Detection of Stickies Using Infrared Thermography

Daniel D. Finkler
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DETECTION OF STICKIES USING INFRARED THERMOGRAPHY

by

Daniel D. Finkler

A Thesis submitted
in partial fulfillment of
the course requirements for
the Bachelor of Science Degree

Western Michigan University
Kalamazoo, Michigan
April 1997
THE DETECTION OF STICKIES USING INFRARED THERMOGRAPHY

Daniel D. Finkler
Western Michigan University, 1997

With the growth in use of recycled material for the production of paper has come the problem of contaminants. The contaminants cause all sorts of problems in the paper making system. The most problematic and costly group of contaminants are known as “stickies”. The current methods for detecting stickies are both time consuming and subjective to operator opinions. With the use of infrared thermography, both of these problems can be solved.

Handsheets containing various contaminants were made to two different weights, on two different handsheet formers. These handsheets were placed in an oven to raise their temperature to 105 °F. The sheets were removed from the oven one at a time and scanned using an Agema 470 infrared camera. During the scans a digital picture was taken and stored on a 3.5” computer disk. The images were analyzed using IRwin computer software.

The images showed that the large chunks of milk jug and silica gel could easily be detected, but the small pieces of sandwich bag, trash bag, and cleaner rejects could not. The detectability of the materials depended primarily on their thickness.
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INTRODUCTION

In the past few decades, the trend in the paper industry has been to use increasing amounts of recycled fibers. The reason for this has been increased environmental concerns, government mandates, and consumer demands. It is estimated that 75% of all of the paper mills in the United States are utilizing some form of recycled paper as a source for their furnish. In December of 1993, the American Forest and Paper Association announced that, the paper industry achieved their goal of recovering 40% of all the paper produced in the United States and is now striving to recover 50% by the year 2000.

This growing utilization of secondary fiber across all paper grades has made it necessary to process lower quality wastepaper, which comes with a high concentration of contaminants. Most of these contaminants are implemented during the converting process to enhance the final properties of the paper. The group of contaminants that pose the greatest problem to paper makers are those which include hot melt adhesives, pressure sensitive adhesives, coating binders, thermoplastic resins, and waxes. This group of materials is commonly referred to as “stickies” and is frequently sited as the major source of machine downtime, reduced product quality, equipment failure and in line process deficiencies. In addition, it is generally believed that the control of stickies is the biggest barrier to increasing the recycled content in paper production today.

Stickies cause problems because they tend to deposit on the forming fabrics, internal surfaces of headboxes, wet press felts, press rolls, uhle boxes, dryer felts, dryer cans, and other papermaking equipment. Once a sticky deposits on a surface its tacky
nature attracts other stickies and the deposit grows fairly quick. As the deposits grow they cause all sorts of quality and runnability problems. If the stickies deposit on the forming fabric, it can cause drainage problems, high vacuum levels, moisture profile variances, holes in the sheet, and even cause sheet breaks. In addition, the stickies significantly shorten the life of the machine clothing, thus increasing machine down time and decreasing production and machine efficiency. The current method to combating the life shortening affect of stickies is to implement expensive chemical treatment programs (7). If the stickies could be detected and removed prior to getting to the papermachine a lot of money could be saved in lost down time, off quality product and lost clothing life.

The problems associated with stickies are complicated, because there is no real efficient way to determine the quantity of stickies present in the paper making system. All of the methods currently developed to test for stickies are both time consuming and subjective to operator opinions, it is believed that with the use of infrared thermography both of these problems will be solved. The reason for this belief comes from the fact that different materials have varying heat capacities and emissivities, thus they should emit different amounts of thermal energy under any given condition. These different energies can be detected using an infrared camera, and thus be used to quantify and identify the contaminants.
BACKGROUND

Previously I explained some the problems that are associate with stickies and how there needs to be a more reliable test for their detection. With all that in mind I will now explain the past work that has been done on this project and then explain the theories behind this test.

Previous Work

The only previous work done on using infrared thermograph to detect stickies was done by Timothy Lobbes, in the fall of 1995 (9). Tim started the work on this topic by placing a cylinder of three different known materials (polystyrene, polypropylene, and polyester) on a blotter paper, heating them up to 105 °C, and then scanning them with the infrared camera. He saw that the different substances, when removed from the heat and allowed to cool, showed up as different temperatures. He contributed this difference to the materials different heat capacities.

I did some preliminary work to better understand what was causing the temperature changes and it lead me to Fourier’s Law of heat conduction. Fourier’s Law explains how heat is transferred through a slab. I used Fourier’s Law to calculate the heat loss curves for slabs of various diameters and thicknesses. I made these calculations using the same materials and conditions used during Tim Lobbes thesis. The results from these calculations can be found in Appendix 2. These results from these calculation showed that the size and thickness of the material greatly affected the rate of heat loss of all of the material. The results also showed that the various substances lost heat at different rates proportional to their heat capacities and thermal
conductivities. It was hoped that these plots would match up with the heat loss of the contaminants used during this experiment, but no time measurement could be acquired during this experiment.

Theory of Infrared Thermography

Infrared refers to the proportion of the electromagnetic spectrum from 1 to 1000 microns wavelength. Infrared thermometers have been in commercial use since the 1960's, monitoring such jobs as the production of packaging films, automobile parts, medical products, coated papers, building materials, and textiles. Infrared thermometers are actually optoelectronic sensors that capture the invisible IR energy naturally emitted from all objects. Emissivity is the term used to quantify the energy emitting characteristics of different materials. Since all materials posses different emissivities, it is believed that different materials should emit varying amounts of thermal energy under a steady state condition and thus allow an infrared camera to distinguish between the substances.
GOAL

Develop a quick, easy, nonsubjective test procedure for the detection of stickies.

OBJECTIVES

1) Determine if infrared thermography could be utilized for the detection of stickies.

2) Determine the affect that the size of the contaminant had on it’s detection.

3) Determine the affect that thickness had on the detection of stickies.
EXPERIMENTAL PROCEDURES

Materials

Unrefined, bleached, softwood Kraft was used as the cellulose fiber. The contaminants that were used included small pieces of milk jug, silica gel, white styrofoam beads, Hefty tall white kitchen trash bags, and Ziploc sandwich bags. These contaminants were chosen, because they were believed to represent contaminants found in everyday contaminant streams.

Equipment

The equipment used during this experiment included the Noble and Woods handsheet former, British handsheet former, laboratory handsheet press, laboratory dryer can, Aminco oven, Tmi model 549 micrometer, and an Agema 470 infrared camera.

Procedure

Handsheets were made to two different weights (one and two grams oven dried) using the unrefined bleached Kraft softwood pulp. Contaminants were added to the pulp slurry before it was dumped into the headbox of the respective handsheet former. All of the contaminants were cut into small pieces using a utility knife. After the handsheets were formed, they were passed through the laboratory press once and then placed on the dryer can to dry. After drying the samples were weighed to check grammage and then the Tmi 546 micrometer was used to measure caliper. The next day the samples were placed in the Aminco oven and allowed to reach 105 °C. The samples were then removed from the oven and placed in front of the infrared camera.
A digital picture was taken of the sample once the temperature of the whole sheet was within the detection range of the camera. The digital images were stored on a 3.5" computer disk. This disk was then loaded into Paul Stewart's computer so the digital images could be analyzed using the IRwin thermal image analysis software.
PRESENTATION OF RESULTS

The results for this experiment are displayed in Figures 1-13, which can be found in Appendix 1. The setup of the figures is as follows: the IR image is in the upper left corner with the temperature profile line just below it. This profile comes from the line that is drawn across the IR image. In the upper right corner is a picture of what the sample actually looks like. Just below the picture is the results box, this contains the temperatures of all the points that were labeled on the IR image and reports some relevant data about the profile line. In the lower left hand corner is a print out of the temperature of the contaminant (represented on the IR image as point 1), the temperature of the cellulose fiber (2), the temperature of the background paper (3), and the temperature difference between the contaminant and the cellulose fiber.

Figures 1-7 show the scans that were performed on Noble and Wood handsheets. These sheets were made to two different weights (one and two grams O.D.), and contained different contaminants. Figure 1 shows that in a one gram handsheet the pieces of milk jug were 10.2 °F hotter than the cellulose fiber. Figure 2 shows that in a two gram handsheet the pieces of milk jug were only 7.0 °F hotter than the cellulose fiber. Figure 3 shows that the silica gel in a one gram handsheet was 10.0 °F hotter, but Figure 4 and 5 shows that in a two gram handsheet it was only 6.3 °F and 7.0 °F hotter than the cellulose fiber respectively. Figure 6 shows two large temperature peaks at the edges that were 8.2 °F above the rest of the sheet. This sheet was two grams and contained a high concentration of cleaner rejects. Figure 7
contains both cleaner rejects and silica gel. The sheet is two grams and shows two temperature peaks that are 8.3 °F hotter than the cellulose.

Figures 8-13 are scans of British handsheets made to one and two grams O.D., and contain various contaminants. Figure 8 is a one gram sheet that contains cleaner rejects. The profile line is fairly flat, but does show a couple of hot spots that are 4.0 °F hotter than the rest of the sheet. Figure 9 is a two gram handsheet that contains cleaner rejects. The profile line is relatively flat, but does have a hot spot that is 2.9 °F hotter than the rest of the sheet. Figure 10 is a one gram handsheet that contains pieces of trash bag. The profile line does not show any hot spots, but does have a mysterious cold spot. Figure 11 is a two gram handsheet that contains pieces of trash bags. The profile line is extremely flat. Figure 12 is a one gram handsheet containing pieces of milk jug and some cleaner rejects. The image shows many hot spots, and the profile line shows numerous peaks that are 3.8 °F hotter than the rest of the cellulose fibers. Figure 13 shows a one gram handsheet with pieces of sandwich bag. The profile line shows a couple of peaks that are 4.0 °F hotter than the rest of the sheet.
DISCUSSION

Explanation of Procedures and Observations

Handsheets were made on two different handsheet formers, to two different weights, and mixed with six different contaminants. The contaminants that were used were chosen, because it was felt that they represented some of the more common contaminants found in today’s waste streams, and they gave a wide range of thicknesses. The handsheets were made to two different weights to determine the affect of mass and thickness on the detectability of the contaminants. The handsheets were all going to be formed on the Noble and Wood handsheet former, but when the cleaner rejects were used they tended to stick to the forming screen when placed on the dryer can. Problems also occurred when the styrofoam beads were to be formed into the sheets. The styrofoam tended to float and did not make it into any of the sheets: therefore, it could not be scanned.

After the sheets were formed and dried they were placed in the Aminco laboratory oven to be heated. This was done in order to heat the sheets to a temperature that would be well above the ambient temperature, so that when they would be removed they would have to lose a significant amount of energy before gaining equilibrium with the surroundings. As the thermal energy of the samples was dissipated the Agema 470 infrared camera was used to detect the changes. An accurate temperature could not be detected for the sheet until it was in the range set for the camera. The detection range for the camera was set between 98.7 °F and 74.5
This temperature range was selected because the temperature of the one gram Noble and Woods handsheets fell so rapidly that a large window was needed to allow adequate time for a snap-shot of the sample to be taken. The temperature of the one gram Noble and Woods handsheet fell below 98.7°F in approximately three seconds. The temperature of the two gram Noble and Woods handsheets and the one gram British handsheets took approximately five seconds to drop into range. The two gram British handsheets took approximately 7-10 seconds to drop into range. The reason for the difference in time to reach the temperature range, I believe, was caused by differences in thickness and mass. The one gram British handsheet had the same mass as the one gram Noble and Woods handsheet, but it took longer for the British handsheet to reach the temperature range because it was 0.003" thicker than the Noble and Woods handsheet. Likewise, it took 2-5 seconds longer for the two gram British handsheet to cool down to the temperature range than it did for the two gram Noble and Woods handsheet, because the British handsheet was 0.005" thicker than the Noble and Woods.

Discussion of Results

The first sheet that was tested was made on the Noble and Woods handsheet former with one gram of pulp and some pieces of milk jug. The scan of this sheet (Figure 1 in Appendix 1) shows that there are approximately fourteen separate spots in the sheet. Since the pieces of milk jug could be seen with the naked eye, they were matched up with the picture of the scan. The location of the spots matched exactly what was seen with the naked eye. When the spots were examined, using the
specialized software, they appeared hotter than the rest of the sheet by 3-10 °F. I believe the reason that each spot was not the same temperature was caused by variation in size and thickness. The pieces of milk jug were tested and their thickness ranged between 0.014" and 0.017". The hottest spot was 10.2 °F hotter than the surrounding cellulose fiber. When examined, that piece of milk jug appeared to be about the same size as the rest, but was found to be the thickest.

Figure 2 shows the scan done on a two gram handsheet that contained pieces of milk jug. It was seen that the milk jug pieces still appeared hotter than the cellulose fiber, but only by 4-7 °F. I believe the reason that the milk jugs had a lower temperature differential with the cellulose was caused by the fact that there was a larger mass of fiber. The added gram of fiber also added thickness to the sheet, raising the thickness from 0.003" to 0.005". I believe that this added mass and thickness slowed the dissipation of heat in the sheet, and reduced the temperature differential between the sheet and the contaminant.

Figure 3 shows the scan of a one gram Noble and Woods handsheet that contains pieces of silica gel. This scan shows a few different spots, with the hottest spot being 10.0 °F hotter than the rest of the sheet. Again these spots agreed with a visual inspection of the sheet. After inspection of the pieces in the sheet it was determined that the temperature differences between the pieces where contributed by differences in size.

Figures 4 and 5 are from the same scan of a two gram Noble and Woods handsheet that contains silica gel. The difference between the two figures is the
location of the profile line and of the points. Figure 4 shows a profile line across the large hot spot in the middle of the sheet. This profile line shows four peaks in the large area, which leads me to believe that this area was made up of multiple pieces. After visual inspection, this hypothesis was proven correct. In Figure 5 the profile line was move to pass through the hot spot in another direction. This line provided much the same results, with it showing two separate peaks in the large center hot spot. This scan was very helpful in showing how the this test can distinguish between spots that are right next to each other.

Figure 6 shows a scan of a two gram Noble and Woods handsheet that contained cleaner rejects. The scan shows two large temperature peaks at the edge of the sheet. Since the cleaner rejects are very small, it is not believed that these peaks are cause by one piece. Instead it is believed that a large concentration may have been responsible for the large peaks. I believe the small size of the cleaner rejects are responsible for the difficulty of their detection.

Figure 7 shows a two gram Noble and Woods handsheet that contains cleaner rejects and silica gel. The profile line shows two large temperature peaks at either end of the line. These peaks were shown to match up with pieces of silica. The temperature differential between the cellulose and the silica was 8.3 °F. This matches up with the results found in the previous scans of the silica pieces. Again the small size of the cleaner rejects hampered their detection. Perhaps with a tighter temperature range and better resolution they may be detectable.
Figures 8 - 13 are all of British handsheets. Figure 8 contains a scan of a one gram sheet that contained cleaner rejects. Again the profile line did not show any direct correlation between temperature peaks and the location of any contaminants, however, the high temperature area could possibly be associated to the large concentrations of the contaminants.

Figure 9 shows the scan of a two gram sheet containing cleaner rejects. This scan was unable to detect any of the contaminants.

Figure 10 is a scan of a one gram sheet that contains pieces of trash bag. The scan was unable to detect any noticeable temperature peaks. I believe that this result was caused by the extremely small thickness (0.002") of the trash bag in relation to the thickness of the sheet (0.006"). I believe that the mass of the sheet over powered any temperature variation that could be contributed to the trash bag.

Figure 11 shows a two gram handsheet that contained pieces of trash bag. This scan also shows no sign of any contaminants. I believe that the mass and thickness of the cellulose fiber over powered the small pieces of trash bag.

Figure 12 shows a one gram handsheet that contains pieces of milk jug and some cleaner rejects. Again, the test was unable to detect the small cleaner rejects, but it was successful in locating the pieces of milk jug. The pieces of milk jug showed up as temperature peaks of about 4 °F. I believe the reason that the milk jug pieces were so easily detected is a result of their size and thickness. The milk jug pieces are approximately three times thicker than the sheet and about eight times thicker than the cleaner rejects.
Figure 13 shows a one gram handsheet that contains pieces of sandwich bag. The scan appeared to show two temperature peaks. After a visual inspection, these peaks were proven to matched up with the locations of two of the pieces of the sandwich bag. Since the sandwich bag is relatively thin (0.003”), and not all of the sandwich bag pieces were detected, it is believed that their large surface areas allowed them to be detected.
CONCLUSIONS

From the data previously presented, I have concluded that the size and thickness of the contaminant are key to the detection of the contaminant. As the size and thickness of the contaminant increases, so does the temperature differential between itself and the cellulose fiber in the sheet. If two different particles are of identical size and thickness, their temperature differential will be contributed to their heat capacities and emissivities. Thickness is more important than size to the detectability of a contaminant. Particles with large surface area, but were very thin (less than 0.005") lost heat much more rapidly than particles that had thickness greater than 0.010". The detection of particle with thicknesses less than .010" and sizes less than 1 mm$^2$ were not detectable under these testing conditions.
RECOMMENDATIONS

1) Determine some way to control environment. Control temperature to slow down any thermal changes.

2) Minimize the temperature range for the IR camera, this will give better resolution of the results.

3) Determine if different types of fibers affect the detection of the contaminants.

4) Develop algorithm relating size, thickness, emissivity, and temperature differential.

5) To allow more research to be done on this project, a new infrared camera and computer software should be purchased.
WORKS CITED


Appendix 1

Figures of IR Scans Containing Contaminants
STICKIES

ADVISOR: BILL FORESTER
STUDENT: DANIEL FINKLER
THERMOGRAPHER: PAUL STEWART
INSPECTION CO: INFRATECH CORP.

LOCATION: WMU PILOT PLANT
DATE: 2/26/97
CONTAMINANT: MILK JUG

Temperature of Contaminant: 94.0 °F
Temperature of cellulose fiber: 83.9 °F
Temperature of Background: 80.9 °F
Temperature Rise Above Fiber: 10.2 °F

Figure 1
Temperature of Contaminant: 96.5 °F
Temperature of cellulose fiber: 89.5 °F
Temperature of Background: 81.4 °F
Temperature Rise Above Fiber: 7.0 °F

Figure 2
STICKIES

ADVISOR: BILL FORESTER
STUDENT: DANIEL FINKLER
THERMOGRAPHER: PAUL STEWART
INSPECTION CO: INFRATECH CORP.

LOCATION: WMU PILOT PLANT
DATE: 2/26/97.
CONTAMINANT: SILICA GEL

Temperature of Contaminant: 94.2 °F
Temperature of cellulose fiber: 84.2 °F
Temperature of Background: 82.2 °F
Temperature Rise Above Fiber: 10.0 °F

Figure 3
Temperature of Contaminant: 96.1 °F  
Temperature of cellulose fiber: 89.8 °F  
Temperature of Background: 82.0 °F  
Temperature Rise Above Fiber: 6.3 °F

**Figure 4**

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STICKIES

ADVISOR: BILL FORESTER
STUDENT: DANIEL FINKLER
THERMOGRAPHER: PAUL STEWART
INSPECTION CO: INFRATECH CORP.

LOCATION: WMU PILOT PLANT
DATE: 2/26/97.
CONTAMINANT: SILICA GEL

Temperature of Contaminant: 96.9 °F
Temperature of cellulose fiber: 89.9 °F
Temperature of Background: 91.2 °F
Temperature Rise Above Fiber: 7.0 °F

Figure 5
STICKIES

Temperature of Contaminant: 95.7 °F
Temperature of cellulose fiber: 87.5 °F
Temperature of Background: 82.6 °F
Temperature Rise Above Fiber: 8.2 °F

Figure 6
STICKIES

ADVISOR: BILL FORESTER
STUDENT: DANIEL FINKLER
THERMOGRAPHER: PAUL STEWART
INSPECTION CO: INFRATECH CORP.

LOCATION: WMU PILOT PLANT
DATE: 2/26/97
CONTAMINANT: CLEANER REJECTS AND SILICA

Figure 7

Temperature of Contaminant: 97.3°F
Temperature of cellulose fiber: 89.0°F
Temperature of Background: 82.5°F
Temperature Rise Above Fiber: 8.3°F
STICKIES

Temperature of Contaminant: 97.4 °F
Temperature of cellulose fiber: 93.4 °F
Temperature of Background: 82.8 °F
Temperature Rise Above Fiber: 4.0 °F
**STICKIES**

**ADVISOR:**
BILL FORESTER

**STUDENT:**
DANIEL FINKLER

**THERMOGRAPHER:**
PAUL STEWART

**INSPECTION CO.:**
INFRATECH CORP.

**LOCATION:**
WMU PILOT PLANT

**DATE:**
2/26/97

**CONTAMINANT:**
CLEANER REJECTS

---

**Profile**

- **Temperature of Contaminant:** 97.5 °F
- **Temperature of cellulose fiber:** 94.6 °F
- **Temperature of Background:** 82.7 °F
- **Temperature Rise Above Fiber:** 2.9 °F

---

**Results**

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---

**Figure 9**

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ADVISOR: BILL FORESTER
STUDENT: DANIEL FINKLER
THERMOGRAPHER: PAUL STEWART
INSPECTION CO: INFRATECH CORP.

LOCATION: WMU PILOT PLANT
DATE: 2/26/97
CONTAMINANT: TRASH BAG

Temperature of Contaminant: 91.2 °F
Temperature of cellulose fiber: 94.8 °F
Temperature of Background: 83.2 °F
Temperature Rise Above Fiber: -3.6 °F

Figure 10
Temperature of Contaminant: 96.6 °F
Temperature of cellulose fiber: 97.0 °F
Temperature of Background: 83.0 °F
Temperature Rise Above Fiber: -0.4 °F

Figure 11
STICKIES

Temperature of Contaminant: 98.2 °F
Temperature of cellulose fiber: 94.2 °F
Temperature of Background: 82.9 °F
Temperature Rise Above Fiber: 4.0 °F

Figure 13
STICKIES

ADVISOR: BILL FORESTER
STUDENT: DANIEL FINKLER
THERMOGRAPHER: PAUL STEWART
INSPECTION CO: INFRATECH CORP.

LOCATION: WMU PILOT PLANT
DATE: 2/26/97.
CONTAMINANT: MILK JUG AND CLEANER REJECT

Temperature of Contaminant: 97.4 °F
Temperature of cellulose fiber: 93.6 °F
Temperature of Background: 83.0 °F
Temperature Rise Above Fiber: 3.8 °F

Figure 12
Appendix 2

Graphs of Time vs. Temperature Calculations Done on Polyester, Polypropylene, and Polystyrene
Figure 14
Different Thicknesses of Polypropylene
Temperature, (°F)

Figure 15
Different Thicknesses of Polystyrene
Temperature, (°F)
Figure 16
Different Thicknesses of Polyethylene
Temperature, (oF)

Figure 17
0.003 Thickness
Temperature, (oF)
Figure 18
0.006 in. Thickness
Temperature, (°F)

polypropylene  polystyrene  polyethylene

Figure 19
0.009 in. Thickness
Temperature, (°F)

polypropylene  polystyrene  polyethylene
Figure 20
0.012 in. Thickness
Temperature, (°F)

- polypropylene
- polystyrene
- polyethylene