Removal of hot-melt adhesives with through-flow cleaners

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ABSTRACT: This study is a follow-up to a series of experiments involving the effect of hot-melt adhesive (HMA) density on through-flow cleaner HMA removal efficiency. The trials reported in this study evaluated the effects of HMA particle size and pulp slurry temperature as well as HMA density. Pilot-scale, preparation, and separation sequences were established to assess the HMA particle removal efficiencies. Results show that HMA particle density pulp slurry temperature, and HMA particle size affect the removal efficiency of HMA particles. Data are presented showing the effect of each of these variables on removal efficiencies. In the range investigated, particle size did not have a large effect on removal efficiecy. A mathematical relationship was developed, and the correlation ofdetermination was 0.832. Future ***studies*** *should include the effect of HMA particle shape on removal efficiency*

KEYWORDS: Adhesives, cleaners, cleaning, density, efficiency hot melts, particle size, removal temperature.

The objective of this study was to investigate the relationship between hot-melt adhesive (HMA) density and through-flow cleaner removal efficiency. Through-flow cleaners are hydrocyclones designed to remove lightweight contaminants from pulp slurries. A previous study showed that, under certain conditions, HMA contaminant-removal efficiencies by through-flow cleaning is strongly controlled by HMA density[2].

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On a pilot-plant scale, this study investigates the removal efficiency of various low-density adhesives from pulp slurries. The HMA density values examined are limited to those less than water because these are typical of most commercial HMA densities. We investigate how the removal efficiencies of HMA contaminants are affected by HMA density, HMA particle size, and pulp slurry temperature.

We also derive an empirical relationship between removal efficiency and various combinations of HMA density and slurry water temperature.

Experimental procedure

Adhesive preparation

The HMAs were received in the form of cast blocks (76 x 76 x 25 mm) or as pieces from a cast sheet that was approximately 12.7 mm thick. All HMAs used in this study incorporated a dark blue dye in their formulations to allow detection in handsheets. Density of the HMAs was determined according to ASTM Method D-792, with confidence levels determined using an NIST-certified glass standard. Hot melts A to C and E to F **(Table I)** were melted

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[1]The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin. This article was written and prepared by U.S. government employees on official time, and it is therefore in the public domain and not subject to copyright.

[2]Wise, E. M. and Arnold, J. M., *Tappi J.* 75(9): 181(1992).

I. Summary of hot-melt adhesive study[a]

	Immersion liquid					
	Water		Acetone		Isopropanol	
Hot-melt sample	Density	SD	Density	SD	Density	SD
NIST[b]	-	-	-	-	2.2018	0.0002
C	-	0.0015	-	0.0011	0.9513	0.0009
A	0.9533	0.0008	0.9805	-	0.9813	0.0006
A (heated to 132°C)	0.9828	-	-	-	0.9824	0.0021
B (heated to 145°C)	-	-	-	-	0.9808	0.0004
B	-	0.0015	-	-	1.0005	0.0010
D	1.0020	-	-	-	0.9404	0.0007
E (heated to 121°C)	-	-	-	-	0.9132	0.0010
F (heated to 143°C)	-	-	-	-	0.8944	0.0025
F (heated to 169°C)	-	-	-	-	0.8978	0.0006
G (heated to 125°C)	-	-	-	-	0.9652	0.0023
H (heated to 123°C)	-	-	-	-	0.9652	0.0023
I (heated to 119°C)	-	-	-	-	0.9698	0.0002

[a]Density given in g/cm^3

[b]Certified glass, density = 2.201855 g/cm^3; standard deviation (SD) = ± 0.000060

and spread on unprinted bond paper, forming a film. After cooling the film, the sheet was disintegrated in a blender, generating a water, fiber, adhesive slurry. This slurry was screened in an atmospheric, vibrating slot screen using 0.254-mm slots to remove the fiber. Small adhesive particles passing through the slots were discarded with the fiber. The adhesive retained on the screen was then rescreened using 0.406-mm slots to remove oversized particles. The accepts, which passed through this screen, were assumed to have a size range of 0.254-0.406 mm. This adhesive was air dried to form a powder suitable for salting a fiber slurry used for trial work.

To evaluate the effect of particle size, the powder of a given adhesive was further fractionated using standard Tyler screens of 1.4 and 0.7 mm^2 (14 and 20 mesh). Adhesives B, C, and E were separated into fine, intermediate, and course fractions, providing the powders for Trials 7, 8, and 10.

Adhesives G, H, and I for Trial 11 were similarly powdered, except that the blending time was reduced from 20 to 10 min, and the adhesive was screened only through the 0.254-mm slots. The intent was to increase the particle size for this trial.

To determine if the density of the melted and resolidified powder was the same as the density of the hot melt as received, a portion of the melted Adhesive A was recast into new blocks, with the remainder being spread on the paper.

The density of the recast blocks was determined to be that of the powder. No significant difference in density was found, and recast blocks were used for subsequent density determinations, Table I gives the density of the HMAs used in this study.

Fiber slurry preparation

Bleached hardwood kraft drylap pulp, repulped at 4% solids, was slot-screened at 0.305 mm, with the accepts passing to a stock tank. The slurry was then diluted to a target value of 0.75% solids. Stirring and recirculation maintained the uniformity of the slurry concentration. Aliquots of slurry were fed from this primary stock tank to the through-flow cleaner feed tank.

Through-flow cleaner trials

The through-flow cleaners used in these trials were 76-mm-diam. models made by Beloit Corp. (Uni-Flow) and Black Clawson Co. (X-Clone). The trials were duplicated to eliminate design differences. Trial I was a preliminary trial used to refine procedures.

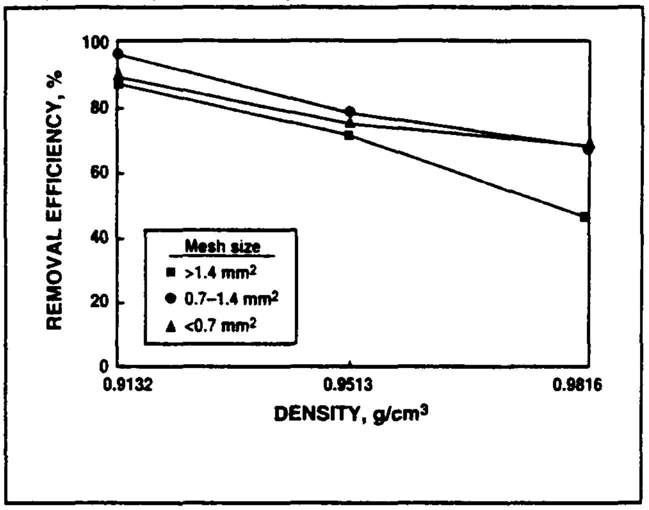
Trials 2 to 5 evaluated Adhesives A to C for the effect of density on removal efficiency. Trial 2 had a cleaner reject line plug during sample collection; consequently, Trial 5 was merely a repeat of Trial 2. For Trials 2 to 5, one hot-melt powder per trial was added to the stock tank to provide a constant hot-melt concentration. For Trials 6 to 11, the cleaner feed tank was filled with slurry from the primary stock tank; a preweighed amount of powder was added to the feed tank and thoroughly mixed. The feed tank provided sufficient slurry for one pass through each cleaner. The tank was then cleaned and again filled with slurry from the primary stock tank, with anew charge of powder added at a target value of 0.2% ovendry pulp basis.

In the feed tank, the slurry was continuously stirred and recirculated to maintain a uniform dispersion of hot melt. For a fiber pass through a cleaner, the slurry was pumped through a "Y," with one leg feeding slurry to the through-flow cleaner

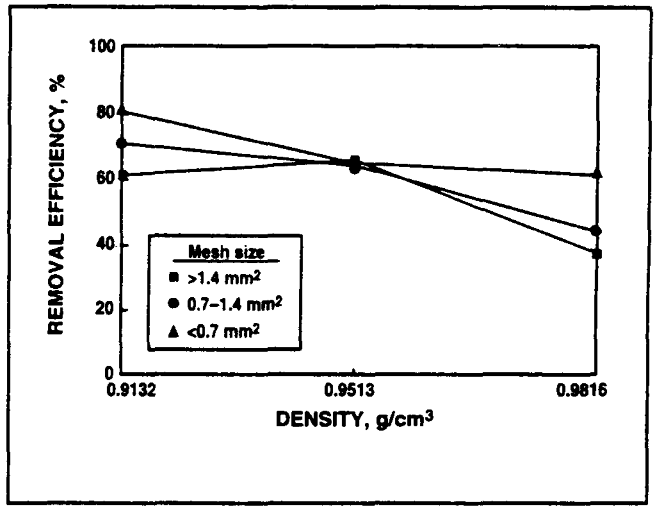
II. Results of hot melt study

Trial	Density, g/cm³	Temp., °C	Mesh size, mm²	Feed solids, %	Accepts solids, %	Feed speck Count	Feed speck Area, %	Accepts speck Count	Accepts speck Area, %	Removal efficiency based on % Speck count	Removal efficiency based on % Speck area
2	0.9513	21	-	0.8406	0.9809	207	0.04560	87	0.01615	58.02	64.58
3	1.0005	21	-	0.7400	0.6124	266	0.07063	248	0.06264	6.63	11.32
				0.7363	0.8688	275	0.06853	257	0.06305	6.55	7.99
4	0.9816	21	-	0.7380	0.7840	255	0.06702	172	0.03918	32.83	41.53
				0.7338	0.8645	254	0.06503	161	0.03796	36.80	41.62
5	0.9513	21	-	0.7108	0.7740	209	0.04322	104	0.01791	50.03	58.57
				0.7143	0.8515	218	0.06911	112	0.01937	48.82	71.97
6	0.9513	66	-	0.7360	0.7930	302	0.06925	103	0.01409	6581	79.65
	0.9513	44	-	0.7800	0.0839	251	0.05276	75	0.01194	70.16	77.38
	0.9816	66	-	0.8205	0.8855	267	0.07797	143	0.03238	46.44	58.47
	0.9816	44	-	0.8118	0.8685	243	0.07902	129	0.03017	47.01	61.82
	0.9513	66	-	0.7258	0.8305	322	0.06999	118	0.01578	63.30	77.45
	0.9513	44	-	0.7732	0.8728	237	0.05540	86	0.01675	63.85	69.76
	0.9816	66	-	0.6325	0.7312	322	0.09603	134	0.02503	58.39	73.93
	0.9816	44	-	0.7985	0.9278	256	0.08523	133	0.03402	48.09	60.09
7	0.9513	44	1.4	0.7373	0.8040	257	0.04579	84	0.01291	67.44	71.80
	0.9513	44	1.4, 0.7	0.7300	0.7820	152	0.04730	53	0.01061	65.52	77.56
	0.9513	44	0.7	0.7368	0.8222	185	0.04953	59	0.01037	68.16	79.07
	0.9513	44	1.4	0.7572	0.8360	220	0.03968	85	0.01225	61.36	69.14
	0.9513	44	1.4, 0.7	0.7422	0.8365	147	0.04708	59	0.01128	59.97	76.05
	0.9513	44	0.7	0.7312	0.8312	231	0.05280	91	0.01623	60.56	69.26
8	0.9816	44	1.4	0.8818	0.9268	80	0.02282	49	0.01070	38.99	53.11
	0.9816	44	1.4, 0.7	0.7830	0.8655	91	0.06064	52	0.01510	42.27	75.10
	0.9816	44	0.7	0.7970	0.8378	179	0.06237	67	0.01811	62.38	70.97
	0.9816	44	1.4	0.8665	0.9892	92	0.02409	61	0.01502	33.70	37.65
	0.9816	44	1.4, 0.7	0.7760	0.8968	95	0.05680	53	0.02247	4418	60.45
	0.9816	44	0.7	0.7928	0.8945	205	0.07247	87	0.02513	57.63	65.33
9	0.8961	32	-	0.7918	0.8627	155	0.06862	38	0.00742	75.62	89.19
	0.9132	32	-	0.7954	0.8585	128	0.07058	39	0.01171	69.25	83.40
	0.8961	32	-	0.8016	0.9138	207	0.09198	40	0.00947	80.52	89.70
	0.9132	32	-	0.7860	0.8964	159	0.08895	41	0.01261	74.43	85.83
10	0.9132	44	1.4	0.7215	0.7658	93	0.06320	29	0.00675	68.82	89.32
	0.9132	44	1.4, 0.7	0.6868	0.7550	71	0.07959	21	0.00378	70.77	95.25
	0.9132	44	0.7	0.6962	0.7815	199	0.09479	39	0.01113	80.28	88.26
	0.9132	44	1.4	0.7112	0.8024	88	0.05522	42	0.00950	52.27	82.80
	0.9132	44	1.4, 0.7	0.6882	0.7385	76	0.08734	23	0.00513	69.54	94.13
	0.9132	44	0.7	0.6900	0.0818	247	0.09978	49	0.01377	80.08	86.20
11	0.9540	44	-	0.8805	0.9418	200	0.12513	101	0.03749	49.31	70.04
	0.9652	44	-	0.8722	0.9602	165	0.11696	94	0.03028	42.86	74.11
	0.9698	44	-	0.8792	0.9700	202	0.10124	98	0.02351	51.49	76.78
	0.9540	44	-	0.8640	0.9912	213	0.14550	110	0.04015	48.35	72.41
	0.9652	44	-	0.8830	1.0123	182	0.11816	100	0.03687	45.04	68.79
	0.9698	44	-	0.8888	1.0308	222	0.10726	118	0.03445	46.73	67.88

1. Effect of particle size on removal efficiency based on speck area compared with particle density



2. Effect of particle size on removal efficiency based on speck count compared with particle density



and the second leg passing slurry back to the feed tank as a recirculation line. This latter leg was the stream used to collect feedstream samples, because it was equivalent to the stream passing to the cleaner. Concurrent with the feedstream sample collection, the corresponding accept samples were collected from the cleaner outlet. Flow rates were determined by collecting two timed 20-L samples from the accepts stream and two timed 4-L samples from the reject line.

For Trials 2 to 5, four passes through each cleaner were made, and four samples of feed and accepts were collected for each pass. Subsequent trials reduced the number of passes and samples per pass, but both cleaners were used in each trial.

Trial 6 examined the effect of temperature on removal efficiency. Trials 7 and 8 looked at the effect of particle size on removal efficiency. Trial 9 extended the range of examined densities and was similar in procedure to Trials 2-5. Trial 10 extended the particle size effect of Trials 7 and 8 to a density of 0.91 g/cm³.

Trial 11 repeated Trials 2-5 and 9, with additional density values in the midrange of the study. By reducing the amount of processing, larger particles were prepared, and greater removal efficiencies were anticipated. The intent of this trial was to locate a critical density, if it exists, where higher densities would result insignificantly lower removal efficiencies and lower densities would improve removal efficiencies. The idea for using larger particles for Trial 11 was based on the results of Trials 7, 8, and 10, which suggested that larger particles would be easier to remove by the cleaners.

Determination of residual adhesive

Handsheets were made from the feed and accepts and conditioned according to TAPPI Test Method T 205 om-88. The HMAs were dyed by the manufacturer for contrast enhancement with respect to the pulp. The sheets were then evaluated for speck count using an Optimax Speckcheck instrument (using a Hewlett Packard ScanJet IIc flatbed 400-dpi scanner connected to a Dell 486 Dimension computer). Speck area was determined automatically by the instrument and reported as the percentage of the total area measured. The range of particles was 0.02-5.0 mm². This is the same range used on the dirt estimation chart in TAPPI Test Method T 437 om-90.

Rcsults and discussion

Table 11 is a summary of this study, listing results in the order they were performed. The results of the initial trials were discussed with the cooperators, and additional trials were performed as mutually agreed. This process was carried out several times. In **Figs. 1 and 2,** all data generated by further fractionating the screened HMA particles through sieves and adding these particles separately to the pulp slurries were plotted separately from those obtained from pulps containing only the screened HMA particles. Both types of data were then compiled to illustrate the relationships between variables of interest.

The percentage removal efficiency of the cleaners was calculated as follows:

$$E = 1 - (A_{acc} / A_{feed}) \times 100 \qquad (1)$$

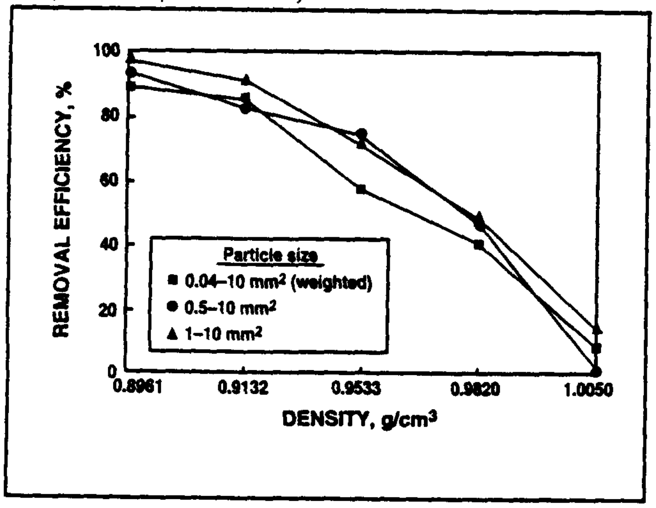
where

E = removal efficiency, %

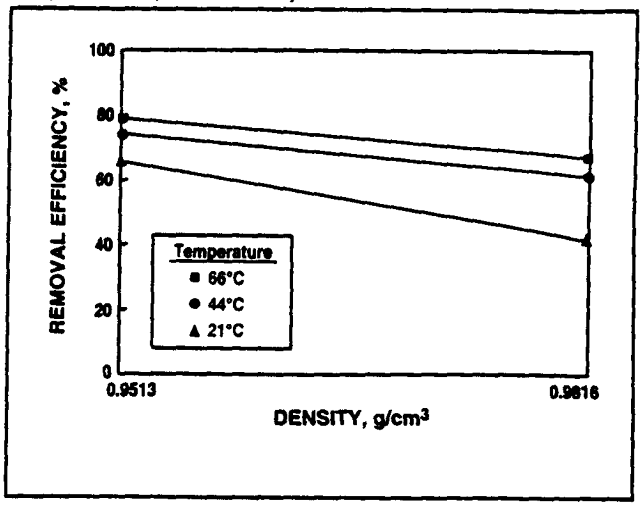
A_{acc} = accept area of HMA particles, mm²

A_{feed} = feed area of HMA particles, mm².

3. Effect of particle size on removal efficiency based on speck area compared with particle density



4. Effect of temperature on removal efficiency based on speck area compared with particle density



Effect of HMA particle size and particle density

From the data presented in **Fig. 3,** density is shown to have a profound effect on the removal efficiency of HMA particles from a pulp slurry. These data are a combination of trials performed at 21°C and 32°C on contaminated pulps that were screened before cleaning. Because two different temperatures were combined for data in this figure, the results are somewhat shifted. However, in general, the results are what we expected from the previous study.

In **Fig. 1,** the data are removal efficiency baaed on speck area at 44°C. Speck area gave results that were more in line with that expected than did the results based on speck count. The speck count results have less of an effect on HMA density than on removal efficiency. Speck area is a more logical basis for calculating the removal efficiencies than speck count, because particle size has an effect on removal efficiency merely reporting the count does not include particle size differences.

Removal efficiencies based on speck count in **Fig. 2** show that a shoulder exists in the removal efficiencies for the largest particles, i.e., those that were retained on the 1.4-mm² (14-mesh) screen aperture. This agrees well with the data from Wise and Arnold[2]. For this large-size fraction, removal efficiencies were essentially the same at about 65% removal for the HMA densities of 0.9132 and 0.9513 g/cm³. These results suggest that any changes we can make to keep the contaminants large improves contaminant removal efficiency. These changes could include greater-consistency pulping and formulating HMAs so that they do not produce small particle sizes during recycling.

Effect of pulp slurry temperature on HMA removal efficiency

Increasing the temperature caused an incresae in removal efficiency. This is a well-known phenomenon attributed to the reduction in water viscosity as the slurry temperature is increased. In **Fig. 4,** increasing the temperature from 21°C to 44°C increased the removal efficiencies for both the 0.9513- and 0.9816- g/cm³ density HMAs.

Increasing from 44°C to 66°C also increased the removal efficiencies, but to a lesser degree. In **Fig. 5,** the same trials are reported as those in **Fig. 4,** except that in **Fig. 5,** the removal efficiencies were calculated based on speck count. Again, we see the same improvement of removal efficiency with temperature. At one set of conditions shown in **Fig. 5,** increasing the temperature from 44°C to 66°C for the 0.9513- g/cm³ density HMA, the removal efficiency decreased slightly.

Mathematical correlations

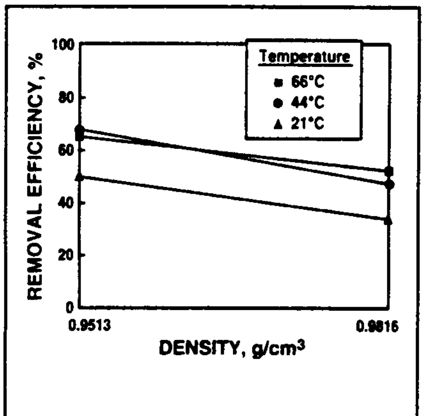
Table III lists the calculations for coefficients of determination *(R^2)* for mathematical relationships between HMA removal efficiencies and measured and controllable process variables The lowest R^2 values were the differences between water and the HMA density. For this relationship, the values were 0,605 and 0.681 for removal efficiencies based on speck area and speck count, respectively.

The next-best fit was found between the removal efficiency squared and the HMA densities. The values for R^2 were 0.590 and 0.688 for area and count, respectively, based on removal efficiencies. The best fits, 0.832 and 0.699, were between log (100 - $E)^{0.33}$ α {(1 - p)/µ)}$^{0.5}$. The 0.832 value signifies a very good fit for this correlation.

This last correlation is an expression that considers both the density of the HMA and the viscosity of the

[3]Kvalseth, T. O., *The American Statistician* 39(4): *279(1985).*

5. Effect of temperature on removal efficiency based on speck count compared with particle size



III. Coefficients of determination: HMA adhesive contaminant removal efficiencies compared with various mathematical correlations.

Correlation *	Efficiency Area	Efficiency Count
$E\alpha\ (1-\rho)^{0.5}$	0.605	0.681
$E^{2}\alpha\rho$	0.590	0.688
$\{\log\ (100-E)\}^{0.33}$		
$\alpha\{(1-\rho)/\mu\}^{0.5}$	0.832	0.699

*E=efficiency of HMA removal; ρ=density of HMA
μ=viscosity of pulp slurry water during trials

pulp slurry water. This suggests that not only does the density of the HMA adhesive have an effect on removal efficiency, but the temperature of the pulp slurry has a large effect. No attempt to model the effect of particle size was made, because the particle size range examined in this study did not have a large effect on cleaner removal efficiency. The good correlation also indicates that particle size for the range we studied is not a large factor.

Concluding remarks

The results of this study are summarized as follows:

- The removal of HMA from pulp slurry is a function of density.The lower the HMA density, the easier the removal of the HMA
- The size of the HMA particles influences the removal efficiency from pulp slurries. The larger the particle, the greater the removal efficiency for HMA particles in the range of 0.04 to 10.0 mm^2. For the range of particles in the 1.4 and 0.7 mm^2 aperture screens (14-20 mesh), a shoulder in the removal efficiency compared with HMA particle density curve was detected for the particles greater than 1.4 mm^2 (14 mesh). However, for the range investigated in this study, particle size had a relatively small effect on cleaner removal efficiency.
- The temperature of the pulp slurry affects the removal efficiency of HMA from a pulp slurry. The higher the temperature, the greater the removal efficiency. Increasing the temperature from 21°C to 44°C increased the removal efficiency in every trial. Increasing the temperature from 44°C to 55°C also increased the removal efficiency, but to a lesser degree.
- The following mathematical relationship between removal efficiency and hot-melt density and pulp slurry temperature was developed:

$$\log(100 - E)^{0.33}\ \alpha\ \{(1 - \rho)/\mu\}^{0.5} \quad (2)$$

Coefficients of determination for this relationship were 0.832 and 0.699 for efficiencies based on HMA speck area and HMA count, respectively. ■

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