*b* color value of the last measuring process is displayed, as well as the deviations da*, db, dL* and dE from an L*a*b* color value specified by the operator. The deviations from the target value are also displayed in graphical form. The measurement can be triggered either by an external trigger, by a predefined time interval or as a single event via mouse click. In the file, the measurement data is automatically recorded after each measurement, and the current 100 measurement values are displayed on the screen.

Record results of: SPECTRO3 MSM DOCAL Scope V1.3

DATE	TIME	X	Y	Z	L*	a*	b*	delta E	delta L*	delta a*	delta b*	COLOR	TEMPs	COMMENT
07-16-2023	15:13:48	285	508	244	44.703	-42.079	24.922	0.169	0.162	-0.046	-0.012	0	38	FC049 45°/0°
07-16-2023	15:16:34	284	506	243	44.615	-42.011	24.924	0.078	0.074	0.022	-0.011	0	38	
07-16-2023	15:18:46	284	507	243	44.651	-42.067	24.977	0.123	0.110	-0.034	0.043	0	38	
07-16-2023	15:20:31	286	509	245	44.746	-42.003	24.894	0.211	0.205	0.030	-0.041	0	38	
07-16-2023	15:21:57	285	508	244	44.696	-42.100	24.941	0.169	0.155	-0.067	0.007	0	38	
07-16-2023	15:22:51	284	506	244	44.638	-41.994	24.902	0.109	0.097	0.039	-0.032	0	38	
07-16-2023	15:24:32	286	509	245	44.738	-42.065	24.968	0.202	0.197	-0.032	0.034	0	38	
07-16-2023	15:26:30	287	510	246	44.774	-42.043	24.916	0.234	0.233	-0.010	-0.018	0	38	
07-16-2023	15:28:55	284	506	243	44.642	-42.031	24.952	0.102	0.100	0.002	0.018	0	38	
07-16-2023	15:31:06	284	506	243	44.623	-42.010	24.896	0.093	0.082	0.024	-0.038	0	39	
07-16-2023	15:33:29	284	507	243	44.659	-42.095	24.956	0.135	0.118	-0.062	0.022	0	39	
07-16-2023	15:35:30	286	508	245	44.724	-42.057	24.908	0.187	0.183	-0.024	-0.027	0	38	
07-16-2023	15:38:43	285	507	244	44.658	-42.028	24.923	0.118	0.117	0.005	-0.011	0	38	

The stored measured values can be displayed with Microsoft EXCEL®.

2. Color measurement of recyclates

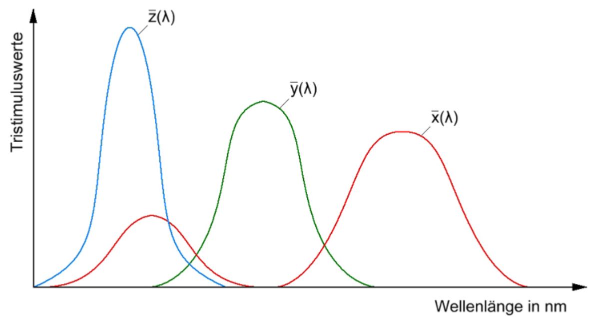
What is the best way to measure the color of recyclates? Commercially available handheld devices are quite suitable for measuring the color of flat, preferably homogeneous surfaces. Due to the relatively small light spot of these instruments, an attempt to measure the color directly on the plastic granules usually ends up with an estimated value rather than a reliable and reproducible measurement result. For this reason, the user often first produces injection-molded plates from the respective recycled material, which provide the flat surface required for the color measuring instruments. Ultimately, however, this procedure primarily increases the time required, which means that production has to wait longer than necessary for the necessary feedback from the laboratory. This may result in avoidable rejects due to non-compliance with color values. In contrast, faster feedback can be obtained with the innovative laboratory and inline systems from Sensor Instruments, which will be presented in the following. But first a short excursion to the basics of color measurement

2.1 Color measurement - basics

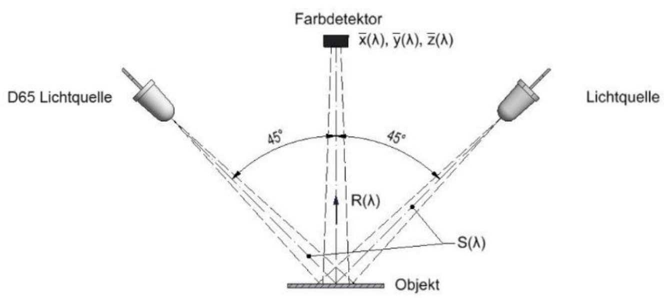
2.1.1 What is color?

Color is created by illuminating objects with electromagnetic radiation in the wavelength range between 380nm and 780nm or by self-luminous devices that emit light in the visible range.

The human eye divides the received visible light with the help of the light-sensitive color receptors (cone cells) present in the retina in the back of the eye into three areas: RED (X) GREEN (Y) BLUE (Z).



The diagram shows the relationship between the sensitivity of the red-, green- and blue-sensitive cone cells as a function of wavelength. The color values X Y Z, the so-called tristimulus values, are the mathematical description of the information provided by the light-sensitive cones. In order to calculate these values, the spectral emission behavior S as a function of wavelength must first be known. Light similar to D65 is usually used for color measurement. In the measuring systems from Sensor Instruments, so-called Sun-light LEDs provide light similar to D65. However, the diffuse light reflection on the object to be checked is also decisive for the color impression, in our case the diffuse light reflection on the plastic granulate R as a function of the wave-length. If we now take into account the color sensitivity x,y,z, as a function of wavelength, of the three different light-sensitive cones, the tri-stimulus values X Y Z can be calculated:



$S(\lambda)$= relative spectral power distribution of the lightning source

$\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$= color-matching functions for CIE 2° Standard Observer (1931)

$R(\lambda)$= spectral reflectance of sample

$$X=K*\int_{380nm}^{780nm} S(\lambda)*\bar{x}\ R(\lambda)*d\lambda$$

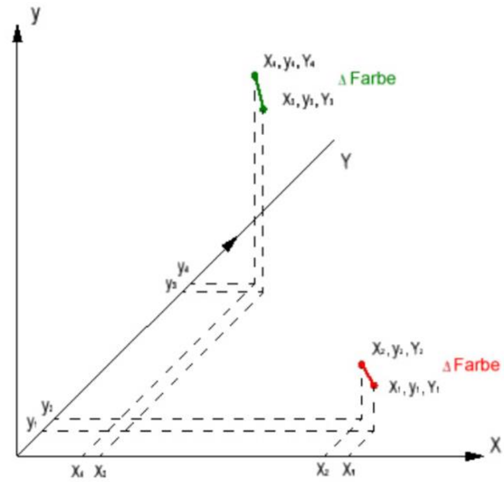
$$Y=K*\int_{380nm}^{780nm} S(\lambda)*\bar{y}*R(\lambda)\ d\lambda$$

$$Z=K*\int_{380nm}^{780nm} S(\lambda)*\bar{z}*R(\lambda)\ d\lambda$$

$$K=\frac{100}{\int_{380nm}^{780nm} S(\lambda)\ \bar{z}\ R(\lambda)*d\lambda}$$

The ratio of the color components X Y Z now defines a certain color. In the course of time, methods were introduced to better describe a color. First, standardized color values were introduced:

$$x=\frac{X}{X+Y+Z} \quad y=\frac{Y}{X+Y+Z} \quad z=\frac{Z}{X+Y+Z}=1-x-y$$



With the x, y, Y - values (Y x y-CIE color system) it was now possible to separate a color into the actual hue x, y and the intensity value Y (rather this is the green tristimulus value). However, it turned out that with this method a color change in dx, dy or dY at different locations in the color space was perceived by the viewer as having different intensities.

*2.1.2 The L*a*b* - color space*

The L*a*b* color system was introduced in order to be able to mathematically describe a color difference that the observer perceives to be the same. A color difference between two neighboring colors that can just be perceived by the human eye, and this at any point in the color space, now also provides the same mathematically determined color distance dE. Xn, Yn and Zn represent the tristimulus values X Y Z for a perfectly reflecting diffuser (e.g. a white, matte surface): Xn = 95.05 Yn = 100 Zn = 108.9

$$L^*=116\left(\frac{Y}{Y_n}\right)^{1/3}-16$$

L*= lightness variable

$$a^*=500\left[\left(\frac{X}{X_n}\right)^{1/3}-\left(\frac{Y}{Y_n}\right)^{1/3}\right]$$

a*= chromaticity coordinate for the green/red shift

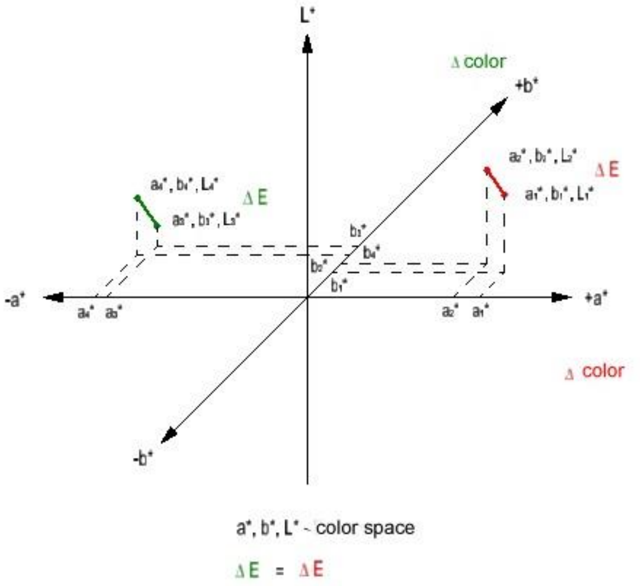
$$b^*=200\left[\left(\frac{Y}{Y_n}\right)^{1/3}-\left(\frac{Z}{Z_n}\right)^{1/3}\right]$$

b*= chromaticity coordinate for the blue/yellow shift

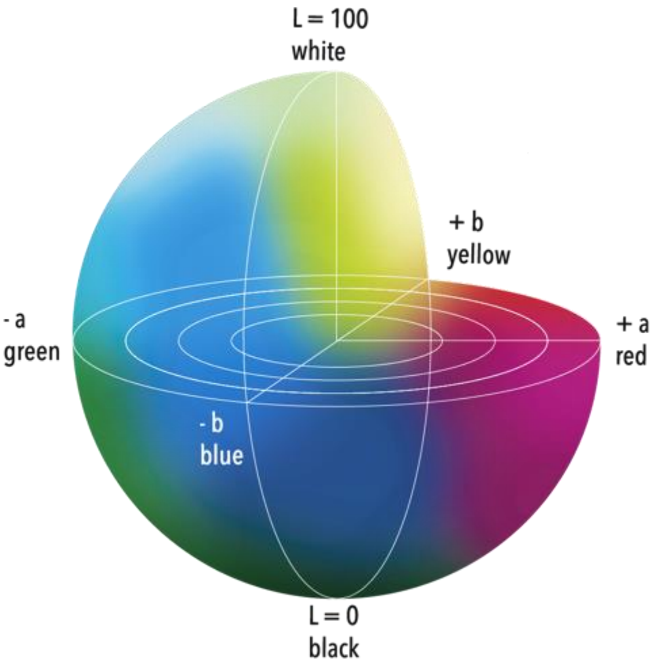
XYZ= tristimulus values

The L*a*b* color system (also referred to as CIELAB) is the most frequently used system for color determination. In 1976, it was defined by the CIE as one of the equidistant color spaces, so that the main problem of the Yxy color system could be solved: Equal distances of two color shades in the Y, x, y - color space do not lead to sensitively equal color differences. The color space of the L*a*b* - system is defined by the brightness L* and the color coordinates a* and b*. With the help of the a* - value a RED/GREEN - shift is defined (-a* -> direction GREEN, +a* -> direction RED), while the b* - value indicates a BLUE/YELLOW - shift (-b* -> direction BLUE, +b* -> direction YELLOW). A high L* value, on the other hand, indicates that the object is bright, while a low L* value indicates that the object is quite dark. In the following a few L*a*b* - values of recyclates of different colors are already listed here

$$\Delta E=\sqrt{(\Delta a^*)^2+(\Delta b^*)^2+(\Delta L^*)^2}$$

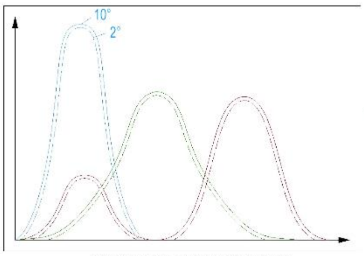


Color of recyclate	L*	a*	b*
Light beige	92.76	-3.03	8.92
Light grey	87.49	-3.87	-5.45
Light blue	64.07	-11.65	-15.19
Dark blue	33.19	-6.51	-28.55
Red	34.75	48.43	15.80
Green	53.33	-43.41	28.30
Dark green	26.40	-8.92	4.01
Yellow	80.98	19.97	86.82
Dark grey	25.73	-1.78	-0.92
Olive	33.72	-8.80	8.97
Wine red	24.18	10.12	1.94

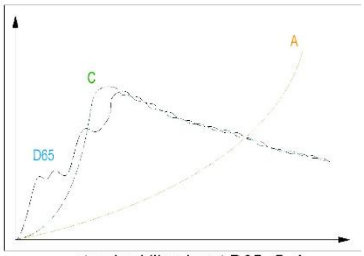


2.1.3 Measuring geometries in color measurement

In addition to the so-called true color detector, a detector that is based on the human color perception, a light source is also required that should correspond as well as possible to the standard. The D65 standard has prevailed in most cases. The Sunlight LEDs used in the color measurement systems from Sensor Instruments are based on this standard light curve.



tristimulus valus function
(visibility curve)
2°-, 10°-standard observer

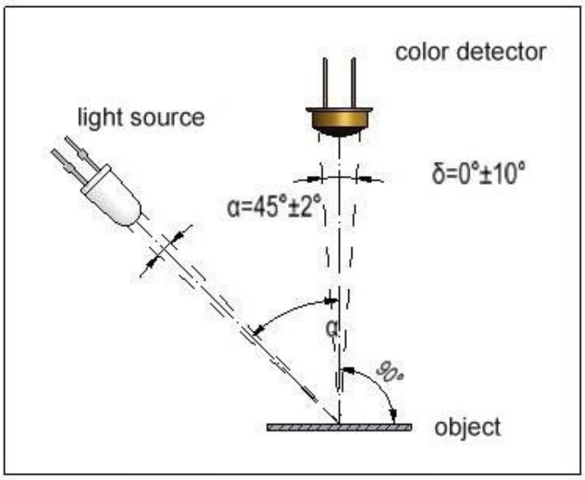


standard illuminant D65, C, A

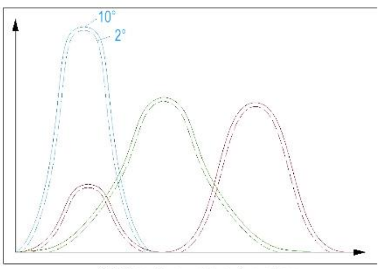
However, not only the wavelength characteristic is decisive for a color measurement, but also the radiation characteristic of the light source used, as well as the alignment of the light source and the color detector. The measurement geometry is therefore another important point that must be taken into account in a color measurement. In the following, the two measuring geometries that are used in the measuring systems of Sensor Instruments will be explained in more detail.

2.1.3.1 The 0°/45° - method

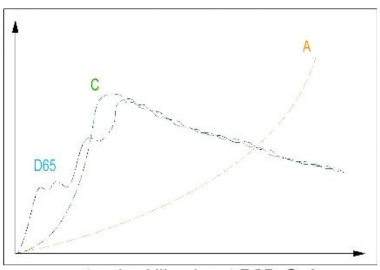
With the 0°/45° method, the light irradiation on the object is perpendicular to the target surface, i.e. at 0° to the normal of the target surface. The idea behind this arrangement is to avoid direct reflection in the direction of the color detector, so that only diffusely reflected light (from a flat surface) can reach the receiver. However, since pellets have a spherical, cylindrical or oval surface, which can also be very shiny in the case of some pellets, direct reflections can also occur with this method. However, these can be reduced considerably by increasing the distance from the sensor to the target surface (at Sensor Instruments the distance was increased to 85mm). In addition, this measurement geometry can be used with fiber optic bundles, which means that the 0°/45° measurement system can be used even at high temperatures of the recyclates.



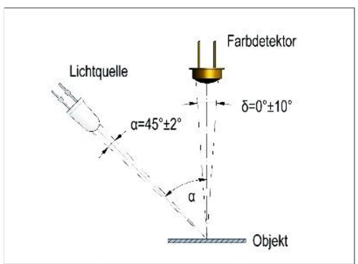
45°/0° measurement geometry



tristimulus valus function
(visibility curve)
2°-, 10°-standard observer



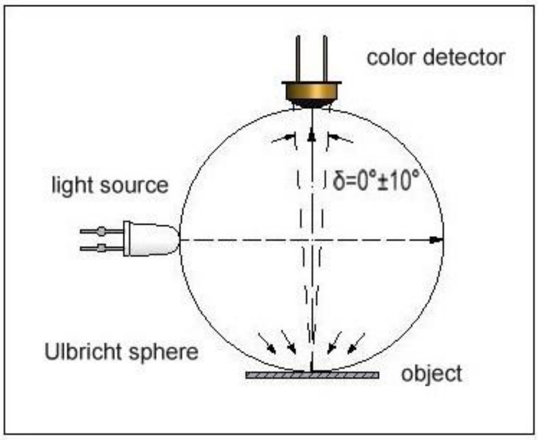
standard illuminant D65, C, A



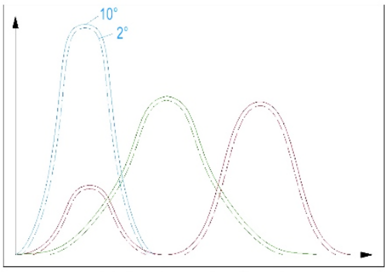
45°/0° method

2.1.3.2 The diffus/0° - method

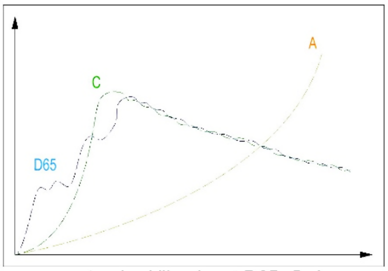
This is an approximation of the d/8° principle used in handheld as well as laboratory instruments. In the d/8° method, light is illuminated from the entire half-space by means of an integrating sphere (Ulbricht sphere, this is a hollow sphere, the inside of which is coated with white matt, which ensures homogeneous, diffuse light scattering), while the color detector is directed at 8° to the normal to the surface to be measured. In order for light to be emitted into the entire half-space by means of the integrating sphere, it is necessary to work with this measuring system resting on the object. Thus, an inline application of a measuring system using the d/8° method is almost impossible if there is continuous movement of the objects to be measured. An approximation to an "integrating" diffuser (Ulbricht squere) is a volume diffusing disk, which distributes the light of a cluster of sunlight LEDs as homogeneously as possible into the entire half-space. Of course, since inline a certain distance to the object must be maintained, this can only be an approximation to the d/8° method. Moreover, the receiver is not located at 8°, but at 0°. Although the diffuse/0° method is not, strictly speaking, a standardized measuring method, this measuring method provides excellent results, especially for inhomogeneous surfaces, specifically for a granular surface.



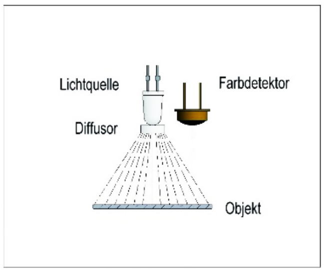
d/0° measurement geometry



tristimulus valus function
(visibility curve)
2°-, 10°-standard observer

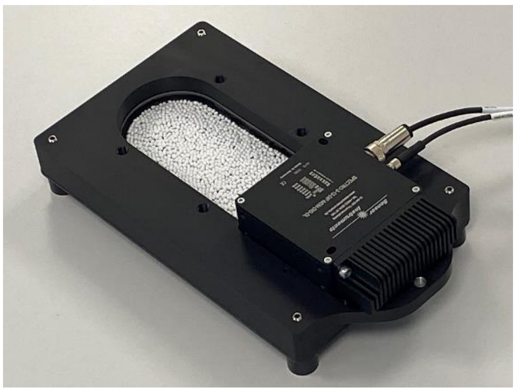


standard illuminant D65, C, A

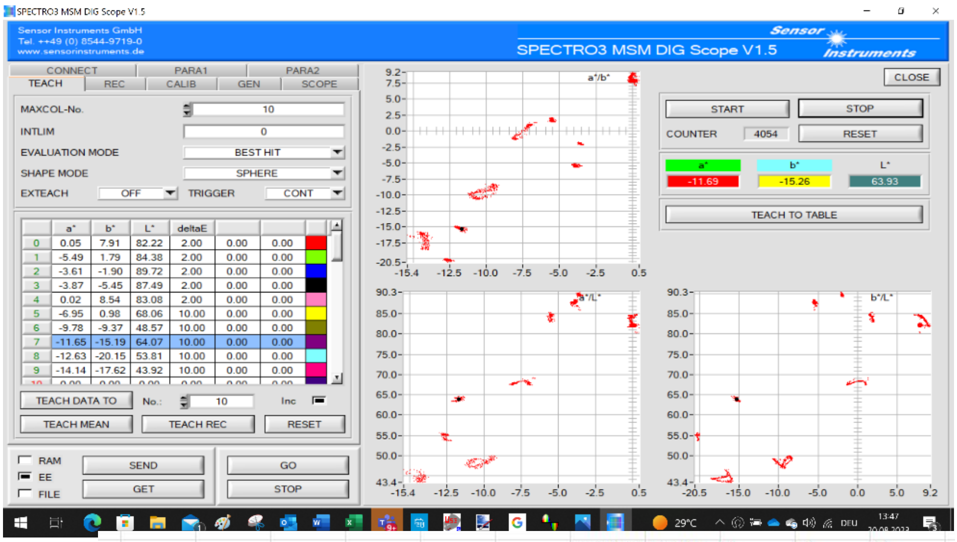


diffus/0° method

At this point, we will anticipate the somewhat more detailed explanations of the measuring systems in Chapter 2.2 and perform measurements on various recycled materials using the SPECTRO-3-DIF/0°-CMU measuring unit. With this measuring system, the color sensor is separated from the respective recyclate only by a 9mm thick crown glass plate. The total distance between the sensor system and the granulate surface is approx. 15mm. The respective recyclate sample is filled into a flat insertion tray included in the scope of delivery and then pushed into the slot provided under the crown glass plate. After the measurement has been started, it is recommended to move the insertion tray in the guide, so that the influence of the random position of the individual granules on the color measurement result can be considerably reduced.



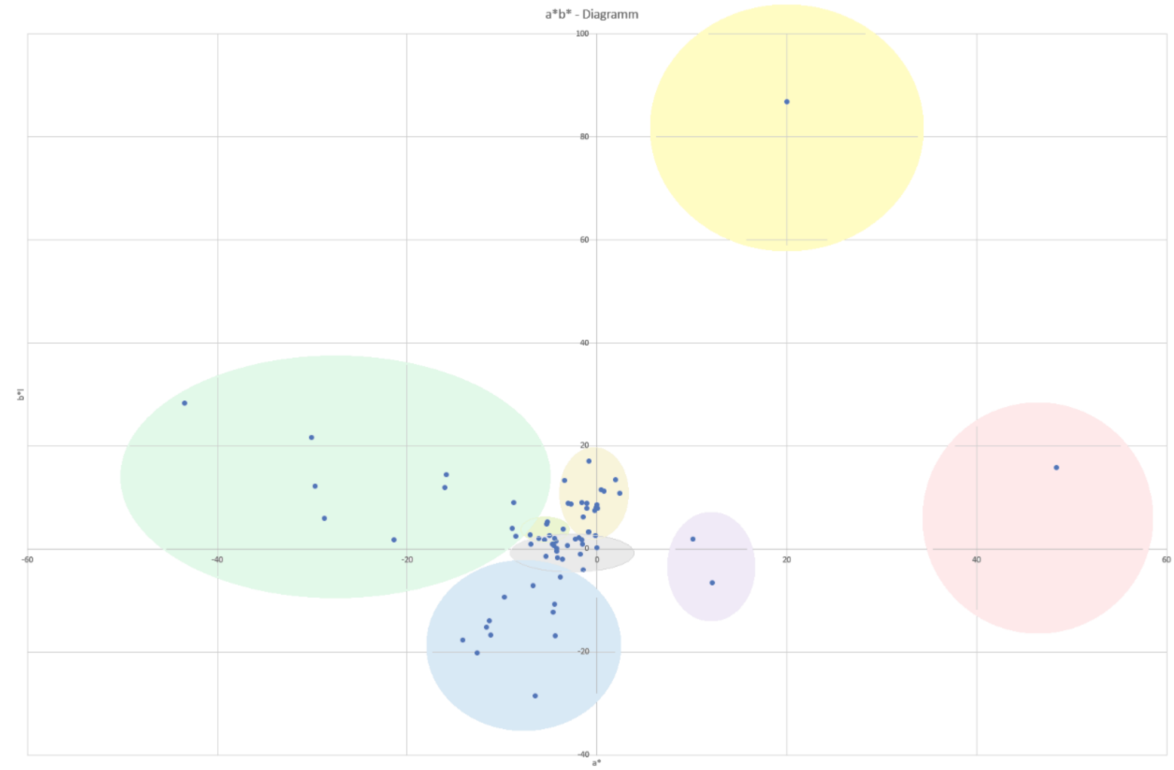
2.1.3.2.1 Color measurements on different recyclates with the SPECTRO-3-DIF/0° system



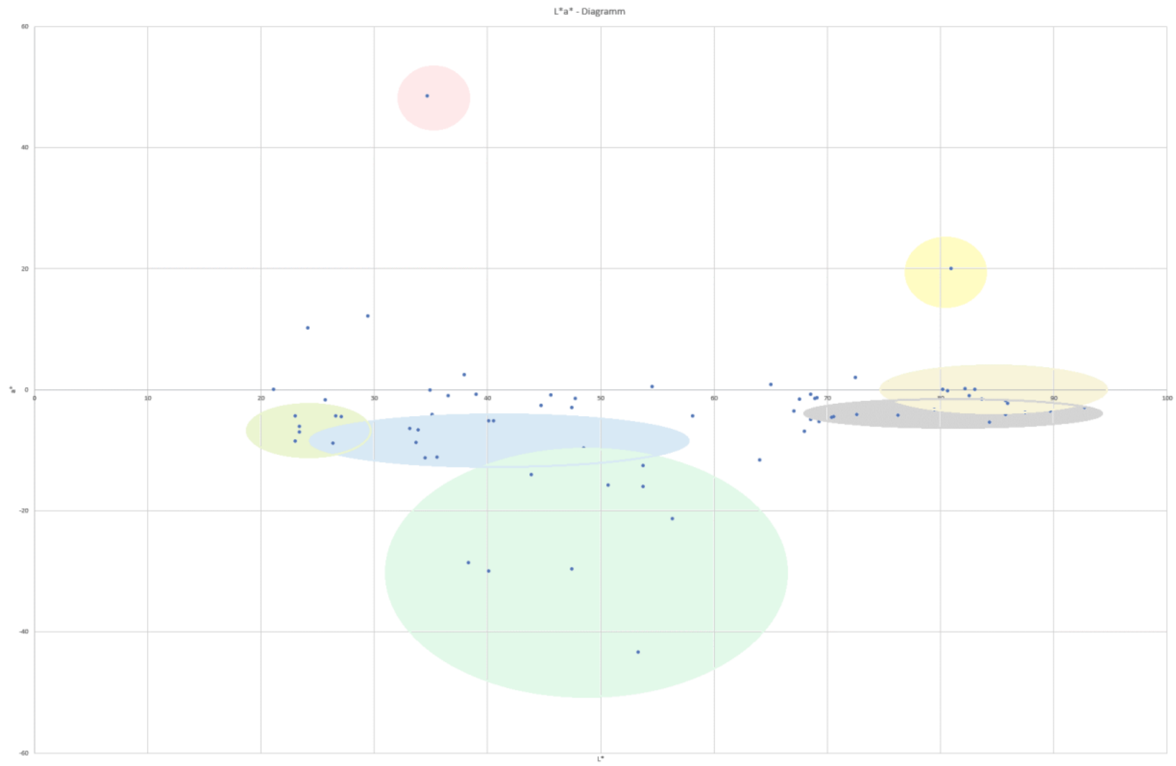
After the calibration of the measuring system, for this there are also different methods, which are explained in more detail under 2.2, the actual measuring process can begin. In addition to the DOCAL software, the MSM DIG Scope V1.5 can also be used for this purpose. The red point clouds each represent a recycled sample, which are shown in three different views of the color space (a*b*, a*L* and b*L*).

The cloud structure is obtained by moving the insertion tray in which the respective recyclate sample is located. The mean value from each sample is entered in the table. In the above example, 10 recyclate samples were entered. The results from all the recyclate samples available for testing were then entered into an EXCEL table. The recyclate samples shown in the photos correspond to the position in the EXCEL table, so that the reader can get a first impression between a recyclate color and the corresponding L*a*b* value. As expected, the gloss as well as the structure of the measuring surface could be compensated quite well by the diffuse/0° method in connection with the movement of the recyclates during the measuring process.

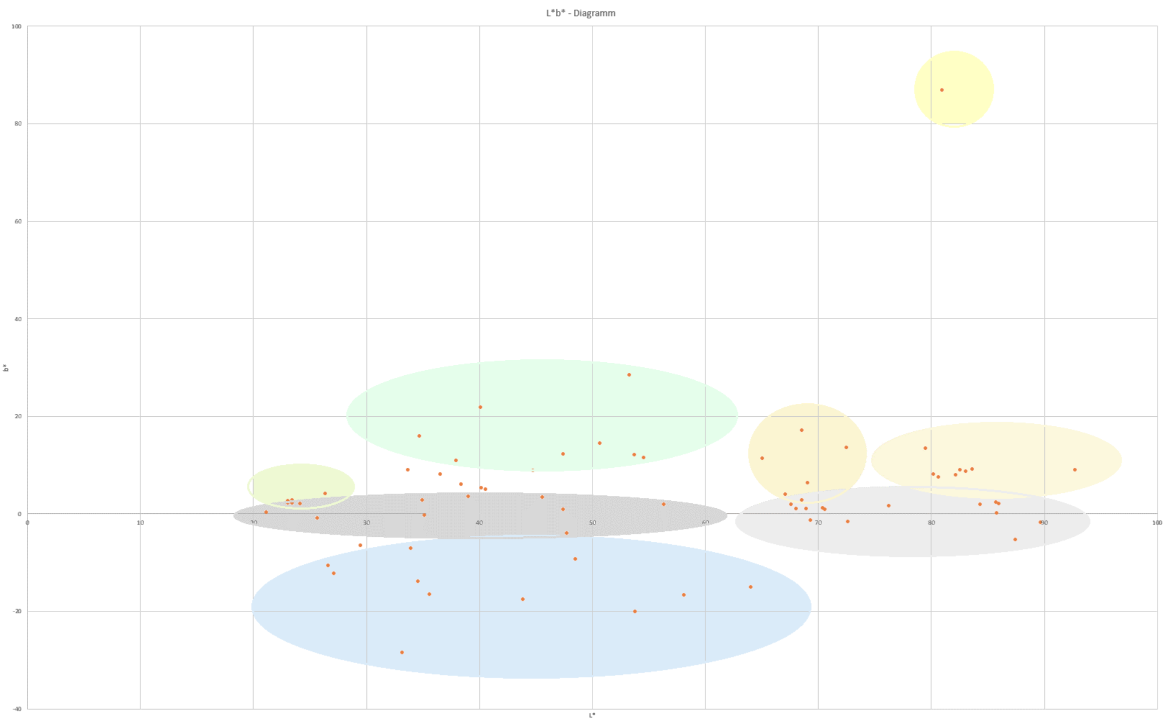
SPECTRO 3 MSM DIG V1.5 Nr.	REZYKLAT Nummer	L*	a*	b*
0	15	83,67	-1,62	8,99
1	52	80,22	-0,06	7,99
2	64	85,99	-2,3	1,96
3	18	92,76	-3,03	8,92
4	10	79,51	-3,42	13,36
5	54	70,46	-4,7	1,01
6	16	82,59	-1,09	8,93
7	46	80,67	-0,23	7,48
8	55	67,61	-1,61	1,86
9	53	70,61	-4,53	0,72
0	41	82,22	0,05	7,91
1	35	84,38	-5,49	1,79
2	1	89,72	-3,61	-1,9
3	30	87,49	-3,87	-5,45
4	36	83,08	0,02	8,54
5	61	68,06	-6,95	0,98
6	62	48,57	-9,78	-9,37
7	17	64,07	-11,65	-15,19
8	65	53,81	-12,63	-20,15
9	38	43,92	-14,14	-17,62
0	2	29,52	12,13	-6,55
1	3	34,75	48,43	15,8
2	25	33,95	-6,71	-7,12
3	7	33,19	-6,51	-28,55
4	23	35,63	-11,19	-16,63
5	66	40,6	-5,28	4,9
6	9	58,15	-4,38	-16,78
7	47	26,63	-4,47	-10,69
8	50	23,46	-7,03	2,71
9	6	34,58	-11,33	-13,95
0	21	56,35	-21,39	1,86
1	67	50,68	-15,88	14,42
2	11	53,33	-43,41	28,3
3	4	47,48	-29,68	12,17
4	44	38,4	-28,7	6,02
5	48	23,07	-8,55	2,52
6	68	23,46	-6,13	2,07
7	69	26,4	-8,92	4,01
8	51	40,19	-5,22	5,23
9	24	53,78	-16,04	11,99
0	70	34,97	-0,19	2,64
1	59	45,63	-0,9	3,3
2	72	39,07	-0,83	3,38
3	12	47,8	-1,48	-4,08
4	42	35,19	-4,23	-0,39
5	8	44,78	-2,71	8,68
6	14	36,59	-1,08	7,95
7	34	38,01	2,43	10,79
8	31	54,6	0,41	11,47
9	28	47,48	-3,09	0,73
0	5	69,12	-1,43	6,31
1	43	85,77	-1,92	2,26
2	13	72,53	1,96	13,52
3	37	65,06	0,76	11,2
4	22	68,6	-0,86	17,01
0	27	67,13	-3,56	3,85
1	33	85,8	-4,22	0,12
2	26	72,67	-4,15	-1,71
3	39	68,59	-5	2,67
4	20	76,27	-4,28	1,5
5	19	25,73	-1,78	-0,92
6	57	21,19	0,02	0,23
7	56	68,96	-1,51	0,96
8	63	69,34	-5,37	-1,45
9	45	80,98	19,97	86,82
5	73	40,15	-30,09	21,69
6	74	33,72	-8,8	8,97
7	75	23,07	-4,47	2,05
8	76	24,18	10,12	1,94
9	77	27,17	-4,59	-12,27



a*b* - diagram with the a*b* - measured values of the 70 different recyclates



L*a* - diagram with the L*a* - measured values of the 70 different recyclates



L*b* - diagram with the L*b* - measured values of the 70 different recyclates

Image of various recyclates that were available during the color measurements.

2.2 Sensor systems for color control in the laboratory and inline

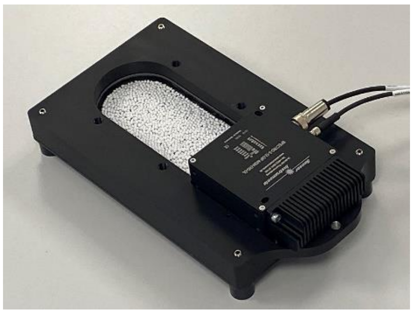
Although handheld devices for determining the color of recyclates are already available and used on the market, the achievable measuring accuracy is limited. The reason for this is not so much to be found in the measuring accuracy of the handheld devices - with a flat and also homogeneous measuring surface, these devices deliver excellent results - but rather in the size, the shape and the random arrangement of the individual granules and the light spot of the color measuring device. The typical light spot size of handheld colorimeters is 10mm in diameter. Depending on the shape (spherical, elliptical and cylindrical) of the pellets, their dimensions are in the range of 2mm and 5mm in diameter or height.

This results in a detection area of 10mm in diameter with a not inconsiderable shadowed area, from which no noticeable light contribution to the color measurement occurs. The pellets therefore appear darker than the flat surface (e.g. color platelets), which is reflected in the color measurement in the form of a lower L* value.

Depending on the pellet surface, there are also disturbing light reflections. A proportion of this in turn reaches the reception area of the sensor system and thus falsifies the a*b* color values. Due to the random arrangement of the pellets, a reliable correction of the L*a*b* values does not appear to be very effective, since the position of the individual grains changes from measurement to measurement.

This can be remedied by continuous measurement of the pellets during the movement of the pellet stream and, in addition, by a large illuminated detection area. Sensor Instruments uses two different methods in this respect, which are used both in the inline systems and in the laboratory instruments. In the inspection glass method, a 9mm thick, clear and temperature-resistant crown glass separates the plastic pellets from the sensor system. The pellets are positioned on the inside of the inspection glass and are guided along it by gravity or mechanical movement. Sensor Instruments has both 0°/45° - color sensors and diffuse/0° - sensors.

- 0°/45° - color sensors emit white light at an angle of 0° to the normal (perpendicular light emission from the sensor cover glass) and at 45° is observed by means of receiver optics.
- The diffuse/0° sensors, on the other hand, have a cluster of white light LEDs (similar to D65), which in turn are covered by a volume diffusing glass (frosted glass pane). This results in ideally diffusely scattered homogeneous light. The small receiver aperture is surrounded by the diffusing panel and covered only by a clear glass pane. Thus, only light at 0° to the normal (perpendicular to the glass cover of the receiver) can reach the color detector. For measurement reasons, the sensor must be positioned quite close (a few mm) to the inspection glass.



Both methods (0°/45° and diffuse/0°) are suitable for color measurements using the ***inspection glass method***.

With the ***direct method***, on the other hand, there is no object between the plastic granulate surface and the sensor. The 0°/45° method is primarily suitable here, since the distance between the object surface and the sensor head is 85mm; with the diffuse/0° method, the distance would be just 10mm. Although the direct method attempts to keep the distance between the color sensor and the plastic granule surface constant with the aid of a deflector plate, this succeeds at best in the millimeter range. At a distance of only 10 mm, however, a change in distance would have a not inconsiderable effect and would thus impair color measurement.

2.2.1 Color sensor systems for the laboratory

2.2.1.1 Color sensor systems for the laboratory according to the inspection glass method

As already mentioned at the beginning, both color sensor methods are suitable for the inspection glass method, and the following devices are available for this purpose:

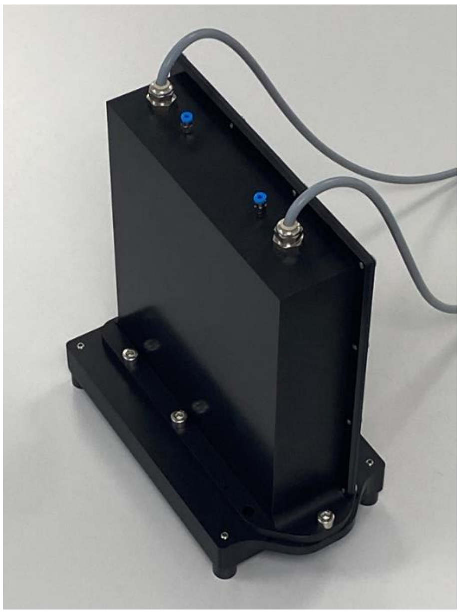
a) SPECTRO-3-0°/45°-MSM-LAB-ANA-LF

b) SPECTRO-3-0°/45°-MSM-LAB-DIG-LF

c) SPECTRO-3-DIF/0°-MSM-LAB-DIG-LF

These laboratory color measurement systems have a large funnel (LF) with a capacity of slightly more than 10 liters. The instrument is powered by an external +24V power supply (available as an option) and is connected to a PC via a USB or Ethernet adapter cable. By means of a slide the channel is opened in the direction of the collection box (9 liters). Light barriers monitor the presence of the so-called placeholder plate, the plastic granulate channel as well as the position of the slide and activate the measurement if all conditions are fulfilled. After the plastic granulate has passed through, the measurement is automatically stopped and an entry is made in the selected file of the DOCAL - PC - software. Furthermore, the system is equipped with a calibration unit, for this purpose only the placeholder plate has to be removed and instead the desired plastic calibration cards have to be inserted one after the other. It is possible to choose between different standards (RAL 0°/45°, RAL diffuse/0° or company internal standards). With the help of the calibration wizard, the operator is guided through the calibration process. Up to now, a measuring accuracy of better dE = 0.3 could be proven with these laboratory devices.

Other color measurement systems that use the inspection glass method are the following two compact devices (Compact Measuring Unit -> CMU):



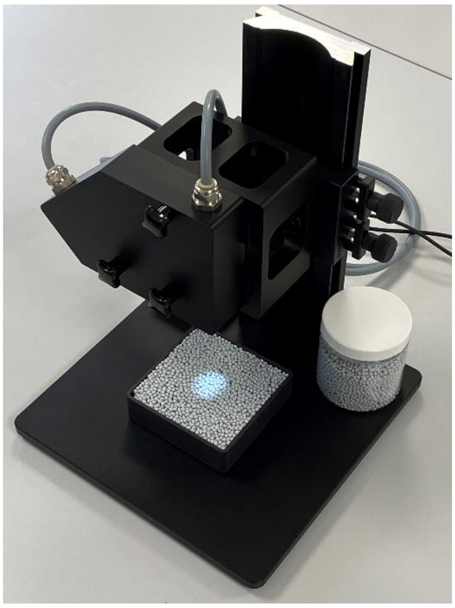
a) SPECTRO-3-0°/45°-MSM-CMU

b) SPECTRO-3-DIF/0°-MSM-CMU

The first operates according to the 0°/45° method, while the second uses the diffuse/0° method. Both systems are characterized by their extremely compact design; moreover, the color measuring system is also suitable for calibrating the color measuring systems. For this purpose, a slot is provided on the unit, with the aid of which the plastic calibration cards (for example RAL plastic cards) can be positioned in front of the sensor system. A further slot is provided for feeding in the plastic granules to be measured. Typ. 0.1 liters of plastic pellets fit into the insertion compartment. This device can therefore also be used for pellet samples where only a small quantity is available for the color tests. In order to be able to measure with the appropriate accuracy, the insert including the pellets must be moved during the test. The measurement results are thus quite comparable with those of the ...-LF devices. The color sensor is connected to the PC via a serial interface (USB adapter or Ethernet adapter) and the power supply is provided by an external +24V power supply unit. Both the +24V power supply and the interface adapters are available from Sensor Instruments as accessories. In a direct comparison of the two device types, the ...-LF series certainly scores in terms of user convenience, while the ...-CMU series is more attractive in terms of price.

2.2.1.2 Color sensor systems for the laboratory using the direct method

Only instrument types that work according to the 0°/45° method can be used for the direct method. For this purpose, a SPECTRO-3-FIO-MSM-DIG-DL is used in conjunction with the KL-D-0°/45°-85-1200-D-S-A3.0 optics front end and mounted on a suitable tripod (manual tripod -> MTP):



a) SPECTRO-3-0°/45°-MTP

The plastic pellets intended for color measurement are filled into the tray included in the scope of delivery and then moved on the stand table during the measurement process so that the light spot sees different areas of the pellet surface, thereby obtaining a better measurement result. Measurement accuracies of dE = 0.3 can also be achieved with this method. Calibration is carried out on granules from which samples have been prepared in the form of plastic plates and measured with a hand-held colorimeter. The L*a*b* values are then entered into the calibration table as target values, while the matching granules are placed in the color measuring system and measured while moving. Of course, this system is also suitable for calibration to RAL cards. In this case, the RAL cards in question are placed one after the other on the tray in which the plastic pellets are normally located.

2.2.1.3 Color measurement systems for mobile laboratory according to the inspection glass method

The mobile laboratory version can be used to obtain color measurement results more quickly. This is also available with 0°/45° and diffuse/0° methods:

a) SPECTRO-3-0°/45°-MSM-MOBILE-DIG-P

b) SPECTRO-3-0°/45°-MSM-MOBILE-ANA-P

c) SPECTRO-3-DIF/0°-MSM-MOBILE-DIG-P

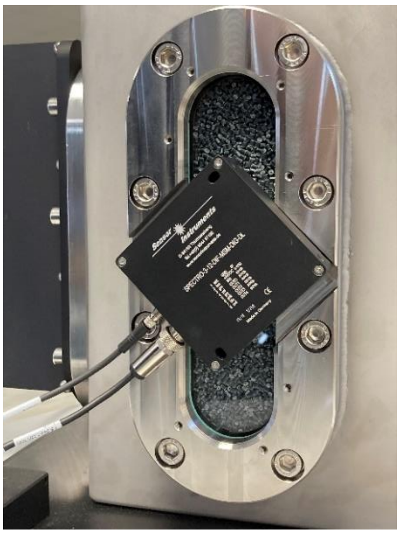
The mobile unit has a powerful battery and can thus be operated independently of the 220V - network. Furthermore, a panel - PC is integrated with. Optionally, a printer can also be added. These devices can also be operated via the DOCAL software. A charger for charging the Li-Ion battery is included in the delivery.

2.2.2 Color sensor systems for inline use

2.2.2.1 Color sensor systems for inline use according to the inspection glass method

Inline acquisition of product data is naturally the fastest method to be able to react promptly to any deviations in product quality. Sensor Instruments follows the approach of working inline with the same sensor technology as is used in the laboratory. This means that the recorded measured values are more comparable and, in addition, the operator does not have to familiarize himself with different measuring devices.

First of all, a suitable position for mounting the inspection glass must be found for an inline measurement. For this purpose, Sensor Instruments offers not only the sight (inspection) glasses but also the matching stainless steel frames, which are either welded or, if necessary, screwed to the designated position of the system. The stainless steel frames are prepared to accommodate the appropriate sensors and on the inside (pellet side) it is ensured that the pellets slide along the inside of the inspection glass as laminar as possible. At certain locations in the plant, both the product and the installation area can reach temperatures that an optoelectronic measuring system could not withstand, which is why Sensor Instruments also uses systems in which the optoelectronic part is separated from the optomechanical front end. The two components are connected by means of robust and temperature-resistant optical fibers. This ensures that both the optomechanical front end and the inspection glass can be exposed to temperatures of up to 150°C. The following two systems, both of which use the optoelectronic part, are based on the same principle.



This applies to the following two systems, both of which use the 0°/45° process:

a) SPECTRO-3-0°/45°-MSM-INLINE-DIG

b) SPECTRO-3-0°/45°-MSM-INLINE-ANA

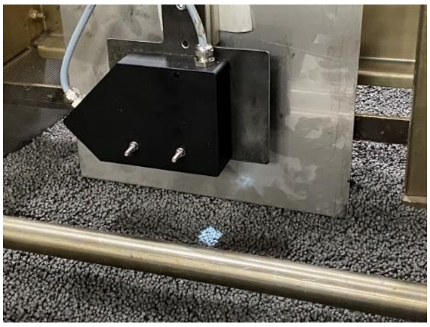
If, on the other hand, the temperature range is "normal" (up to 60°C), a system that works according to the diffuse/0° method can also be used.:

a) SPECTRO-3-DIF/0°-MSM-INLINE-DIG

The SPECTRO-3-20-DIF-MSM-DIG-DL color sensor is mounted directly on the inspection glass. A calibration unit is available for both systems, which can also be used to calibrate the measuring systems on site. The calibration unit is designed to accept RAL plastic cards, calibration is carried out via the calibration assistant of the DOCAL software. Customer-specific calibration cards can also be accommodated by the calibration unit using special adapter frames. Both the 0°/45° systems and the diffuse/0° unit can be mounted on the CALIB-0°/45° calibration unit.

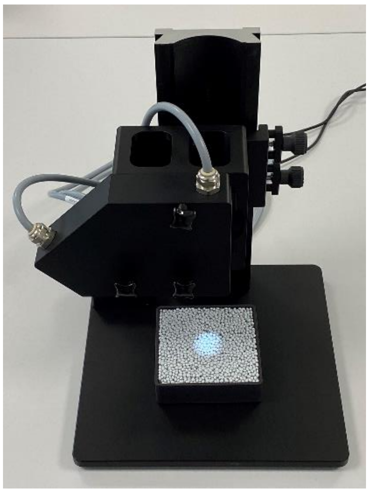
A panel PC is available for displaying the color measurement values and for transferring the measurement data. Corresponding interfaces (3x USB and 1x Ethernet) are available. The robust design of the SI-PCC-500-15", the panel PC is located in a stainless steel housing, allows the use on site at the plants in the immediate vicinity of the inline systems.

2.2.2.2 Color sensor systems for inline use according to the direct method



If it is not desirable, respectively not possible to place inline systems in conjunction with inspection glasses the direct method could be applied. In this case measurements should be taken at the points of the pellet stream where the plastic granulate in motion, e.g. where is transported via a vibratory conveyor line. Due to the height fluctuation of the granulate flow, which can be contained by an integrated deflector plate but not completely eliminated, the 0°/45° method can be used here, since these systems have a larger working distance (85 mm), which means that height fluctuations in the millimeter range are less significant. With the help of the KL-D-0°/45°-85-1200-D-S-A3.0 optomechanical front end, it is also possible to work on systems where higher temperatures (up to 150°C) prevail. The SPECTRO-3-FIO-MSM-DIG-DL optoelectronic control unit should be placed in a location where the ambient temperature is below 60°C. The optomechanical front end can also be used in systems with higher temperatures (up to 150°C). The optomechanical fiber optic front end is equipped with a 1.2m fiber optic cable as standard. However, versions with a 3m (KL-D-0°/45°-85-3000-D-S-A3.0) and a 5m light guide (KL-D-0°/45°-85-5000-D-S-A3.0) are also available. The control electronics is docked to the SI-PCC-500-15" panel PC by means of a USB adapter. The measurement data transmission from the panel PC to the QA is carried out via Ethernet.

The SPECTRO-3-0°/45°-MSU laboratory system serves as the calibration unit. The calibration process requires that the KL-D-0°/45°-85-1200-D-S-A3.0 optomechanical front end including the SPECTRO-3-FIO-MSM-DIG-DL control electronics must first be removed from the system and positioned on the SPECTRO-3-0°/45°-MSU measuring stand.



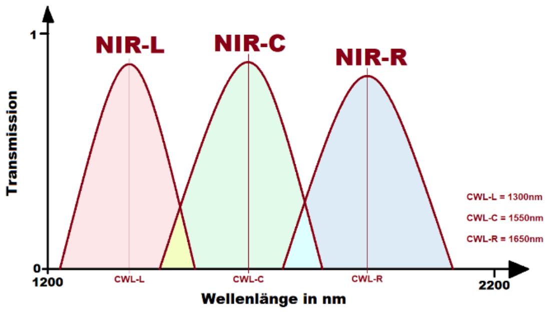
Calibration is performed directly on the plastic granulate, which should also include injection molding platelets that have previously been measured with color handheld devices. With the aid of the calibration wizard in the DOCAL PC software, the L*a*b* color values of the plastic plates can be entered in the calibration table. The corresponding XYZ color values are determined after placing the dish with the respective pellets and moving the dish after starting the measured value recording and then entered in the calibration table. Instead of the plastic pellets, it is also possible to calibrate on the RAL plastic cards. These can then be placed in the inverted dish. The distance to the sensor front end is then 85mm. The required RAL cards can be read in one after the other. The software wizard of the DOCAL - PC - software provides good services here.

3. NIR - sensor systems for the control of the plastic type in the laboratory as well as inline

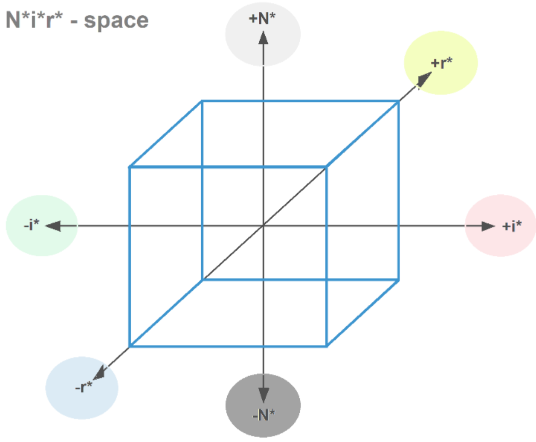
3.1 The NIR three-range method - a proven sensor principle adapted from the visible range

Offner spectrographs are usually used in the recycling sector for the separation of various plastics and form the core of so-called hyperspectral cameras. With these cameras, in combination with a broadband NIR light source (powerful halogen lamps), a moderate spatial resolution and at the same time a good spectral resolution of the objects to be examined can be achieved. In a slightly different setup, the light of a powerful halogen lamp is directed by means of optics onto the mirrors of a polygon scanner and in the further course the bundled NIR light hits an object; this in turn reflects a part of the non-absorbed light via polygon scanner onto a receiver optics and from this on the further way onto the entrance aperture of a NIR grating spectrometer. The advantage of both methods is the spectral detection of a large NIR wavelength range with additional spatial resolution. This makes it possible to detect different objects, which are transported on a conveyor belt, for example, and which pass through the detection range of the sensor at the same time, but lying next to each other, as separate objects and at the same time can be spectrally distinguished.

In the case of plastic pellets, on the other hand, it is less a question of spectral examination of each individual pellet, but rather of an integral procedure that can detect as many plastic pellets as possible during a measuring process and thus provide the most reliable information possible about the quality or purity of the product. The complex technology that would be required for additional determination of the local position can thus be dispensed with. In principle, a NIR spectrometer including optics and NIR broadband illumination, but without local resolution, could be considered, which would nevertheless turn out to be a rather cost-intensive solution.



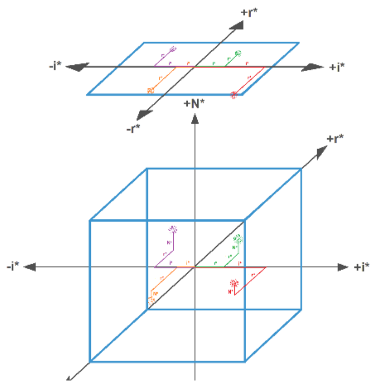
A more cost-effective alternative to this is a system in which the three-range method is used. In this measuring method, three different NIR LED types, each LED type covering a specific wavelength range in the NIR (the near infrared wavelength range), are directed onto the plastic pellets to be examined and a part of the light not absorbed by the pellets is detected, converted and fed to an electronic evaluation system by means of a broadband NIR receiver. In analogy to the three-range color evaluation in the visible wavelength range, the color values are also calculated from the raw color data NIR-L, NIR-C and NIR-R (analogous to RED-X, GREEN-Y and BLUE-Z): N*i*r* (analogous to L*a*b*)



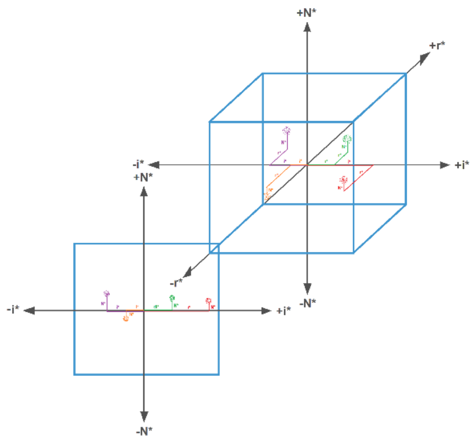
N* provides information about the gray value of the granules to be examined. The higher the N* value, the lighter the granules.

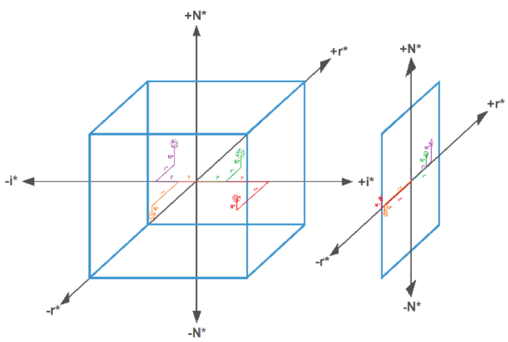
i* provides information on the reflectance curve between the medium NIR (with a central wavelength of 1550nm) and the short NIR wavelength range (1300nm - central wavelength). A high negative i* value indicates increased reflection from the granules at NIR-C, while a high positive i* value indicates increased reflection from the granules at NIR-L.

r* shows the reflection curve between the medium NIR wavelength range (1550nm - central wavelength) and the long NIR wavelength range (with a central wavelength of 1650nm). A high negative r* value indicates an increased reflection at the granules around NIR-R, while a high positive r* value indicates an increased reflection at the granules around NIR-.

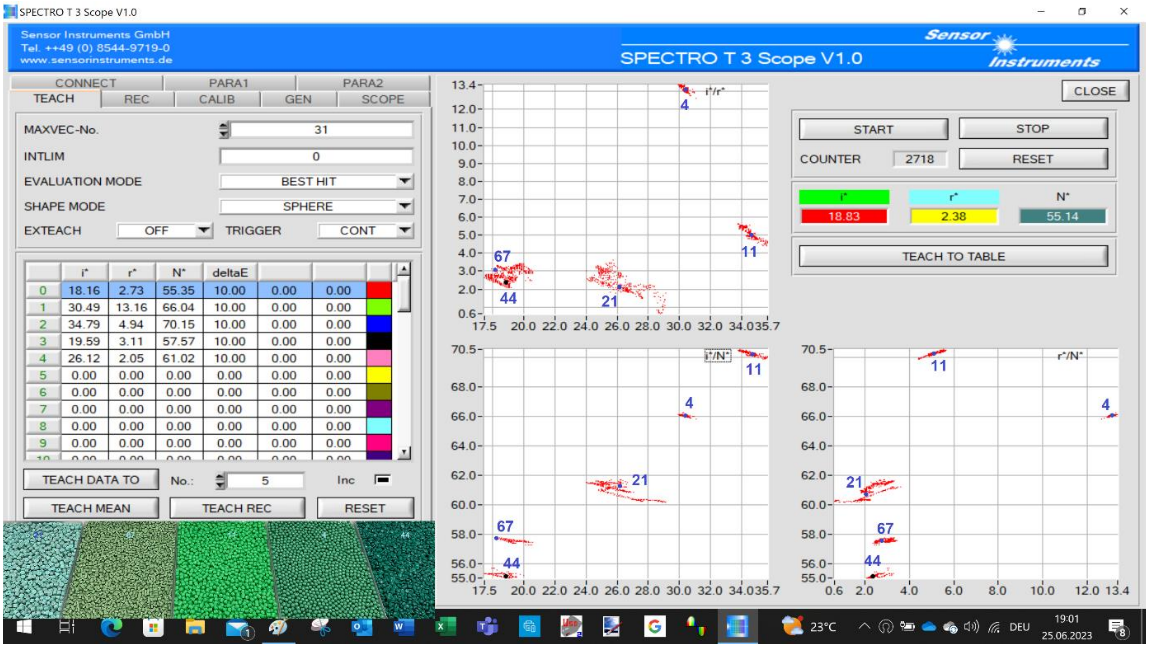


To make the N*i*r* space clearer on the screen, three different views were created: View of the N*i*r* - Space from a) above i*r*, b) from the side r*N* and c) from the front i*N*. These three diagrams are displayed in the SPECTRO T 3 Scope V1.0 PC software. The following is a screenshot of this Windows® interface in which 5 different plastic recyclates were measured using an NIR sensor that operates according to the diffuse/0° method. The individual point clouds are clearly visible, their centers provide information about the 5 different recyclates. The point clouds result from the different positions of the pellets in the detection range of the sensor system during a complete measurement. After completion of a measurement, the average value of the respective point cloud is determined, which then results in the respective centers. The SPECTRO-T-3-Scope V1.0 - PC software is primarily used for parameterization of the sensor system, as well as for more in-depth analysis of the individual pellets. With the DOCAL software, which is also





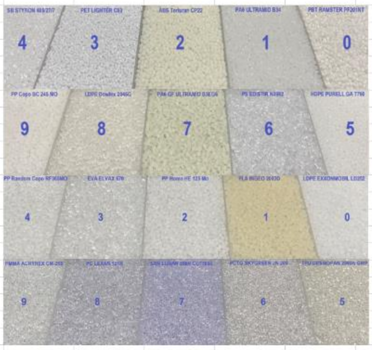
available here, the respective centers are already determined and the result is displayed numerically in the form of an N*i*r* value. The deviations in N* (dN*), in i* (di*) as well as in r* (dr*) are displayed numerically as well as graphically in the respective slides.



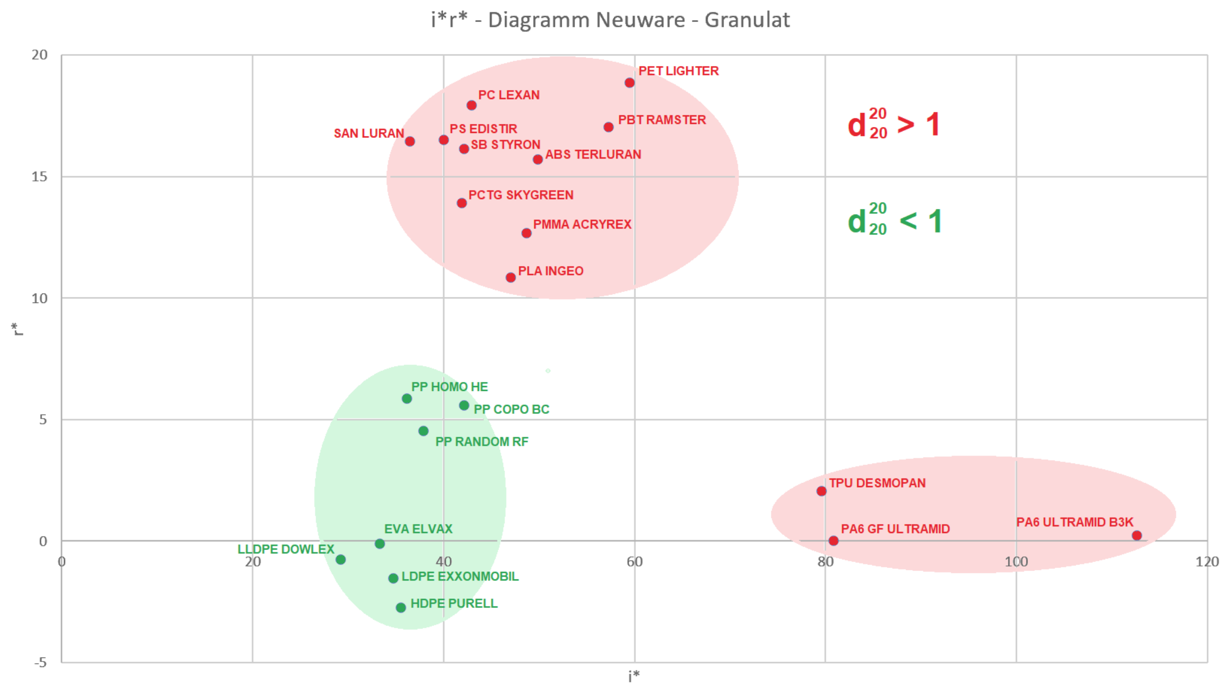
PC – Software SPECTRO T 3 Scope V1.0

With the diffuse/0° method and using the inspection glass method, a number of recyclates as well as virgin granules have already been examined. A short summary can be seen in the following diagrams:

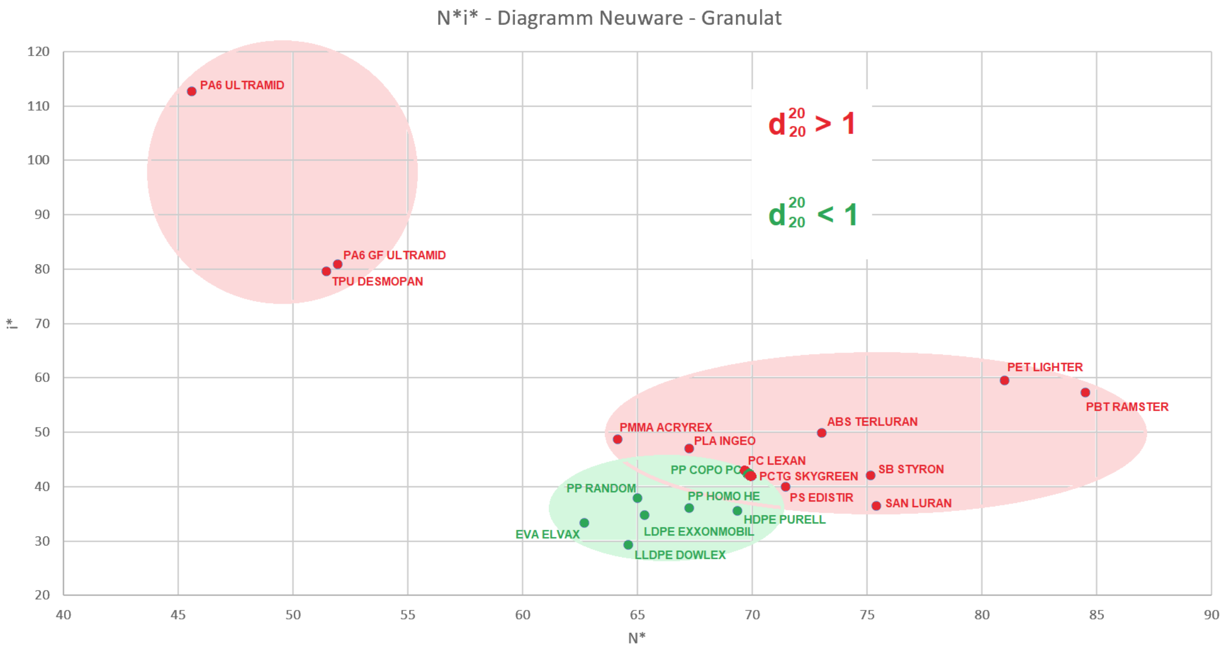
NEUWARE - GRANULATPROBEN GEMESSEN MIT DEM SPECTRO-T-3-60-NIR/NIR-D20						
GRANULAT - BEZEICHNUNG	$d^{2°}_{20}$ rel. Dichte zu Wasser	Kunststoffart	N*	i*	r*	SPECTRO T3 Scope V1.0 Nummer
PBT RAMSTER PF201NT	>1	PBT	84,49	57,25	17,03	0
PA6 ULTRAMID B3K	>1	PA6	45,58	112,64	0,23	1
ABS TERLURAN GP22	>1	ABS	73,01	49,84	15,7	2
PET LIGHTER C93	>1	PET	81	59,51	18,86	3
SB STYRON 485/27/7	>1	PS	75,14	42,11	16,13	4
HDPE PURELL GA 7760	<1	HDPE	69,34	35,49	-2,75	5
PS EDISTIR N3982	>1	PS	71,45	40,01	16,52	6
PA6 GF ULTRAMID B3EG6	>1	PA6	51,94	80,84	0	7
LLDPE DOWLEX 2045G	<1	LLDPE	64,6	29,24	-0,77	8
PP COPO BC 245 MO	<1	PP	69,89	42,11	5,58	9
LDPE EXXONMOBIL LD252	<1	LDPE	65,31	34,76	-1,54	0
PLA INGEO 2003D	>1	PLA	67,26	47,06	10,84	1
PP HOMO HE 125 MO	<1	PP	67,26	36,13	5,88	2
EVA ELVAX 670	<1	EVA	62,7	33,33	-0,1	3
PP RANDOM RF 365 MO	<1	PP	65,01	37,87	4,55	4
TPU DESMOPAN 2590A GMP	>1	TPU	51,44	79,62	2,06	5
PCTG SKYGREEN JN200	>1	PCT-G	69,97	41,87	13,9	6
SAN LURAN 358N CC77850	>1	Acrylester	75,39	36,44	16,46	7
PC LEXAN 121R	>1	PC	69,65	42,97	17,94	8
PMMA ACRYREX CM-205	>1	PMMA	64,15	48,65	12,66	9



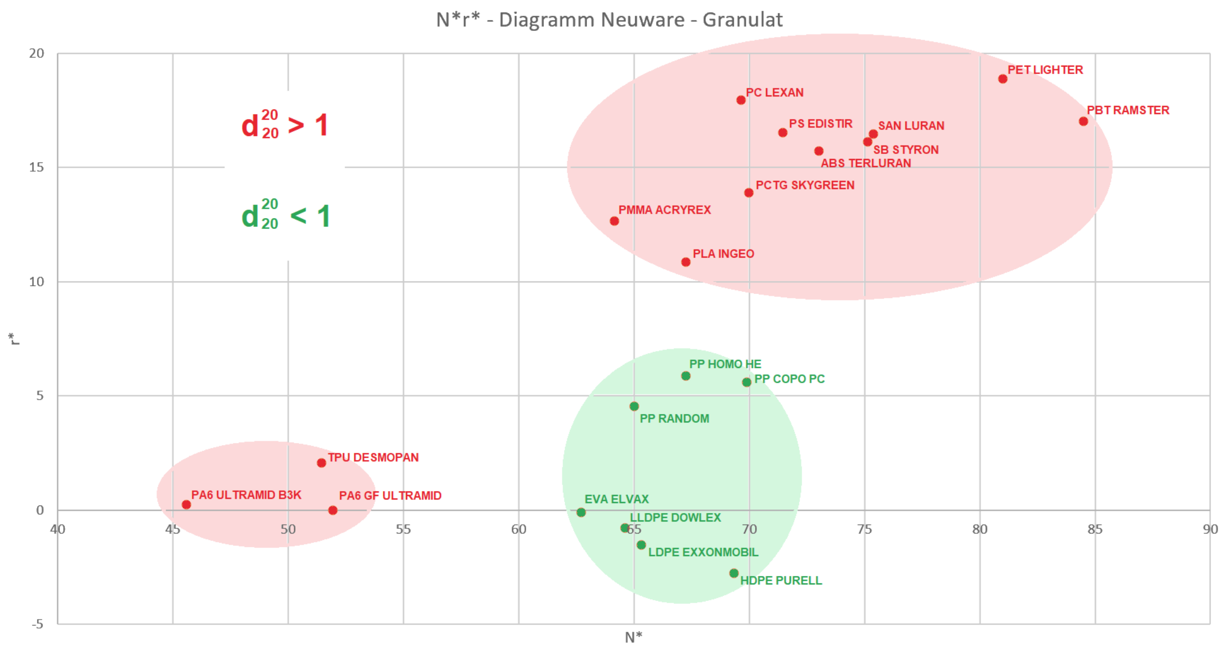
N*i*r* - Measured values on different Virgin materials



i*r*-Diagram



N*i*-Diagram



N*r*-Diagram

In the case of the virgin granules examined, the differences between the individual types can be seen quite clearly. Especially in the i*r* diagram, the individual groups are clearly separated from each other. But also with the measurements on the recyclates quite good results could be achieved:

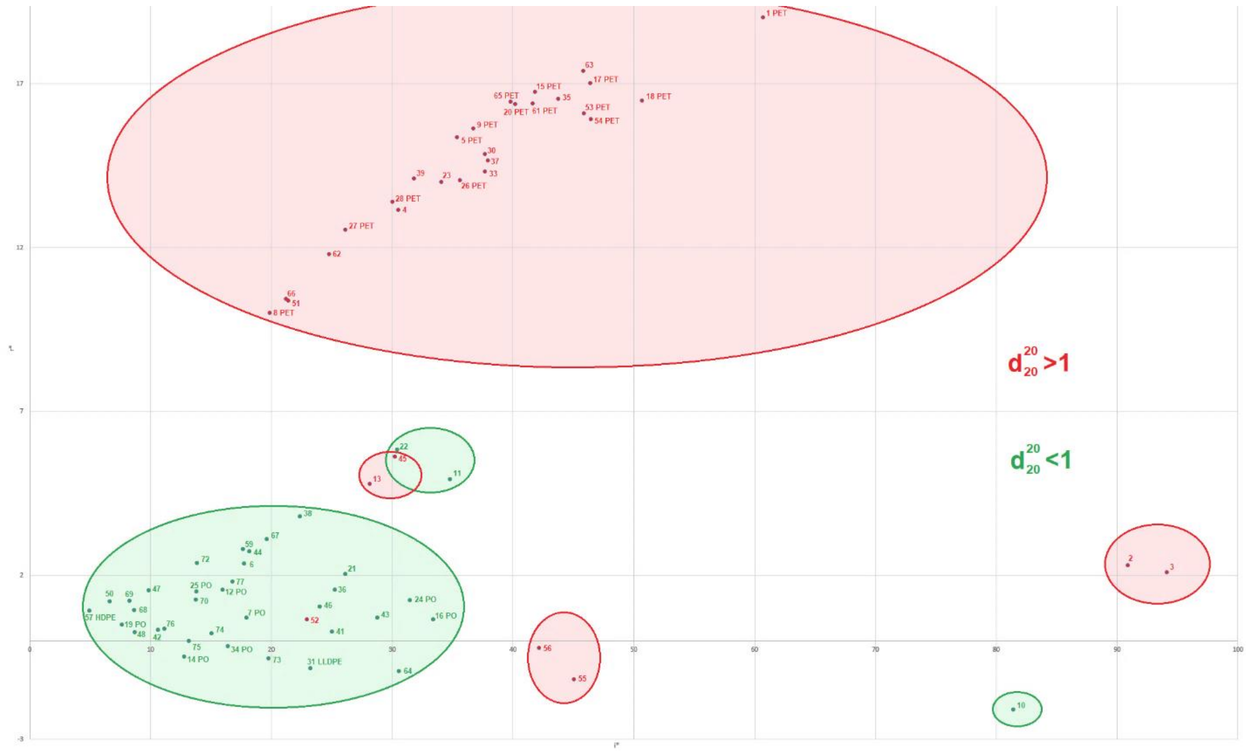
REZYKLATE GEMESSEN MIT DEM SPECTRO-T-3-60-NIR/NIR

REZYKLAT - BEZEICHNUNG	d^{20}_{20} rel. Dichte zu Wasser	Kunststoffart	N*	i*	r*	SPECTRO T3 Scope V1.0 Nummer
10 BEIGE-WEISS SEMITRANSPARENT	<1	PO	52,86	81,39	-2,09	0
18 WEISS	>1	PET	72,06	50,66	16,5	1
64 WEISS SEMITRANSPARENT	<1		69,6	30,52	-0,92	2
52 BEIGE	>1		80,69	22,95	0,66	3
15 WEISS	>1	PET	75,05	41,81	16,76	4
53 GRAU	>1	PET	75,64	45,84	16,11	5
55 GRAU-BEIGE	>1		74,76	45,04	-1,16	6
46 HELLBEIGE	<1		81,28	23,99	1,05	7
16 HELLBEIGE	<1	PO	76,63	33,39	0,66	8
54 GRAU	>1	PET	75,54	46,45	15,93	9
36 BEIGE	<1		81,85	25,24	1,57	0
30 HELLBLAU	>1		71,06	37,69	14,86	1
1 WEISS	>1	PET	83,04	60,67	19,04	2
35 HELLGRÜNBLAU	>1		77,39	43,73	16,55	3
41 BEIGE	<1		81,3	24,99	0,29	4
38 HELLBLAU	<1		65,05	22,37	3,81	5
65 HELLBLAU	>1	PET	77,56	39,79	16,46	6
17 HELLBLAU	>1	PET	78,82	46,39	17,03	7
62 GRAUBLAU	>1		62,49	24,78	11,8	8
61 HELLBLAU MIX	>1	PET	75	41,6	16,41	9
23 BLAU TRANSPARENT	>1		60,2	34,06	14	0
7 BLAU	<1	PO	59,54	17,91	0,71	1
25 GRAUBLAU	<1	PO	39,51	13,76	1,51	2
3 ROT	>1		56,23	94,09	2,1	3
2 VIOLETT	>1		54,23	90,88	2,31	4
6 BLAU	<1		48,61	17,73	2,36	5
50 DUNKELGRÜN	<1		34,74	6,59	1,21	6
47 DUNKELBLAU	<1		37,81	9,83	1,54	7
9 HELLBLAU	>1	PET	73,57	36,68	15,64	8
66 OLIV	>1		61,07	21,18	10,44	9
44 GRÜN	<1		55,35	18,16	2,73	0
4 GRÜN	>1		66,04	30,49	13,16	1
11 HELLGRÜN	<1	PO	70,15	34,79	4,94	2
67 OLIV	<1		57,57	19,59	3,11	3
21 TÜRKIS	<1	PO	61,02	26,12	2,05	4

N*i*r* - Measured values for different Virgin materials - Part-1

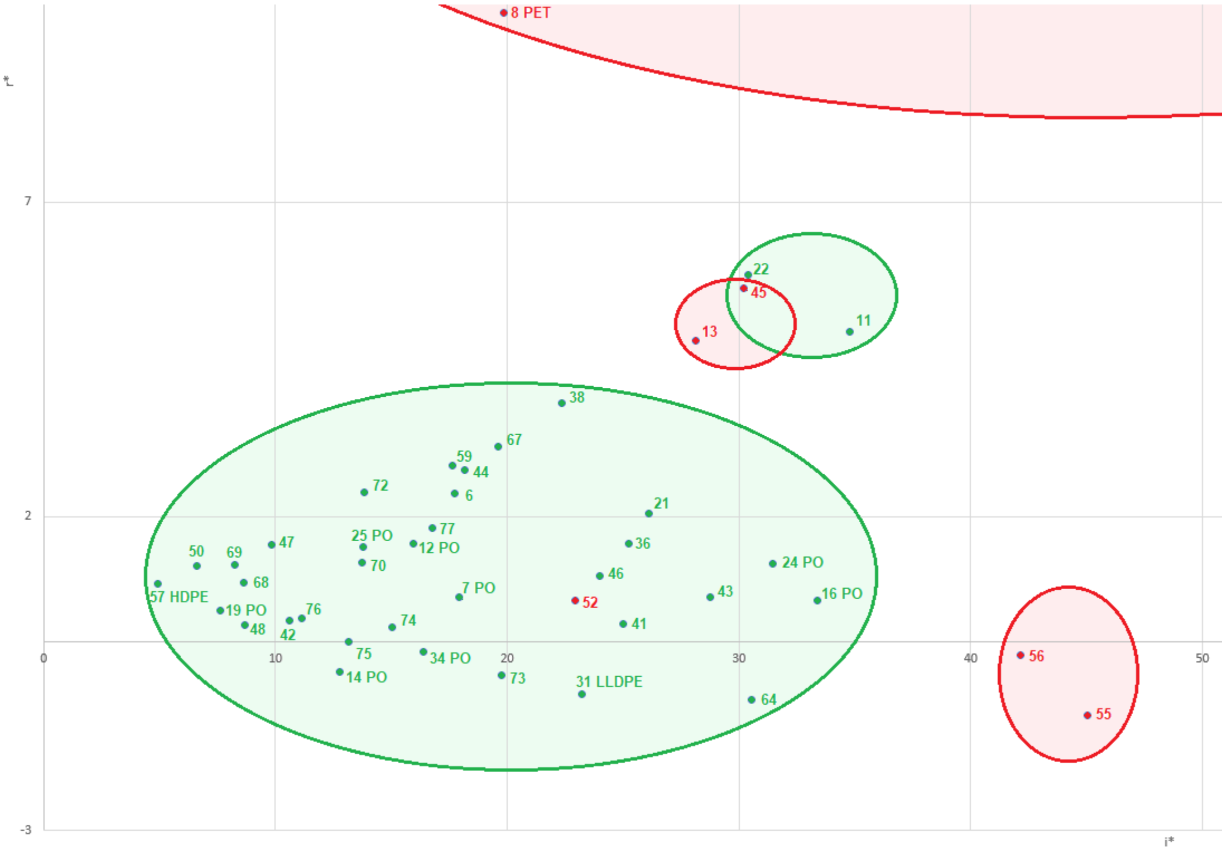
24 TÜRKIS	<1	PO	76,34	31,46	1,25	5
51 OLIV	>1		60,8	21,39	10,38	6
69 DUNKELGRÜN	<1		35,85	8,24	1,23	7
68 DUNKELGRÜN MIX	<1		34,59	8,64	0,95	8
48 DUNKELGRÜN	<1		34,4	8,67	0,27	9
42 GRAUGRÜN	<1		45,38	10,59	0,35	0
12 GRAU	<1	PO	42,18	15,93	1,57	1
72 GRAUBEIGE	<1		46,15	13,85	2,38	2
59 GRAU	<1		52,07	17,61	2,81	3
70 DUNKELGRAU	<1		41,65	13,73	1,26	4
28 GRAU TRANSPARENT	>1	PET	63,24	30	13,4	5
31 BEIGE	<1	LLDPE	58,02	23,22	-0,83	6
34 BRAUN	<1	PO	52,78	16,36	-0,15	7
14 OLIV	<1	PO	51,69	12,79	-0,48	8
8 OLIV TRANSPARENT	>1	PET	52,7	19,87	10,01	9
22 BEIGE TRANSPARENT	<1	PO	63,61	30,4	5,85	0
37 BEIGE	>1		70,25	37,9	14,67	1
13 BEIGE	>1		74,14	28,11	4,79	2
43 WEISS TRANSPARENT	<1		69,08	28,75	0,71	3
5 BEIGE	>1	PET	75,19	35,34	15,37	4
20 HELLGRAU	>1	PET	77,56	40,16	16,39	5
39 GRÜNGRAU	>1		72,35	31,8	14,11	6
26 GRAU	>1	PET	68,05	35,61	14,06	7
33 GRAUWEISS MIX	>1		69,54	37,66	14,32	8
27 GRÜNGRAU	>1	PET	65,69	26,09	12,56	9
45 GELB	>1		89,91	30,18	5,63	0
63 GRAU	>1		79,53	45,78	17,4	1
56 HELLGRAU	>1		74,45	42,14	-0,2	2
57 SCHWARZ	<1	HDPE	32,95	4,91	0,93	3
19 DUNKELGRAU	<1	PO	34,64	7,63	0,51	4
77 BLAU FC 387	<1		28,48	16,75	1,82	5
76 ROT FC 071	<1		38,46	11,11	0,37	6
75 GRÜN FC 144	<1		16,09	13,15	0	7
74 GRÜN FC 040	<1		37,19	15,05	0,23	8
73 GRÜN FC 049	<1		57,26	19,74	-0,52	9

N*i*r* - Measured values with different Virgin materials - Part-2

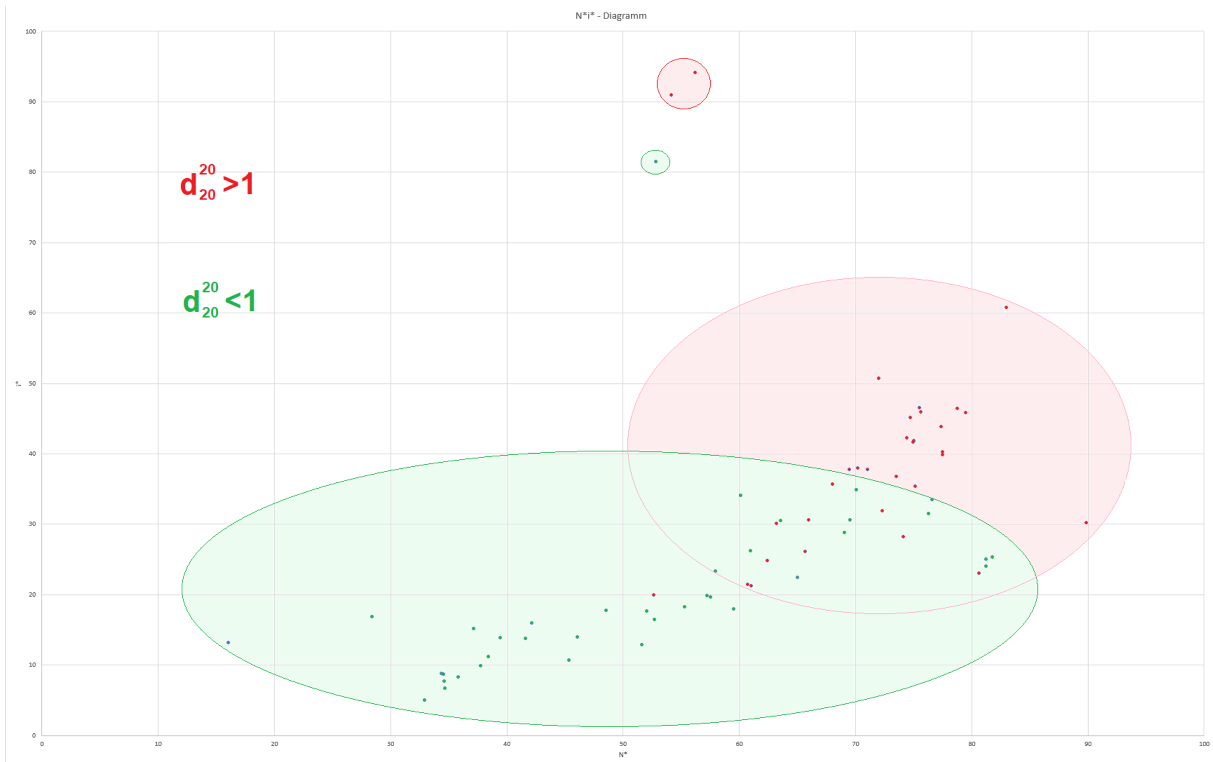


i*r* - Diagram

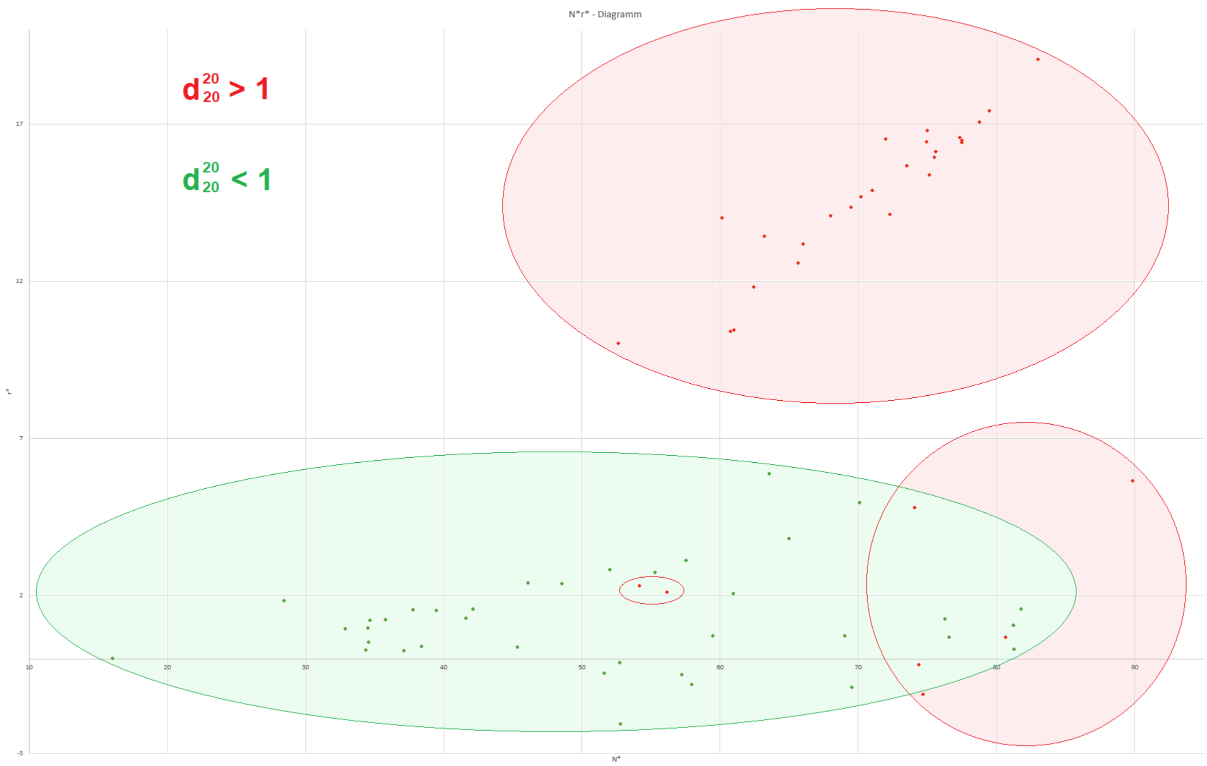
The types of plastics can also be clearly distinguished in the case of recyclates (for example, PET from poly-olefins).



*i*r* - Diagram zoomed*



*N*i* - Diagram of the studied recyclates*



N*r* - Diagram of the studied recyclates

3.2 NIR - Sensors and measuring geometry for NIR detection

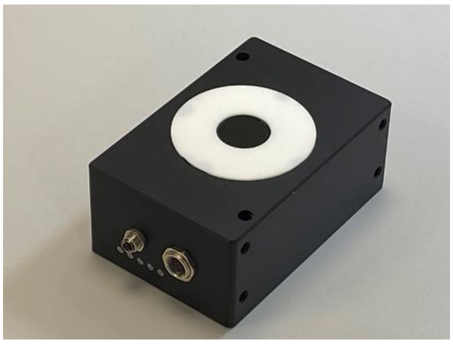
As with color sensing, it is also important to minimize the direct reflection of the illumination in NIR detection. Analogous to color measurement, two measurement geometries are available for this purpose:

3.2.1 NIR - Sensor according to the 0°/45° - method

An optical fiber version is used for this purpose. The optomechanical front end is thus connected to the control unit on the transmitter and receiver side via fiber optics. The light of the three NIR LED types is coupled into the transmitting fiber optic cable via the fiber optic connector. The NIR light irradiation at the front end is perpendicular to the granule surface, whereas the receiving light guide views the plastic granule surface at an angle of 45° (0°/45° method). The light guide version SPECTRO-T-3-FIO-NIR/NIR (control electronics) + KL-D-0°/45°-22-d80/d110-A3.0-NIR (front end) is primarily used in locations with high plastic pellet temperatures and high ambient temperatures. The control electronics has 5 digital outputs. The sensor system is supplied via +24V DC. The N*i*r* values are output via the serial interface.

3.2.2 NIR - Sensor according to the diffuse/0° - method

Sensors such as the SPECTRO-T-3-10-DIF-NIR/NIR, which operate according to the diffuse/0° method, use light sources that illuminate the entire half-space; there is no preferred direction for the emitted light. In addition to a cluster consisting of three different types of NIR LEDs, each of which has a beam angle of +/- 64°, a so-called volume diffuser (frosted glass pane) is used as a diffuser. Due to the process, the distance between the light emission at the sensor and the granulate surface to be measured must be reduced to a minimum. In the case of the inspection glass method, however, a 9 mm thick crown glass plate separates the sensor from the granulate surface, so that a minimum distance of approx. 10 mm must be expected. However, the crown glass plate (refractive index n = 1.6) reduces the optical distance again to approx. 6mm. The glass cover for the detector area is arranged in the center of the scattering glass plate. The optical axis of the receiver side is parallel to the normal (0°) and thus meets the granule surface perpendicularly



3.3 NIR - Sensor systems for the laboratory

3.3.1 NIR - Sensor systems for the laboratory according to the inspection glass method

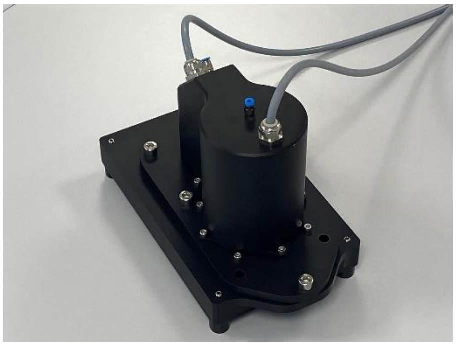
For the laboratory, NIR sensor systems with large funnels are available, as well as systems in which granulate samples from 0.15 liters are sufficient for analysis:

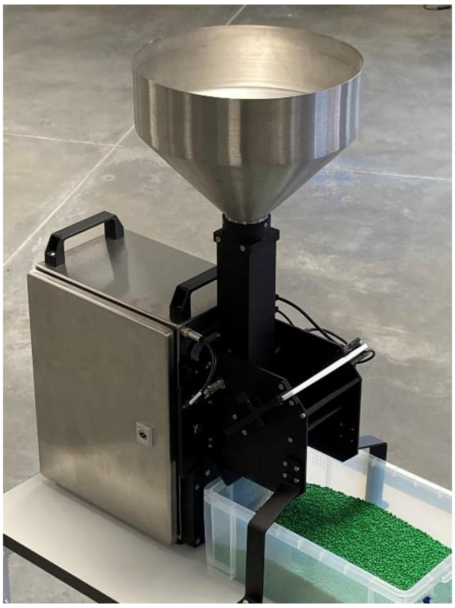
a) SPECTRO-T-3-0°/45°-LAB-LF

b) SPECTRO-T-3-DIF/0°-LAB-LF

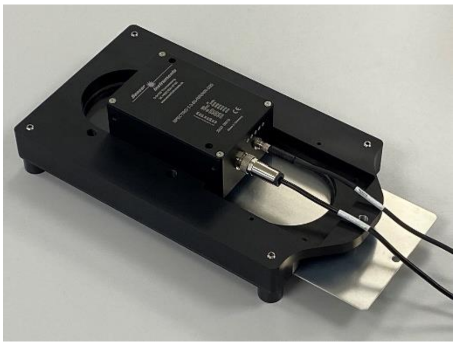
c) SPECTRO-T-3-0°/45°-LAB-CMU

d) SPECTRO-T-3-DIF/0°-LAB-CMU





The SPECTRO-T-3-0°/45°-LAB-LF and SPECTRO-T-3-0°/45°-LAB-CMU NIR sensor systems are fiber optic systems. The ...-LAB-LF system can hold up to 10 liters of plastic granulate and form an average value from this, whereas the ...-LAB-CMU system manages with a plastic granulate quantity of approx. 0.15 liters. In the ...-LAB-CMU model, the N*i*r* average value is calculated after a time window, which can be set using the DOCAL software, has elapsed. While the time window is open, the pellet sample is moved through the detection range of the sensor system, thus the N*i*r* result is much less influenced by the random position of the pellets. As with the color measurement systems, approximately comparable accuracy values can be achieved with the NIR measurement systems with both systems (...-LF and ...-CMU). Since the dE value is also used in the NIR systems to evaluate the distance between two plastic granules in the N*i*r* space, a certain accuracy comparison with the color measurement systems is possible. It should be noted that an accuracy of around dE = 0.3 is also achieved with the NIR measuring systems. As with all measuring systems, calibration of the NIR measuring systems is



advisable at certain intervals. Various calibration samples are available for this purpose. All calibration samples can be used in connection with the respective instruments. For this purpose, a slot is provided in the respective measuring system, which is used to hold the calibration samples. The calibration of the NIR measuring systems is best carried out with the calibration assistant of the CALIB PC software. The GARDOBOND OAA6014/4 aluminum plate (clean and free of grease and oil) is used for the intensity calibration of the three NIR channels (NIR-L, NIR-C and NIR-R), while further calibration samples are used for the calibration of the measuring system in the respective N*i*r* subspace.

3.3.2 NIR - Sensor systems for the mobile laboratory according to the inspection glass method

Waiting too long for the results from the lab? In this case, the mobile laboratory can provide a remedy. The systems are similar to the ...-LF types, but have a self-sufficient power supply by means of a lithium-ion battery. Furthermore, a printer, which is also battery powered, is available as an option. The sensor system can transmit the measured results via Ethernet and USB interfaces. Furthermore, a panel PC is integrated in the robust stainless steel housing. In addition to a wireless computer mouse, a wireless keyboard is also included in the scope of delivery. The Li Ion battery can be supplied via the charger, which is also included. Thanks to the stainless steel funnel (with a capacity of approx. 10 liters), hot recyclate can also be filled into the funnel. With the enclosed stainless steel chute, the hot granulate can be filled into the hopper. The aluminum channel, the POM slide and the inspection glass made of crown glass are also temperature

The following system types are available:

a) SPECTRO-T-3-0°/45°-MOBILE-P

b) SPECTRO-T-3-DIF/0°-MOBILE-P

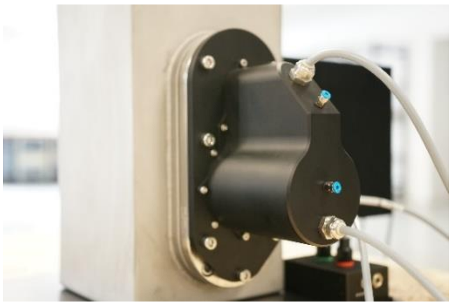
With the 0°/45° method, the NIR light source is directed vertically onto the inspection glass and onto the pellets lying directly behind it. The receiver optics look at 45° onto the illuminated plastic pellet.

In the diffuse/0° method, on the other hand, the transmitter delivers diffuse NIR light. The emitter light comes from almost the entire half-space; the receiver, on the other hand, is directed at 0° to the normal and thus perpendicular to the inspection glass on the granulate surface illuminated with NIR light.

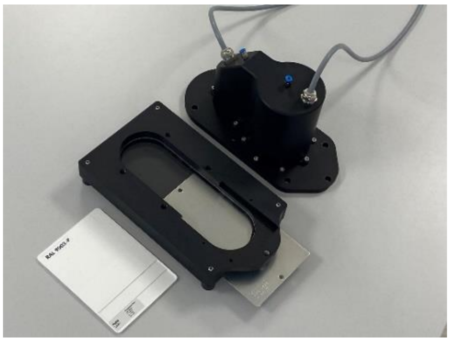
With both methods, the direct reflection is suppressed as far as possible. Since direct reflection is a surface effect (gloss), this type of reflection does not provide any information about the plastic material. Diffusely reflected light, on the other hand, provides spectral information about the composition of the respective plastic due to the interaction (partial absorption) with the plastic matrix. Tests have shown that even with transparent virgin material (clear, transparent granules) good measurement results could be achieved.

3.4 NIR - Sensor systems for inline operation

3.4.1 NIR - sensor systems for inline operation according to the inspection glass method



The SPECTRO-T-3-0°/45°-INLINE fiber optic system can be used for inline NIR measurements at higher temperatures, i.e., temperatures beyond 60°C. The core of this system is the SPECTRO-T-3-FIO-NIR/NIR control electronics in conjunction with the KL-D-0°/45°-22-d80/d110-A3.0-NIR fiber optic front end. The heart of this system is the SPECTRO-T-3-FIO-NIR/NIR control electronics in conjunction with the KL-D-0°/45°-22-d80/d110-A3.0-NIR fiber optic front end, which is additionally integrated into a protective housing. In addition, the protective housing can be pressurized with compressed air. The DOCAL PC software is also used here for recording measurement data and for displaying the measured values in graphical and numerical form. For the purpose of calibration, the NIR sensor front end can be removed and placed on the CALIB-0°/45° calibration unit. Different plastic cards as well as an aluminum plate of the type GARDOBOND OAA6014/4 are available for the calibration process. The aluminum plate is also used here for the intensity adjustment of the individual NIR channels



The far more compact NIR measuring system, on the other hand, is the SPECTRO-T-3-DIF/0°-INLINE system. The outer component of the stainless steel crown glass holder was mechanically modified to accommodate the sensor system. The modifications to the inner component, which is directed towards the granulate side, ensure a laminar granulate flow in contact with the inspection glass. For calibration, the sensor system is unscrewed and positioned on the CALIB-DIF/0° calibration unit. In addition to the GARDOBOND OAA6014/4 aluminum plate, various plastic cards are also available for calibration. The calibration procedure is carried out with the aid of the DOCAL PC software. The operator is guided through the calibration process by means of a calibration assistant. The data recording as well as the graphical and numerical reproduction of the measurement results on the PC is also carried out here by the DOCAL software. Usually, the DOCAL software on a SI-PCC panel PC is used for the inline systems. The data transfer from the Inline systems takes place via the USB adapter cable. The measured values are displayed on the monitor of the panel PC in graphical and numerical form.

4. Marker - detection systems to distinguish the marked from the non-marked plastic granules in the laboratory as well as inline

The guidelines "New rules for plastic - recyclates in contact with food" of the associations of the plastic - processing industry (GKV) and the plastic - recyclers (BDE, bvse), based on the new EU - Commission Regulation No. 2022/1616 on recycled plastics in contact with food from September 15, 2022, state that PET - waste may be used "with a **maximum of 5%** materials and articles that have been used in contact with materials or substances other than food". This regulation applies to post-consumer PET waste.

How can PET packaging that has been used in contact with foodstuffs be distinguished from PET packaging that has been used in contact with materials or substances other than foodstuffs? If, in addition, the color of the packaging is the same in both cases, e.g. transparent clear or transparent but slightly bluish, even a combination of color and NIR sorting devices during the pre-sorting of recycled packaging during separation may prove to be unsuitable. Image processing systems, on the other hand, can use labels or sleeves on the packaging to identify the intended use of the packaging. Barcodes, QR codes and digital watermarks make sorting easier. After pre-sorting and subsequent shredding of the packaging, the flakes are washed and sorted again. To stay with the above example, transparent PET flakes would have to be separated from transparent PET flakes. Since any additional information applied to the flakes has been removed by the size reduction and subsequent cleaning process, the additional re-sorting does not improve the sorting result. However, since flake sorting in particular normally makes the decisive contribution to improving the grade purity of crushed material, it is questionable whether the above 5% rule can be complied with.

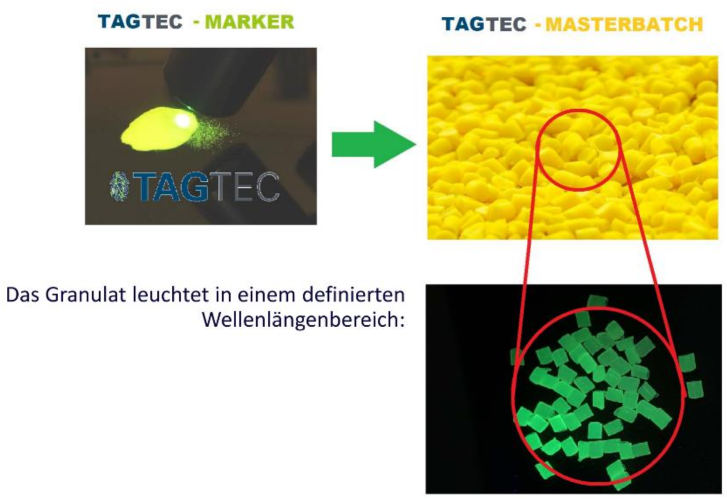
But what if PET packaging, which is used in contact with materials and substances other than food, were labeled with a marker and this marker were anchored in the plastic matrix during packaging production? If, in addition, this marker were temperature-resistant, long-lasting and of small particle size and, moreover, in low concentration in the end product, in the entire packaging, in the flakes but also in the recyclate, well and reliably detectable?

4.1 TAGTEC – Masterbatches

TAGTEC (Taggant Technology) markers are special masterbatches from Gabriel-Chemie GmbH in Gumpoldskirchen, Austria. The masterbatches contain about 0.1% markers. Depending on the application, the markers are phosphorescent or fluorescent particles with a particle size of typically 1 µm to 10 µm in diameter. The respective masterbatch is added to the plastic base material by means of a metering unit at a mixing ratio of 1% to 2%. Which masterbatch is best used where and which detectors are available?

These questions will now be explained in more detail below.

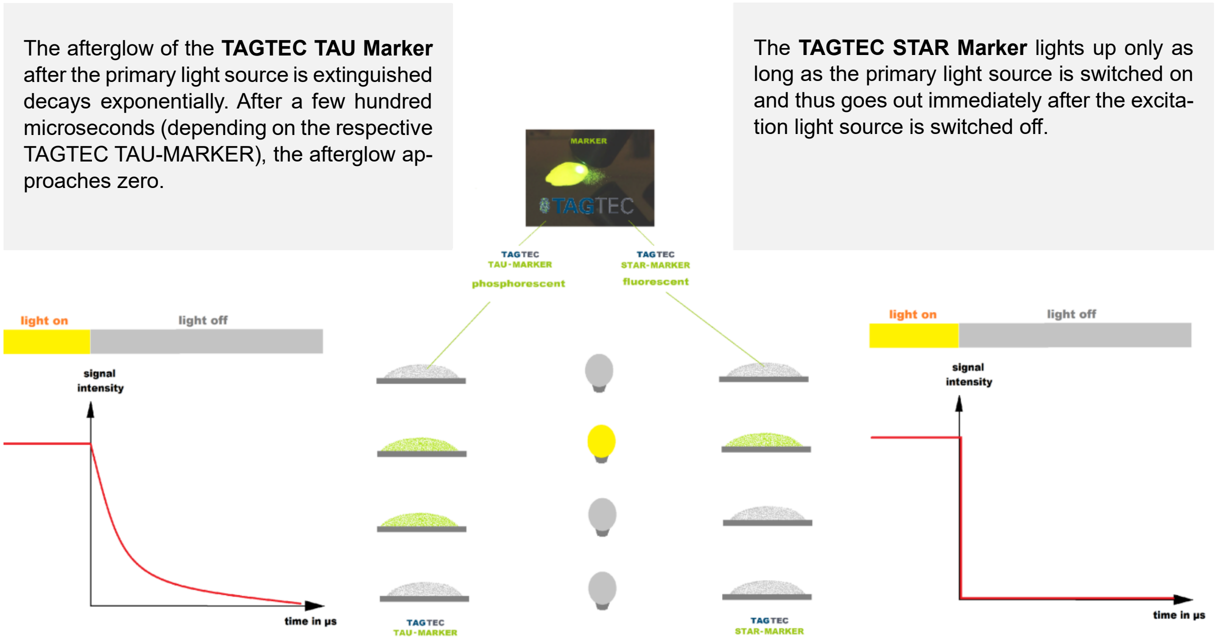
4.1.1 TAGTEC - Masterbatches with phosphorescent and fluorescent markers



In the case of phosphorescent and fluorescent TAGTEC masterbatches, the inorganic marker particles are introduced into the plastic matrix in a mixing ratio of typically 0.1% to 0.2%. Depending on the application, phosphorescent or fluorescent marker particles are used. Depending on the application, different plastic types are available. The particle size of the markers can also be selected and is in the range between 1µm and 10µm in diameter. As a rule, the mixing ratio between masterbatch and plastic base material is 1% to 2% masterbatch content, resulting in a marker concentration in the end product of typically 10ppm and 40ppm. Due to the different sensitivity of the individual markers, however, deviations in the concentrations or mixing ratios from the empirical values mentioned may occur. According to their physical properties, the TAGTEC markers can be divided into two groups:

a) **Phosphorescent TAGTEC markers (TAU Markers)**, with afterglowing property, i.e. after switching off the excitation light suitable for the respective marker, the marker emits light in a defined wavelength range; the light signal thereby decreases exponentially with a time constant (TAU) characteristic for the respective TAGTEC marker. TAU describes the time at which the excitation signal drops to 1/e (to approx. 37%).

b) **Fluorescent TAGTEC markers (STAR Markers)**, emit light upon excitation with primary light suitable for the respective marker. Secondary emission (the wavelength range depends on the marker) ends at the same time as the primary light is switched off. Primary light excitation is typically in the UVA or blue wavelength range.

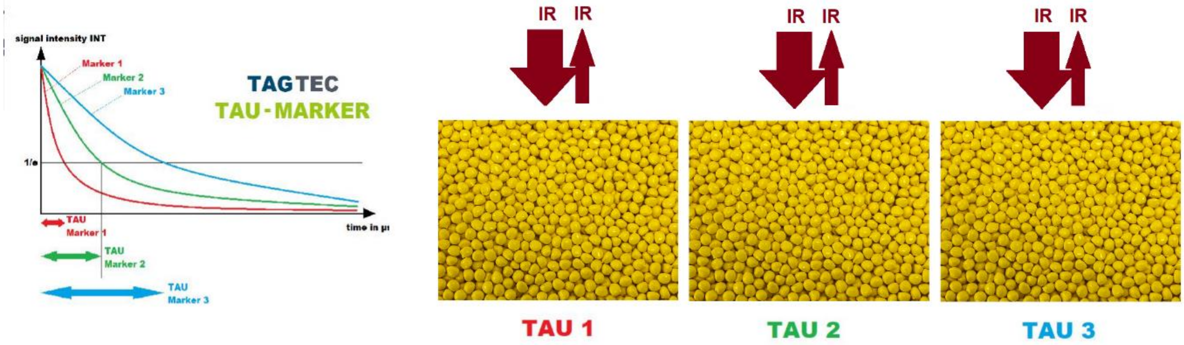


Phosphorescent (left) and fluorescent TAGTEC markers (right)

While most fluorescent TAGTEC markers can be excited in the UV-A range as well as in the visible wavelength range, the excitation spectrum for the phosphorescent TAGTEC markers extends from the UV-A range to the NIR range:

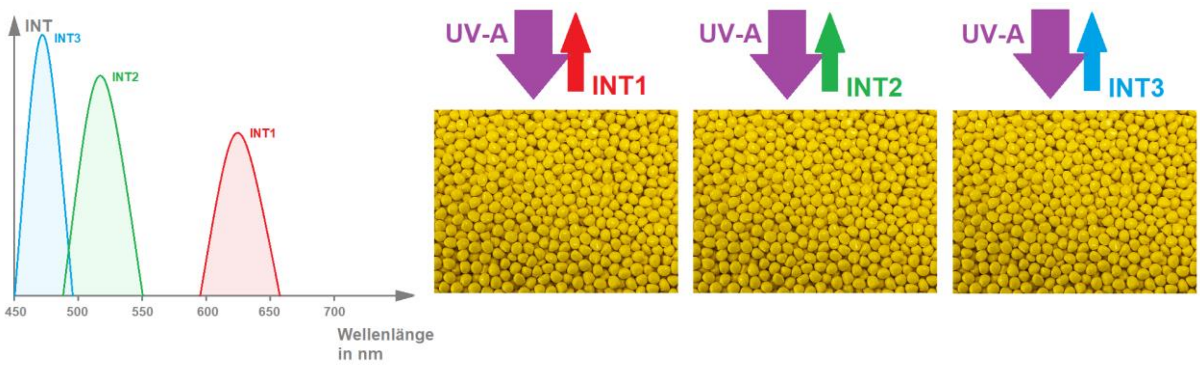
a) **Phosphorescent TAGTEC markers (TAU Markers):**

<u>Primary emission (excitation):</u>	<u>Secondary emission (Response):</u>	<u>TAU (Decay constant)</u>
UV-A	BLUE	100µs … 1ms
UV-A	GREEN	100µs … 1ms
BLUE	NIR	100µs … 1ms
GREEN	NIR	100µs … 1ms
RED	NIR	100µs … 1ms
IR	IR	100µs … 1ms



b) **Fluorescent TAGTEC markers (STAR Markers):**

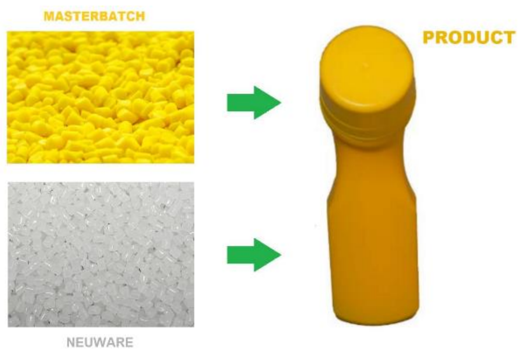
<u>Primary emission (excitation):</u>	<u>Secondary emission (Response)</u>
UV-A	BLUE
UV-A	GREEN
UV-A	RED
BLUE	RED
BLUE	NIR
RED	NIR



Due to their inorganic composition, TAGTEC markers are very resistant and insensitive to chemical and physical influences. This means that plastic products can still be reliably identified and recycled even after long life cycles, contamination and heavy use. Another advantage is the toxicological harmlessness of TAGTEC markers. Many of these markers are approved for contact with food and meet the high requirements of the German ÖkoTex standard.

4.2 Plastic product manufacture

Up to now, the production of a plastic product or plastic packaging has been carried out by using virgin material. By adding a so-called masterbatch, the specific properties are imparted to the product (e.g. color, flame retardancy, UV protection). After the masterbatch has been added, extrusion takes place. In this process, the thermoplastic is given its final shape under high pressure and temperature in an injection molding tool.

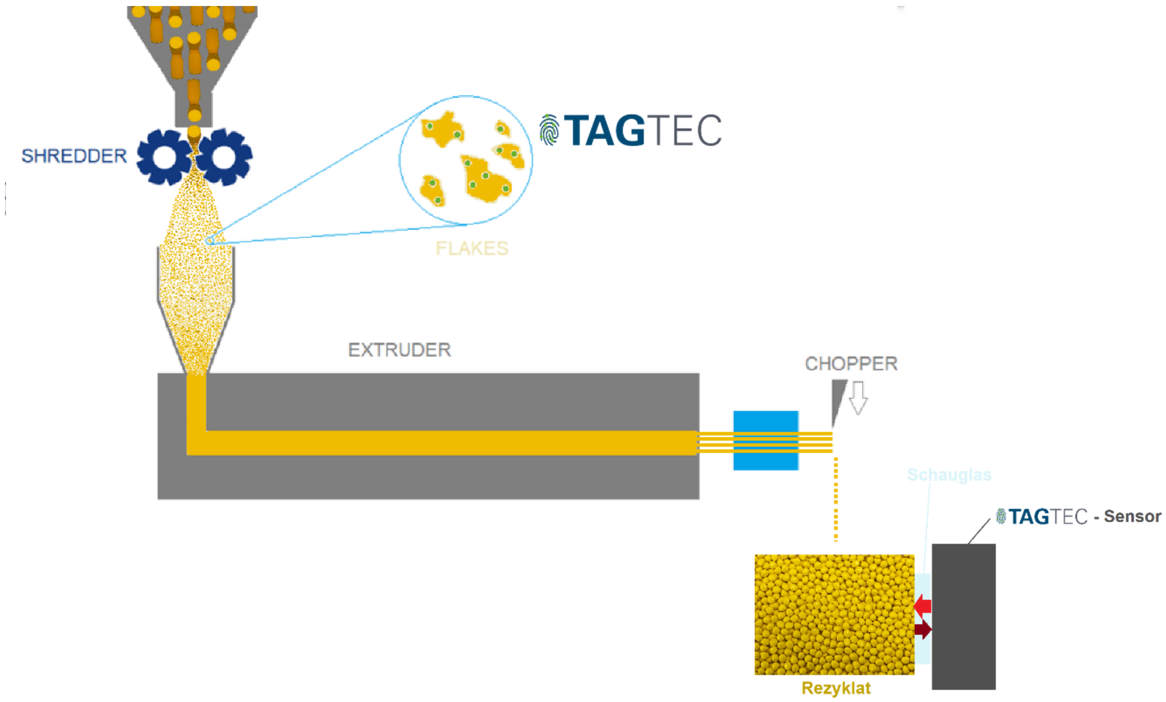


4.2.1 Marking a plastic product

By applying TAGTEC markers in a TAGTEC Masterbatch, it is now possible to produce a product which, purely visually and in terms of mechanical properties, does not differ in any way from the above product.

4.2.2 Recycling of the plastic products

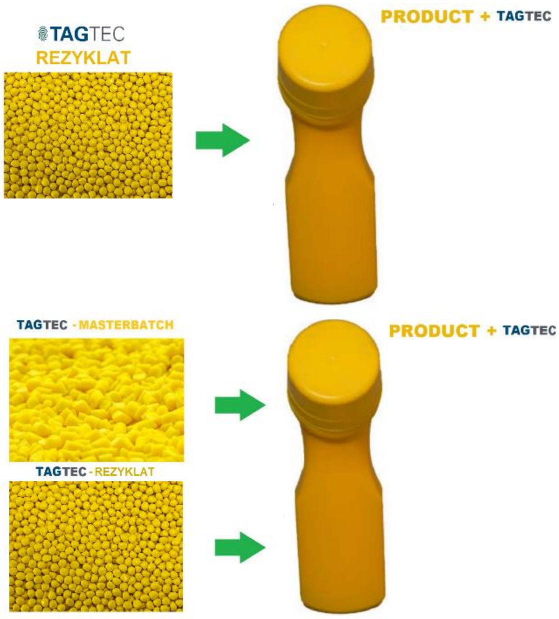
If suitable sensor technology is used, the differences between the two products can be precisely determined. If the sensor technology is integrated into appropriate sorting systems, both products can be separated from each other, crushed and washed during the recycling process. If the post-sorting systems are equipped with appropriate sensors, marked flakes can also be distinguished from non-marked flakes, enabling recyclates to be produced with a correspondingly high degree of grade purity.

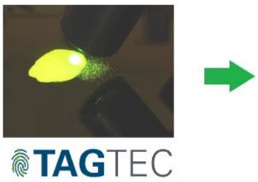


The purity of the recyclates can now be checked by means of sensors. The corresponding sensor system is separated from the recyclate flow only by a inspection glass. The signal strength at the TAGTEC sensor provides information about the proportion of TAGTEC markers in the recyclate.

4.2.3 Use of recycled materials in the manufacturing process of plastic products

If it is determined by means of sensors that the TAGTEC marker content required for the manufacture of a new product is achieved by the recyclate, a new product can be manufactured without additional metering of the TAGTEC masterbatch. In practice, however, it will usually not be possible to avoid adding masterbatch, since it is likely that marked recyclate will be mixed with unmarked recyclate in the recycling process. Using "intelligent" dosing units, the proportion of TAGTEC recyclate in the recyclate is determined with the aid of TAGTEC sensors and added as necessary so that the TAGTEC marker proportion in the end product reaches the required level.





4.3 TAGTEC - Sensors

Sensor Instruments offers easy to operate handheld readers as well as inline sensors for the detection of phosphorescent as well as fluorescent TAGTEC – markers. The handheld devices are usually battery-operated with wireless capabilities (Bluetooth), if required. The inline sensors are +24V - operated devices with PLC interfaces, and could be applied in the laboratory and inline measuring systems and are presented below.

4.3.1 LUMI-TAU – Inline – Sensors

Phosphorescent TAGTEC markers are monitored during production and especially in the granulate state with the aid of LUMI-TAU-INLINE-SL sensors. The main focus is on determining the respective TAU value. But also the initial intensity INT, i.e. the signal strength from which on the measuring signal is evaluated, is of importance, as it informs about the amount of TAGTEC - marker in a certain product. The individual LUMI-TAU-INLINE-SL devices differ primarily in the LEDs used, as well as in the photodiodes used and the matching filter glasses. In total there are 5 different types to choose from:

a) LUMI-TAU-INLINE-SL-IR/IR

b) LUMI-TAU-INLINE-SL-R/IR

c) LUMI-TAU-INLINE-SL-UV/BL

d) LUMI-TAU-INLINE-SL-BL/IR

e) LUMI-TAU-INLINE-SL-GN/IR

In addition, the LUMI-TAU-INLINE has 4 digital outputs (0V/+24V); via the serial interface (RS232), by means of external adapters, a connection to USB, Ethernet or Profinet can be established. The sensors can be parameterized by means of PC software.

4.3.2 SPECTRO-T-1 – Inline – Sensors

The inline control of fluorescent markers in granules is performed by the sensors of the SPECTRO-T-1 series. These have a cluster of LEDs that provide diffuse light with the aid of two volume diffuser discs (frosted glass discs) arranged one above the other. In the central part of the diffusing disk is the opening including a filter glass for the receivers. Here, too, a cluster of photodiodes suitable for the respective wavelength range is provided. The following four different types are offered in this series:

a) SPECTRO-T-1-10-DIF-UV/BL

b) SPECTRO-T-1-10-DIF-BL/YL

c) SPECTRO-T-1-10-DIF-R/IR

d) SPECTRO-T-1-10-DIF-BL/IR

5 digital outputs (0V/+24V) are available at the 8-pin round socket. These types also have an RS232 interface and various adapter cables (USB, Ethernet and Profinet) are available.

4.4 TAGTEC – Systems for the laboratory according to the inspection glass method

For the laboratory, TAGTEC sensor systems with large funnels (approx. 10 liters capacity) are available, as well as systems in which granulate samples from 0.15 liters are sufficient for analysis. The system variants are available for the phosphorescent (a) to j)) as well as for the fluorescent (k) to r)) TAGTEC markers.) TAGTEC - Marker:

a) LUMI-TAU-IR/IR-LAB-LF

b) LUMI-TAU-R/IR-LAB-LF

c) LUMI-TAU-BL/IR-LAB-LF

d) LUMI-TAU-UV/BL-LAB-LF

e) LUMI-TAU-GN/IR-LAB-LF

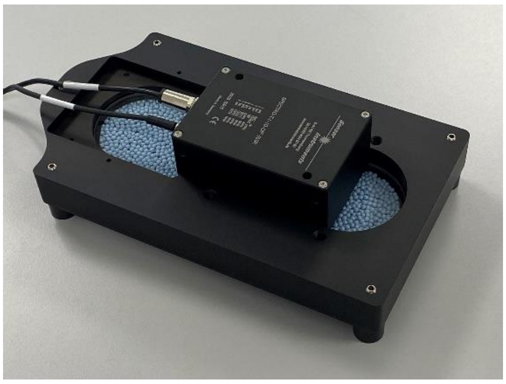
f) LUMI-TAU-IR/IR-LAB-CMU

g) LUMI-TAU-R/IR-LAB-CMU

h) LUMI-TAU-BL/IR-LAB-CMU

i) LUMI-TAU-UV/BL-LAB-CMU

j) LUMI-TAU-GN/IR-LAB-CMU



k) SPECTRO-T-1-DIF/0°-UV/BL-LAB-LF

l) SPECTRO-T-1-DIF/0°-BL/YL-LAB-LF

m) SPECTRO-T-1-DIF/0°-R/IR-LAB-LF

n) SPECTRO-T-1-DIF/0°-BL/IR-LAB-LF

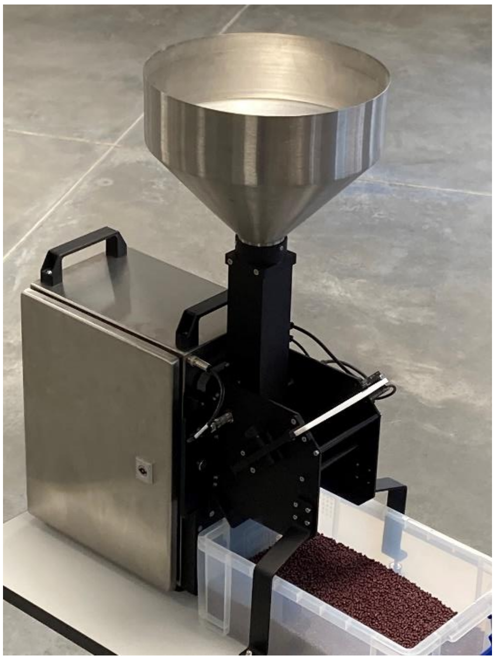
o) SPECTRO-T-1-DIF/0°-UV/BL-LAB-CMU

p) SPECTRO-T-1-DIF/0°-BL/YL-LAB-CMU

q) SPECTRO-T-1-DIF/0°-R/IR-LAB-CMU

r) SPECTRO-T-1-DIF/0°-BL/IR-LAB-CMU

A inspection glass (crown glass) with a thickness of 9mm separates the recyclate to be examined from the sensor surface in both versions. A PC or laptop is not included in the scope of delivery. However, the DOCAL PC software and the parameterization software can be easily installed under Windows®. The PC can be connected to the LAB-LF or LAB-CMU measuring system via USB adapter or Ethernet adapter. To increase the accuracy of the system, the measurement is also performed during the movement of the pellets. This makes the measurement more independent of the random position of the individual grains in the field of view of the receiver part. For the calibration of the sensor systems, plastic cards with different TAGTEC markers and different concentrations are offered. The calibration can be carried out on the respective device. Corresponding cut-outs allow the insertion of the plastic calibration cards. The CALIB-LUMI-TAU and CALIB-SPECTRO-T-1 calibration dishes also have a inspection glass (crown glass) of 9mm thickness. These are also suitable for holding the respective inline systems during an upcoming calibration. With the DOCAL software, a calibration can be conveniently carried out using the calibration wizard. The software guides the operator through the steps necessary for calibration. In the monitoring mode (DOCU mode), both the TAU values and the INT values, as well as the date and time, are stored in a file specified by the operator. Furthermore, any deviations from the respective setpoint are displayed on the monitor, so that the operator can react in time to excessive drifts.



4.5 TAGTEC – Systems for mobile laboratory according to the inspection glass method

By checking the recyclates in the immediate vicinity of the production plants, the measurement results can be determined virtually in real time. This allows a much faster reaction and countermeasures in the event of a fault. Essentially, these are laboratory measuring systems of the -LF series. In addition, the measuring system is equipped with a lithium ion battery and mounted on a mobile unit. In contrast to the -LF, the mobile measuring system has a panel PC integrated in the stainless steel housing, 3 USB interfaces and an Ethernet interface. In addition to a wireless computer mouse, a wireless keyboard is also included in the scope of delivery. A self-sufficient label printer is also available as an option. Especially for on-site use at the production facilities, it is necessary that the components exposed to the hot recyclate are designed to be temperature-resistant, which is why a stainless steel hopper (capacity of 10 liters), a product channel made of aluminum, a slide made of resistant plastic and a inspection glass made of crown glass are used.

The following TAGTEC - measuring systems for mobile (at-line) use are available:

a) LUMI-TAU-IR/IR-MOBILE-P

b) LUMI-TAU-R/IR-MOBILE-P

c) LUMI-TAU-BL/IR-MOBILE-P

d) LUMI-TAU-UV/BL-MOBILE-P

e) LUMI-TAU-GN/IR-MOBILE-P

f) SPECTRO-T-1-DIF/0°-UV/BL-MOBILE-P

g) SPECTRO-T-1-DIF/0°-BL/YL-MOBILE-P

h) SPECTRO-T-1-DIF/0°-R/IR-MOBILE-P

i) SPECTRO-T-1-DIF/0°-BL/IR-MOBILE-P

4.6 TAGTEC - Sensor systems for inline operation according to the inspection glass method

TAGTEC measuring systems for inline operation are used in conjunction with inspection glasses. The specially prepared inspection glasses for use in conjunction with the respective sensors are included in the scope of delivery. The inner frame of the two stainless steel parts of the inspection glass holder is usually welded to the control position provided for this purpose, but a screw solution can also be implemented. For further data processing or display of the measured values including the deviations from the specified reference, the DOCAL software can also be used here, which is already installed on the optionally available industrial PC of the type SI-PPC-500-15". The panel PC is housed in a robust stainless steel case. 3 USB and one Ethernet interface are available. A wireless computer mouse and a wireless keyboard are included in delivery. The connection to the inline systems is made either via Ethernet or USB. Corresponding interface adapters are optionally available. For the connection via USB for example cab-4/USB-2m as well as cab-4/USB-5m and via Ethernet cab-4/ETH-500 in connection with an external CAT5 cable cab-eth/M12D-RJ45-flx-2m, cab-eth/M12D-RJ45-flx-5m, cab-eth/M12-RJ45-flx-10m or cab-eth/M12D-RJ45-flx-20m. For calibration of the inline measuring systems the two units CALIB-LUMI-TAU and CALIB-SPECTRO-T-1 can be used.

The following inline measuring systems are offered:

a) LUMI-TAU-IR/IR-INLINE

b) LUMI-TAU-R/IR-INLINE

c) LUMI-TAU-BL/IR-INLINE

d) LUMI-TAU-UV/BL-INLINE

e) LUMI-TAU-GN/IR-INLINE

f) SPECTRO-T-1-DIF/0°-UV/BL-INLINE

g) SPECTRO-T-1-DIF/0°-BL/YL-INLINE

h) SPECTRO-T-1-DIF/0°-R/IR-INLINE

i) SPECTRO-T-1-DIF/0°-BL/IR-INLINE

5.0 Conclusion

With the measuring systems from Sensor Instruments for recyclate control with respect to color, plastic type and TAGTEC markers, comprehensive sensor product families are now available for the laboratory (off-line), mobile laboratory control (at-line) and for in-line use.

By early detection of product deviations by means of trend display, countermeasures can be taken at an early stage, thus maintaining product quality at a high level.