Image analysis for measuring adhesive contaminants in pulp

John H. Klungness, Luis E. Fernandez, and Pamela L. Plantinga
Chemical engineer, chemical engineer, and mathematical statistician, respectively, USDA Forest Service, Forest Products Laboratory, Madison, Wis. 53705-2398

ABSTRACT *Image analysis (IA) has the potential for measuring contaminants in recycled wastepaper pulps more accurately, more reproducibly, and more easily than the conventional visual method. An IA method was used to measure a hot-melt adhesive (HMA) contaminant in simulated old-corrugated-container pulp. The effects of handsheet preparation variables and light sensitivity were determined. Weight concentrations of HMA estimated by the IA and visual methods were also compared to the HMA concentration obtained by solvent extraction. The IA method showed greater sensitivity to the presence of HMA than the visual method or solvent extraction, and it also supplied vital information regarding HMA distribution. The IA method could be adapted for detecting and reporting the size distribution of many hydrophobic, heat-sensitive, adhesive contaminants in most recycled wastepaper pulp.*

KEYWORDS
Analysis
Adhesives
Contaminants
Handsheets
Image analysis
Optical measurement
Pulps
Recycling
Wastepaper

Accurate methods that are readily performed and that yield reproducible results are needed for measuring the concentration and size distribution of contaminants in wastepaper pulps *(1)*. Contaminant removal is now and will probably remain for some time the primary technical barrier to recycling *(2)*. In recent years. the amount of recycled wastepaper has varied from 20% to 25% of the U.S. paper and paperboard production. thus representing a major raw material for the paper industry *(3,4)*.

At present, no single satisfactory contaminant-measuring method exists, nor has any method been widely adopted *(1)*. Factors that contribute to the complexity of method requirements include the great variations between the many wastepaper grades *(5)*, which contain heterogeneous and ever-changing contaminants *(6)*, and the wide range of paper grades made from recycled wastepaper, which vary vastly in their tolerance for contaminants. Also, contaminant-measuring methods are used by different groups (for example. those engaged in manufacturing, technical service, and equipment development), and each group has different measuring requirements.

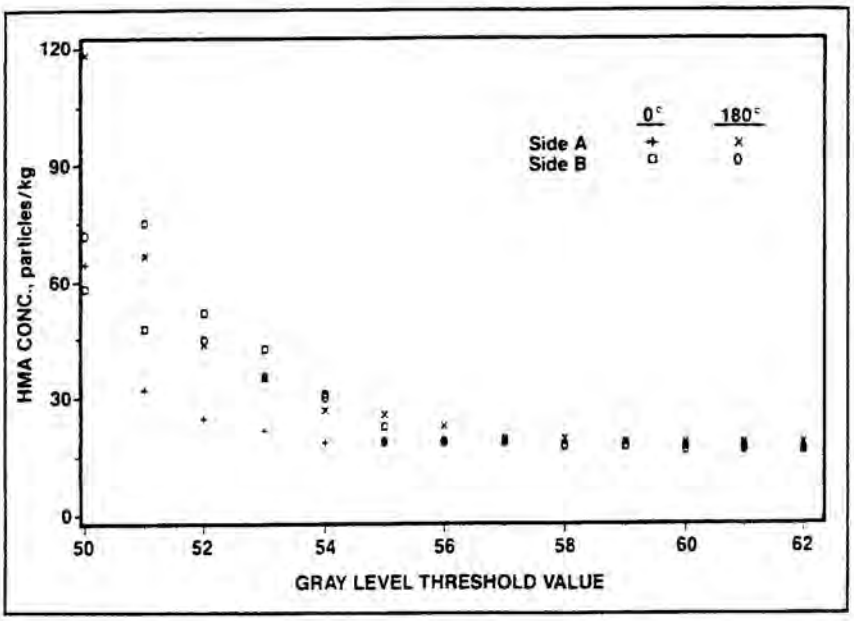
Visual contaminant-measuring methods are usually time-consuming and difficult to perform. They are dependent on the operator, and the results are therefore difficult to reproduce. An emerging area of technology, image analysis (IA), has shown some promise for improved contaminant measurements *(7, 8)*. In considering IA as a tool for measuring contaminants in recycled wastepaper pulp, our purpose here is to demonstrate general principles that can be incorporated into contaminant-measuring methods for the specific needs of individual users.

We report an IA method employing a technique for enhancing sample contrast, which permits greater visual contrast of hydrophobic, heat-sensitive contaminant particles (or hot-melt adhesives, HMA) from hydrophilic wood pulp. The important independent variables involved in the IA method for determining the specific number of HMA particles were as follows:

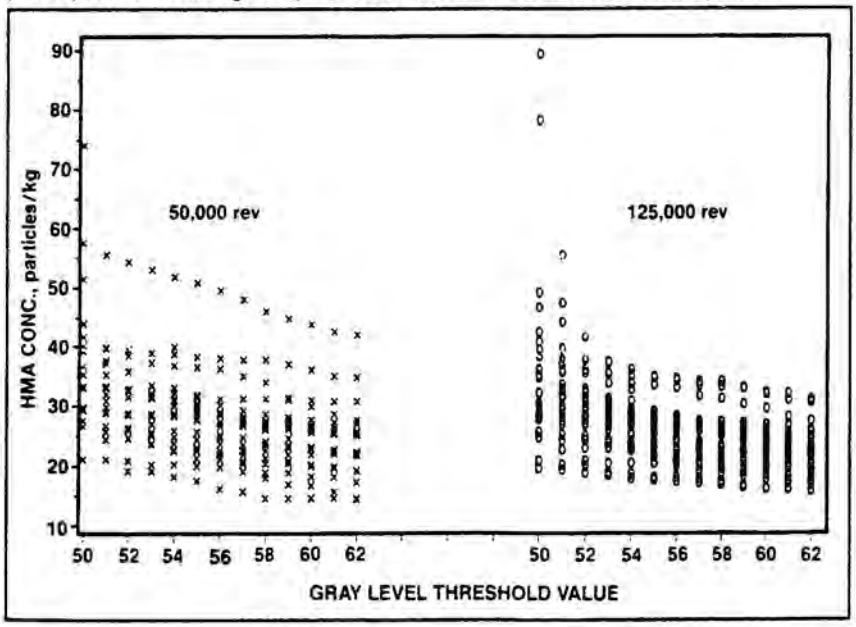
- Gray level threshold (light sensitivity)
- Orientation of handsheets during measurement
- Dispersion of the contaminant during pulp fiberization as reflected by the number of revolutions of the agitator of the British Disintegrator prior to handsheet preparation
- Handsheet basis weight.

The IA technique was compared with a visual measuring technique with respect to measurements of the number and size of HMA particles. The amount of HMA was also deter-

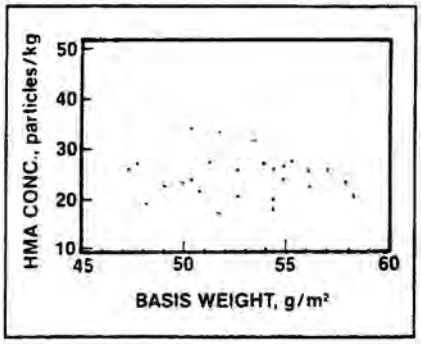
1. The number of hot-melt adhesive (HMA) particles per kilogram of oven-dry solids in a typical handsheet over a range of gray level threshold values



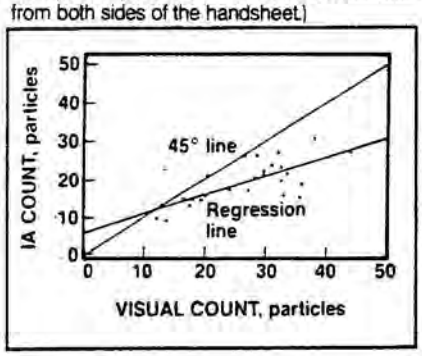
2. The number of HMA particles/kg of o.d. solids in handsheets by detection level. Each data point represents the average of top and bottom sides and initial and 180°-rotated positions



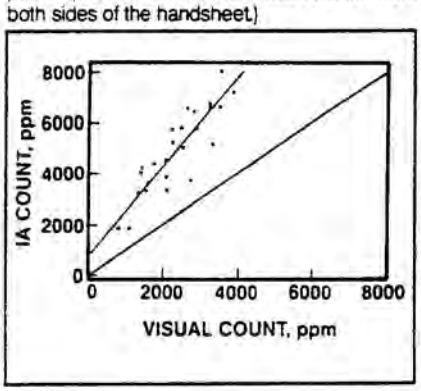
3. The number of HMA particles/kg of o.d. solids in handsheets compared to handsheet basis weight (125,000 revolutions, gray level threshold of 57)



4. The number of HMA particles in handsheets counted by the IA and visual methods (Each data point represents the mean of values taken from both sides of the handsheet.)



5. The area of HMA particles in handsheets detected by IA and visual methods (Each data point represents the mean of values taken from both sides of the handsheet.)



mined gravimetrically by solvent extraction.

Results and discussion

Image analysis

The specific number of HMA particles counted was constant over a range of gray level threshold values. As shown by **Fig. 1,** the specific number of HMA particles remained at about 20 for a gray level threshold range from 57 to 62 (on a unitless scale of 0-64) for a typical handsheet. Also, the orientation of the handsheet during measurement did not affect the specific number of HMA particles when measured over the gray level threshold range from 57 to 62. Handsheet orientation involved four measurements: the initial measurement, 180° rotation, inverting the handsheet, and another 180° rotation.

The amount of fiberizing imparted to the pulp slurry did not affect the IA method of measuring the specific number of HMA particles. **Figure 2** shows the effect of 50,000 agitator revolutions (according to TAPPI T205) compared to 125,000 agitator revolutions in the British Disintegrator for all handsheet basis weights. The results overlapped; there was as

much variability between handsheets at each level of agitator revolutions as there was between the two levels of revolutions. Because there was slightly less variability associated with the 125,000 revolutions, we recommend using the higher number of revolutions.

When the contaminated pulp was given 125,000 agitator revolutions in the British Disintegrator prior to handsheet preparation, the handsheet basis weight (over the range of basis weights studied) did not affect the number of HMA particles measured by IA. **Figure 3** shows the specific number of HMA particles compared to handsheet basis weight. The handsheet basis weight measured varied from 47.5 to 59.1 g/m^2. The data show considerable scatter, and no trend or correlation was observed. At 50,000 revolutions, the specific number of HMA particles slightly decreased as handsheet basis weight increased. This decrease further supports the use of 125,000 revolutions.

Because the grayness level and handsheet orientation had no effect on the number of HMA particles and because of the large variability between handsheets, we believe that when measuring the quality of pulp using IA, it is generally preferable to take one measurement from several handsheets rather than several measurements from a few handsheets. One obtains a better estimate of the contamination this way. The number of handsheets needed depends on the precision required.

6. The handsheet template in the closed position.

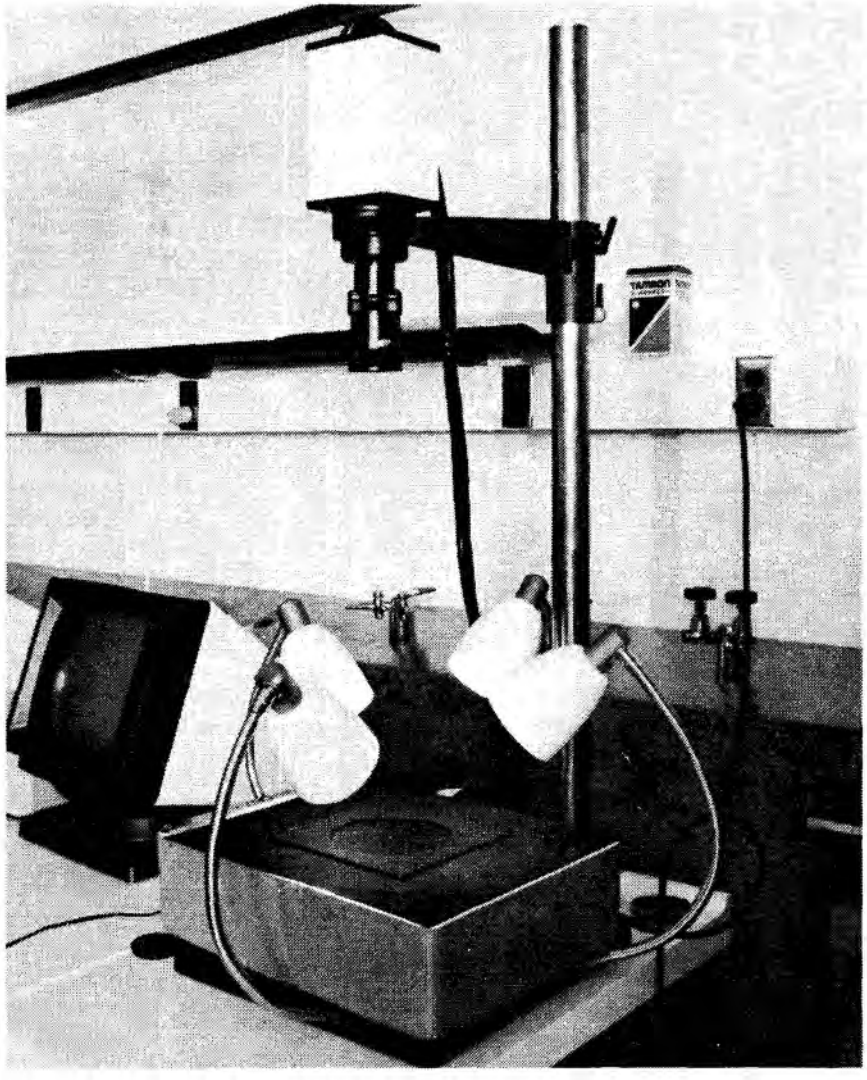


Image analysis compared to visual measurements

The specific number of HMA particles per handsheet measured by IA was fewer than the specific number measured visually **(Fig. 4).** AI1 the data points lie on or below the 45° line. The visual method may have resulted in a higher specific number of HMA particles. If so, this makes the IA method more selective (that is, not as likely to measure other types of materials) than the visual method with respect to measuring hydrophobic, heat-sensitive adhesive contaminants. The standard deviation of the regression line (s) is 5.77, and the correlation coefficient squared (R^2) between the two methods obtained by simple regression analysis is 0.56.

The opposite trend was observed for the total area covered by the HMA particles. In **Fig. 5,** all the data points lie above the 45° line, indicating that the surface area measured by IA (in parts per million of handsheet surface area) was greater than that measured by the visual method. This result is probably due to the differences in lighting used for the two methods. The IA method uses both transmitted and incident light, while the visual method uses only incident light. The IA method completely detects any portion of an HMA particle partially covered by pulp on the handsheet surface, whereas the visual method detects only that portion of the HMA particle illuminated by incident light. Thus, the visual method gives measurement over a smaller surface area because only the portion of particles visible on the handsheet surface is measured. The standard deviation of the regression line is 406.95, and the R^2 between IA and visual total area-measuring methods is 0.78.

Solvent extraction

A randomly selected sample of the pulp contaminated with HMA particles was subjected to solvent extraction to determine the amount of HMA. by weight. Weight concentration by solvent extraction was determined to compare the IA and visual methods with an absolute value.

In practice, solvent extraction to measure weight concentration is unacceptable for two reasons. First, weight concentration measurements tell nothing about how Contaminants are distributed. Second, solvent extraction depends on having a blank without contamination, because natu-

I. Weight concentration of HMA particles measured by solvent extraction, the visual method, and image analysis

Method of measure	Mean conc. of HMA particles, ppm	Coeff. of variation
Solvent extraction	1,213[a]	0.10
Visual method	2,276[b]	0.38
Image Analysis	4,769[b]	0.36

[a]Weight concentration of HMA in pulp.
[b]Weight concentration of HMA in the handsheet, assuming HMA-contaminated areas have the same apparent density and thickness as the overall handsheet.

ral extractives in wood pulp are also removed. Uncontaminated controls are not available in industrial situations, but even if they were available, information on how the contaminants are distributed is vital. Contaminants that are uniformly distributed throughout the sheet need to be differentiated from those that are not. Both the IA and visual methods are sensitive to contaminant distribution.

The results of IA and the visual methods, which measure the surface area, and the results of solvent extraction, which measures concentration by weight, were not expected to be the same. The IA and visual methods should give higher weight concentrations than solvent extraction weight concentrations. With IA and visual methods. the HMA-contaminated areas are assumed to have the same apparent density and sheet thickness as the overall handsheet, rather than much lower HMA apparent density and sheet thickness in the contaminated area. This assumption overstates the concentration of HMA determined by IA and visual methods with respect to the absolute weight concentration, but all the concentrations are expressed on the same weight basis.

Results comparing the IA and visual methods to solvent extraction are given in **Table I.** The concentration of HMA measured by weight was approximately half that measured by the visual method and a quarter that measured by IA. Thus, the IA method showed the greatest sensitivity to the presence of HMA particles. The solvent extraction measurement gave relatively less variability than the visual or IA methods. The IA and visual methods resulted in relatively the same coefficient of variation.

Conclusions

The IA method was developed so as to be insensitive to gray level threshold, handsheet orientation, the amount of agitation used in pulp sample fiberizing, and handsheet basis weight within selected ranges. Compared to the visual method, the 1.4 method detected fewer HMA particles, which may be attributed in part to greater selectivity for measuring only HMA particles. The IA method also measured greater concentration of HMA particles by surface area than did the visual method. This difference is probably due to the ability of IA to detect HMA particles buried or partially buried in the handsheet.

Solvent extraction determination of HMA concentration, by weight, gave a concentration about half that measured by the visual method and about a quarter that measured by the IA method. Thus, the IA method showed the greatest sensitivity to the presence of HMA particles and also supplied vital information regarding HMA distribution.

This IA method developed for measuring HMA contaminants could be adapted for detecting many hydrophobic. heat-sensitive, adhesive contaminants present in most recycled wastepaper pulps. We conclude that the IA method is easier and quicker for the operator to use than the visual method. The principles illustrated here could be adapted and modified to suit specific situations.

Materials and experimental procedures

Materials and sample preparation

A pulp slurry was prepared from single-wall corrugated fiberboard panels contaminated with HMA, which were used to simulate the old-corrugated-container (OCC) grade of wastepaper. The method has been described in detail previously *(9).* All of the panels were obtained from the same commercial lot and were identical to those described previously *(9).*

Molten HMA was applied to the panels. We fiberized the panels in a Morden Slushmaker* for 1 h at 80°C and 3% consistency. Next, the stock was diluted and screened through a 0.3-mm slotted, vibrating, flat screen. This process removed oversized contaminant particles. The accepted stock was thickened by a drum washer to a final solids content of about 20%.

Handsheet preparation

Handsheets were prepared from the HMA-contaminated pulp as described in TAPPI T 205 (57-63 g/m^2) with the exception of drying. After wet pressing the sheets, we dried them on a 130°C hotplate to complete dryness. (The handsheets were removed when steam generation stopped.) The heat applied to the handsheet melted the HMA. The molten HMA spread within the handsheet, increasing the area contaminated with HMA.

HMA visual measurement

After the handsheets were dried, we measured the number and the area of the HMA particles as described previously *(10).* The results were reported as the specific number of HMA particles, or the number of HMA particles per kilogram of oven-dry (o.d.) solids. The results were also reported as parts per million (ppm) on the basis of the handsheet area.

HMA IA measurement

There are four major operations typically involved in IA *(11):*

1. Sample contrast enhancement
2. Image capture and segmentation
3. Object detection
4. Analysis.

The sample contrast enhancement of HMA particles prior to IA was specially designed and was found through extensive experimentation to be essential for our method. Sample contrast enhancement resulted in a well defined image, which made all the subsequent processing more accurate, reproducible, and simple.

Sample contrast enhancement. In image enhancement, we used dyeing and illumination. Handsheets

*The use of trade names in this publication is for reader information and does not imply endorsement by the U.S. Dept. of Agriculture of any product or service.

were dyed with a water-soluble black ink. The handsheets were dipped in a tray containing the ink and were dried between blotters on a 130°C hotplate. The handsheets were again dipped in ink and were allowed to dry in air overnight at room conditions. The ink stained the pulp fibers but not the area contaminated by HMA. Thus, dyeing caused a sharp contrast between the HMA particles and the dyed pulp background.

Two methods of illumination were used simultaneously. In the first method, a template was used to hold the handsheet to be measured. The template was constructed to fit over a lightbox **(Fig. 6).** Transmitted fluorescent light illuminated areas contaminated with HMA but not the pulp background. Measurements were made in a darkened room.

The second method of illumination was incident lighting. We used this lighting to enhance the contrast between the HMA particles and the dyed pulp handsheet. The angle of incidence and intensity of the lighting was the same for each handsheet. However, the method could cause scattering of the transmitted light by refracting the light passing through the transparent HMA particles. This effect would tend to overstate the size of the particles.

Image capture and segmentation. The remaining operations in image analysis were next performed using a Quantimet 970 manufactured by Cambridge Instruments, Inc. The first major operation, image capture, was performed with a scanning high-resolution camera (Chalnicon Scanner). The image was digitized by computer.

The segmenting step included adjusting the gray level threshold. Sixty-four levels of image grayness, or energy levels, were available with our equipment. We wanted a threshold grayness for creating a binary image of either black or white pixels or light points that would accurately reproduce the captured image. Care was needed in this step to separate the HMA particle images from the surrounding dyed pulp background without detecting light spots caused by variations in handsheet formation. The gray level threshold can be programmed to be selected automatically or interactively—that is, relying on operator judgment. We found relying on operator judgment to be easier and less likely to result in a large error.

Object detection. The third major operation. object detection, involved the measurement of the area of each HMA particle. In this step, the number of pixels, above a certain minimum number, were counted to give the area of each particle. The minimum area for detection was set high enough to not count particles below 0.3 mm^2, similar to the minimum size counted in the visual method.

Analysis. The fourth major operation in IA differed from the previous three major operations in that the result was not a better image or one that was in some way changed but was one that provided information about the contents of the image. The information we generated was as follows:

1. Number of HMA particles per handsheet
2. HMA particles per handsheet in ppm
3. Mean particle area
4. Degree of variability of the measurement.

Solvent extraction

Samples of contaminated and uncontaminated pulps were ground in a Wiley mill to 30 mesh. They were dried in an oven at 105°C to a constant weight. Three samples of each were extracted in a soxhlet using 1,1,1-trichloroethane as solvent. The extracted pulps were air dried and then oven dried at 105°C to a constant weight. The mean weight loss of the contaminated pulp minus the mean blank weight loss was taken as the HMA content.

Literature cited

1. Krueger, W. C. and Bower, D. F., Tappi 64(7): 39(1981).
2. Hendry, I. and Bernard, R., Proceedings of 1982 European Seminar on Technological Progress in Recycling of Paper and Board, Commission of the European Communities, Brussels, p. 80.
3. Mies, W. E., Allan, D. R., Pollitzer, S., Adams, D. A., and Irons, P. J., Pulp and paper North American industry factbook, Pulp and Paper Week, Miller Freeman Publications, San Francisco, 1982, p. 253.
4. McGrath, R. M., Pulp & Paper 61(10): 80(1987).
5. Franklin, W. E., Franklin, M. A., and Hunt, R. G., Wastepaper: the future of a resource 1980–2000, American Paper Institute, New York, 1982.
6. Franklin W. E. and Hunt, R. G., Paper recycling: impacts of contaminants 1973–1985, prepared for the Solid Waste Council of the Paper Industry, Franklin Associates Ltd., Prairie Village, Kansas, 1975.
7. McCool, M. A. and Taylor, C. J., Tappi 66(8): 69(1983).
8. Jordan, B. D., Nguyen, N. G., and Bidmade, M. L., Pulp Paper Can. 84(6): TR60(1983).
9. Klungness, J. H., Tappi 70(3): 131(1987).
10. Klungness, J. H., Oroskar, A. R., and Crosby, E. J., Tappi 67(6): 78(1984).
11. Anonymous, Image analysis: principles and practice, 1st edn., Joyce-Loebl, Short Run Press, Great Britain, 1985, p. 6.

We gratefully acknowledge the assistance of Roger C. Pettersen for solvent extraction measurements and the assistance of Richard W. Shilts for handsheet preparations and visual measurements of contaminants.

Received for review July 13, 1988.

Accepted Aug 9, 1988.

Presented at the 1988 Pulping Conference.