LABORATORY- AND PILOT-SCALE EVALUATIONS OF ENVIRONMENTALLY BENIGN PSA STAMPS

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ABSTRACT

Since the introduction of pressure-sensitive adhesive (PSA) postage stamps in 1989, their popularity with the stamp-buying public has grown each year. Currently, more than 93% of the total volume of stamps produced is PSA stamps. With the increased use of pressure-sensitive adhesives in a variety of products ranging from labels to envelopes and stamps, concerns about their environmental impact have emerged, especially with respect to recycling. To address these concerns, the U.S. Postal Service initiated an environmentally benign PSA program to develop PSA stamps that do not adversely affect the recovered paper recycling. As part of this program, experimental adhesives were evaluated for stamp performance specifications, laboratory recycling, and pilot-scale recycling. Phase IV of this program involved printed commercial postal stamp production with benign PSA adhesives. Three printing methods were used: intaglio, offset, and gravure. These stamps were processed through the USPS test mail program and provided the feedstock for post-consumer recycling trials using the USPS Laboratory and Pilot Recycling Protocols. Results of the laboratory and pilot recycling trials of the new benign PSA adhesives show PSAs that are effectively removed in the recycling process can be developed.

INTRODUCTION

For many years, the U.S. Postal Service (USPS) has tried to continually improve the adhesives used on stamps. These efforts have addressed both conventional gummed adhesives and the newer pressure-sensitive adhesives (PSAs). Although the PSA stamp was first issued in 1974, it was the second issue in 1989 that resulted in a dramatic increase in usage. Since then, the annual volume of PSA stamps has grown to approximately 32 billion (1).

With the increased use of PSA in a variety of products including stamps, concerns about their environmental impact have emerged. The USPS has a clear commitment to recycling, waste reduction, the use of nontoxic adhesives and inks, and the use of recycled-content materials in stamp production. To help meet these ends, the USPS initiated a program to develop PSA postage stamps that do not adversely affect the environment.

The (USPS Environmentally Benign PSA Program focuses on both pre- and post-consumer stamp products in the waste stream. Pre-consumer stamp product waste is derived from stamp paper production, printing and finishing operations, and out-of-specification stamp materials. Post-consumer waste consists mainly of stamps and labels on envelopes in home and office paper waste. The intent of this program is to develop PSA stamp and label products that can be successfully and economically recycled into paper products. Mill-scale trials will be conducted at mills that currently produce printing and writing grades of paper using recycled fiber.

Not only must the PSA be recyclable, the stamp products must meet all the stamp performance requirements specified in USPS-P-1238 (2). These requirements include permanent adhesion to envelope substrates and archival ability (ability to withstand long-term aging). In Phase III of the USPS Environmentally Benign PSA program, suppliers of the USPS were solicited for candidate PSA stamp stocks. In Phase III, test protocols for evaluating the recylability of the unprinted candidate stamp adhesive materials at the laboratory and pilot scales were developed by Specialized Technology Resources (STR)

and the USDA Forest Service, Forest Products Laboratory (FPL); an image analysis protocol was also developed. Input from all parts of the industry was solicited for help in developing these protocols. These protocols were improved in Phase IV to handle printed stamp materials.

Industry (paper manufacturers, PSA producers, converters, paper recyclers, and adhesives and chemical suppliers) is working with the USPS to develop economical, recyclable adhesives (2). Vertical teams were formed by industry to tackle the problem of developing new PSAs that do not contribute to the problem of stickies (3). Vertical team members were able to exchange their expertise and knowledge in the given field to guide development of improved PSAs.

Experimental PSAs were submitted to STR for Phase III evaluation of stamp performance. Those stamps that met the performance requirements were evaluated for laboratory- and pilot-scale recycling. Results of laboratory and pilot recycling of the experimental PSAs (4,5) from Phase III showed that the performance of the various adhesives could be distinguished. The PSAs could undergo the recycling process in both laboratory- and pilot-scale facilities and be removed with low contaminant levels in the final product. The 14 new adhesives that were developed for use in the environmentally benign program are represented by two general classes of PSAs based on their chemical composition: synthetic rubber and formulated acrylics.

The 14 experimental PSAs that were deemed acceptable from Phase III underwent extensive converting, printing, and finishing trials and mail processing test procedures. For Phase IV, all 14 adhesives were submitted to both laboratories for stamp performance evaluations. Recycling trials were conducted on the printed finished stamp material at both facilities. Mill recycling trials will be conducted on the candidate PSAs to compare laboratory- and pilot-scale recycling results. After all protocols are finalized, the USPS will issue specifications that will include recycling requirements for PSA stamps. The USPS will mandate that all future stamp products conform to these new requirements.

Only post-consumer results of the laboratory- and pilot-scale recycling trials conducted at both laboratories are presented in this paper. The three printing methods (gravure, offset and intaglio) used for stamp production were examined for their effects on recycling and on the PSA recycling.

EXPERIMENTAL METHODS

Both facilities evaluated the adhesive stamp materials on the basis of two main criteria: stamp performance and recycling (2). Fourteen PSAs were evaluated for stamp performance and recycling properties.

Stamp Performance

The PSA performance requirements were based on established test methods in the USPS-P-1238 stamp specification. Three main properties were examined:

- Permanence of the adhesive bond between stamp and envelope substrate
- Aging (visible or physical changes) of stamp materials in three environments
- Ability of stamp to be removed from the envelope by soaking in water

Recycling

Adhesives were evaluated for recyclability at the laboratory and pilot scales. The post-consumer configuration was 47% copy paper, 48% wove envelope paper, and 5% printed stamp stock by weight for the benchmarks. For the experimental PSAs, the post-consumer feedstock was a sheet of 75.2-g/m^2 copy paper in a USPS printed wove envelope made from 90.24-g/m^2 stock and sufficient test stamps applied to give a 5% stamp stock. The composition of this feed was 44% copy paper, 51%, envelope paper, and 5% stamp stock (1% PSA).

Laboratory-scale Recycling Evaluations

The PSA benchmark stamp stock material was prestained with Morplas[1] 1003 blue dye so that the adhesive particles would be highly visible throughout the process (3). The dyed stamp face was then laminated to either envelope paper or release liner to simulate post- and pre-consumer waste stock. The laminated stamp stock was then pulped in a 1-lb (0.45-kg) pulper, Adirondack Machine Model 450H, at 15% consistency, 46°C, and pH 10 for 8 minutes. The pulped sample was passed through a 12-cut (0.30-mm) Valley flat screen. The accepts were then screened with 6-cut (0. 15-mm) slots. Flotation was carried out on the accepts for 5 minutes in a Denver cell at 1% consistency with 0.75% surfactant.

Fifteen handsheets (60 g/m^2) were made according to TAPPI T-205 sp-95 at the pulper and from each screen accepts stream. Handsheets from the benchmark materials were then scanned using a HP flatbed scanner and an Optomax Speckcheck Dirt Counter system to determine the level of contaminant having an area greater than 0.02 mm^2. For the experimental PSA feedstock, handsheets were scanned both before and after staining them with Solvent Blue 58 in toluene/isopropanol solution, then washing the dried stained handsheets with methanol. The threshold gray scale level was the same for both staining methods.

Pilot-scale Recycling Evaluations

The PSA stamp material was pulped in a Voith high consistency pulper, model HC-1.5, at 12.5% consistency, 43°C, and pH 10 for 20 minutes. The pulp was then pressure screened (Voith MULTIFRACTOR model 00) through 0.30-mm slots followed by 0.10-mm slots. Accepts were sent through two passes of forward cleaning, two passes of through-flow cleaning, flotation, and finally dewatered over a drum washer. Drum washer accepts were stored for future paper machine trials. Fiber recovery loops were included at the screens and forward cleaners.

For all accepts streams, 60 g/m^2 handsheets were made according to TAPPI T-205 sp-95, except that a single (2-min) pressing was done. Fifteen handsheets were made at each accepts stream, except for the final accepts where 40 handsheets were made to provide statistical significance. Handsheets were scanned on an Apogee Image Analysis system to determine the level of ink and contaminant present having an area greater than 0.02 mm^2. The handsheets were then dyed with Solvent Blue 58 in toluene and isopropanol, washed in methanol, and rescanned on an Apogee Image Analysis system to determine the level of adhesive and contaminant present having an area greater than 0.02 mm^2.

DISCUSSION

Benchmark Recycling Trials

To evaluate the effectiveness of recycling operations to remove the PSAs, trials were run on various materials at laboratory- and pilot-scale. One material evaluated was the copy paper, wove envelope carrier stock blend and another was a blend of stamp facestock papers that were used in the laboratory- and pilot-scale trials. These materials were run to determine a baseline contaminant level. Results shown in Tables 1 and 2 indicate that these materials had low contaminant levels with an average ppm (parts per million) value of less than 5. Additional postal pressure sensitive adhesives currently used by the USPS were also evaluated. Some of the material evaluated included linerless coil, express mail labels, change of address labels, and a PSA used in stamp applications. Results of the laboratory-scale evaluations are given in Table 1; pilot-scale results are given in Tables 2 and 3.

[1]The use of trade or firm names is for information only and does not imply endorsement by the U.S. Department of Agriculture or the United States Postal Service of any product or service.

Laboratory evaluation of the carrier stock for post-consumer experimental adhesive stamps (USPS printed stamp envelope with a sheet of copy paper inserted) showed that the contaminant level was the same for both stained and unstained handsheets, confirming that no other contaminants, such as synthetic polymeric adhesives, were used in making the envelopes. These contaminant levels were the same for the copy paper/envelope paper blend used as carrier stock for the benchmarks. Pilot-scale evaluation also found the same results for the mail envelope carrier stock; results are given in Tables 1 and 3.

In addition to the PSA benchmark materials previously used in Phase III, two postal products containing PSA were used for the benchmark trials. The change of address label has repositionability requirements and uses only a small amount of adhesive, whereas the Express Mail label requires a high tack and strong bond so it has a high adhesive coat weight. Moreover, this product is printed by a flexographic process, which is similar to offset printing. Results of these evaluations are given in Tables 1 and 3 for both laboratory and pilot protocols. A graphic representation of these results, shown in Figures 3 and 4, indicate that the Express Mail label had high ppm values after pulping and 0.30-mm screening, but the adhesive particles were effectively removed by 0.15-mm slotted screen in the laboratory process. In the pilot-scale process, these particles are removed by flow-through cleaners and flotation. Flotation was also effective for adhesive removal in the laboratory recycling process. However, both processes still had appreciable adhesive residues after flotation. Washing appeared to remove many of the particles in the pilot-scale protocol. The Change of Address label had high adhesive ppm values after pulping and screening. With both laboratory and pilot processes, there was a high amount of adhesive residues present, even after flotation.

Two PSA stamp products currently being used by the USPS are the linerless coil stamp and an unprinted PSA stamp (which we called standard PSA). In the laboratory and pilot processes, the standard PSA produced high adhesive ppm values at the pulper. for the standard PSA, screening and flotation in the laboratory and pilot processes removed the adhesive particles. Screening and flotation effectively removed the adhesive in the linerless coil in both processes.

Phase IV involved recycling printed stamp material; therefore, recycling trials were conducted on water-activated gum stamp materials with designs printed with three methods (gravure, offset, and intaglio) currently used by the USPS. This was done to determine the effect of the various printing methods on the recycling process. Results from these recycling trials are given in Tables 1 and 3. Each printing ink uses its own pigment binder technology. The gravure ink has a solvent based lacquer binder, the offset ink uses a ultra-violet light cure binder, while the intaglio ink uses an oxidative cured resin in a high boiling organic solvent as its binder technology. As shown in Figures 1 and 2, the gravure print method produced very small ink particles throughout the recycling process. Average ppm values were low for both laboratory and pilot trials (<8 ppm). Both the intaglio and offset print methods produced high contaminant levels in the pulper. Both printing methods produced inks that were difficult to remove through the screening process at laboratory and pilot scale. For the offset printing, the ppm value after screening was 41 (laboratory) and 280 (pilot) and for intaglio the ppm value was 260 (laboratory) and 240 (pilot). Flotation was effective in removing the intaglio printing inks in laboratory recycling with a final ppm value of 7, but the pilot recycling flotation was not as effective with a ppm value of 78. The recycling trials at the laboratory and pilot scale demonstrated that the three print methods produced ink particles that were drastically different in behavior from each other.

Figures 5 and 6 compare the recycling results of a gravure printed stamp laminate analyzed by both the pre-staining method with Morplas Blue 1003 and the post-staining/washing method with Keystone Blue 58. For both post-consumer and pre-consumer (with release liner) feedstocks, these two stain methods were used to develop a contrast between the adhesive particles and the white paper background of the handsheets. Both staining methods gave identical results in laboratory tests. The post-stain method used in the pilot-scale protocol gave similar results, with a very close correlation for handsheets made from the fine screen and flotation accepts. Differences between the two processes for pulper samples and 0.03-mm screen can be partially attributed to the different equipment used in pulping and screening.

Experimental Adhesives

The postconsumer feedstock consisted of envelope stock that went through the mail field test as described by Riley (6). Fourteen experimental PSA adhesives were evaluated at both the laboratory- and pilot-scale level. For each adhesive and print method, the feed consisted of stamped envelopes having equal parts of each of the three face papers. Results of the laboratory-scale recycling trials are shown in Tables 4-8, and the pilot-scale trials are shown in Tables 9-15. Comparisons of laboratory- and pilot-scale results are shown in Figures 7-18.

Gravure Printing. Comparisons of laboratory- and pilot-scale results for the gravure-printed stamps are shown in Figures 7-10. These figures again show that the pilot-scale protocol tended to give greater ppm values upon pulping for the 14 adhesives but there was not a clear-cut pattern after the first screening. Data in Figure 9 suggest that the 0.10-mm pressure screen used in the pilot process was slightly more effective in removing the adhesive particles than was the laboratory process 0.15-mm screen. The laboratory process tended to give lower ppm values after flotation. The Conclusion reached from these data is that for gravure printed substrates, all 14 adhesives show excellent removability, with the vast majority having total contaminant residues of less than 10 ppm using both recycling protocols.

Offset Printing. Comparisons of laboratory and pilot results for offset printed stamps are shown in Figures 11-14. There does not appear to be any trend between the two protocols for the pulper samples, but the pilot-scale tended to have lower contaminant levels after 0.30-mm screening. After fine screening, both systems gave comparable results. Flotation results show that the laboratory process gave total contaminate levels below 10 ppm for all but one adhesive. The pilot process averaged about 15 ppm for all adhesives. Offset printed stamps showed good PSA and ink removability, but the residual contaminate levels were greater than for gravure printed stamps. In part, this was caused by the poorer removability of the offset inks.

Intaglio Printing. Comparisons of laboratory- and pilot-scale results for intaglio printed stamps are shown in Figures 15-18. On average, the pilot-scale process gave greater total contaminant levels after pulping than did the laboratory process. After coarse screening, the two recycling systems showed the same performance for all but four of the adhesives. For three adhesives, the laboratory process showed much greater ppm values after 0.30-mm screening, and the pilot-scale process showed a similar discrepancy for one adhesive. Adhesives that tended to form flat two-dimensional particles were not as efficiently removed by the laboratory 0.30-mm flat screening, while the pilot-scale 0.30-mm pressure screening did not remove the adhesive that tended to have more round three-dimensional particles. This relationship was also observed after fine screening, although it was not as pronounced as in the coarse screening. The total contaminant residues after screening of the intaglio printed stamps were the highest of the three print methods. The laboratory recycling process did not remove the intaglio ink throughout the whole screening operation but partially removed the offset ink. This would account for the increased residues after screening for the intaglio print process. For the pilot scale, the intaglio ink residues after screening were the highest of all the print methods. All other unit operations continued to remove the intaglio inks. Data indicate that most intaglio printed stamps showed excellent removability by both protocols, with final contaminant levels in the 5-10 ppm range.

CONCLUDING REMARKS

The combined efforts of the U.S. Postal Service (USPS), Specialized Technology Resources (STR), and the USDA Forest Service, Forest Products Laboratory (FPL), have resulted in a product evaluation process that covers the performance, laboratory recyclability, and pilot-scale recyclability of pressure-sensitive adhesives (PSAs). A unique, extensive recycling database on USPS protocols has been developed for a wide range of PSAs. These studies show that at a 1% PSA level, good removability of adhesive and ink can be obtained. Although there are some interactions with offset- and intaglio based-ink systems, typical unit operations in recycling mills, such as through flow cleaners, flotation cells and washers, can remove both

the ink and adhesive particles that are not removed by screening. Data also indicate that PSAs can be developed that can be effectively removed by the recycling process and meet the requirements for stamp performance.

A unique and extensive recycling database based on USPS protocols been created for a wide variety of PSAs. This database can be used as a reference for the development and evaluation of environmentally benign postage stamps, other postal products as well as paper-to-paper labels.

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Table I. Laboratory recyclability of benchmark materials[a]

	Image Analysis of Results[b]											Reject analysis[e]	
	Before screen		After 0.30-mm screen			After 0.15-mm screen			After flotation			% Rejects	Total % recovered
Sample description	Ct/m^2	ppm	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	%Eff.	After 12 Cut	By screen
Copy /Wove paper	55	2±3	67	3±3		55	3±4		46	3±4		0.03	0.05
Facestock Blend paper	80	5±6	25	1±1		63	3±3		55	2±2		0.14	0.15
Gravure WAG[c]	42	1±1	92	5±5		80	5±4		71	5±7		0.02	0.12
Offset WAG[c]	1250	85±42	1040	67±22	21	840	41±18	39	410	17±7	74	0.03	0.11
Intaglio WAG[c]	6850	270±44	6730	270±38		6810	260±32		140	7±5		0.04	0.07
Linerless Coil[d]	1090	850±420	330	51±38	94	243	13±6	74	29	2±2	97	62	63
Std PSA[d]	4900	4900±920	730	380±170	92	170	23±28	94	38	1±2	96	77	19
Change of address label[d]	32300	1390±230	8400	340±40	75	19000	620±37		420	38±9	89	0.28 g	0.42 g
Express mail label[d]	18000	10000	4500	1600	84	1850	200	88	350	35	82	4.97 g	5.77 g
100% Mail envelope[f]	38	2±5	63	3±4		96	5±5		34	2±3		0.03	0.04
100% mail envelope[g]	38	2±3	80	4±5		108	5±5		34	2±4			

[a]Denotes configuration of 5% stamp stock or label stock/47.5% copy paper/47.5% wove envelope paper.

[b]Average of 15 handsheets. Threshold = 140 gvs. Ct/m^2 = count per square meter. ppm = parts per million. ± one standard deviation

[c]WAG = water activated gum stamp. no staining of adhesive prior to pulping.

[d]Adhesive pre-stained with Morplas Blue prior to pulping.

[e]Total % Recovered = weight of adhesive recovered divided by weight of adhesive in stamps, based on converter's coating weight. Adhesive level in charge in Change of Address and Express Mail Labels.

[f]Unstained handsheets.

[g]Stained and washed per USPS Task IV Image Analysis Protocol.

Table II. Pilot recyclability of benchmark adhesives[a]

	Image Analysis of Accepts[b]									
	Copy/Wove paper		Facestock blend paper		Gravure WAG[c]		Offset WAG[c]		Intaglio WAG[c]	
Sample point	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm
Pulper	70	3±3	111	11±26	121	4±3	8077	350±69	7820	540±131
0.30-mm pressure screen	49	3±4	97	4±4	63	3±3	7815	310±32	7631	390±71
0.10-mm pressure screen	51	2±2	102	4±6	136	6±5	7622	280±31	6745	240±27
Forward cleaner Feed	4	4±4	77	4±4	121	5±4	7752	280±31	7195	250±37
1st Forward cleaner	75	3±2	165	9±10	102	5±4	2281	86±14	3816	126±21
2nd Forward cleaner	37	2±3	169	6±7	73	4±6	867	29±10	2644	93±12
1st Through-flow cleaner	75	4±4	77	5±4	184	8±6	847	33±12	2194	71±14
2nd Through-flow cleaner	46	2±2	53	5±13	107	4±3	910	31±13	2431	84±21
LaMort flotation	58	4±5	82	5±8	58	4±4	828	31±14	2164	78±11
Drum washer	43	2±2	58	4±7	67	3±6	550	19±8	1353	45±13

[a]Denotes configuration of 5% stamp stock/47.5% copy paper/47.5% wove envelope paper.
[b]Average of 15 handsheets, except for drum washer where 40 handsheets were used. Threshold = 140 gvs. Ct/m^2 = count per square meter. ppm = parts per million. ± one standard deviation Handsheets were stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.
[c]WAG = water activated gum stamp.

Table III. Pilot recyclability of benchmark adhesives[a]

	Image Analysis of Accepts[b]									
	Linerless coil		Change of address label		Express mail label		Standard PSA		100% mail envelope	
Sample point	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm
Pulper	1036	710±373	32481	1870±378	4765	3760±1070	3438	8230±1820	68	5±6
0.30-mm pressure screen	470	94±69	37483	2150±389	3607	1360±411	1714	1140±253	208	8±5
0.10-mm pressure screen	228	13±9	35227	1960±438	1133	75±43	358	47±30	107	3±3
Forward cleaner Feed	232	15±9	26608	1460±312	586	55±29	504	65±64	58	2±2
1st Forward cleaner	194	12±6	34055	1970±412	552	36±18	726	100±51	87	5±7
2nd Forward cleaner	150	7±4	24230	1330±354	596	63±50	402	41±22	39	1±3
1st Through-flow cleaner	73	4±4	7786	450±187	237	18±15	320	35±39	87	3±3
2nd Through-flow cleaner	44	3±5	6857	380±60	165	15±20	257	22±18	53	2±3
LaMort flotation	73	13±36	1089	85±88	169	12±16	208	12±13	39	2±2
Drum washer	47	3±5	127	8±14	104	8±11	138	7±8	49	2±3

[a]Denotes configuration of 5% stamp stock or stamp stock/47.5% copy paper/47.5% wove envelope paper.
[b]Average of 15 handsheets, except for drum washer where 40 handsheets were used. Threshold = 140 gvs. Ct/m^2 = count per square meter. ppm = parts per million. ± one standard deviation Handsheets were stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.

Table IV. Laboratory recyclability performance of experimental PSA[a]

		Image Analysis of Accepts[b]											Reject analysis[c]	
		Before screening		After 0.30-mm screen			After 0.15-mm screen			After flotation			% Re-covered	Total % re-covered
Sample descrip-tion	Printing method	Ct/m^2	ppm	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	% Eff.	After 12 cut	By screen-ing
33202	Gravure	8650	2950±440	7960	2080±480	30	950	110±44	95	63	7±9	94	69	102
33202	Offset	12600	3770±800	13400	3440±860	9	4620	510±170	85	130	17±24	97	45	53
33202	Intaglio	18000	3800±520	16200	3050±420	20	12100	1070±210	65	120	20±28	98	65	86
33204	Gravure	13700	3280±450	11500	2760±360	16	3140	520±130	81	25	1±2	100	41	79
33204	Offset	19600	4450±620	12900	2730±340	39	2120	200±66	92	88	7±8	97	23	61
33204	Intaglio	21100	3760±500	18000	2670±440	29	7800	380±71	86	38	2±4	99	54	77
33206	Gravure	14700	4140±450	9200	2380±650	43	2640	530±150	78	71	4±5	99	37	71
33206	Offset	21200	4800±560	10600	2160±380	55	1780	300±270	86	29	3±6	99	56	82
33206	Intaglio	25600	4690±540	24300	4190±680	11	7360	460±86	89	50	3±5	99	47	84

[a]Denotes post-consumer configuration of 5% stamp stock/44% copy paper/51% printed wove envelope.

[b]Average of 15 handsheets. Threshold = 140 gvs. Ct/m^2 = count per square meter. ppm = parts per million. ± one standard deviation % Eff. = percent efficiency for Image Analysis = percent ppm removed by each unit operation. Handsheets stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.

[c]Total % Recovered = weight of adhesive recovered divided by weight of adhesive in stamps. based on converter‘s coating weight.

Table V. Laboratory recyclability performance of experimental PSA[a]

		Image Analysis of Accepts[b]											Reject analysis[a]	
		Before screening		After 0.30-mm screen			After 0.15-mm screen			After flotation			% Re-covered	Total % Re-covered
Sample description	Printing method	Ct/m^2	ppm	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	% Eff.	After 12 Cut	By screen-ing
33208	Gravure	11700	4310±930	6540	1920±390	55	2280	530±140	72	42	12±29	98	93	120
33208	Offset	18300	5300±730	9460	2350±320	56	2240	210±56	91	34	3±9	99	111	130
33208	Intaglio	26200	6080±970	23800	5560±500	9	9760	1000±200	82	46	18±37	98	56	92
33210	Gravure	8170	3870±910	2300	650±130	83	440	42±26	94	42	2±3	95	98	99
33210	Offset	9750	4630±850	5240	1700±330	68	1110	130±64	92	84	7±13	94	76	94
33210	Intaglio	17900	4550±700	11600	2000±440	56	8840	440±77	78	63	14±38	97	77	104
33212	Gravure	10100	4020±620	6460	1210±400	45	560	90±90	96	38	2±3	98	23	79
33212	Offset	12200	4180±940	10700	3010±480	28	1610	170±41	94	63	5±6	97	48	82
33212	Intaglio	18400	4200±540	10100	1480±380	65	9680	450±70	70	63	10±17	98	73	98

[a]Denotes post-consumer configuration of 5% stamp stock/44% copy paper/51% printed wove envelope.

[b]Average of 15 handsheets. Threshold = 140 gvs. Ct/m^2= count per square meter. ppm = parts per million. ± one standard deviation % Eff. = percent effciency for Image Analysis = percent ppm removed by each unit operation. Handsheets stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.

[c]Total % Recovered = weight of adhesive recovered divided by weight of adhesive in stamps. based on converter‘s coating n-eight.

Table VI. Laboratory recyclability performance of experimental PSA[a]

Sample description	Printing method	Image Analysis of Accepts[b]											Reject analysis[c]	
		Before screening		After 0.30-mm screen			After 0.15-mm screen			After flotation			% Re-covered	Total % Re-covered
		Ct/m^2	ppm	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	% Eff.	After 12 Cut	By screen-ing
33214	Gravure	7480	2790±410	1800	350±120	88	860	76±61	78	92	7±11	91	90	93
33214	Offset	7800	2960±690	4030	850±160	71	900	110±29	87	84	4±4	96	90	98
33214	Intaglio	11900	2520±490	8340	930±140	63	5140	200±46	79	92	6±8	97	85	97
33216	Gravure	10200	2790±390	8230	1590±260	43	440	78±95	95	63	5±8	94	65	84
33216	Offset	5470	2410±390	2910	660±130	73	390	34±28	95	80	9±14	73	71	79
33216	Intaglio	8900	2260±350	6170	520±81	77	5320	190±23	63	46	2±2	99	87	90
33218	Gravure	7580	4120±630	4280	1710±370	58	820	130±47	92	46	2±3	98	72	95
33218	Offset	9470	5130±1670	5600	1790±300	65	1180	130±43	93	55	4±11	97	73	86
33218	Intaglio	19100	5110±770	11400	1630±320	68	11600	600±87	63	140	11±21	98	77	90

[a]Denotes post-consumer configuration of 5% stamp stock/44% copy paper/51% printed wove envelope.

[b]Average of 15 handsheets. Threshold = 140 gvs. Ct/m^2= count per square meter. ppm = parts per million. ± one standard deviation % Eff. = percent efficiency for Image Analysis = percent ppm removed by each unit operation. Handsheets stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.

[c]Total % Recovered = weight of adhesive recovered divided by weight of adhesive in stamps. based on converter's coating weight

Table VII. Laboratory recyclability performance of experimental PSA[a]

		Image Analysis of Accepts[b]											Reject analysis[c]	
		Before screening		After 0.30-mm screen			After 0.15-mm screen			After flotation			% Recovered	Total % Re-covered
Sample descrip-tion	Printing method	Ct/m^2	ppm	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	% Eff	After 12 Cut	By screen-ing
33220	Gravure	990	460±260	220	30±31	94	180	13±11	57	42	8±13	38	106	107
33220	Offset	2050	880±340	580	67±38	92	350	21±14	69	42	1±2	94	80	82
33220	Intaglio	8110	890±540	7080	260±40	71	7110	240±33	9	84	3±3	99	92	93
33222	Gravure	1380	720±500	440	43±20	94	180	12±12	71	25	3±9	73	85	87
33222	Offset	1830	720±250	620	50±32	93	430	23±11	54	42	5±10	80	95	96
33222	Intaglio	9600	720±220	8750	320±33	56	9230	330±35		50	3±5	99	105	105
33224	Gravure	3160	1100±400	2270	280±99	74	1020	60±25	79	34	2±2	98	83	93
33224	Offset	4990	1180±230	3280	410±150	66	1680	110±55	72	140	9±15	92	65	83
33224	Intaglio	12000	1450±520	8310	420±68	71	10200	390±59	8	55	2±3	99	70	83

[a]Denotes post-consumer configuration of 5% stamp stock/44% copy paper/51% printed wove envelope.

[b]Average of 15 handsheets. Threshold = 140 gvs. Ct/m^2= count per square meter. ppm = parts per million. ± one standard deviation % Eff. = percent efficiency for Image Analysis = percent ppm removed by each unit operation. Handsheets stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol

[c]Total % Recovered = weight of adhesive recovered divided by weight of adhesive in stamps. based on converter‘s coating weight.

Table VIII. Laboratory recyclability performance of experimental PSA[a]

		Image Analysis of Accepts [b]											Reject analysis[c]	
		Before screening		After 0.30-mm screen			After 0.15-mm screen			After flotation			% Re-covered	Total % Re-covered
Sample descrip-tion	Printing method	Ct/m^2	ppm	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	% Eff.	Ct/m^2	ppm	% Eff.	After 12 Cut	By screen-ing
33226	Gravure	23400	1660±450	27400	2090±280		2520	410±250	80	76	7±11	98	43	60
33226	Offset	62800	5070±900	36000	3000±830	41	5480	1110±370	63	84	10±20	99	24	76
33226	Intaglio	32600	3150±530	13400	760±170	76	9170	490±93	35	55	3±3	99	56	86
33228	Gravure	550	220±230	280	27±46	88	280	13±5	50	21	3±8	79	114	114
33228	Offset	1060	330±320	350	20±16	94	480	22±11		34	1±2	94	90	90
33228	Intaglio	6950	610±350	6680	250±28	59	6700	240±42	4	67	4±6	98	103	103

[a]Denotes post-consumer configuration of 5% stamp stock/44% copy paper/51% printed wove envelope.

[b]Average of 15 handsheets. Threshold = 140 gvs. Ct/m^2= count per square meter. ppm = parts per million. ± one standard deviation. % Eff. = percent efficiency for Image Analysis = percent ppm removed by each unit operation. Handsheets stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.

[c]Total % Recovered = weight of adhesive recovered divided by weight of adhesive in stamps. based on converter‘s coating weight

Table IX. Pilot recyclability of experimental adhesives[a]

	Image Analysis of Accepts[b]											
	33202						33204					
	Gravure		Offset		Intaglio		Gravure		Offset		Intaglio	
Sample point	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm
Pulper	5142	3680±998	11084	3220±73	11704	1470±601	3966	2940±796	19959	7070±1386	20424	4240±861
0.30-mm pressure screen	4227	1630±722	6677	610±182	11021	530±92	775	190±99	13132	2150±547	14585	1020±310
0.10-mm pressure screen	305	12±8	4784	160±39	11050	400±69	194	7±7	9752	420±97	12706	450±80
Forward cleaner feed	276	15±18	2237	68±12	9394	330±77	252	9±8	5225	200±52	10982	390±71
1st Forward cleaner	407	31±27	1646	51±13	3467	120±21	140	8±10	2968	120±26	2552	87±15
2nd Forward cleaner	121	9±12	1835	63±19	145	7±6	116	8±9	3220	160±53	97	4±4
1st Through-flow cleaner	126	12±24	1264	40±13	160	7±7	19	1±1	1898	82±36	107	5±3
2nd Through-flow cleaner	140	16±24	1162	36±9	97	3±5	5	1±5	1603	79±50	92	4±3
LaMort flotation	48	7±12	247	8±4	48	2±2	39	2±3	499	23±19	92	3±3
Drum washer	42	4±8	178	7±7	162	5±5	40	2±3	356	14±12	74	3±4

[a]Denotes post-consumer configuration of 5% stamp stock/44% copy paper/51% printed wove envelope.

[b]Average of 15 handsheets. except for drum washer where 40 handsheets were used. Threshold = 140 gvs. Ct/m^2 = count per square meter. ppm = parts per million. ± one standard deviation. Handsheets were stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.

Table X. Pilot recyclability of experimental adhesives[a]

	Image Analysis of Accepts[b]											
	33206						33208					
	Gravure		Offset		lntaglio		Gravure		Offset		Intaglio	
Sample point	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm
Pulper	10769	6210±1254	28569	11470±2009	14651	3340±878	11442	6320±1247	15974	2840±656	23736	4760+884
0.30-mm pressure screen	8484	3990±674	8929	1100±371	11311	1400±305	10909	3700±710	9815	650±206	20909	2230±363
0.10-mm pressure screen	1937	280±107	11195	810±254	9466	350±48	3646	370±118	7002	240±31	15204	670±119
Forward cleaner feed	1346	200±123	2959	110±32	8028	300±54	2804	320±108	4726	150±20	13984	670±91
1st Forward cleaner	1758	300±116	2407	110±49	1516	79±58	1365	140±95	2547	88±20	4358	280±115
2nd Forward cleaner	838	150±70	3370	280±99	203	18±16	964	77±63	1738	63±17	2029	240±68
1st Through-flow cleaner	1574	340±95	1535	55±18	208	10±10	935	110±32	1961	71±17	1065	120±54
2nd Through-flow cleaner	678	150±119	1264	60±44	169	7±4	634	77±32	1467	44±11	862	120±69
LaMort flotation	68	9±18	499	27±23	34	3±4	199	31±28	402	13±11	257	22±22
Drum washer	94	10±14	169	8±9	53	2±3	300	32±27	238	10±8	271	27±24

[a]Denotes post-consumer configuration of 5% stamp stock/44% copy paper /51% printed wove envelope.

[b]Average of 15 handsheets. except for drum washer where 40 handsheets were used. Threshold = 140 gvs. Ct/m^2 = count per square meter. ppm = parts per million. ± one standard deviation Handsheets were stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.

Table XI. Pilot recyclability of experimental adhesives[a]

	Image Analysis of Accepts[b]											
	33210						33212					
	Gravure		Offset		Intaglio		Gravure		Offset		Intaglio	
Sample point	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm
Pulper	5312	4390±994	17703	5440±1582	16008	5760±949	11636	8580±1351	10856	2110±1453	16764	4590±1082
0.30-mm pressure screen	2528	880±176	12197	1120±230	13064	1920±314	5389	2140±703	11873	1860±809	16584	2130±355
0.10-mm pressure screen	252	18±25	11578	420±53	12803	500±77	697	52±38	6203	210±32	11583	440±87
Forward cleaner feed	107	4±5	6179	200±24	9558	370±66	1235	110±45	4915	230±85	9907	370±88
1st Forward cleaner	82	2±2	4310	140±45	1753	73±24	281	19±15	3554	150±53	1738	64±19
2nd Forward cleaner	68	6±8	3486	120±36	295	14±9	339	29±16	1937	61±18	155	6±5
1st Through-flow cleaner	77	5±9	2833	87±17	765	37±24	237	28±19	2518	120±47	107	4±4
2nd Through-flow cleaner	29	1±2	2547	75±19	169	14±21	199	12±11	1598	70±29	160	11±19
LaMort flotation	44	3±5	1104	44±35	58	7±14	45	9±18	494	15±6	63	3±3
Drum washer	65	3±3	792	38±22	198	19±26	93	6±8	468	17±12	289	11±9

[a]Denotes post-consumer configuration of 5% stamp stock/44% copy paper/51% printed wove envelope.

[b]Average of 15 handsheets except for drum washer where 40 handsheets were used. Threshold = 140 gvs. Ct/m^2 = count per square meter. ppm = parts per million. ± one standard deviation Handsheets were stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.

Table XII. Pilot recyclability of experimental adhesives[a]

	Image Analysis of Accepts[b]											
	33214						33216					
	Gravure		Offset		Intaglio		Gravure		Offset		Intaglio	
Sample point	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm
Pulper	6077	6770±1310	11810	6240±2231	11812	5910±888	5903	4500±1145	10183	4200±823	15272	3880±836
0.30-mm pressure screen	1961	780±337	11752	1970±495	14953	1520±253	1482	434±431	6232	820±223	10745	540±159
0.10-mm pressure screen	378	18±7	8900	370±102	13079	540±85	320	16±11	4121	150±28	9239	320±77
Forward cleaner feed	160	17±33	5738	210±39	10251	390±44	189	7±5	1627	55±14	10144	350±51
1st Forward cleaner	73	6±9	400	150±39	1666	71±22	116	5±4	1516	47±11	2808	94±22
2nd Forward cleaner	34	2±2	2818	110±35	378	25±22	87	4±4	1148	36±12	189	7±6
1st Through-flow cleaner	73	4±5	2537	83±18	770	43±22	87	9±20	1138	35±8	97	5±6
2nd Through-flow cleaner	15	1±3	2213	72±17	252	16±4	53	2±3	751	24±8	102	7±12
LaMort flotation	44	2±3	852	29±14	73	3±4	53	3±4	232	9±7	121	5±7
Drum washer	40	3±5	521	18±9	93	4±4	71	4±11	242	11±18	234	9±9

[a]Denotes pos-tconsumer configuration of 5% stamp stock/44% copy paper/51 printed wove envelope.

[b]Average of 15 handsheets except for drum washer where 40 handsheets were used. Threshold = 140 gvs. Ct/m^2 = count per square meter. ppm = parts per million. = one standard deviation. Handsheets were stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.

Table XIII. Pilot recyclability of experimental adhesives[a]

	Image Analysis of Accepts[b]											
	33218						33220					
	Gravure		Offset		Intaglio		Gravure		Offset		Intaglio	
Sample point	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm
Pulper	9747	9510±1389	15786	6800±2033	8899	8900±1583	7626	8120±2459	9345	3750±1047	26366	5600±904
0.30-mm pressure screen	4484	1630±461	9621	830±485	19054	1500±358	3559	960±145	6358	470±130	20308	1600±131
0.10-mm pressure screen	431	27±23	7999	290±74	17122	670±92	1622	130±35	4634	170±53	19088	790±182
Forward cleaner feed	508	51±41	4053	130±35	15103	570±87	751	54±19	2213	76±14	16289	670±136
1st Forward cleaner	988	130±130	3099	99±20	3084	120±27	920	94±51	1947	65±16	5636	240±42
2nd Forward cleaner	232	20±15	2626	100±35	305	13±6	465	37±21	1244	39±10	2247	180±56
1st Through-flow cleaner	305	38±36	1884	56±13	92	4±3	150	11±13	1356	43±12	581	34±14
2nd Through-flow cleaner	378	41±31	1564	47±12	247	9±6	116	6±7	1133	37±13	252	15±13
LaMort flotation	111	15±17	470	14±5	68	3±3	53	2±2	305	9±5	111	7±9
Drum washer	174	18±20	494	21±13	71	4±6	64	3±5	205	8±5	327	13±11

[a]Denotes post-consumer configuration of 5% stamp stock/44% copy paper /51% printed wove envelope.

[b]Average of 15 handsheets except for drum washer where 40 handsheets were used. Threshold = 140 gvs. Ct/m^2 = count per square meter. ppm = parts per million. ± one standard deviation . Handsheets were stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.

Table XIV. Pilot recyclability of experimental adhesives[a]

	Image Analysis of Accepts[b]											
	33222						33224					
	Gravure		Offset		Intaglio		Gravure		Offset		Intaglio	
Sample point	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm
Pulper	5907	4070±881	9936	2730±1143	24225	7620±1291	16676	7030±1042	14609	4570±732	38069	10180±1360
0.30-mm pressure screen	3356	600±183	6919	450±112	19354	1400±155	11026	2250±399	14507	1490±279	27930	3820±495
0.10-mm pressure screen	1119	78±27	6169	200±51	18822	800±85	5467	400±102	7195	250±25	22976	1120±106
Forward cleaner feed	600	46±26	3191	100±18	12420	510±104	5094	400±88	3992	170±39	20618	1090±69
1st Forward cleaner	702	54±28	2276	75±17	4377	210±56	5631	460±101	4130	200±45	11287	800±88
2nd Forward cleaner	378	26±13	1787	55±15	489	59±77	6527	540±75	2503	110±29	6784	560±105
1st Through-flow cleaner	261	17±13	2116	67±18	213	11±5	3777	260±91	2871	130±22	3486	270±65
2nd Through-flow cleaner	223	12±10	1240	35±10	291	16±10	1729	110±25	1830	70±17	1729	120±46
LaMort flotation	184	7±6	392	11±4	107	7±13	315	23±16	479	18±9	353	18±15
Drum washer	120	6±8	318	10±7	218	11±9	202	13±14	380	12±6	280	17±14

[a]Denotes post-consumer configuration of 5% stamp stock/44% copy paper/51% printed wove envelope.

[b]Average of 15 handsheets except for drum washer where 40 handsheets were used. Threshold = 140 gvs. Ct/m^2= count per square meter. ppm = parts per million. ± one standard deviation. Handsheets were stained with Keystone Blue 58 and then washed with methanol by USPS Task IV Image Analysis Protocol.

Table XV. Pilot recyclability of experimental adhesives[a]

	Image Analysis of Accepts[b]											
	33226						33228					
	Gravure		Offset		Intaglio		Gravure		Offset		Intaglio	
Sample point	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm	Ct/m^2	ppm
Pulper	1719	400±149	22168	3400±669	18115	1510±632	683	1050±964	5869	950±769	12817	2580±1006
0.30-mm pressure screen	1903	230±108	8609	420±136	13621	520±67	291	19±16	5017	180±37	11607	430±61
0.10-mm pressure screen	165	6±5	7234	230±29	14013	520±104	136	4±3	5656	170±26	10696	380±57
Forward cleaner feed	402	27±17	4266	130±20	11311	410±93	107	5±5	3249	100±24	10043	350±65
1st Forward cleaner	310	33±22	3206	120±36	1666	60±14	126	5±4	2542	76±23	1540	52±14
2nd Forward cleaner	450	57±31	2978	140±47	736	28±8	63	3±4	2562	80±24	247	21±25
1st Through-flow cleaner	339	41±29	1850	60±14	232	8±6	44	3±9	2131	63±5	731	28±14
2nd Through-flow cleaner	16	20±19	1559	50±15	228	13±13	29	5±15	1685	55±14	102	4±4
LaMort flotation	126	7±9	460	18±11	121	5±4	29	1±2	228	7±5	126	6±7
Drum washer	60	7±12	358	26±44	56	3±4	74	5±5	218	8±15	127	7±12

[a]Denotes post-consumer configuration of 5% stamp stock/445% copy paper /51% printed wove envelope.

[b]Average of 15 handsheets except for drum washer where 40 handsheets were used. Threshold = 140 gvs. Ct/m^2 = count per square meter. ppm = parts per million. ± one standard deviation . Handsheets were stained with Keystone Blue 58, then washed with methanol by USPS Task IV Analysis Protocol.

Figure 1.

Comparison of Printing Methods on Laboratory Recyclability

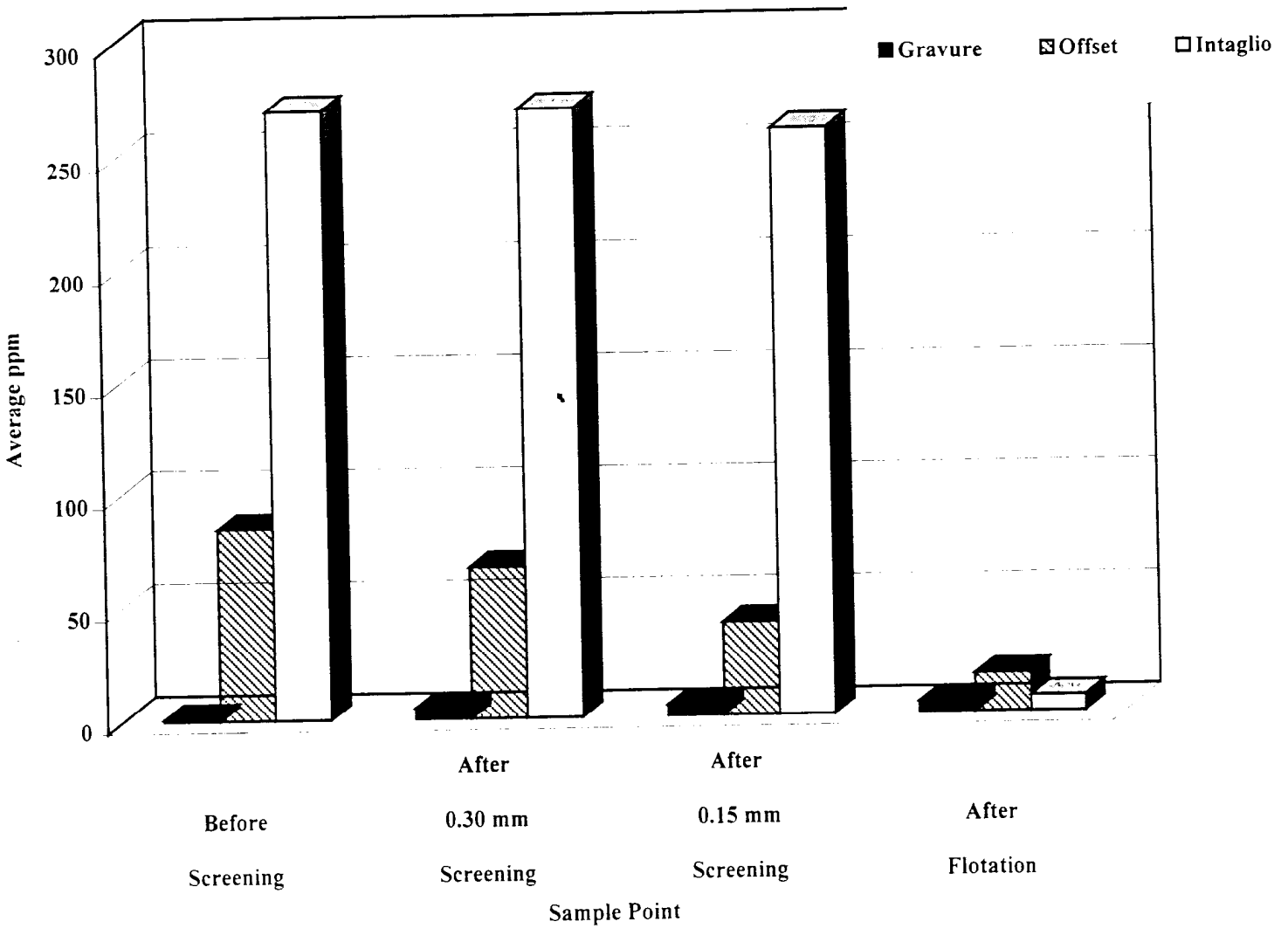


Figure 2.
Comparison of Printing Methods of Pilot Scale Recyclability

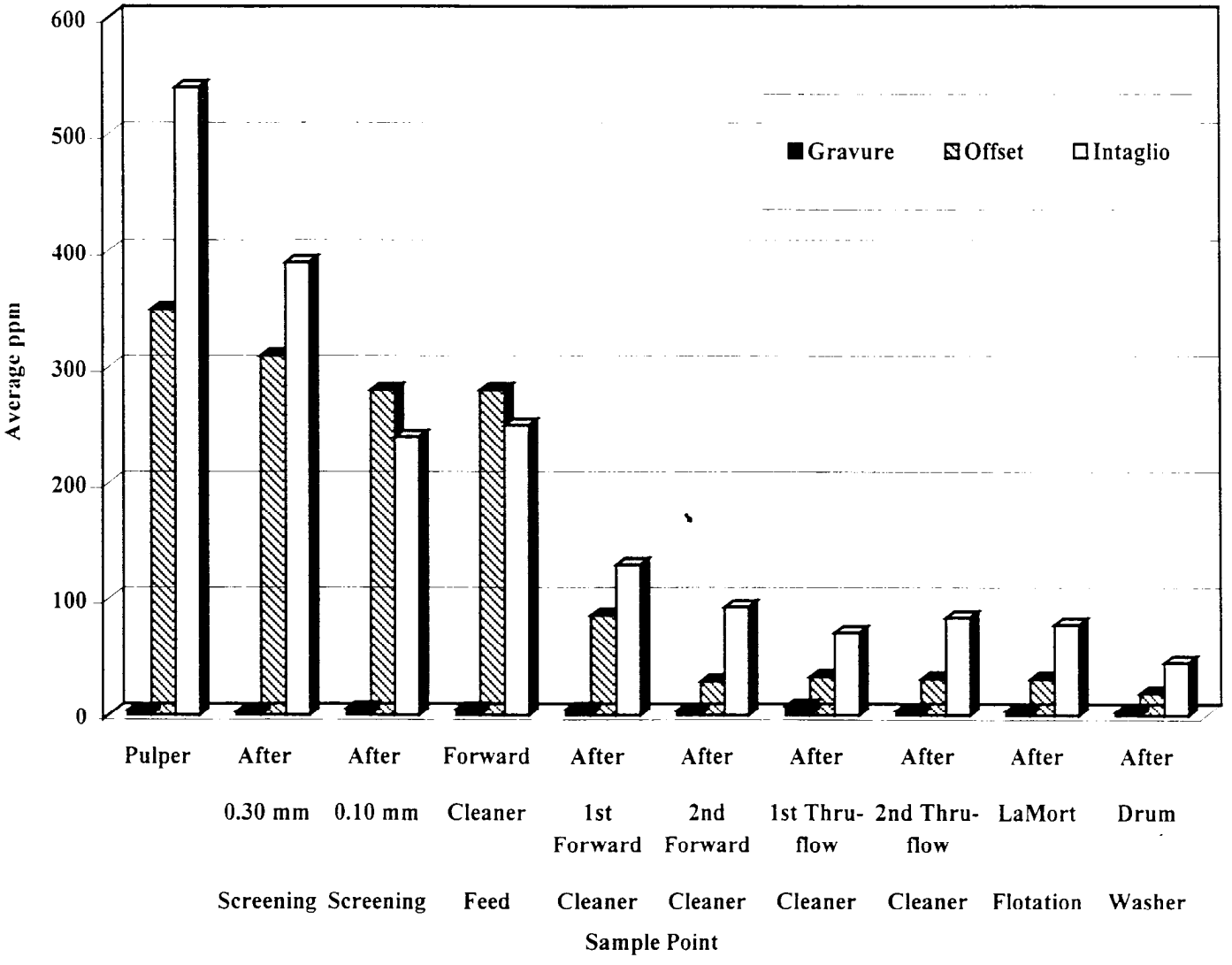


Figure 3.
Laboratory Scale Recycling of Various Benchmark Adhesives

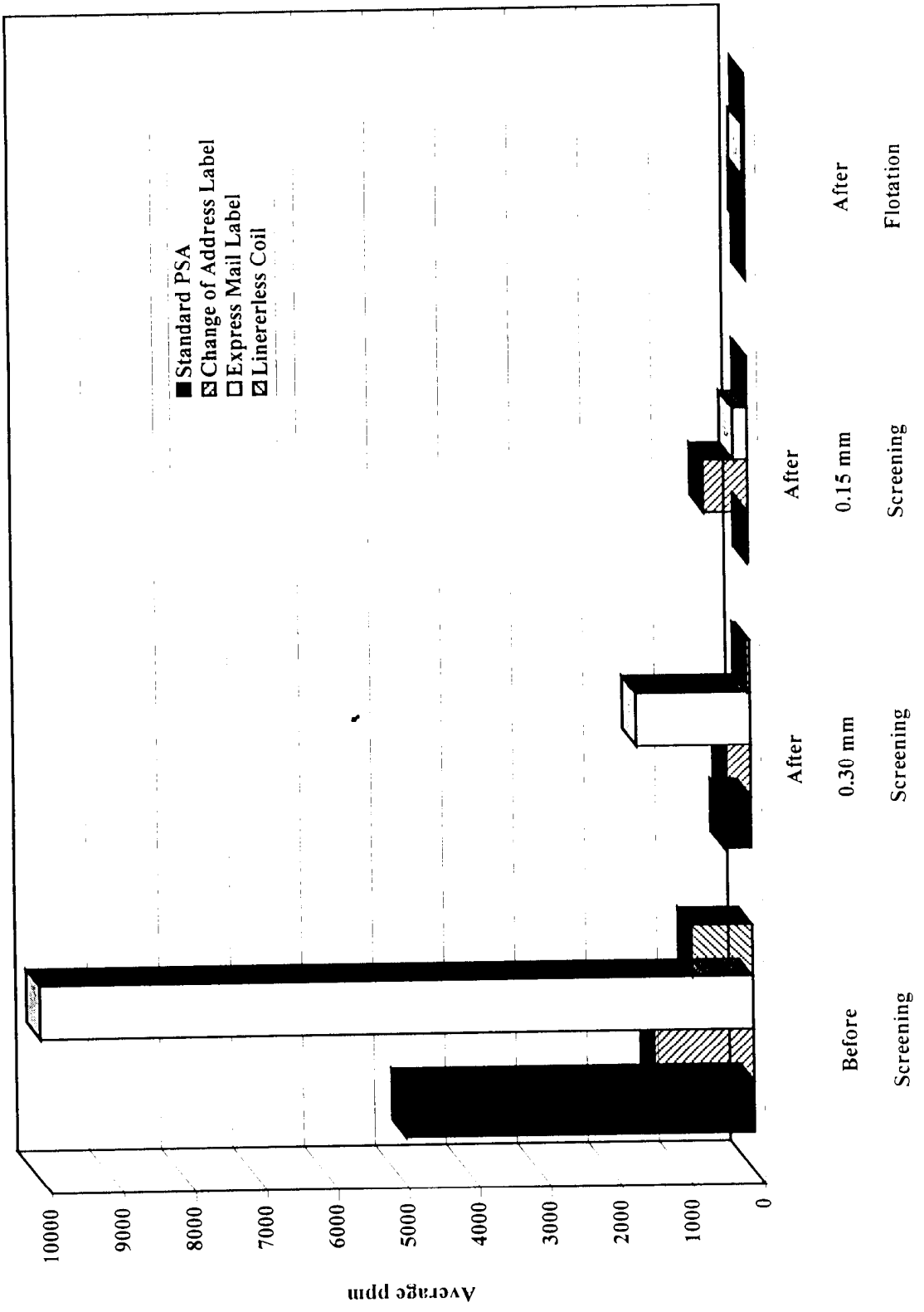


Figure 4.
Pilot Scale Recycling of Various Benchmark Adhesives

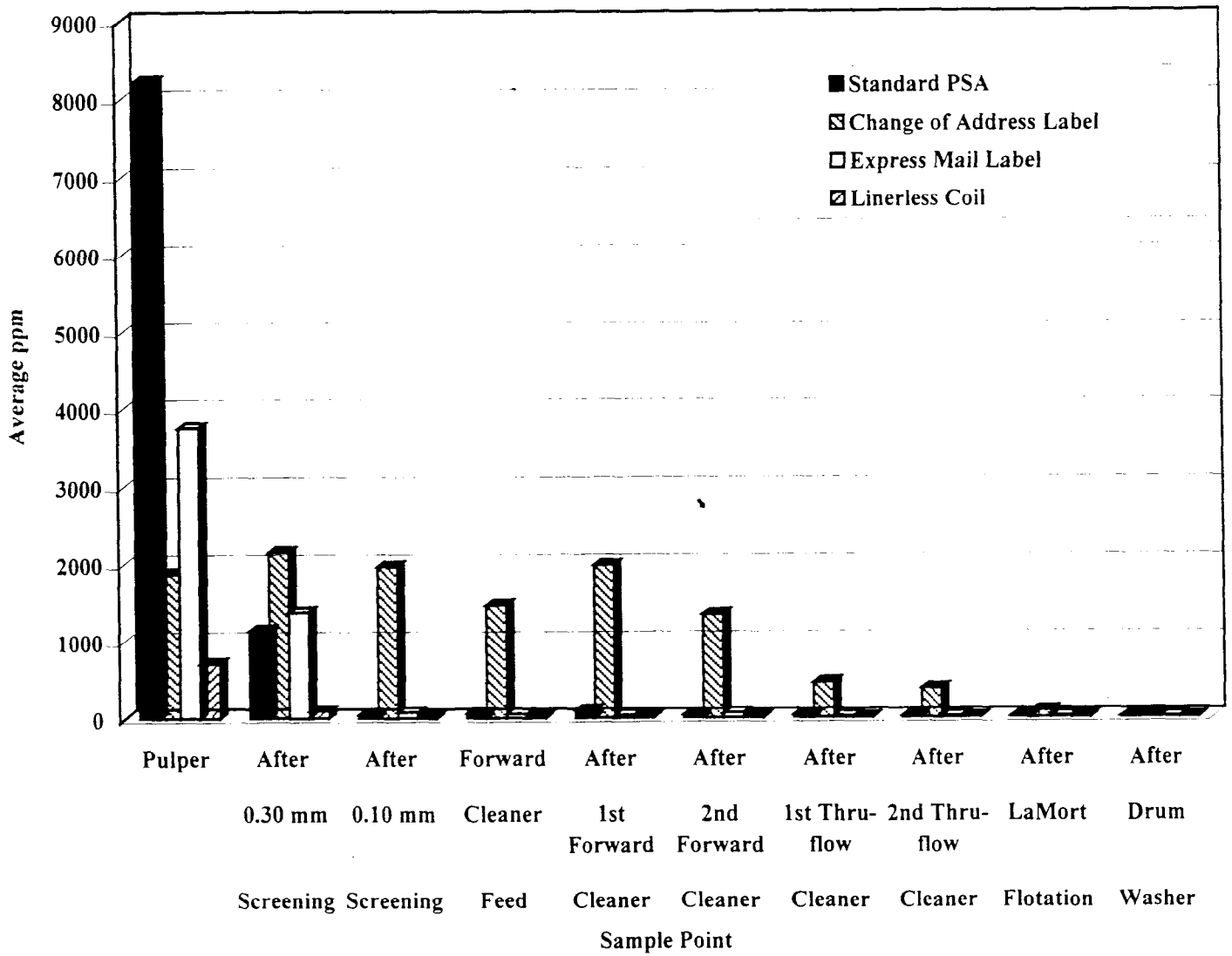


Figure 5.
Recyclability of Gravure Printed Laminate (Post-Consumer)

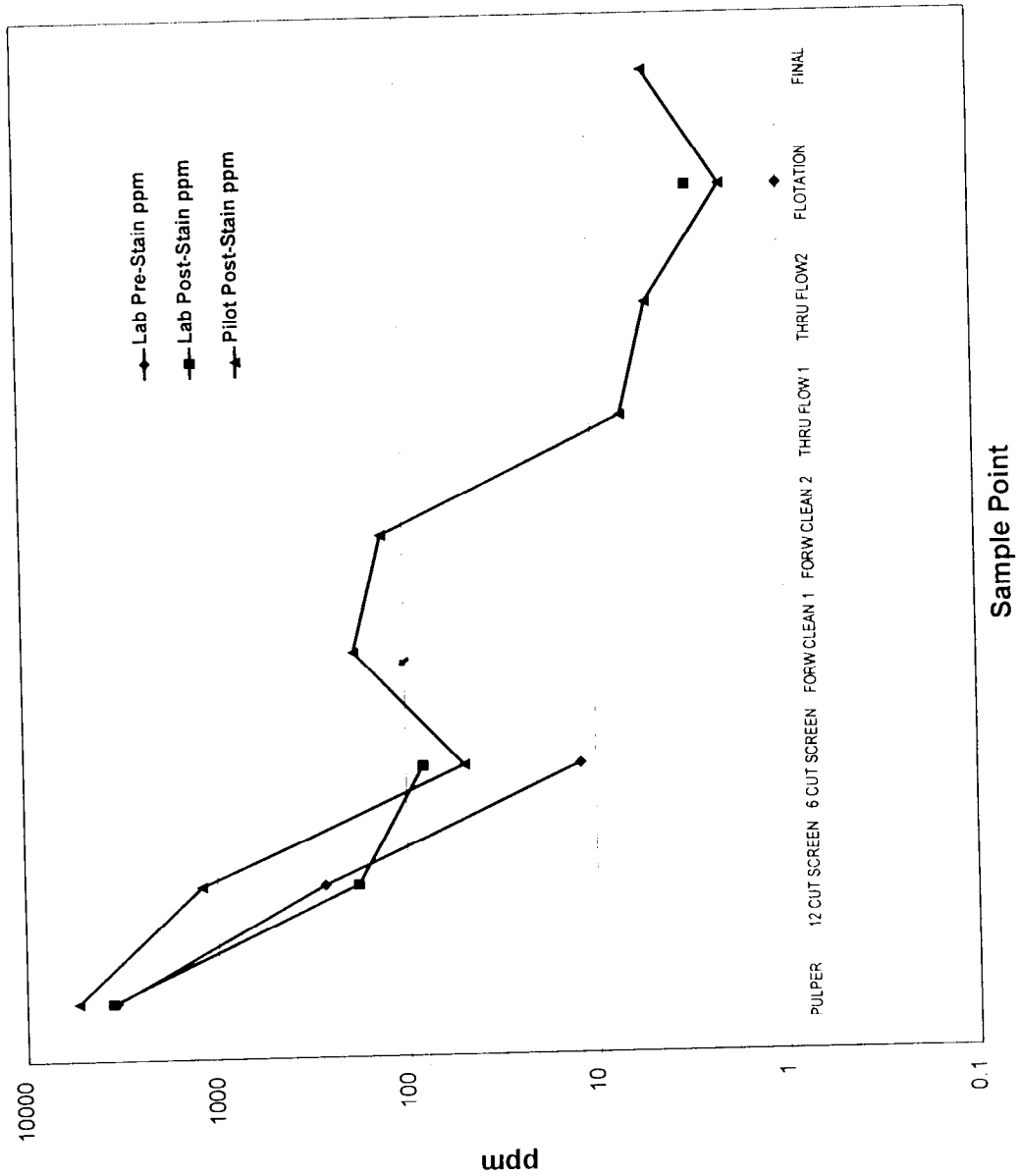


Figure 6.
Recyclability of Gravure Printed Laminate (Pre-Consumer)

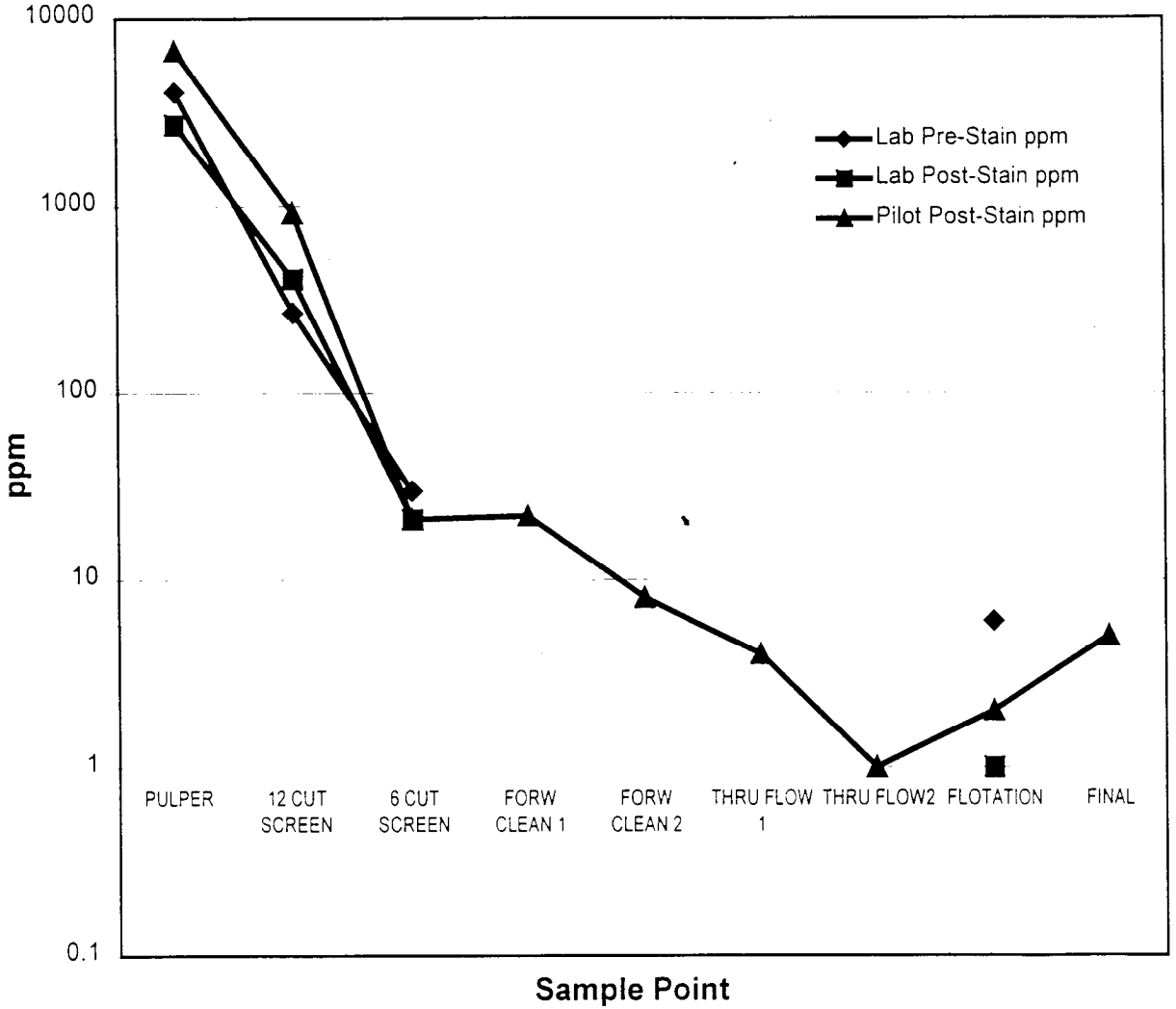


Figure 7.
Comparison of Gravure Print Method on Laboratory and Pilot Recyclability at Pulper

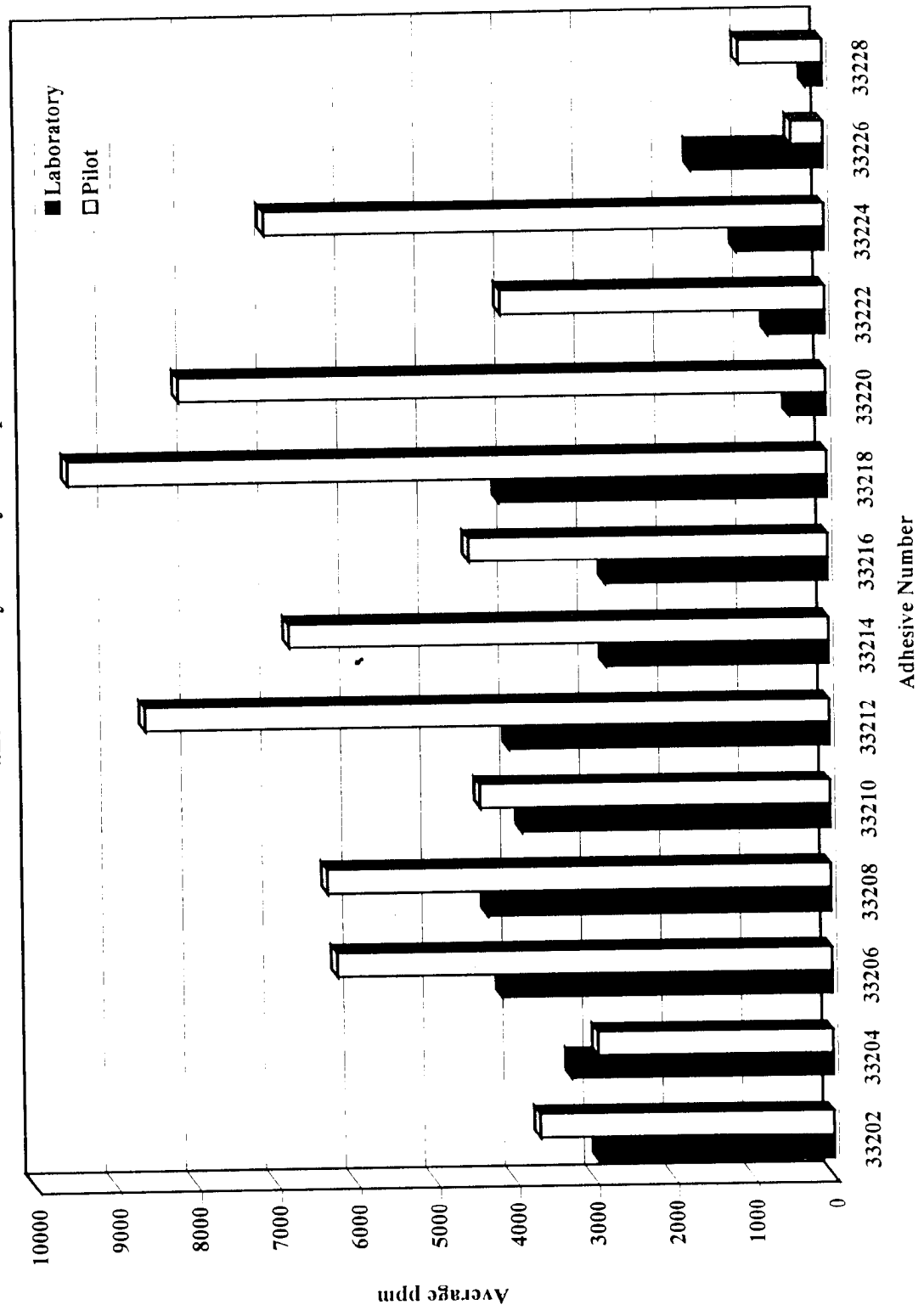


Figure 8.
Comparison of Gravure Print Method on Laboratory and Pilot Recyclability After 1st Screening

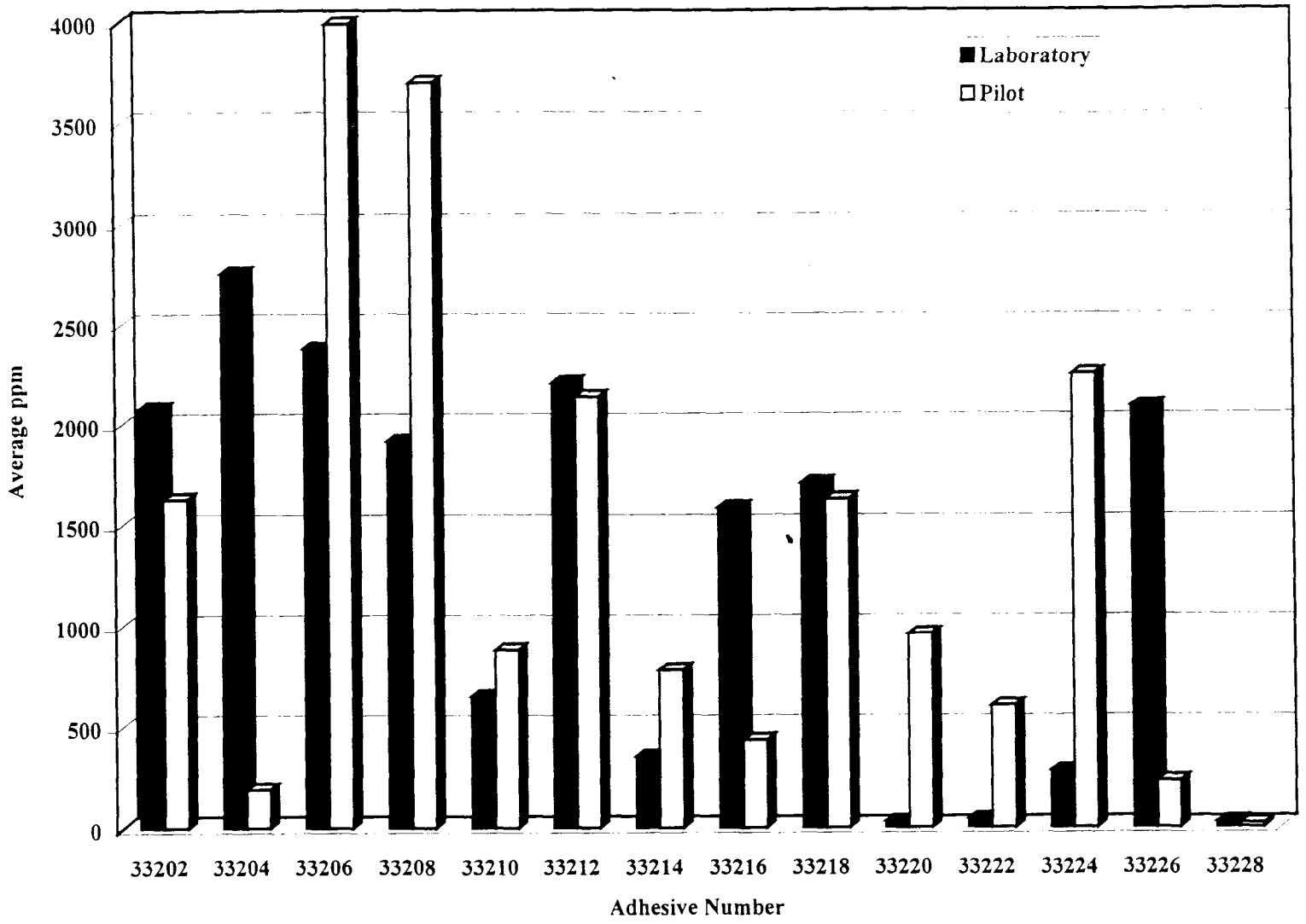


Figure 9.
Comparison of Gravure Print Method on Laboratory and Pilot Recyclability After 2nd Screening

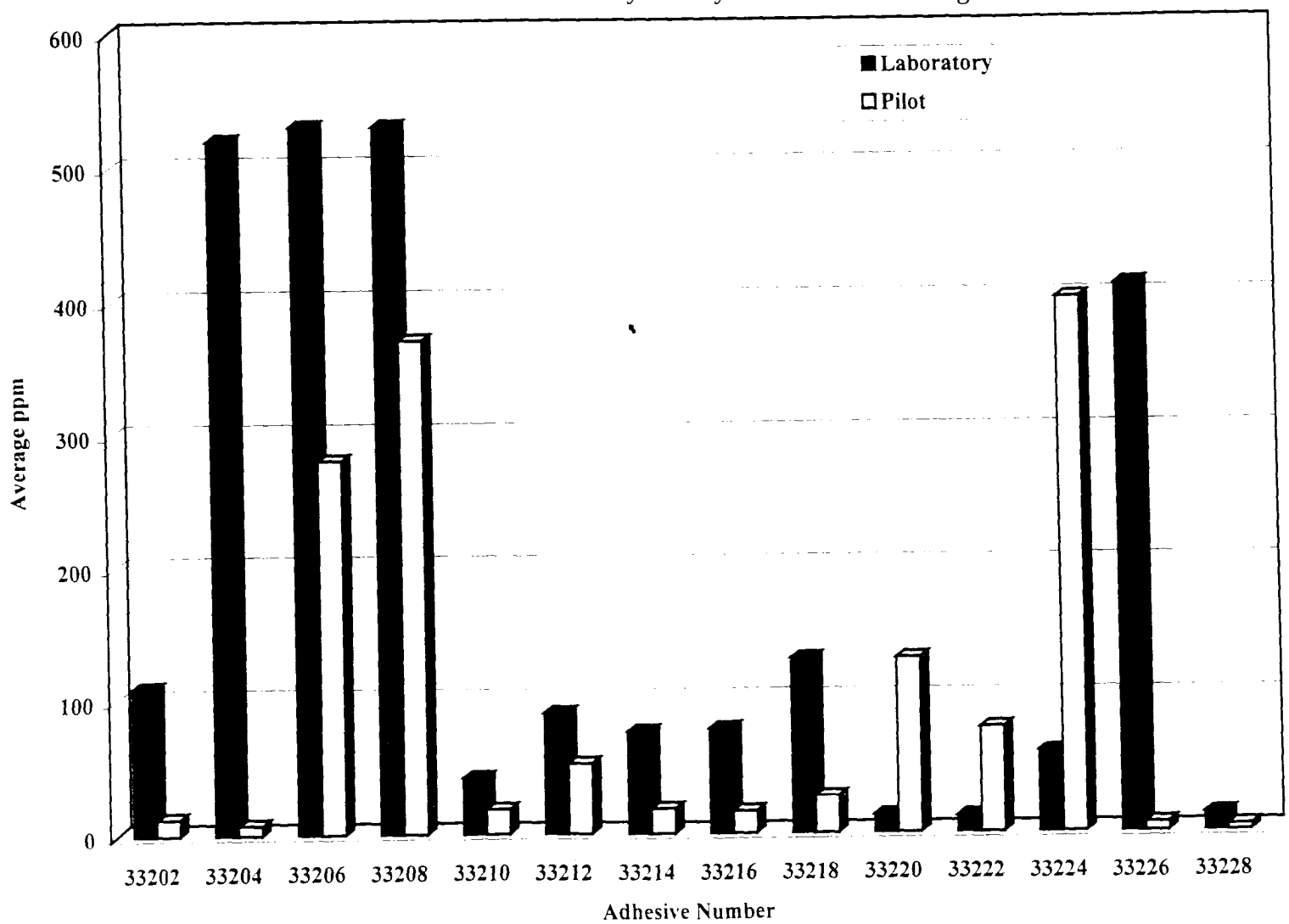


Figure 10.
Comparison of Gravure Print Method on Laboratory and Pilot Recyclability After Flotation

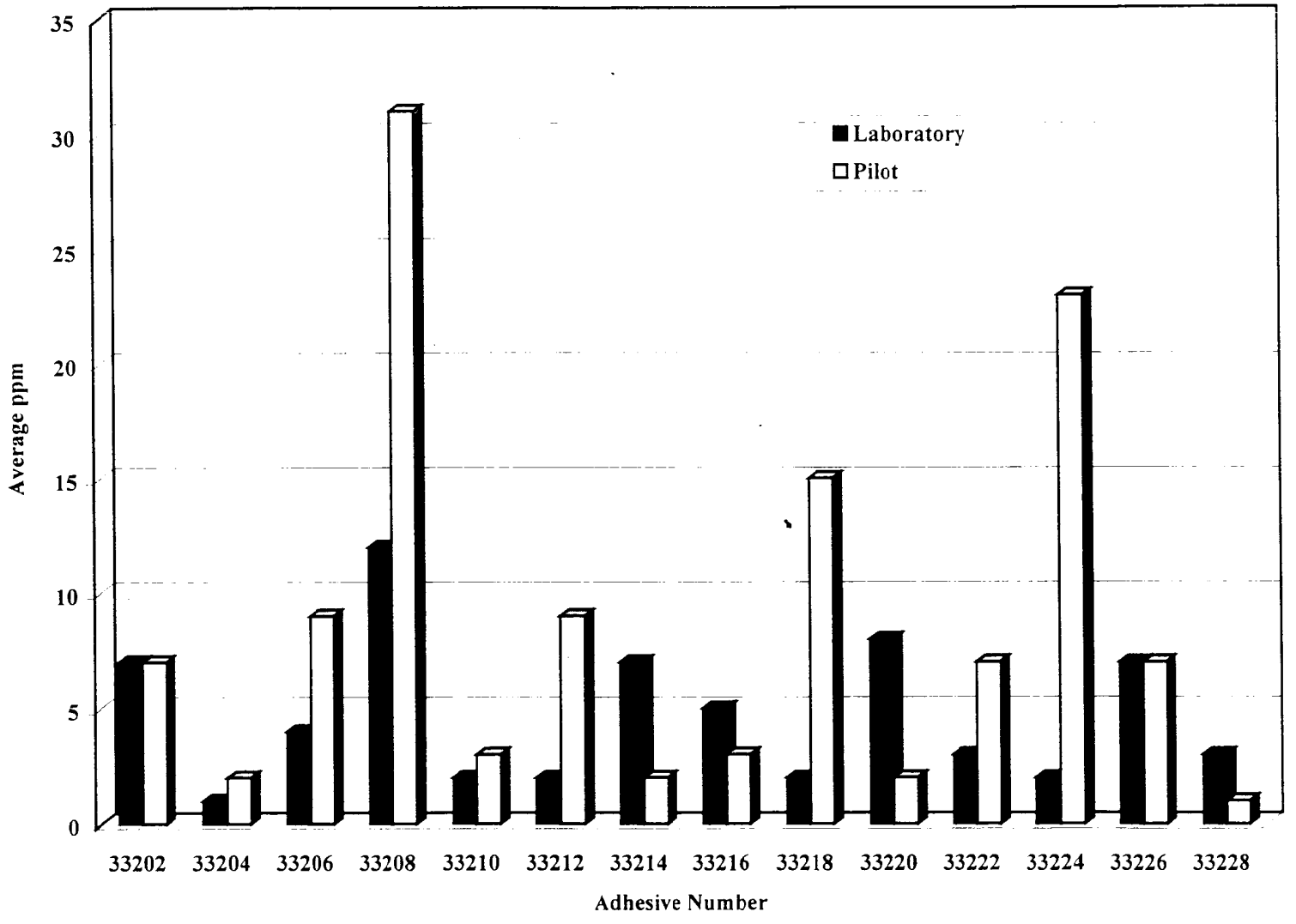


Figure 11.

Comparison of Offset Print Method on Laboratory and Pilot Recyclability at Pulper

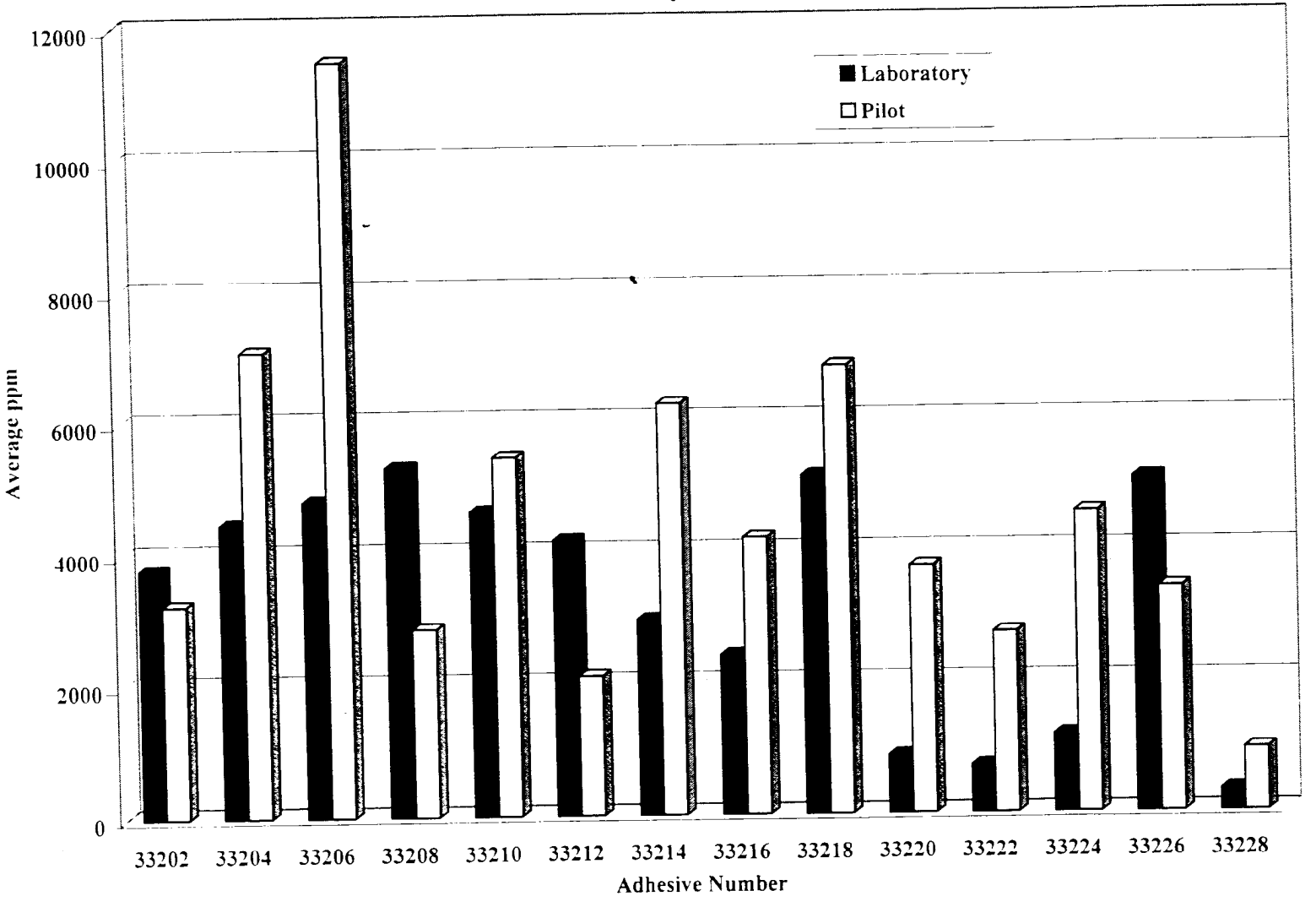


Figure 12.
Comparison of Offset Print Method on Laboratory and Pilot Recyclability After 1st Screening

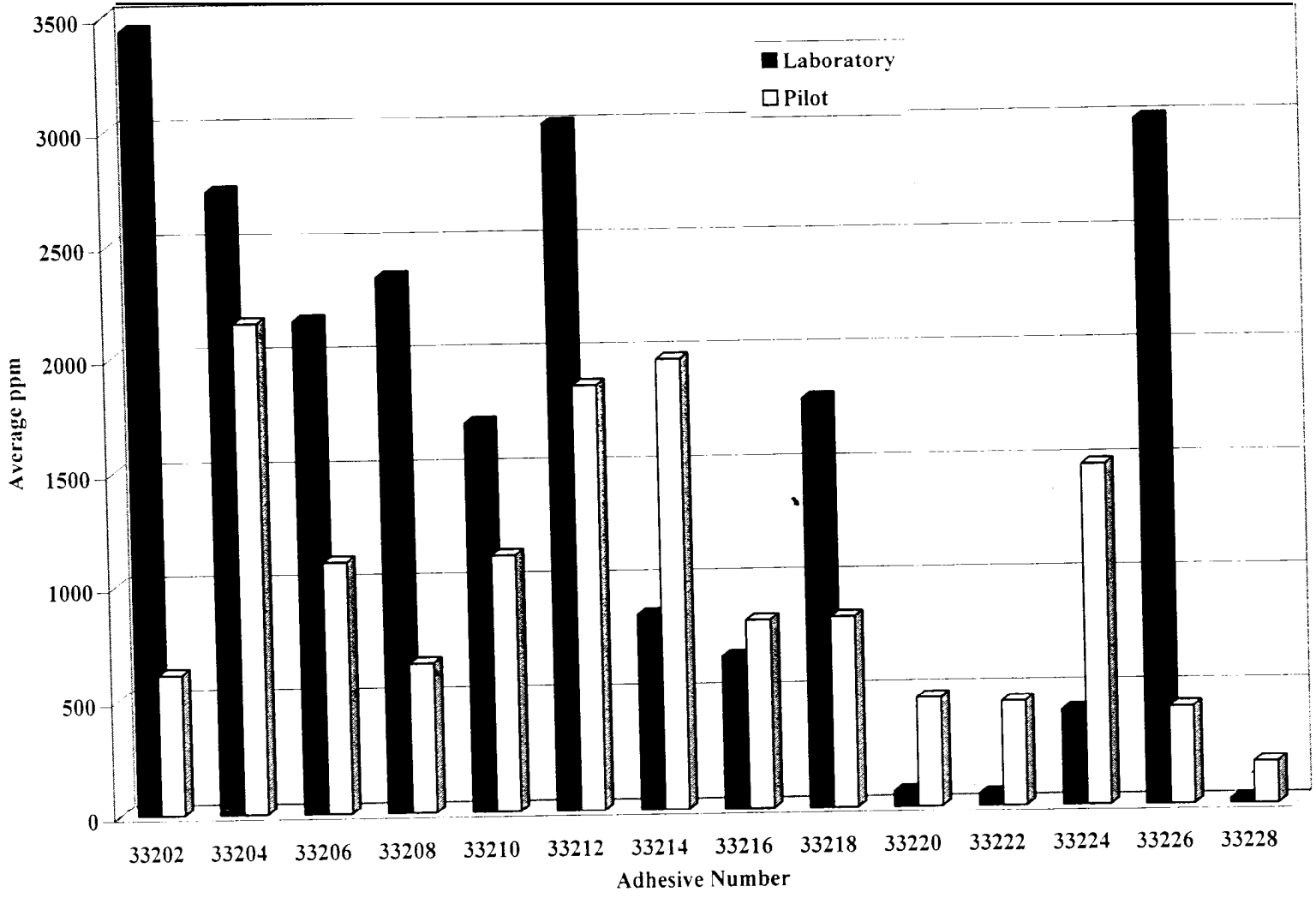


Figure 13.

Comparison of Offset Print Method on Laboratory and Pilot Recyclability After 2nd Screening

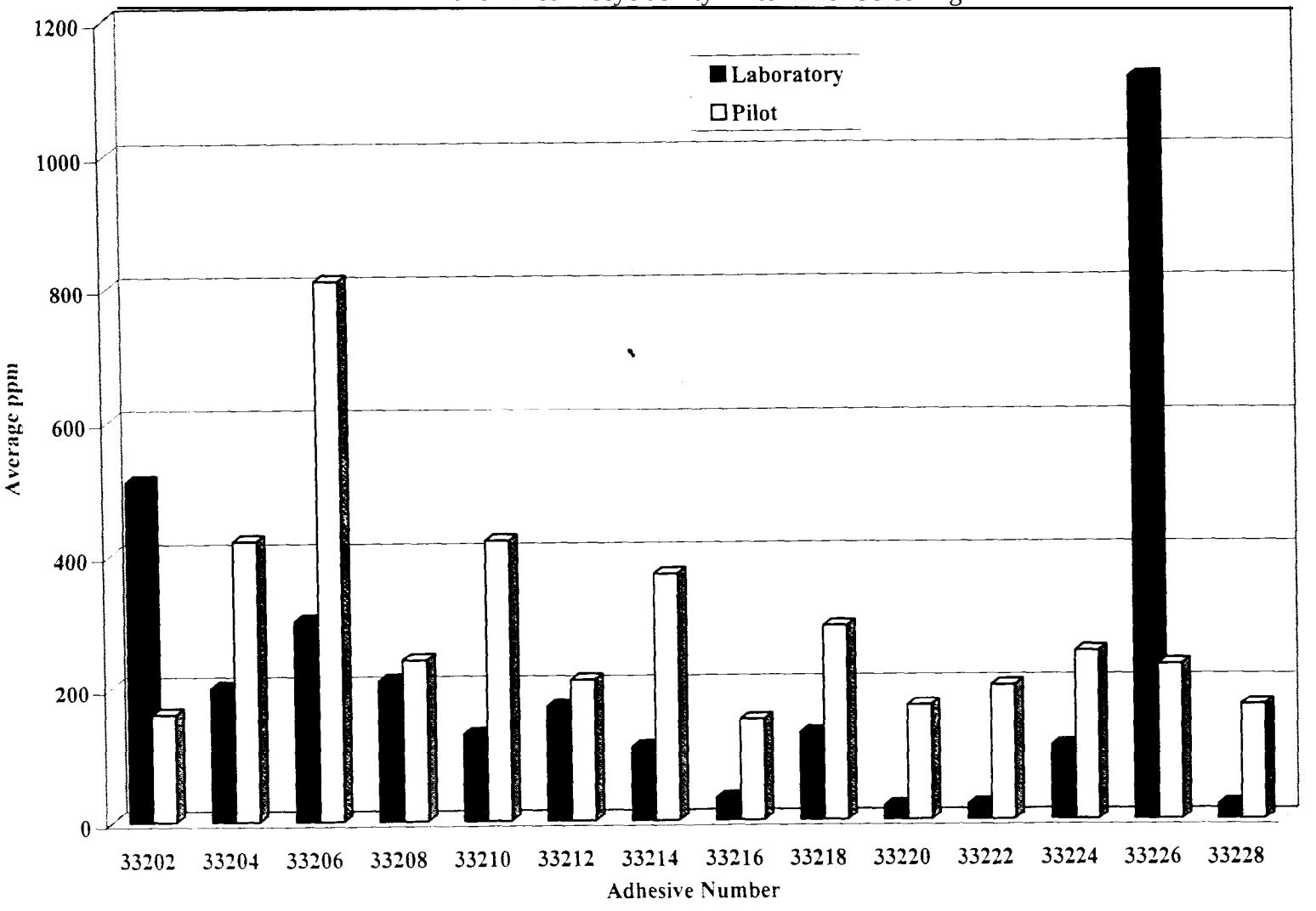


Figure 14.
Comparison of Offset Print Method on Laboratory and Pilot Recyclability After Flotation

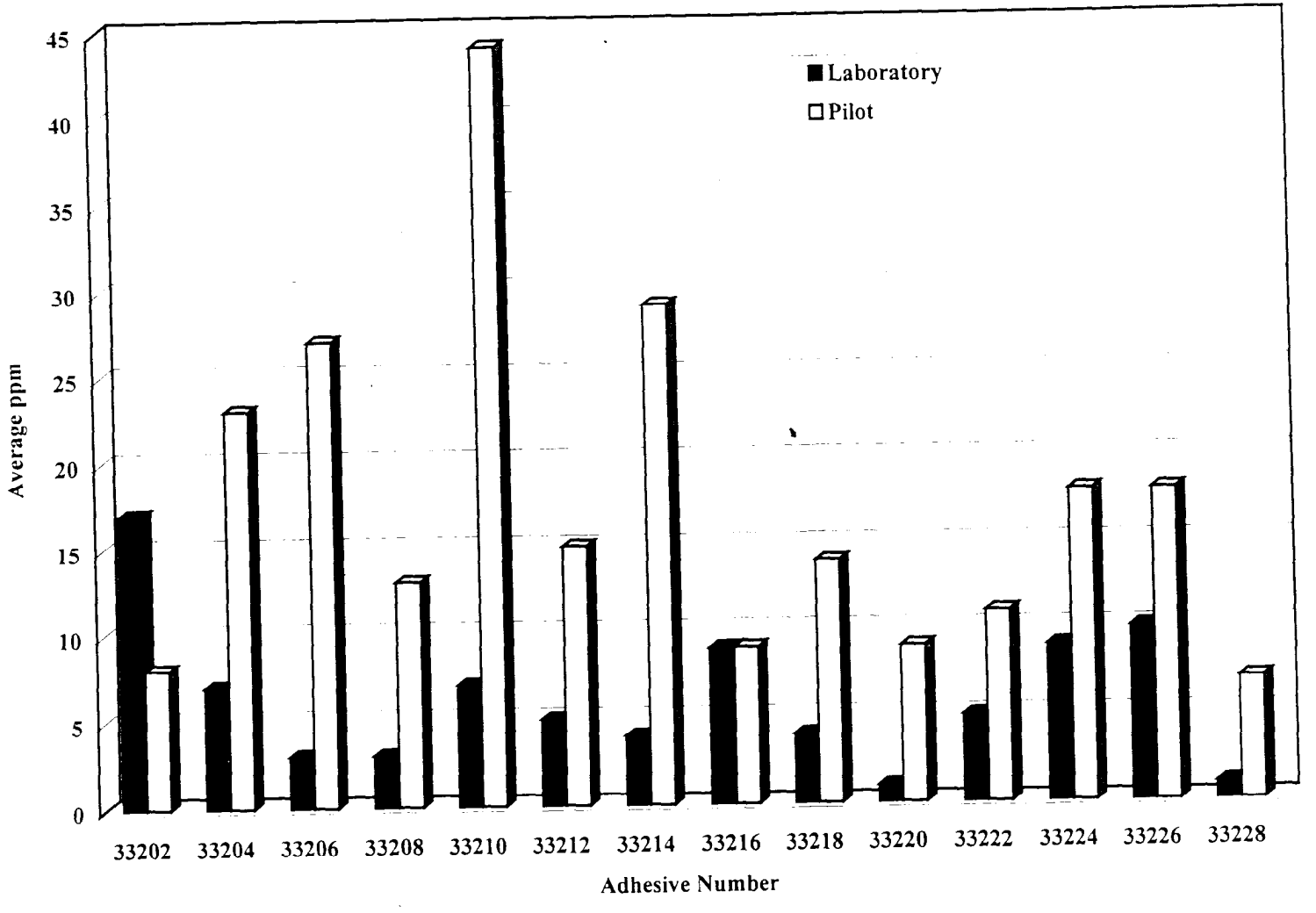


Figure 15.

Comparison of Intaglio Print Method on Laboratory and Pilot Recyclability at Pulper

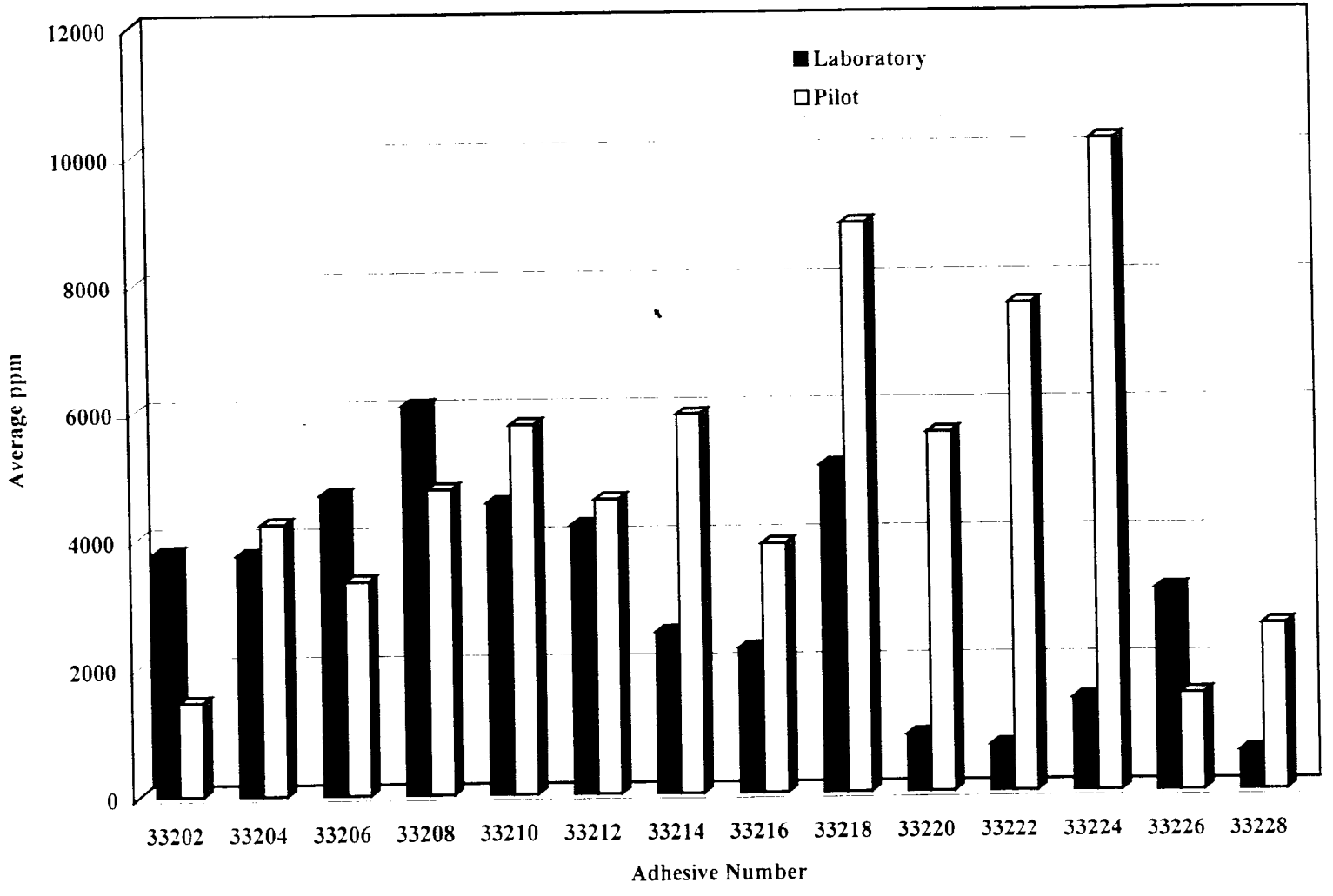


Figure 16.
Comparison of Intaglio Print Method on Laboratory and Pilot Recyclability After 1st Screening

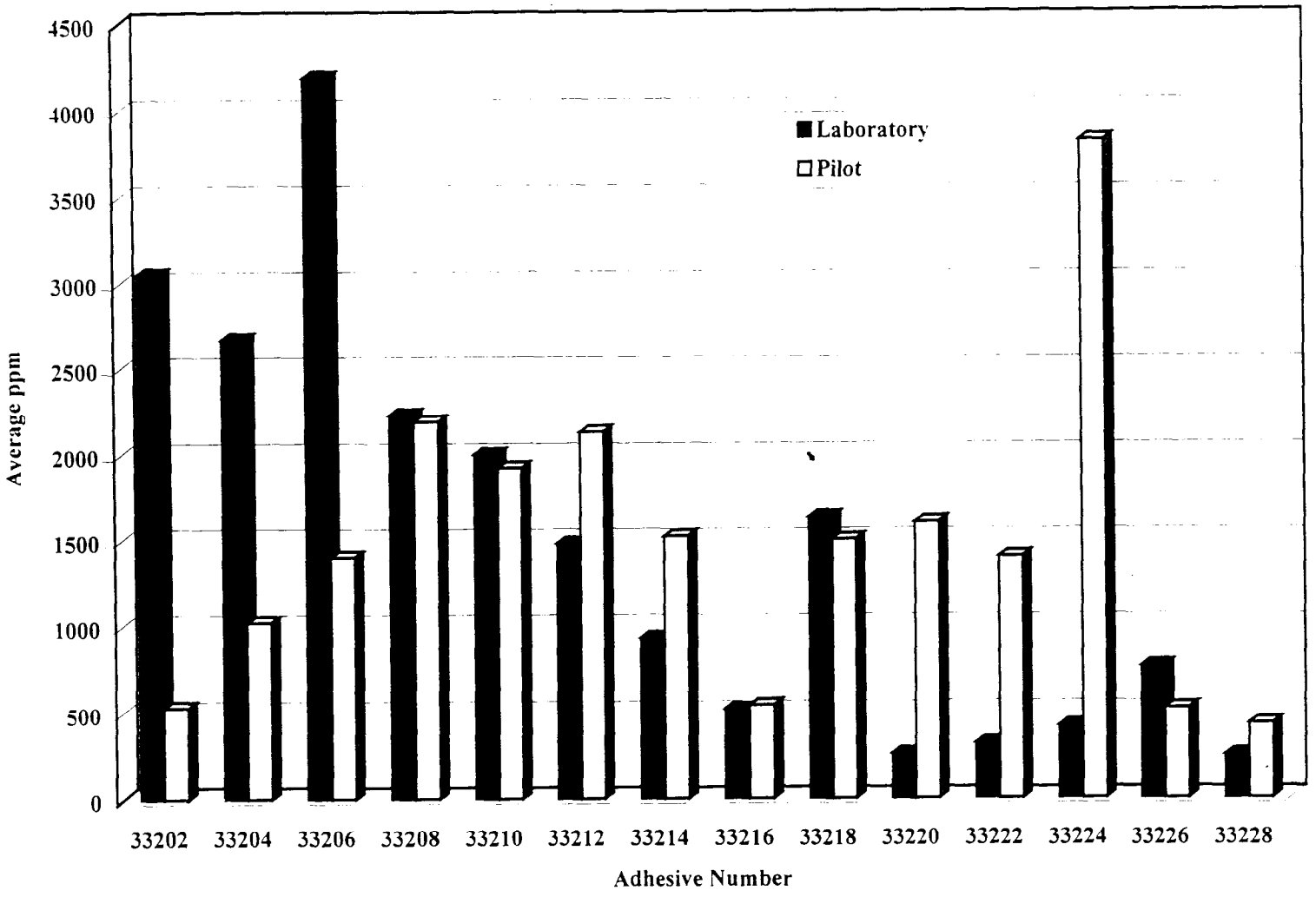


Figure 17.
Comparison of Intaglio Print Method on Laboratory and Pilot Recyclability After 2nd Screening

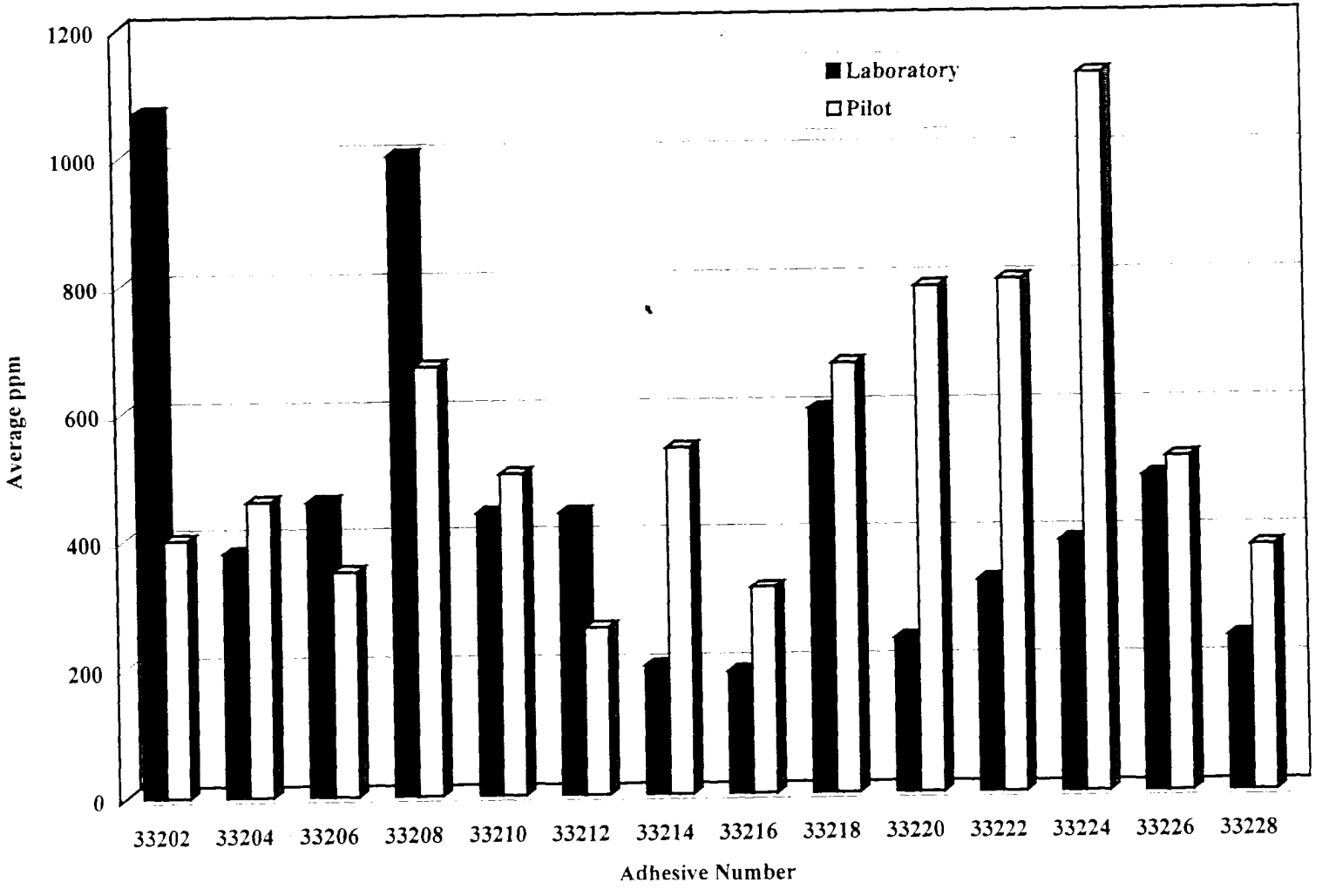
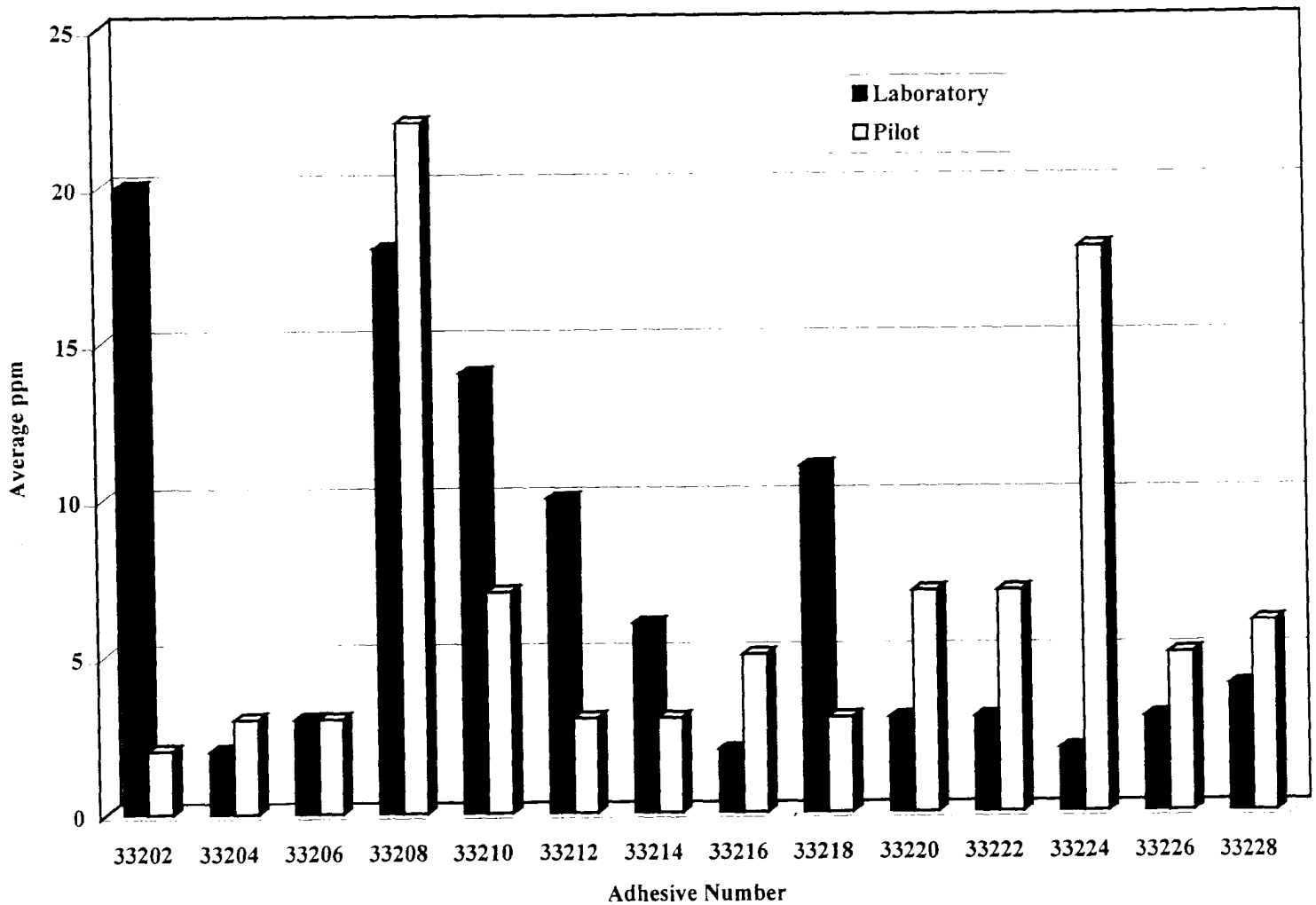


Figure 18.
Comparison of Intaglio Print Method on Laboratory and Pilot Recyclability After Flotation



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