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THE USE OF HYDROPHOBIC PLASTICS AS  
INK COLLECTORS DURING DEINKING  
OF NEWS WASTE

by

Brian L. Pahl

A Thesis Submitted To the Faculty of the  
Department of Paper Science and Engineering  
In Partial Fulfillment of the  
Degree of Bachelor of Science

Western Michigan University

Kalamazoo, Michigan

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## SUMMARY

The following study reports the performance of polyethylene and polystyrene in two different forms as ink collectors during deinking. Following a brief case history of conventional deinking and a detailed discussion of deinking with plastic as an ink collector, many variables affecting this process are analyzed. Although the results were somewhat erratic, some generalizations can be made. The polystyrene in the porous form provided maximum ink removal. This can be attributed to its ability to retain adsorbed ink particles. Regardless of the system used, ink removal increased with additional collector surface area. Nevertheless, some re-dispersion of ink particles was evident at longer collection times. The separation of the plastic particles from the pulp following deinking was easily achieved due to their buoyant characteristics.

Over-all, the plastic used in this study at the amounts economically feasible were inadequate by themselves to obtain desirable brightnesses. It is suggested that this process be used along with conventional deinking to obtain high brightness recycled pulp.

## INTRODUCTION

Although paper recycling has been on the upward trend in the last twenty years, figures show that it has done so moderately, (1,2). Most officials agree that paper and paper products comprise roughly 50% by weight of most municipal solid waste. Therefore, it would seem beneficial to reclaim the fiber portion for use as fuel and paper making, and at the same time reduce the solid waste load to the ever decreasing land fill areas. Nevertheless, Trout (1) points out that although paper recycling in the United States had increased 50% from 1945 to 1969, U.S. consumption of paper and paperboard rose by 20% during the same time period. This indicates that recycling has not yet progressed enough to seriously affect today's solid waste problems.

The many reasons for this so-called "delay" in the advancement of paper recycling are both technical and economical (2). The latter is usually associated with geographical location. If the mill is located in a rural area substantial distance from a metropolitan area, it becomes costly to ship waste paper stock from metropolitan collection sites to the mill. In addition, these mills historically are users of virgin fiber and located in areas where pulpwood is in sufficient supply. They do not have and could not afford the necessary equipment to process large quantities of waste paper which must be sorted, deinked, and bleached.

Technologically, the use of secondary fiber in the manufacture of paper and paperboard is hindered by grade quality (2). Cleanliness perhaps plays the biggest role in determining whether or not secondary fiber can be used in producing a specific grade. Wastepaper is most often contaminated with plastics, namely, thermoplastics and pressure-sensitive materials. Such

plastics find their way into the mainstream of waste paper as components of flying splices, seals, labels, functional coatings and laminations. Once in the mainstream, these materials often become part of the finished product and cause translucent spots called "shiners" in the sheet after supercalendering (1).

Although large contaminants in waste paper are readily removed by screening and centrifugal cleaning, thermoplastics and pressure-sensitive materials are not removed efficiently and economically by current recycling processes. Only through hot solvent extraction can some of these contaminants be removed from the furnish.

As a result, Sparks and Puddington (3) have proposed the use of this plastic contaminants as ink collectors during deinking. Since these thermoplastics are hydrophobic (no affinity for  $H_2O$ ) they should indeed adsorb ink particles during deinking. Therefore, it is this study's objective to evaluate polyethylene and polystyrene, under controlled laboratory conditions, as ink collectors in an economical deinking system.

#### THE USE OF PLASTICS AS INK COLLECTORS

In their study, Sparks and Puddington (3) found hydrophobic plastics could indeed adsorb ink on to their surfaces similar to air bubbles during conventional flotation.

One possible explanation can be derived from earlier work by Puddington and Smith (4) in which the spherical agglomeration of barium sulfate was studied. It was found that finely divided barium sulfate, being hydrophilic, formed into discrete spheres of 0.5 to 1.0 mm when suspended in dry benzene. Therefore, the hydrophilic barium sulfate aggregated in such a way as to limit its surface area to the hydrophobic benzene.

The same principle can be used to describe the phenomenon happening with the plastic adsorption of ink. The plastic, being hydrophobic, orients itself in a manner to keep its surface available to the ink particles present in the suspension. This may be one reason why, as Trout states, these plastic contaminants present in waste paper tend to agglomerate when softened during conventional deinking. However, it may be more easily conceivable to think of the water within the slurry as being unable to adsorb onto the hydrophobic plastic, thus allowing the complete surface of the plastic to be available to the ink particles.

The deinking process carried out by Sparks and Puddington (3) consisted of the addition and subsequent dissolving of the surfactant and caustic builder in hot water. Paper was added to a 3% consistency and pulped at 4500 rpm for 2 minutes in a waring blender. Prior to adding the collecting particles to the slurry it was necessary to deactivate the surfactant by precipitation with calcium chloride to insure the surfaces of the collecting particles would remain uncontaminated. The collectors consisting of polyethylene, polyvinylchloride, polystyrene, sulfur, wax, and coated sand, separately or in various combinations, were usually used in spherical form. The time of collection ranged up to 15 minutes at about 2500 rpm of agitation. The collecting particles were later separated from the fiber by screening, centrifugal cleaning, and magnetic attraction depending on the size and type of collector used. As a result, brightnesses of 51.0-61.2% were achieved. The reasons for this procedure and the variables affecting it will be discussed next.

#### VARIABLES AFFECTING INK REMOVAL WITH PLASTIC

##### Type and Concentration of Surfactant



It is common knowledge that in order to obtain satisfactory cleaning during deinking of waste news it is necessary to use a surfactant. The surfactant used may be one of the many available to the manufacturer. It is usually up to his discretion as to which surfactant will compliment his deinking process. However, for this system there are a few restrictions placed on the type of surfactant which can be used. The detergent will act like the ink and attach itself to the hydrophobic plastic, whereby limiting the amount of surface area available for the ink. Obviously, this is detrimental to the process. Hence, it is necessary to select a surfactant which can be deactivated and precipitated from the system prior to addition of collecting solids. The best surfactants for this purpose are then those soaps composed of fatty acids, such as sodium linoleate and sodium oleate. These surfactants can be easily precipitated from the solution as a calcium salt upon addition of calcium chloride. Once the precipitate is removed the hydrophobic collectors can be added. The results of Sparks and Puddington (3) show that the more soluble soaps provide maximum cleaning.

The tendency for surface contamination of the collecting solids by surfactant increases at very high surfactant concentrations, whereby deactivation and precipitation becomes more difficult. If no calcium chloride is added, thus no precipitation taking place, little improvement in brightness is obtained.

#### Type of Builder and Hydrogen Ion Concentration (pH)

Usually a surfactant must be complimented with a suitable builder in order to obtain maximum cleaning during deinking of waste news. As the surfactants, there is a restriction to the type of builder desirable for this process. It is common knowledge that high amounts of caustic, render-

ing a high pH reading, causes substantial yellowing of high groundwood content papers, such as newsprint. This is due to the noncellulose, lignin content of groundwood reacting with the caustic (5). Sparks and Puddington (3) found that at a pH greater than 10, brightness decreased substantially. Therefore, the builder used, being caustic, must be controlled. This can be done by simply controlling the caustic concentration to keep the pH less than or equal to 10. However, this set point is very sensitive and can easily be over shot. Sodium silicate seems to be ideal for a builder in this process since it has its own buffering action which will maintain the pH of the system close to 10 over a large range of addition concentrations.

Also at high pH values the ink particles tend to become peptized (3) thus reducing ink adsorption onto the hydrophobic collectors. The surface of the collector be it plastic or wax, can also be affected, like the ink, by high caustic concentrations. With this in mind, it is therefore very crucial to precipitate the builder out of the system along with the surfactant. Here sodium silicate has an advantage also in that it can be precipitated out with calcium chloride.

#### Type and Surface Characteristics of Collector

Obviously the type of collector used in this process is a very important factor in obtaining maximum ink removal from the fiber suspension. Sparks and Puddington (3) used various materials and their combinations with varying success. It can be concluded that besides being hydrophobic, thermoplastic materials provided the best ink adsorption. This could be due to the softening of the plastic surface from the hot dilution water which gives birth to a surface which can trap and adhere to the ink particles

more readily. Also these thermoplastics are more flexible under the agitation necessary for good circulation of the plastics throughout the suspension. Brittle plastics will break into small discrete particles during agitation. These small particles are then very difficult to remove from the fiber suspension after ink removal is completed.

A more rough, ragged surface opposed to one that is very flat and smooth tends to have better success in keeping the ink adhered to its surface. High shear forces created from agitation, tend to cause ink particles adhered to smooth surfaces to become redispersed. Once redispersed these ink particles become very small and thus difficult to re-collect. Rough surfaces also tend to minimize the tendency for two colliding collectors to "scrap off" each other's adhering ink.

The density of the collector should be a factor in this system. A more porous, less dense object will trap ink into its pores and virtually protect it from surrounding shear forces. Also a less dense material such as foamed polystyrene will float easily in water thereby aiding in eventual plastic removal.

#### The Shape of the Collector

In addition to surface characteristics, the shape or dimensions of the collector will also influence ink adsorption. Sparks and Puddington (3) restricted their study to collectors of spherical shape. Perhaps, as will be suggested later, shapes such as planar, cylindrical, and pyramidal may enhance in adsorption and protect adhered ink from shear forces.

#### Shear Rate

The role shear forces play in stripping the ink from the collector surfaces has already been mentioned. The severity of this, of course, is dependent upon the type, size, shape, and density of the collector used.

However, in general, at increased shear rates (high agitation) the shear forces created will tend to strip adhered ink from the collector or simply prohibit adsorption completely (3).

#### Number of Collector Particles Used

Perhaps the most influential factor affecting the ink removal capabilities of this particular system is the frequency of collision between the collecting solids. As mentioned earlier, the removal of adsorbed ink, as a result of particle collision, is minimized by using collectors with relatively rough surfaces. Nevertheless, the variable is largely controlled by the number of particles used as collectors. The more particles used, greatly increases the number of collisions which can possibly hinder ink removal. Also of concern is the collision of the collecting particles with the walls of the hydropulper or, in this case the warning blender, which strips the collecting solids of the adhering ink.

Rather than the number of collecting particles in the system, the total surface area is the major factor. It can be varied by changes in the number of particles of a specific diameter or increasing the diameter of a select amount. Regardless, of the choice there is a maximum brightness obtainable with increased surface area, after which diminishing returns prevail.

Theoretically, one would think that the amount of surface area needed to collect 100% of the ink would be the total surface area of the newsprint which is covered by ink. Sparks and Puddington (3) used weight ratios of plastic to dry fiber as high as 5:1. Nelson (6) in a bleaching study of secondary fiber found encouraging results at low levels of plastic addition such as 0.7% of dry furnish.

Since most of these thermoplastics range in price from 30¢ to 40¢ per

pound (7) one must first determine the optimum amount necessary for effective ink removal and then consider as to whether or not it is economically feasible to use this amount. Certainly the findings of Nelson's study are encouraging in this manner. Such effectiveness at low levels may be a result of the ink particles agglomerating prior to adsorption on the hydrophobic collectors. Once agglomerated these larger ink particles need less hydrophobic surface area to adhere to. In other words, the hydrophobic solids become coated with ink more than one particle thick.

#### Collector Particle Size

The optimum particle size for the collecting solids is dependent on the shape. For instance, when using spherical shaped particles as collectors it is economically desirable to use the small diameter spheres as possible to limit the amount of plastic in the core or non surface areas, since adsorption is purely a surface phenomenon. When dealing with more flat shapes the larger the particles the larger the useable surface area. Nevertheless, there is an optimum size both economically and performance wise. As previously mentioned, when it is desired to increase the total collecting surface area one can increase the size of the collecting solids or increase their number. This choice is dependent upon the shape of the collecting particle and the magnitude to shear generated with agitation. Sparks and Puddington (3) found that maximum ink adsorption was achieved when using particles of approximately 0.5 mm and less in diameter.

#### Collection Times

The brightness of the finished product decreases almost linearly (3) with increased time of collection. This is simply due to the greater amount of particle to particle collisions which "strip" each other of adhering ink. During this redispersion the ink particles often are broken into smaller

particles which are increasingly more difficult to collect. It is conceivable to think of these ink particles as being constantly collected and redispersed with additional time until they are divided into particles much too small to collect effectively.

#### Type of Ink to be Removed

When recycling waste news, the manufacturer is involved with the removal of "black" ink. This ink is a simple composition of carbon (graphite) and mineral oil with absorption of the ink into the paper substrate. Particles representative of this kind of ink seem to have great affinity toward hydrophobic solids. However if one is going to deink waste news he must concern himself with the colored advertizing inserts which are typically printed with rotogravure inks which included various combinations of pigments, dyes, solvents and binders (5). It is uncertain as to how effective hydrophobic materials can adsorb these particles. Perhaps the pigments, solvents, and binders will interfere with the adhering phenomenon of the ink unto the plastic particles.

#### SEPARATION OF COLLECTING SOLIDS FROM THE CLEANED PULP

The biggest challenge to this deinking system is the removal of the plastic collectors once collection is completed. If large enough, the plastic particles may be separated from the cleaned pulp by screening. Any particles still remaining must be removed by means of centrifugal cleaning. It is then important not to break the ink particles down excessively, since very small, light ink particles can not be separated from the pulp by centrifugal cleaners. Perhaps this should be the leading factor determining initial particle size of the collectors. Sparks and Puddington (3) were able to successfully remove 95% of the added plastic through screening

and centrifugal cleaning of pulp following ink collection. Since the specific gravity of these plastics are quite low they should tend to rise to the surface when the suspension is allowed to settle. A wetting agent may aid this separation process. Once this plastic is on the surface it can easily be skimmed off.

#### ADVANTAGES AND DISADVANTAGES

The major disadvantages of this system, theoretically, are the separation of the collecting particles from the pulp after ink collection is completed and the initial cost of the plastic. Separation may become difficult if the size of the plastic particles are too small initially or are broken down into smaller particles during collection. Nevertheless, through screening and centrifugal cleaning at least 95% of the plastic added should be recovered. Since these plastics are somewhat costly, their use can only be justified if massive recycling is implemented or if small quantities are only used.

Advantages include: one-step deinking, deinking at high consistencies up to 3%, and the obsolescence of flotation equipment. At the hydropulper the plastic is introduced, thus the pulping and deinking take place at the same locality, prior to screening and cleaning. Pulp slurry consistencies of 3% can be used successfully, thereby reducing the total amount of water used and the amount of pumps needed to circulate the system. A reduction in pumps used can be very influential toward total energy consumption. Since these plastics are light in mass, they will float to the surface bringing with them adsorbed ink. Therefore, flotation equipment is not required. This property will also be beneficial to the final separation of the plastic from the pulp following deinking.

One added advantage of this system which should be considered for economic reasons is the recycling of the collectors. Although there is no substantial evidence to support this, it may be possible to reclaim and clean used plastic for reuse until it becomes too saturated with ink for effective ink adsorption.



# EXPERIMENTAL DESIGN

The purpose of an experimental design is to simply enable one to obtain the most results with minimal work. This is usually achieved by careful planning so that a great deal of flexibility is given to the experimenter in meeting his objective. The following table shows by attempt to incorporate such a design.

TABLE 1.- Chart of Experimental Design

TYPE OF PLASTIC		POLYSTYRENE				POLYETHYLENE			
LEVEL OF ADDITION (cm <sup>2</sup> )		64	128	640	1280	64	128	640	1280
TIME OF COLLECTION	10 MIN.		X X	X X	X X	X X		X X	X X
	30 MIN.	X X		X X	X X	X X	X X		X X

X-- Conditions ran

## Choice of Collector

When choosing materials to act as ink collectors, one must first consider how hydrophobic the material is. That is the material should not adsorb water so that its surface area will be available for ink adsorption. Secondly, the material should have some thermoplasticity in order to obtain maximum ink removal. And finally, one should consider the material's relative surface energy, since the adsorption of ink onto its surface is solely a surface phenomenon.

To fulfill these requirements, two different types of plastics were chosen to evaluate as ink collectors, namely, polyethylene and polystyrene both in commercial form.

The polyethylene used consisted of the standard "trash can liner". White polyethylene was used so that ink adsorption could be detected. The polystyrene was of a porous form, similar to the common "coffee cup". However, it consisted of a single sheet of film with much more flexibility. Such plastic is often used in packaging as interleaves. Once again white plastic aided in ink detection.

Polyethylene (8) being the lightest in weight of all commercial plastics has a specific gravity of 0.92 in the solid form. Its thermoplasticity in addition to its "lightness" gives one the ability to safely predict its success as an ink collector. Polystyrene, on the other hand, has a specific gravity over 1 (approximately 1.20) (8). However, in this thesis work, polystyrene of a very light density (porous) was used. This not only aids in ink collection but the final separation of the plastic from the deinked stock. Due to the availability of these two plastics in this form, I opted not to purchase polyethylene and polystyrene from a supplier with a pre-determined size and shape, but to use them as they come most often

in commercial form. Plastic of this form would seem to be most affordable to the deinker as scrap from plastic extrusion facilities. Also, such plastic may very well be a contaminate within the waste paper prior to processing.

Since both plastics were of a film or planar form, maximum surface area per given weight in addition to extreme flexibility was achieved.

#### Selection of Variables

For simplicity, the plastics were cut into 2 cm x 2 cm squares. This at first glance may seem a bit large for the total process, but for experimental purposes, sizes smaller than this would have been extremely difficult to cut and later separate from the system. Furthermore, by using the plastics in planar form of the same dimensions, I was able to compare the plastics deinking abilities on an equal surface area basis rather than total weight. Refer to Table 1. The surface areas of the plastics were determined by considering the top and bottom portions of the plastic squares only. The edges were considered neglectible. Likewise, the pores within the polystyrene were not accounted for in calculating the collectors surface area.

In addition to the types, shapes, and sizes of plastics used, many other factors greatly determine the collectors ability to adsorb and retain ink particles. Some of which are degree of agitation or circulation, time of ink collection, and level of collector addition.

The degree of agitation was kept constant during deinking in order not to introduce additional variables. Nevertheless, the actual agitation or degree of circulation of the collectors changed with varying addition levels at a constant propeller speed. This would be expected since the consistency of the whole system does indeed change with varying levels of plastic addition. Although this was known, little could be done to com-

pensate for this without a great deal of study toward this subject, itself.

The two variables looked at most closely were the level of plastic addition and the time of ink collection. An exponential range of collector addition levels allowed me to obtain a wide scatter of results from which curves could be plotted to determine an optimal point. Thus surface areas of  $64 \text{ cm}^2$ ,  $128 \text{ cm}^2$ ,  $640 \text{ cm}^2$  and  $1280 \text{ cm}^2$  were chosen. These surface areas were initially determined by selecting a range of additional levels on a weight percentage basis since it was felt that additional levels much greater than 10% (based on O.D. fiber) would be economically unfeasible for an industrial size operation. In addition, proper circulation of the collecting plastics was impossible at addition levels greater than 10%. Thus  $1280 \text{ cm}^2$  was determined to be my maximum level of addition. Furthermore, by knowing the plastic's equivalent weight corresponding to each level of surface area, the quantities of plastic could be obtained by weight measurement rather than laborious particle counting. Refer to page 30.

Unfortunately, due to limited experimental time the length of collection was limited to two time levels, namely 10 minutes and 30 minutes. The time of collection refers to the actual time the plastic is within the system collecting ink until agitation ceases and the plastic is removed.

With such a design both time levels could be run with at least three levels of plastic addition in order that a curve consisting of three points could be derived. Refer to Table 1. It was decided that both collecting times would be run at the maximum addition level of  $1280 \text{ cm}^2$ , in order that the maximum ink removal possible could hopefully be determined.

#### Experimental Procedure

The procedure for this study can best be described by the following outline of sequential steps:

- 1) Weigh out 50 grams (O.D.) of waste newsprint in a 3 liter stainless steel beaker. Add 1467 milli-liters of warm (130°F) tap water and disintegrate into a slurry.
- 2) Disperse 0.02 grams (0.4% based on 50 gram O.D. fiber) of sodium oleate (surfactant), 0.20 grams (4.0%) of sodium silicate (builder and buffer), and 0.025 grams (0.5%) of sodium peroxide (bleach) in 200 milli-liters of warm water.  
It was found that the sodium peroxide was necessary to bleach out some of the "toner" dyes in order that ink removal could be evaluated. Without sodium peroxide, ink removal occurs but without a detectable increase in brightness.
- 3) Add the dispersed chemicals to the slurry to a total volume of 1667 milli-liters. The slurry should now be at a 3% consistency. Pulp the system for 15 minutes with low but adequate agitation. The pH should remain around 10.
- 4) Following pulping, deactivate the surfactant and builder with sufficient calcium chloride to convert them to their sodium salts. Wash the pulp with warm water on a buchner funnel to remove the sodium salts.
- 5) Separate the pulp into two components, 25 grams, O.D. each. Use one component to make a blank pad prior to deinking. Empty the other 25 grams of pulp back into the 3 liter beaker and add sufficient warm water to make a slurry of 2% consistency.  
It was found that in order to achieve proper circulation of the collectors a slurry at 2% would have to be used.
- 6) Weigh out the quantity of plastic needed and add accordingly. Pulp at 4500 revolutions per minute to allow maximum circulation. Allow up to 10 or 30 minutes for ink collection.
- 7) Empty the slurry into a setting pan and dilute one half to allow the plastic to separate from the fiber and float to the top. Skim off the plastic which comes to the surface.
- 8) Make buchner funnel pads or handsheets of each run.
- 9) Evaluate each pad or handsheet for brightness. It was found that the initial brightness of all the 50 gram samples ranged in brightness (G.E.) from 36 to 42, thus suggesting a large variance in the amount of ink on each 50 gram sample. Therefore, it was necessary to run blanks on each run and to record the eventual brightness after deinking as units of increased brightness rather than actual brightness.

## EXPERIMENT MATERIALS

### Equipment

1-3liter stainless steel beaker  
1-200°F thermometer  
1-variable speed laboratory mixer  
1-1 3/4 inch diameter propeller  
1-setting pan (any dimension)  
Mettler Scale (nearest 0.01)  
Brightness meter G.E.  
Buchner funnel

### Materials and Chemicals

Sodium Oleate-neutral powder (Merck and Co., Inc.)  
Sodium Silicate  
Sodium Peroxide-granular (Natheson, Coleman and Bell)  
Calcium Chloride-fine granular  
Warm tap water (130°F)  
News Print (Kalamazoo Gazette)  
Polyethylene (trash can liner)  
Polystyrene (packaging interleaf)

## RESULTS AND CONCLUSIONS

The average standard deviation for the following results was  $\pm 0.4$ . Since this is relatively high for this particular study it is the author's feeling that the data be received as general trends rather than specific values, particularly at lower levels of plastic addition ( $64 \text{ cm}^2$  and  $128 \text{ cm}^2$ ). It is at these lower levels of addition that the data becomes interchangeable thus further discussion of these values would bring forth a false analysis. Nevertheless, interesting phenomena do occur between the different plastics, particularly at higher levels of plastic additions. Thus, it is essential that these generalizations be discussed in more detail.

From Figures 1 and 2 on page 23 it can be seen that, as expected, the maximum increase in brightness is achieved with the greatest available surface area for collection ( $1280 \text{ cm}^2$ ). Such a relationship seems to be somewhat linear with polyethylene particles used in this study (Figure 1), whereas with polystyrene the increase in brightness with additional surface area increases more abruptly past  $640 \text{ cm}^2$  relative to addition levels below  $640 \text{ cm}^2$ .

With both plastics the over-all efficiency of ink removal decreased with increased collection time past 10 minutes (Fig. 3 and 4). However, since only two time levels were studied, such conclusions may be subject to error.

Both plastics proved to be inadequate ink collectors at the addition levels studied to obtain desirable G.E. brightnesses of 55 to 60.

## DISCUSSION

The performance of the polyethylene particles in this study can be

readily predicted due to the linear characteristics of the curves in Figure 1. This is true, regardless of the length of collection. With the two curves in Figure 1, relatively similar in slope, location and shape, it can be concluded that the controlling variable in ink collection with polyethylene is the amount of available surface area for the ink to adhere to. Although somewhat logical the relationship is not so simple. At addition levels less than or equal to  $1280 \text{ cm}^2$  a collection time of 10 minutes is sufficient in obtaining maximum ink removal for each particular system. In other words, the ink collection potential of polyethylene (at this particular size) at these levels of addition, is achieved somewhere within 10 minutes. Further time for collection is detrimental.

It is unfortunate that an exact optimal time of collection cannot be determined from this study, but from Figure 1 and 3 it can be seen that collection efficiency is slightly worse with a collection time of 30 minutes. Perhaps this is due to re-dispersion of the ink particles from shear caused by particle collisions and propeller agitation. Once re-dispersed, the particles become very small and the probability that they will come in contact with the polyethylene collectors becomes increasingly less. This may also explain why the 10 minute curve and the 30 minute curve in Figure 1 seems to disjoin at higher levels of polyethylene addition. At higher levels of polyethylene addition, more ink is collected relative to lower levels. However, with increased collection time, higher levels create more particle collision whereby re-dispersion of the ink occurs. This conclusion is also depicted by the  $1280 \text{ cm}^2$  line in Figure 3 which has the largest negative slope.

In contrast to the polyethylene, the polystyrene used in this experiment does not perform predictable as an ink collector. There is a marked



difference in ink collection at all levels of addition between the two times of collection. At lower levels (less than  $1000 \text{ cm}^2$ ), maximum ink collection was achieved within 10 minutes, (Figure 2). After 10 minutes it appears that re-dispersion may have occurred without re-adsorption. Thus the potential of the polystyrene used in this study as an ink collector when introduced in low levels (less than  $1000 \text{ cm}^2$ ) is achieved somewhere within 10 minutes. As with the polyethylene collectors, it is unfortunate that an optimal time of collection can not be determined accurately, but nevertheless, there is a quantity of surface area at which the ink collection is identical regardless of the length of time used for collection. From Figure 2, this point is obtained at an addition level of  $1000 \text{ cm}^2$ . Although this point is nowhere near optimization, it can be used as the pivot point by which the relationship between the quantity of polystyrene added and the time required to obtain a reasonable increase in brightness is reversed. Such a point can be used to determine a specific system to deink waste newsprint to a particle brightness.

Beyond addition levels of  $1000 \text{ cm}^2$ , sufficient surface area is added to prohibit re-dispersion and maximum ink removal is obtained at 30 minutes of collection, (Figures 3 and 4).

In view of all experimental error it can be concluded that plastic of the low density, porous form such as the polystyrene used in this study is most effective as an ink collector. Such plastic not only has excellent adsorption properties for ink but it also tends to protect adhered ink from extraneous shear forces which cause re-dispersion. Such re-dispersion of ink was a common phenomenon when using the smooth surface polyethylene particles. It may have been so prominent that deinking at collection times of 5 minutes or less may have given optimum results. This can only be speculated.

In addition to its ability to adsorb and retain ink particles, plastic of the porous form has a great deal of buoyancy. Such a characteristic is advantageous to the final plastic removal following ink collection. This property was used successfully in this study by diluting the slurry after ink collection, to approximately  $\frac{1}{2}$  of 1% consistency until all the plastic particles had floated to the surface, where they could be easily skimmed off. The polyethylene particles were also removed by this method, although more dilution was necessary to allow the particles to surface. It would be safe to conclude that with both plastics, 99.9% of that added was removed following deinking with this method of separation.

The large standard deviations for this study (-0.4) reflect the large amount of experimental error encountered. Much of the experimental error is due to the varying initial brightness of each 50 gram newsprint sample. This suggests that each sample of newsprint had varying amounts of ink particles attached to them. Thus the probability of an ink particle coming in contact with a collecting particle was somewhat different at all repetitions of a specific run. Although this is relatively slight in relation to that incurred by varying addition levels, it could explain some of the discrepancy in the results. However, the exact magnitude can not be determined. A solution to this problem will be discussed later.

From Table 1 it can be seen that the actual brightnesses achieved from this type of deinking is relatively low compared to conventional side-hill or floatation deinking. This suggests that at an affordable price, deinking of this type may only be used as an initial deinking step with subsequent simple side-hill washing or as a "toning up" process following conventional deinking in order to achieve higher brightness pulps. Only through massive recycling of the plastic could this process be used for deinking waste newsprint by itself.

FIGURE 1.

POLYETHYLENE

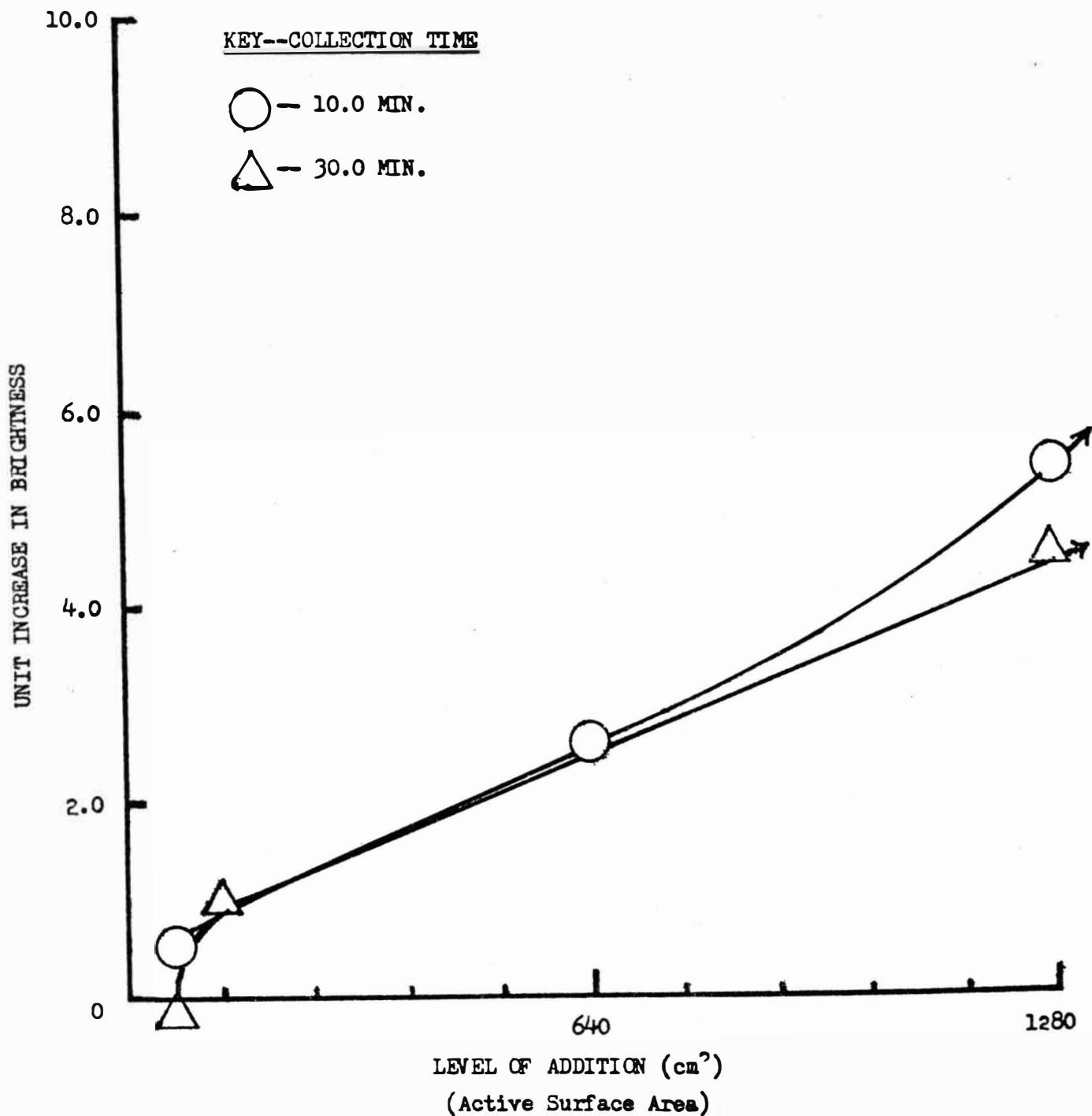


FIGURE 2.

POLYSTYRENE

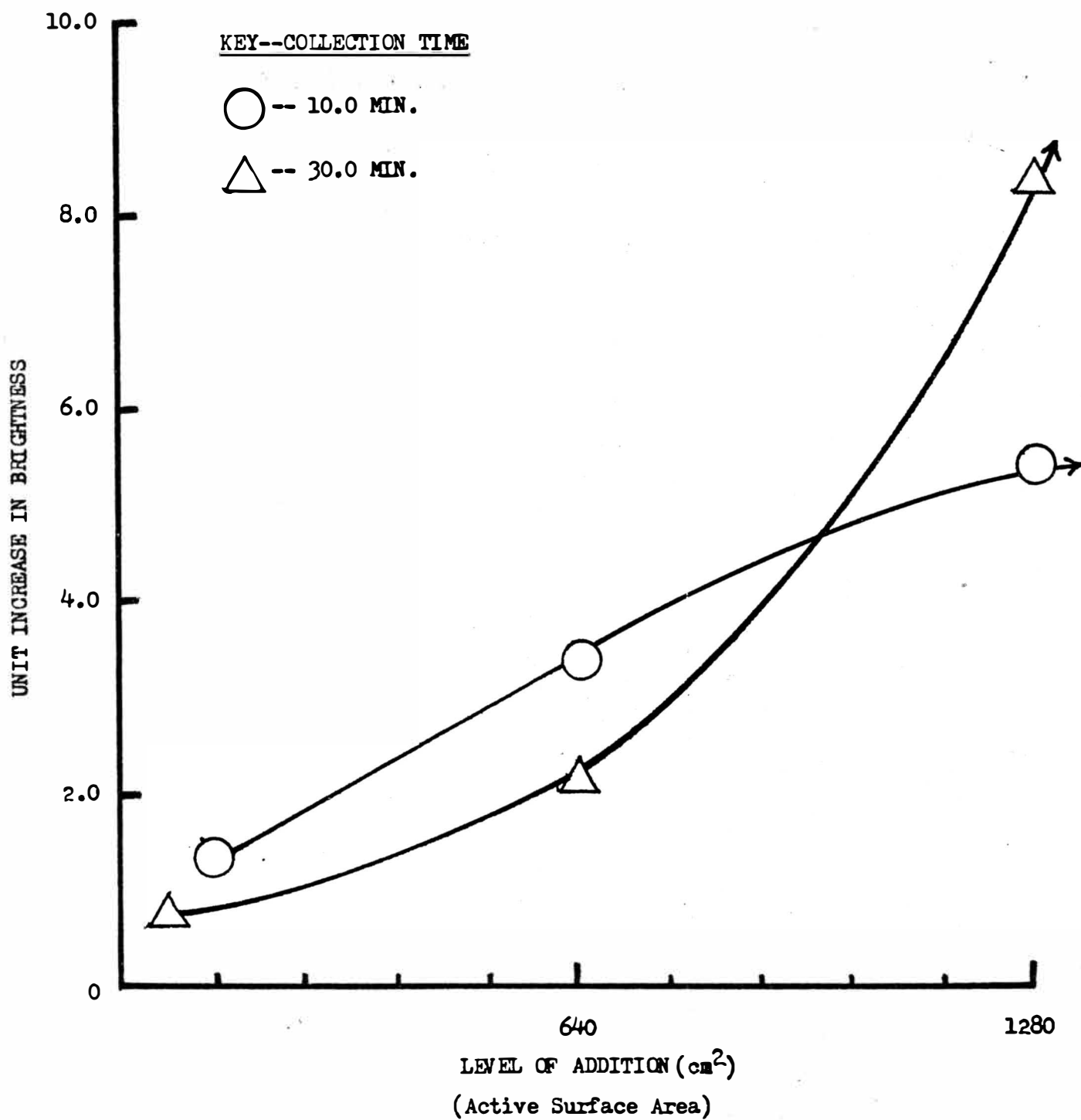


FIGURE 3.

POLYETHYLENE

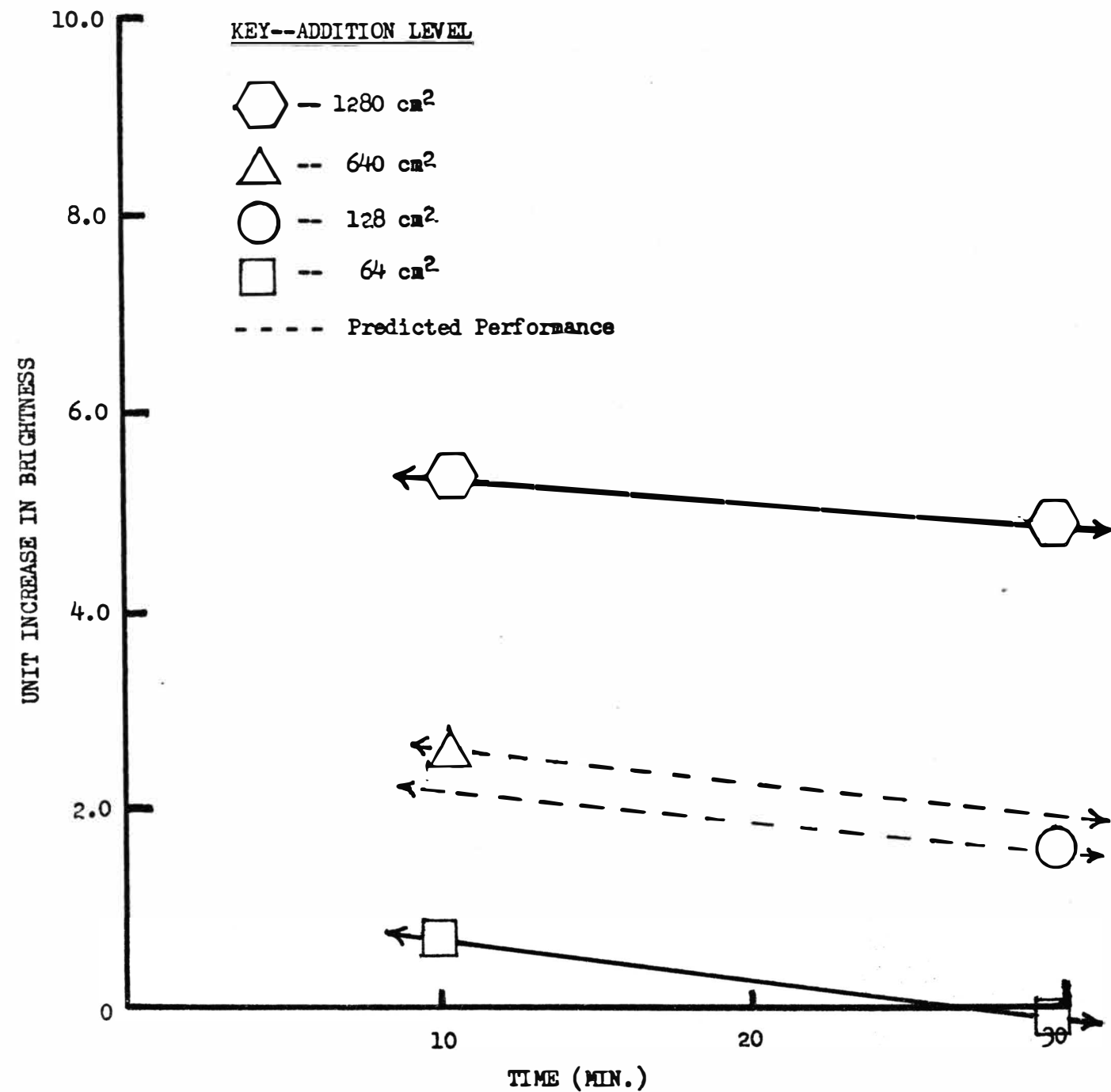


FIGURE 4.

POLYSTYRENE

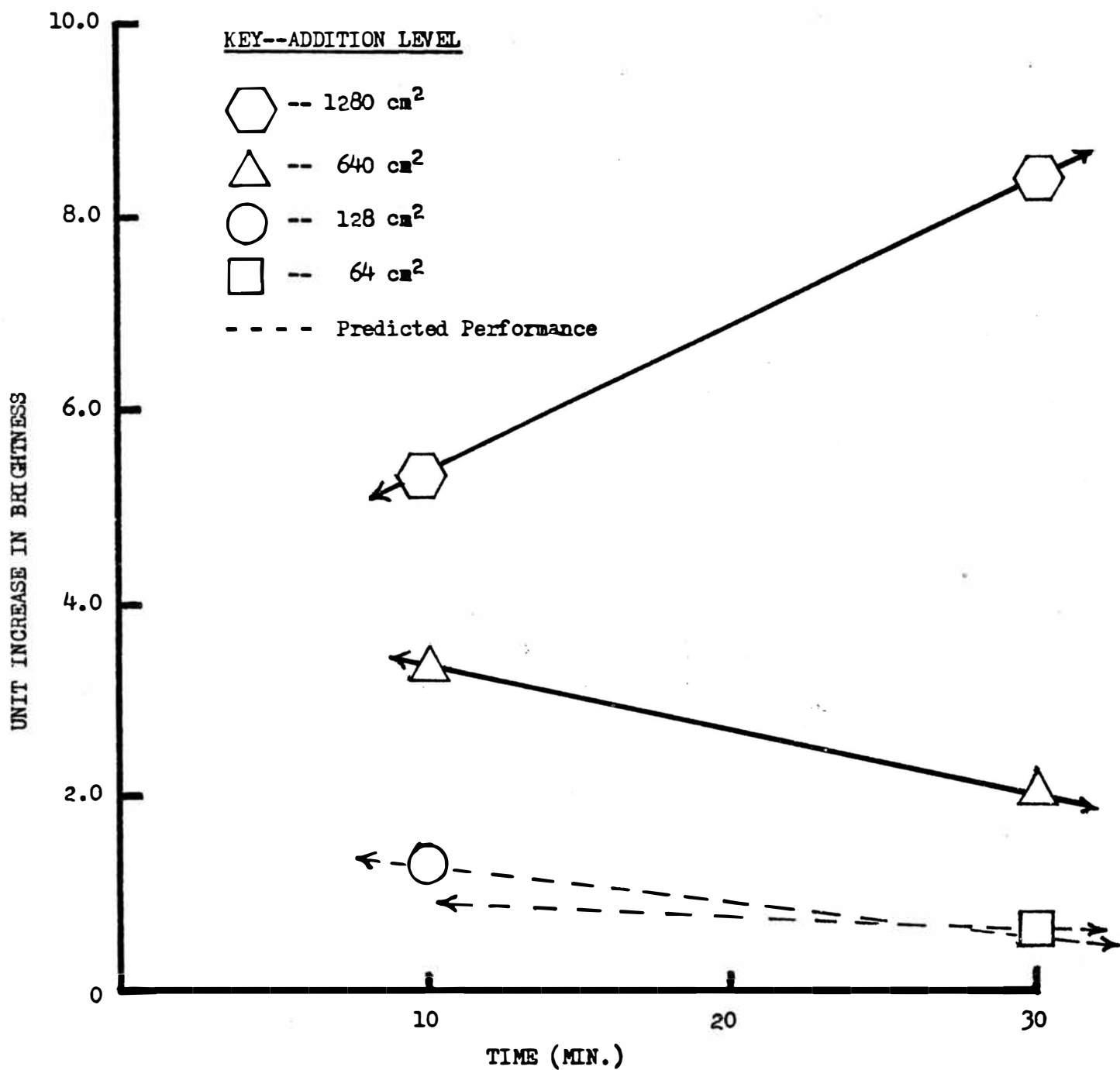


TABLE 2.

## TABULATED RESULTS

<u>COLLECTOR</u>	<u>LEVEL OF ADDITION</u>	<u>TIME OF COLLECTION</u>	<u>INITIAL BRIGHTNESS</u>	<u>FINAL BRIGHTNESS</u>	<u>DIFFERENCE</u>
Polyethylene	64 cm <sup>2</sup>	10 min.	38.6	39.3	+ 0.7
Polyethylene	64 cm <sup>2</sup>	10 min.	39.7	40.1	+ 0.4
Polyethylene	640 cm <sup>2</sup>	10 min.	39.4	42.4	+ 3.0
Polyethylene	640 cm <sup>2</sup>	10 min.	40.1	42.3	+ 2.2
Polyethylene	1280 cm <sup>2</sup>	10 min.	39.4	45.5	+ 6.1
Polyethylene	1280 cm <sup>2</sup>	10 min.	40.3	45.1	+ 4.8
Polyethylene	64 cm <sup>2</sup>	30 min.	41.8	41.8	0.0
Polyethylene	64 cm <sup>2</sup>	30 min.	41.2	41.0	- 0.2
Polyethylene	128 cm <sup>2</sup>	30 min.	39.0	40.4	+ 1.4
Polyethylene	128 cm <sup>2</sup>	30 min.	38.4	39.9	+ 1.5
Polyethylene	1280 cm <sup>2</sup>	30 min.	39.7	44.3	+ 4.6
Polyethylene	1280 cm <sup>2</sup>	30 min.	39.1	43.9	+ 4.8
Polystyrene	128 cm <sup>2</sup>	10 min.	40.8	41.8	+ 1.0
Polystyrene	128 cm <sup>2</sup>	10 min.	42.1	43.5	+ 1.4
Polystyrene	640 cm <sup>2</sup>	10 min.	38.7	41.5	+ 2.8*
Polystyrene	640 cm <sup>2</sup>	10 min.	38.9	42.3	+ 3.4
Polystyrene	1280 cm <sup>2</sup>	10 min.	39.6	41.0	+ 2.5*
Polystyrene	1280 cm <sup>2</sup>	10 min.	40.3	44.3	+ 4.0
Polystyrene	64 cm <sup>2</sup>	30 min.	40.1	40.8	+ 0.7
Polystyrene	64 cm <sup>2</sup>	30 min.	37.8	38.2	+ 0.4
Polystyrene	640 cm <sup>2</sup>	30 min.	39.7	41.6	+ 1.9
Polystyrene	640 cm <sup>2</sup>	30 min.	41.3	43.5	+ 2.2
Polystyrene	1280 cm <sup>2</sup>	30 min.	39.1	47.0	+ 7.9
Polystyrene	1280 cm <sup>2</sup>	30 min.	36.2	45.3	+ 9.1
Blank - trim				53.0	
Blank - trim				53.4	
* Polystyrene	1280 cm <sup>2</sup>	10 min.	38.5	44.9	+ 6.4
* Polystyrene	640 cm <sup>2</sup>	10 min.	38.9	42.1	+ 3.2

\* - Denotes re-checks on skeptical data

TABLE 3.

## SUMMARY OF RESULTS

<u>POLYETHYLENE</u>			
<u>TIME OF COLLECTION</u>	<u>LEVEL OF ADDITION</u>	<u>BRIGHTNESS INCREASE</u>	<u>STANDARD DEVIATION</u>
10 min.	64 cm <sup>2</sup>	0.6	± 0.2
10 min.	640 cm <sup>2</sup>	2.6	± 0.6
10 min.	1280 cm <sup>2</sup>	5.5	± 0.9
30 min.	64 cm <sup>2</sup>	- 0.1	± 0.1
30 min.	128 cm <sup>2</sup>	1.5	± 0.1
30 min.	1280 cm <sup>2</sup>	4.7	± 0.1

<u>POLYSTYRENE</u>			
<u>TIME OF COLLECTION</u>	<u>LEVEL OF ADDITION</u>	<u>BRIGHTNESS INCREASE</u>	<u>STANDARD DEVIATION</u>
10 min.	128 cm <sup>2</sup>	1.2	± 0.3
10 min.	640 cm <sup>2</sup>	3.3	± 0.1
10 min.	1280 cm <sup>2</sup>	5.2	± 1.7
30 min.	64 cm <sup>2</sup>	0.6	± 0.2
30 min.	640 cm <sup>2</sup>	2.1	± 0.2
30 min.	1280 cm <sup>2</sup>	8.5	± 0.8

AVERAGE STANDARD DEVIATION FOR BOTH PLASTICS -- ± 0.4



## MATHEMATICAL FORMULAS

Brightness Increase = Initial Brightness - Final Brightness

$$\text{Standard Deviation} = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$$

where ;  $n$  = number of measurements

$x_i$  = particular measurement

$\bar{x}$  = mean value

# MATHEMATICAL CONVERSIONS

## POLYSTYRENE

Weight/Unit of Active Surface Area\*  $1.97 \times 10^{-3} \text{ g/cm}^2$

<u>LEVEL OF ADDITION (SURFACE AREA)</u>	<u>WEIGHT PERCENTAGE OF O.D. FIBER</u>	<u>ACTUAL WEIGHT ADDED</u>
1280 $\text{cm}^2$	$\approx 10.0\%$	2.50g
640 $\text{cm}^2$	$\approx 5.0\%$	1.25g
128 $\text{cm}^2$	$\approx 1.0\%$	0.25g
64 $\text{cm}^2$	$\approx 0.5\%$	0.13g

## POLYETHYLENE

Weight/Unit of Active Surface Area\*  $2.58 \times 10^{-3} \text{ g/cm}^2$

<u>LEVEL OF ADDITION (SURFACE AREA)</u>	<u>WEIGHT PERCENTAGE OF O.D. FIBER</u>	<u>ACTUAL WEIGHT ADDED</u>
1280 $\text{cm}^2$	$\approx 13.0\%$	3.28g
640 $\text{cm}^2$	$\approx 6.5\%$	1.64g
128 $\text{cm}^2$	$\approx 1.3\%$	0.32g
64 $\text{cm}^2$	$\approx 0.7\%$	0.16g

\*-- Active surface area refers to that area used to calculate surface area. This consists of both sides of the planar square thus neglecting the edges and any internal pores. For example, a 2 cm x 2 cm square particle would have an active surface area of  $(2 \text{ cm} \times 2 \text{ cm}) \times 2$  (top and bottom) = 8  $\text{cm}^2$ .

## RECOMMENDATIONS

Although many generalizations could be made from this study, much still is to be discovered. Many variables such as collector size and collection agitation were not looked at in this experiment due to limited time. In addition, many more variables were discovered while implementing this experiment. Questions such as "What is the optimal collection time?" were unanswered. Answers to this and other questions can not be answered by just one study. Therefore, the following statements should act as guidance for additional studies.

Since the level of surface area introduced to the system is limited due to economical and operational reasons, it is recommended that simple studies be conducted to determine the optimal particle size and shape for whatever type of plastic one wishes to use. Once one knows how large of an operation he is going to employ and at what type and quantity of plastic he can afford economically or his system can accomodate, he can then experimentally determine the optimal size and shape of this plastic at a particular addition level. Following this experiment one involving a wide range of numerous collection times can be employed to determine the optimal collection time for this particular system.

It is also suggested that more careful planning goes into the selection of the kind of plastic used. It is best to obtain the plastic from a supplier so that its exact composition is known. Many manufacturing facilities use a mixture of "scrap" when extruding or molding.

In addition the method of agitation needs to be looked at more closely. The simple beaker with a mixer is sufficient in most cases, but the difference in circulation of the collector particles at a constant propeller speed

is quite profound between low and very high levels of addition. Furthermore, the exact degree of agitation is impossible to reproduce between runs with this type of system. Perhaps a counter-current system would be beneficial in this regard. With such a system the degree of agitation should be more uniform among varying collector addition levels. In addition, particle propellor collisions which cause ink redispersion, would be avoided. The time of collection would be controlled by the input rate of the pulp slurry. Such a system could be implemented in the laboratory or industrial size.

Since the actual brightness values obtained were not high, it is suggested that plastic be used only as a "toning up" process following conventional deinking to a minimal brightness level. In addition, conventionally deinking a large batch to a minimal level avoids the problem of varying initial brightnesses encountered in this study. Since all of the testing will be completed from a "mother batch", much experimental error is then avoided.

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