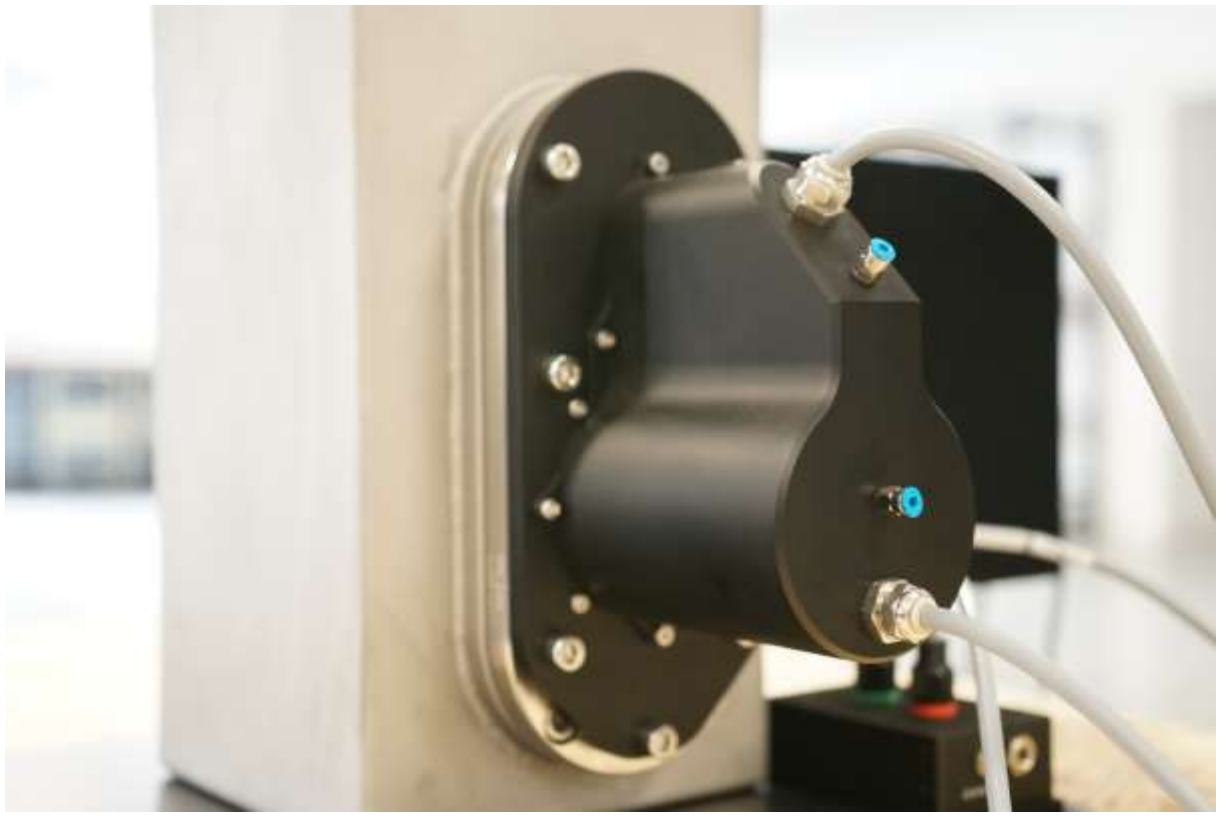
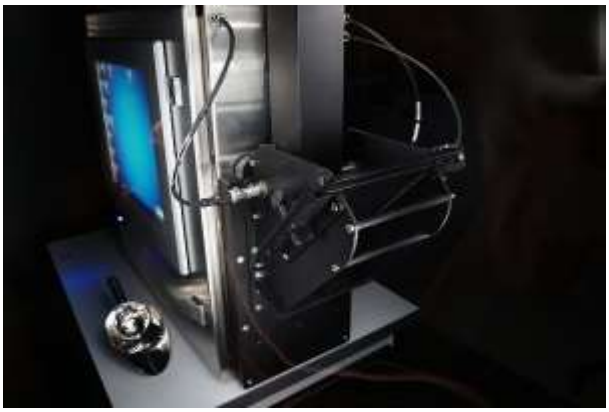
Checking the plastic type of recyclates and virgin material using NIR technology





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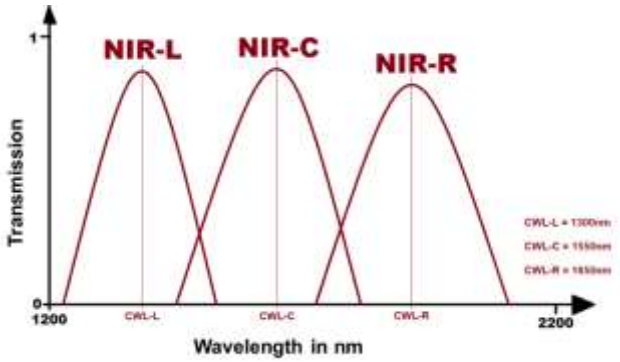
1. The sensor technology

1.1 The NIR three-range procedure – a proven sensor principle borrowed from the visible wavelength range

Open spectrographs, designed as hyperspectral cameras, are usually used in the recycling sector to perform the separation of different plastics. Working in combination with a broadband NIR light source (e.g. built up from high-intensity halogen spotlights), these cameras combine a moderate spatial resolution with a good spectral resolution of the objects. A further procedure directs a high-intensity NIR light source onto a surface to be scanned via a polygon mirror, whilst an optical unit is directed onto the polygon mirror. This means that part of the NIR light impinges on it after it has impinged on and been reflected from the object via the rear optical path, from where it is directed onto the aperture of an NIR grating spectrometer. Both procedures enable the spectral detection of a relatively large NIR wavelength range with simultaneous spatial resolution. This means for example, that different objects adjacent to each other on a conveyor belt and which pass through the detection area simultaneously are detected as separate objects, whilst being spectrally differentiated.

Plastic granulates on the other hand, do not require individual spectral differentiation. Instead, an integral process should record as many plastic pellets as possible at the same time, thereby obtaining reliable information about the quality or purity of the product. The complex technology that would be necessary to determine the spatial resolution is unnecessary and can be dispensed with. In principle however, an NIR spectrometer with optics and NIR illumination could be considered, but would represent a cost-intensive solution.

A more cost-effective alternative is a system that works in accordance with the three-range procedure. This measuring procedure directs three different NIR LED types (each LED type covers a specific wavelength range in the NIR) at the plastic granulate to be investigated, and a broadband NIR receiver detects the light reflected diffusely by the pellets. This is converted and passed on to an evaluation unit.



Analogous 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 grey value of the object to be examined. The higher the N* value, the brighter the object surface.

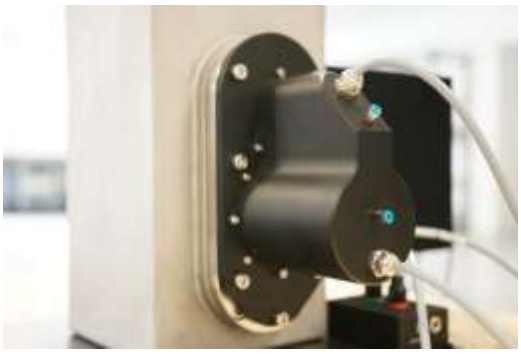
i*: provides information about the course between the medium NIR wavelength range (1550nm - central wavelength range) and the short NIR wavelength range (1300nm - central wavelength range). A high negative i* value indicates a reflection from the object around NIR-L, whilst a high positive i* value indicates a reflection from the object around NIR-C.

r*: shows the progression between the medium NIR wavelength range and the long NIR wavelength range (1650nm - central wavelength range). A high negative r* value indicates a reflection from the object around NIR-C, whilst a high positive r* value indicates a reflection from the object around NIR-R.

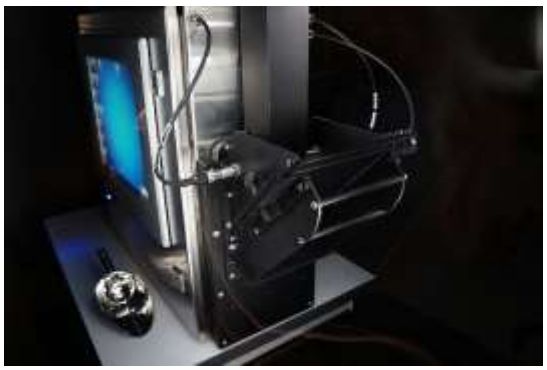
1.2 NIR sensor technology in fiber-optic and fixed-optic design

Two NIR sensor types are currently available:

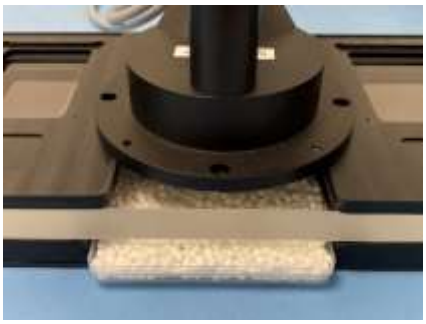
The fiber optic version **SPECTRO-T-3-FIO-NIR/NIR** + **KL-D-0°/45°-22-1200-d80/d110-A3.0-NIR** is primarily used in locations with high plastic granulate temperatures (above 100°C). The KL-D-0°/45°-22-1200-d80/d110-A3.0-NIR sensor head is connected to the evaluation unit by the optical fibre cable (1200mm length). The control electronics have 5 digital outputs; binary coded, 31 different products can be stored and provided with tolerances. The 0°/45° procedure is used here, i.e. the NIR light irradiation is perpendicular to the surface of the plastic granulate, whereas the receiving fiber optic considers the surface of the plastic granulate at an angle of 45°. Using the RS232 interface, the raw data and the N*i*r* values can be transmitted digitally in series. An RS232/USB and an RS232/EtherNet adapter are also available. To perform inline measurements, the sensor head can be integrated into a protective housing and the protective housing pressurized with compressed air, thus preventing contamination of the optics. The sensor head is mounted on a specially prepared sight glass by means of a protective housing. The sensor head and protective housing are positioned on a calibration tray to perform calibration. Defined plastic cards are available for calibration, which have been manufactured from various plastics. The N*i*r* values are stored in a file; each plastic card can be called up during calibration by means of the number reserved for the card. The selected card is then inserted into the calibration tray. After acknowledgement, the calibration software reads the triple value N*i*r* stored under the selected card from the file and enters it in the calibration table. This procedure can now be performed for the existing plastic calibration cards. The sensor head is remounted on the sight glass after calibration has been completed. The sensor can also be integrated in a laboratory device. Seeking to use the same measuring equipment as far as possible to perform laboratory measurements, care was taken with the laboratory device to direct the same sensors onto the plastic granulate in the same spacing through the same type of sight glass. A battery-powered mobile device version is also available in addition to the laboratory device. The N*i*r* values are displayed numerically and graphically using the Windows® DOCAL software and are saved in a file in EXCEL® format.



A measurement system with fixed optics is also available in addition to the fibre optic version. The **SPECTRO-T-3-60-NIR/NIR-D20** NIR sensor works in accordance with the d/0° procedure, i.e. diffuse **NIR** light passes through the sight glass onto the granulate surface. At 0° to the normal on the other hand, the sensor's reception window is directed at the granulate surface. The rest of the measuring process is similar to the measuring process using fibre optics. An inline version is also available for this version. The sensor is mounted on a sight glass specially prepared for this purpose. The NIR sensor is directed through a 9mm thick crown glass onto the plastic granulate to be measured. The calibration of the measurement system is performed using a calibration tray and the corresponding calibration standards (plastic plates made of various plastics). To this end, the NIR sensor is dismounted from the sight glass and fixed to the calibration tray. A suitable recess is provided on the calibration tray for this purpose. For the measuring system with fixed optics, however, it is necessary to ensure that a temperature of 70°C is not exceeded at the mounting area of the sight glass enclosure. Otherwise, the fibre optic variant should be used. The fixed-optics NIR sensor is also available in the laboratory device; the optical arrangement here is identical to the placement on the sight glass. As with the fibre optic version, a mobile unit is available for this purpose. Calibration, measurement and measurement data storage are performed using the Windows® DOCAL PC software. The laboratory and mobile devices can be used to determine an N*i*r* measured value over a volume of type 3 litres. The result is correspondingly precise.



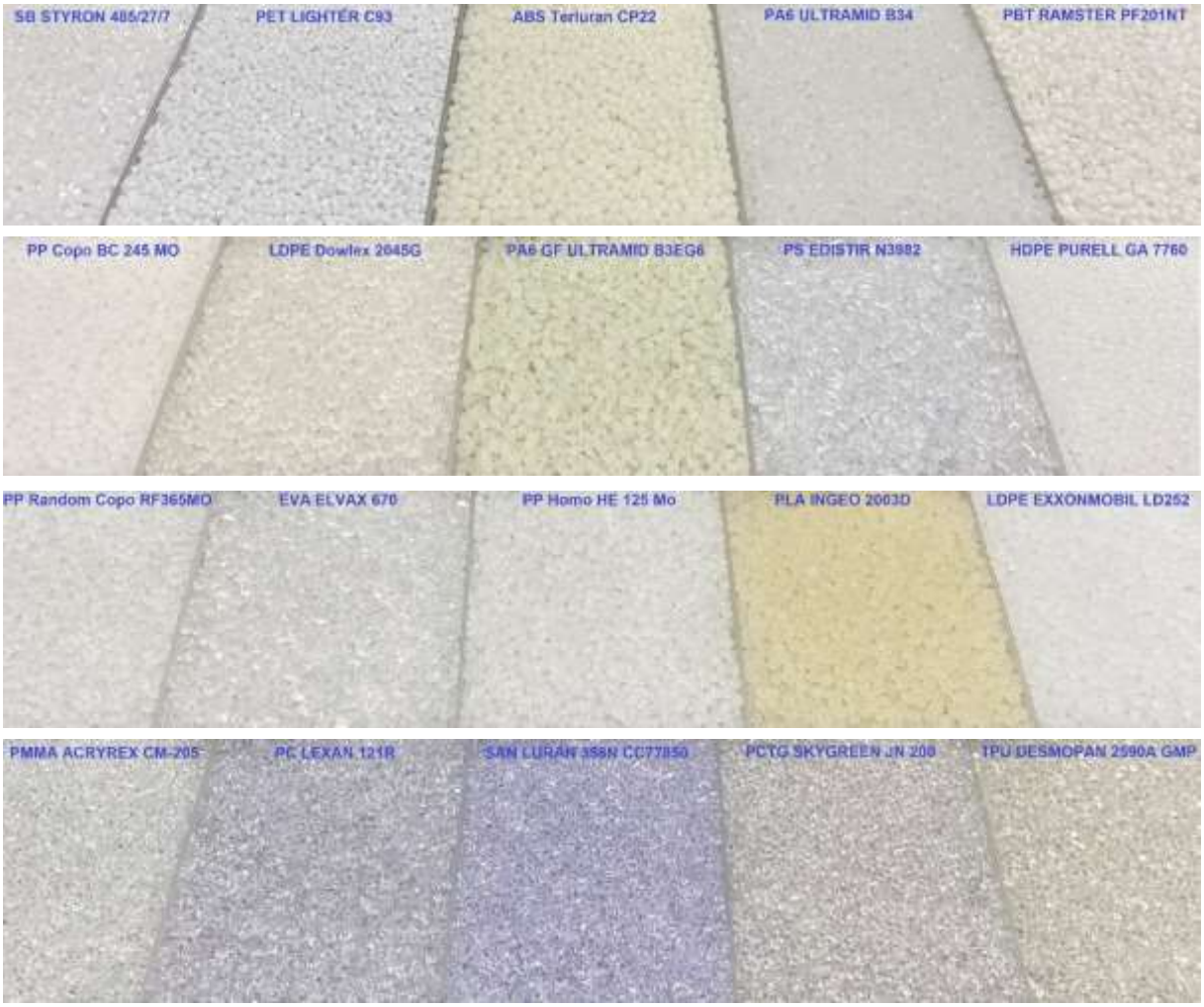
If on the other hand, only a small amount of plastic granulate material is available for the investigation, the type of plastic can also be determined using a reduced measurement set-up. Here, too, measurements are taken at almost the same distance from the granulate and under comparable optical conditions. A suitable fixture is available for both the SPECTRO-T-3-FIO-NIR/NIR + KL-D-0°/45°-22-1200-d80/d110-A3.0-NIR fibre optic version and the SPECTRO-T-3-60-NIR/NIR-D20 fixed optic version.



Examination of virgin material with regard to the type of plastic using NIR technology

2. Investigating the plastic type of virgin material using NIR technology

The following virgin material plastic granulates were investigated for their NIR behaviour:



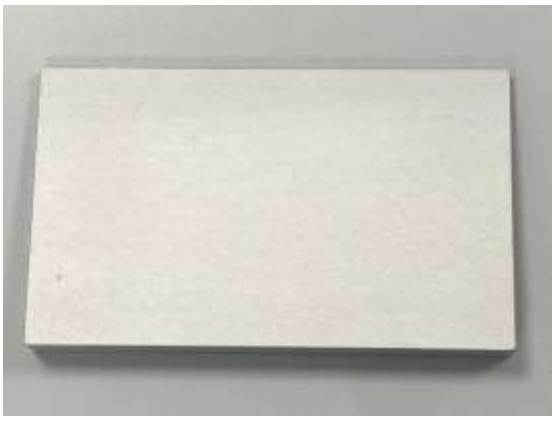
2.1 Measurement results with the SPECTRO-T-3-60-NIR/NIR-D20

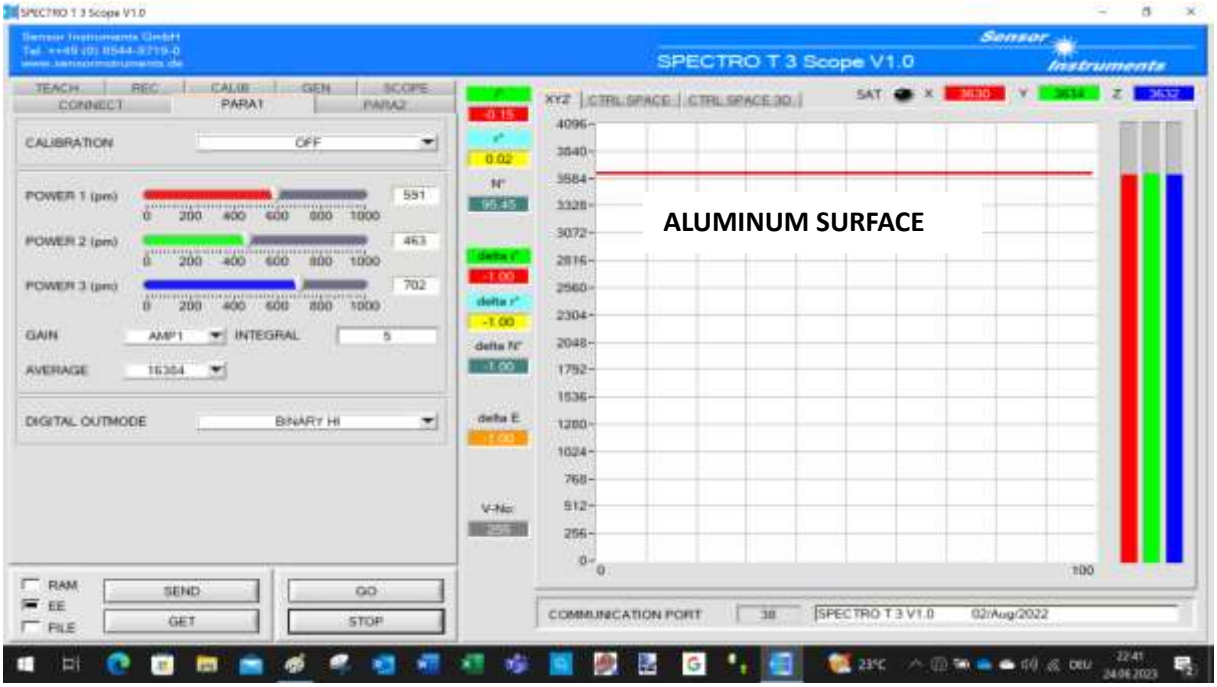
2.1.1 The compact measuring device

As not enough pellets were available from the individual granulate samples to fill the funnel of the laboratory device sufficiently, the more compact measuring device was used instead, in which a flat tray filled with pellets is placed below the glass plate in front of the sensor. To reduce the influence of the random arrangement of the pellets in the detection area, the tray was moved underneath the sensor during the measurement (forwards, backwards movement). The same glass plate (material: crown glass) is used as with the sight glasses. The compact measuring device is also suitable for receiving the calibration cards (plastic type calibration). The compact measuring device can thus also be used as a calibration unit. The capacity of the pellet trays is c 0.1 litre.

2.1.2 Referencing the sensor

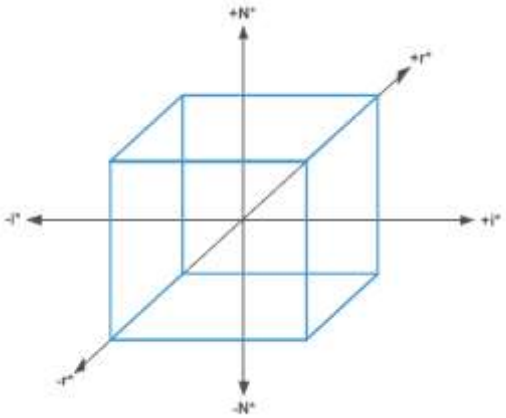
The optimal setting of the available dynamic range of the sensor is achieved using an aluminium surface that ensures constant reflection in the NIR range. The aluminium plate serves as a reference surface for the white alignment. The three available NIR LED light sources are set in such a way that the received signals display the same value for each wavelength range and are at a value of c. 3600. The NIR LED transmission powers can be set using the Windows® software **SPECTRO T3 Scope**.



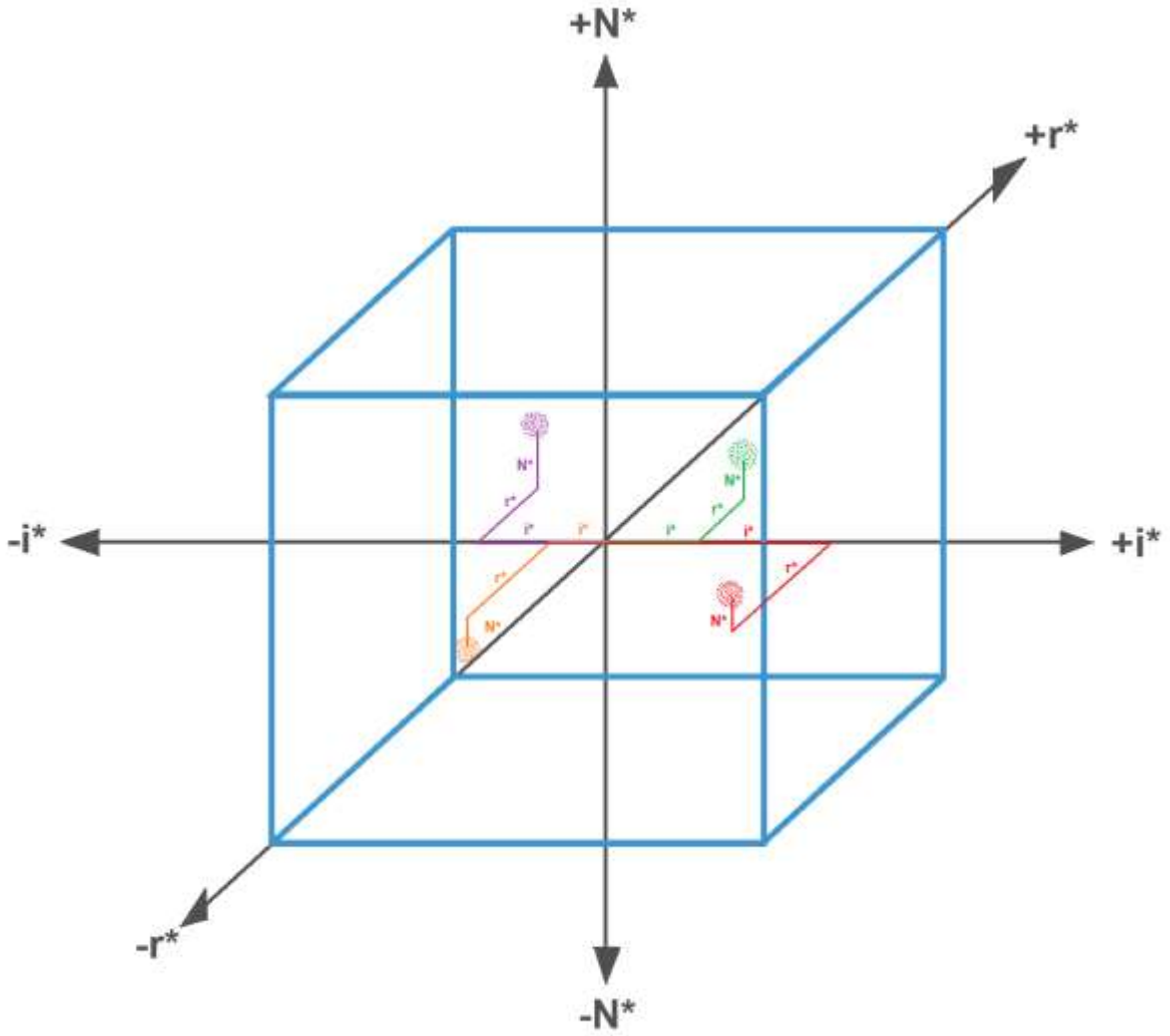


Windows® software SPECTRO T3 Scope V1.0

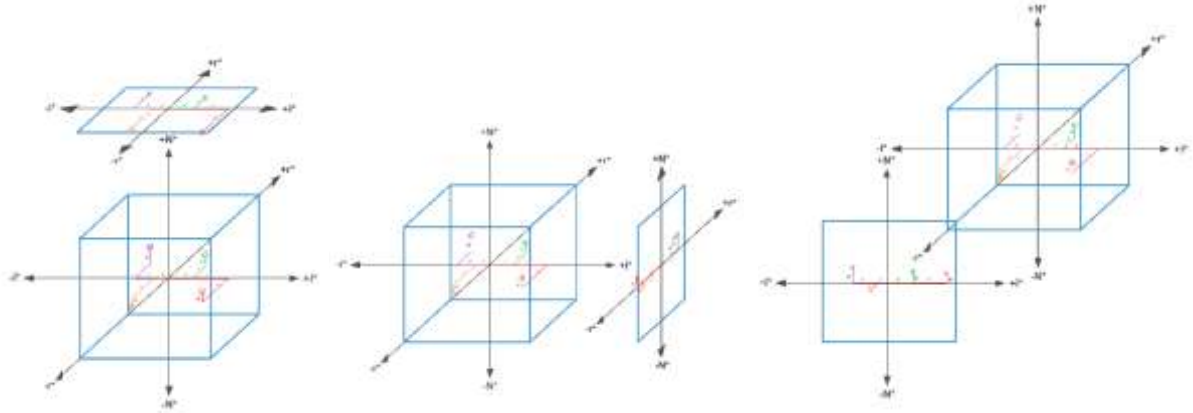
2.1.3 Displaying the N*i*r* values



The N*i*r* values are determined from the received signals X (NIR-L), Y (NIR-C) and Z (NIR-R) in accordance with the method for calculating the L*a*b* color values. For example, a certain type of plastic occupies a certain place in the three-dimensional N*i*r* space. As already mentioned, N* provides information about the grey value, while i* provides information about the signal course in the lower (X-Y) and r* about the signal course in the upper NIR wavelength range (Y-Z). The following figure shows the N*i*r* values of four different types of plastic: N*i*r*, N*i*r*, N*i*r* and N*i*r*.

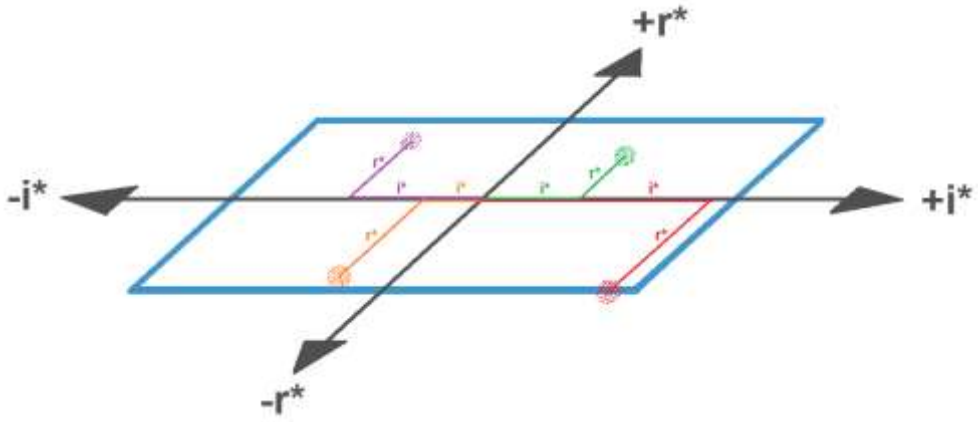


Representation of e.g. four different types of plastic in the N*i*r* space. The points in the point clouds should express the individual measured values. The variation results from the different positions of the pellets during a measurement. At the end of a measuring process, the individual measured values are averaged. The **CTRL SPACE 3D** Windows® user interface displays the three views (front, side and from above) to facilitate the display in three-dimensional N*i*r* space

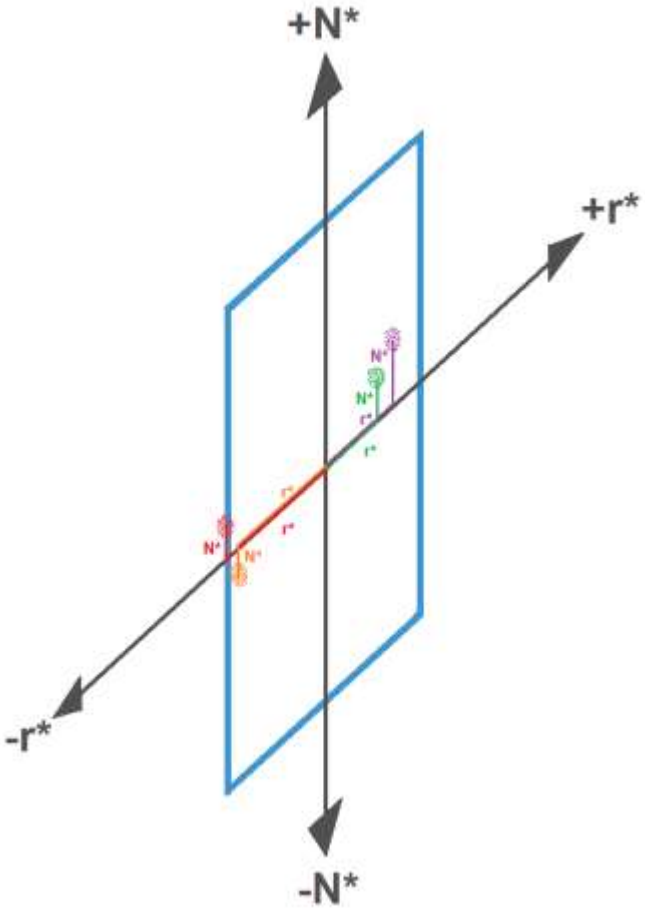


3 views: from above from the side from the front

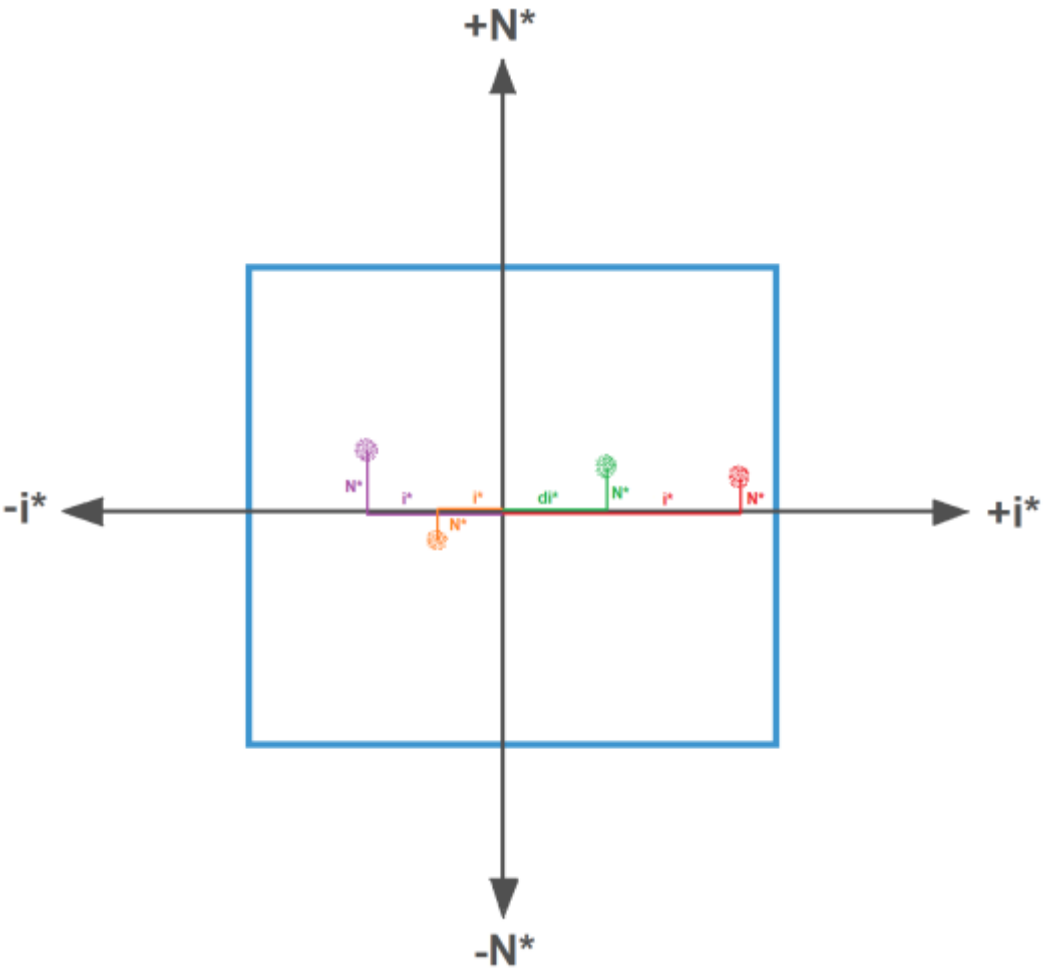
The i*r* diagram provides information about the course of the individual plastic samples in the NIR spectrum, while the i*N* and r*N* diagram provides information about the grey value and the wavelength course in the lower (i*N*) and upper (r*N*) range.



i*r* diagram



r*N* diagram

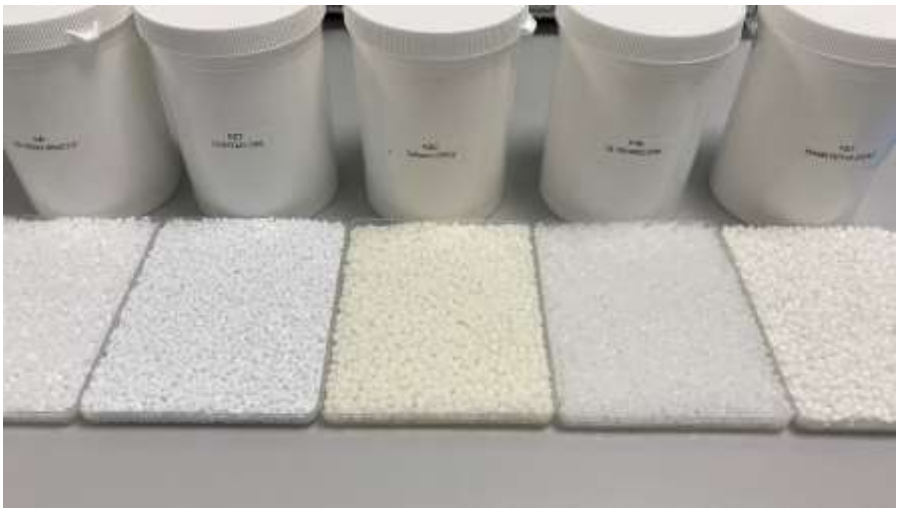


i*N* diagram

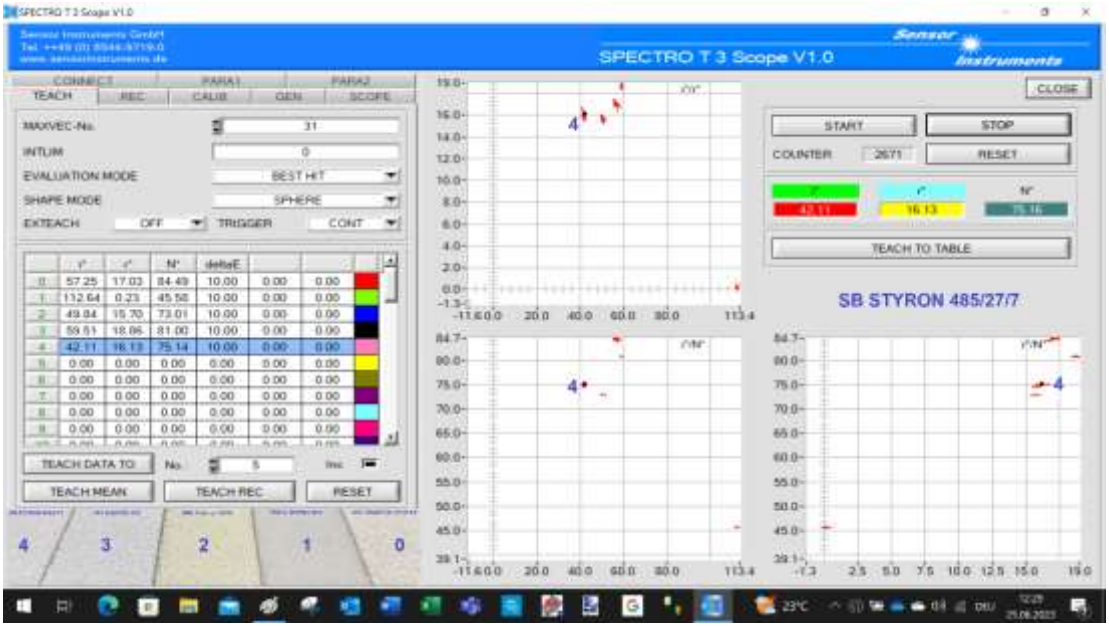
2.1.4 Determining the N*i*r* measured values

First, the following granulate samples were examined:

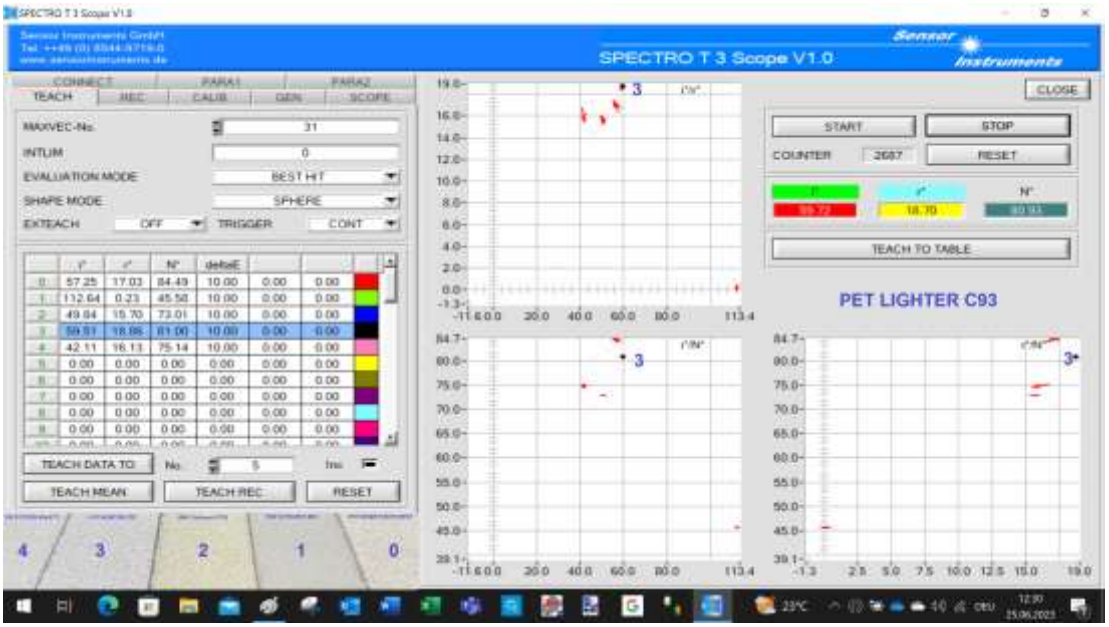
a) SB STYRON 485/27/7
b) PET LIGHTER C93
c) ABS Terluran GP22
d) PA6 ULTRAMID B3K
e) PBT RAMSTER PF201NT



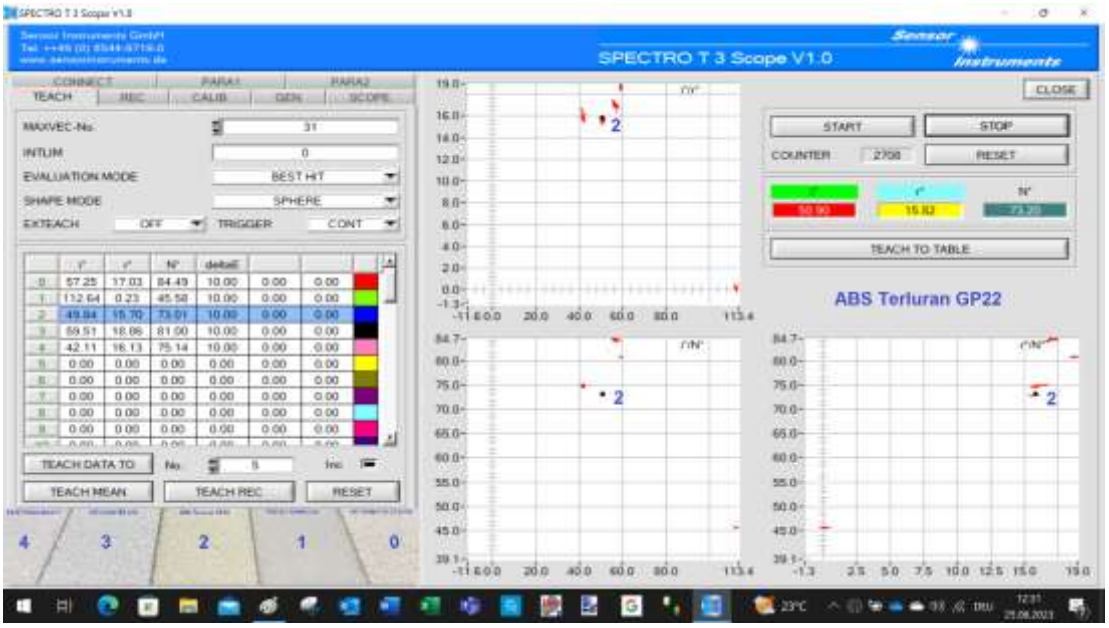
The pellet trays were fed into the compact measuring device one after the other and the measured values were recorded using the **SPECTRO T3 Scope** PC software.


SPECTRO T 3 Scope V1.0
SB STYRON 485/27/7

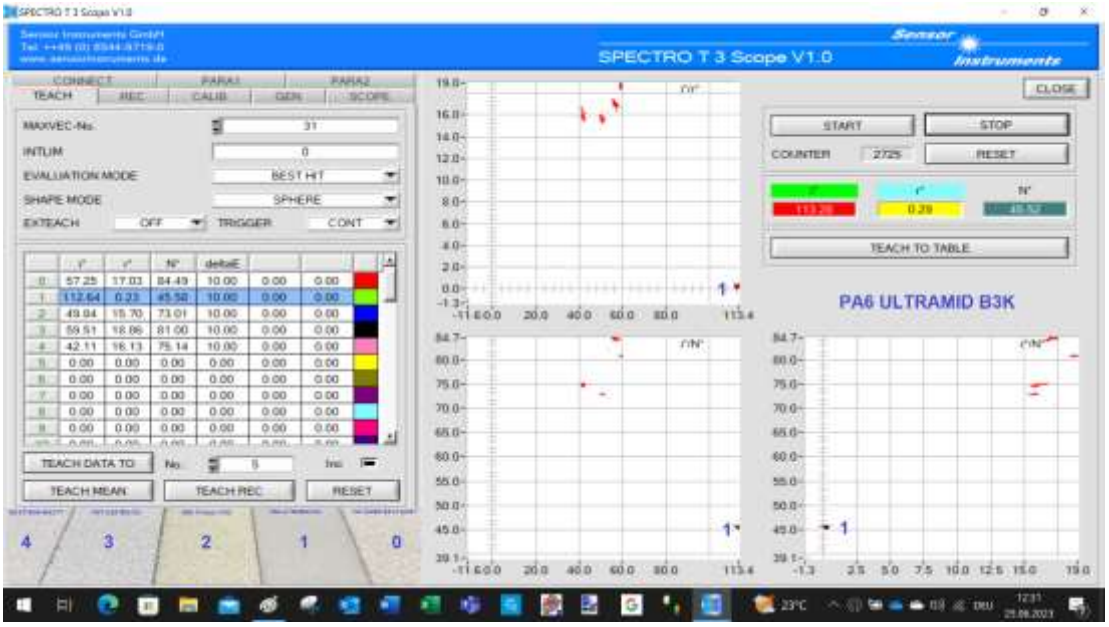
a)


SPECTRO T 3 Scope V1.0
PET LIGHTER C93

b)


SPECTRO T 3 Scope V1.0
ABS Terluran GP22

c)


SPECTRO T 3 Scope V1.0
PA6 ULTRAMID B3K
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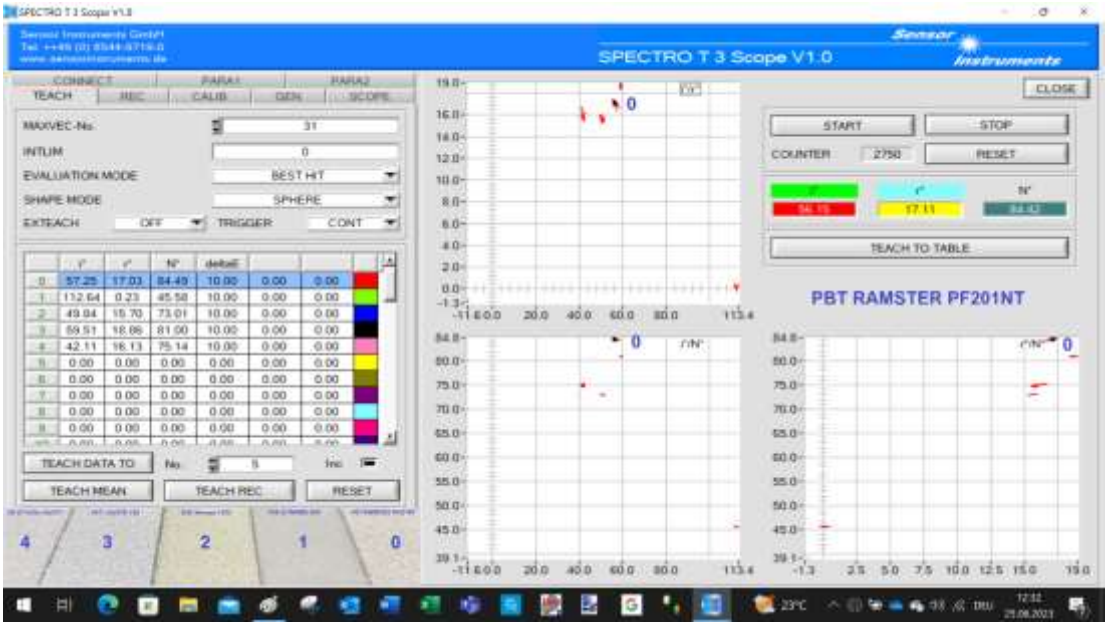
STOP
RESET
TEACH TO TABLE
CLOSE

d)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PBT RAMSTER PF201NT
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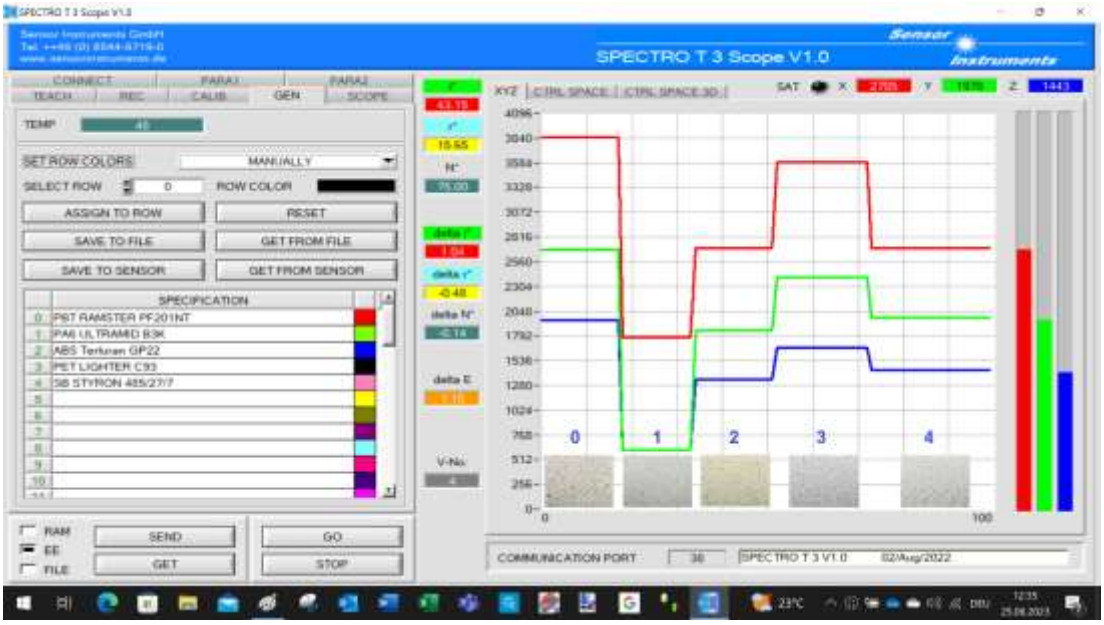
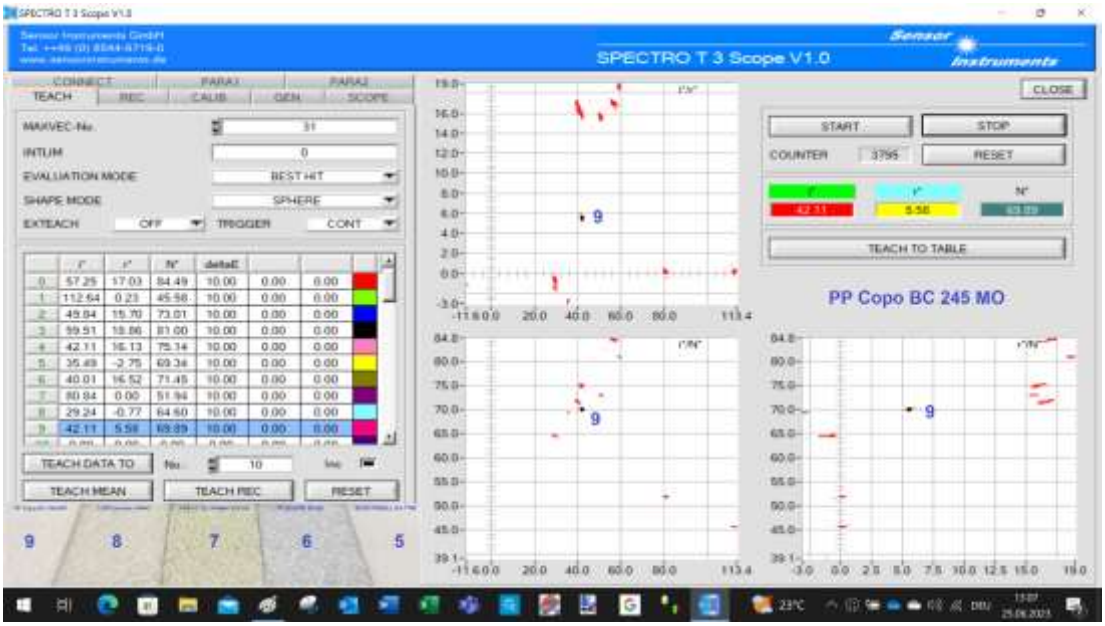
STOP
RESET
TEACH TO TABLE
CLOSE

e)

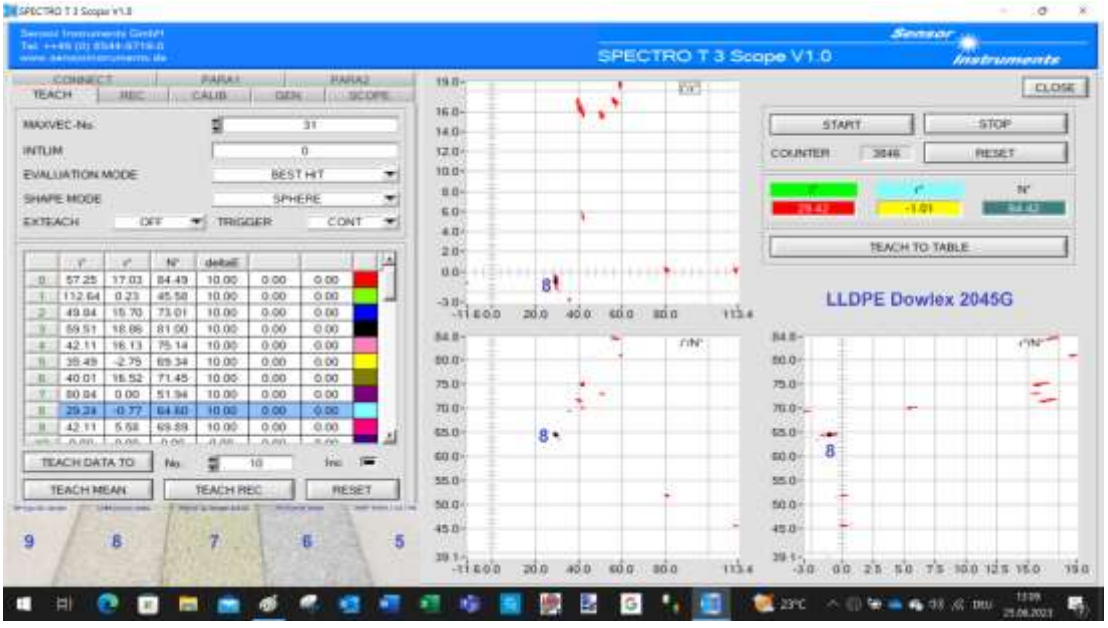

SPECTRO T 3 Scope V1.0
SEND
GET
GO
STOP

This is followed by the next 5 samples:

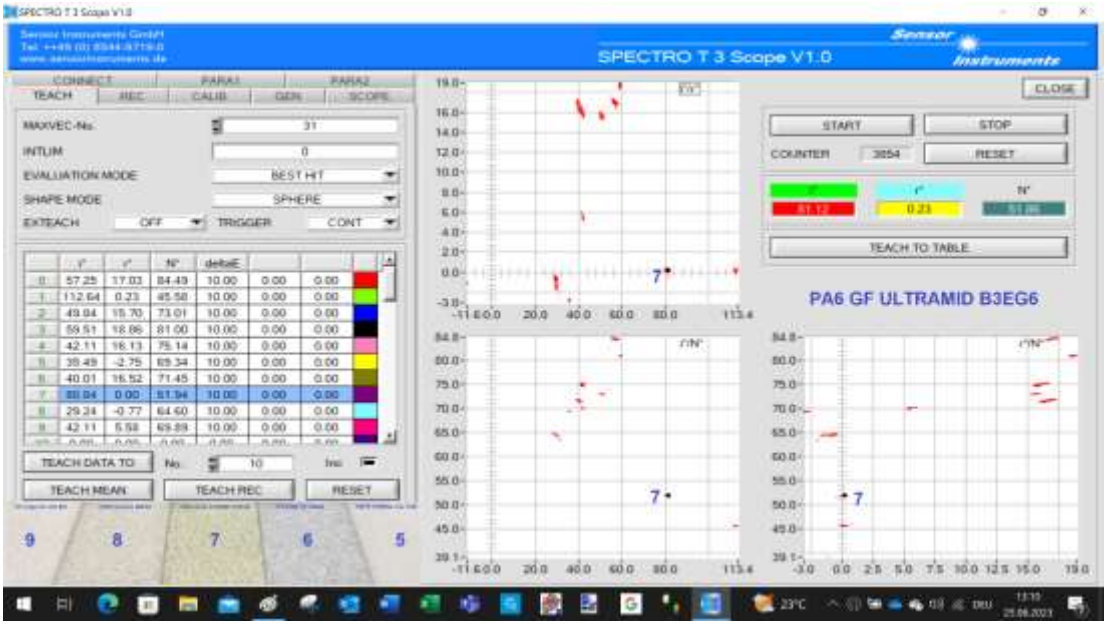
f) PP Copo BC245 MO
g) LLDPE DOWLEX 2045G
h) PA6 GF ULTRAMID B3EG6
i) PS EDISTIR N3982
j) HDPE PURELL GA 7760



f)



g)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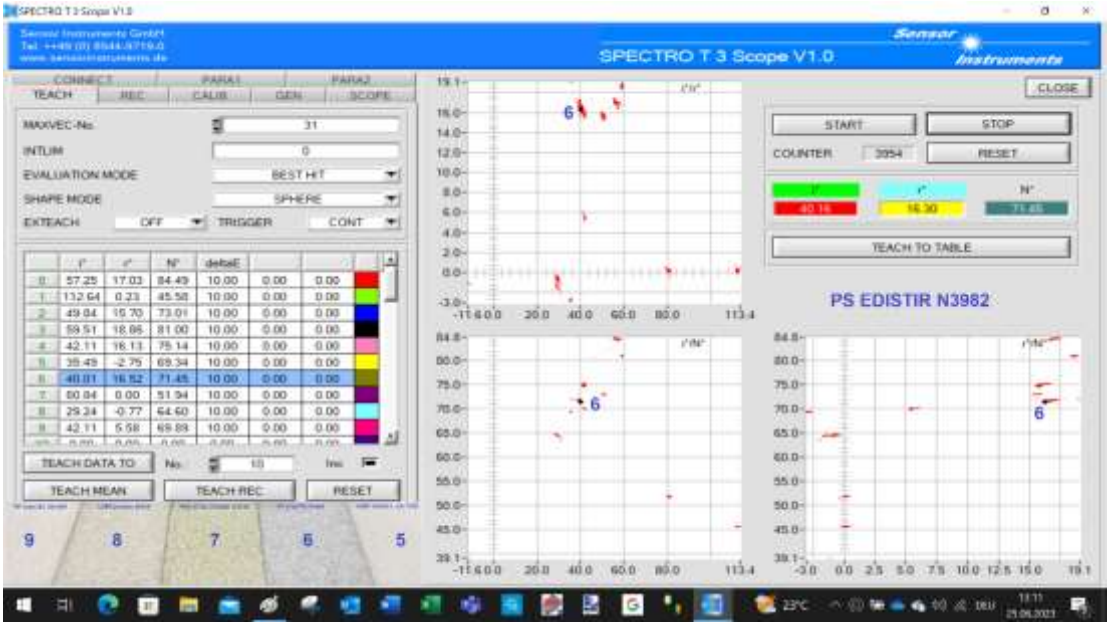
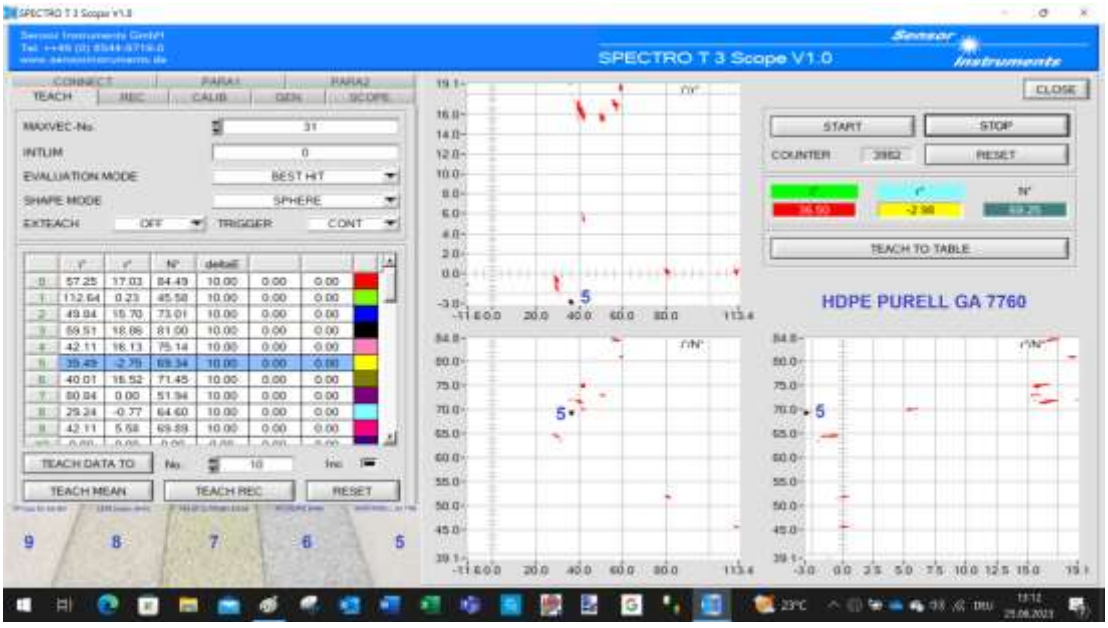
PA6 GF ULTRAMID B3EG6

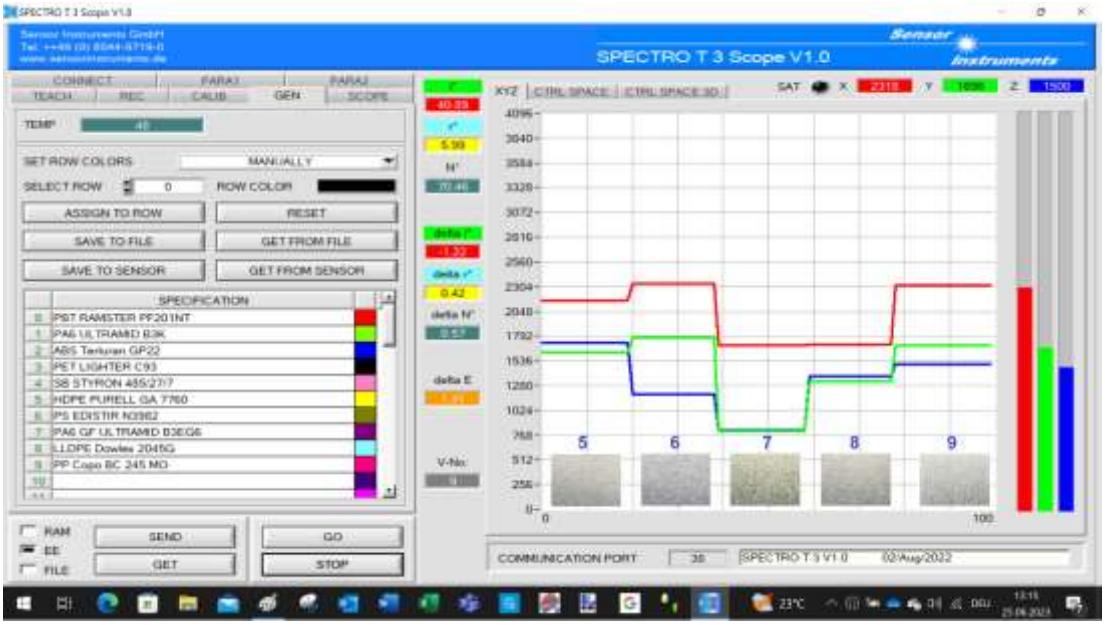
h)


SPECTRO T 3 Scope V1.0
PS EDISTIR N3982

i)

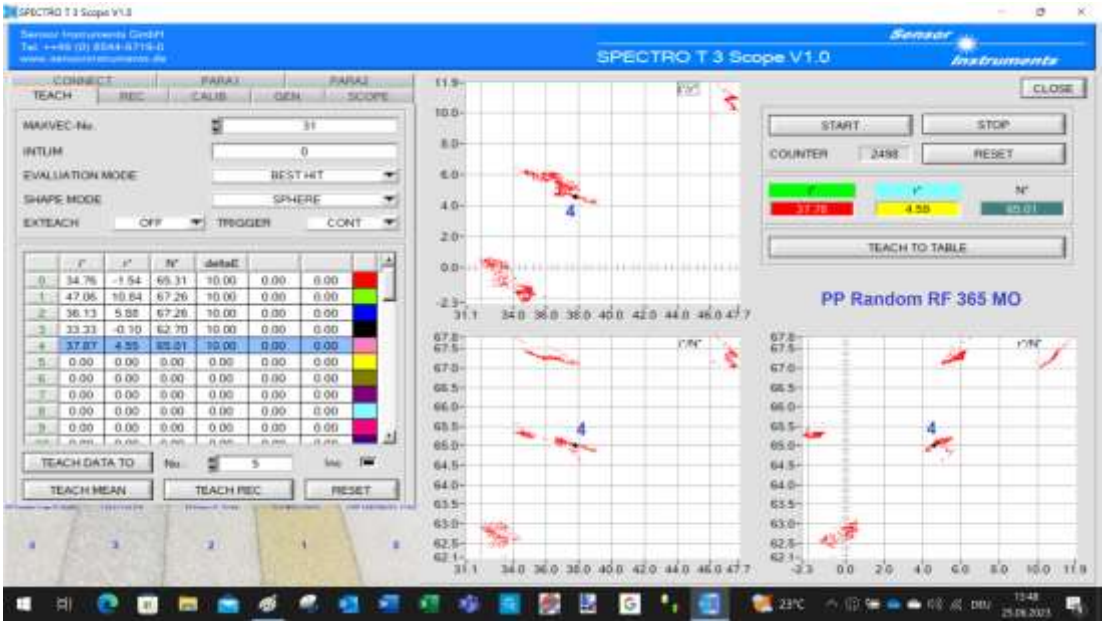

SPECTRO T 3 Scope V1.0
HDPE PURELL GA 7760

j)

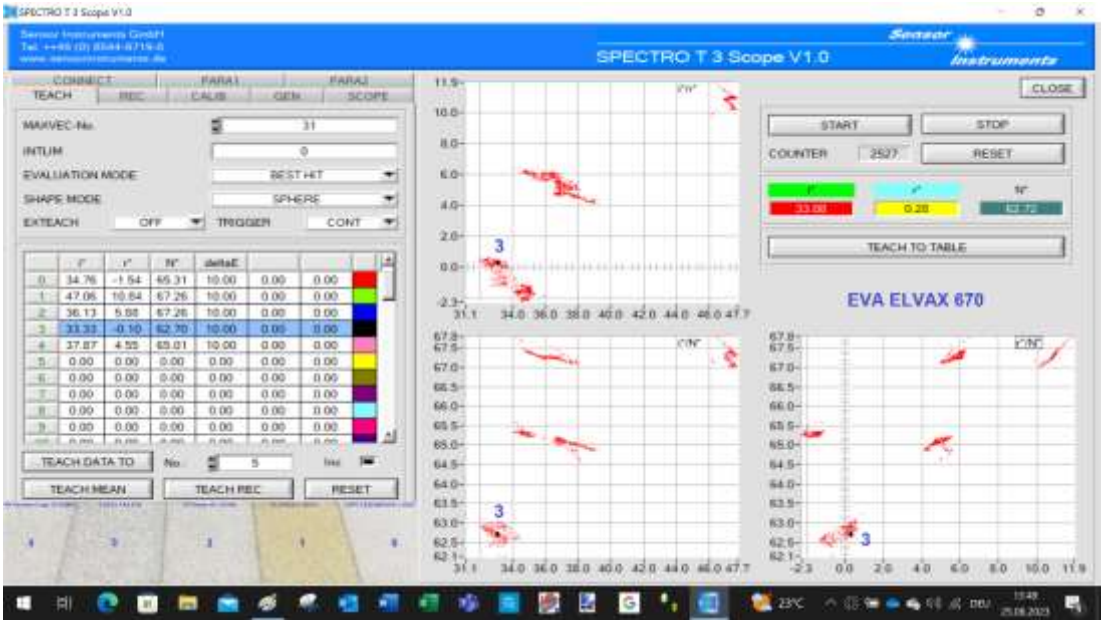


Another 5 virgin granulate samples:

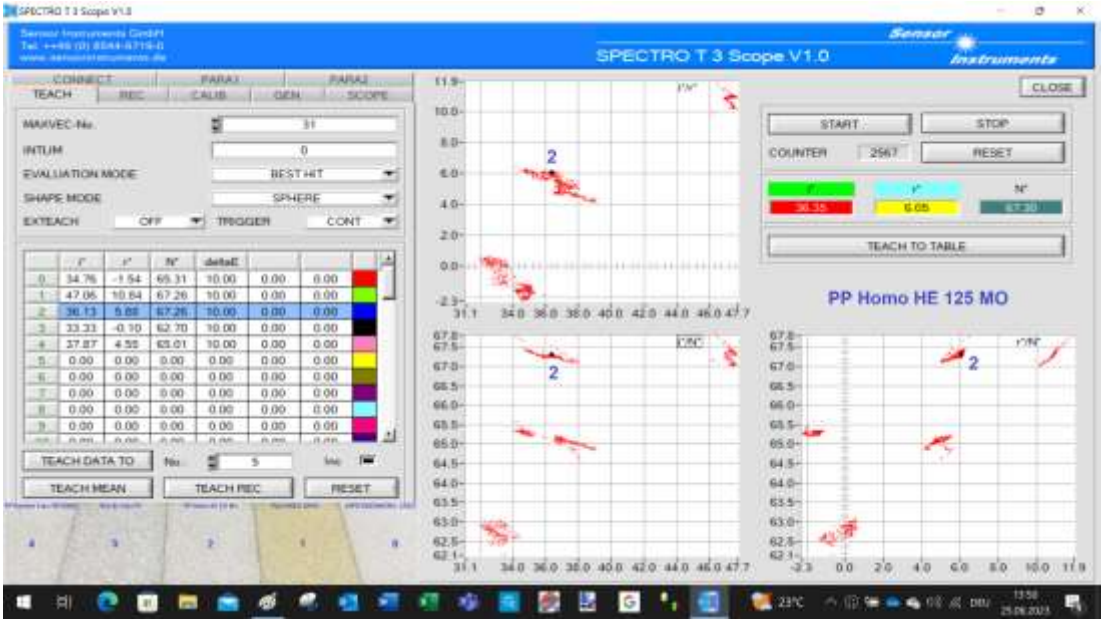
k) PP Random Copo RF 365 MO
l) EVA ELVAX 670
m) PP Homo HE 125 MO
n) PLA INGEO 2003D
o) LDPE EXXONMOBIL LD252



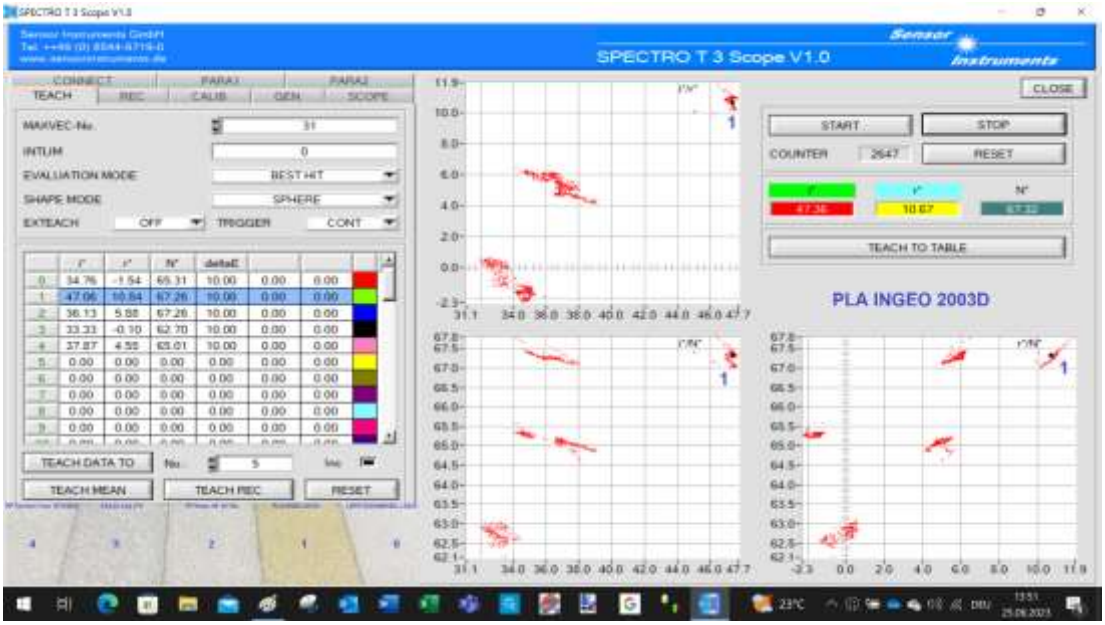
k)


SPECTRO T 3 Scope V1.0
EVA ELVAX 670

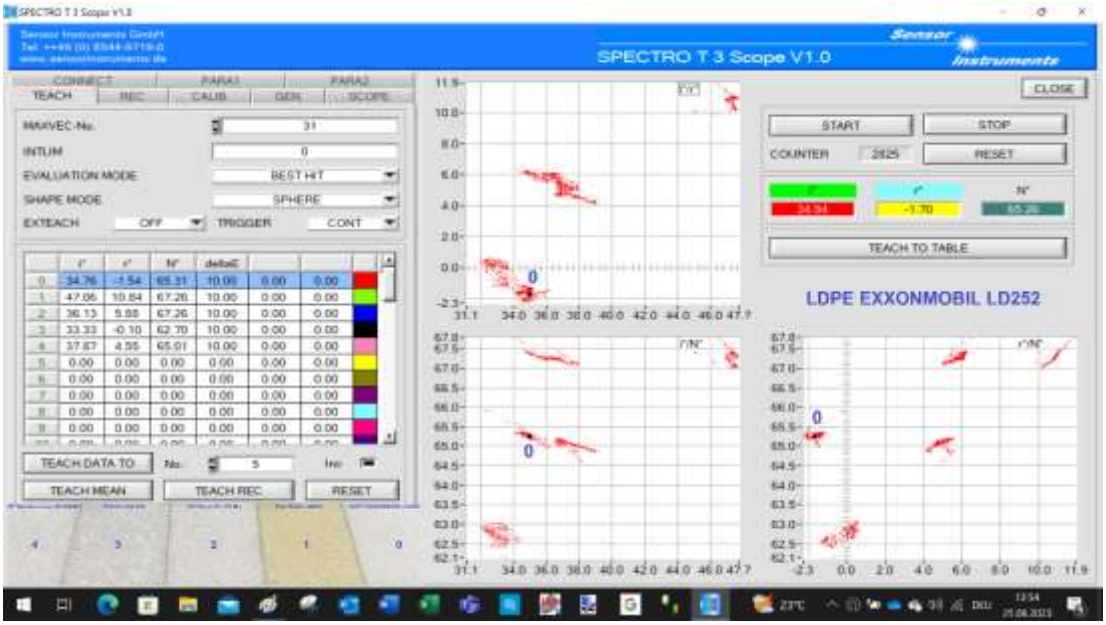
l)


SPECTRO T 3 Scope V1.0
PP Homo HE 125 MO

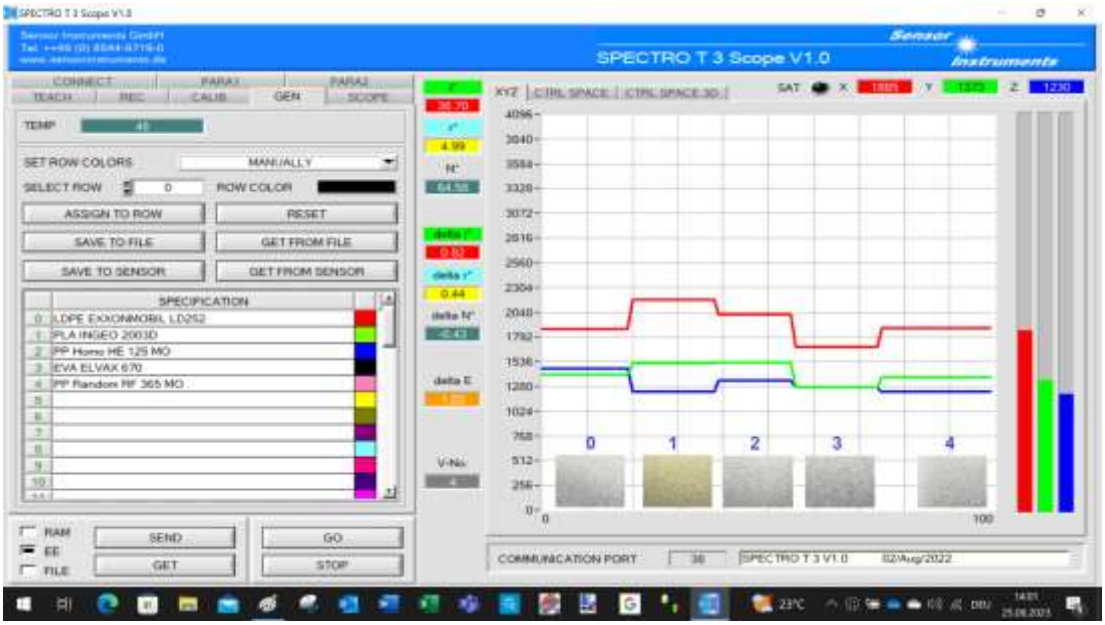
m)


SPECTRO T 3 Scope V1.0
PLA INGEO 2003D

n)

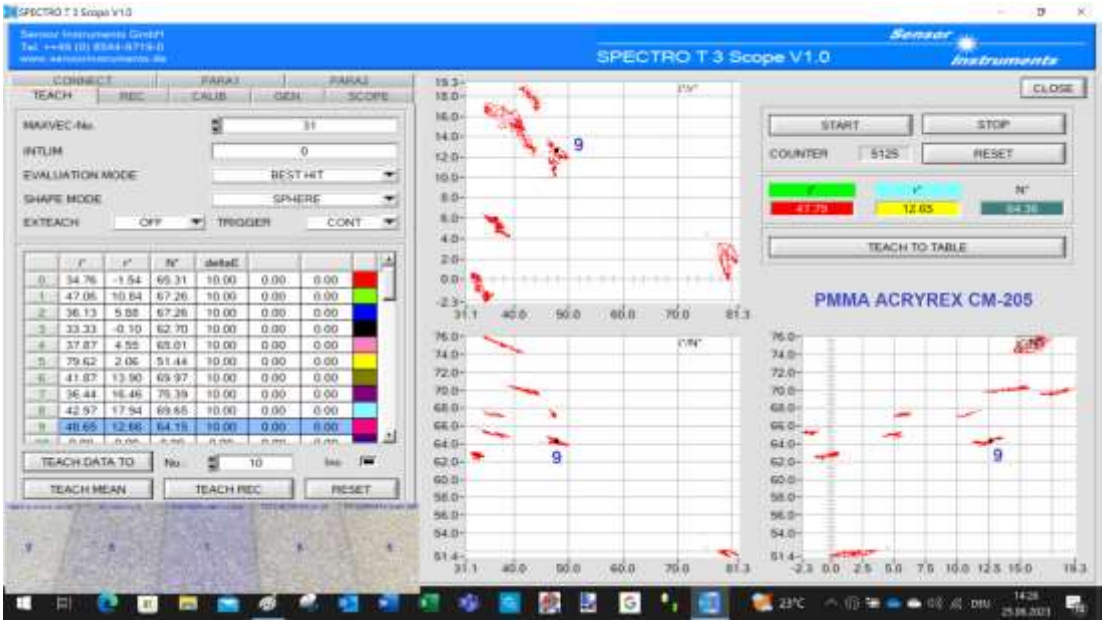


o)



And the next 5 virgin granulate samples:

p) PMMA ACRYREX CM-205
q) PC LEXAN 121R
r) SAN LURAN 358N CC77850
s) PCT6 SKYGREEN JN200
t) TPU DESMOPAN 2599A GMP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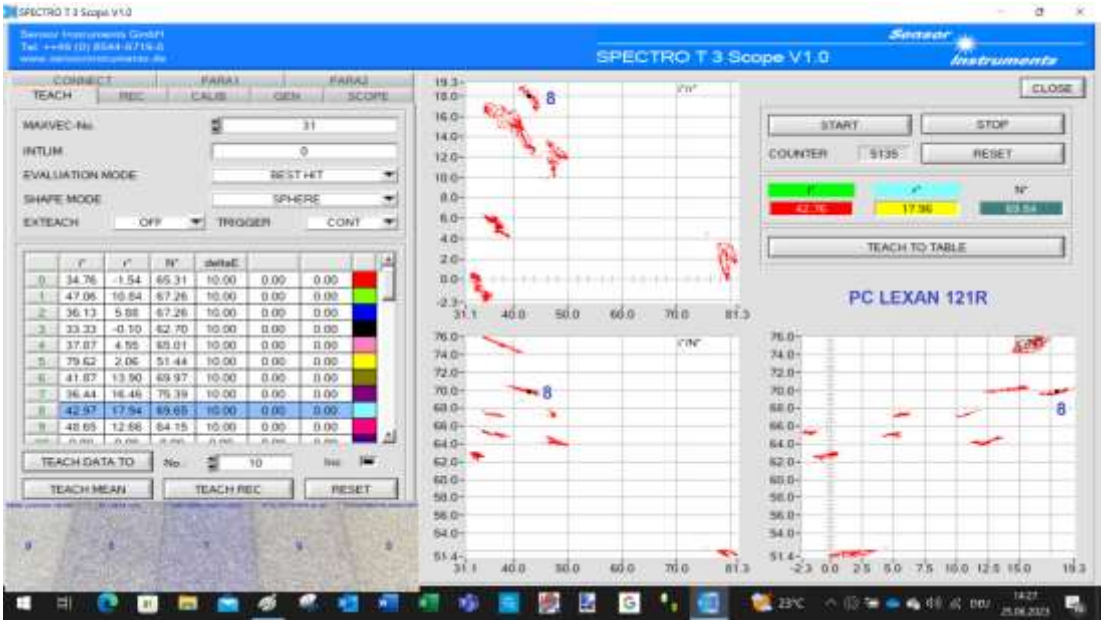
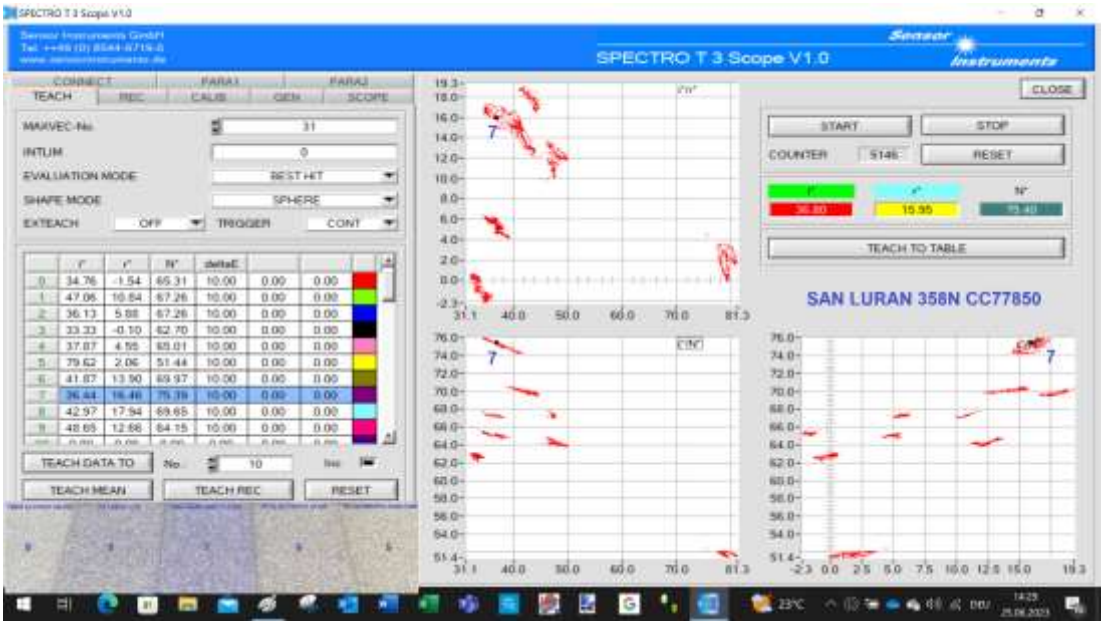
PMMA ACRYREX CM-205

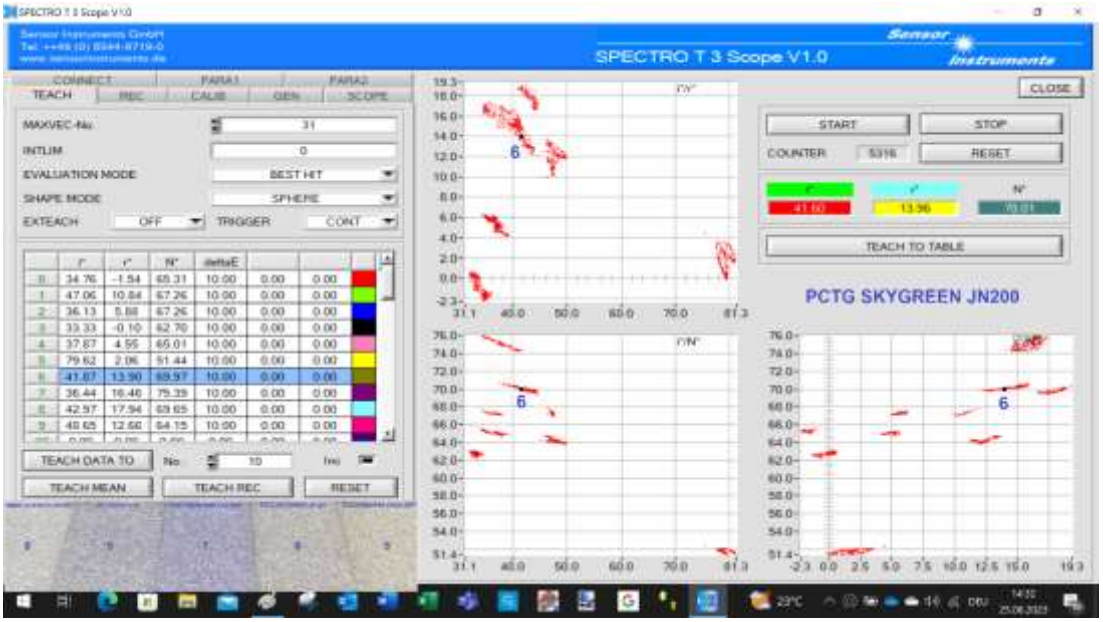
p)


SPECTRO T 3 Scope V1.0
PC LEXAN 121R

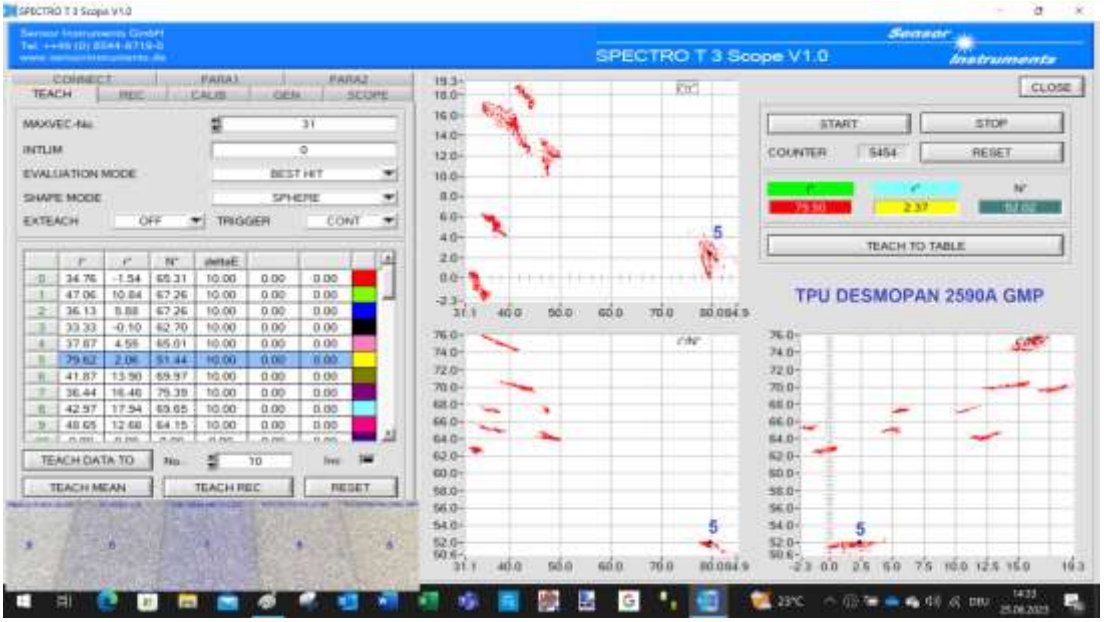
q)


SPECTRO T 3 Scope V1.0
SAN LURAN 358N CC77850

r)


SPECTRO T 3 Scope V1.0
PCTG SKYGREEN JN200
START
STOP
RESET
CLOSE
TEACH TO TABLE

s)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TPU DESMOPAN 2590A GMP
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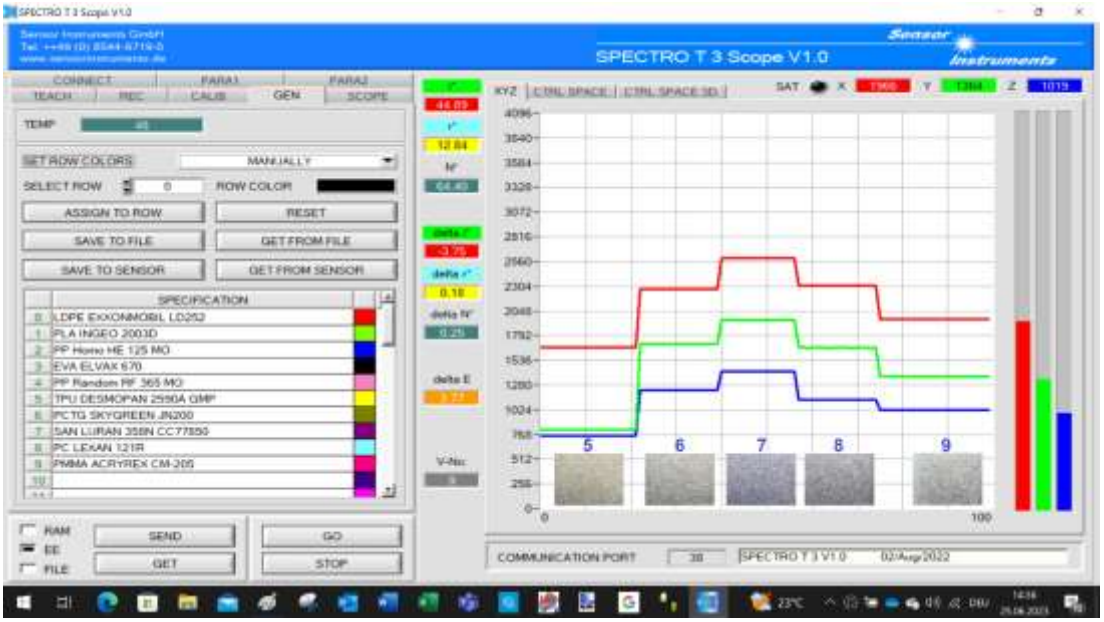
TEACH TO TABLE

t)


SPECTRO T 3 Scope V1.0
SEND
GET
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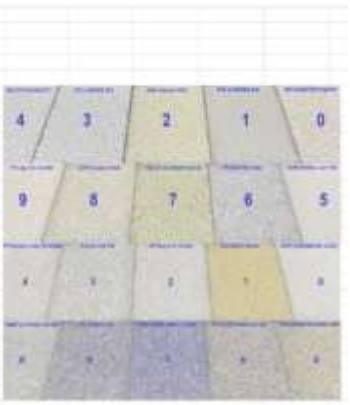
2.1.4 Summary of the measurement results in relation to virgin material

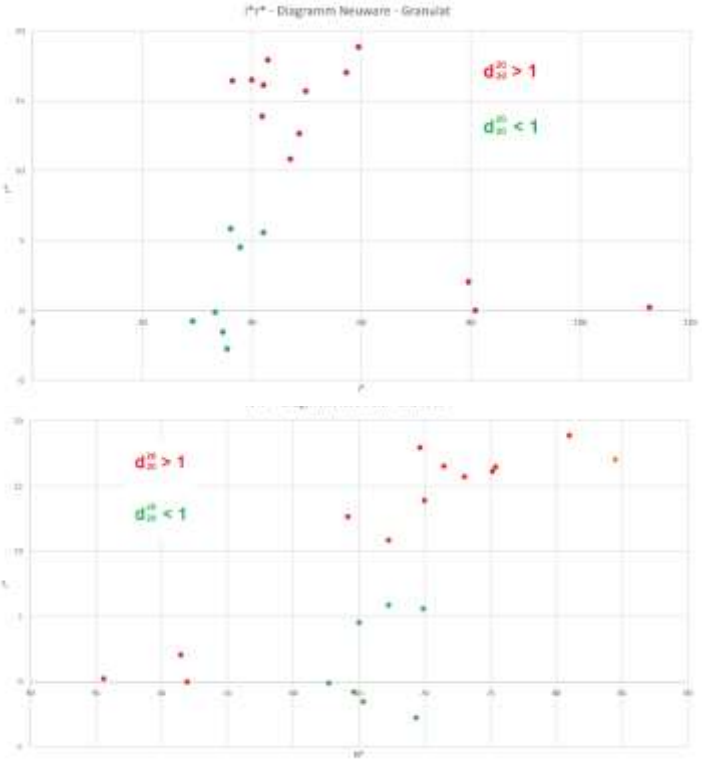
Fortunately, reproducible measurement results can also be achieved using the transparent granulate samples. This is probably due to the fact that the work was performed with diffuse lighting and at a viewing angle of around 0° to the normal. This means that direct reflections from the pellets, which would have affected the measurement result, could be kept away from the receiver side as far as possible.

Summarized in a table, the following values were produced for the 20 different products:

Virgin granule samples measured with SPECTRO-T-3-60-NIR/NIR-D20

Granule name	Rel. density to water	Plastic type	N*	i*	r*	SPECTRO T3 Scope V1.0 Number
PET RAMTEX PI 2GENT	>1	PET	84,49	57,25	17,01	0
PAG 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	83	59,51	18,86	3
SB STYRON 485/2777	>1	PS	75,34	42,11	16,11	4
HDPE PURELL GA 7760	>1	HDPE	69,34	35,49	-1,75	5
PS 124378 N3082	>1	PS	71,45	40,01	16,52	6
PA6 GF ULTRAMID B3G6	>1	PA6	51,94	80,89	0	7
LLDPE DOWLEX 2045G	>1	LLDPE	64,9	29,24	-0,77	8
PP COPO BC 245 MO	>1	PP	69,89	42,11	5,58	9
LDPE CRISTAMIDE LD253	>1	LDPE	65,31	34,76	1,54	0
PLA INGEO 2003D	>1	PLA	67,26	47,06	10,84	1
PP HOMO HC 125 MO	>1	PP	67,26	36,13	1,69	2
EVA ELVAX 670	>1	EVA	62,7	33,33	0,1	3
PP RANDOM RC 365 MO	>1	PP	65,03	37,87	4,55	4
TPU DESMOPAN 2590A GMF	>1	TPU	51,64	79,62	2,06	5
PCTG SKYGREEN IN200	>1	PCT-G	69,97	41,87	15,9	6
SAN LURAN 358N CC72850	>1	Acrylester	75,39	36,46	16,36	7
PC LEXAN 121R	>1	PC	69,65	42,97	17,98	8
PMMA ACRYREX CM-205	>1	PMMA	64,35	48,65	12,66	9





When displaying the measured values in the individual diagrams (i*r*, N*i* and N*r* diagrams), an accumulation of plastic pellets with a specific weight below 1 can be observed within a certain sector, whereas virgin pellets with a specific weight above 1 are outside this sector. Furthermore, the i*r* diagram shows that the PP types within the specific density of <1 are located in the upper part of the green-marked area of the i*r* diagram, whilst the LLDPE, LDPE, HDPE as well as EVA type are found in the lower green-marked area. A grouping of the PA6 types inc. TPU can be observed for the virgin granulates with a specific density of >1, Both the N*i*- and the N*r*-diagram show that the N*-value of these granulate types is far below the values of the other granulate types. This subgroup thus appears darker in the NIR range in comparison to the other types. The following table divides the individual granulates into different groups:

Hoher i* - Wert (> 70):	Hoher r* - Wert (>10):	Niedriger i* - (<50) **und** niedriger r* - Wert (<10):
TPU DESMOPAN	PET LIGHTER	PP HOMO HE
PA6 GF ULTRAMID	PC LEXAN	PP COPO BC
PA6 ULTRAMID B3K	PBT RAMSTER	PP RANDOM RF
	PS EDISTIR	EVA ELVAX
	SAN LURAN	LLDPE DOWLEX
	SB STYRON	LDPE EXXONMOBIL
	ABS TERLURAN	HDPE PURELL
	PCTG SKYGREEN	
	PMMA ACRYREX	
	PLA INGEO	

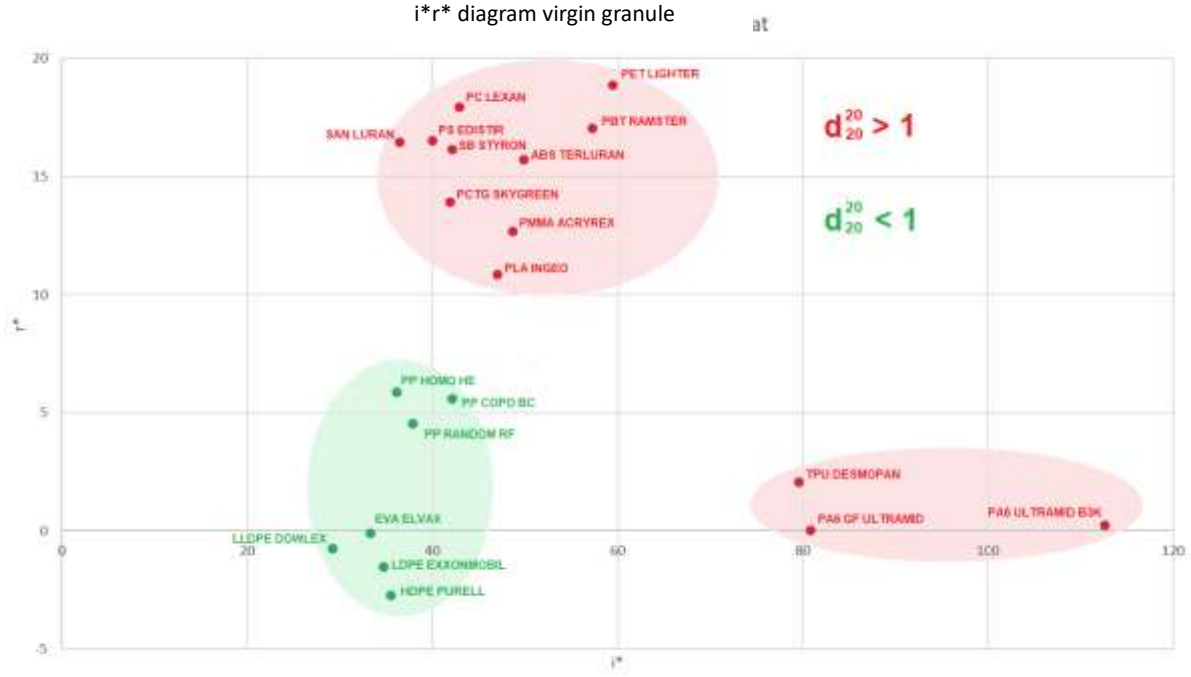
Niedriger N* - Wert (<55):	Hoher N* - Wert (>75):
TPU DESMOPAN	PET LIGHTER
PA6 ULTRAMID B3K	PBT RAMSTER
PA6 GF ULTRAMID	SAN LURAN
	SB STYRON

It should also be added that some of the virgin granulate samples are clear articles, i.e. optically highly transparent in the visual wavelength range. Transparent materials are less prone to diffuse backscattering, which means that a lower signal strength (N*) should be observable with these samples. The samples measured are of the following types:

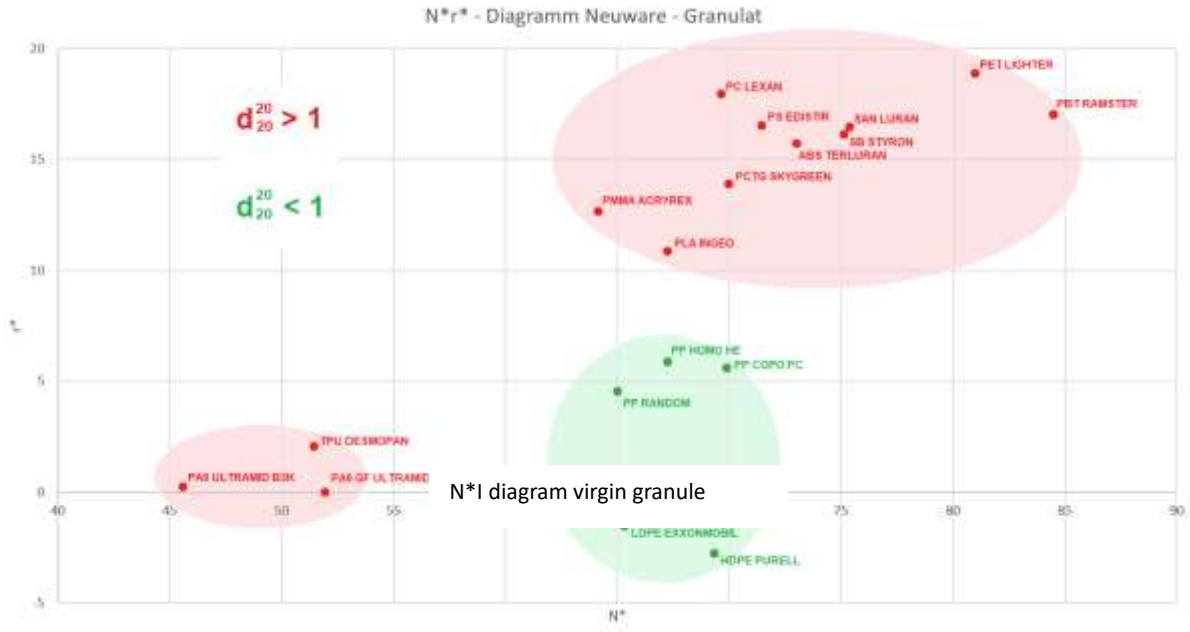
SAN LURAN, PC LEXAN, PCTG SKYGREEN, TPU DESMOPAN, PMMA ACRYREX, EVA ELVAX, PS EDISTIR, LLDPE DOWLEX

However, since no direct relationship can be established between the visually transparent appearance of the granulate samples and the N* value, it can be assumed that the optically transparent behaviour of these materials is primarily limited to the visual wavelength range.

i*r* diagram virgin granule

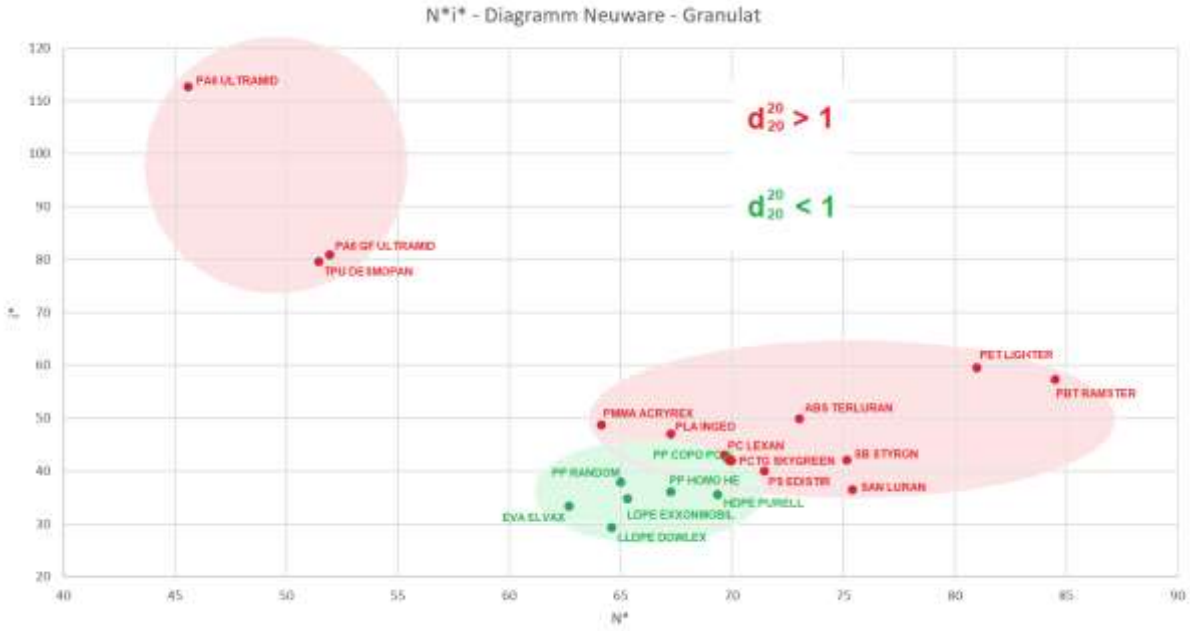


The i*r* diagram above shows the classification of the measured virgin granulate samples in the individual groups (highlighted in color). In particular, the green group could be subdivided further, into a subgroup with an r* value <2 and into a group of polyethylenes inc. the copolymer ethylene vinyl acetate with an r* value >2 into a group of polypropylenes. In the i* value, a slight difference in the two subgroups can also be seen: PP group: i* >36 and for the PE/EVA group: i* <36.



N*I diagram virgin granule

The group formation can also be observed rather well in the N*i* diagram. Polyurethanes and polyamides appear to absorb NIR light more strongly than other types of plastic, with surfaces appearing bright at least in the visible wavelength range.



N*i* diagram


Untersuchung verschiedener Rezyklate
im Hinblick auf die Kunststoffart

3. Using NIR technology to investigate the plastic type of various recyclates

The NIR absorption behaviour of almost 70 different recyclates was investigated:


48
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45

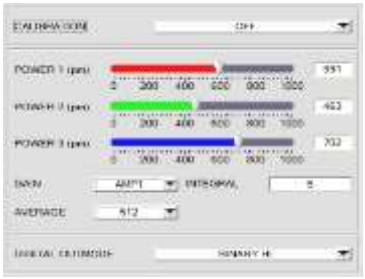
3.1 Measurement results with the SPECTRO-T-3-60-NIR/NIR-D20

3.1.1 The compact measuring device

The compact measuring device is also used to determine the N*i*r* values (the capacity of the pellet trays is c. 0.1 litre), as there was not enough material available to use the laboratory device with the large funnel to examine the samples (c. 2-3 litres of recyclate material per sample would be suitable). To determine an average value and to avoid a dependence of the measurement result on the random position of the pellets in the detection zone of the measuring device as far as possible, we recommend moving the pellet tray in the measuring device during the measuring process. The duration of the measurement can be set in the Windows® PC software.

3.1.2 Referencing the sensor

The aluminium plate (reference surface) is also used for this purpose and in consequence, the same setting parameters are used. The average value has no influence on the signal heights and can be increased to 16384 accordingly. Only the scanning time and the measuring accuracy are increased through this step.



3.1.3 Determining the N*i*r* measured values

The almost 70 recyclate samples are grouped into groups of 5 so that the graphical representation in the GUI does not become too unclear.

<u>1. Quintet</u>

a) 10 beige-white semi-transparent PO, specific weight <1

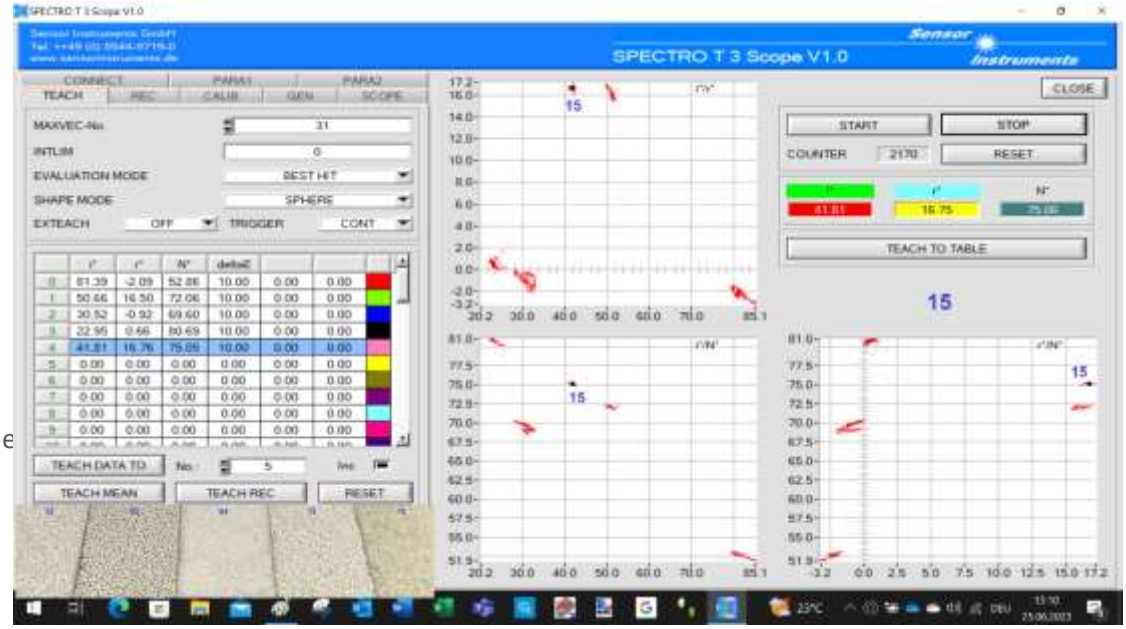
b) 18 white PET, specific weight >1

c) 64 white semi-transparent, specific weight <1

d) 52 beige, specific weight >1

e) 15 white PET, specific weight >1

e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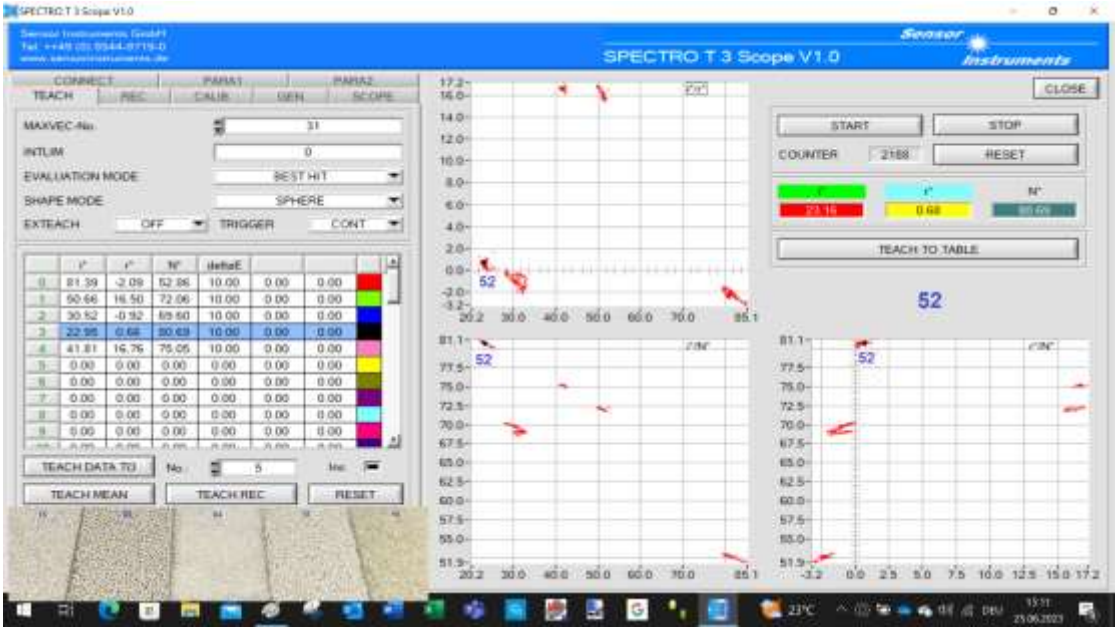
d)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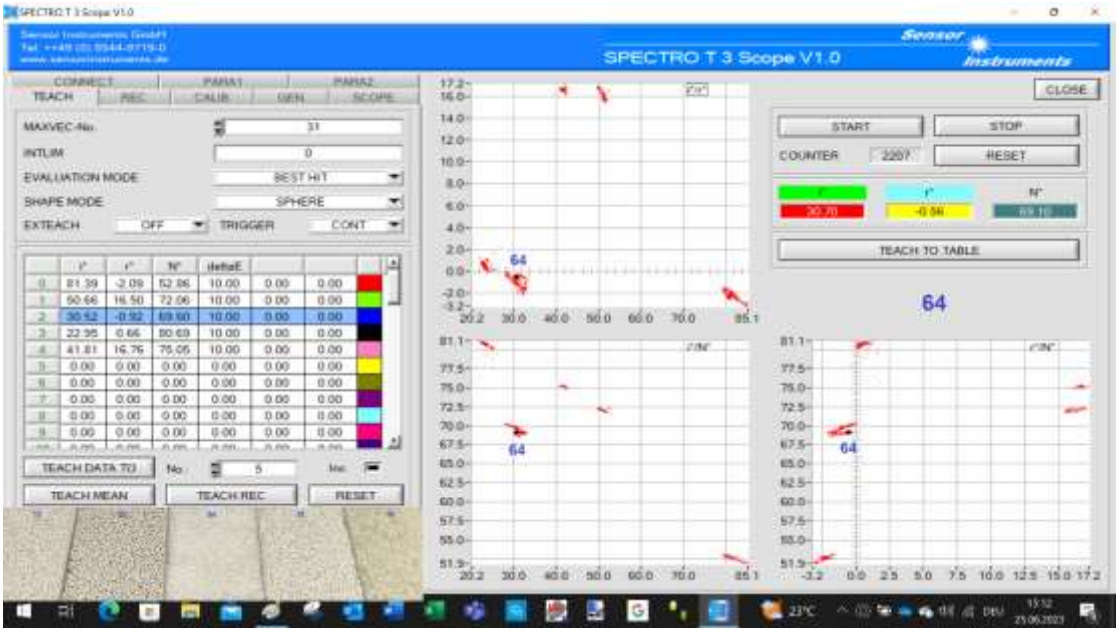
c)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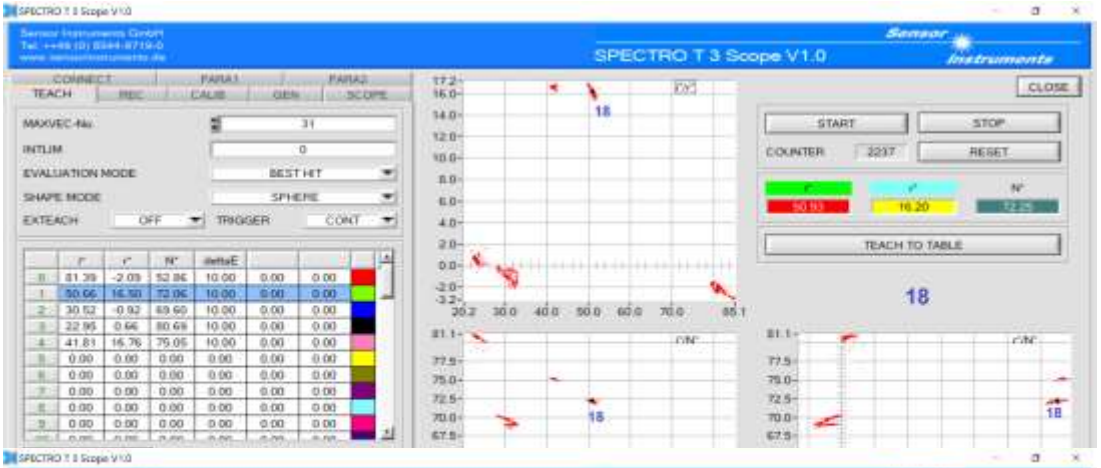
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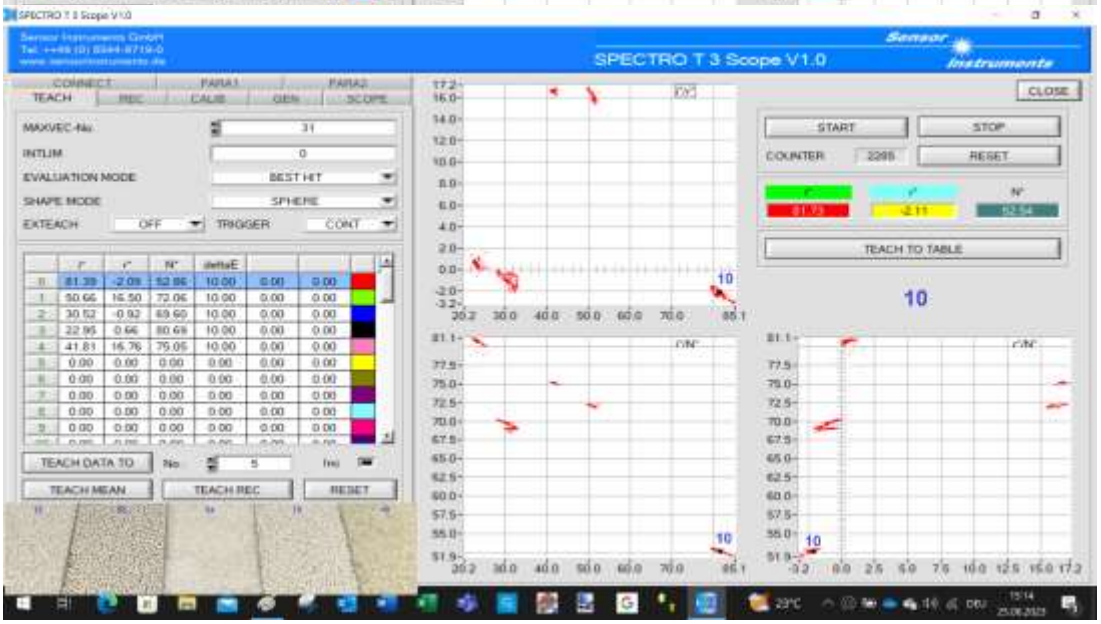
b)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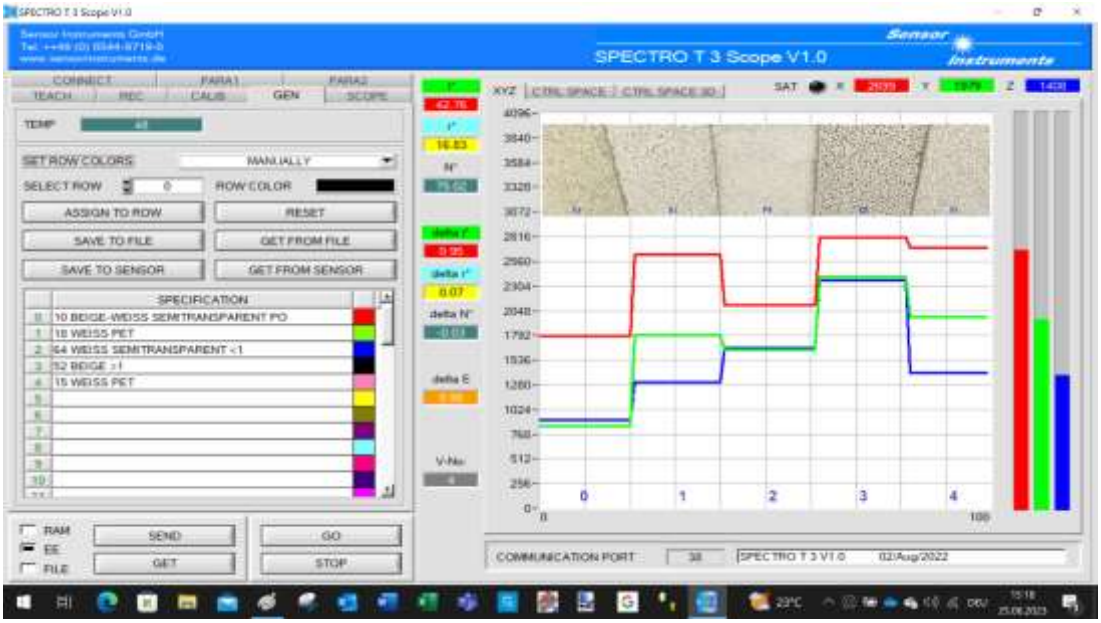
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SAVE TO SENSOR
GET FROM SENSOR
SPECIFICATION
10 BEIGE-WEISS SEMITRANSPARENT PO
18 WEISS PET
64 WEISS SEMITRANSPARENT <1
52 BEIGE >1
15 WEISS PET
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GO
STOP
COMMUNICATION PORT
SPECTRO T 3 V1.0
02/Aug/2022

2. Quintet

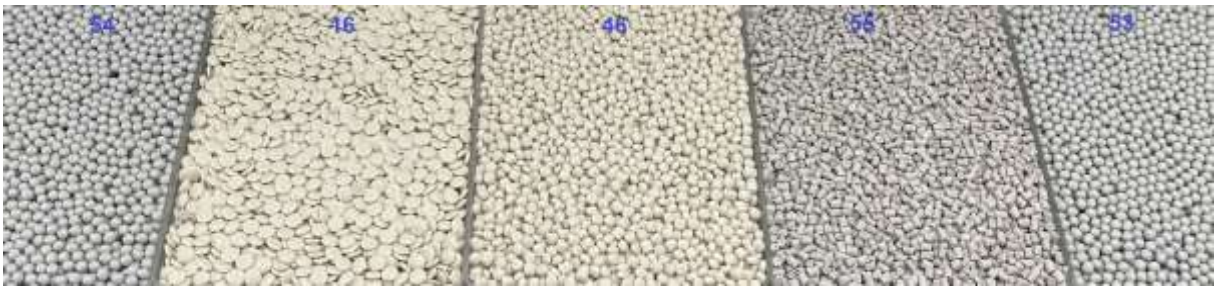
f) 53 grey PET, specific weight >1

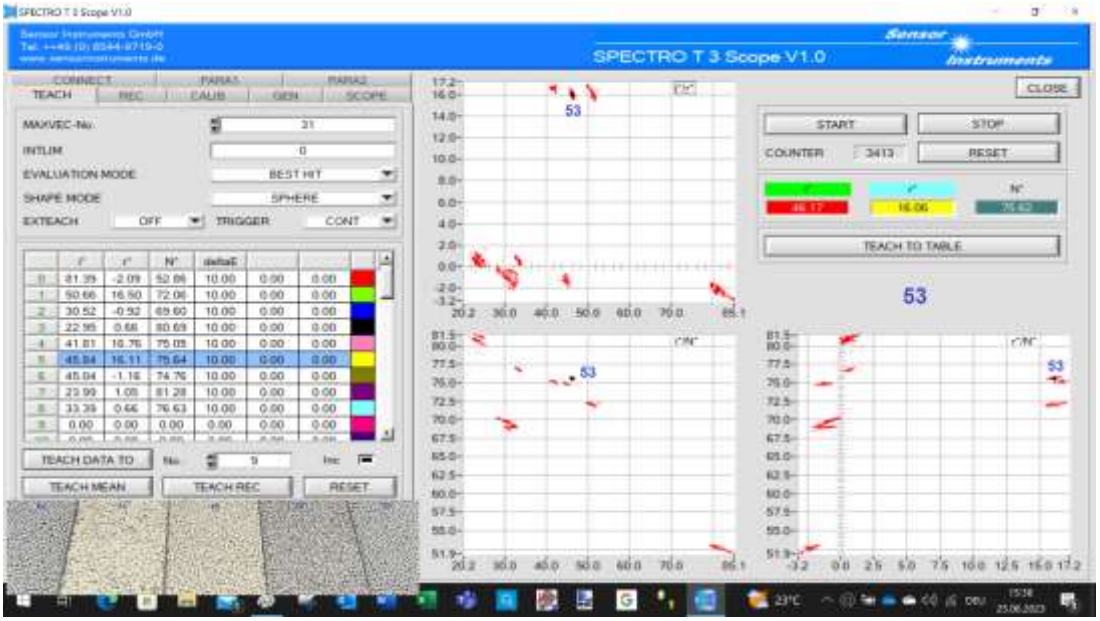
g) 55 grey-beige, specific weight >1

h) 46 light beige, specific weight <1

i) 16 light beige PO, specific weight <1

j) 54 grey PET, specific weight >1





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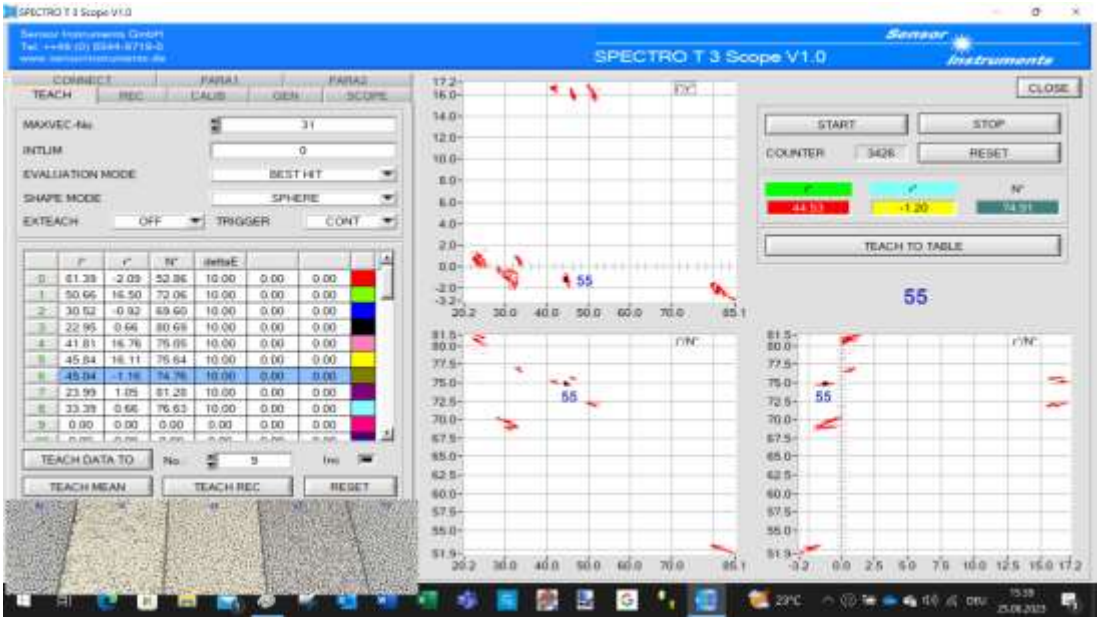

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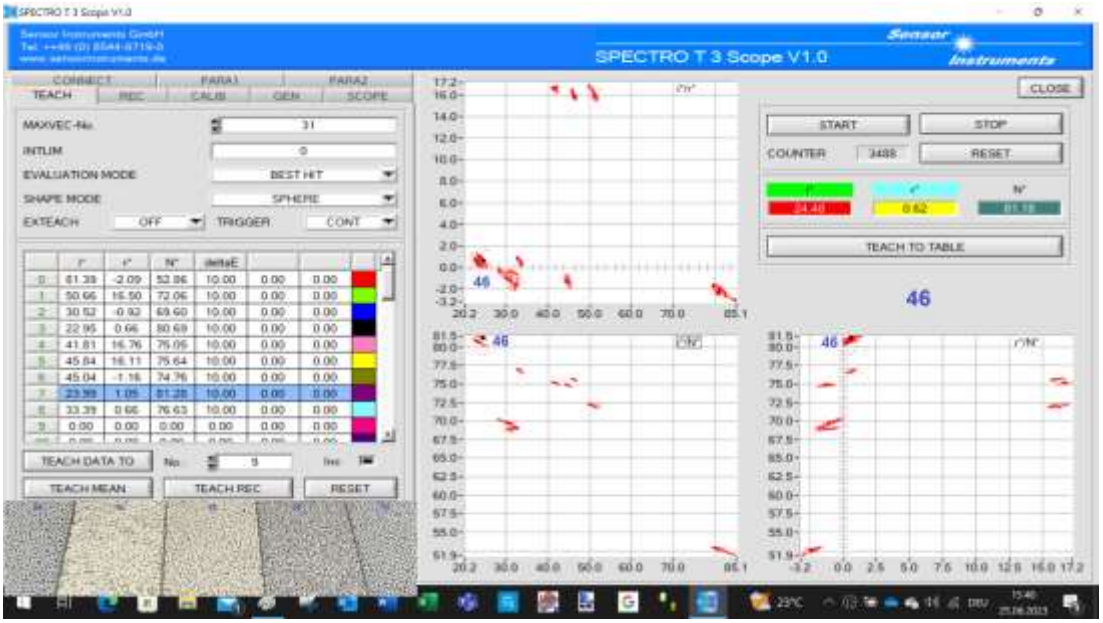
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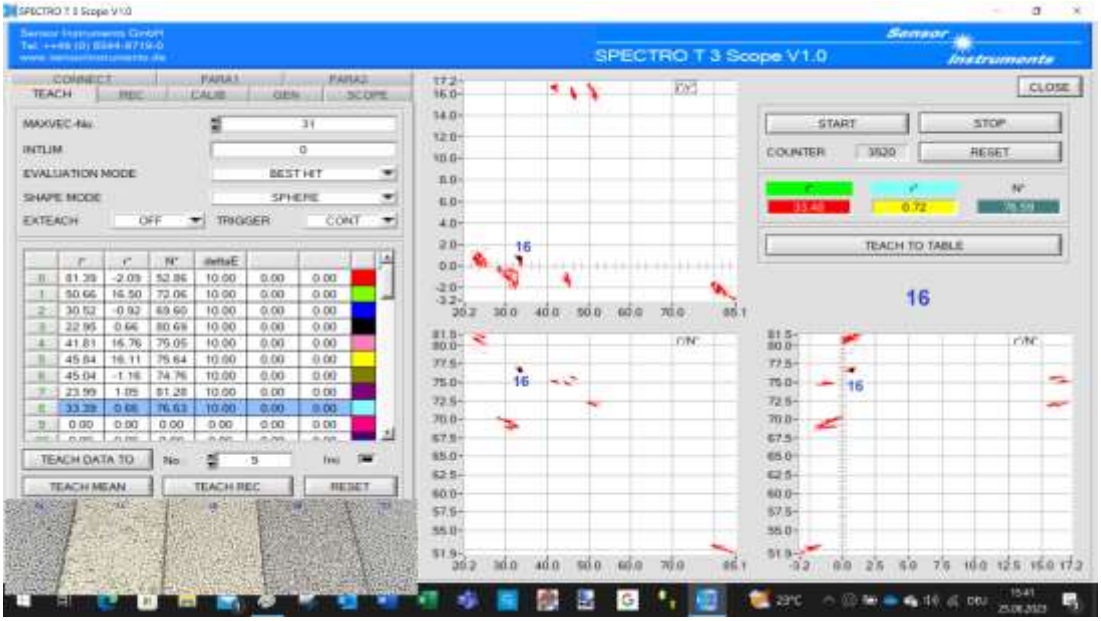
h)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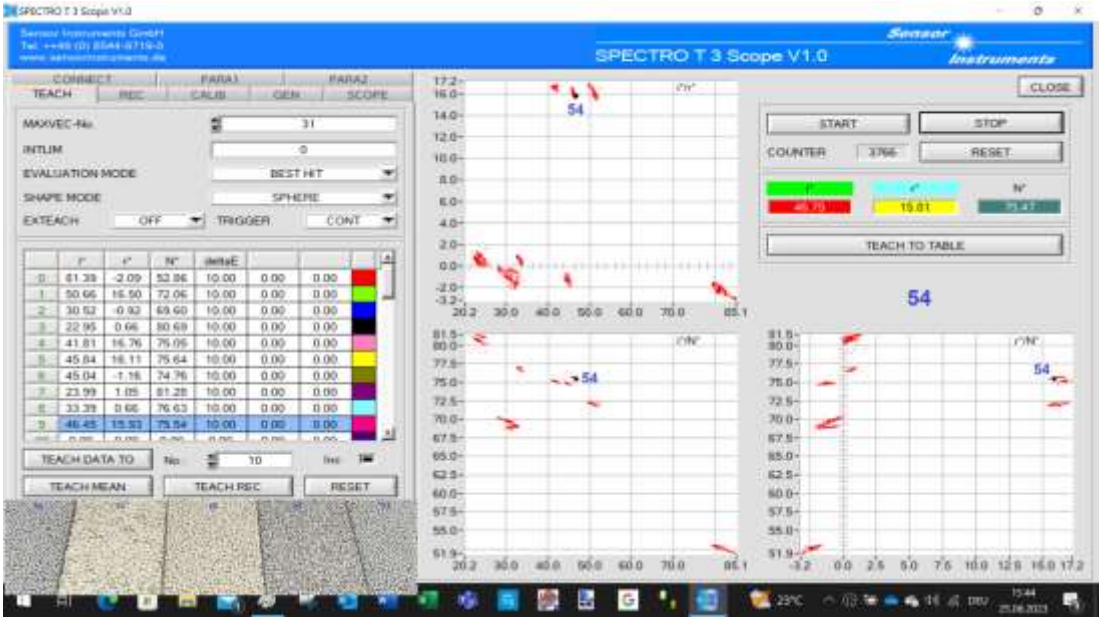
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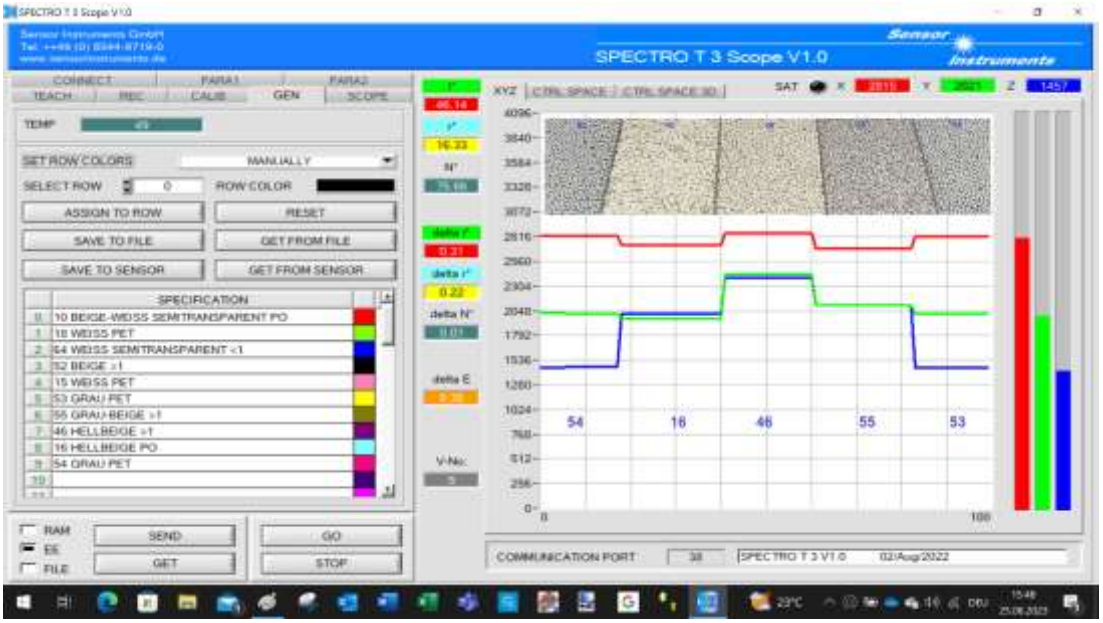
j)



3. Quintet

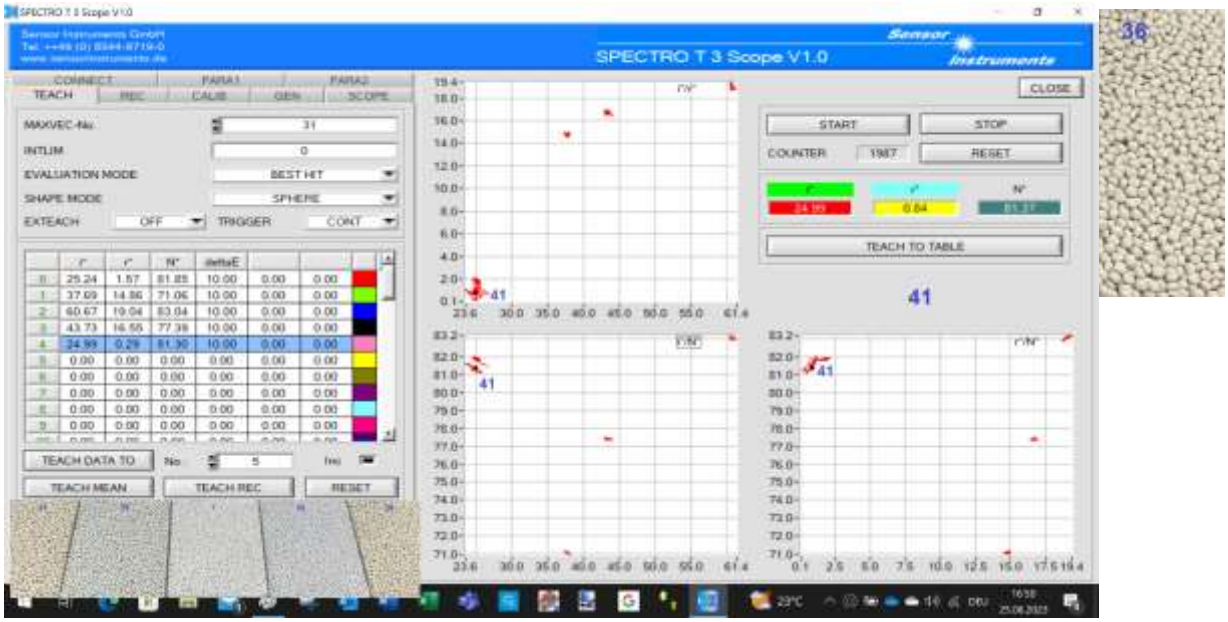
d) 36 beige, specific weight < 1

l) 30 light blue, specific weight >1

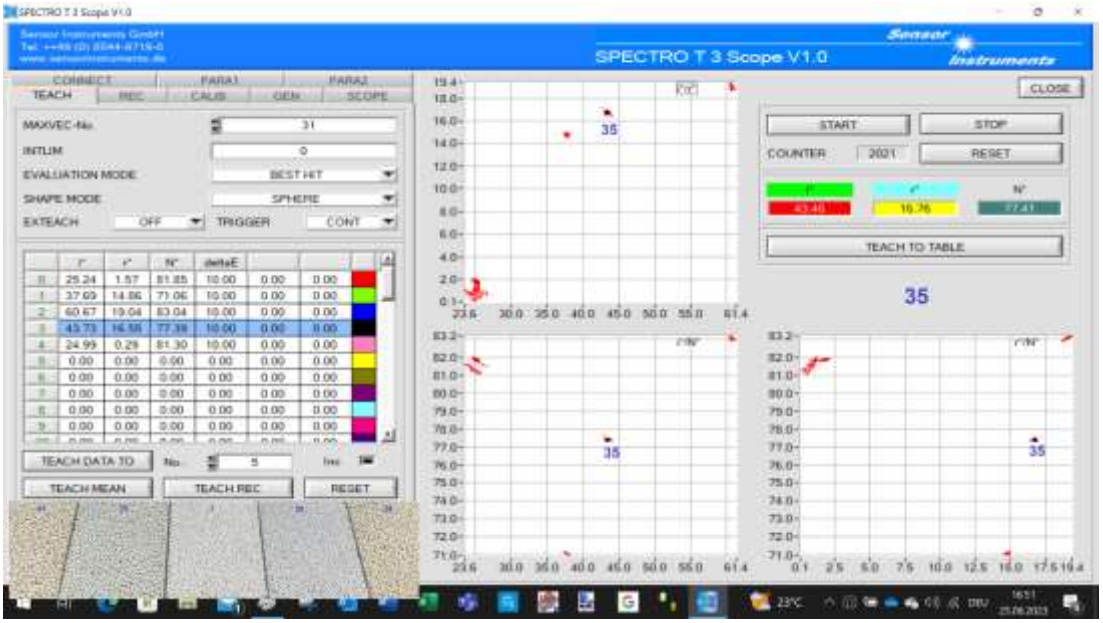
m) 1 white PET, specific weight >1

n) 35 light aquamarine, specific weight >1

o) 41 beige, specific weight <1



o)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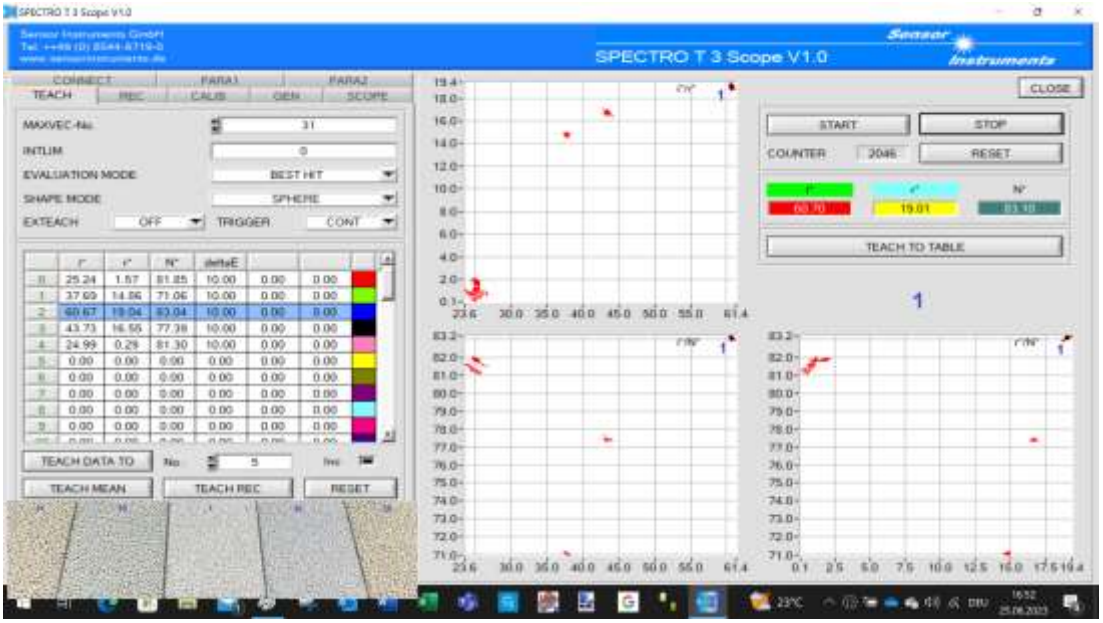
n)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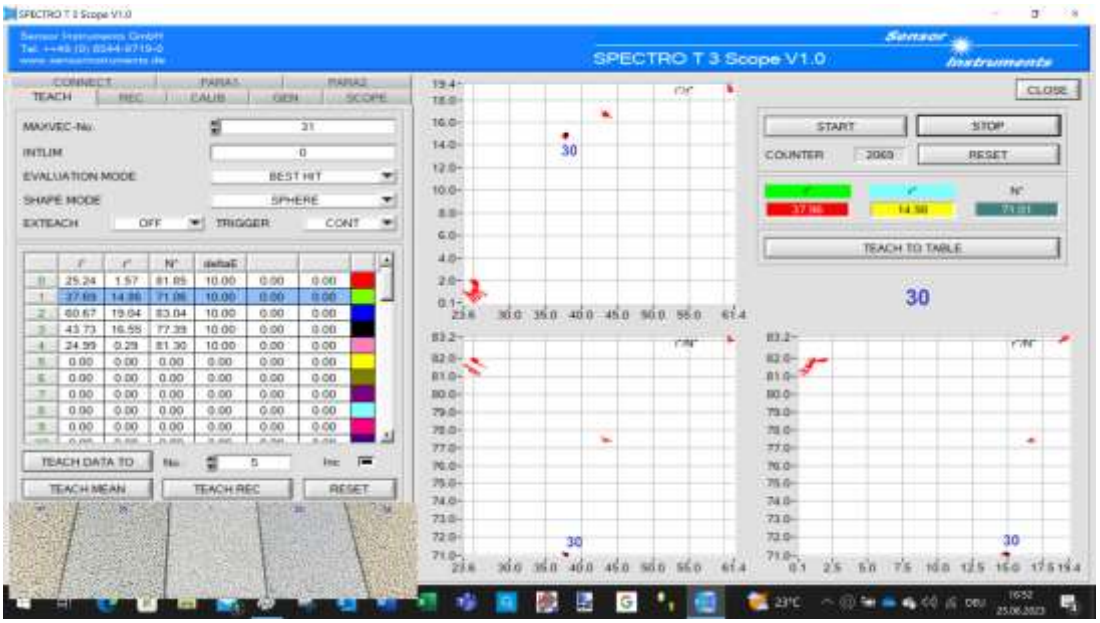
m)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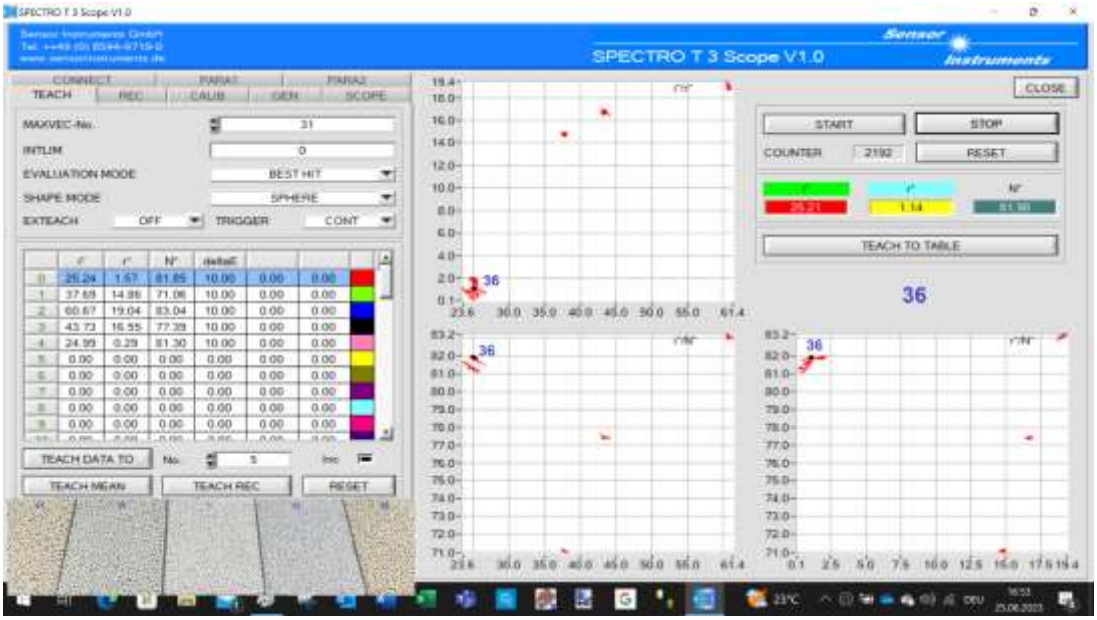
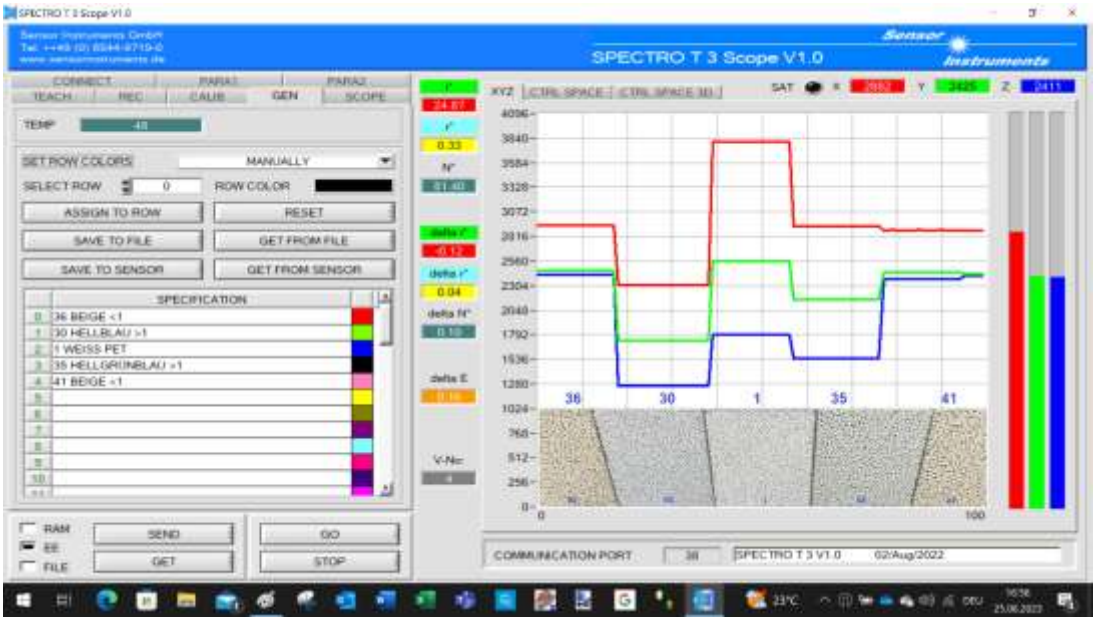
l)



k)



4. Quintet

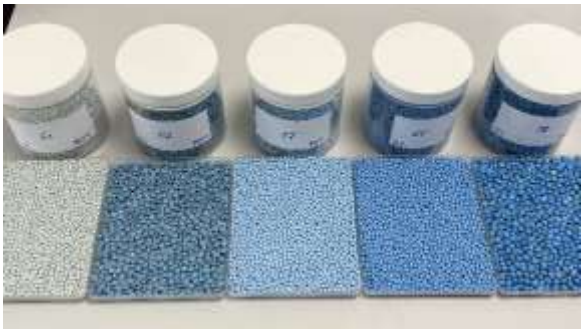
p) 38 light blue, specific weight <1

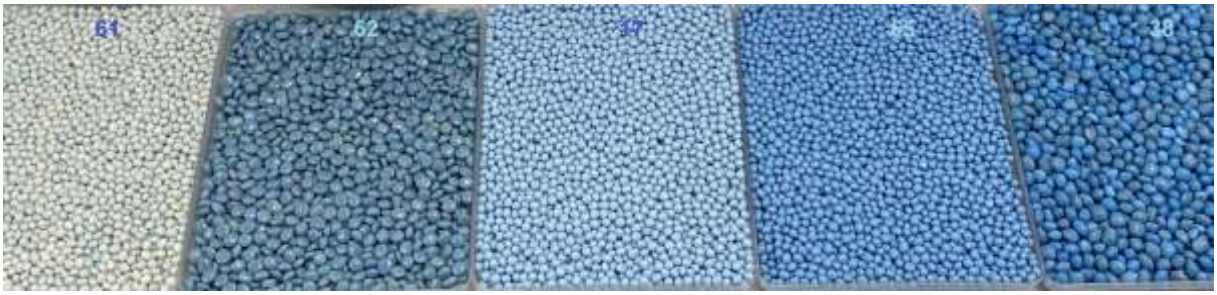
q) 65 light blue PET, specific weight >1

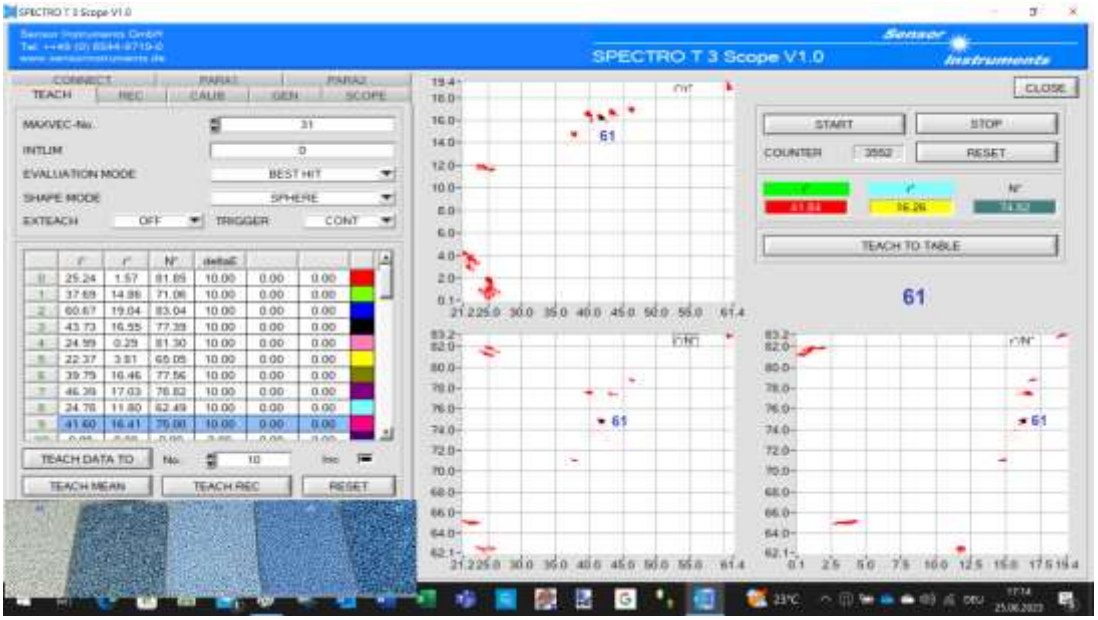
r) 17 light blue PET, specific weight >1

s) 62 grey-blue, specific weight >1

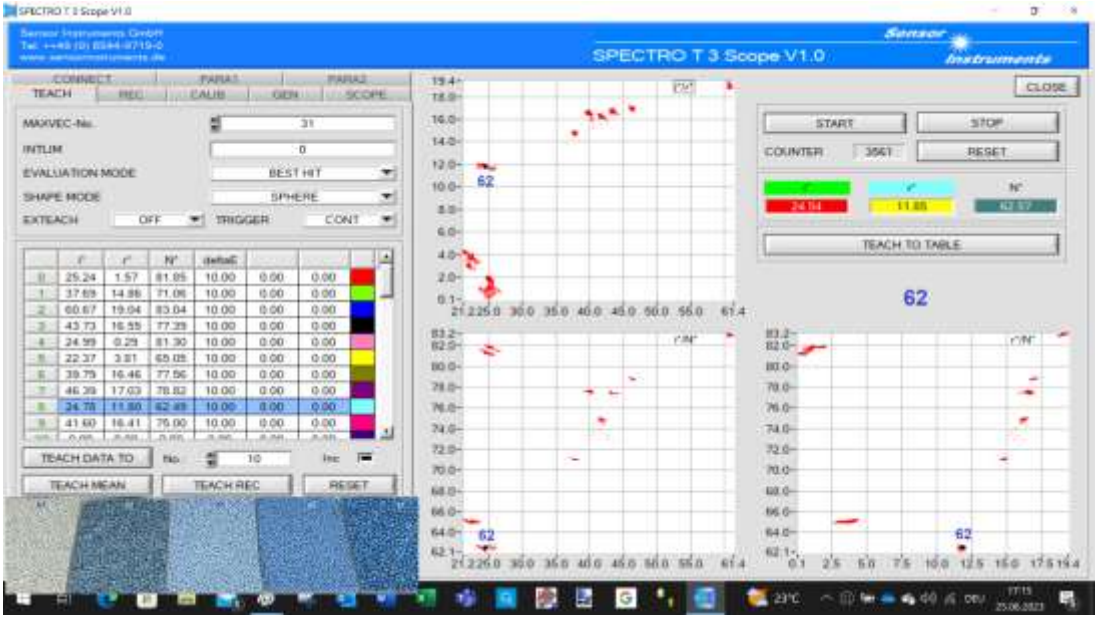
t) 61 light blue mix PET, specific weight >1






SPECTRO T 3 Scope V1.0
Sensor Instruments
CLOSE
START
STOP
COUNTER
RESET
TEACH TO TABLE
61
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

t)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Sensor Instruments
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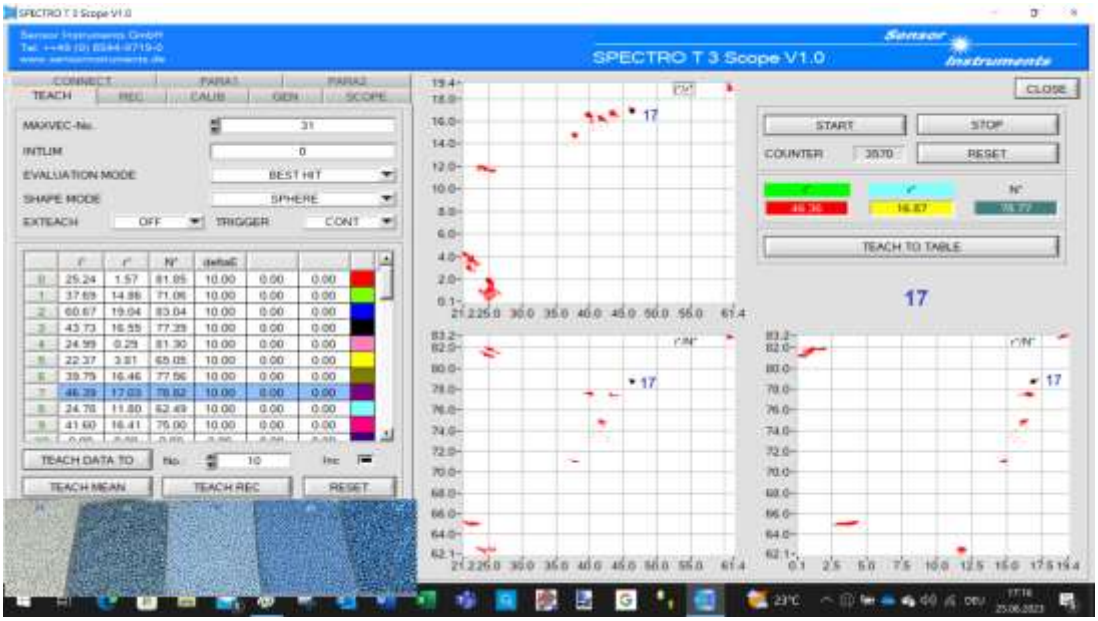
COUNTER
RESET
TEACH TO TABLE
62
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

s)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TEACH TO TABLE
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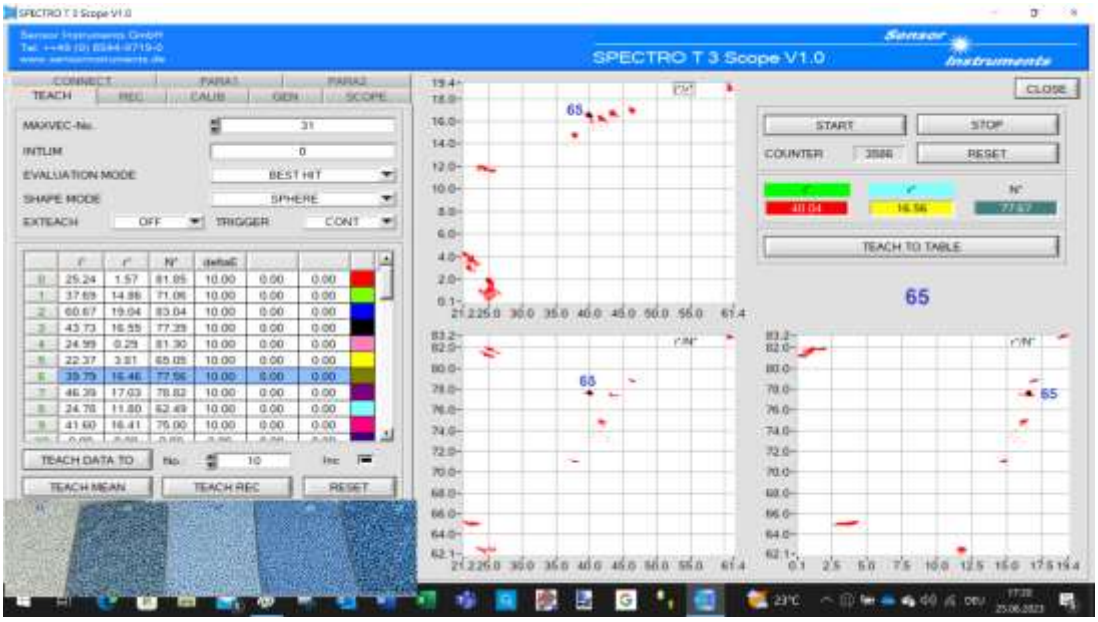
TEACH MEAN
TEACH REC
RESET

r)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Sensor Instruments
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REC
CALIB
GEN
SCOPE
PARA1
PARA2
MAXVEC-No.
INTLIM
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
TEACH MEAN
TEACH REC
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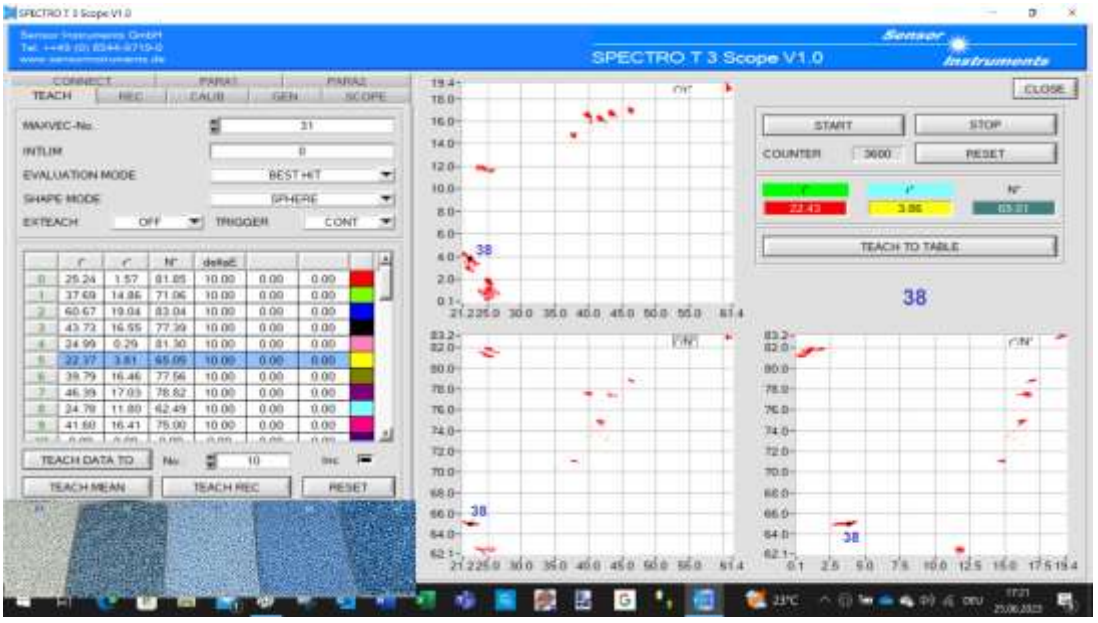
CLOSE
START
STOP
COUNTER
RESET
TEACH TO TABLE
65

q)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Sensor Instruments
CONNECT
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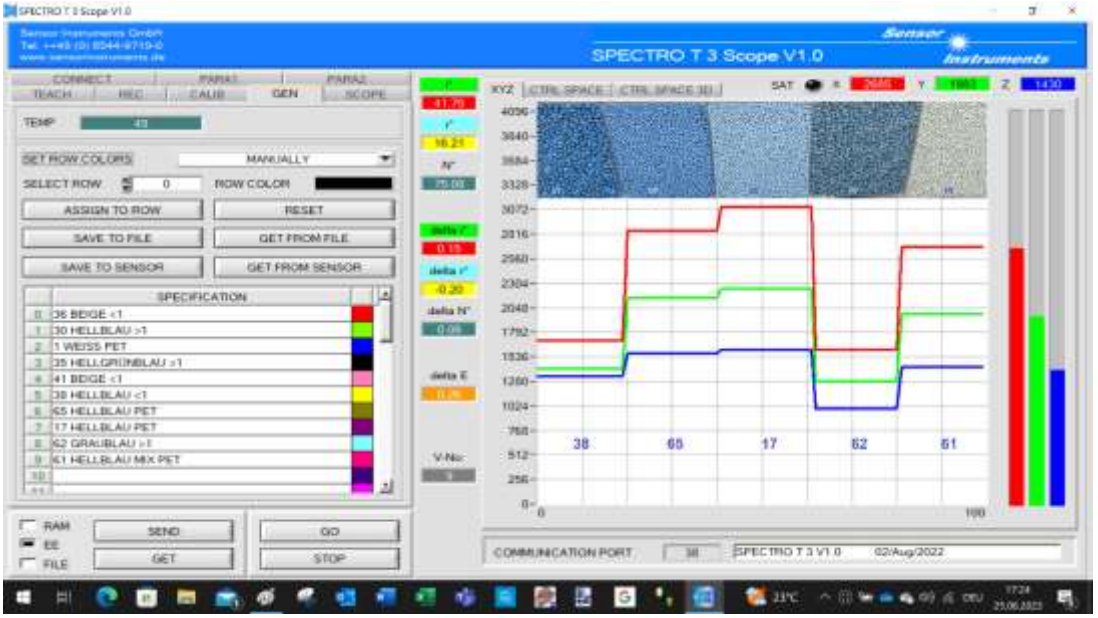
REC
CALIB
GEN
SCOPE
PARA1
PARA2
MAXVEC-No.
INTLIM
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET
CLOSE
START
STOP
COUNTER
RESET
TEACH TO TABLE
38

p)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Sensor Instruments
CONNECT
TEACH
REC
CALIB
GEN
SCOPE
PARA1
PARA2
TEMP
SET ROW COLORS
MANUALLY
SELECT ROW
ROW COLOR
ASSIGN TO ROW
RESET
SAVE TO FILE
GET FROM FILE
SAVE TO SENSOR
GET FROM SENSOR
SPECIFICATION
RAM
EE
FILE
SEND
GET
GO
STOP
COMMUNICATION PORT
SPECTRO T 3 V1.0
02/Aug/2022

5. Quintet

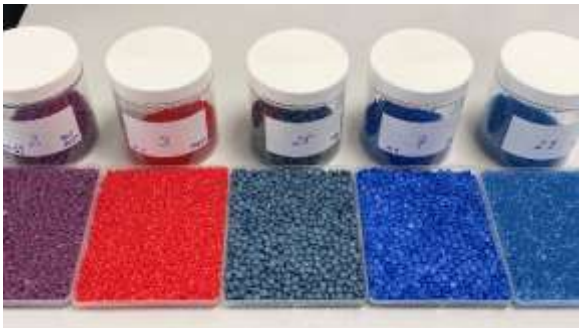
u) 23 blue transparent, specific weight >1

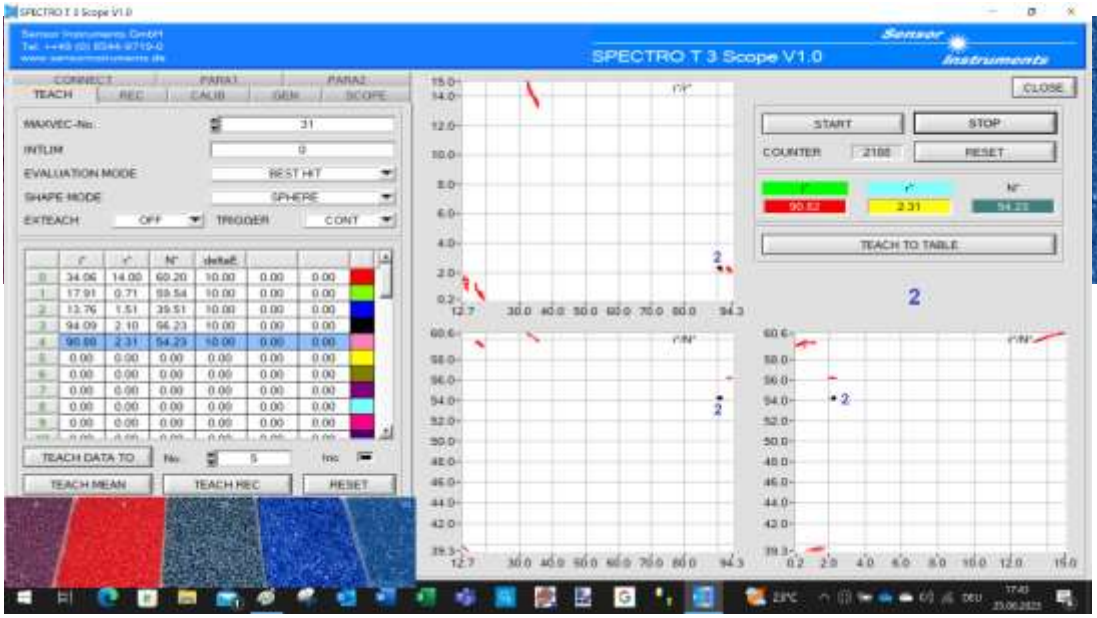
v) 7 blue PO, specific weight <1

w) 25 grey-blue PO, specific weight <1

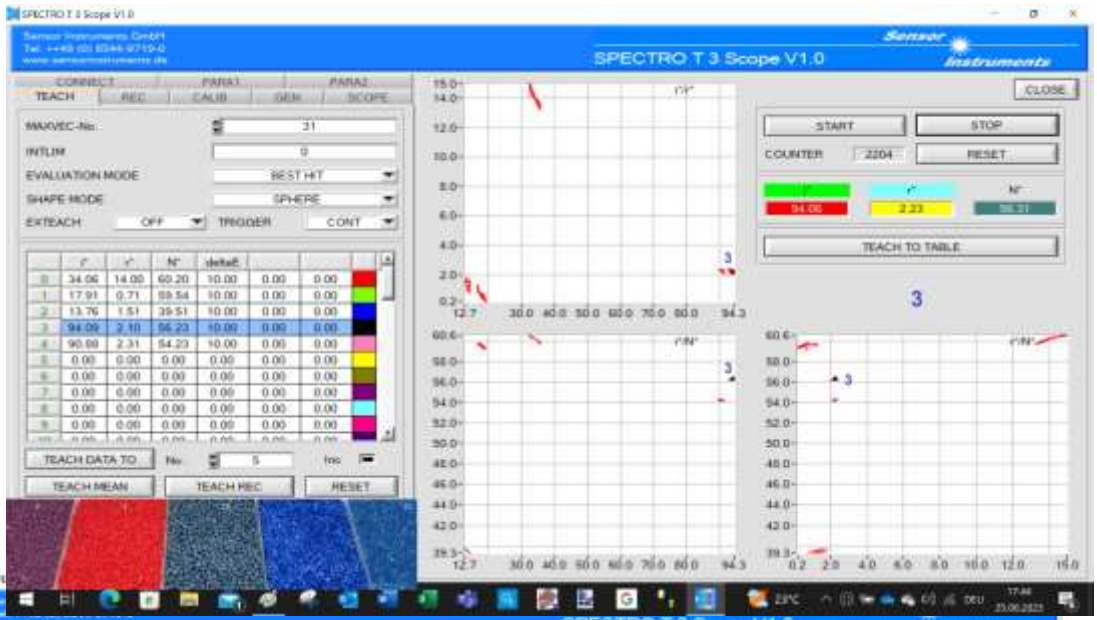
x) 3 red, specific weight >1

y) 2 violet, specific weight >1

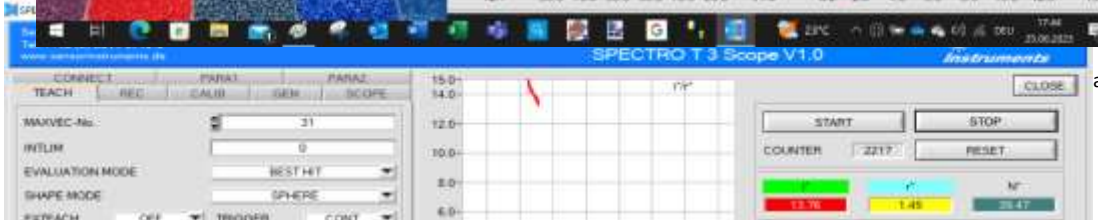




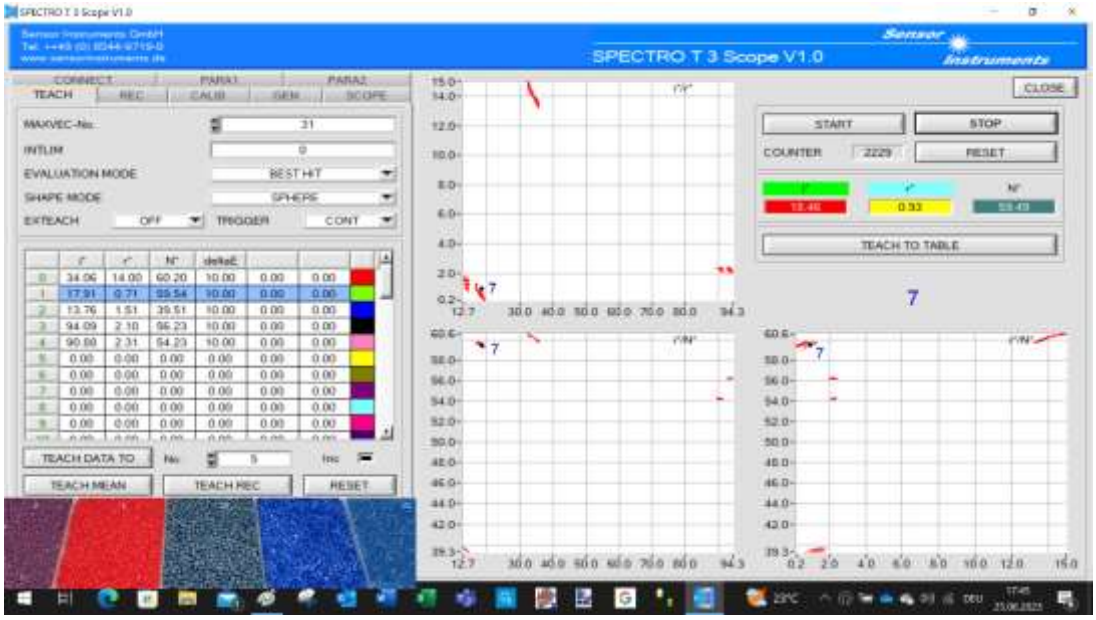
y)



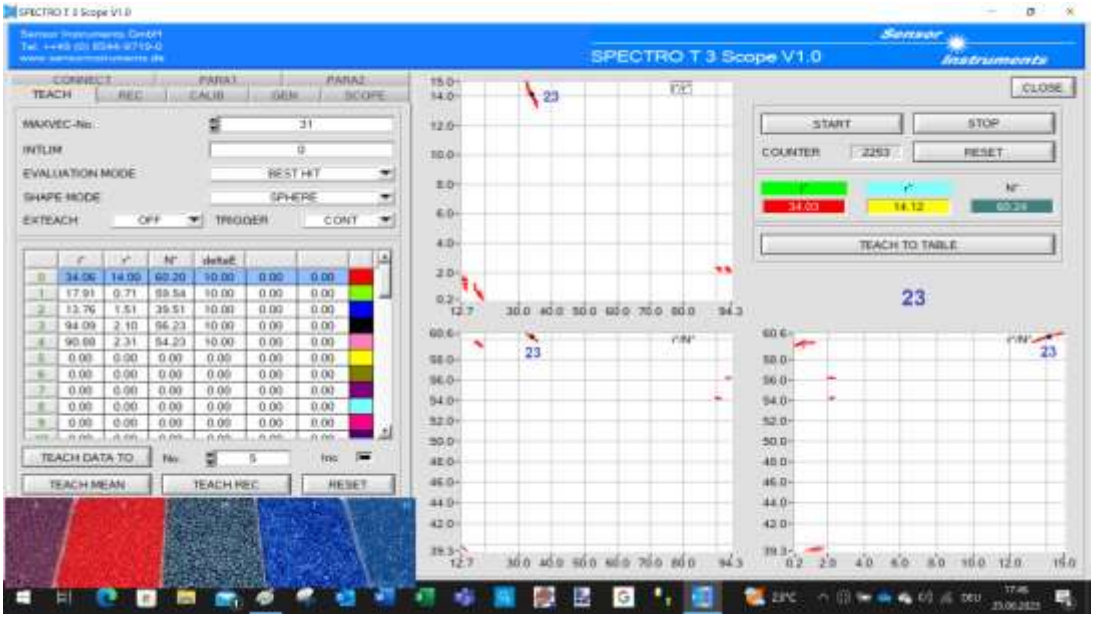
x)



w)


SPECTRO T 3 Scope V1.0
Sensor Instruments
CONNECT
PARA1
PARA2
TEACH
REC
CALIB
GEN
SCOPE
MAXVEC-No.
31
INTLIM
0
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
No.
5
Inc
TEACH MEAN
TEACH REC
RESET
CLOSE
START
STOP
COUNTER
2229
RESET
TEACH TO TABLE
7

v)


SPECTRO T 3 Scope V1.0
Sensor Instruments
CONNECT
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PARA2
TEACH
REC
CALIB
GEN
SCOPE
MAXVEC-No.
31
INTLIM
0
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
No.
5
Inc
TEACH MEAN
TEACH REC
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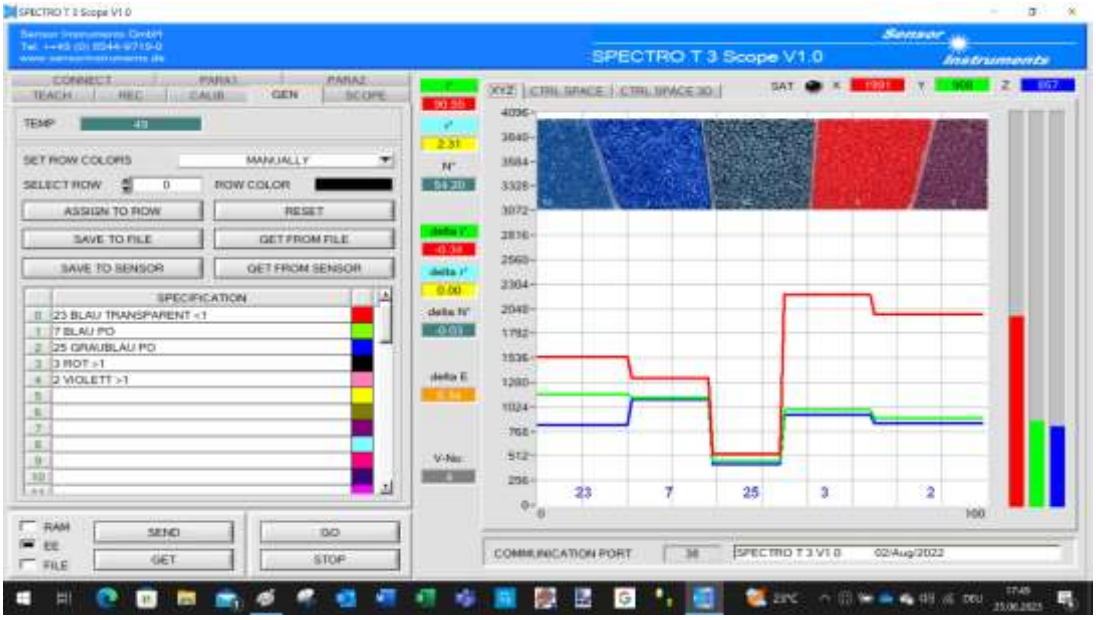
CLOSE
START
STOP
COUNTER
2253
RESET
TEACH TO TABLE
23

u)



6. Quintet

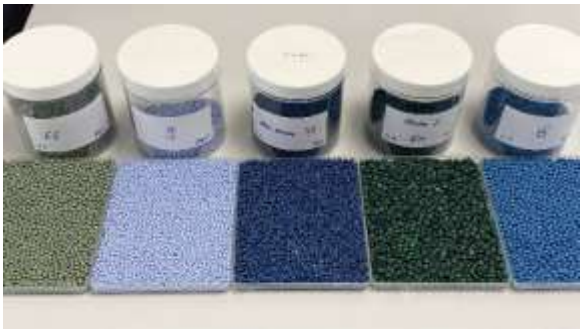
z) 6 blue, specific weight <1

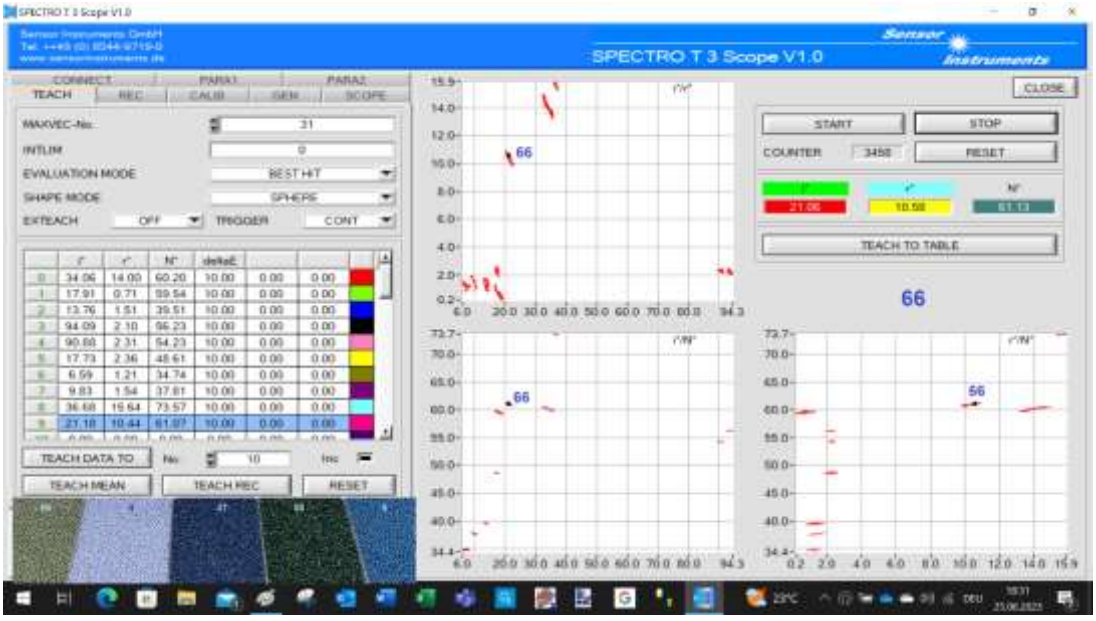
A) 50 dark green, specific weight <1

B) 47 dark blue, specific weight <1

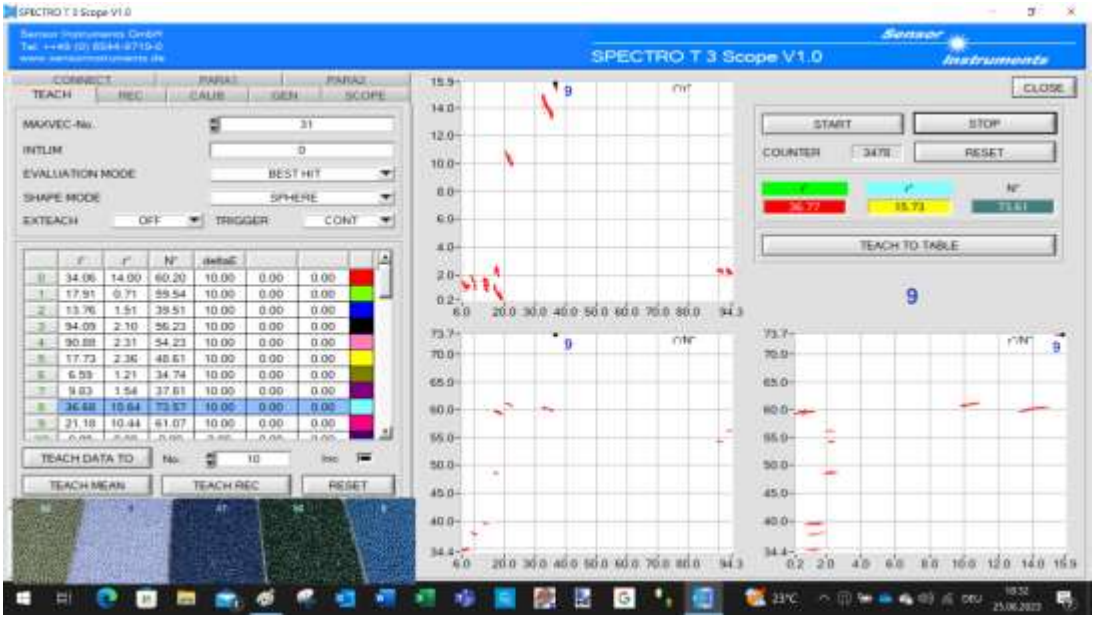
C) 9 light blue PET, specific weight >1

D) 66 olive, specific weight >1

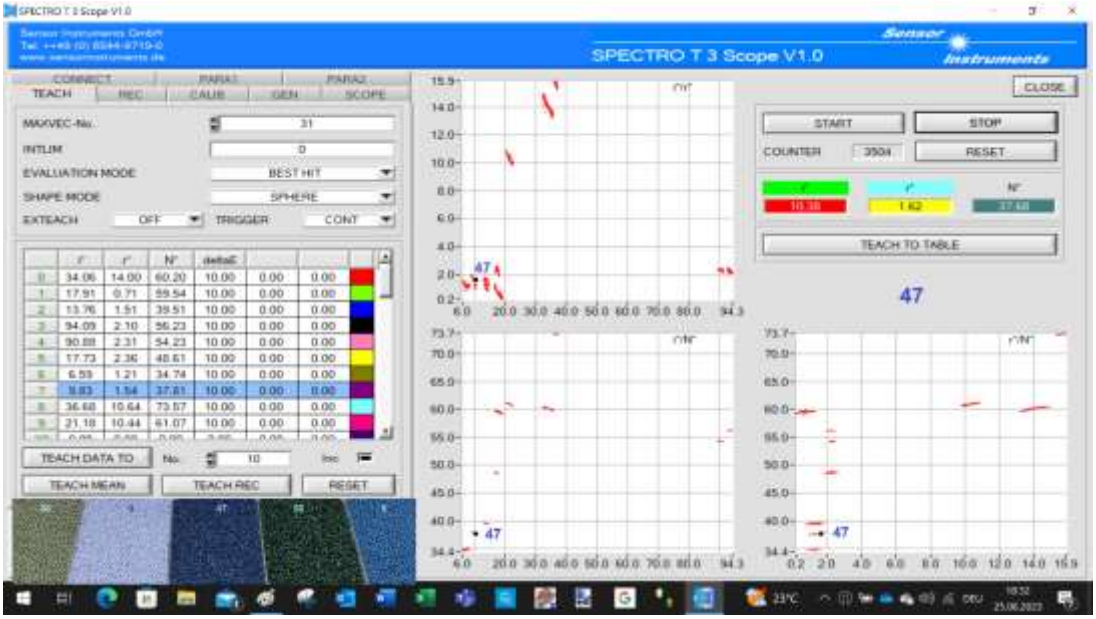




D)


SPECTRO T 3 Scope V1.0
Sensor Instruments
CLOSE
START
STOP
COUNTER
RESET
TEACH TO TABLE
MAXVEC-No.
INTLIM
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

C)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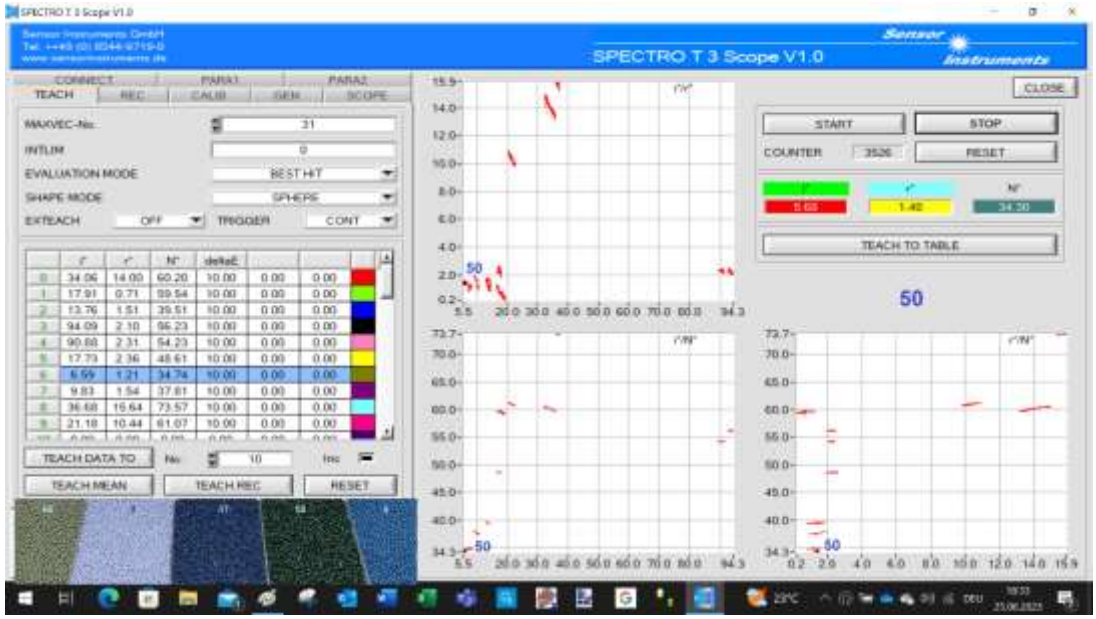
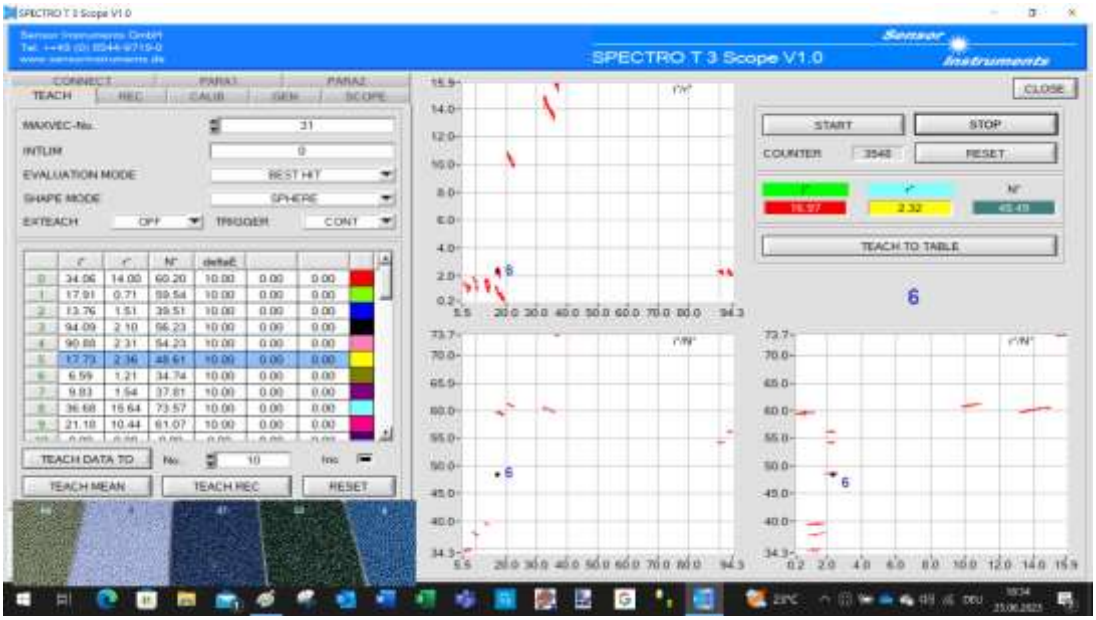
Sensor Instruments
CLOSE
START
STOP
COUNTER
RESET
TEACH TO TABLE
MAXVEC-No.
INTLIM
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

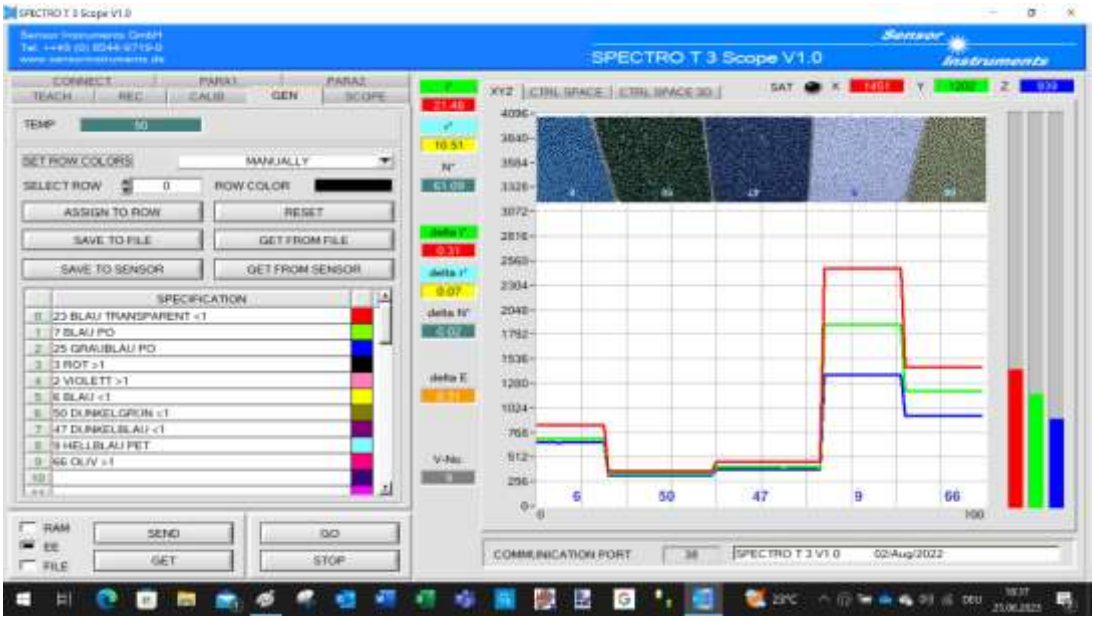
B)


SPECTRO T 3 Scope V1.0
Sensor Instruments
CLOSE
START
STOP
COUNTER
RESET
TEACH TO TABLE
MAXVEC-No.
INTLIM
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

A)



z)



7. Quintet

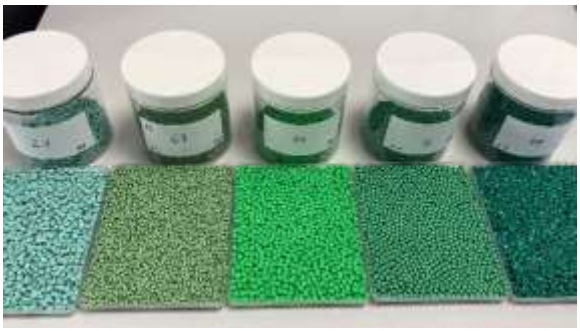
E) 44 green, specific weight <1

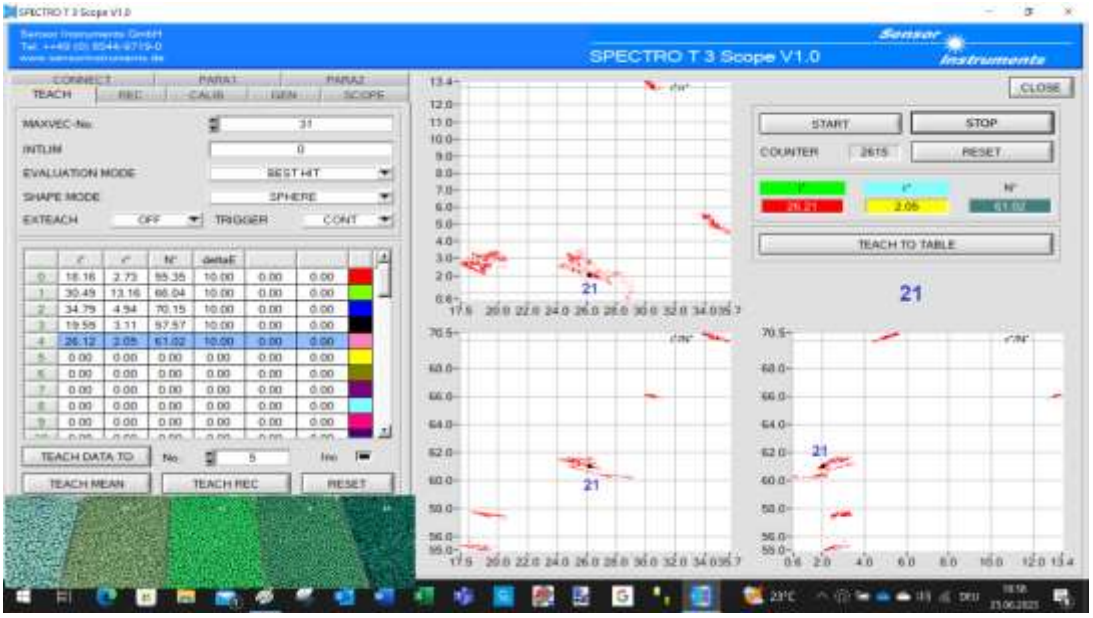
F) 4 green, specific weight <1

G) 11 light green PO, specific weight <1

H) 67 olive, specific weight <1

I) 21 turquoise PO, specific weight <1

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Sensor Instruments
CONNECT
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REC
CALIB
PARA1
GEN
PARA2
SCOPE
MAXVEC-No.
31
INTLIM
0
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
No.
5
Inc
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TEACH REC
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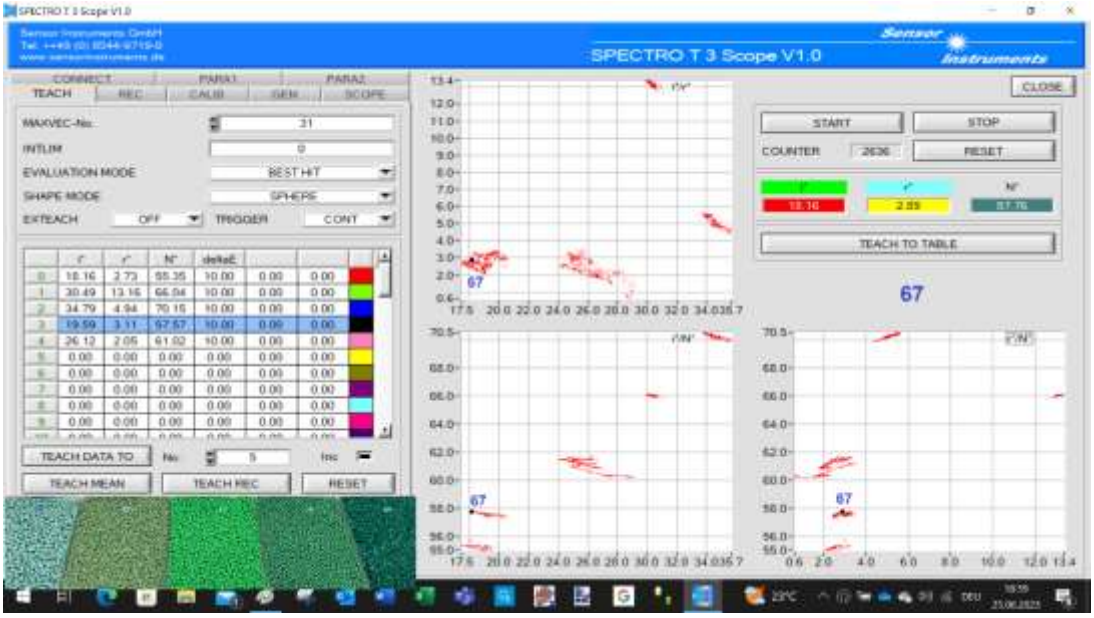
CLOSE
START
STOP
COUNTER
2615
RESET
TEACH TO TABLE
21

I)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Sensor Instruments
CONNECT
TEACH
REC
CALIB
PARA1
GEN
PARA2
SCOPE
MAXVEC-No.
31
INTLIM
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EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
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TEACH MEAN
TEACH REC
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START
STOP
COUNTER
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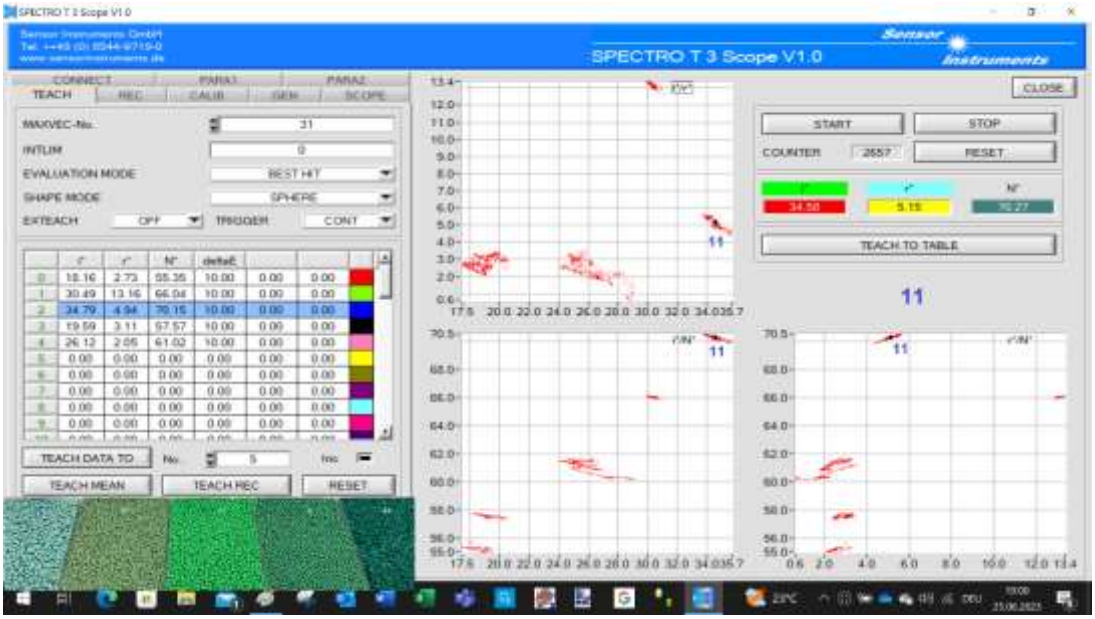
TEACH TO TABLE
67

H)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PARA1
GEN
PARA2
SCOPE
MAXVEC-No.
31
INTLIM
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EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
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TEACH MEAN
TEACH REC
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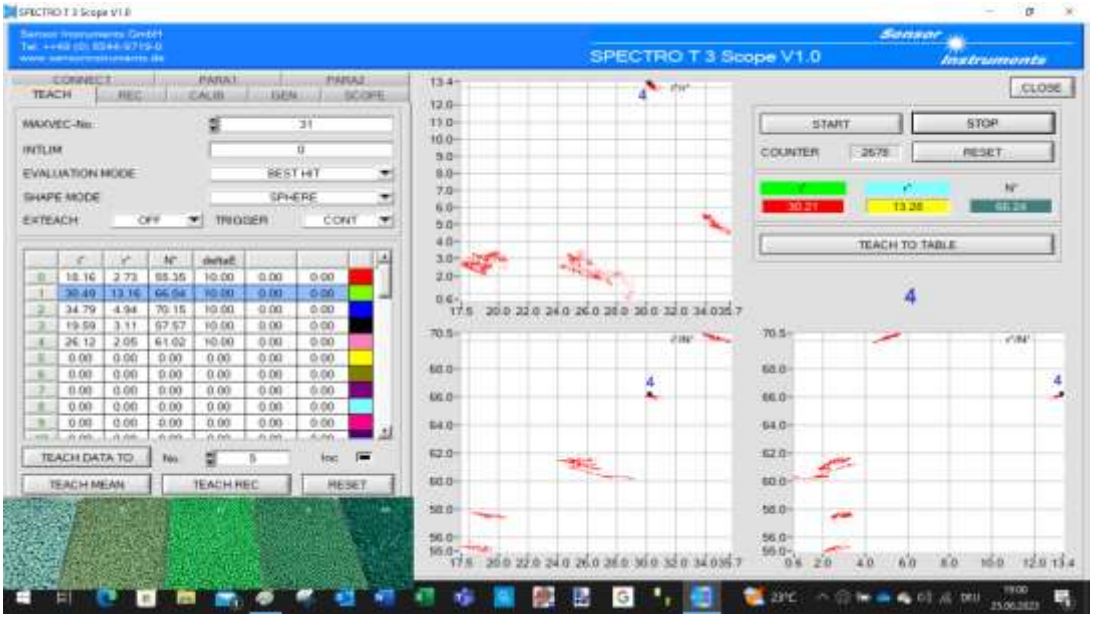
START
STOP
COUNTER
2657
RESET
TEACH TO TABLE
11

G)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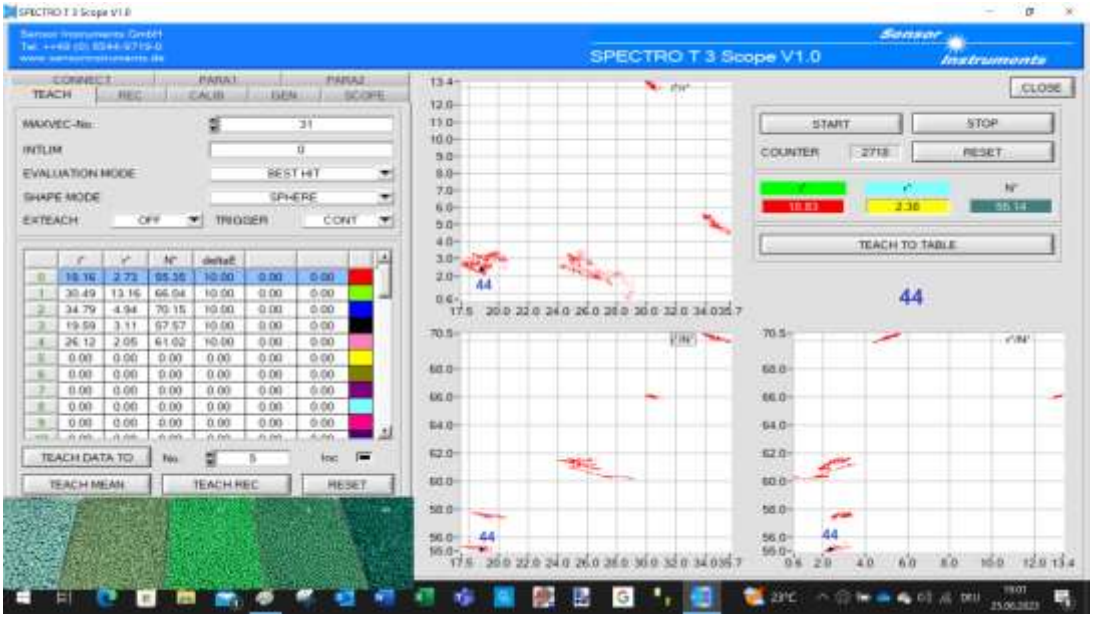
COUNTER
RESET
TEACH TO TABLE
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

F)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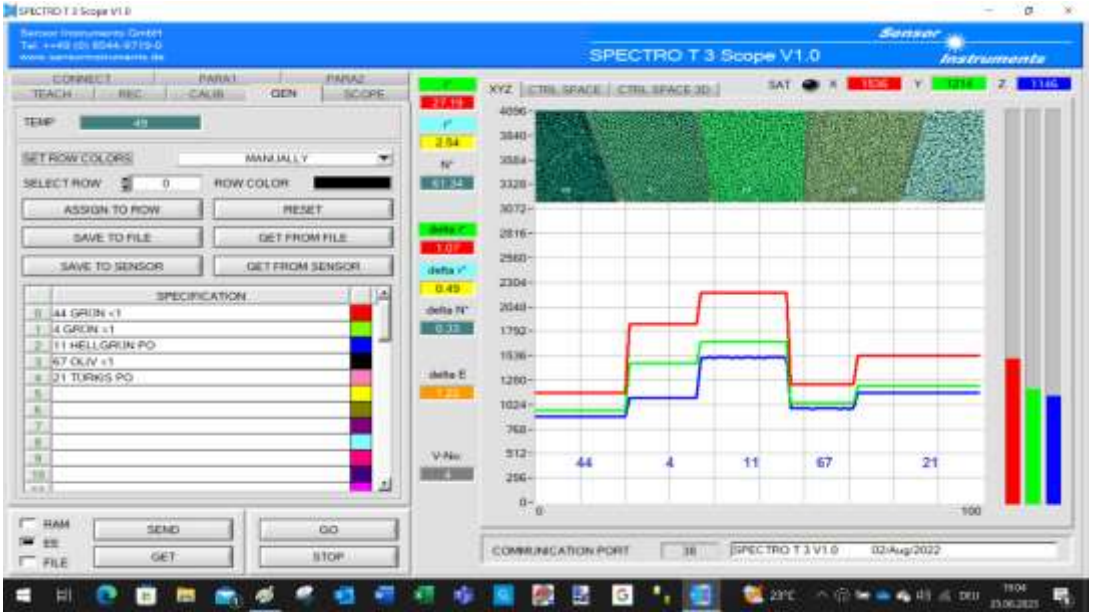
COUNTER
RESET
TEACH TO TABLE
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

E)


SPECTRO T 3 Scope V1.0
Sensor Instruments
SEND
GO
GET
STOP
COMMUNICATION PORT

8. Quintet

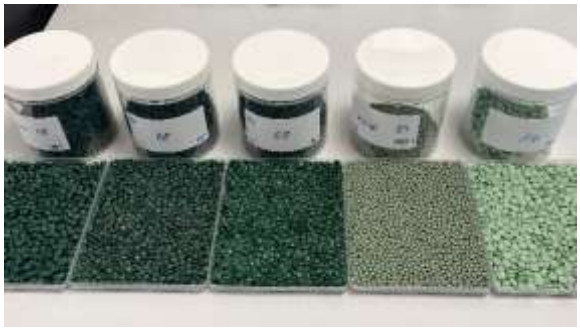
J) 24 turquoise PO, specific weight <1

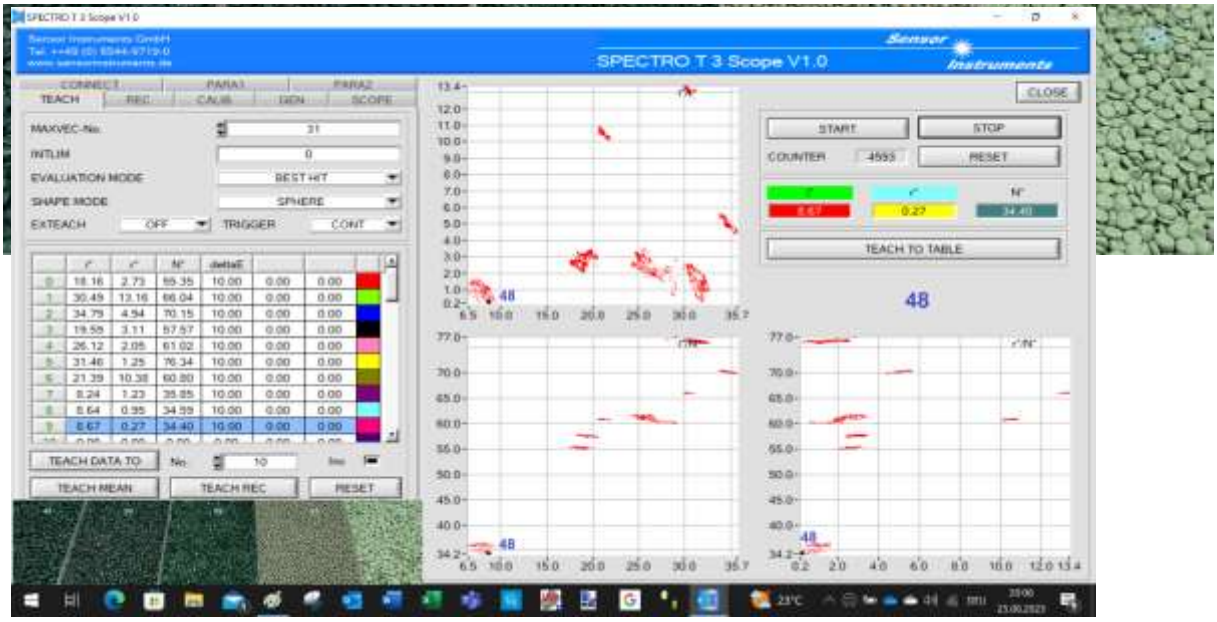
K) 51 olive, specific weight> 1

L) 69 dark green mix, specific weight <1

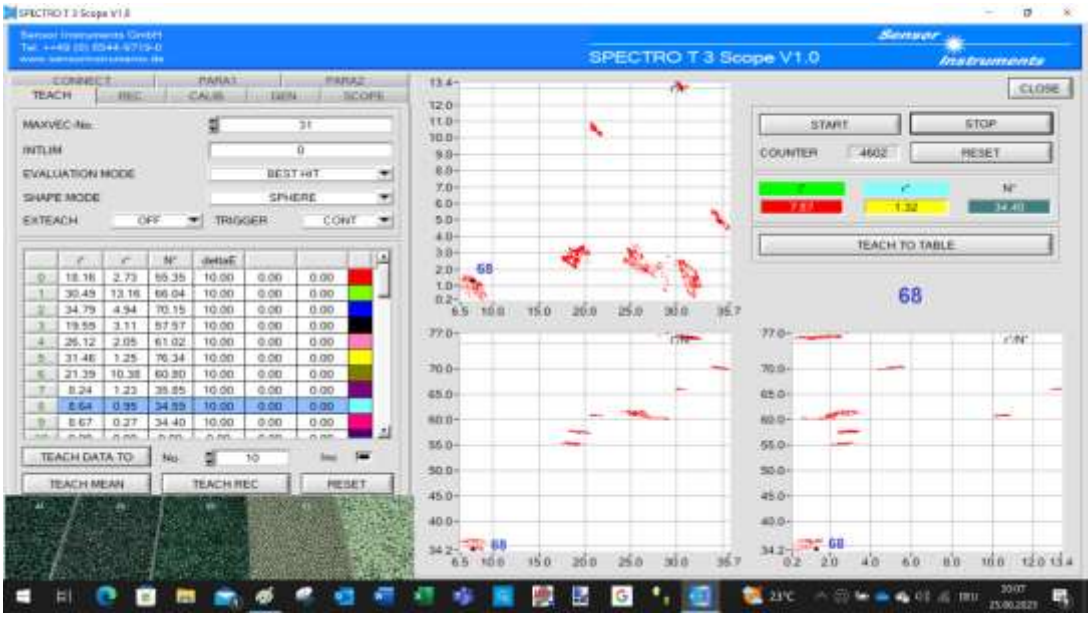
M) 68 dark green mix, specific weight <1

N) 48 dark green, specific weight <1

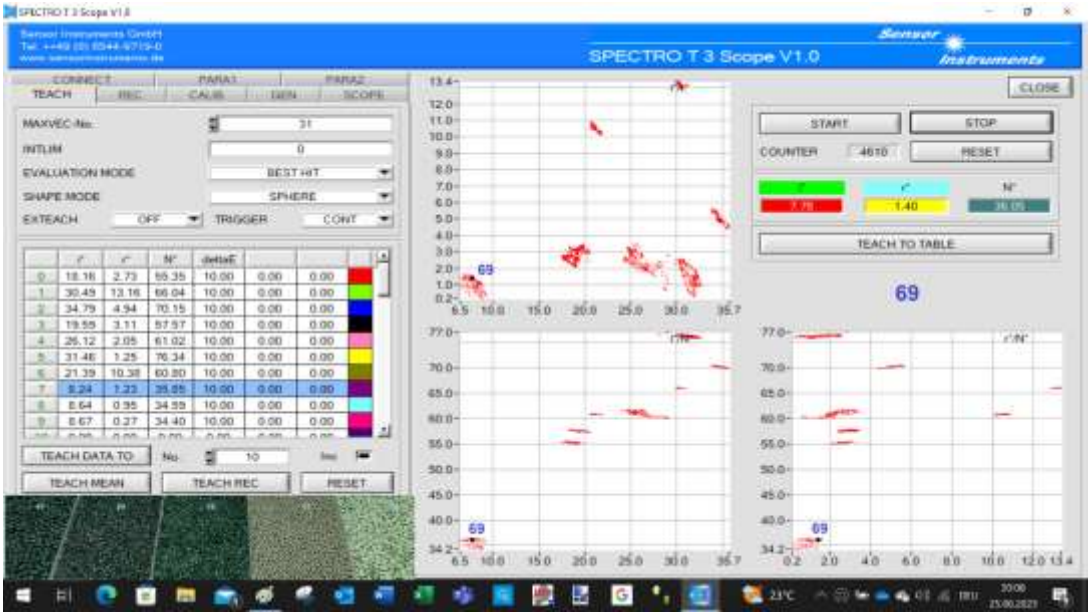




N)



M)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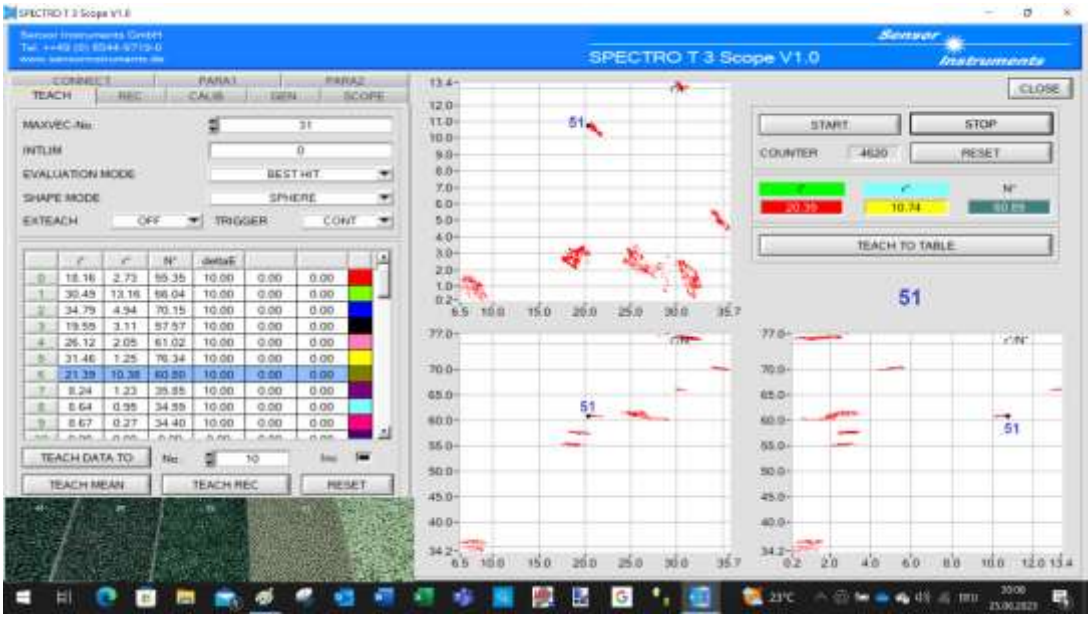
Sensor Instruments
CLOSE
START
STOP
COUNTER
RESET
TEACH TO TABLE
69
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

L)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STOP
COUNTER
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TEACH TO TABLE
51
TEACH DATA TO
TEACH MEAN
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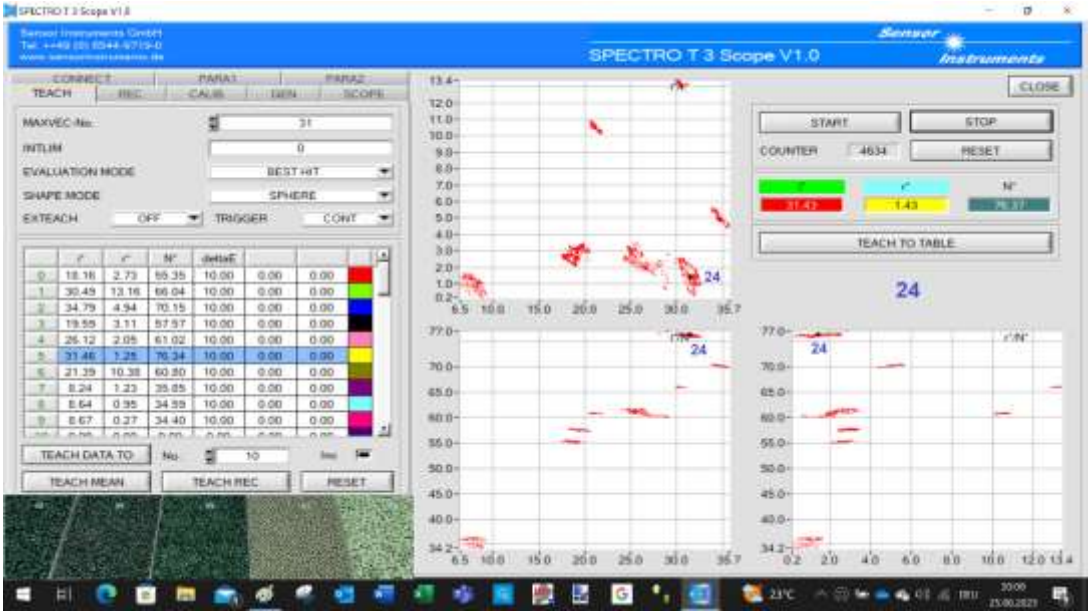
K)


SPECTRO T 3 Scope V1.0
Sensor Instruments
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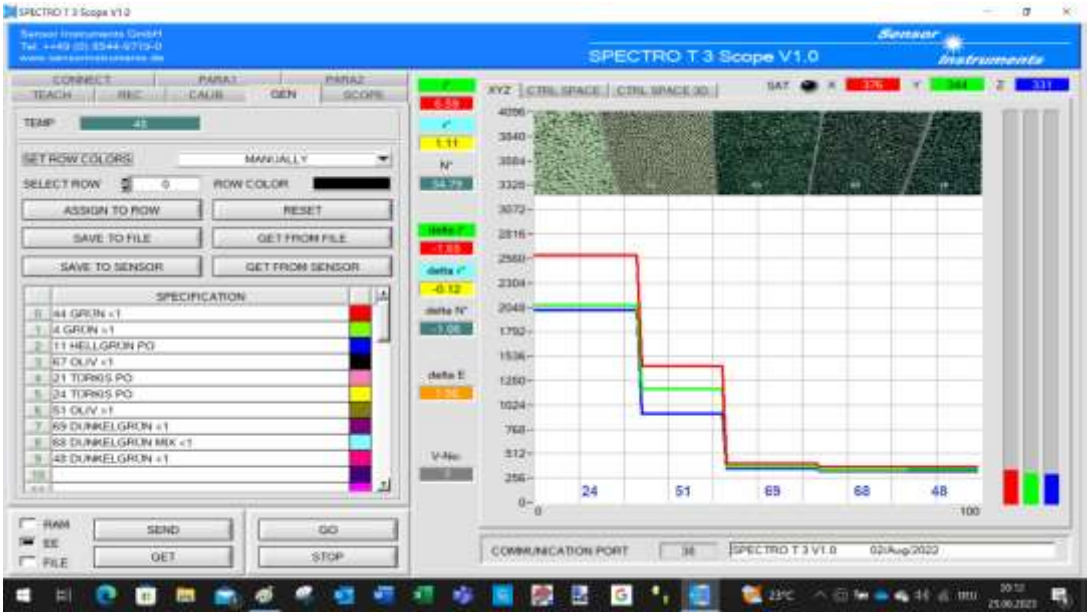
STOP
COUNTER
RESET
TEACH TO TABLE
24
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

J)



9. Quintet

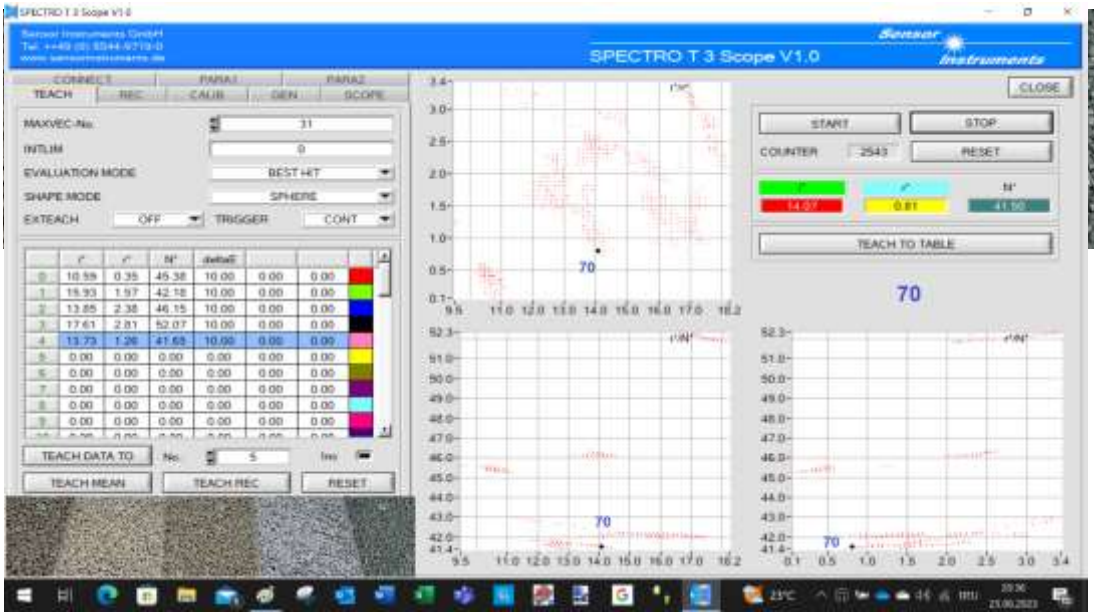
O) 42 grey-green, specific weight <1

P) 12 grey PO, specific weight <1

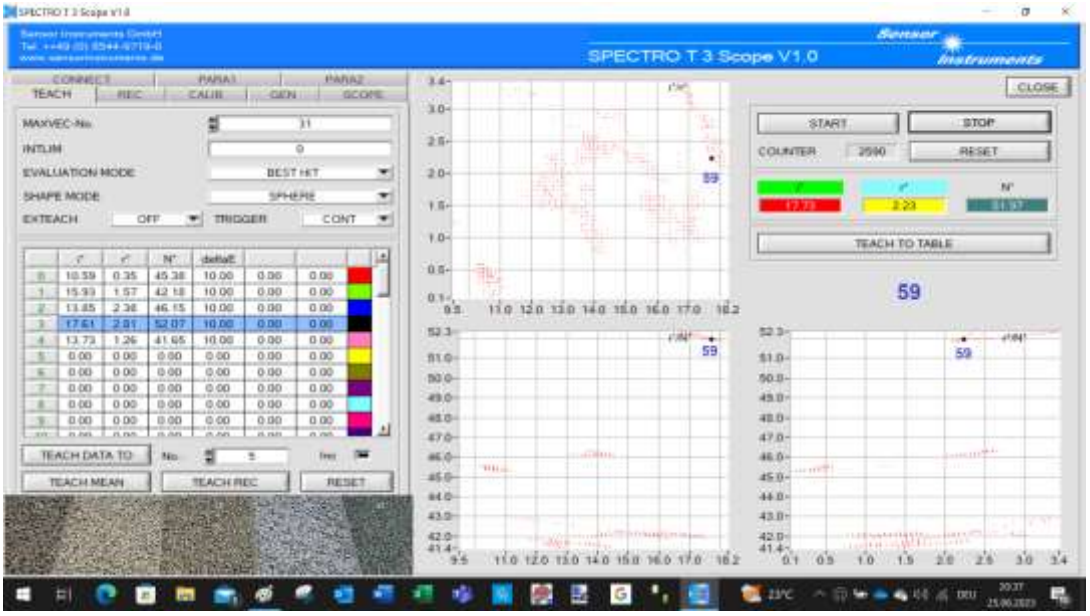
Q) 72 grey-beige, specific weight <1

R) 59 grey, specific weight < 1

S) 70 dark grey, specific weight <1



S)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Sensor Instruments
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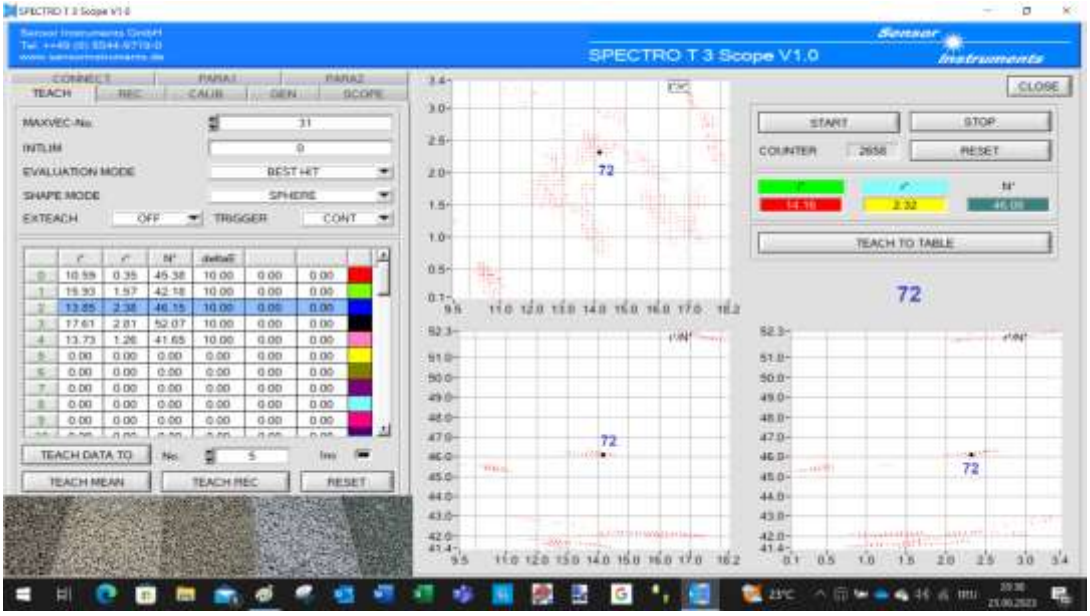
STOP
COUNTER
RESET
TEACH TO TABLE
59
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

R)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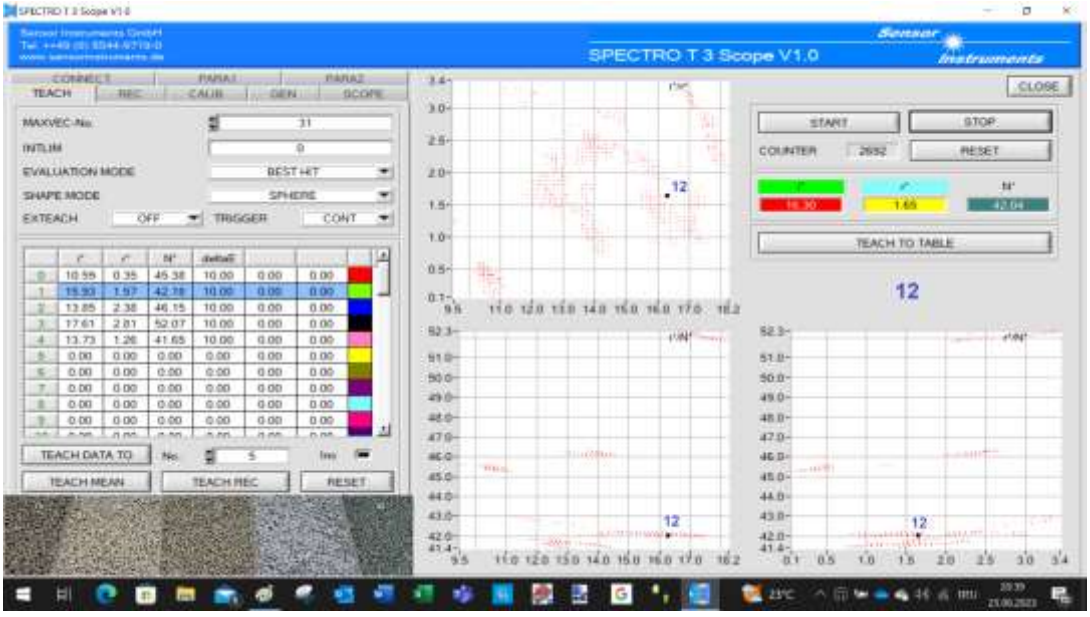
Sensor Instruments
CLOSE
START
STOP
COUNTER
RESET
TEACH TO TABLE
72
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

Q)


SPECTRO T 3 Scope V1.0
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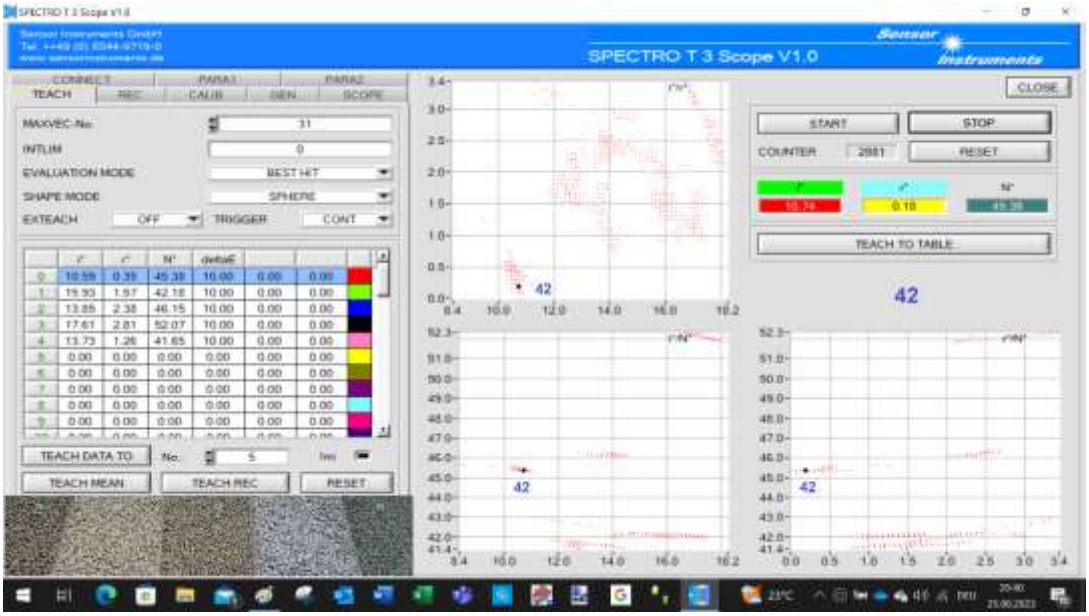
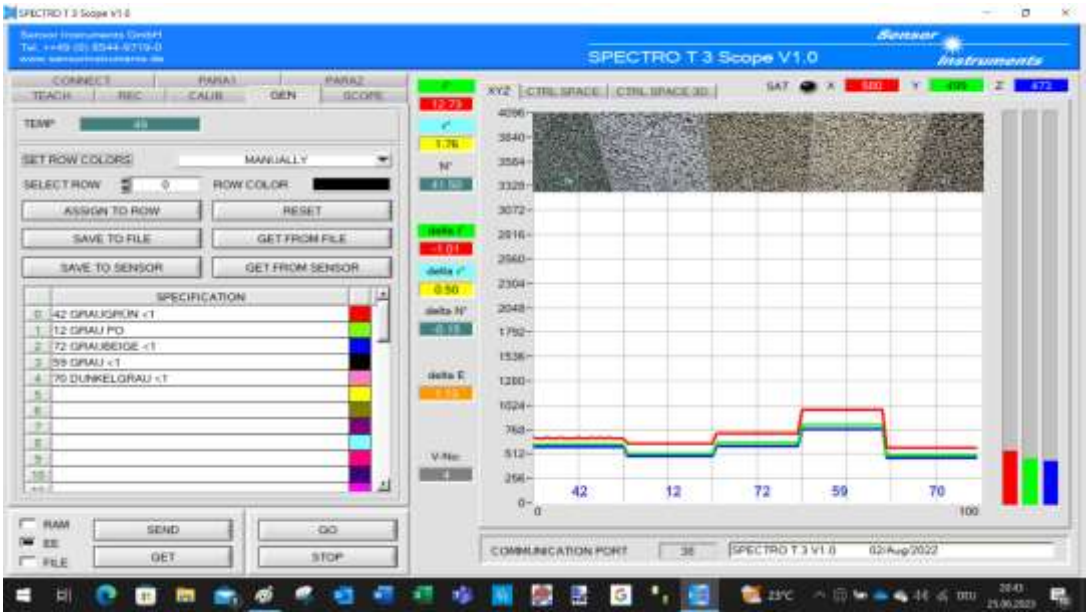
STOP
COUNTER
RESET
TEACH TO TABLE
12
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

P)



O)



10. Quintet

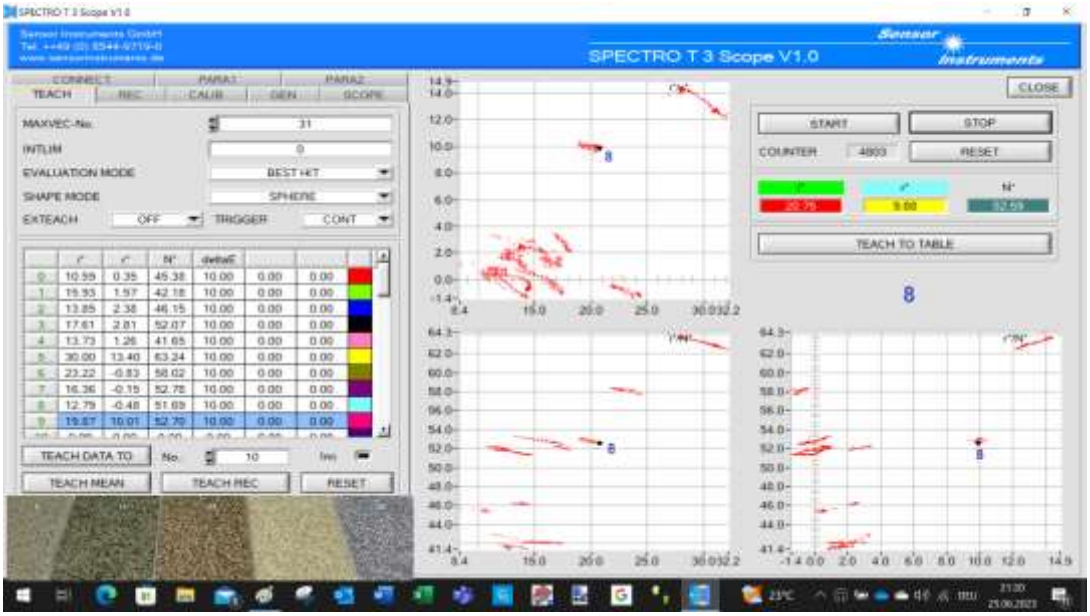
T) 28 grey transparent PET, specific weight >1

U) 31 beige LLDPE, specific weight< 1

V) 34 brown PO, specific weight <1

W) 14 olive PO, specific weight <1

X) 8 olive transparent PET, specific weight >1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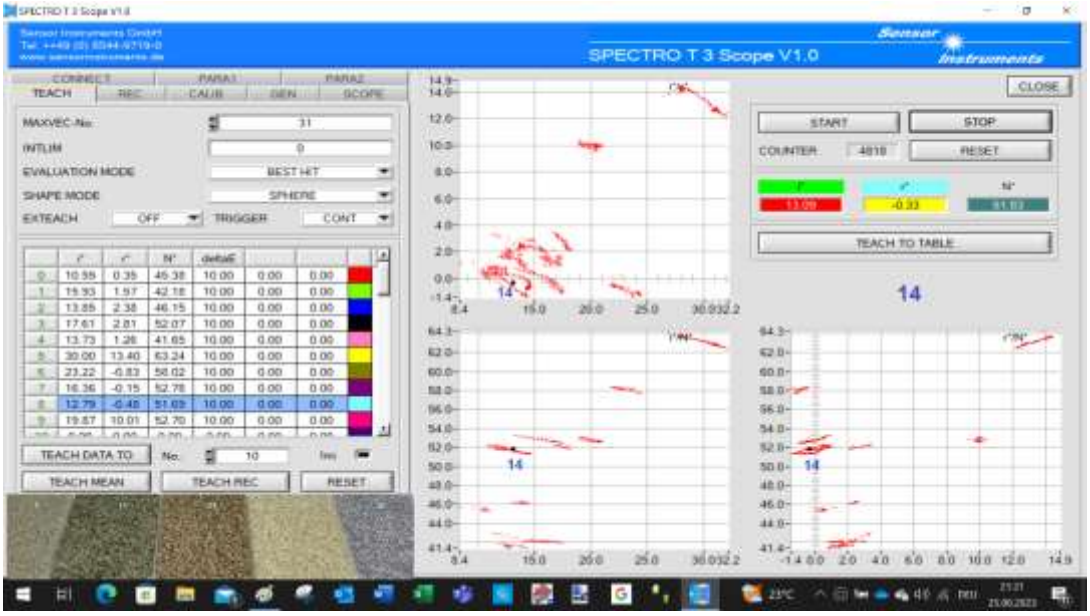
X)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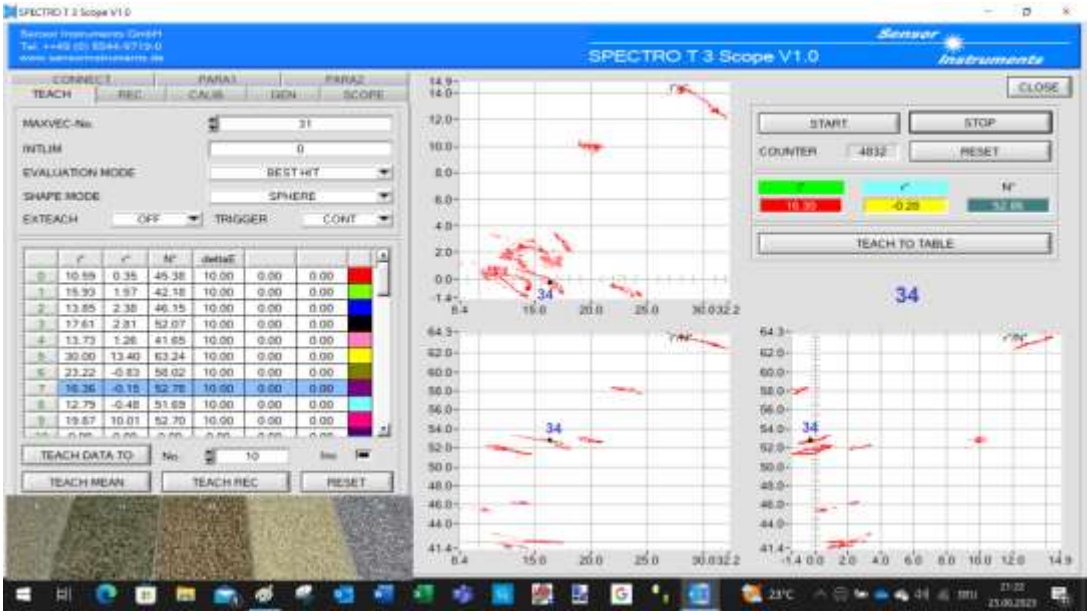
W)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TEACH REC
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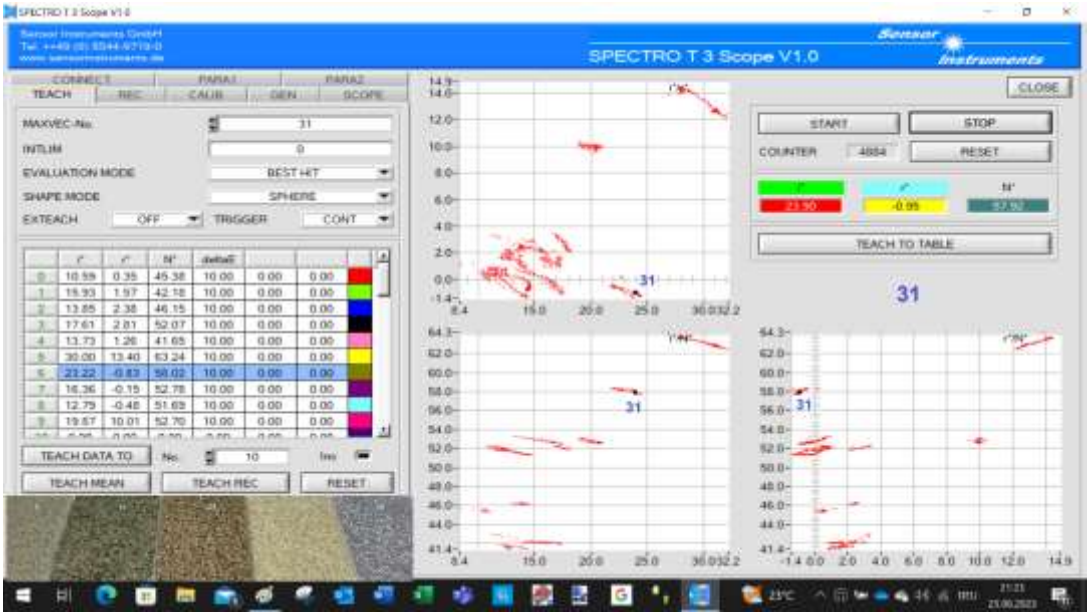
V)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INTLIM
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
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TEACH MEAN
TEACH REC
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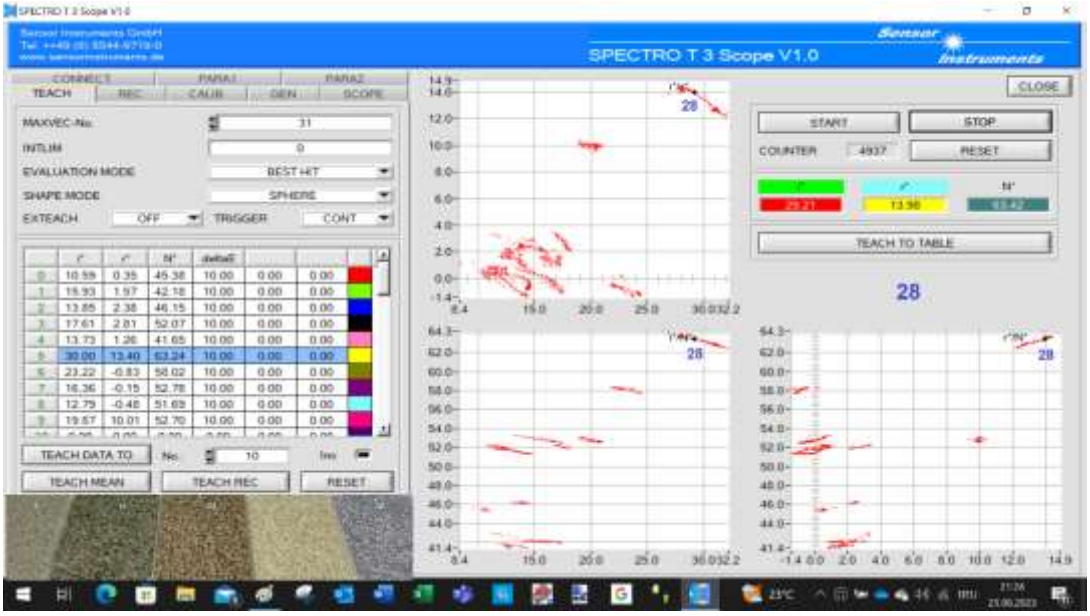
U)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SHAPE MODE
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TEACH DATA TO
No.
Inc
TEACH MEAN
TEACH REC
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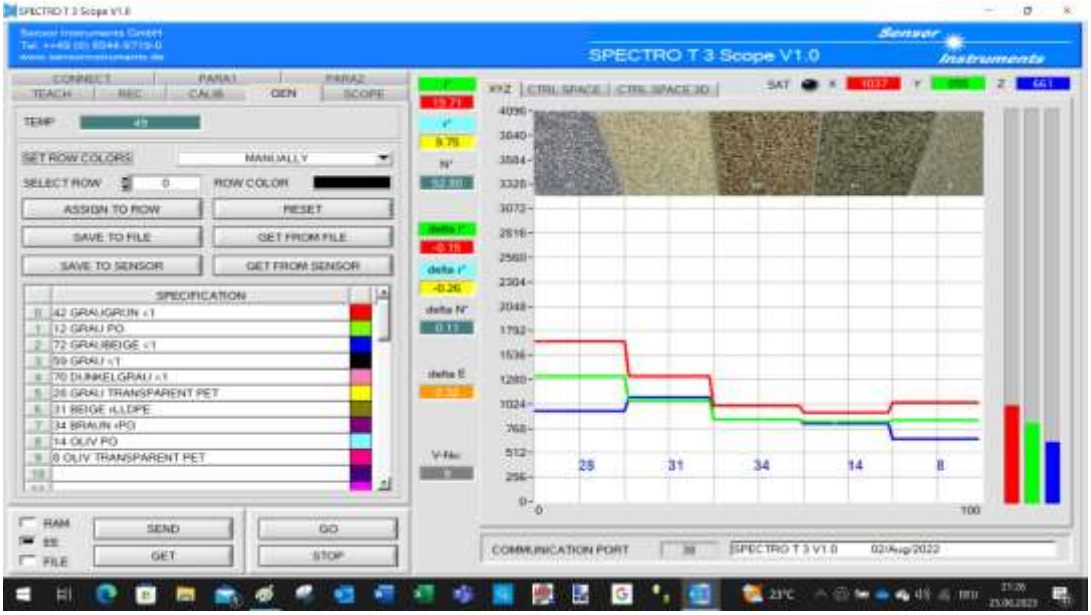
T)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MANUALLY
SELECT ROW
ROW COLOR
ASSIGN TO ROW
RESET
SAVE TO FILE
GET FROM FILE
SAVE TO SENSOR
GET FROM SENSOR
SPECIFICATION
RAM
EE
FILE
SEND
GET
GO
STOP
COMMUNICATION PORT
SPECTRO T 3 V1.0

11. Quintet

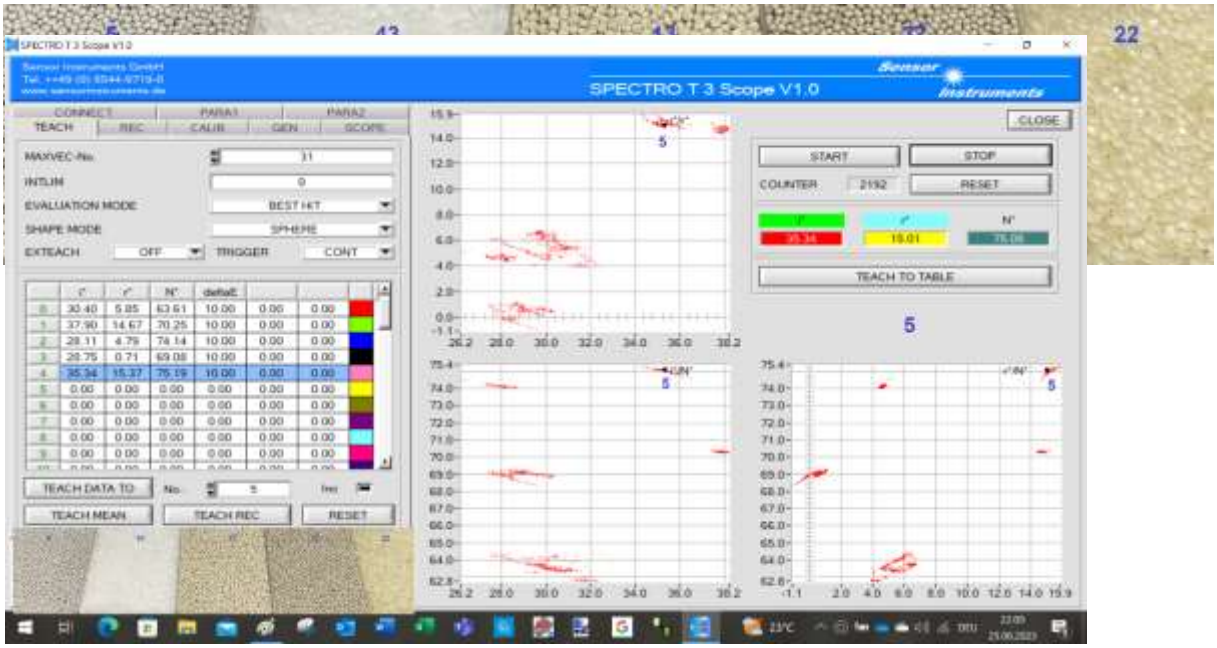
Y) 22 beige transparent PO, specific weight< 1

Z) 37 beige, specific weight >1

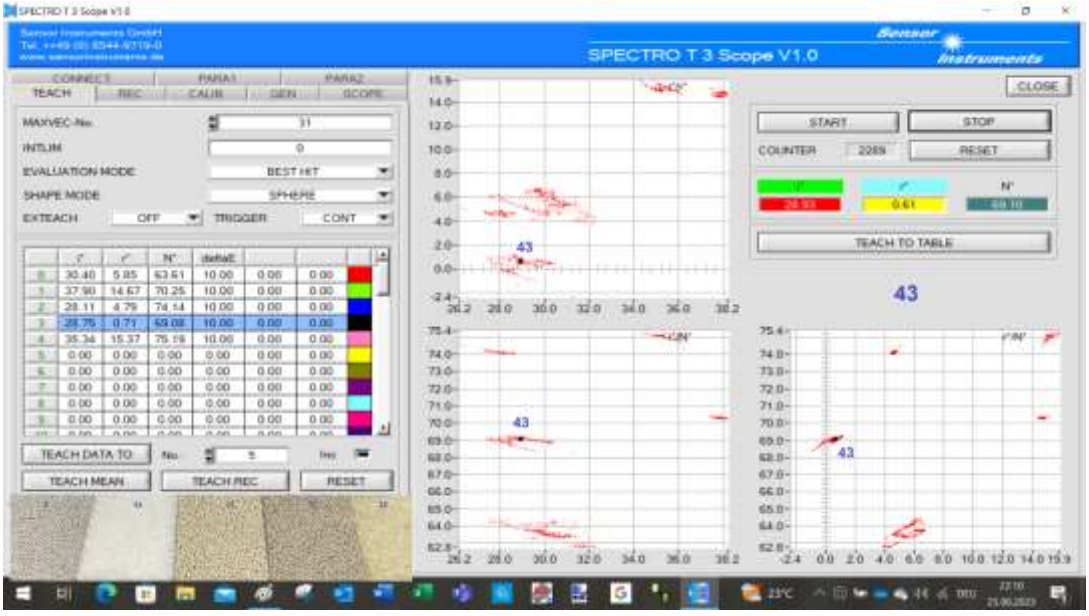
aa) 13 beige, specific weight >1

bb) 43 white transparent, specific weight <1

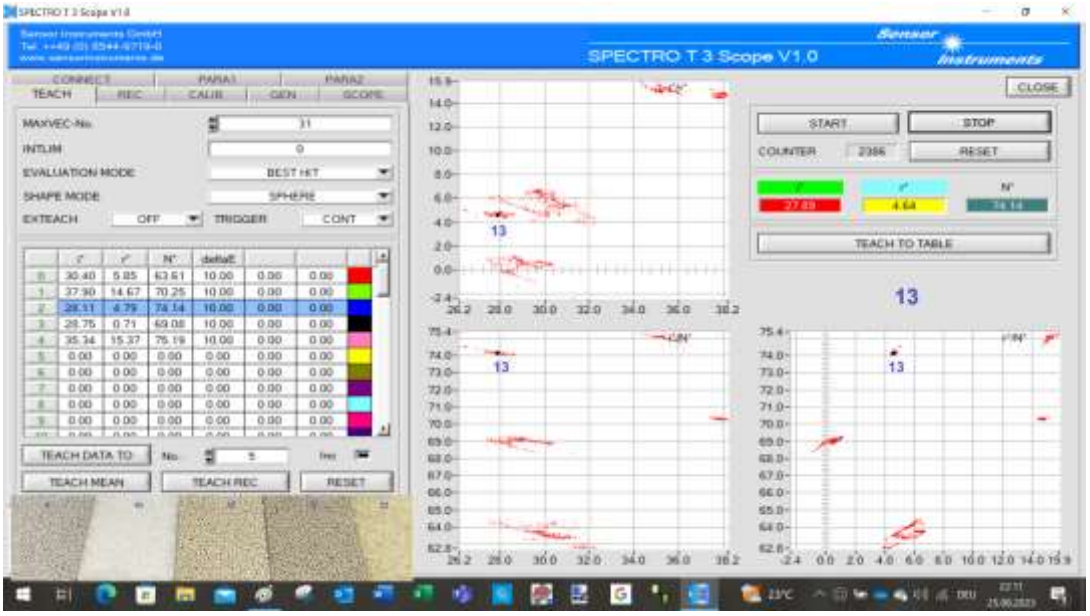
cc) 5 beige PET, specific weight >1



cc)



bb)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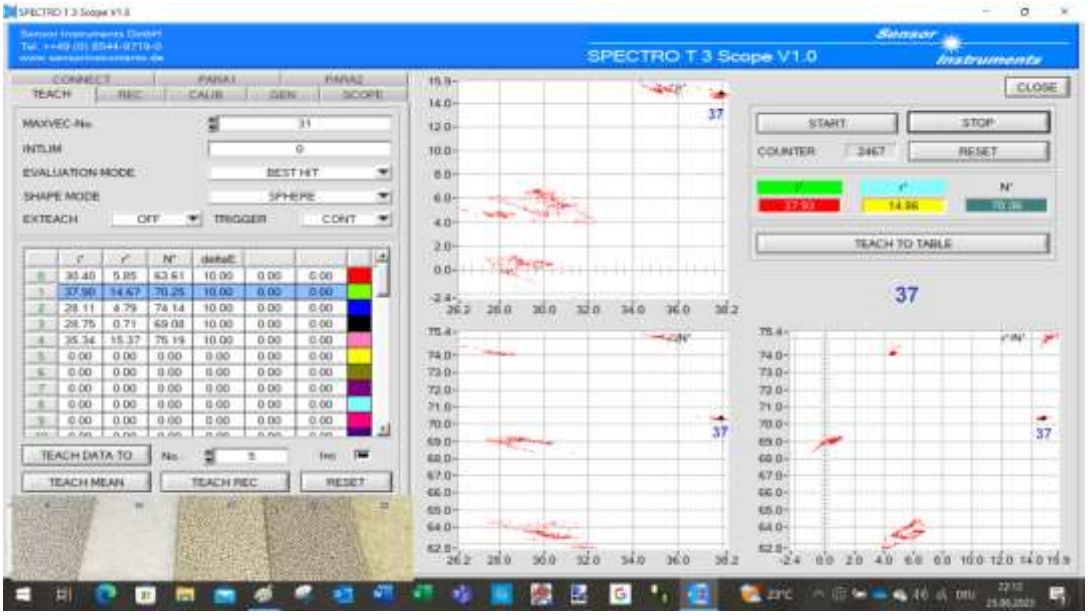
INTLIM
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
No.
TEACH MEAN
TEACH REC
RESET

aa)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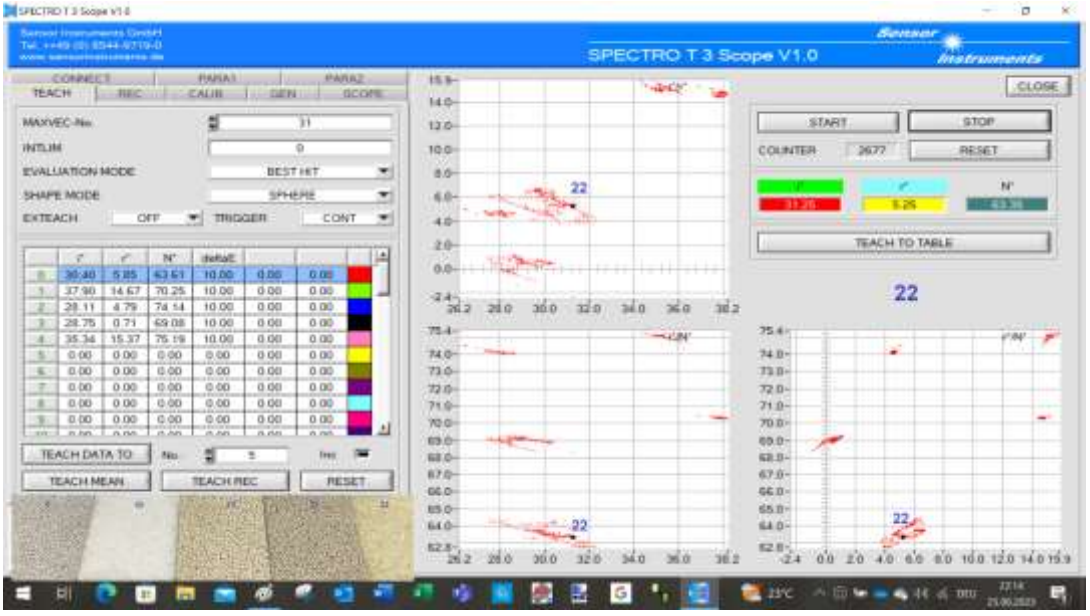
COUNTER
RESET
TEACH TO TABLE
MAXVEC-No.
INTLIM
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
No.
TEACH MEAN
TEACH REC
RESET

Z)


SPECTRO T 3 Scope V1.0
Sensor Instruments
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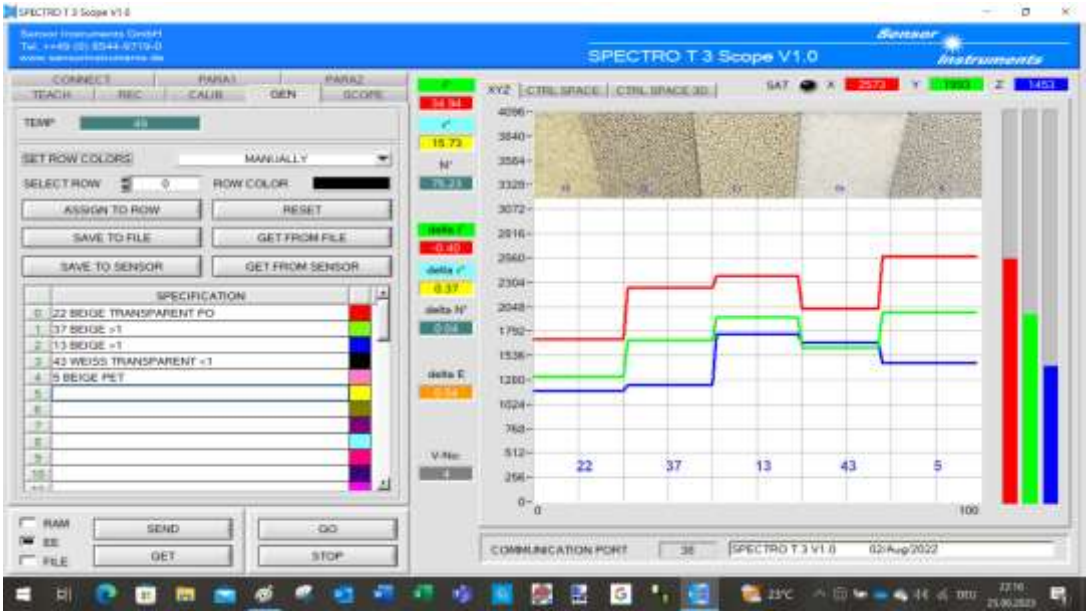
START
STOP
COUNTER
RESET
TEACH TO TABLE
MAXVEC-No.
INTLIM
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
No.
TEACH MEAN
TEACH REC
RESET

Y)



12. Quintet

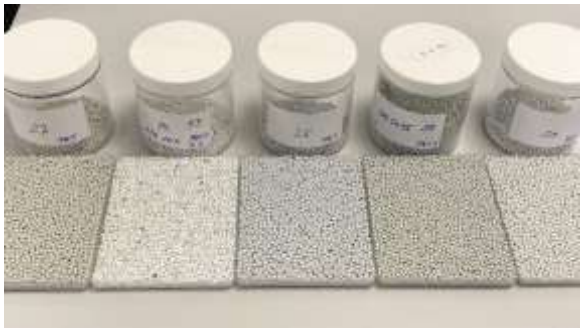
dd) 20 light grey PET, specific weight >1

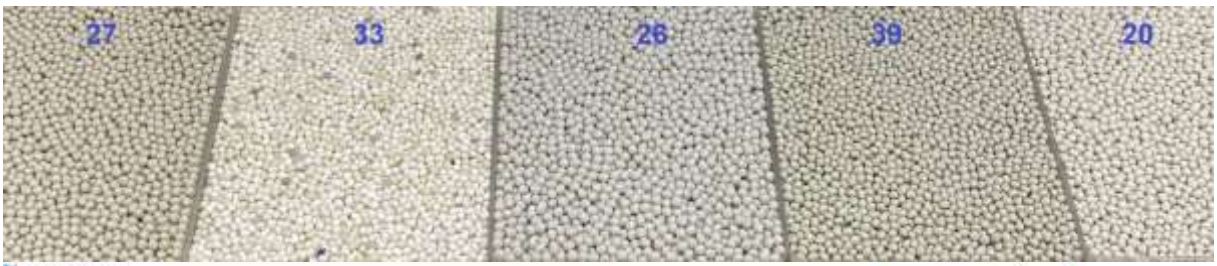
ee) 39 green-grey, specific weight >1

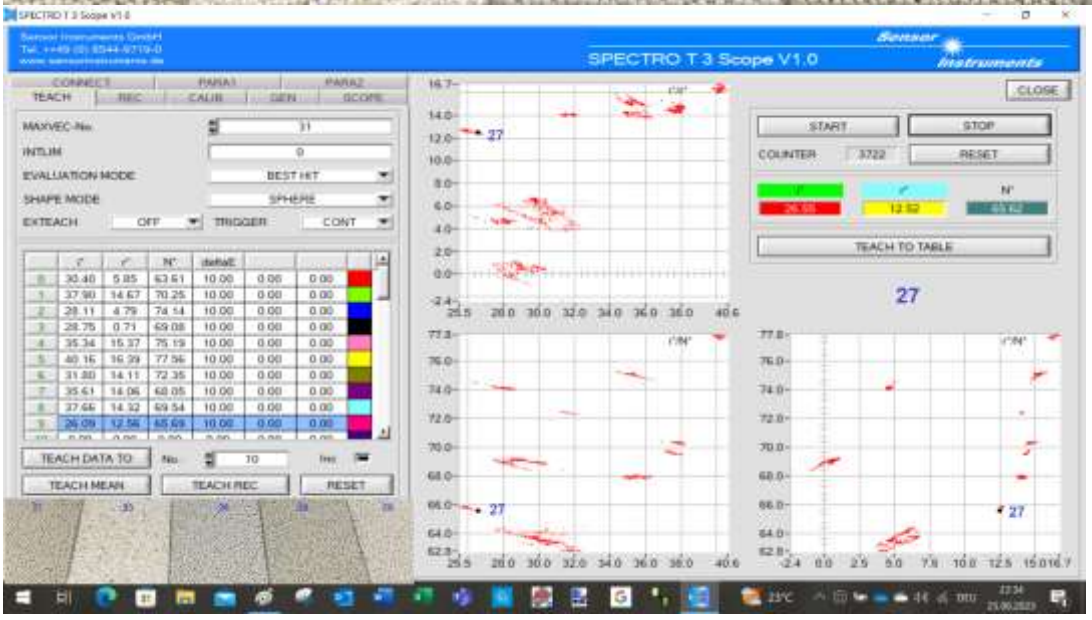
ff) 26 grey PET, specific weight >1

gg) 33 grey-white mix, specific weight> 1

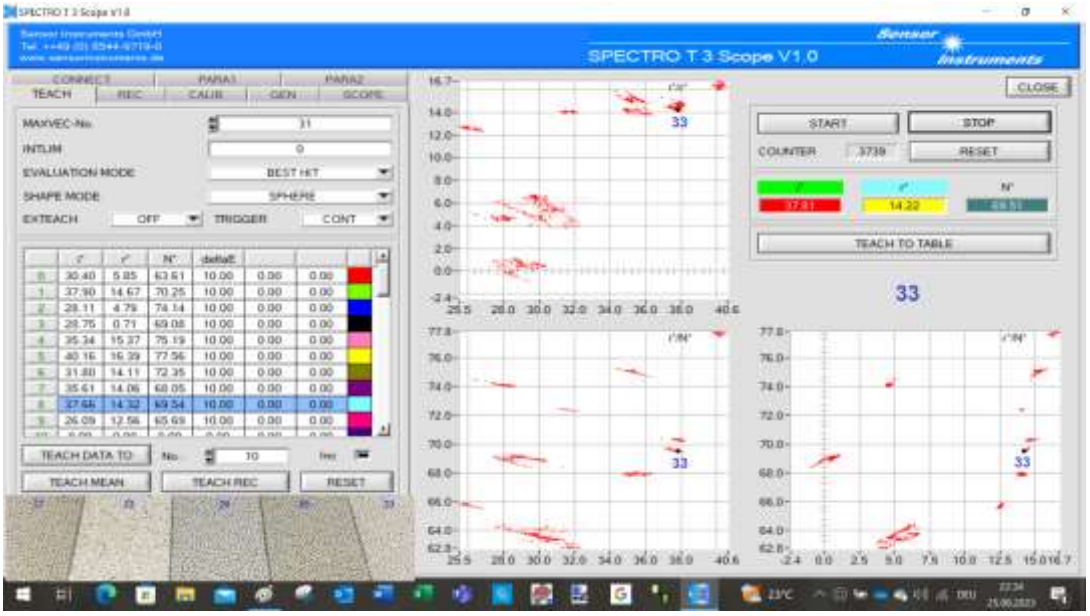
hh) 27 green-grey PET, specific weight >1







hh)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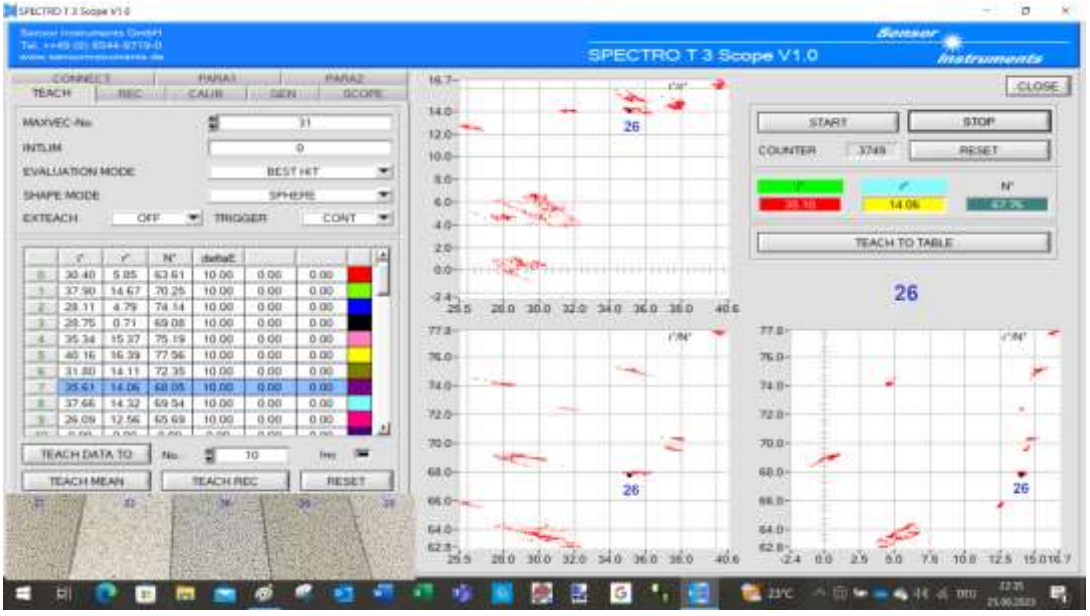
Sensor Instruments
CLOSE
START
STOP
COUNTER
RESET
TEACH TO TABLE
33
MAXVEC-No
INTLIM
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
No
TEACH MEAN
TEACH REC
RESET
gg)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COUNTER
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MAXVEC-No
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EVALUATION MODE
BEST HIT
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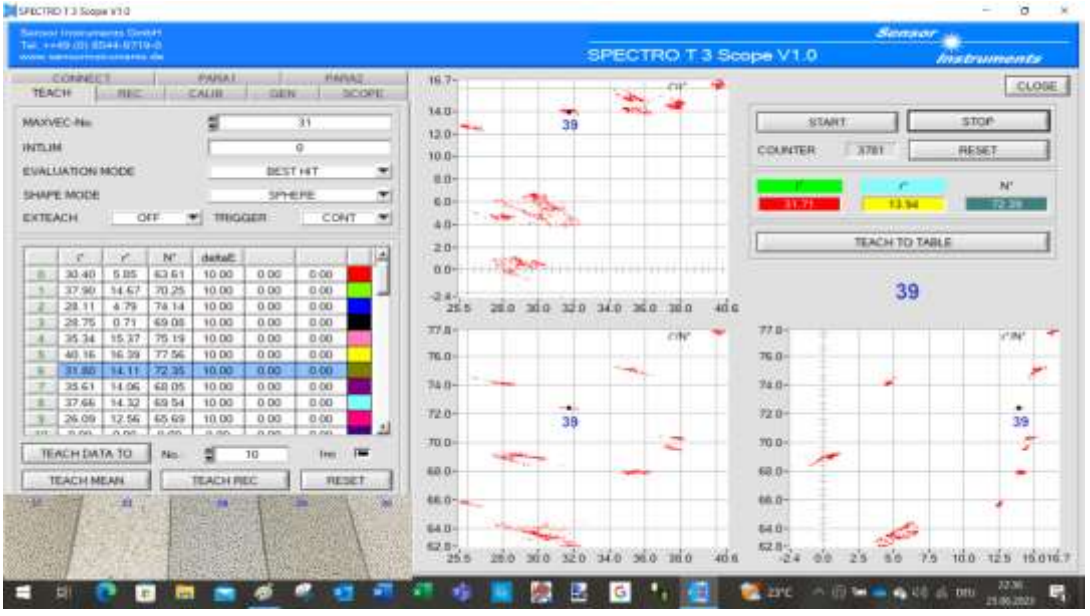
TRIGGER
CONT
TEACH DATA TO
No
TEACH MEAN
TEACH REC
RESET
ff)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START
STOP
COUNTER
RESET
TEACH TO TABLE
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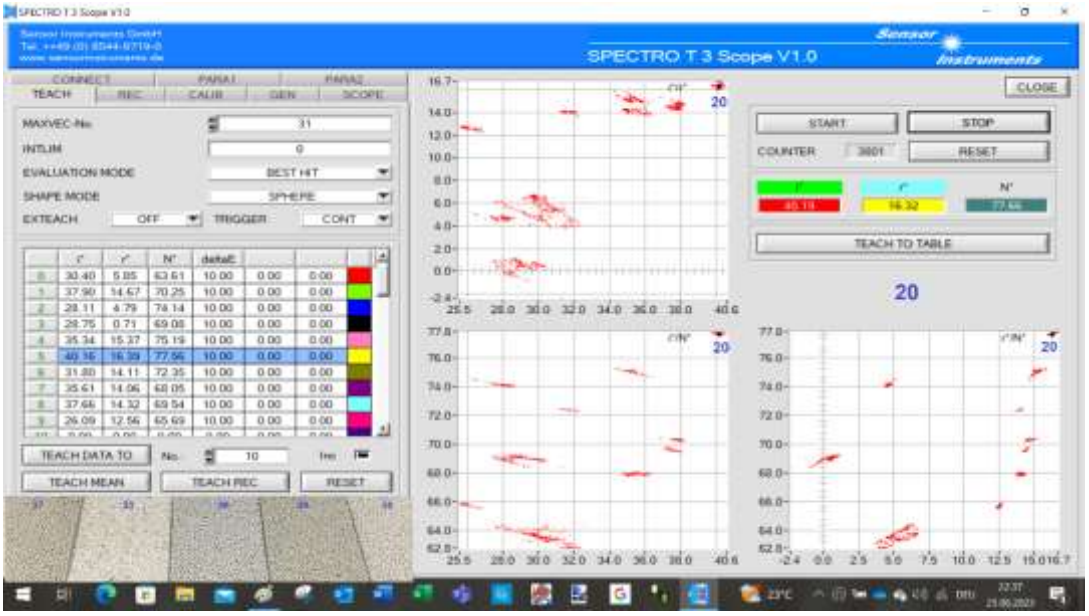
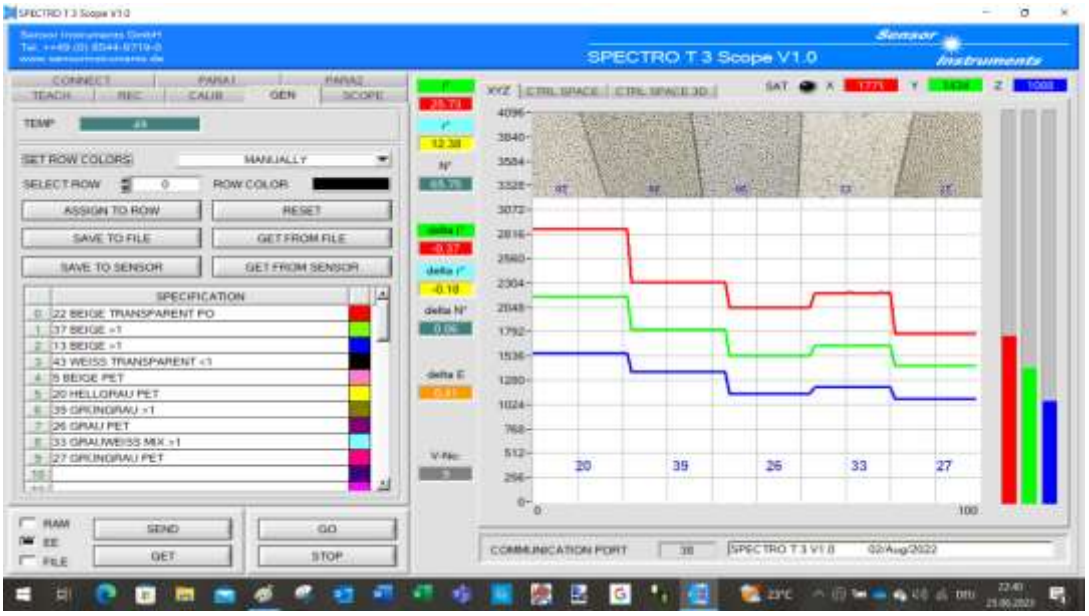
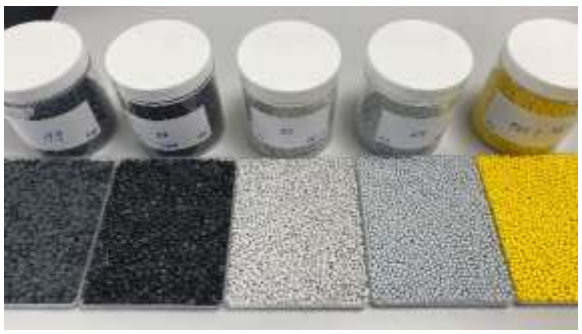
MAXVEC-No
INTLIM
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
CONT
TEACH DATA TO
No
TEACH MEAN
TEACH REC
RESET
ee)



dd)



13. Quintet



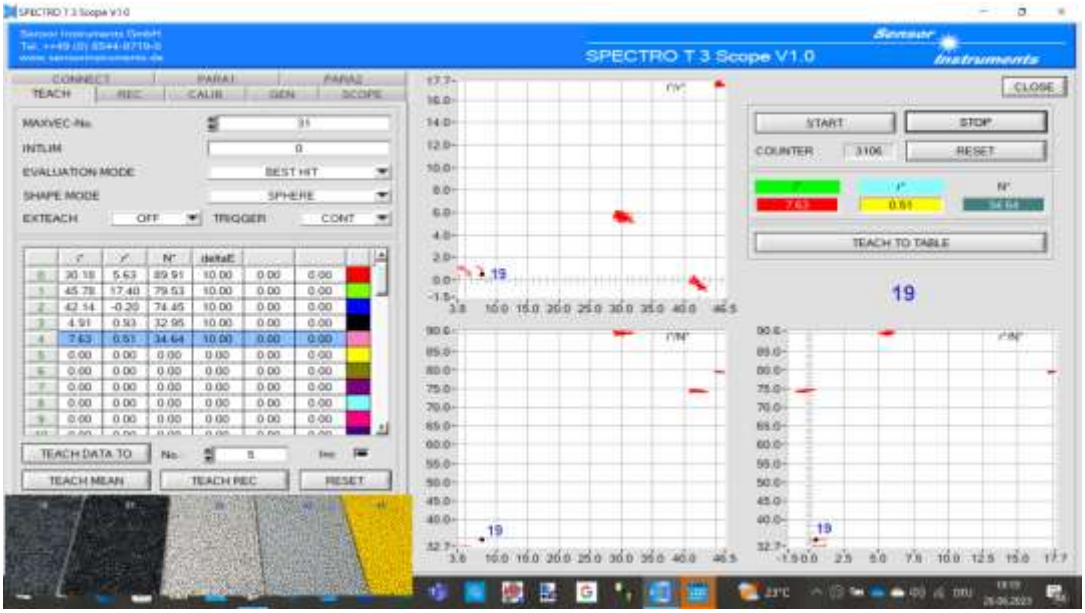
ii) 45 yellow, specific weight >1

jj) 63 grey, specific weight > 1

kk) 56 light grey, specific weight >1

ll) 57 black HDPE, specific weight <1

mm) 19 dark grey PO, specific weight <1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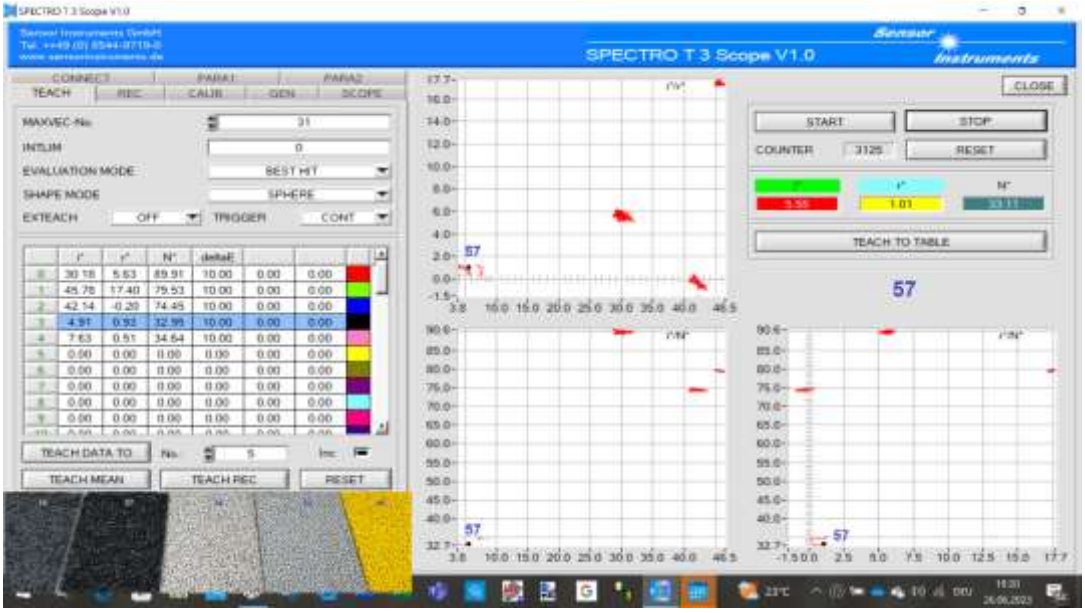
START
STOP
COUNTER
RESET
TEACH TO TABLE
19
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

mm)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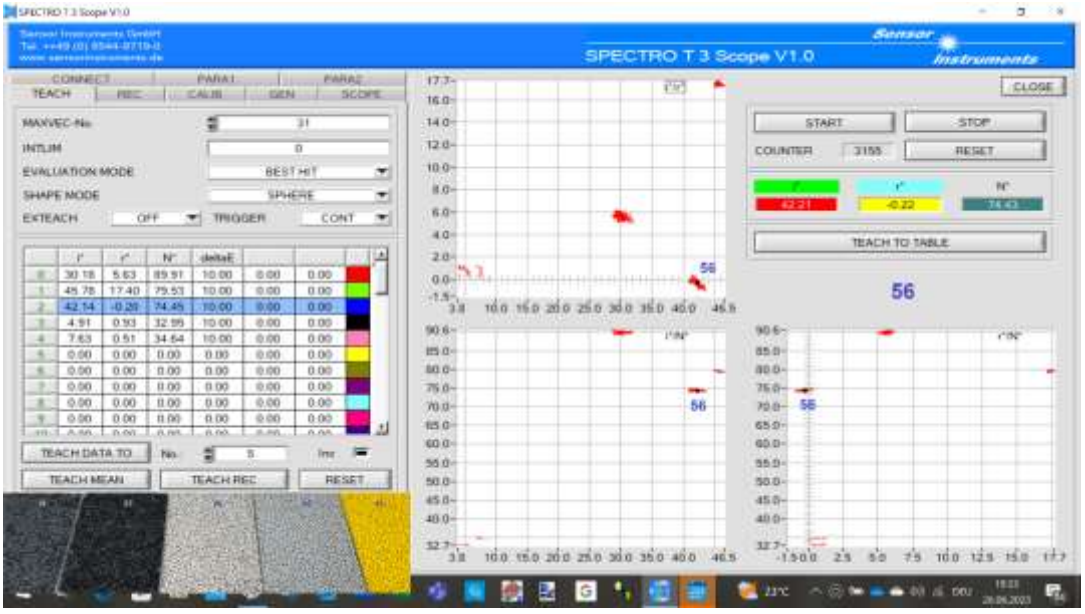
STOP
COUNTER
RESET
TEACH TO TABLE
57
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

ll)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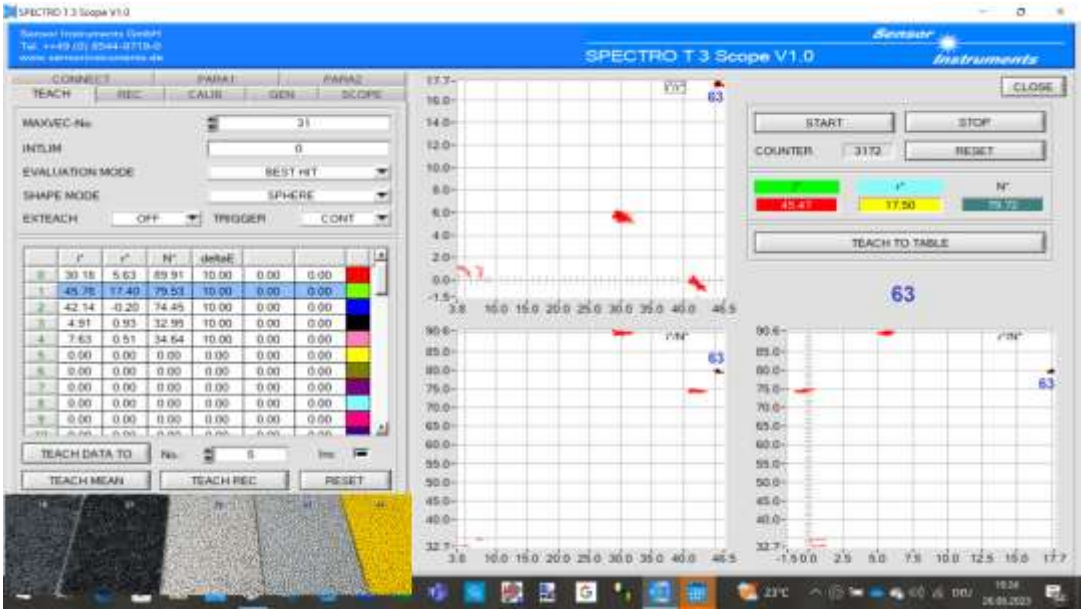
RESET
TEACH TO TABLE
56
TEACH DATA TO
TEACH MEAN
TEACH REC
RESET

kk)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MAXVEC-No
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INTLIM
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EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
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TRIGGER
CONT
TEACH DATA TO
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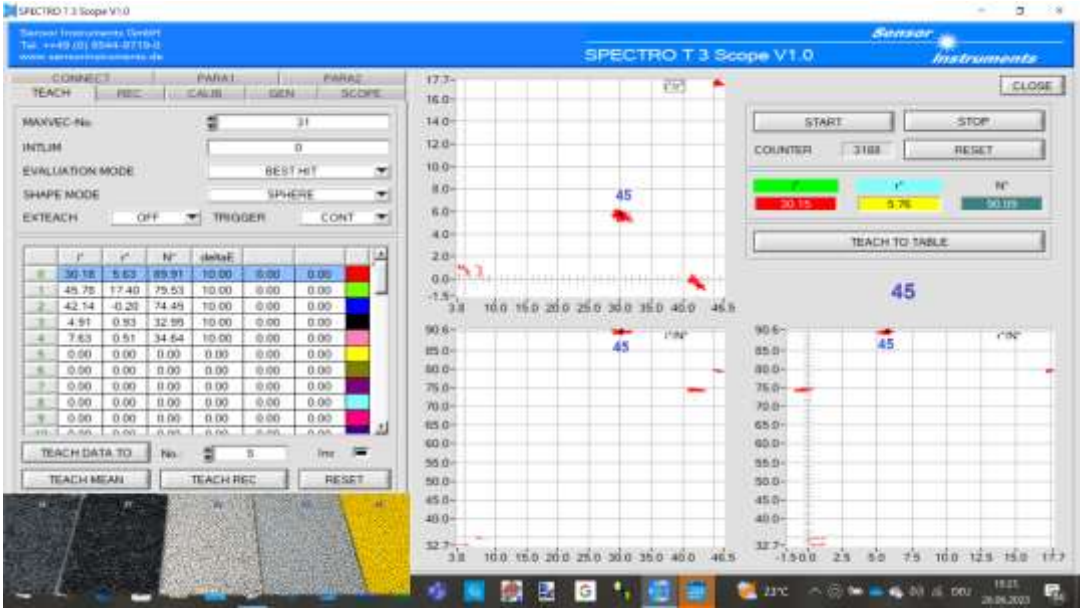
TEACH TO TABLE
63

jj)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BEST HIT
SHAPE MODE
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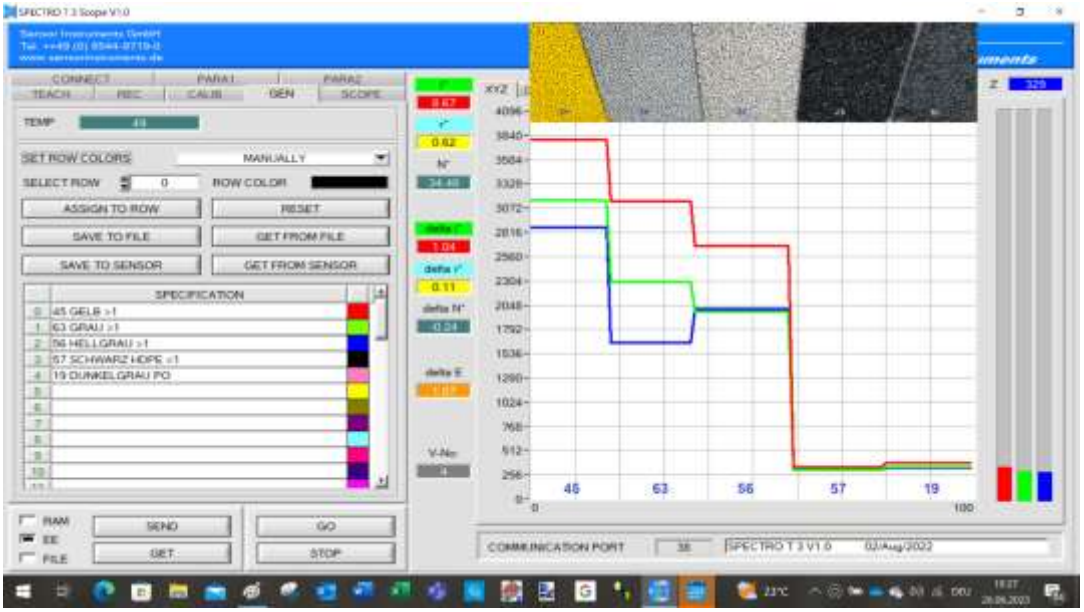
45

ii)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GEN
SCOPE
TEMP
SET ROW COLORS
MANUALLY
SELECT ROW
0
ROW COLOR
ASSIGN TO ROW
RESET
SAVE TO FILE
GET FROM FILE
SAVE TO SENSOR
GET FROM SENSOR
SPECIFICATION
0 45 GELB >1
1 63 GRAU >1
2 56 HELLGRAU >1
3 57 SCHWARZ HDPE <1
4 19 DUNKELGRAU PO
RAM
EE
FILE
SEND
GET
GO
STOP
COMMUNICATION PORT
SPECTRO T 3 V1.0
02/Aug/2022

14. Quintet

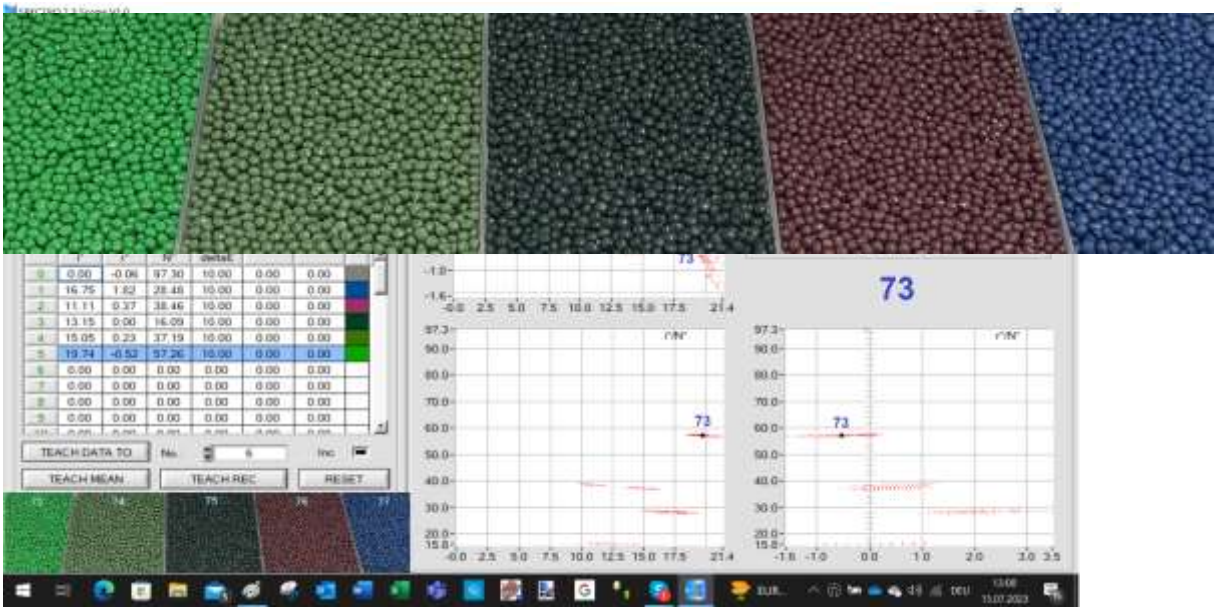
nn) 77 blue FC 387, specific weight <1

oo) 76 red FC 071, specific weight< 1

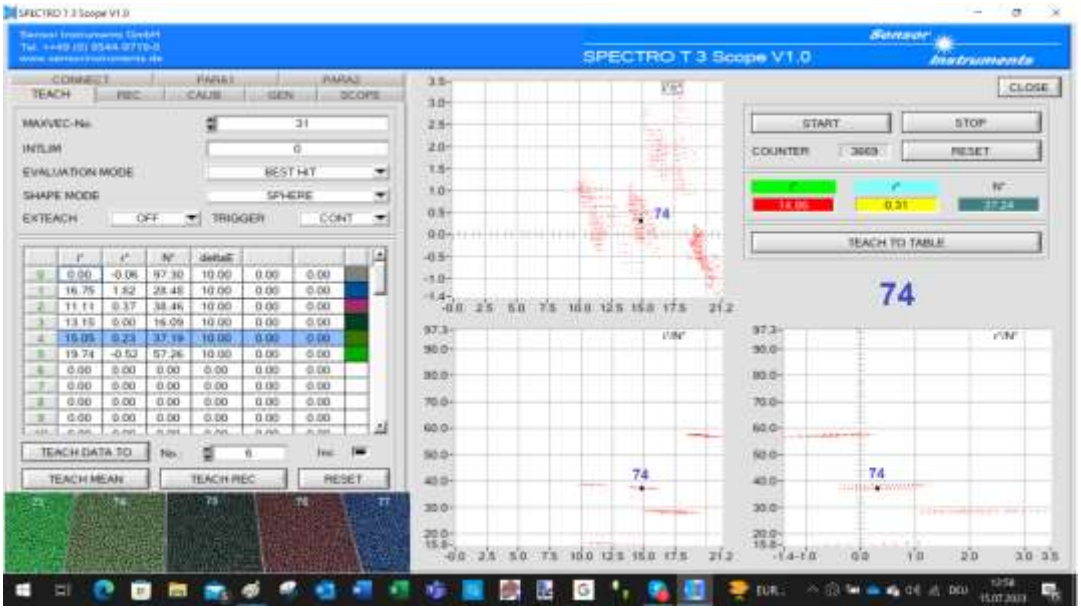
pp) 75 green FC 144, specific weight <1

qq) 74 green FC 040, specific weight <1

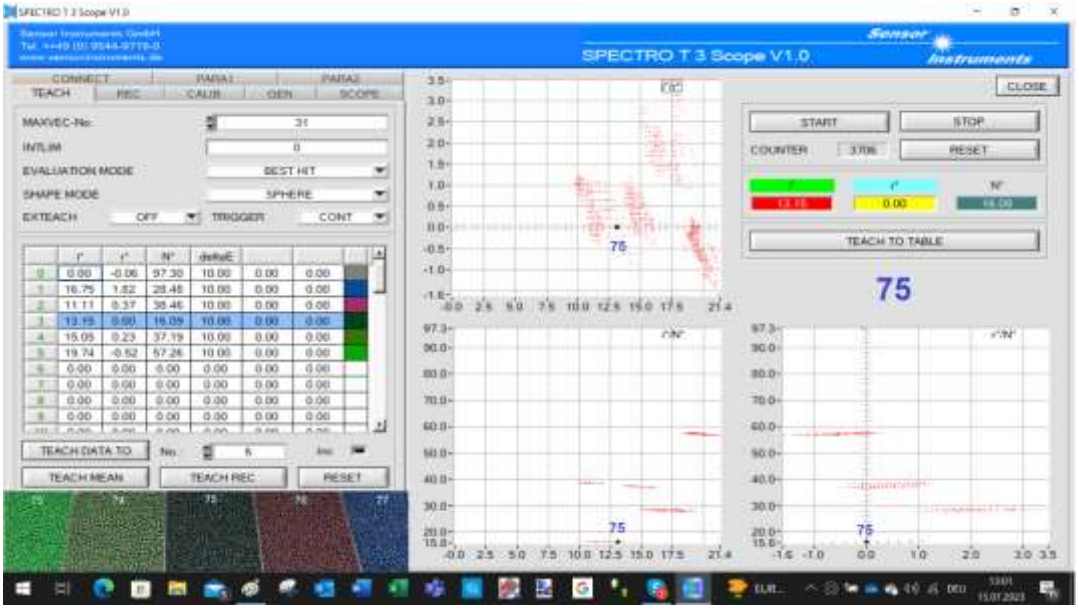
rr) 73 green FC 049, specific weight <1



rr)



qq)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SCOPE
MAXVEC-No.
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SHAPE MODE
SPHERE
EXTEACH
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TRIGGER
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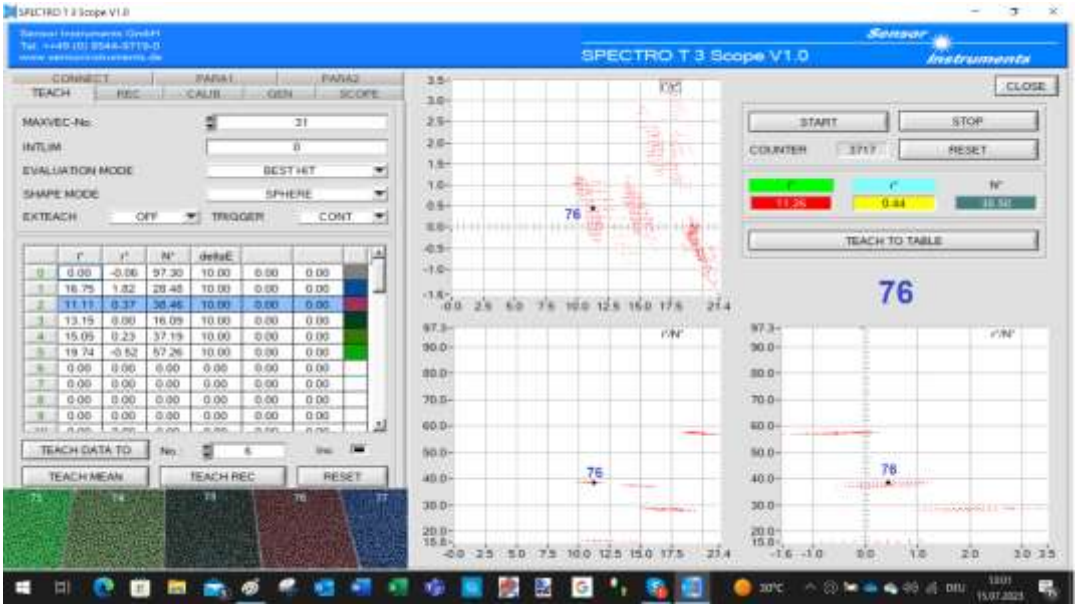
6
TEACH MEAN
TEACH REC
RESET
CLOSE
START
STOP
COUNTER
RESET
TEACH TO TABLE
75

pp)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Sensor Instruments
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PARA2
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GEN
SCOPE
MAXVEC-No.
31
INTLIM
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EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
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TRIGGER
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6
TEACH MEAN
TEACH REC
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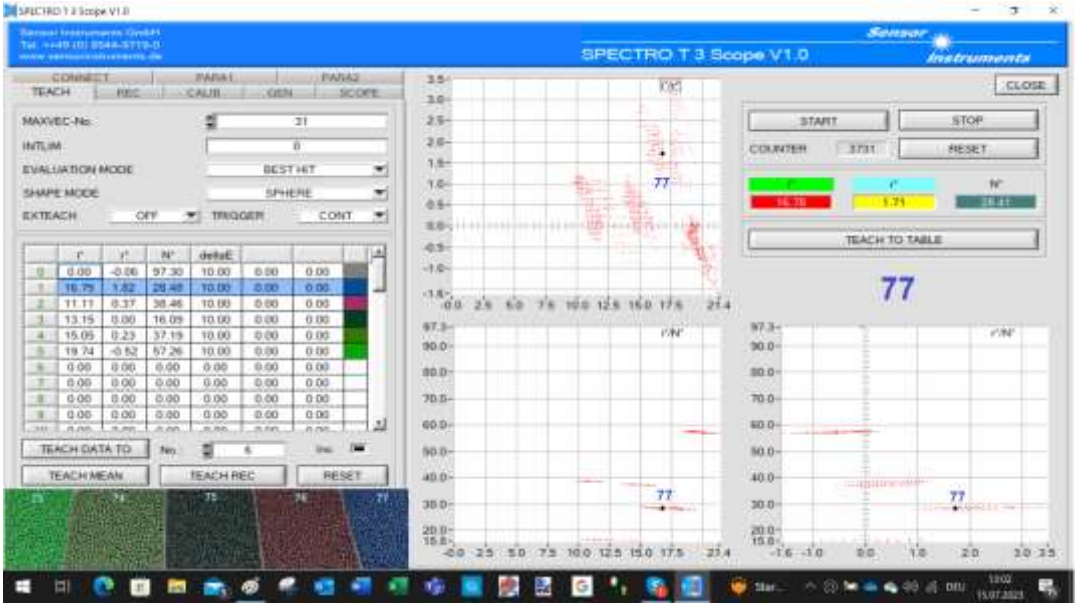
START
STOP
COUNTER
RESET
TEACH TO TABLE
76

oo)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GEN
SCOPE
MAXVEC-No.
31
INTLIM
0
EVALUATION MODE
BEST HIT
SHAPE MODE
SPHERE
EXTEACH
OFF
TRIGGER
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6
TEACH MEAN
TEACH REC
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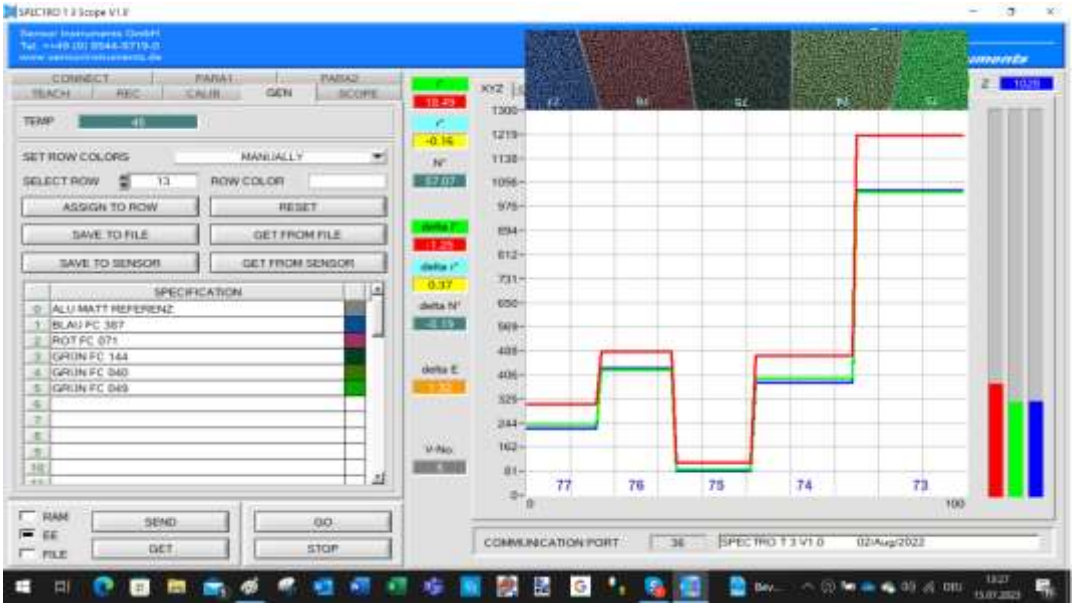
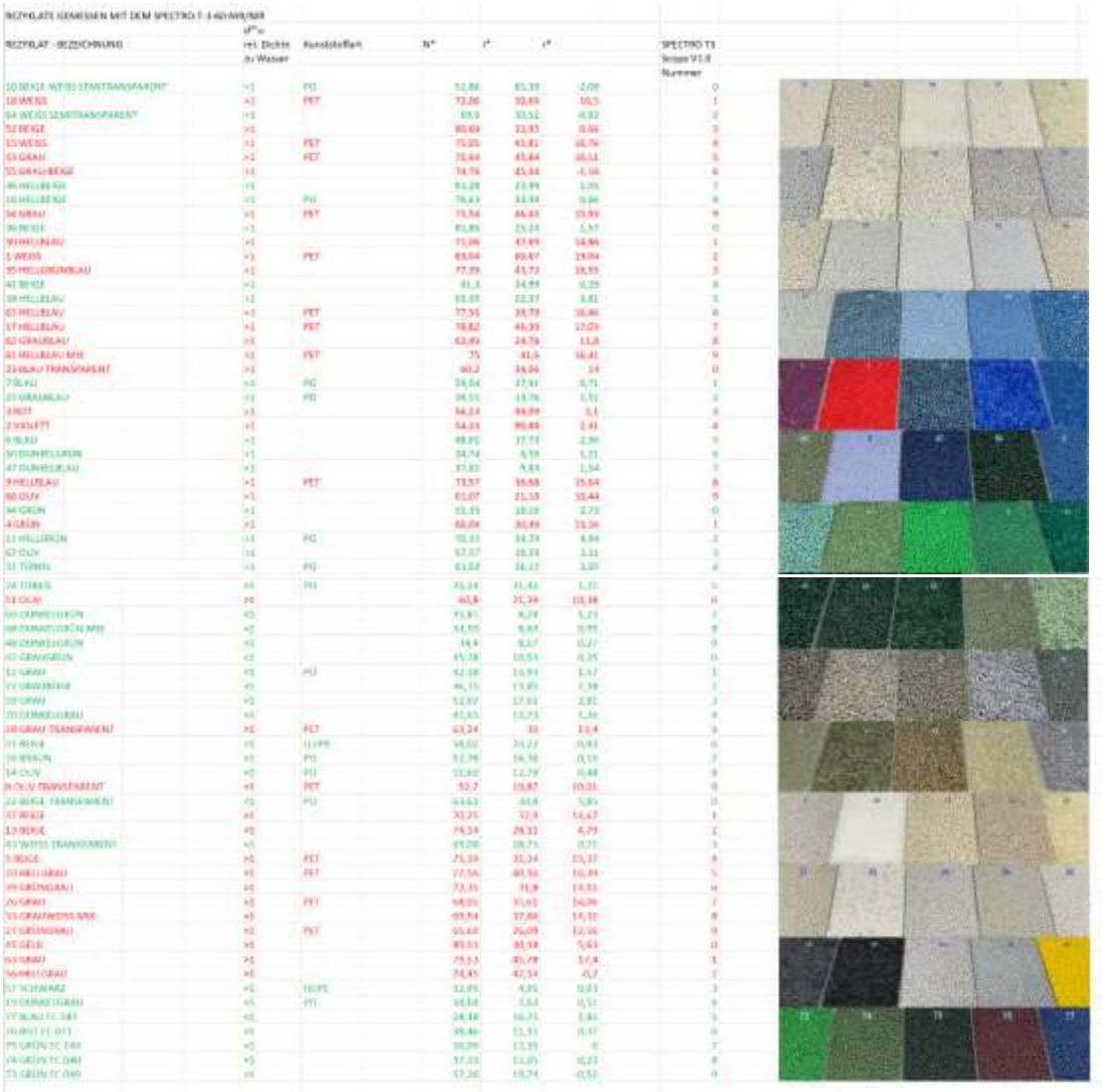
CLOSE
START
STOP
COUNTER
RESET
TEACH TO TABLE
77

nn)



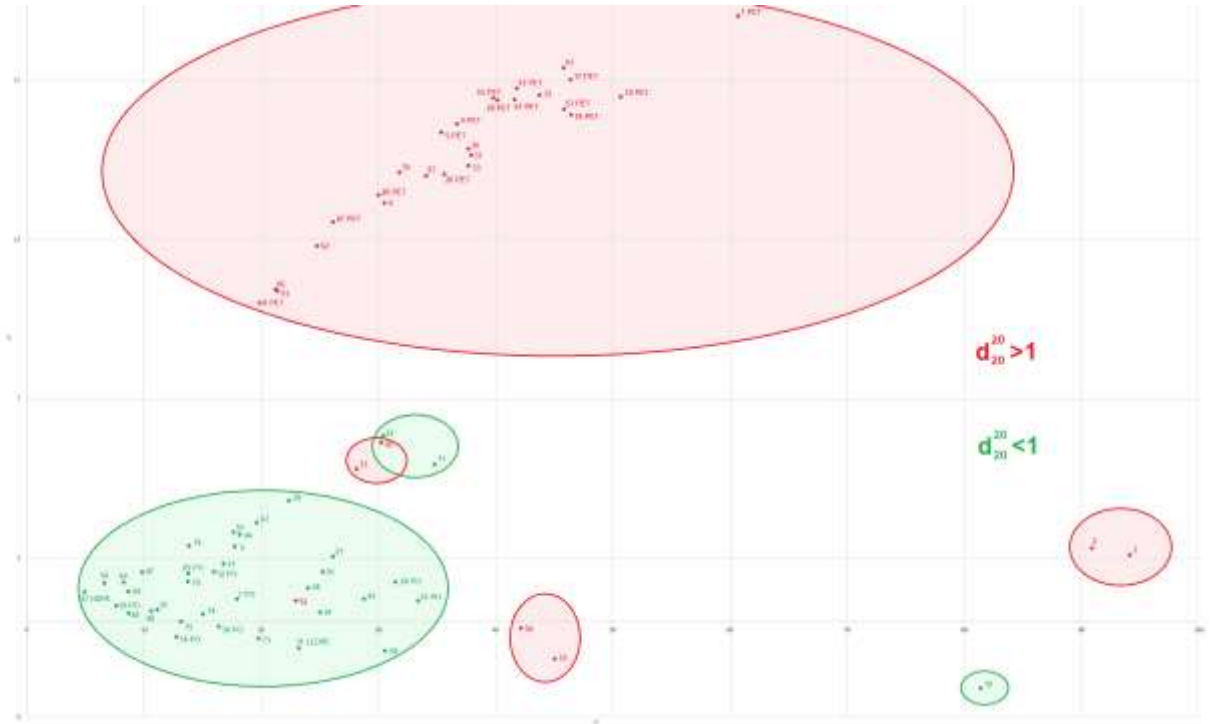
3.1.4 Summary of the measurement results in relation to recyclates

The following two tables list the N*i*r* values of the individual recyclates and subdivide them by color according to specific weight <1 and specific weight >1.

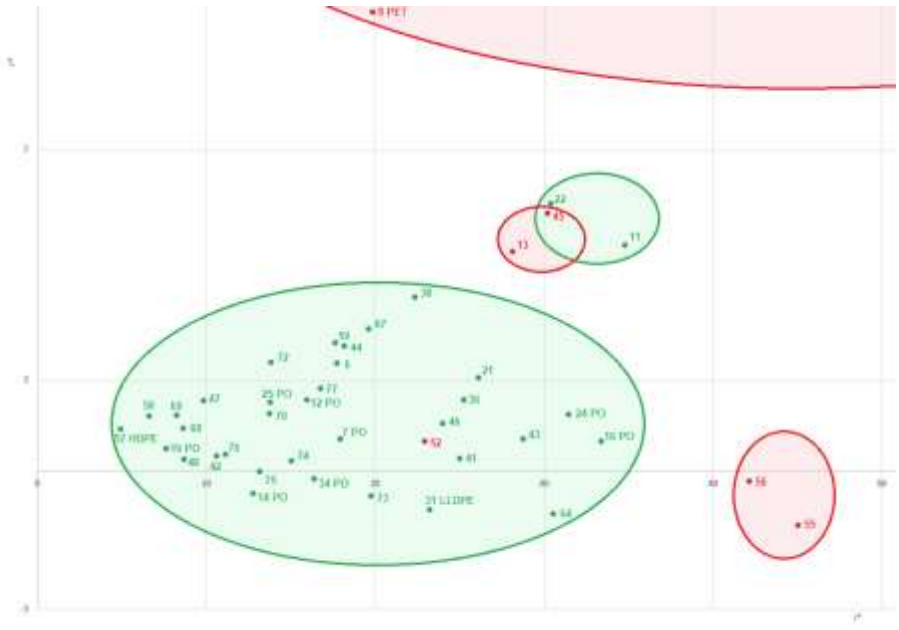


*3.1.4.1 i*r* diagram*

The following table shows the placement of the different recyclates in the i*r* diagram. Here, too, the specific weight provides an initial indication of the classification of the recyclates into certain groups, especially since it was not known for all the recyclates examined which type of plastic they actually were. The i*r* diagram marks the recyclates for which information regarding the plastic type was provided by the respective recycling company. The PETs and the POs certainly form the two main groups in the i*r* diagram. The placement of the recyclates is very similar to the placement of the virgin granulates.



Certain parallels were also presented by the subgroup with the specific weight >1 at i* >80, which suggest that recyclates 2 and 3 could be PA6- or TPU-based plastics.



Strictly speaking, 45 is not a recyclate in the conventional sense, but rather a masterbatch. The appearance of recyclates 13 and 52 indicates that they are not PET-based recyclates. The same applies to the recyclates 56 and 55, although both have a high i* value and are thus located outside the PO group in the i*r* diagram. Recyclates 11 and 22, on the other hand, have an untypically high r* value for PO.

55: N* = 74.76 i* = 45.04 r* = -1.16

56: N* = 74.45 i* = 42.14 r* = -0.20

11: N* = 70.15 i* = 34.79 r* = 4.94

22: N* = 63.61 i* = 30.40 r* = 5.85

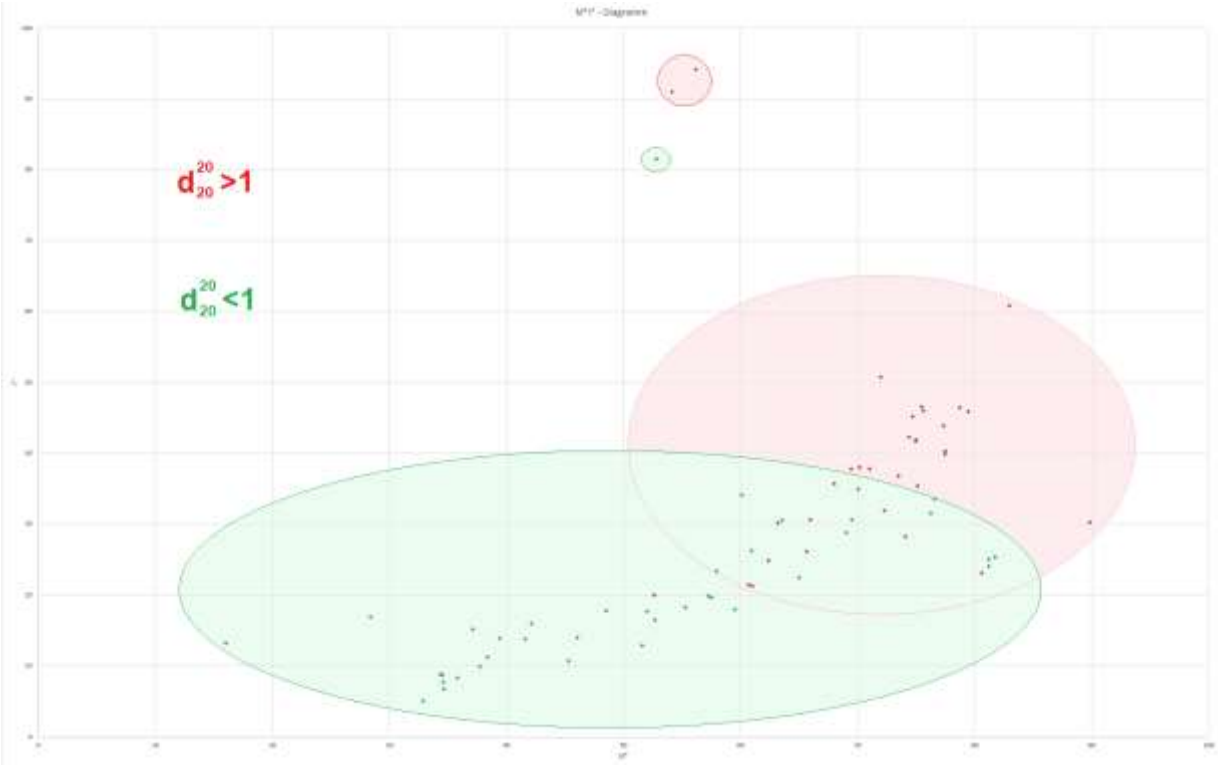
2: N* = 54.23 i* = 90.88 r* = 2.31

3: N* = 56.23 i* = 94.09 r* = 2.10

13: N* = 74.14 i* = 28.11 r* = 4.79

52: N* = 80.69 i* = 22.95 r* = 0.66

*3.1.4.2 N*i* diagram*

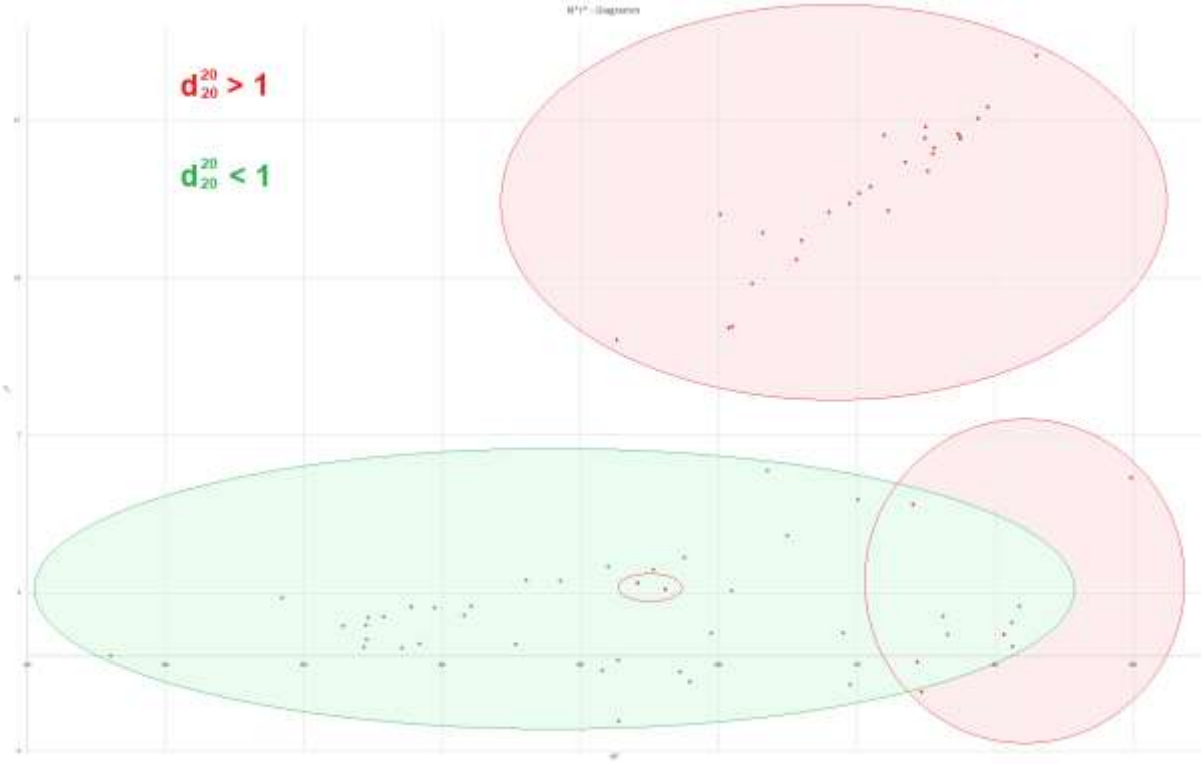


In the N*i* diagram, both main groups overlap (specific weight <1 and specific weight >1), but the recyclates with the specific weight >1 tend to be on the right-hand side (higher N* value) of the diagram. However, recyclate 8 stands out due to its rather low N* value. The reason for the low N* value ("grey value") is probably to be found in the semi-transparent nature of this recyclate. From the sensor's point of view, a part of the impinging infrared light is lost.

8: N* = 52.7 i* = 19.87 r* = 10.01

*3.1.4.3 N*r* diagram*

The N*r* diagram shows the separation between PET- and PO-based recyclates. The two recyclates with specific weights >1 and low N* and r* values have a high i* value, so that although there is an apparent overlap in the N*r* diagram, this is not presented in the spatial view.



4. Conclusion

In the case of both virgin granulates and recyclates, the three-range procedure appears to produce a clear distinction between the individual articles. This means that we provide a cost-effective, easy-to-use and compact measuring unit that can be used both in a laboratory and in an inline context.