



CASE STUDY REPORT

C108

The Effects of Caustic

On Behalf of

PFE



Overview

This study aimed to look at how PET recyclability is evaluated in practice. Hot caustic washing is a standard PET recycling step because it helps detach labels and adhesives, while wash-water screening is used specifically to determine whether inks and adhesives disperse into the wash stream and thereby increase filtration and wastewater burden. APR's PET wash-water and plaque protocols treat wash-water contamination, plaque color, haze, and inclusions as key indicators of whether labels, inks, adhesives, or additives impair recycled PET quality. RecyClass and EPBP also frame hot caustic wash around roughly 85°C, caustic soda, and surfactant as representative of PET bottle recycling conditions.

This context matters because this dataset answers more than a narrow chemistry question. It can be used to decide how severe the hot wash should be for each feedstock, to estimate the tradeoff between downstream plaque quality and wash-water/filter burden, and to give packaging-design or sourcing feedback about which label systems are more tolerant of realistic recycling conditions. In short, the data is useful for process optimization, quality control, and design-for-recycling conversations. Please note that the results of this study only pertain to the parameters tested and the scope is limited to such.

Conclusions

The overarching conclusion is that caustic concentration does affect the produced data, but the effect is strongly feedstock-specific, not universal. In the extracted plaque dataset, the flake-type and caustic interaction was exceptionally large for all three primary end-use responses: plaque L* (partial $\eta^2 \approx 0.82$), plaque b* (partial $\eta^2 \approx 0.73$), and plaque haze (partial $\eta^2 \approx 0.80$). In other words, the impact of NaOH depends heavily on whether the stream is unlabeled stock, mixed-label flake, or labeled PCR. Partial η^2 shows how much of the outcome can be explained by a particular factor or effect, in this case, the concentration of the caustic.

For stock flake, the statistical signal is weak-to-moderate, and the practical effect is tiny: plaque L stayed between 92.92 and 93.08, plaque b between 2.57 and 2.90, and haze between 2.61 and 2.84 across the entire NaOH range. Meanwhile, 10 μm collected filter weight increased from 0.0205 g at 0% to 0.1463 g at 4%, so higher caustic adds process burden without a meaningful product-quality gain.

For the 50/50 label blend, NaOH clearly matters and the effect is large. The best overall balance was at 2% NaOH: plaque haze fell from 48.38 to 15.13, plaque L rose from 77.86 to 87.73, and plaque b fell from 8.76 to 3.00. Although 4% also improved the blend strongly, it did not materially beat 2% on plaque haze and imposed more filtration burden, with 10 μm collected filter weight rising from 0.0908 g at 2% to 0.1595 g at 4%.

For PCR, the response is nonlinear. The best overall setting in this dataset is 0.5% NaOH: plaque haze improved from 67.99 to 56.32, plaque L rose from 71.54 to 77.76, plaque b fell from 19.28 to 14.39, and black specks fell from 93% to 70%. Higher caustic did not produce monotonic improvement; in fact, 2% was worse than control on plaque haze and L*, and 4% carried a large filtration penalty, with ten μm collected filter weight reaching 0.9097 grams. These results may not be conclusive as PCR variability is large and hard to quantify and control.



In operational terms, the study supports a feedstock-segmented wash strategy rather than one caustic setpoint for all PET streams: use minimal caustic for clean unlabeled stock, around 2% for this mixed-label 50/50 stream, and around 0.5% for this labeled PCR stream unless additional process goals justify a different tradeoff. The strongest overall result was interaction: caustic does not push all feedstocks in the same direction. In the extracted plaque data, the interaction term was highly significant for L, b, and haze, which means the caustic-response curve changes shape by feedstock. Put plainly, stock, mixed-label flake, and PCR should not be treated as though they share one optimal NaOH setting. The optimal setting found for this PCR may not apply for all PCR as feedstock, machinery, other chemistry and many other factors affect individual facilities' wash performance. Each typical feedstock should be evaluated to find the best balance between minimal caustic and best quality. Full statistical and graphical analyses can be found in the annexes



Stock Summary

Property	Control	Test 1	Test 2	Test 3	Test 4
Wash Floatables (%)	0.00%	0.00%	0.00%	0.00%	0.00%
10µm Filter to Tap Ratio	3.46	2.84	3.27	2.71	4.15
10µm Collected Filter Weight (grams)	0.0205	0.0352	0.0569	0.0858	0.1463
Filtered Water Colors ΔE	NA	5.68	4.93	4.58	2.84
Lights Removed (%)	0.67%	1.05%	0.59%	0.67%	0.73%
Plaque Colors L*	92.92	93.03	93.08	93.04	93.01
Plaque Colors a*	-0.06	-0.08	-0.06	-0.05	-0.11
Plaque Colors b*	2.62	2.74	2.57	2.64	2.90
Plaque Colors Haze (%)	2.84	2.61	2.64	2.72	2.77
Black Specks	0%	0%	0%	0%	0%



50/50 PS and SS Blend Summary

Property	Control	Test 1	Test 2	Test 3	Test 4
Wash Floatables (%)	0.62%	0.39%	0.74%	0.34%	0.44%
10µm Filter to Tap Ratio	72.91	121.09	388.08	164.92	165.8
10µm Collected Filter Weight (grams)	0.0169	0.0199	0.0726	0.0908	0.1595
Filtered Water Colors ΔE	NA	0.36	1.00	1.80	3.36
Lights Removed (%)	2.19%	1.57%	1.80%	1.28%	1.15%
Plaque Colors L*	77.86	82.11	80.37	87.73	86.87
Plaque Colors a*	-3.07	-1.40	-2.22	-0.88	-0.79
Plaque Colors b*	8.76	3.86	3.91	3.00	3.19
Plaque Colors Haze (%)	48.38	31.82	36.43	15.13	19.60
Black Specks	0%	0%	0%	0%	0%



PCR Summary

Property	Control	Test 1	Test 2	Test 3	Test 4
Wash Floatables (%)	8.51%	9.68%	9.46%	9.55%	9.83%
10µm Filter to Tap Ratio	36.86	34.66	53.29	53.79	55.78
10µm Collected Filter Weight (grams)	0.1325	0.2163	0.3505	0.4721	0.9097
Filtered Water Colors ΔE	NA	3.60	2.65	3.70	4.78
Lights Removed (%)	25.08%	25.34%	25.34%	26.07%	25.86%
Plaque Colors L*	71.54	77.76	72.11	67.31	73.62
Plaque Colors a*	0.07	-1.10	-0.67	-0.34	-1.13
Plaque Colors b*	19.28	14.39	17.87	20.38	15.40
Plaque Colors Haze (%)	67.99	56.32	71.55	75.98	58.28
Black Specks	93%	70%	82%	81%	73%



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Stock Granulation

References:

PET-P-03

Test Summary:

Granulate incoming articles to the required grind size.

Procedure:

Articles are manually fed into a grinder with screen holes ranging from 9.5 to 12 mm in diameter.

Incoming Article	Ground Article
	



Stock Wash and Sink/Float Evaluation

References:

PET-P-04

Test Summary:

Remove any contamination from PET and help liberate labels, adhesives, coatings, and layers.

Procedure:

Wash

PET flake is added to tap water at a 4:1 ratio of water to flake and heated to $85 \pm 2^{\circ}\text{C}$. Triton X-100 surfactant is added at a 0.3% concentration, and caustic NaOH is added at the required concentration. The flakes and water are mixed with an impeller for 15 minutes at 546 rpm. After 15 minutes, the impeller is stopped, and the mixture is removed from the heat source and allowed to sit for five minutes. After five minutes, the wash water, floatables, and sinkables are retained.

Rinse

The sinking fraction of the washed PET flake is added to tap water at a 4:1 ratio of water to flake and heated to $45 \pm 2^{\circ}\text{C}$. The flakes and water are mixed with an impeller at, at least 546 rpm for five minutes. After five minutes, the mixture is removed from the heat and allowed to sit for five minutes. After five minutes, the rinse water, floatables, and sinkables are retained.

Sink/Float

The rinsed PET flake is added to tap water at an 8:1 water-to-flake to water ratio. The tank is agitated by hand or at 500 rpm for five minutes and then allowed to sit for five minutes. After five minutes, the floatables and sinkables are retained.

Data Table:

Variable	Wash Temperature ($^{\circ}\text{C}$)	Rinse Temperature ($^{\circ}\text{C}$)	Starting Flake Weight (kg)	Total Floatables (grams)	Total Floatables (%)
Control	86	46	2.27	0.00	0.00%
Test 1	86	44	2.27	0.00	0.00%
Test 2	85	43	2.27	0.00	0.00%
Test 3	86	44	2.27	0.00	0.00%
Test 4	85	45	2.27	0.00	0.00%

Stock Wash/Rinse Pictures

Variable	Settled Waters		Shaken Waters	
	Wash	Rinse	Wash	Rinse
Control				
Test 1				
Test 2				
Test 3				
Test 4				

Stock Washed Flake/Floatable Pictures

Variable	Washed Flake	Floatables
Control		NOT APPLICABLE
Test 1		NOT APPLICABLE
Test 2		NOT APPLICABLE
Test 3		NOT APPLICABLE
Test 4		NOT APPLICABLE



Stock Wash Water Evaluation

References:

PET-S-01

Test Summary:

Visual evaluations of the wash water are conducted to determine the characteristics of the label substrate, inks, and adhesives utilized within the label. The water is examined for suspended ink or adhesive. If ink or adhesive is seen, the water is evaluated.

Procedure:

500 mL of water is transferred into a graduated cylinder, allowed to settle for 30 minutes, then ranked depending on the amount of settling of the inks and adhesive. After the setting evaluation, the wash water is passed through a 250-mesh screen using a Buchner funnel. The filtered water is ranked by its appearance. The wash water is then filtered again with a Whatman Grade 1 filter (10µm) using a Buchner funnel. The time it takes to filter the wash water is measured and compared to the time it takes for clean tap water to filter. The filtered water is ranked by its appearance.



Stock Wash Water Filtration Evaluation

Variable	Control	Test 1	Test 2	Test 3	Test 4
250-Mesh Evaluation					
250-Mesh Starting Weight (g)	2.3082	2.2983	2.2722	2.2752	2.3139
250-Mesh Ending Weight (g)	2.3185	2.3136	2.2838	2.3225	2.3791
250-Mesh Collected Weight (g)	0.0103	0.0153	0.0116	0.0473	0.0652
250-Mesh Collection (Y/N)	Y	Y	Y	Y	Y
250-Mesh Appearance Ranking	B	B	B	B	B
10µm Evaluation					
10µm Filter Starting Weight (g)	0.8061	0.7901	0.7880	0.8318	0.7990
10µm Filter Ending Weight (g)	0.8266	0.8253	0.8449	0.9176	0.9453
10µm Filter Collected Weight (g)	0.0205	0.0352	0.0569	0.0858	0.1463
10µm Filter Collection (Y/N)	Y	Y	Y	Y	Y
10µm Filter Appearance Ranking	C	C	A	A	B
10µm Filter Time (s)	154.66	126.96	146.27	121.45	185.61
Tap Water Filter Time (s)	44.74				
10µm Filter Time / Tap Water Filter Time	3.46	2.84	3.27	2.71	4.15

Ranking System for Filtering Evaluation:

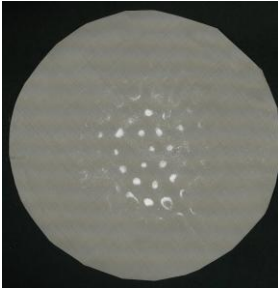
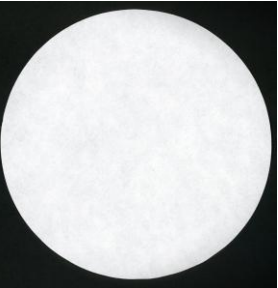
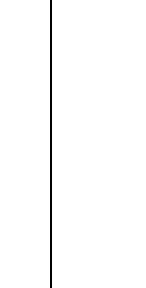
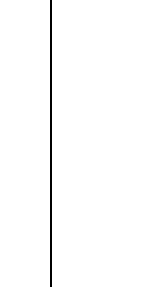
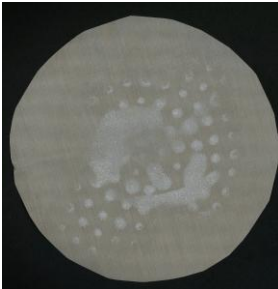
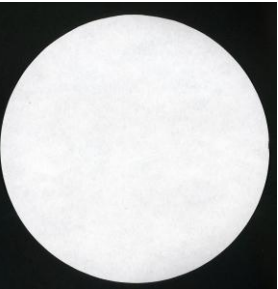
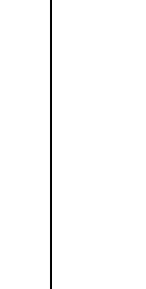
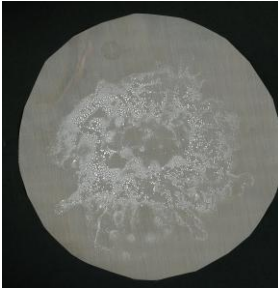
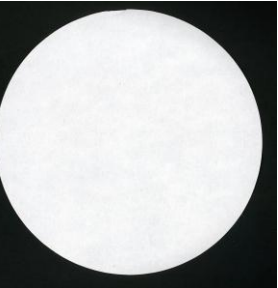
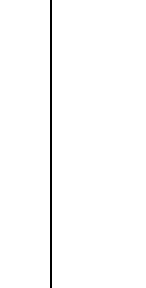
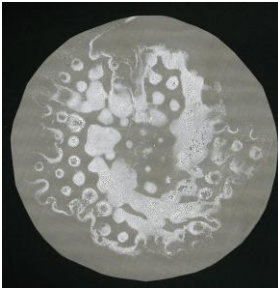
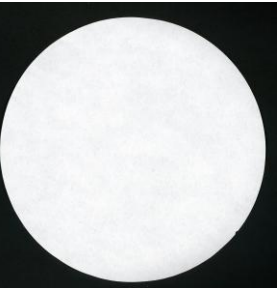
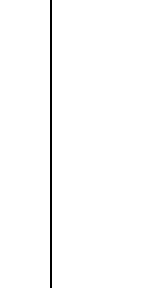
250-Mesh Evaluation

- Appearance after filtering is like the starting material.
- Some level of colored material or adhesive was filtered out.
- Most colored material was filtered out.

10µm Filter Evaluation

- Appearance after filtering is like the starting material.
- Some level of colored material was filtered out.
- Most colored material was filtered, but the water is still hazy.
- Color and haze are absent in the filtered water.

Stock Filter Pictures

Variable	250-Mesh Screen	10µm Filter Paper	Settled Waters		Shaken Waters	
			Wash	Filtered	Wash	Filtered
Control						
Test 1						
Test 2						
Test 3						
Test 4						



Stock Filtered Water Colors

References:

ASTM D6290

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the degree of yellowness under daylight illumination of transparent, translucent, or opaque plastics

Equipment:

Konica Minolta 36dG

Procedure:

The color analyzing equipment is set up on transmittance and calibrated using pure white and black standards. A 10 mm sample cell is filled to the brim with filtered water. The cell is inserted into the machine, and the equipment runs the color test. The test indicates L*, a*, and b* values. This test is completed in a conditioned laboratory at a temperature of $23 \pm 2^{\circ}\text{C}$ and a relative humidity of $50 \pm 10\%$.



Stock Filtered Water Colors Data Table

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average	ΔE
Control	85.82	0.72	4.69	85.82	0.72	4.68	NA
	85.83	0.72	4.69				
	85.82	0.72	4.67				
	85.82	0.72	4.67				
	85.81	0.73	4.67				
Test 1	81.83	-1.54	8.02	81.84 (-3.98)	-1.55 (-2.27)	8.03 (3.35)	5.68
	81.84	-1.54	8.02				
	81.83	-1.55	8.03				
	81.84	-1.55	8.03				
	81.84	-1.55	8.03				
Test 2	85.68	1.04	9.59	85.58 (-0.24)	1.04 (0.31)	9.59 (4.91)	4.93
	85.56	1.03	9.58				
	85.56	1.04	9.59				
	85.55	1.03	9.59				
	85.55	1.04	9.59				
Test 3	87.49	0.74	8.94	87.49 (1.67)	0.73 (0.01)	8.95 (4.27)	4.58
	87.49	0.73	8.95				
	87.49	0.73	8.95				
	87.49	0.73	8.95				
	87.49	0.73	8.95				
Test 4	88.50	0.46	5.54	88.51 (2.69)	0.46 (-0.26)	5.54 (0.86)	2.84
	88.51	0.46	5.54				
	88.51	0.47	5.54				
	88.52	0.45	5.53				
	88.53	0.46	5.54				



Stock Elutriation

References:

PET-P-05

Test Summary:

Remove lights (fines, labels, layers) from washed flake before extrusion.

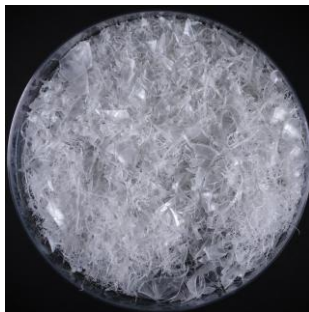
Procedure:

The elutriator is calibrated using the washed and dried control flake to adjust the air speed until the value of 0.5% for lights removed is achieved. Once the elutriator is calibrated, the rest of the control and tests are run. Airspeed, heavies' weight, lights' weight, and the percentage of lights are recorded for each test. Heavies are then prepared for the next steps of processing.

Data Table:

Variable	Air Speed (m/s)	Heavies Weight (kg)	Lights Weight (grams)	Lights Removed (%)
Control	6.52	1.75	11.74	0.67%
Test 1	6.52	1.75	18.57	1.05%
Test 2	6.52	1.82	10.74	0.59%
Test 3	6.52	1.81	12.18	0.67%
Test 4	6.52	1.85	13.65	0.73%

Stock Heavies/Lights Pictures

Variable	Heavies	Lights
Control		
Test 1		
Test 2		
Test 3		
Test 4		



Stock Heavies Colors

References:

ASTM D6290

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the degree of yellowness under daylight illumination of transparent, translucent, or opaque plastics.

Equipment:

Konica Minolta 36d

Procedure:

The color analyzing equipment is set up on reflectance and calibrated using pure white and black standards. The sample cell is filled to the brim with randomly selected flakes. The cell is inserted into the machine, and the equipment runs the color test. The test indicates L*, a*, and b* values. This test is completed in a conditioned laboratory at a temperature of $23 \pm 2^{\circ}\text{C}$ and a relative humidity of $50 \pm 10\%$.

Stock Heavies Colors Data Table

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Control	66.45	-0.05	-0.08	66.80	-0.04	-0.21
	67.45	0.01	-0.21			
	66.54	-0.04	-0.37			
	66.77	-0.02	0.06			
	66.81	-0.08	-0.44			
Test 1	67.28	-0.05	-0.03	66.65 (-0.15)	-0.03 (?0.01)	-0.18 (0.03)
	68.49	0.00	-0.04			
	64.65	-0.03	-0.12			
	67.11	-0.01	-0.62			
	65.71	-0.04	-0.11			
Test 2	68.48	-0.02	0.04	65.96 (-0.84)	-0.03 (0.01)	0.01 (0.22)
	63.07	-0.06	0.43			
	65.52	0.02	-0.13			
	66.07	-0.04	-0.37			
	66.66	-0.03	0.08			
Test 3	68.75	0.02	-0.04	68.05 (1.25)	0.01 (0.05)	-0.07 (0.14)
	67.59	-0.01	0.02			
	68.85	0.00	0.04			
	67.55	-0.01	-0.26			
	67.51	0.05	-0.13			
Test 4	68.63	0.02	0.09	66.87 (0.07)	0.01 (0.05)	-0.03 (0.18)
	66.35	-0.02	0.08			
	67.63	0.00	-0.26			
	65.18	0.05	0.05			
	66.58	-0.02	-0.12			



Stock Flake Bake Evaluation

References:

PET-S-10

Test Summary:

Determine the color changes of the flake after baking.

Procedure:

One hundred grams of flake is placed into a convection oven heated at 220°C for 60 minutes.

Stock Flake Pictures

Variable	Before Baking Flake		After Baking Flake	
Control				
Test 1				
Test 2				
Test 3				
Test 4				



Stock Baked Flake Colors

References:

ASTM D6290

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the degree of yellowness under daylight illumination of transparent, translucent, or opaque plastics.

Equipment:

Konica Minolta 36dG

Procedure:

The color analyzing equipment is set up on reflectance and calibrated using pure white and black standards. The sample cell is filled to the brim with randomly selected flakes. The cell is inserted into the machine, and the equipment runs the color test. The test indicates L*, a*, and b* values. This test is completed in a conditioned laboratory at a temperature of $23 \pm 2^{\circ}\text{C}$ and a relative humidity of $50 \pm 10\%$.

Stock Baked Flake Colors Data Table

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Before Baking Control	66.45	-0.05	-0.08	66.80	-0.04	-0.21
	67.45	0.01	-0.21			
	66.54	-0.04	-0.37			
	66.77	-0.02	0.06			
	66.81	-0.08	-0.44			
After Baking Control	72.42	-0.17	-0.38	71.30 (4.50)	-0.17 (-0.13)	-0.64 (-0.43)
	70.40	-0.13	-0.46			
	71.38	-0.19	-0.77			
	71.33	-0.21	-0.80			
	70.98	-0.17	-0.81			
Before Baking Test 1	67.28	-0.05	-0.03	66.65	-0.03	-0.18
	68.49	0.00	-0.04			
	64.65	-0.03	-0.12			
	67.11	-0.01	-0.62			
	65.71	-0.04	-0.11			
After Baking Test 1	73.37	-0.08	0.30	72.37 (5.72)	-0.11 (-0.08)	0.15 (0.33)
	71.12	-0.16	-0.06			
	72.84	-0.09	0.55			
	73.48	-0.10	0.19			
	71.04	-0.14	-0.21			



Stock Baked Flake Colors Data Table Continued

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Before Baking Test 2	68.48	-0.02	0.04	65.96	-0.03	0.01
	63.07	-0.06	0.43			
	65.52	0.02	-0.13			
	66.07	-0.04	-0.37			
	66.66	-0.03	0.08			
After Baking Test 2	74.32	-0.31	-0.05	73.35 (7.39)	-0.26 (-0.23)	-0.04 (-0.05)
	72.92	-0.31	-0.72			
	74.49	-0.31	-0.04			
	70.14	-0.15	0.24			
	74.86	-0.22	0.38			
Before Baking Test 3	68.75	0.02	-0.04	68.05	0.01	-0.07
	67.59	-0.01	0.02			
	68.85	0.00	0.04			
	67.55	-0.01	-0.26			
	67.51	0.05	-0.13			
After Baking Test 3	73.42	-0.25	0.38	73.35 (5.30)	-0.18 (-0.19)	1.02 (1.09)
	73.70	-0.17	1.41			
	73.53	-0.21	0.10			
	73.29	-0.14	1.57			
	72.83	-0.15	1.63			



Stock Baked Flake Colors Data Table Continued

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Before Baking Test 4	68.63	0.02	0.09	66.87	0.01	-0.03
	66.35	-0.02	0.08			
	67.63	0.00	-0.26			
	65.18	0.05	0.05			
	66.58	-0.02	-0.12			
After Baking Test 4	76.69	-0.39	0.31	74.64 (7.77)	-0.38 (-0.39)	0.56 (0.59)
	73.02	-0.35	1.01			
	71.07	-0.33	0.44			
	75.21	-0.41	0.83			
	77.19	-0.42	0.23			



Stock Plaque Processing and Testing

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Stock Injection

References:

PET-P-08

Test Summary:

Injection mold 3mm plaques to test for color and haze values.

Procedure:

Injection material is prepped in a dryer until the moisture content is below 50 ppm. PET is injection molded at a target melt temperature of 275°C. The injection unit is purged between each test innovation. Melt, room, and mold temperatures are recorded for each variable.

Data Table:

Variable	Moisture Content (ppm)	Melt Temperature (°C)	Mold Temperature (°C)
Control	19	275	25
Test 1	21	275	24
Test 2	16	275	25
Test 3	13	275	25
Test 4	45	275	26

Operating Conditions:

Zone 1 Temperature (°C)	Zone 2 Temperature (°C)	Zone 3 Temperature (°C)	Nozzle Temperature (°C)
265	266	266	275

Stock Injection Molded Plaques Pictures

Control	
Test 1	
Test 2	

From left to right, the plaque thicknesses are 3.0 mm, 2.0 mm, and 1.0 mm.

Stock Injection Molded Plaques Pictures Continued

Test 3



Test 4



From left to right, the plaque thicknesses are 3.0 mm, 2.0 mm, and 1.0 mm.



Stock Plaque Colors

References:

PET-P-08

PET-S-09

ASTM D1003

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the color values L^* , a^* , b^* , and haze of a 3mm injection-molded plaque. Visually identify the presence of black specks and inclusions. The data is designed to be correlated to the production of reproduced bottles.

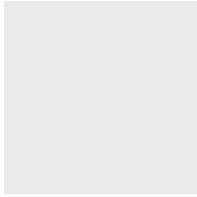
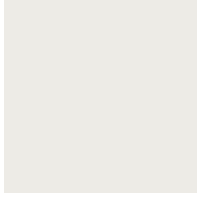
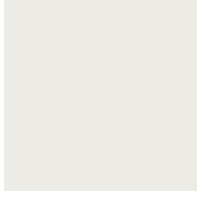
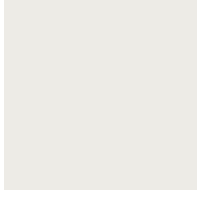
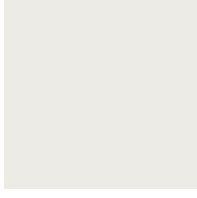
Equipment:

Konica Minolta 36dG

Procedure:

Pellets are dried to a moisture level below 50 ppm and injection molded into 3mm plaques. The color analyzing equipment is set up on transmittance and calibrated using pure white and black standards. The molded plaque is inserted into the testing location, and the equipment runs the color test. The test indicates L^* , a^* , and b^* values and haze percentage.

Stock Plaque Colors Data Table

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average	Haze	Haze Average	Plaque L*a*b* Swatch
Control	92.88	-0.07	2.69	92.92	-0.06	2.62	2.84	2.84	
	92.93	-0.05	2.66				2.78		
	92.89	-0.09	2.64				2.83		
	92.93	-0.04	2.59				2.89		
	92.99	-0.04	2.53				2.87		
Test 1	92.93	-0.13	3.19	93.03 (0.11)	-0.08 (-0.02)	2.74 (0.12)	2.74	2.61 (-0.23)	
	93.03	-0.08	2.73				2.54		
	93.07	-0.04	2.54				2.53		
	93.06	-0.09	2.75				2.58		
	93.04	-0.04	2.47				2.65		
Test 2	93.10	-0.06	2.56	93.08 (0.16)	-0.06 (0.00)	2.57 (-0.05)	2.62	2.64 (-0.20)	
	92.98	-0.08	2.78				2.70		
	93.10	-0.06	2.55				2.63		
	93.11	-0.05	2.50				2.65		
	93.11	-0.04	2.48				2.61		
Test 3	92.89	0.07	2.89	93.04 (0.12)	-0.05 (0.01)	2.64 (0.02)	2.88	2.72 (-0.12)	
	93.08	-0.05	2.47				2.70		
	93.11	-0.06	2.45				2.54		
	93.03	-0.12	2.84				3.00		
	93.11	-0.08	2.56				2.50		
Test 4	93.04	-0.10	2.79	93.01 (0.08)	-0.11 (-0.05)	2.90 (0.28)	2.70	2.77 (-0.07)	
	92.89	-0.18	3.39				2.80		
	92.99	-0.09	2.82				2.70		
	93.07	-0.09	2.76				2.68		
	93.05	-0.08	2.76				2.96		

Plaques are not randomly selected. Operators select five plaques that are free of imperfections that may alter results.

The plaque swatch visually represents the L*a*b* values, not including haze or transparency.



Stock Black Specks/Inclusions

References:

PET-S-09

Test Summary:

Visually identify the presence of black specks and inclusions. Data is designed to be correlated to the production of reproduced bottles.

Equipment:

Ryan Quality Control Size Chart

Procedure:

Injection-molded plaques are held in front of a diffused white light source, and black specks or other inclusions larger than 0.1 mm^2 or 0.36 mm in diameter are identified visually, with no magnification. Pictures of inclusions are taken with an 85-magnification microscope only after visual identification.



Stock Black Specks/Inclusions Data Table

Variable	Percentage of Plaques with Inclusions
Control	0%
Test 1	0%
Test 2	0%
Test 3	0%
Test 4	0%

Plaques are not randomly selected. Operators select plaques with inclusions that meet the size criteria.



50/50 Blend of Pressure Sensitive (PS) and Shrink Sleeve (SS)

Flake Processing and Testing

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50/50 PS and SS Blend Granulation

References:

PET-P-03

Test Summary:

Granulate incoming articles to the required grind size.

Procedure:

Articles are manually fed into a grinder with screen holes ranging from 9.5 to 12 mm in diameter.

Incoming Article	Ground Article
	
	



50/50 PS and SS Blend Wash and Sink/Float Evaluation

References:

PET-P-04

Test Summary:

Remove any contamination from PET and help liberate labels, adhesives, coatings, and layers.

Procedure:

Wash

PET flake is added to tap water at a 4:1 ratio of water to flake and heated to $85 \pm 2^{\circ}\text{C}$. Triton X-100 surfactant is added at a 0.3% concentration, and caustic NaOH is added at the required concentration. The flakes and water are mixed with an impeller for 15 minutes at 546 rpm. After 15 minutes, the impeller is stopped, and the mixture is removed from the heat source and allowed to sit for five minutes. After five minutes, the wash water, floatables, and sinkables are retained.

Rinse

The sinking fraction of the washed PET flake is added to tap water at a 4:1 ratio of water to flake and heated to $45 \pm 2^{\circ}\text{C}$. The flakes and water are mixed with an impeller at, at least 546 rpm for five minutes. After five minutes, the mixture is removed from the heat and allowed to sit for five minutes. After five minutes, the rinse water, floatables, and sinkables are retained.

Sink/Float

The rinsed PET flake is added to tap water at an 8:1 water-to-flake to water ratio. The tank is agitated by hand or at 500 rpm for five minutes and then allowed to sit for five minutes. After five minutes, the floatables and sinkables are retained.

Data Table:

Variable	Wash Temperature (°C)	Rinse Temperature (°C)	Starting Flake Weight (kg)	Total Floatables (grams)	Total Floatables (%)
Control	85	43	4.55	28.0	0.62%
Test 1	85	47	4.55	17.5	0.39%
Test 2	83	51	4.55	33.5	0.74%
Test 3	87	44	4.55	15.5	0.34%
Test 4	87	43	4.55	20.0	0.44%

50/50 PS and SS Blend Wash/Rinse Pictures

Variable	Settled Waters		Shaken Waters	
	Wash	Rinse	Wash	Rinse
Control				
Test 1				
Test 2				
Test 3				
Test 4				

50/50 PS and SS Blend Washed Flake/Floatable Pictures

Variable	Washed Flake		Floatables	
Control				
Test 1				
Test 2				
Test 3				
Test 4				

50/50 PS and SS Blend Wash Water Visual Evaluation Pictures

Variable	Unwashed Label vs Washed Label	Settled Wash Waters		Shaken Wash Waters	
		Wash	Rinse	Wash	Rinse
Control					
Test 1					
Test 2					
Test 3					
Test 4					



50/50 PS and SS Blend Wash Water Evaluation

References:

PET-S-01

Test Summary:

Visual evaluations of the wash water are conducted to determine the characteristics of the label substrate, inks, and adhesives utilized within the label. The water is examined for suspended ink or adhesive. If ink or adhesive is seen, the water is evaluated.

Procedure:

500 mL of water is transferred into a graduated cylinder, allowed to settle for 30 minutes, then ranked depending on the amount of settling of the inks and adhesive. After the setting evaluation, the wash water is passed through a 250-mesh screen using a Buchner funnel. The filtered water is ranked by its appearance. The wash water is then filtered again with a Whatman Grade 1 filter (10µm) using a Buchner funnel. The time it takes to filter the wash water is measured and compared to the time it takes for clean tap water to filter. The filtered water is ranked by its appearance.



50/50 PS and SS Blend Wash Water Filtration Evaluation

Variable	Control	Test 1	Test 2	Test 3	Test 4
250-Mesh Evaluation					
250-Mesh Starting Weight (g)	2.3455	2.3584	2.4577	2.4666	2.4378
250-Mesh Ending Weight (g)	2.3519	2.3670	2.5502	2.4971	2.4782
250-Mesh Collected Weight (g)	0.0064	0.0086	0.0925	0.0305	0.0404
250-Mesh Collection (Y/N)	Y	Y	Y	Y	Y
250-Mesh Appearance Ranking	B	B	B	B	B
10µm Evaluation					
10µm Filter Starting Weight (g)	0.8043	0.7916	0.7987	0.7880	0.7963
10µm Filter Ending Weight (g)	0.8212	0.8115	0.8713	0.8788	0.9558
10µm Filter Collected Weight (g)	0.0169	0.0199	0.0726	0.0908	0.1595
10µm Filter Collection (Y/N)	Y	Y	Y	Y	Y
10µm Filter Appearance Ranking	C	C	C	C	C
10µm Filter Time (s)	72.91	121.09	388.08	164.92	165.8
Tap Water Filter Time (s)	42.93				
10µm Filter Time / Tap Water Filter Time	1.70	2.82	9.04	3.84	3.86

Ranking System for Filtering Evaluation:

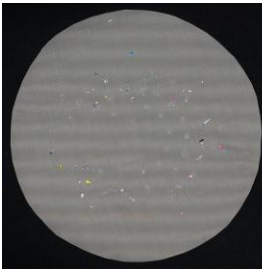
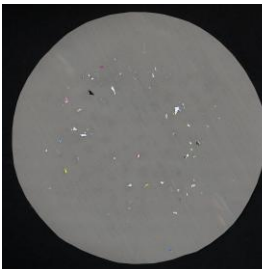
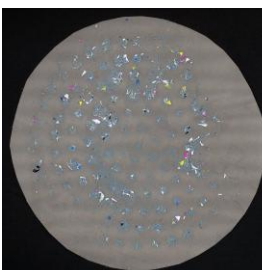
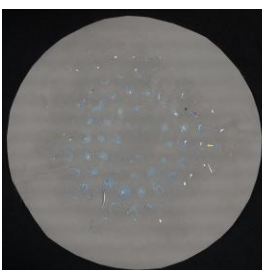
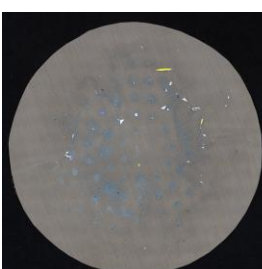
250-Mesh Evaluation

- Appearance after filtering is like the starting material.
- Some level of colored material or adhesive was filtered out.
- Most colored material was filtered out.

10µm Filter Evaluation

- Appearance after filtering is like the starting material.
- Some level of colored material was filtered out.
- Most colored material was filtered, but the water is still hazy.
- Color and haze are absent in the filtered water.

50/50 PS and SS Blend Filter Pictures

Variable	250-Mesh Screen	10µm Filter Paper	Settled Waters		Shaken Waters	
			Wash	Filtered	Wash	Filtered
Control						
Test 1						
Test 2						
Test 3						
Test 4						



50/50 PS and SS Blend Filtered Water Colors

References:

ASTM D6290

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the degree of yellowness under daylight illumination of transparent, translucent, or opaque plastics.

Equipment:

Konica Minolta 36dG

Procedure:

The color analyzing equipment is set up on transmittance and calibrated using pure white and black standards. A 10 mm sample cell is filled to the brim with filtered water. The cell is inserted into the machine, and the equipment runs the color test. The test indicates L*, a*, and b* values. This test is completed in a conditioned laboratory at a temperature of $23 \pm 2^{\circ}\text{C}$ and a relative humidity of $50 \pm 10\%$.

50/50 PS and SS Blend Filtered Water Colors Data Table

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average	ΔE
Control	96.34	-0.13	0.45	96.33	-0.13	0.45	NA
	96.34	-0.13	0.45				
	96.33	-0.13	0.46				
	96.35	-0.14	0.44				
	96.29	-0.14	0.45				
Test 1	96.05	-0.09	0.28	96.02 (-0.31)	-0.09 (0.05)	0.29 (-0.16)	0.36
	95.96	-0.09	0.29				
	96.02	-0.08	0.29				
	96.03	-0.09	0.29				
	96.02	-0.09	0.28				
Test 2	95.36	-0.05	0.38	95.33 (-1.00)	-0.06 (0.08)	0.39 (-0.06)	1.00
	95.30	-0.06	0.39				
	95.32	-0.06	0.39				
	95.34	-0.06	0.39				
	95.34	-0.05	0.40				
Test 3	94.64	-0.02	0.55	94.54 (-1.79)	-0.02 (0.11)	0.56 (0.11)	1.80
	94.49	-0.03	0.54				
	94.52	-0.02	0.58				
	94.54	-0.03	0.57				
	94.51	-0.02	0.58				
Test 4	93.19	0.31	0.76	93.01 (-3.32)	0.32 (0.45)	0.71 (0.26)	3.36
	92.94	0.32	0.71				
	93.01	0.32	0.72				
	93.00	0.32	0.69				
	92.90	0.32	0.68				



50/50 PS and SS Blend Elutriation

References:

PET-P-05

Test Summary:

Remove lights (fines, labels, layers) from washed flake before extrusion.

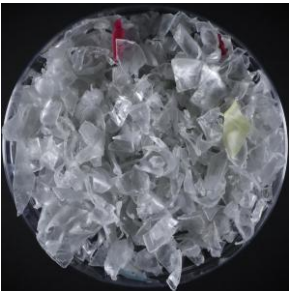
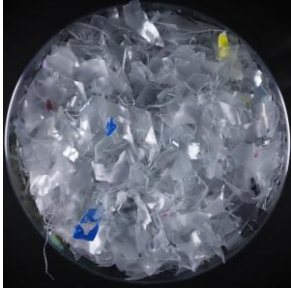
Procedure:

The elutriator is calibrated using the washed and dried control flake to adjust the air speed until the value of 0.5% for lights removed is achieved. Once the elutriator is calibrated, the rest of the control and tests are run. Airspeed, heavies' weight, lights' weight, and the percentage of lights are recorded for each test. Heavies are then prepared for the next steps of processing.

Data Table:

Variable	Air Speed (m/s)	Heavies Weight (kg)	Lights Weight (grams)	Lights Removed (%)
Control	6.52	3.75	83.60	2.19%
Test 1	6.52	3.66	58.52	1.57%
Test 2	6.52	3.81	69.72	1.80%
Test 3	6.52	3.79	49.10	1.28%
Test 4	6.52	3.60	41.82	1.15%

50/50 PS and SS Blend Heavies/Lights Pictures

Variable	Heavies	Lights
Control		
Test 1		
Test 2		
Test 3		
Test 4		



50/50 PS and SS Blend Heavies Colors

References:

ASTM D6290

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the degree of yellowness under daylight illumination of transparent, translucent, or opaque plastics.

Equipment:

Konica Minolta 36dG

Procedure:

The color analyzing equipment is set up on reflectance and calibrated using pure white and black standards. The sample cell is filled to the brim with randomly selected flakes. The cell is inserted into the machine, and the equipment runs the color test. The test indicates L*, a*, and b* values. This test is completed in a conditioned laboratory at a temperature of $23 \pm 2^{\circ}\text{C}$ and a relative humidity of $50 \pm 10\%$.



50/50 PS and SS Blend Heavies Colors Data Table

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Control	63.48	-1.25	0.58	63.14	-1.25	0.39
	62.07	-1.21	0.55			
	64.15	-1.29	0.33			
	63.40	-1.26	0.38			
	62.58	-1.24	0.09			
Test 1	61.94	-1.42	-1.87	63.53 (0.39)	-1.41 (-0.16)	-1.84 (-2.23)
	65.37	-1.51	-1.78			
	63.21	-1.37	-1.82			
	63.75	-1.32	-1.93			
	63.39	-1.41	-1.82			
Test 2	62.42	-1.95	-2.37	62.81 (-0.33)	-1.84 (-0.59)	-2.05 (-2.44)
	63.08	-1.75	-1.60			
	63.10	-2.00	-2.03			
	62.14	-1.79	-2.13			
	63.29	-1.73	-2.13			
Test 3	62.51	-0.91	-1.48	63.99 (0.86)	-0.93 (0.32)	-1.48 (-1.88)
	64.00	-1.03	-1.36			
	64.93	-1.04	-1.37			
	63.6	-0.76	-1.53			
	64.92	-0.89	-1.67			
Test 4	66.56	-1.04	-1.62	65.01 (1.88)	-1.08 (0.17)	-1.45 (-1.84)
	64.91	-1.12	-1.55			
	63.95	-1.09	-1.78			
	64.44	-1.10	-0.92			
	65.20	-1.07	-1.38			



50/50 PS and SS Blend Flake Bake Evaluation

References:

PET-S-10

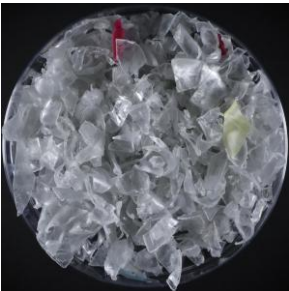
Test Summary:

Determine the color changes of the flake after baking.

Procedure:

One hundred grams of flake is placed into a convection oven heated at 220°C for 60 minutes.

50/50 PS and SS Blend Flake Pictures

Variable	Before Baking Flake	After Baking Flake
Control		
Test 1		
Test 2		
Test 3		
Test 4		



50/50 PS and SS Blend Baked Flake Colors

References:

ASTM D6290

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the degree of yellowness under daylight illumination of transparent, translucent, or opaque plastics.

Equipment:

Konica Minolta 36dG

Procedure:

The color analyzing equipment is set up on reflectance and calibrated using pure white and black standards. The sample cell is filled to the brim with randomly selected flakes. The cell is inserted into the machine, and the equipment runs the color test. The test indicates L*, a*, and b* values. This test is completed in a conditioned laboratory at a temperature of $23 \pm 2^{\circ}\text{C}$ and a relative humidity of $50 \pm 10\%$.

50/50 PS and SS Blend Baked Flake Colors

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Before Baking Control	63.48	-1.25	0.58	63.14	-1.25	0.39
	62.07	-1.21	0.55			
	64.15	-1.29	0.33			
	63.40	-1.26	0.38			
	62.58	-1.24	0.09			
After Baking Control	66.46	-1.31	3.43	67.53 (4.40)	-1.44 (-0.19)	3.89 (3.50)
	66.91	-1.39	4.05			
	69.23	-1.37	3.34			
	65.35	-1.59	4.52			
	69.72	-1.52	4.11			
Before Baking Test 1	61.94	-1.42	-1.87	63.53	-1.41	-1.84
	65.37	-1.51	-1.78			
	63.21	-1.37	-1.82			
	63.75	-1.32	-1.93			
	63.39	-1.41	-1.82			
After Baking Test 1	69.82	-1.53	-0.60	67.39 (3.85)	-1.63 (-0.22)	-0.72 (1.12)
	66.30	-1.53	-1.07			
	68.01	-1.68	-0.42			
	67.35	-1.69	-0.66			
	65.45	-1.70	-0.87			

50/50 PS and SS Blend Baked Flake Colors Continued

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Before Baking Test 2	62.42	-1.95	-2.37	62.81	-1.84	-2.05
	63.08	-1.75	-1.60			
	63.10	-2.00	-2.03			
	62.14	-1.79	-2.13			
	63.29	-1.73	-2.13			
After Baking Test 2	65.18	-2.57	-0.77	66.80 (4.00)	-2.24 (-0.40)	-0.61 (1.44)
	67.60	-2.26	-0.82			
	66.68	-2.23	0.04			
	67.03	-1.87	-0.18			
	67.53	-2.28	-1.32			
Before Baking Test 3	62.51	-0.91	-1.48	63.99	-0.93	-1.48
	64.00	-1.03	-1.36			
	64.93	-1.04	-1.37			
	63.6	-0.76	-1.53			
	64.92	-0.89	-1.67			
After Baking Test 3	71.22	-1.63	-1.92	70.01 (6.02)	-1.47 (-0.54)	-1.50 (-0.02)
	69.37	-1.45	-1.70			
	70.84	-1.40	-1.62			
	68.71	-1.47	-1.17			
	69.92	-1.39	-1.08			



50/50 PS and SS Blend Baked Flake Colors Continued

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Before Baking Test 4	66.56	-1.04	-1.62	65.01	-1.08	-1.45
	64.91	-1.12	-1.55			
	63.95	-1.09	-1.78			
	64.44	-1.10	-0.92			
	65.20	-1.07	-1.38			
After Baking Test 4	69.54	-1.20	-0.57	71.03 (6.02)	-1.23 (-0.14)	-1.07 (0.38)
	70.67	-1.28	-1.27			
	70.15	-1.29	-1.14			
	72.69	-1.14	-1.40			
	72.11	-1.22	-0.96			



50/50 PS and SS Blend

Plaque Processing and Testing

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50/50 PS and SS Blend Injection

References:

PET-P-08

Test Summary:

Injection mold 3mm plaques to test for color and haze values.

Procedure:

Injection material is prepped in a dryer until the moisture content is below 50 ppm. PET is injection molded at a target melt temperature of 275°C. The injection unit is purged between each test innovation. Melt, room, and mold temperatures are recorded for each variable.

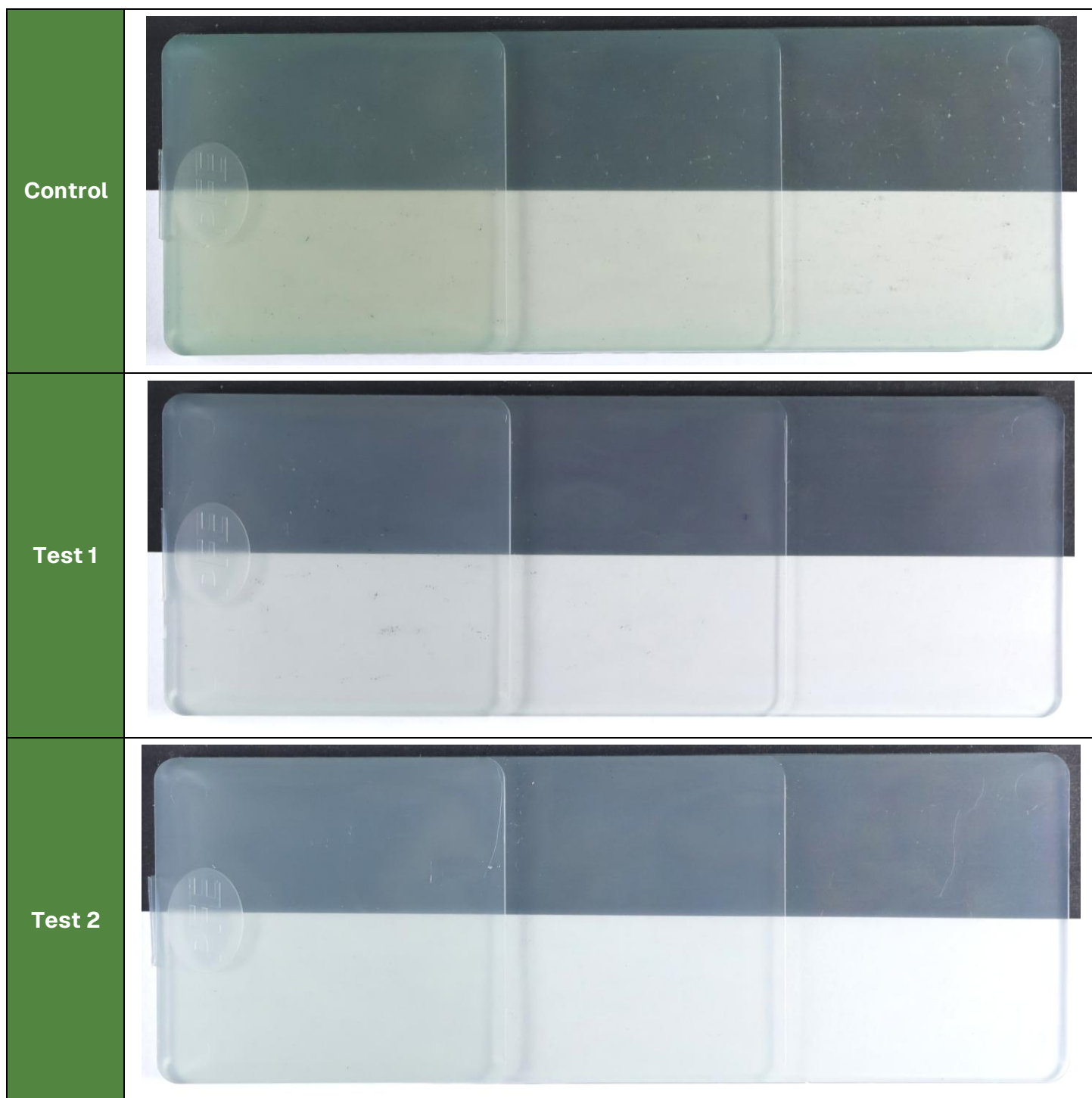
Data Table:

Variable	Moisture Content (ppm)	Melt Temperature (°C)	Mold Temperature (°C)
Control	10	275	23
Test 1	12	275	24
Test 2	24	275	24
Test 3	15	275	24
Test 4	9	275	25

Operating Conditions:

Zone 1 Temperature (°C)	Zone 2 Temperature (°C)	Zone 3 Temperature (°C)	Nozzle Temperature (°C)
265	266	266	275

50/50 PS and SS Blend Injection Molded Plaques Pictures



From left to right, the plaque thicknesses are 3.0 mm, 2.0 mm, and 1.0 mm.

50/50 PS and SS Blend Injection Molded Plaques Pictures Continued



From left to right, the plaque thicknesses are 3.0 mm, 2.0 mm, and 1.0 mm.



50/50 PS and SS Blend Plaque Colors

References:

PET-P-08

PET-S-09

ASTM D1003

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the color values L^* , a^* , b^* , and haze of a 3mm injection-molded plaque. Visually identify the presence of black specks and inclusions. The data is designed to be correlated to the production of reproduced bottles.

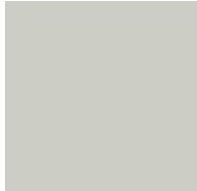
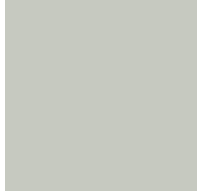
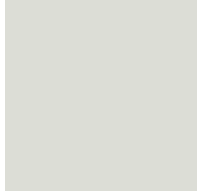
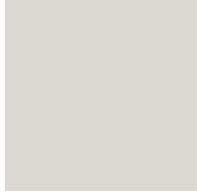
Equipment:

Konica Minolta 36dG

Procedure:

Pellets are dried to a moisture level below 50 ppm and injection molded into 3mm plaques. The color analyzing equipment is set up on transmittance and calibrated using pure white and black standards. The molded plaque is inserted into the testing location, and the equipment runs the color test. The test indicates L^* , a^* , and b^* values and haze percentage.

50/50 PS and SS Blend Plaque Colors Data Table

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average	Haze	Haze Average	Plaque L*a*b* Swatch
Control	74.26	-2.60	8.33	77.86	-3.07	8.76	55.97	48.38	
	79.00	-2.45	9.17				44.34		
	78.80	-3.54	8.58				45.20		
	79.20	-2.60	8.43				46.55		
	78.03	-4.16	9.29				49.83		
Test 1	81.67	-1.89	3.60	82.11 (4.25)	-1.40 (1.67)	3.86 (-4.90)	32.05	31.82 (-16.56)	
	82.40	-1.17	4.11				30.30		
	80.97	-1.27	3.87				35.12		
	82.39	-1.22	4.00				32.57		
	83.12	-1.47	3.70				29.07		
Test 2	80.58	-1.64	3.85	80.37 (2.51)	-2.22 (0.85)	3.91 (-4.85)	35.90	36.43 (-11.95)	
	80.61	-1.91	3.84				35.98		
	78.90	-3.42	3.72				39.56		
	80.87	-2.18	3.99				35.64		
	80.90	-1.93	4.15				35.05		
Test 3	87.28	-0.57	2.94	87.83 (9.87)	-0.88 (2.19)	3.00 (-5.76)	17.23	15.13 (-33.25)	
	87.80	-1.08	3.10				14.77		
	88.12	-0.77	2.76				13.32		
	87.56	-0.89	3.08				15.57		
	87.87	-1.07	3.12				14.77		
Test 4	86.74	-0.57	3.14	86.87 (9.01)	-0.79 (2.28)	3.19 (-5.57)	19.99	19.60 (-28.77)	
	87.02	-0.86	3.26				19.04		
	86.97	-0.79	3.17				18.80		
	87.07	-0.71	3.10				19.02		
	86.55	-1.03	3.26				21.17		

Plaques are not randomly selected. Operators select five plaques that are free of imperfections that may alter results.

The plaque swatch visually represents the L*a*b* values, not including haze or transparency



50/50 PS and SS Blend Black Specks/Inclusions

References:

PET-S-09

Test Summary:

Visually identify the presence of black specks and inclusions. Data is designed to be correlated to the production of reproduced bottles.

Equipment:

Ryan Quality Control Size Chart

Procedure:

Injection-molded plaques are held in front of a diffused white light source, and black specks or other inclusions larger than 0.1 mm^2 or 0.36 mm in diameter are identified visually, with no magnification. Pictures of inclusions are taken with an 85-magnification microscope only after visual identification.



50/50 PS and SS Blend Black Specks/Inclusions Data Table

Variable	Percentage of Plaques with Inclusions
Control	0%
Test 1	0%
Test 2	0%
Test 3	0%
Test 4	0%

Plaques are not randomly selected. Operators select plaques with inclusions that meet the size criteria.



Post Consumer Recycled (PCR) Flake Processing and Testing

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PCR Granulation

References:

PET-P-03

Test Summary:

Granulate incoming articles to the required grind size.

Procedure:

Articles are manually fed into a grinder with screen holes ranging from 9.5 to 12 mm in diameter.

Incoming Article	Ground Article
	



PCR Wash and Sink/Float Evaluation

References:

PET-P-04

Test Summary:

Remove any contamination from PET and help liberate labels, adhesives, coatings, and layers.

Procedure:

Wash

PET flake is added to tap water at a 4:1 ratio of water to flake and heated to $85 \pm 2^\circ\text{C}$. Triton X-100 surfactant is added at a 0.3% concentration, and caustic NaOH is added at the required concentration. The flakes and water are mixed with an impeller for 15 minutes at 546 rpm. After 15 minutes, the impeller is stopped, and the mixture is removed from the heat source and allowed to sit for five minutes. After five minutes, the wash water, floatables, and sinkables are retained.

Rinse

The sinking fraction of the washed PET flake is added to tap water at a 4:1 ratio of water to flake and heated to $45 \pm 2^\circ\text{C}$. The flakes and water are mixed with an impeller at, at least 546 rpm for five minutes. After five minutes, the mixture is removed from the heat and allowed to sit for five minutes. After five minutes, the rinse water, floatables, and sinkables are retained.

Sink/Float

The rinsed PET flake is added to tap water at an 8:1 water-to-flake to water ratio. The tank is agitated by hand or at 500 rpm for five minutes and then allowed to sit for five minutes. After five minutes, the floatables and sinkables are retained.

Data Table:

Variable	Wash Temperature (°C)	Rinse Temperature (°C)	Starting Flake Weight (kg)	Total Floatables (grams)	Total Floatables (%)
Control	86	46	2.27	194	8.51%
Test 1	86	46	2.27	220	9.68%
Test 2	86	47	2.27	215	9.46%
Test 3	85	44	2.27	217	9.55%
Test 4	86	46	2.27	224	9.83%

PCR Wash/Rinse Pictures

Variable	Settled Waters		Shaken Waters	
	Wash	Rinse	Wash	Rinse
Control				
Test 1				
Test 2				
Test 3				
Test 4				

PCR Washed Flake/Floatable Pictures

Variable	Washed Flake	Floatables
Control		
Test 1		
Test 2		
Test 3		
Test 4		



PCR Wash Water Evaluation

References:

PET-S-01

Test Summary:

Visual evaluations of the wash water are conducted to determine the characteristics of the label substrate, inks, and adhesives utilized within the label. The water is examined for suspended ink or adhesive. If ink or adhesive is seen, the water is evaluated.

Procedure:

500 mL of water is transferred into a graduated cylinder, allowed to settle for 30 minutes, then ranked depending on the amount of settling of the inks and adhesive. After the setting evaluation, the wash water is passed through a 250-mesh screen using a Buchner funnel. The filtered water is ranked by its appearance. The wash water is then filtered again with a Whatman Grade 1 filter (10µm) using a Buchner funnel. The time it takes to filter the wash water is measured and compared to the time it takes for clean tap water to filter. The filtered water is ranked by its appearance.

PCR Wash Water Visual Evaluation Pictures

Variable	Unwashed Label vs Washed Label	Settled Wash Waters		Shaken Wash Waters	
		Wash	Rinse	Wash	Rinse
Control					
Test 1					
Test 2					
Test 3					
Test 4					



PCR Wash Water Filtration Evaluation

Variable	Control	Test 1	Test 2	Test 3	Test 4
250-Mesh Evaluation					
250-Mesh Starting Weight (g)	2.2721	2.2810	2.2613	2.2705	2.2216
250-Mesh Ending Weight (g)	2.3427	2.5822	2.3946	2.4907	2.5109
250-Mesh Collected Weight (g)	0.0706	0.3012	0.1333	0.2202	0.2893
250-Mesh Collection (Y/N)	Y	Y	Y	Y	Y
250-Mesh Appearance Ranking	B	B	B	B	A
10µm Evaluation					
10µm Filter Starting Weight (g)	2.3967	2.3950	3.2257	3.1883	3.1978
10µm Filter Ending Weight (g)	2.5292	2.6113	3.5762	3.6604	4.1075
10µm Filter Collected Weight (g)	0.1325	0.2163	0.3505	0.4721	0.9097
10µm Filter Collection (Y/N)	Y	Y	Y	Y	Y
10µm Filter Appearance Ranking	B	B	B	B	B
10µm Filter Time (s)	1,956.01	1,839.27	2,828.04	2,854.44	2,959.99
Tap Water Filter Time (s)	53.07				
10µm Filter Time / Tap Water Filter Time	36.86	34.66	53.29	53.79	55.78

Ranking System for Filtering Evaluation:

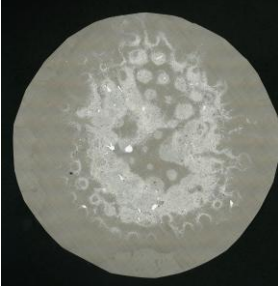
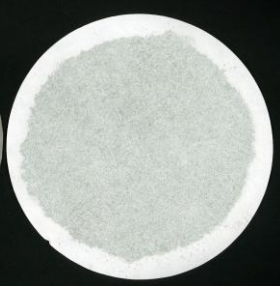
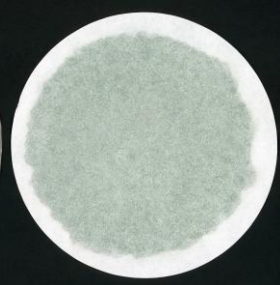
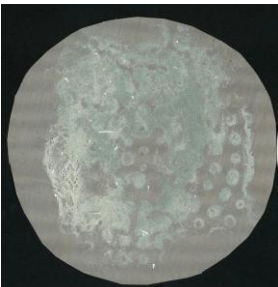
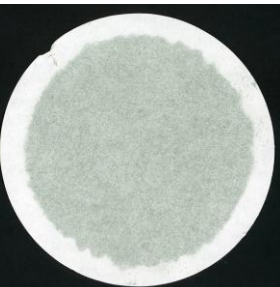
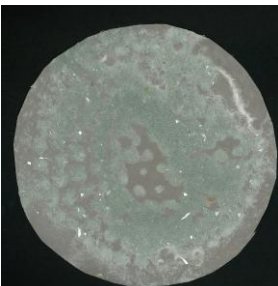
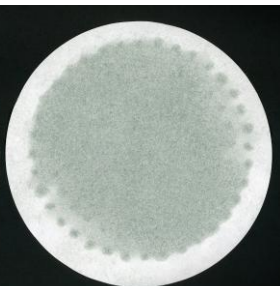
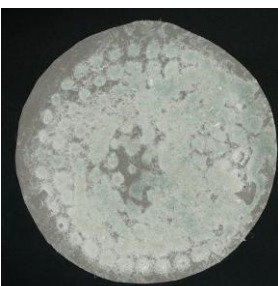
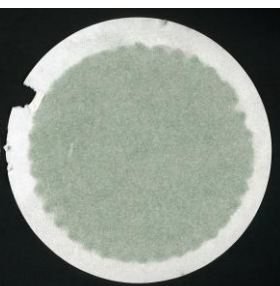
250-Mesh Evaluation

- a. Appearance after filtering is like the starting material.
- b. Some level of colored material or adhesive was filtered out.
- c. Most colored material was filtered out.

10µm Filter Evaluation

- a. Appearance after filtering is like the starting material.
- b. Some level of colored material was filtered out.
- c. Most colored material was filtered, but the water is still hazy.
- d. Color and haze are absent in the filtered water.

PCR Filter Pictures

Variable	250-Mesh Screen	10µm Filter Paper	Settled Waters		Shaken Waters	
			Wash	Filtered	Wash	Filtered
Control						
Test 1						
Test 2						
Test 3						
Test 4						



PCR Filtered Water Colors

References:

ASTM D6290

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the degree of yellowness under daylight illumination of transparent, translucent, or opaque plastics.

Equipment:

Konica Minolta 36dG

Procedure:

The color analyzing equipment is set up on transmittance and calibrated using pure white and black standards. A 10 mm sample cell is filled to the brim with filtered water. The cell is inserted into the machine, and the equipment runs the color test. The test indicates L*, a*, and b* values. This test is completed in a conditioned laboratory at a temperature of $23 \pm 2^{\circ}\text{C}$ and a relative humidity of $50 \pm 10\%$.

PCR Filtered Water Colors Data Table

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average	ΔE
Control	86.80	-0.62	6.42	86.90	-0.60	6.36	NA
	86.78	-0.59	6.38				
	86.93	-0.59	6.33				
	87.22	-0.58	6.24				
	86.79	-0.60	6.42				
Test 1	84.03	-2.56	7.34	85.06 (-2.85)	-2.56 (-1.96)	7.34 (0.98)	3.60
	84.05	-2.56	7.33				
	84.06	-2.56	7.34				
	84.07	-2.56	7.34				
	84.07	-2.56	7.35				
Test 2	88.29	0.14	8.48	88.30 (1.39)	0.14 (0.74)	8.49 (2.13)	2.65
	88.29	0.14	8.48				
	88.30	0.14	8.49				
	88.30	0.14	8.49				
	88.31	0.14	8.49				
Test 3	90.24	0.18	7.82	90.21 (3.30)	0.18 (0.77)	7.84 (1.48)	3.70
	90.21	0.17	7.84				
	90.19	0.18	7.84				
	90.20	0.18	7.84				
	90.20	0.17	7.84				
Test 4	91.30	0.03	4.69	91.34 (4.43)	0.03 (0.63)	4.69 (-1.66)	4.78
	91.32	0.03	4.69				
	91.33	0.03	4.70				
	91.36	0.03	4.69				
	91.37	0.03	4.70				



PCR Elutriation

References:

PET-P-05

Test Summary:

Remove lights (fines, labels, layers) from washed flake before extrusion.

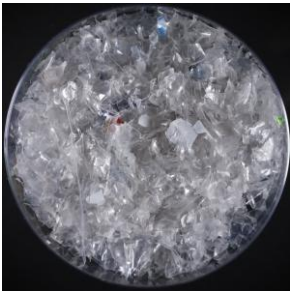
Procedure:

The elutriator is calibrated using the washed and dried control flake to adjust the air speed until the value of 0.5% for lights removed is achieved. Once the elutriator is calibrated, the rest of the control and tests are run. Airspeed, heavies' weight, lights' weight, and the percentage of lights are recorded for each test. Heavies are then prepared for the next steps of processing.

Data Table:

Variable	Air Speed (m/s)	Heavies Weight (kg)	Lights Weight (grams)	Lights Removed (%)
Control	6.52	1.22	407.21	25.08%
Test 1	6.52	1.22	412.96	25.34%
Test 2	6.52	1.24	398.56	25.34%
Test 3	6.52	1.24	435.40	26.07%
Test 4	6.52	1.22	424.49	25.86%

PCR Heavies/Lights Pictures

Variable	Heavies	Lights
Control		
Test 1		
Test 2		
Test 3		
Test 4		



PCR Heavies Colors

References:

ASTM D6290

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the degree of yellowness under daylight illumination of transparent, translucent, or opaque plastics.

Equipment:

Konica Minolta 36dG

Procedure:

The color analyzing equipment is set up on reflectance and calibrated using pure white and black standards. The sample cell is filled to the brim with randomly selected flakes. The cell is inserted into the machine, and the equipment runs the color test. The test indicates L*, a*, and b* values. This test is completed in a conditioned laboratory at a temperature of $23 \pm 2^{\circ}\text{C}$ and a relative humidity of $50 \pm 10\%$.

PCR Heavies Colors Data Table

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Control	65.49	0.36	1.30	64.12	0.42	1.42
	62.87	0.22	0.94			
	65.42	0.49	1.79			
	63.69	0.40	1.56			
	63.12	0.65	1.51			
Test 1	65.81	-1.27	1.72	65.26 (1.14)	-1.05 (-1.48)	1.38 (-0.04)
	65.44	-1.02	1.42			
	65.11	-0.78	1.06			
	65.68	-1.30	1.65			
	64.27	-0.90	1.06			
Test 2	64.28	-1.23	1.56	65.26 (1.14)	-1.33 (-1.75)	1.36 (-0.06)
	65.55	-1.25	1.08			
	67.35	-1.32	1.40			
	65.41	-1.40	1.61			
	63.72	-1.44	1.16			
Test 3	65.50	-1.61	3.46	64.49 (0.37)	-1.42 (-1.85)	1.99 (0.57)
	65.06	-1.82	1.74			
	63.03	-1.00	1.81			
	64.05	-1.42	1.61			
	64.79	-1.26	1.33			
Test 4	64.36	-1.34	1.33	64.81 (0.69)	-1.40 (-1.82)	1.63 (0.21)
	65.06	-1.44	1.91			
	65.18	-1.47	1.69			
	64.19	-1.28	1.48			
	65.27	-1.45	1.75			



PCR Flake Bake Evaluation

References:

PET-S-10

Test Summary:

Determine the color changes of the flake after baking.

Procedure:

One hundred grams of flake is placed into a convection oven heated at 220°C for 60 minutes.

PCR Flake Pictures

Variable	Before Baking Flake	After Baking Flake
Control		
Test 1		
Test 2		
Test 3		
Test 4		



PCR Baked Flake Colors

References:

ASTM D6290

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the degree of yellowness under daylight illumination of transparent, translucent, or opaque plastics.

Equipment:

Konica Minolta 36dG

Procedure:

The color analyzing equipment is set up on reflectance and calibrated using pure white and black standards. The sample cell is filled to the brim with randomly selected flakes. The cell is inserted into the machine, and the equipment runs the color test. The test indicates L*, a*, and b* values. This test is completed in a conditioned laboratory at a temperature of $23 \pm 2^{\circ}\text{C}$ and a relative humidity of $50 \pm 10\%$.

PCR Baked Flake Colors Data Table

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Before Baking Control	65.49	0.36	1.30	64.12	0.42	1.42
	62.87	0.22	0.94			
	65.42	0.49	1.79			
	63.69	0.40	1.56			
	63.12	0.65	1.51			
After Baking Control	64.16	1.19	9.31	64.68 (0.56)	1.22 (0.80)	9.09 (7.67)
	65.50	1.50	9.86			
	63.57	1.08	9.45			
	67.77	0.84	8.54			
	62.40	1.48	8.27			
Before Baking Test 1	65.81	-1.27	1.72	65.26	-1.05	1.38
	65.44	-1.02	1.42			
	65.11	-0.78	1.06			
	65.68	-1.30	1.65			
	64.27	-0.90	1.06			
After Baking Test 1	66.30	-0.61	6.03	67.57 (2.31)	-0.29 (0.76)	6.14 (4.76)
	69.14	-0.12	6.16			
	67.49	-0.46	5.47			
	69.69	-0.25	5.96			
	65.25	-0.01	7.06			

PCR Baked Flake Colors Data Table Continued

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Before Baking Test 2	64.28	-1.23	1.56	65.26	-1.33	1.36
	65.55	-1.25	1.08			
	67.35	-1.32	1.40			
	65.41	-1.40	1.61			
	63.72	-1.44	1.16			
After Baking Test 2	63.41	1.05	10.22	64.51 (0.75)	0.91 (2.24)	9.04 (7.68)
	66.81	0.72	8.80			
	63.71	0.85	9.52			
	67.45	0.70	7.53			
	61.19	1.23	9.13			
Before Baking Test 3	65.50	-1.61	3.46	64.49	-1.42	1.99
	65.06	-1.82	1.74			
	63.03	-1.00	1.81			
	64.05	-1.42	1.61			
	64.79	-1.26	1.33			
After Baking Test 3	63.06	0.95	8.25	63.97 (0.52)	0.66 (2.08)	7.99 (6.00)
	66.32	0.22	7.44			
	63.22	0.96	8.19			
	66.58	0.26	7.68			
	60.67	0.89	8.41			

PCR Baked Flake Colors Data Table Continued

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average
Before Baking Test 4	64.36	-1.34	1.33	64.81	-1.40	1.63
	65.06	-1.44	1.91			
	65.18	-1.47	1.69			
	64.19	-1.28	1.48			
	65.27	-1.45	1.75			
After Baking Test 4	65.16	-0.17	5.74	66.61 (1.80)	-0.32 (1.08)	5.83 (4.20)
	67.61	-0.27	6.66			
	66.47	-0.55	5.03			
	67.38	-0.18	6.82			
	66.43	-0.45	4.89			



PCR Plaque Processing and Testing

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PCR Injection

References:

PET-P-08

Test Summary:

Injection mold 3mm plaques to test for color and haze values.

Procedure:

Injection material is prepped in a dryer until the moisture content is below 50 ppm. PET is injection molded at a target melt temperature of 275°C. The injection unit is purged between each test innovation. Melt, room, and mold temperatures are recorded for each variable.

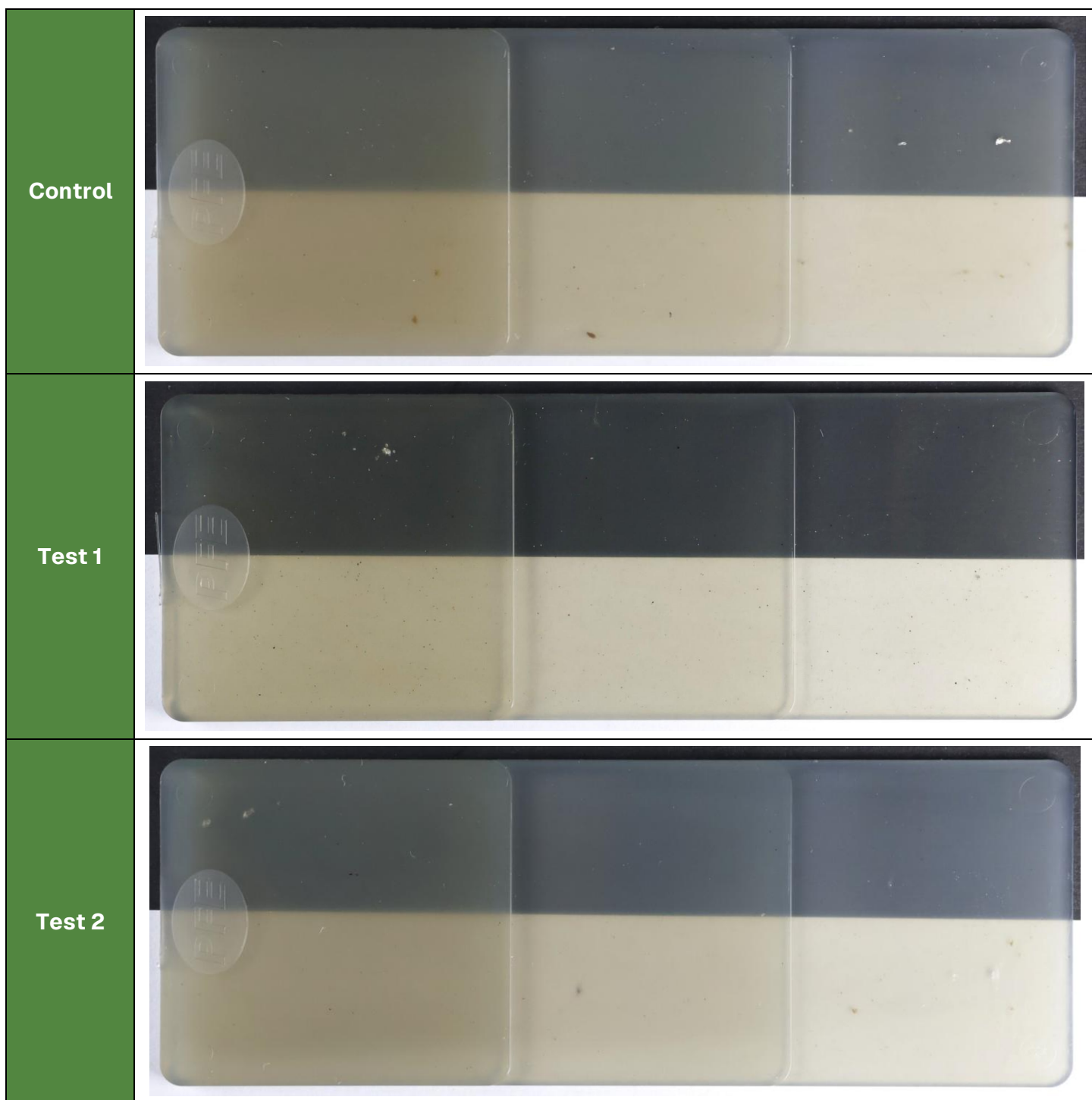
Data Table:

Variable	Moisture Content (ppm)	Melt Temperature (°C)	Mold Temperature (°C)
Control	25	275	25
Test 1	17	275	24
Test 2	35	275	24
Test 3	12	275	26
Test 4	40	275	25

Operating Conditions:

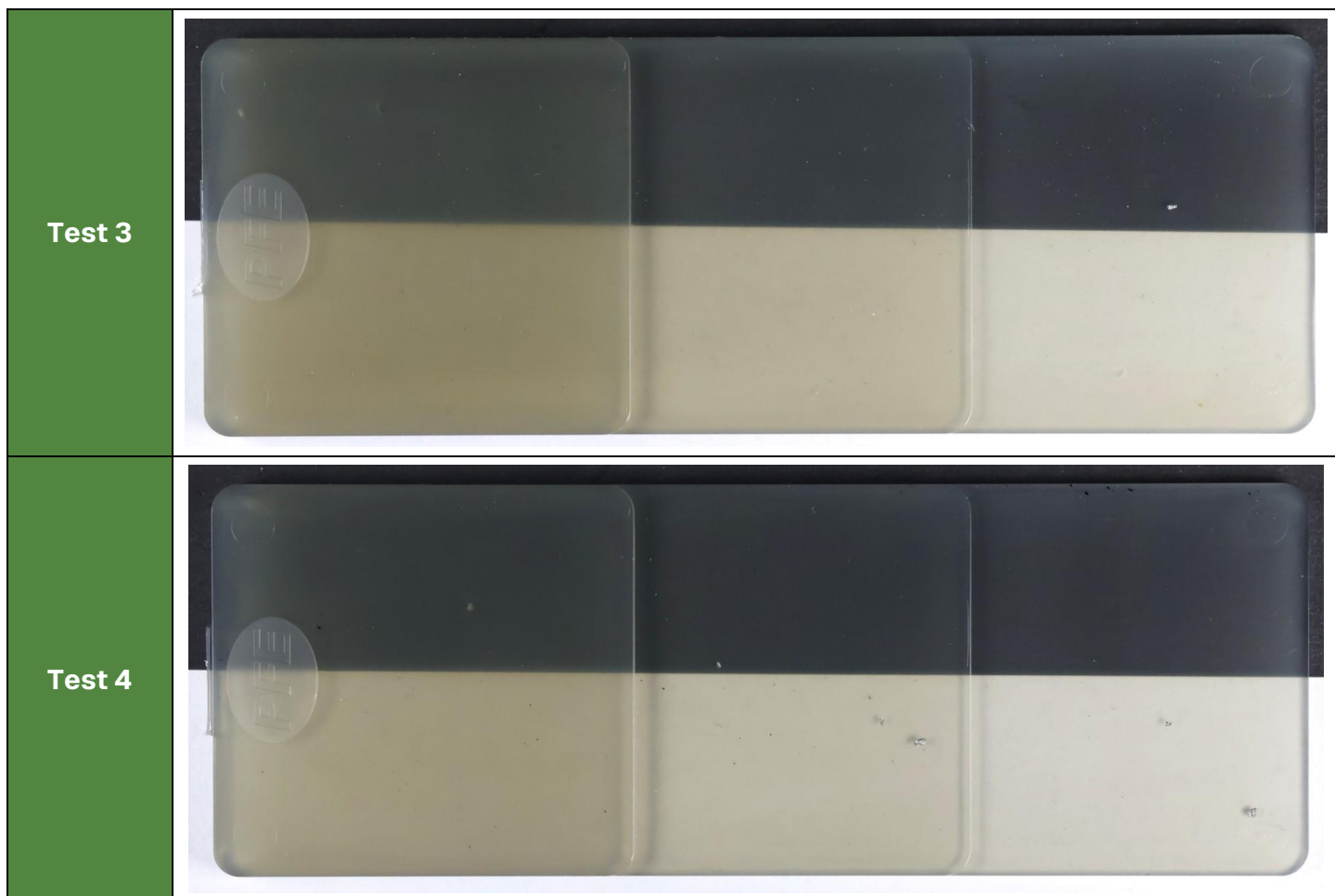
Zone 1 Temperature (°C)	Zone 2 Temperature (°C)	Zone 3 Temperature (°C)	Nozzle Temperature (°C)
265	266	266	275

PCR Injection Molded Plaques Pictures



From left to right, the plaque thicknesses are 3.0 mm, 2.0 mm, and 1.0 mm.

PCR Injection Molded Plaques Pictures Continued



From left to right, the plaque thicknesses are 3.0 mm, 2.0 mm, and 1.0 mm.



PCR Plaque Colors

References:

PET-P-08

PET-S-09

ASTM D1003

Within PFE's scope of ISO 17025 accreditation, certificate number AT-3210.

Test Summary:

Measure the color values L^* , a^* , b^* , and haze of a 3mm injection-molded plaque. Visually identify the presence of black specks and inclusions. The data is designed to be correlated to the production of reproduced bottles.

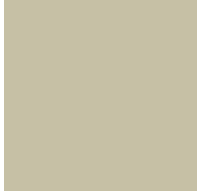
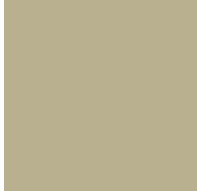
Equipment:

Konica Minolta 36dG

Procedure:

Pellets are dried to a moisture level below 50 ppm and injection molded into 3mm plaques. The color analyzing equipment is set up on transmittance and calibrated using pure white and black standards. The molded plaque is inserted into the testing location, and the equipment runs the color test. The test indicates L^* , a^* , and b^* values and haze percentage.

PCR Plaque Colors

Variable	L* Values	a* Values	b* Values	L* Average	a* Average	b* Average	Haze	Haze Average	Plaque L*a*b* Swatch
Control	69.56	0.61	21.19	71.54	0.07	19.28	70.55	67.99	
	68.60	0.56	21.48				79.27		
	75.57	-0.63	16.72				58.07		
	69.90	0.18	19.81				71.09		
	74.08	-0.39	17.19				60.95		
Test 1	79.24	-1.36	13.04	77.76 (6.22)	-1.10 (-1.17)	14.39 (-4.89)	47.29	56.32 (-11.67)	
	77.81	-1.18	13.91				58.05		
	78.15	-1.17	14.07				52.82		
	78.15	-1.01	14.43				54.36		
	75.44	-0.78	16.50				69.06		
Test 2	72.14	-0.98	17.74	72.11 (0.57)	-0.67 (-0.74)	17.87 (-1.40)	72.98	71.55 (3.57)	
	72.91	-0.85	17.25				68.21		
	70.49	-0.25	18.46				71.77		
	73.47	-0.94	17.00				69.80		
	71.52	-0.32	18.92				75.01		
Test 3	68.49	-0.59	19.13	67.31 (-4.24)	-0.34 (-0.41)	20.38 (1.10)	78.15	75.98 (7.99)	
	64.36	0.37	22.77				78.05		
	64.35	0.39	22.77				78.08		
	68.89	-0.81	19.08				74.24		
	70.44	-1.08	18.15				71.38		
Test 4	73.11	-0.94	15.68	73.62 (2.08)	-1.13 (-1.20)	15.40 (-3.88)	64.35	58.28 (-9.71)	
	74.84	-1.30	14.56				52.04		
	72.74	-1.25	15.72				59.79		
	73.63	-0.98	15.56				55.80		
	73.80	-1.19	15.48				59.41		

Plaques are not randomly selected. Operators select five plaques that are free of imperfections that may alter results.

The plaque swatch visually represents the L*a*b* values, not including haze or transparency.



PCR Black Specks/Inclusions

References:

PET-S-09

Test Summary:

Visually identify the presence of black specks and inclusions. Data is designed to be correlated to the production of reproduced bottles.

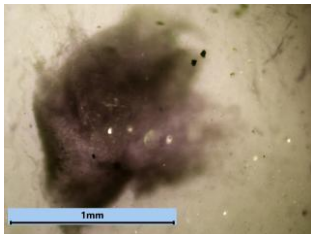
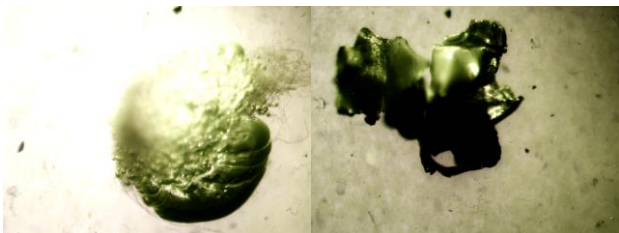
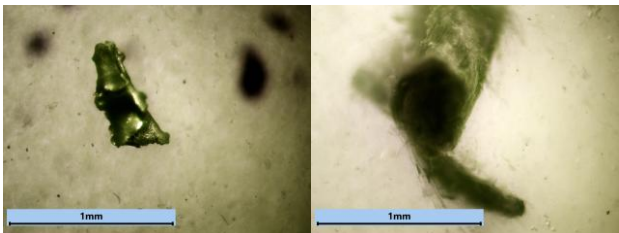
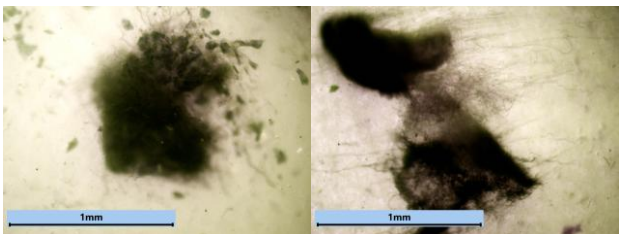
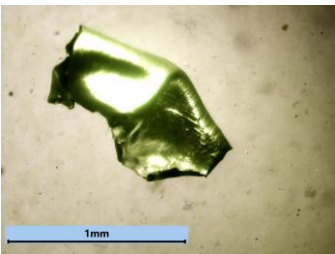
Equipment:

Ryan Quality Control Size Chart

Procedure:

Injection-molded plaques are held in front of a diffused white light source, and black specks or other inclusions larger than 0.1 mm^2 or 0.36 mm in diameter are identified visually, with no magnification. Pictures of inclusions are taken with an 85-magnification microscope only after visual identification.

PCR Black Specks/Inclusions

Variable	Percentage of Plaques with Inclusions	Example Image of Inclusion
Control	93%	
Test 1	70%	
Test 2	82%	
Test 3	81%	
Test 4	73%	

Plaques are not randomly selected. Operators select plaques with inclusions that meet the size criteria.

ANNEX I: Statistical Analysis

The statistical workflow was:

- Descriptive statistics by flake type and caustic level.
- A two-way ANOVA for replicated outcomes.
- A within-feedstock one-way ANOVA.
- Linear-versus-quadratic trend testing using numeric caustic concentration.
- Brown–Forsythe variance checks.
- Shapiro–Wilk residual checks.
- Kruskal–Walli’s sensitivity analyses where assumptions looked questionable.
- Post-hoc pairwise comparisons using Tukey HSD and Holm-adjusted contrasts versus 0%.

The table below gives descriptive statistics for the primary plaque outcomes. Values are calculated from the five plaque measurements reported for each treatment.

Flake type	NaOH %	L* mean $\pm$ SD	b* mean $\pm$ SD	Haze % mean $\pm$ SD
Stock	0	92.92 $\pm$ 0.04	2.62 $\pm$ 0.06	2.84 $\pm$ 0.04
Stock	0.5	93.03 $\pm$ 0.06	2.74 $\pm$ 0.28	2.61 $\pm$ 0.09
Stock	1	93.08 $\pm$ 0.06	2.57 $\pm$ 0.12	2.64 $\pm$ 0.04
Stock	2	93.04 $\pm$ 0.09	2.64 $\pm$ 0.21	2.72 $\pm$ 0.22
Stock	4	93.01 $\pm$ 0.07	2.90 $\pm$ 0.27	2.77 $\pm$ 0.12
50/50 Blend	0	77.86 $\pm$ 2.06	8.76 $\pm$ 0.44	48.38 $\pm$ 4.73
50/50 Blend	0.5	82.11 $\pm$ 0.82	3.86 $\pm$ 0.21	31.82 $\pm$ 2.31
50/50 Blend	1	80.37 $\pm$ 0.84	3.91 $\pm$ 0.16	36.43 $\pm$ 1.79
50/50 Blend	2	87.73 $\pm$ 0.32	3.00 $\pm$ 0.15	15.13 $\pm$ 1.43
50/50 Blend	4	86.87 $\pm$ 0.22	3.19 $\pm$ 0.07	19.60 $\pm$ 0.99
PCR	0	71.54 $\pm$ 3.08	19.28 $\pm$ 2.22	67.99 $\pm$ 8.53
PCR	0.5	77.76 $\pm$ 1.40	14.39 $\pm$ 1.29	56.32 $\pm$ 8.11
PCR	1	72.11 $\pm$ 1.17	17.87 $\pm$ 0.81	71.55 $\pm$ 2.66
PCR	2	67.31 $\pm$ 2.79	20.38 $\pm$ 2.22	75.98 $\pm$ 3.07
PCR	4	73.62 $\pm$ 0.80	15.40 $\pm$ 0.48	58.28 $\pm$ 4.62

The within-feedstock ANOVA and nonparametric sensitivity tests show that all three plaque responses changed very strongly with NaOH concentration in the 50/50 blend and PCR; however, stock showed only modest changes in L and haze, with no convincing effect on plaque b. That is the statistical basis for saying the 50/50 and PCR streams are operationally sensitive to caustic level, whereas clean stock is not meaningfully sensitive in practice. The effect sizes within the 50/50 blend were especially large, with partial η^2 values of about 0.94 for L, 0.99 for b, and 0.96 for haze. The ANOVA table is summarized on below:

Flake Type	Response	F Statistic	P Value	η^2p	Kruskal p
Stock	L	3.86	0.018	0.436	0.034
Stock	b	1.98	0.137	0.284	0.154
Stock	haze	3.16	0.036	0.387	0.038
50/50 Blend	L	77.54	<0.001	0.939	<0.001
50/50 Blend	b	488.08	<0.001	0.990	<0.001
50/50 Blend	haze	130.99	<0.001	0.963	<0.001
PCR	L	16.75	<0.001	0.770	0.001
PCR	b	12.97	<0.001	0.722	<0.001
PCR	haze	10.20	<0.001	0.671	0.002

The trend testing on the primary haze response separates monotonic from nonlinear behavior. The 50/50 blend showed a strong negative linear slope with an additional significant quadratic component. The PCR showed no significant linear trend but a significant quadratic term. The stock showed no meaningful linear trend and only weak evidence of curvature.

Flake Type	Linear Slope	Slope 95% CI	Linear p Value	Quadratic p Value	R ² Quadratic
50/50 Blend	-6.60	[-8.97, -4.23]	<0.001	<0.001	0.835
PCR	-1.04	[-3.83, 1.75]	0.449	0.008	0.294
Stock	0.01	[-0.03, 0.05]	0.656	0.095	0.130

The control-versus-treatment contrasts for plaque haze show where the practical differences are. For the 50/50 blend, every nonzero NaOH level significantly improved haze relative to 0%, with the largest change at 2%: -33.25 haze points with a 95% CI of -36.68 to -29.81. For PCR, only 0.5% produced clearly significant improvement after Holm correction, at -11.67 haze points with a 95% CI of -19.51 to -3.83. Stock showed tiny absolute changes, even when nominally significant.

Flake Type	NaOH %	Δ Haze vs 0%	95% CI	Holm p
Stock	0.5	-0.23	-0.39, -0.08	0.022
Stock	1.0	-0.20	-0.36, -0.04	0.045
Stock	2.0	-0.12	-0.27, 0.04	0.265
Stock	4.0	-0.07	-0.23, 0.08	0.337
50/50 Blend	0.5	-16.56	-19.99, -13.12	<0.001
50/50 Blend	1.0	-11.95	-15.39, -8.52	<0.001
50/50 Blend	2.0	-33.25	-36.68, -29.81	<0.001
50/50 Blend	4.0	-28.77	-32.21, -25.34	<0.001
PCR	0.5	-11.67	-19.51, -3.83	0.022
PCR	1.0	3.57	-4.27, 11.40	0.354
PCR	2.0	7.99	0.16, 15.83	0.092
PCR	4.0	-9.71	-17.54, -1.87	0.053

ANNEX II: Graphical Analysis

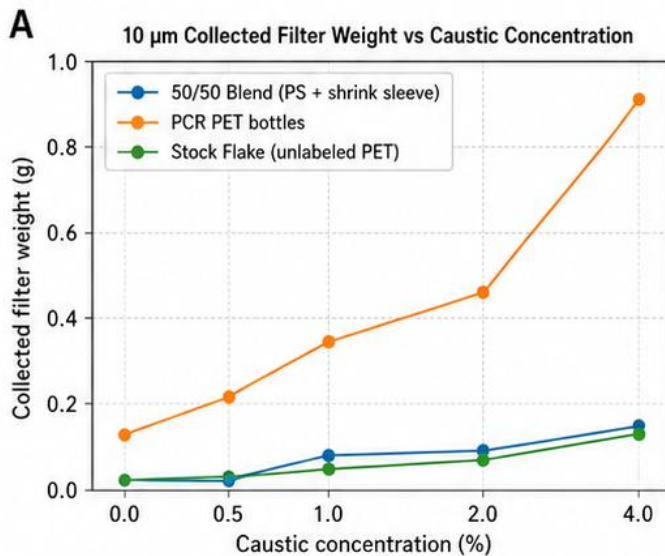


Figure 1. 10 μ m collected filter weight vs. caustic concentration. Captured fine material increases with caustic for all streams, especially PCR.

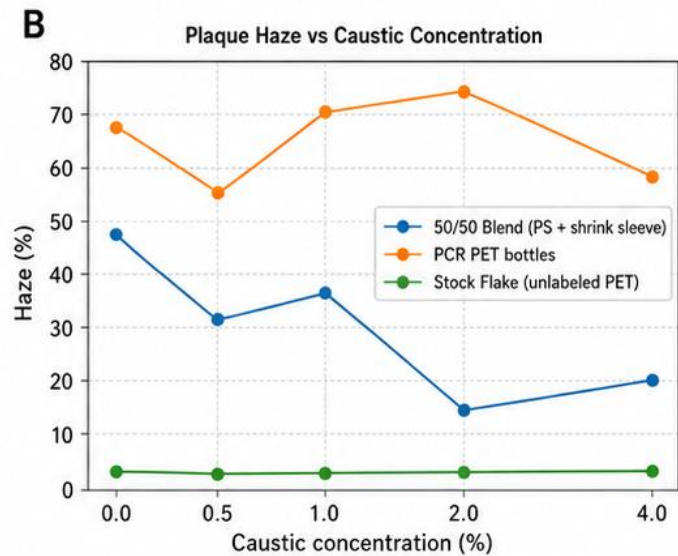


Figure 2. Plaque haze vs. caustic concentration. The 50/50 blend shows the strongest haze reduction, with best clarity around 2% caustic.

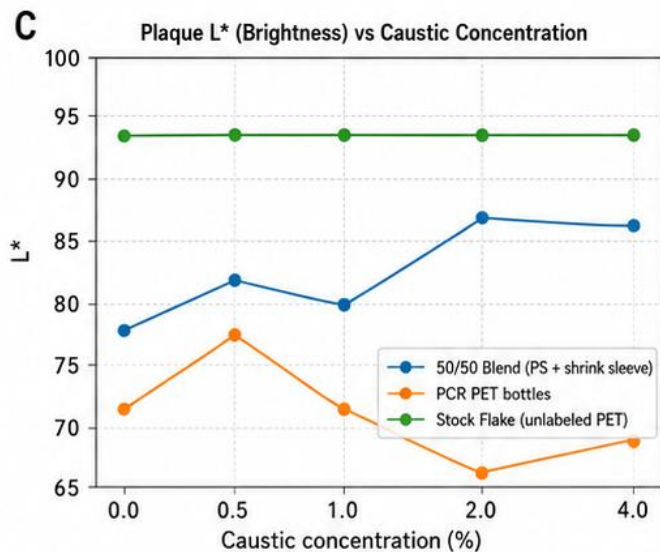


Figure 3. Plaque L* (brightness) vs. caustic concentration. Brightness is stable for stock flake, improves for the 50/50 blend, and remains variable for PCR.

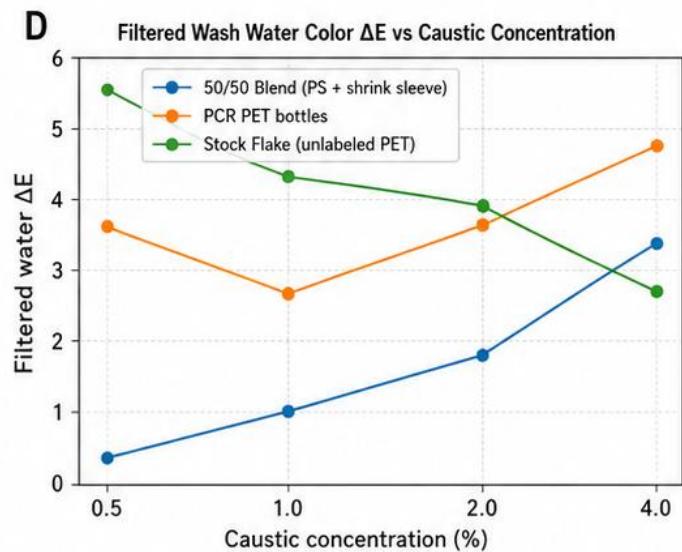


Figure 4. Filtered wash water color ΔE vs. caustic concentration. Wash-water color response varies by stream, indicating different levels of extracted contaminants.



Report Statements

Conformance Statements

Plastics Forming Enterprise (PFE) is an ISO 17025-accredited laboratory whose management system conforms to all standard requirements; all testing within the scope is identified. The results stated in the report are only relevant to the items tested and the tests performed. All testing was completed at PFE's New Hampshire laboratory unless otherwise noted. All sampling was done using random selection by experienced technicians unless otherwise noted.



As required, test specimens are conditioned at $23\pm 2^{\circ}\text{C}$ and $50\pm 10\%$ relative humidity for at least 40 hours by the ASTM D618 procedure A. All customer-supplied data or other information will be identified. PFE will retain available hard copies of records related to this project for at least one year from its completion and available digital copies of documents for a minimum of three years.

Conclusions Statements

Experienced staff members do any interpretations of data with a good knowledge of the materials used during testing. All interpretations or conclusions about data can be found in the conclusions section of the report unless noted. Opinions, interpretations, or statements of conformity included are based on results for which accreditation is held. Opinions, interpretations, or statements of conformity outside the scope of accreditation but based on those results for which accreditation is identified as such by a disclaimer. PFE prides itself on being able to help the clientele understand failures with over 40 years of experience in recycling plastics. PFE does not employ its own decision rules nor set the acceptance criteria. All outliers are determined through an interquartile range and are marked with yellow highlighting. Uncertainty values are available upon request.

Report Authorizations

Report Written by	Report Written on	Report Finalized by	Report Finalized on	Report Approved by	Report Approved on
KL	8/10/2026	ML	8/13/2026	KT	8/17/2026

Date of Amendment	What was Amended?	Reason for Amendment	Amendment Performed by	Amendment Approved by



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