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The Comparison of a Primary and Secondary Amine as Collectors in Froth Flotation Techniques for Primary Clarification of Paper Mill Effluent

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"THE COMPARISON OF A PRIMARY AND SECONDARY
AMINE AS COLLECTORS IN FROTH FLOTATION TECHNIQUES
FOR PRIMARY CLARIFICATION OF PAPER MILL EFFLUENT"

by
Gerard M. Marshall

A Thesis Submitted to the
Faculty of the Department of Paper Science & Engi
in partial fulfillment
of the
Degree of Bachelor Science

Western Michigan University
Kalamazoo, Michigan
November, 1971

ABSTRACT

The following investigation deals with primary clarification by use of froth flotation techniques. A primary amine was compared to a secondary amine in their collection properties at three pH values. pH variation was found to have an effect on the water content in the foam and the amount of solids collected. A higher pH showed less water content in the foam resulting in higher solids content.

The study indicated that sedimentation had better percent solids coupled with it being a less expensive operation enables it to continue while more efficient methods in flotation are sought out.

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INTRODUCTION

Today's paper industry is faced with the growing task of returning clean water back into the streams. (1) Twenty years ago 37% of pulp and papermaking operations had facilities for effluent treatment. Today, 80% of the paper industry that provides 90% of the national production have facilities or pay for them. (2) In 1965 the total paper products industry had spent \$170 million on waste treatment, with a 30% increase in 1966. For the year 1967 12% (\$26 million) of total expenditures were absorbed by effluent-treatment operating costs and 5% by maintenance (1). The actual capital expenditures for treatment exclusive of operating costs in 1968 and 1969 were \$49 million and \$74 million respectively, with projected costs in 1970 of \$113 million, increasing by 1972 to \$177 million.

While it is of prime importance to return clean water back to the stream, technology must be implemented that will maintain operating costs and capital investments of doing so at a minimum. It is within this context that primary clarification by means of froth flotation will be evaluated in this investigation.

LITERATURE REVIEW

Primary Clarification

Primary clarification is the process of removing settleable solids in waste water streams. Screening, sedimentation and flotation are the most common methods used in primary clarification (3).

Screening

There are three classes of screens used in primary treatment, coarse (1.5-6 in.), intermediate (0.25-1.5 in.), and fine (less than 0.25 in.). However, the fine screens remove only 10% of the suspended matter. These screens are mainly used in the protection of equipment since they cannot equal sedimentation tanks for effluent quality or solids removal (3).

Sedimentation

Sedimentation is one of the most fundamental unit operations in water treatment and, perhaps, the oldest. In this process the effluent is pumped into a basin where the settleable solids can fall to the bottom, leaving unsetttable solids in the effluent.

All settling basins have four basic components; an inlet zone, effective settling zone, solids removal zone, and an outlet zone. To obtain maximum performance, inlet velocities, turbulence, and short circuiting should be minimized. Other factors influencing sedimentation are overflow rate, solids loading and detention time. Though earthen

basins have been commonly used due to capital cost advantages, they will not play an important part in future primary solids removal, due to land requirements, sludge handling difficulties and problems maintaining consistent operation. Mechanically cleaned clarifiers will become the standard (3).

Flotation

Flotation is the process through which particles, heavier than water are raised to the surface by bubbles of gas (usually air) to form a foamy layer. Unlike sedimentation where removal is dependant on particle size and density, flotation is based upon the surface properties of the phase to be removed (4).

Developement of Flotation

The mining industry is one of the forerunners in flotation usage to separate wanted ores from worthless rock or vein matter described as gangue. The ore is floated and skimmed off the surface while the gangue settles to the bottom.

The medium used in flotation is normally water with reagents added to aid in the degree of which particulate matter can be made wet, normally known as wettability. The classes of reagents used collectors, frothers, and modifiers (5).

Types of Flotation

The type of flotation can be identified by the condition of the float. It can be froth, foam or the combination of the two (6).

The froth flotation system is characterized by insoluble monolayers at the gas-liquid interface which is formed by surface active molecules and collected ions. When the froth is collapsed these individual molecules agglomerate to form a scum. When particulate matter is present in the system, the suspended solids form a large part of the scum.

In foam flotation the system is maintained by monolayers of soluble surface-active molecules at the gas-liquid interface. The foam consists of a discontinuous gas phase which upon collapse produces no scum since the solids which are concentrated remain soluble.

A third type of froth flotation is called ion flotation. This system utilizes a surfactants in solution to place a surface charge on the gas bubbles of an opposite sign to that of the ions to be collected. As the bubbles rise through the liquid medium they collect both oppositely charged ion and surfactant to form a two phase froth at the surface (7).

Methods

The two major methods of flotation may be distinguished; as dispersed-air, and dissolved-air flotation (4). In dispersed-air systems gas bubbles are generated by diffusion through porous material, homogenizing a gas or liquid stream, or by the mechanical shear of propellers. This method produces bubble size of 1,000 microns. On the other hand, dissolved air flotation generates the gas bubbles by precipitation of the gas from a liquid supersaturated with the gas, producing bubbles of 80 microns. The smaller bubbles have less liquid to displace from the solid

surface once contact is made. Consequently they become enmeshed in the flocculant structure of the solids more readily than would a larger bubble.

Dissolved-air flotation may be further categorized into vacuum and pressure flotation.

Vacuum flotation is the method in which air is dissolved under atmospheric pressure and allowed to precipitate out of solution under a vacuum.

In the pressure flotation methods, gas is dissolved under elevated pressure and allowed to precipitate out at atmospheric pressure.

Pressure flotation requires smaller capital costs and possesses a greater range of pressure variation. Inlet design is not as critical in vacuum flotation, unless the flotation chamber is not carefully designed, resulting in turbulence from the sudden reduction in pressure.

A flotation system consists of a pressurization-depressurization sequence is comprised of a pressurizing pump, air injection facilities, retention tank or contact vessel, back pressure regulating device, flotation device, and chemical feed equipment (3).

The pressurizing pump creates an elevated pressure in order to dissolve the influent gas, as illustrated by Henry's law. Pressurizing heads are usually in the 20-50 psi range.

A common and highly effective way to inject air into solution is

through the suction side of the pressurizing pump (4). It has been shown that 35 to 45 percent of air is dissolved when added to the pump section without air binding. After addition 60 to 80 percent saturation occurs.

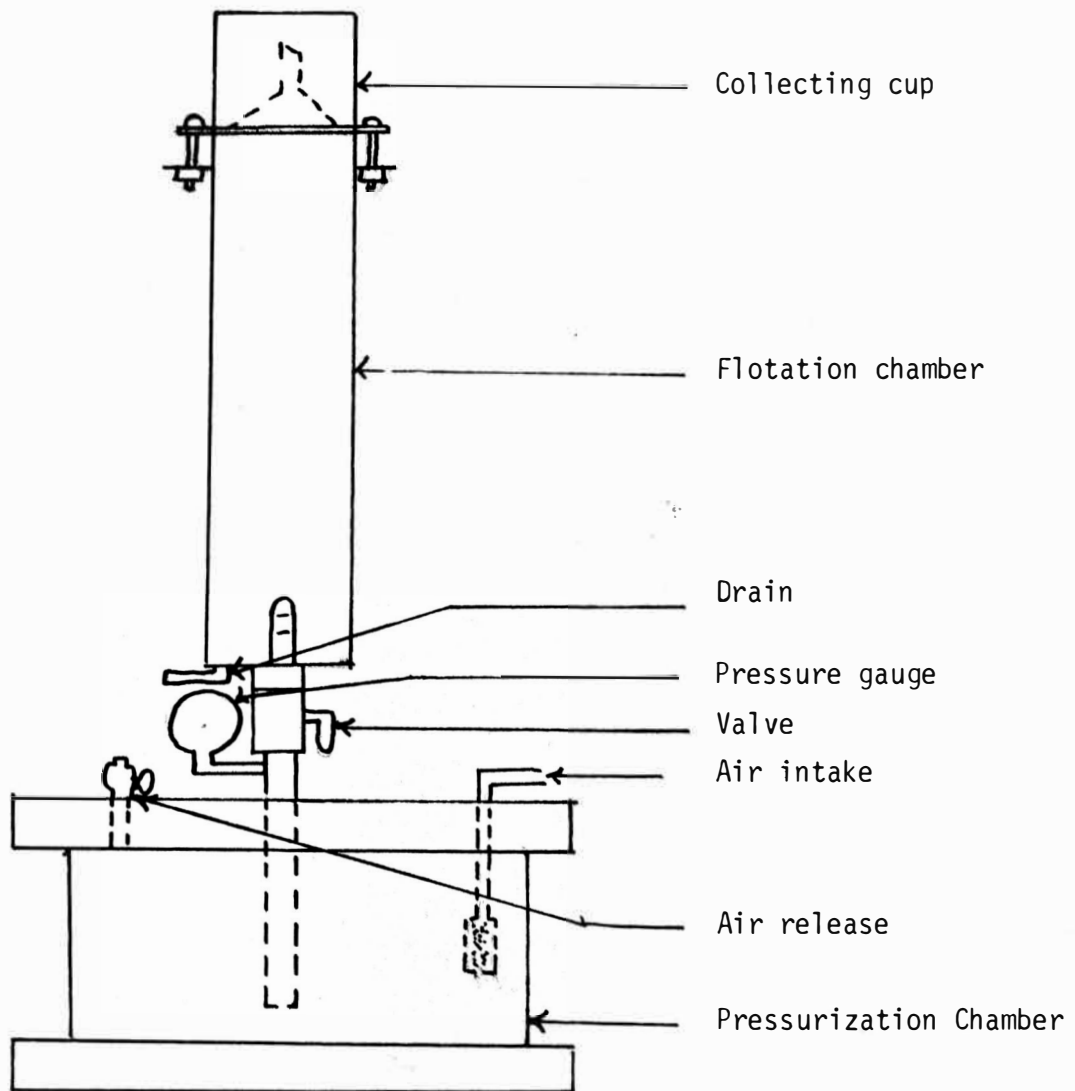
"The retention tank allows for the retainment of the process stream for 30 to 60 seconds". During this time air is dissolved and free air is removed for better efficiency in the proceeding steps (12).

The back pressure regulating device allows for a constant discharge head on the pump. Laboratory apparatus designed for this study is illustrated in Figure 3.

The flotation devices may be classified into two groups. Flotator clarifiers that remove particles exclusively through flotation thus requiring smaller detention tanks. The flotator thickener consists of a single flotation tank that removes through flotation all floatable materials and by the raking of those materials that settle during flotation.

Advantages of Flotation

It has been shown that higher separation rates and solids concentration may be possible with dissolved-air flotation when compared to sedimentation (8). In practice, flotation permits smaller basins, generates volumes of sludge, and allows a higher water recoverage. Furthermore, a flotation unit does not require highly-skilled operators because of its technical simplicity even though it has more moving parts than a clarifier (3).



Collecting cup - (Nylon)
 Flotation Chamber - (2.6 Liter capacity)
 Drain
 Pressure Gauge - (150 psi)
 Valve
 Air intake (1/8 copper tube with air diffuser on end)
 Air release
 Pressurization Chamber - (6" dia. pipe nipple with an open and a blank flange for ends)

Air outlet in flotation chamber is an inverted test tube with horizontal slits.

Applications

A few applications of dissolved-air flotation have been in: canneries, chemical, coal, iron and steel, meat products, mining, soap manufacturing, sugar refineries, and the pulp and paper industry where it has been used in deinking and in save-alls since 1916.

THEORETICAL ASPECTS

Solubility and Precipitation

The flotation process brings the solid, gas, and liquid phases together for a reaction to be carried out.

In dissolved-air flotation air is dissolved under pressure and then allowed to precipitate at a lower pressure. The amount of air dissolved in a liquid is proportional to the absolute pressure of the air (or gas) above the liquid at equilibrium, better known as Henry's Law (4). It may be expressed as:

$$C = k \times p$$

Where C = concentration of gas in solution

p = absolute pressure above the
solution at equilibrium

k = Henry's Law constant

Another important factor is the rate of rise and the diameter of the air bubbles (4). In the preceeding section dissolved-air flotation was said to be better than dispersed-air flotation because of the smaller size of bubble. In a test performed to measure the size of bubble for a more uniform distribution a simulated aeration unit was implemented. Test runs were made at 20 and 50 psi. The bubble size range were nearly identical at at both pressure within the limits of + 30, - 120 microns.

Below 130 microns Stokes law may be used to determine the rate of rise of air bubbles in water.

$$V = D, K$$

Where: V = rate of rise

D = diameter of bubble

K = conversion factor

The solubility of a gas in the liquid medium is also of importance. Solubility is influenced by temperature, dissolved solids and the ionic composition in solution. At greater temperatures and/or greater dissolved solids concentration solubility decreases (5).

Gas precipitation proceeds by the formation of nuclei and their subsequent growth. The size of the air bubbles may be controlled by controlling the number of nuclei through regulation of the gas release (4).

Surface Tension

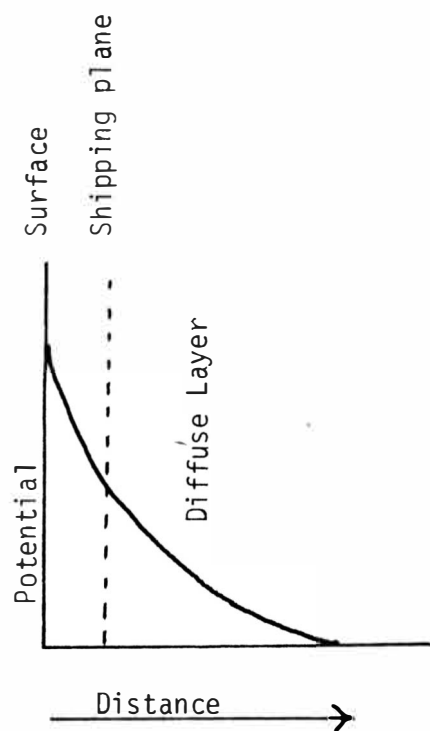
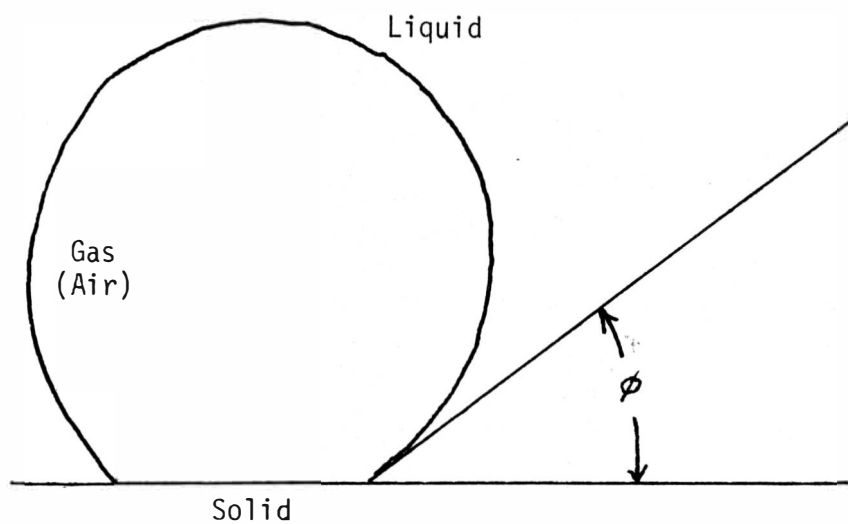
The separation of solid species from one another depend on the relative wettability of surfaces (9). When an air bubble is brought into contact with a clean mineral surface, there is normally no adhesion. However, if a suitable reagent is added the bubble may be attached quite readily. Therefore, in a three phase system (liquid, gas, solid) there will be a point where all three phases come together and form a contact angle (Figure 1). This interfacial tension is expressed through Young's equation:

$$V_{sa} = V_{sl} + V_{la} \cos \phi$$

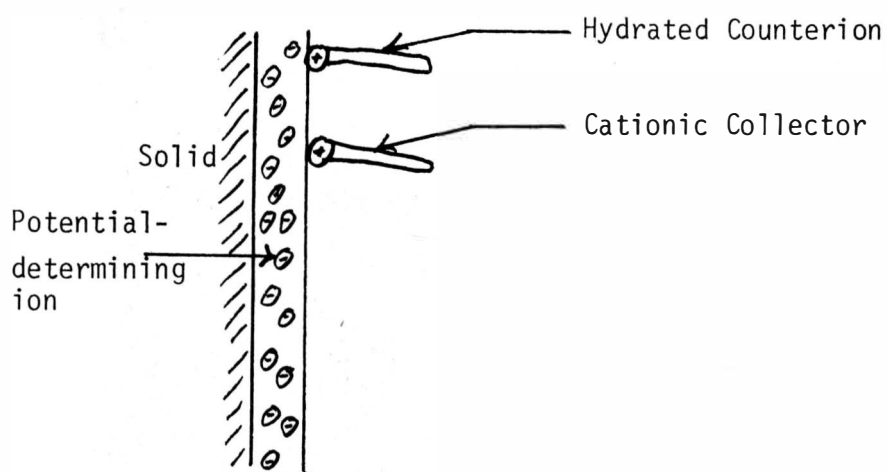
Where: V_{la} = is the liquid-air
surface tension

V_{sl} = solid-liquid surface
tension

Figure 1



(a)



(b)

Figure 2

γ_{sa} = solid-air surface
tension

ϕ = contact angle

This relationship becomes invalid when the contact angle disappears which represents non-flotability. On the other hand if the contact angle is 180° all water would be excluded by wettability of the solid to air. No solid is known to give a contact angle of more than 110° . The solid-liquid interface is formed at the expense of the solid-air and liquid-air interfaces. Therefore, if a solid is being agitated in the presence of a liquid, the addition of a surface active agent to the system will aid the wetting of the solid by air in preference to the liquid. Measurement of the contact angle is made under the assumption that all surfaces are smooth and flat. Never the less, the contact angle has proved very important in flotation research.

Beside the forementioned factors that influence surface tension hydrocarbon chain length is another. In the flotation system collectors of varying length can have different affects on collection and of surface tension (5).

Electrical Double Layer

Particulate matter suspended in aquaous solutions possesses an electric charge due to excess anions or cations on the surface of the solid (10). The ions that determine a surface charge are potential determining ions, and ions near the surface that establish electro-neutrality

are defined as counter ions (Figure 2).

The counter ions approach no closer to the surface than 3 Å. The surface region of oppositely charged ions is called the diffuse double layer and extends out into the solution at varying distances depending on the charge concentration of the counter ions.

For systems containing solids with H^+ or OH^- determining ions, such as Kaolin, the role of pH is of great importance (10). Regulation of pH may indirectly affect potential determining ions. When cellulose fibers are immersed in water they carry a negative charge with respect to the liquid phase. Fines, predominant in white water, have more negative potential than longer fiber due to their great surface charge density.

Flotation may be controlled by pH because it regulates the ionization of collectors from molecular to ionic species which in turn affects adsorption on the particulate matter. At high concentrations of H^+ and OH^- there is competition between these ions and the collector for the mineral surface. Excessive collector concentration causes an interaction between the hydrocarbon chains which result in patches or hemimicelles of collector. Too low a collector concentration produces low recovery (9).

Entrapment of Air

The most fundamental of all theoretical aspects is the entrapment of air into the surface irregularities of a floc structure. With a larger floc structure, possible caused by collector particle complexing, there

is greater probability that a rising air bubble will trap itself instead of missing the floc structure entirely or flowing around it.

Chemical Use in Dissolved-Air Flotation

Three basic classes of chemical reagents used in dissolved-air flotation are collectors, frothers, and modifiers (6).

Collectors

The collector produces a hydrophobic film on the suspended particulate (6). Each collector contains a polar and non-polar group. During attachment to a particle the collector molecule orients itself with the non-polar hydrocarbon group extended outward. This results in a hydrophobic hydrocarbon film on the particle surface. Collectors are classified as either an ionic or cationic. Cationic collectors will attract to a negatively charged potential determining ion layer and anionic collectors will be attracted to a positively charged potential determining ion.

Cellulose and additives such as TiO_2 , clay, rosin, dispersants and talc have been shown to possess a negative potential determining ions (10). Therefore, a cationic collector would be appropriate for use in this study. Among the family of cationic collectors are Amines. Anionic collectors are characterized by an organic-acid group. The acid group is attached to the chain by an oxygen or sulfur atom. Included in this family are carboxylates, acid alkyl sulfates, sulfonates, mercaptans, xanthates, and thiocarbonates (9).

Critical variables affecting optimum collecting conditions for a given

effluent sample are: type of collector (anionic or cationic), length of the hydrocarbon chain, effect of pH, and critical micelle concentration of the collector.

Frothers

Frothers are added to produce a foam to support air bubbles laden with solid particulate (9). This objective is accomplished by imparting temporary toughness to the covering of the film of the bubble. These bubbles are stabilized to a greater extent through adherence to particles (suspended matter) and other bubbles at the surface.

Basically the frother molecules are composed of one hydrophilic end and one hydrophobic portion. The hydrated portion adheres to the water phase and the opposite segment is oriented toward the air-liquid phase; thus strengthening the bubble.

When the froth is skimmed from the surface it should rapidly break down to prevent interference with subsequent operations. Most frothers in service are heteropolar, and all frothers have the ability to lower surface tension.

Modifiers

Modifiers are reagents added to obtain the most effective control in the flotation process. Modifiers are used to regulate pH surface tension, depressants, and activators (6).

LABORATORY PROCEDURE

Since the number of effluent species are endless a waste water sample was synthesized in the laboratory. The formula was a composition of the white water solids taken from a similar one used in a closed system control project for the state of Michigan conducted at Western Michigan University.

The effluent was diluted to a consistency of 250 mg per liter with the following content: Basis weight 56 lb., 50% Domtar Seagull Hardwood, 30% Domtar Q-90 Softwood bleached Kraft, 20% Abitibi Softwood bleached Kraft, Clay 5.75% Ethylated starch-3% on paper, TiO_2 4.19%, Aluminum Sulfate 10%, and Rosin (Pexol) 0.4%.

The original slurry was made at 3% then diluted to 0.5% consistency where it was filtered through a nylon filter (piece of fourdriner wire) into a suction flask.

Since the effluent and collector were going to be mixed on a 1:1 ratio the collector solution was made up at double strength eg. 2% collector solution for a 1% total collector concentration.

The primary amine used was n-Butylamine, secondary amine was Methyl-butylamine. Concentration of 0.1, 0.25, 0.5, and 1.0% were mixed. The frother (terpineol) was added at 0.3 ml per liter. The pH was adjusted in the collector solution and in the white water before the runs.

Flotation Chamber Operation

1. 1.6 liters collector solution were added to the flotation chamber, and the inlet valve opened, and pressure released.
2. When all the liquid had drained into the pressure chamber both valves were closed and the chamber was pressurized to 50 psi, with air for five minutes. (1.3 liters) of synthesized effluent was added to the flotation chamber.
3. The collection cup was tared and then fastened onto the chamber top.
4. The inlet valve was opened and the air saturated collector solution was admitted into the flotation chamber until the column contents reached a level halfway up the inverted funnel. Flotation was permitted for ten minutes.
5. The inlet valve was slowly opened until all the froth had been collected in the separatory cup leaving only water in the chamber and foam in the cup.
6. The drain was opened and the white water collected for evaluation of the residual solids concentration.
7. Pressure release valve was opened.
8. The separatory cup was removed and reweighed to determine foam weight.
9. All collected material was washed from the cup to a preweighed evaporating dish for determination solid weight and consistency.
10. Repeat operations at different pH's and collector concentrations.

A pH range of 5, 7, 9 was used because of the practical aspect of a typical white water coming out of a mill being about neutral. The concentrations of collector used was chosen at .10, .25, .50 and 1.0% for economic reasons.

OBJECTIVES

The objective of this study was to evaluate the potential application of froth flotation for the clarification of waste waters generated by the paper industry, more specifically, the:

1. Building and operation of a laboratory flotation device for studying dissolved-air flotation of a suspended solid.
2. Comparison of the role pH plays in collecting activity of a primary and a secondary amine.
3. Comparison of the performance of the same primary and secondary amines at different effluent suspended solids concentrations.
4. Comparison of the efficiency of primary secondary collectors to a system with no collector present.
5. Comparison of the preceeding collection to sedimentation efficiency.

ANALYSIS OF DATA

1. Record the weight of float and solid weight to determine percent solids.
2. Using standard methods take solid concentration on residual white water to determine percent removal (13).
3. At each concentration of collector plot grams collected vs. original suspended solids to determine if the concentration of suspended solids played an integral part in solid recovery.
4. Plot solid collection and % solid vs. percent collector and analysis curves at each pH.
5. Plot water in-foam content vs. percent collector for a relationship, if any.
6. Compare the dissolved-air flotation results with those of sedimentation (Chart III) of the same white water.

TABLE I

Primary Amine-n-Butylamine

<u>pH-5 Collector Concentration,% (Volume Basis)</u>	<u>Total Froth Weight, g</u>	<u>Solid Weight, g</u>	<u>Water Weight, g</u>	<u>Float Consistency,%</u>	<u>Per Cent Removal</u>	<u>Original Sus- pended Solids Concentration mpl*</u>
0.10	4.23	.027	4.21	0.63	30.5	68
0.25	8.46	.045	8.41	0.53	51.0	
0.50	6.02	.086	5.93	1.42	98.9	
1.00	5.70	.084	5.62	1.46	94.7	
pH-7						
0.10	5.62	.025	5.60	0.44	8.2	2328.
0.25	2.90	.024	2.87	0.82	7.8	
0.50	2.79	.048	2.74	1.73	15.9	
1.00	2.56	.041	2.52	1.59	13.4	
pH-9						
0.10	3.42	.026	3.40	0.75	8.1	346.5
0.25	3.02	.100	2.92	3.31	31.3	
0.50	3.10	.060	3.04	1.94	18.8	
1.00	2.90	.079	2.82	2.71	24.5	

* mpl = milligrams per liter

TABLE II
Secondary Amine-Methylbutylamine

<u>pH-5 Collector Concentration,% (Volume Basis)</u>	<u>Total Froth Weight, g</u>	<u>Solid Weight, g</u>	<u>Water Weight, g</u>	<u>Float Consistency,%</u>	<u>Per Cent Removal</u>	<u>Original Sus- pended Solids Concentration mpl*</u>
pH-5						
0.10	7.26	.163	7.09	2.24	54.1	233.5
0.25	7.34	.167	7.17	2.28	55.2	
0.50	6.34	.148	6.19	2.33	48.7	
1.00	7.25	.183	7.07	2.51	60.2	
pH-7						
0.10	1.94	.068	1.87	3.48	45.0	115.5
0.25	2.31	.065	2.25	2.81	43.4	
0.50	4.69	.056	4.63	1.18	37.1	
1.00	4.06	.045	4.00	1.11	30.1	
pH-9						
0.10	2.84	.013	2.83	0.45	5.2	190.5
0.25	3.50	.016	3.48	0.45	6.5	
0.50	3.42	.021	3.40	0.60	8.4	
1.00	5.26	.039	5.23	0.75	15.9	

* mpl = milligrams per liter

TABLE III
Flotation Without Collectors

<u>Total Froth Weight</u>	<u>Solid Weight</u>	<u>Water Weight</u>	<u>Percent Solid</u>	<u>Percent Removal</u>	<u>Concentration of White Water (mpl)*</u>
3.63g	.031	3.60	.84		87.5
4.53	.042	4.49	.93		

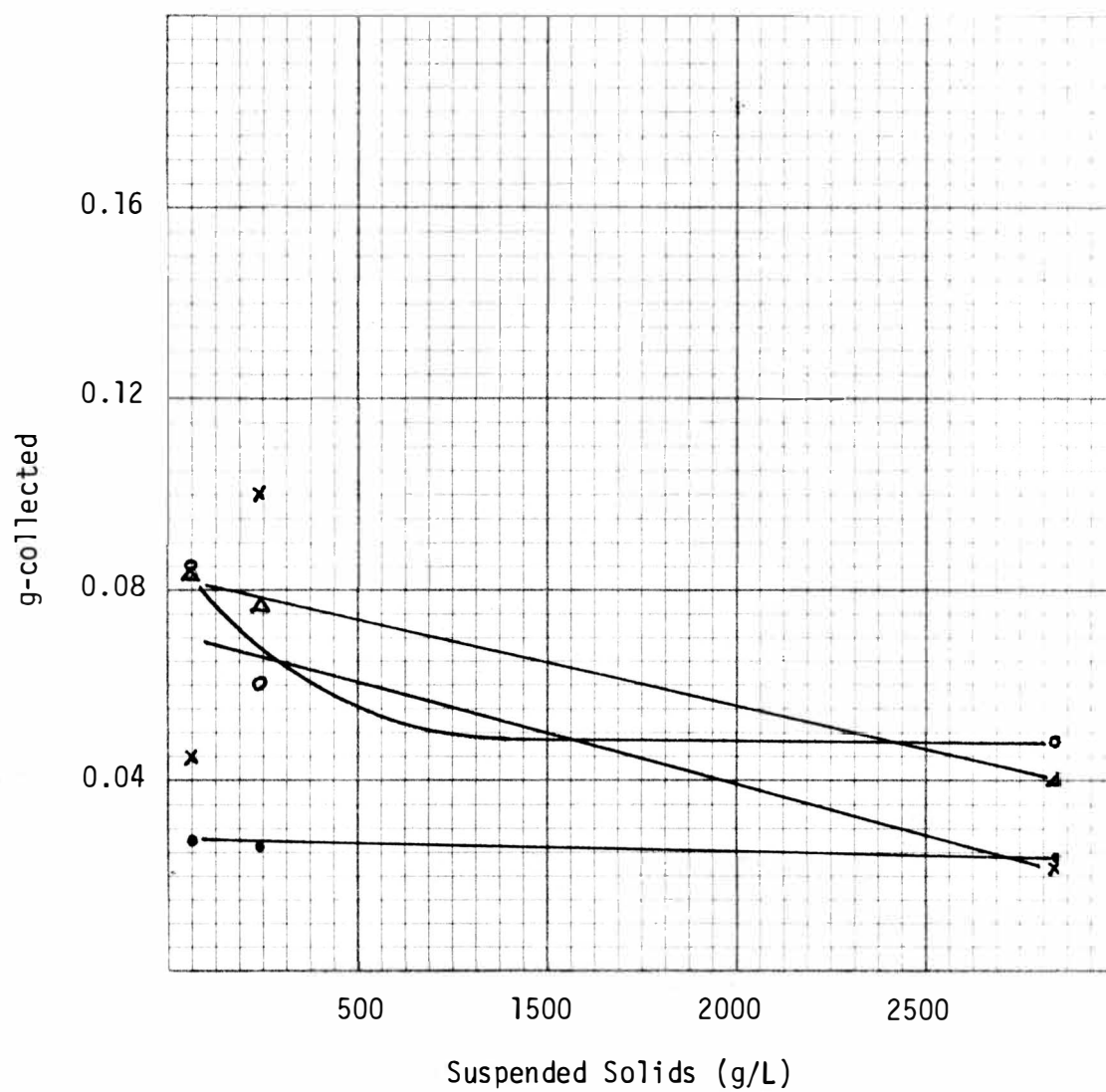
* mpl = Milligrams per liter

TABLE IV

<u>Solids</u>	<u>Percent Solids</u>	<u>Percent Removal</u>	<u>Original Suspended Solids Concentration</u> (mg/l)
.0041	2.75	23.40	87.5

Figure 1a

Primary Amine



- 0.10%
- × 0.25%
- 0.50%
- △ 1.00%

Figure 2a

Primary Amine

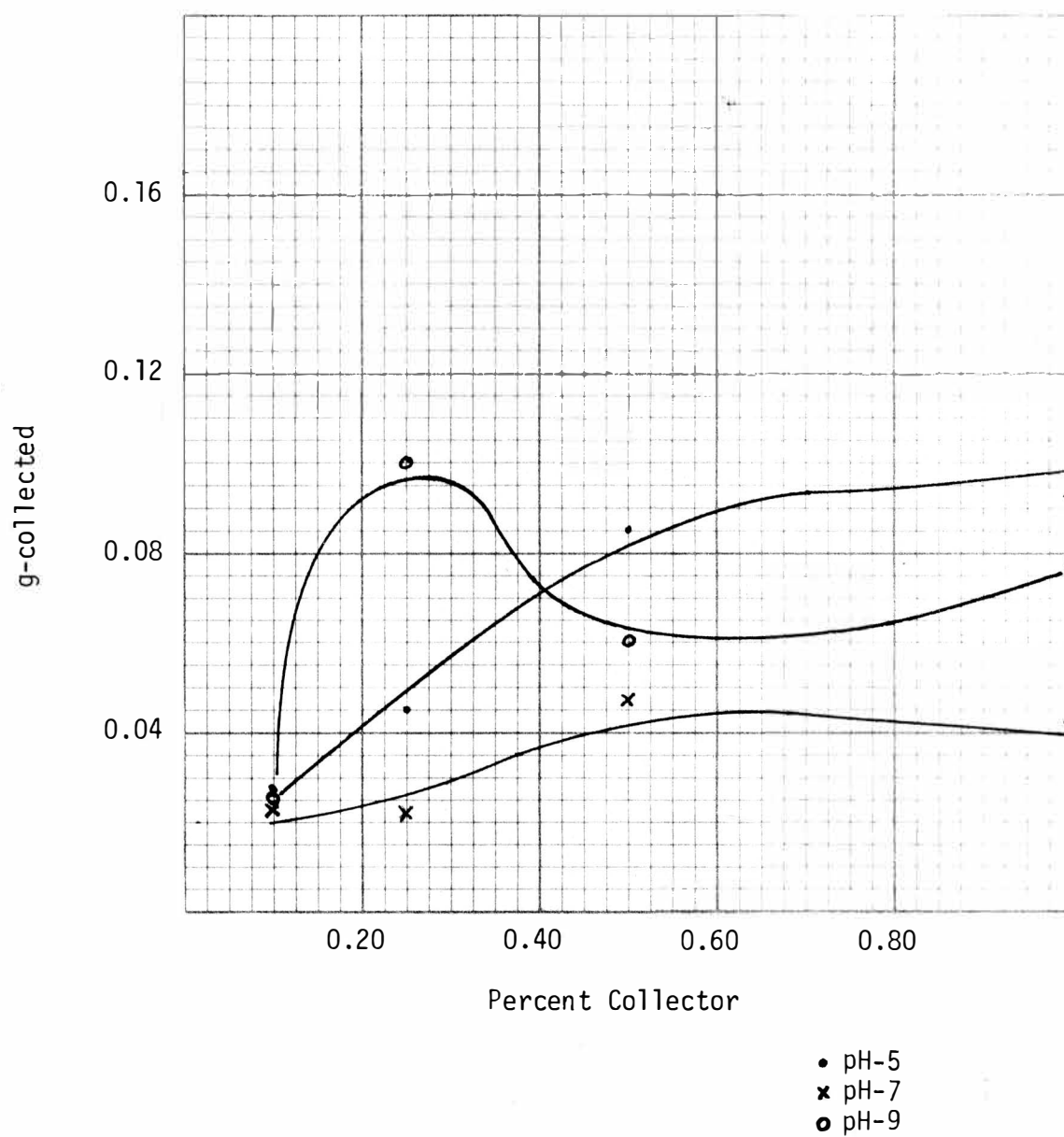


Figure 3a

-27-

Secondary Amine

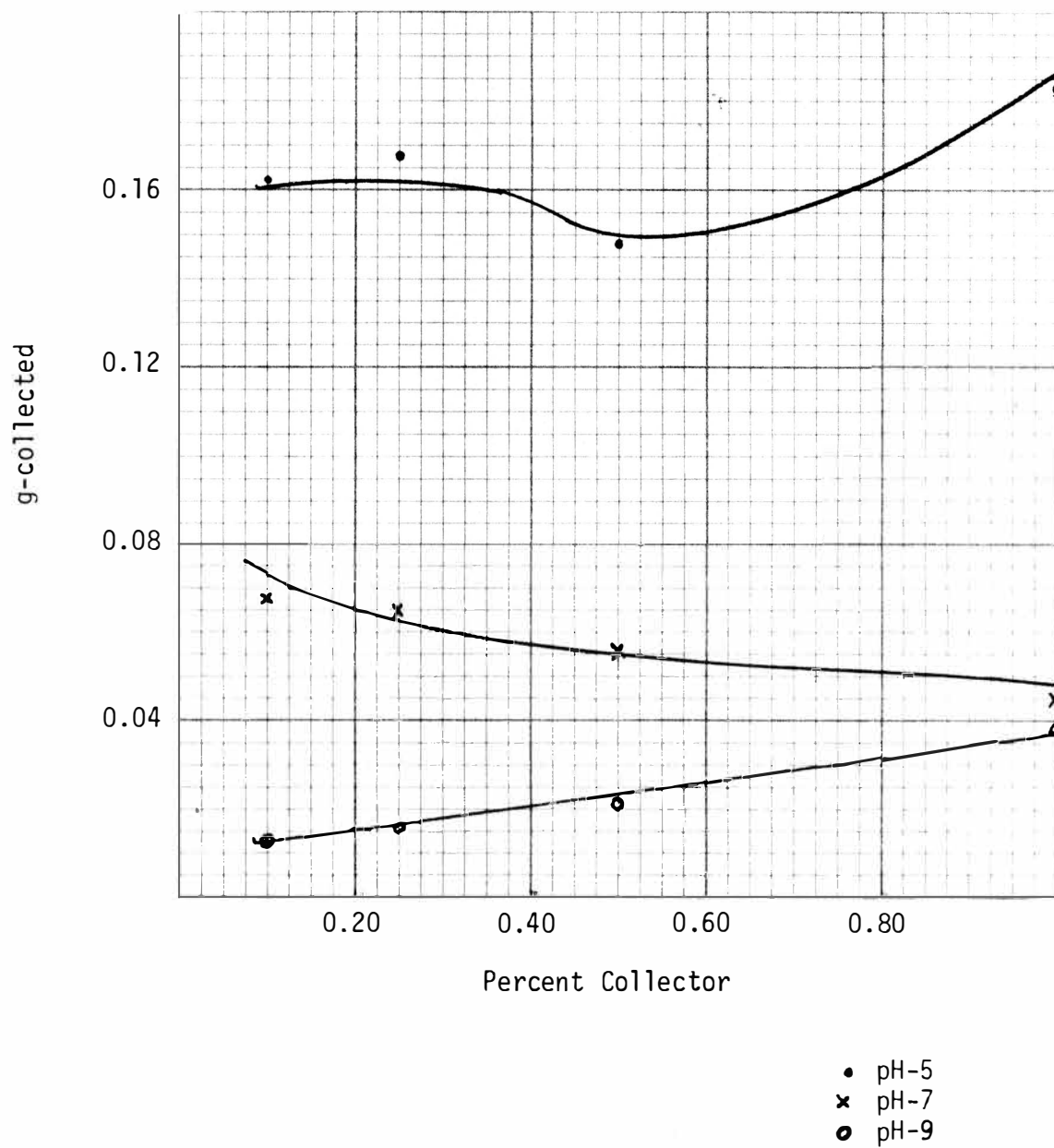


Figure 4a

pH-5

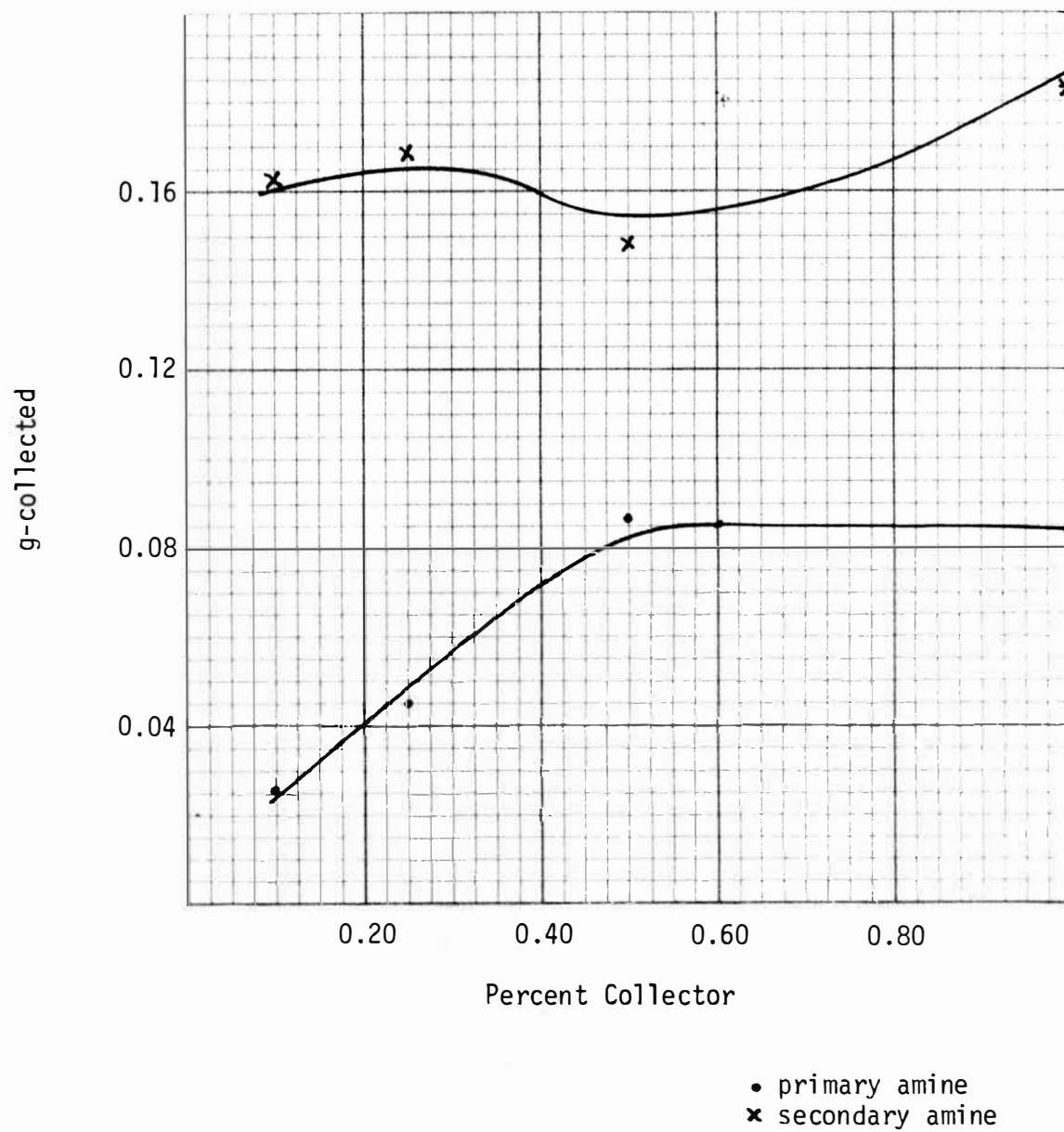


Figure 5a

pH-7

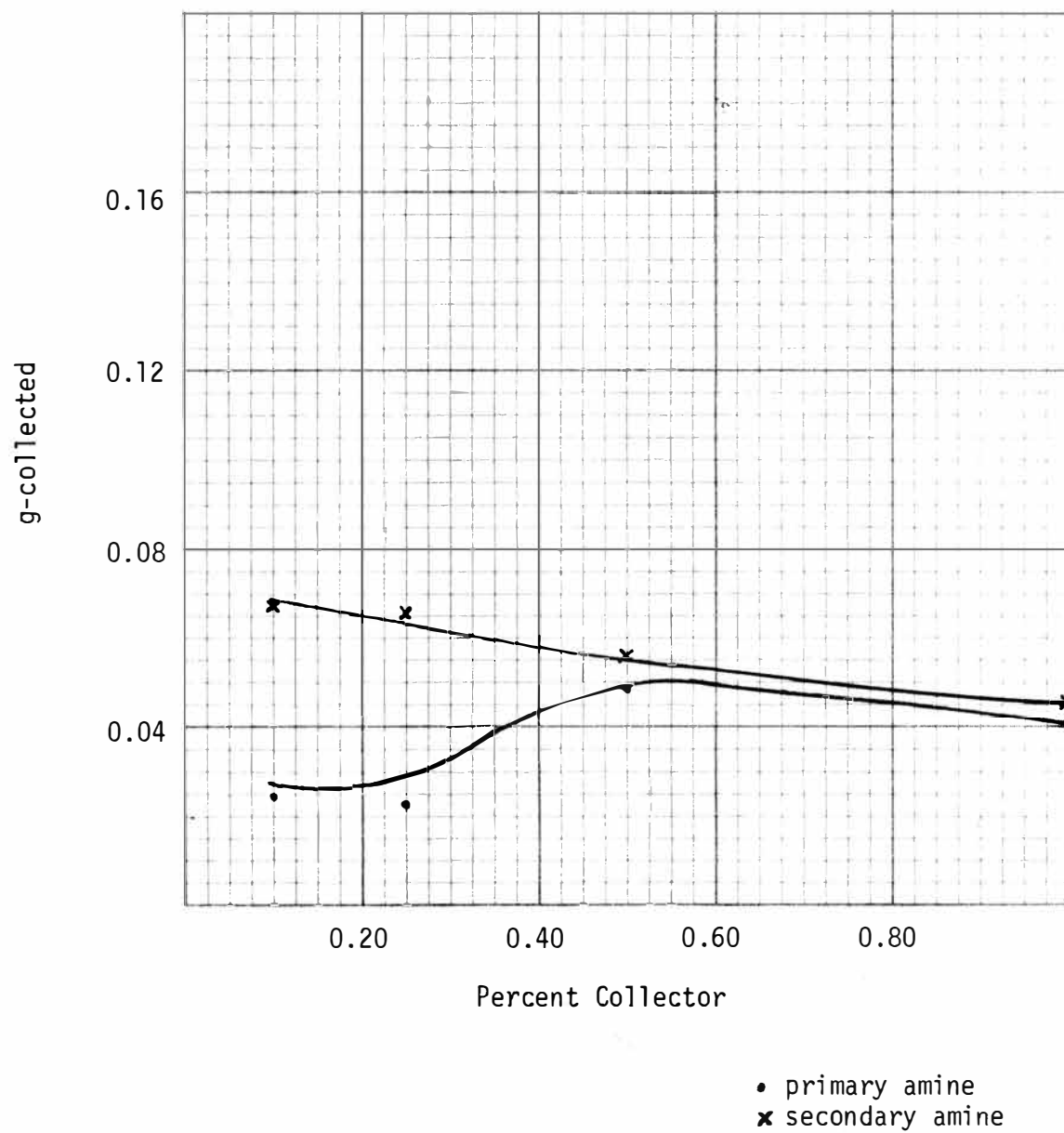


Figure 6a

-30-

pH-9

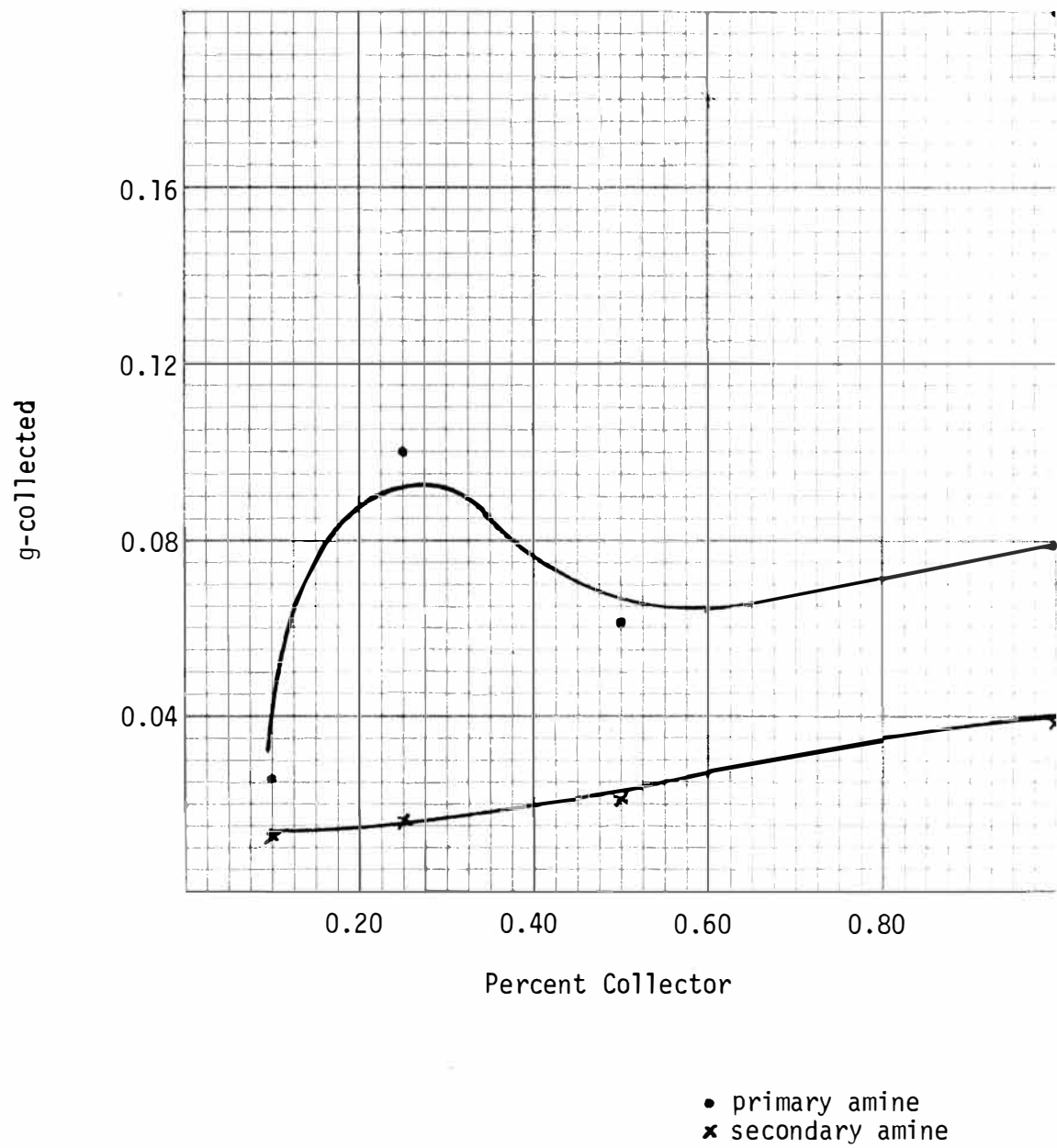


Figure 7a

Primary Amine

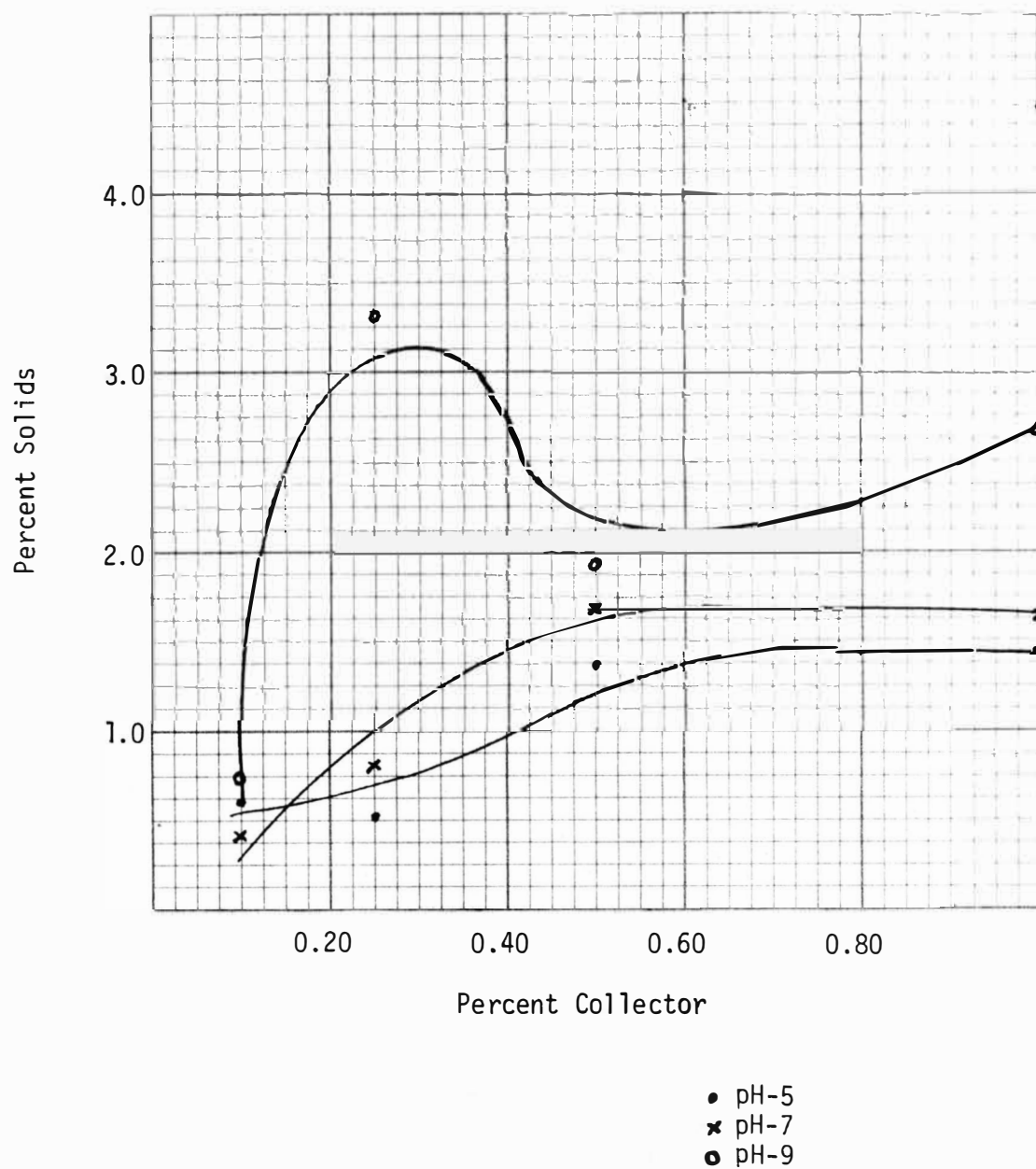


Figure 8a

-32-

Secondary Amine

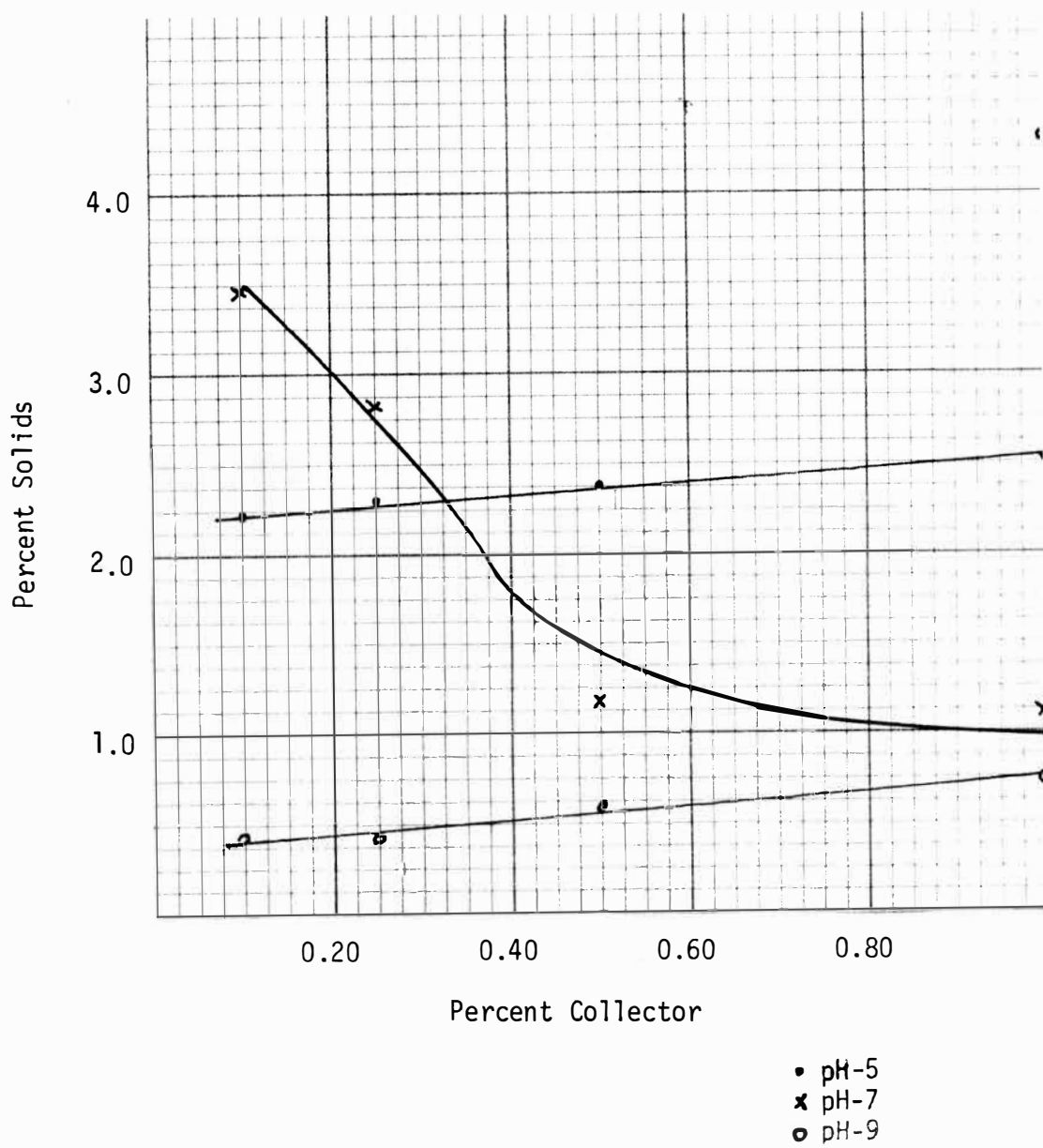


Figure 9a

pH-5

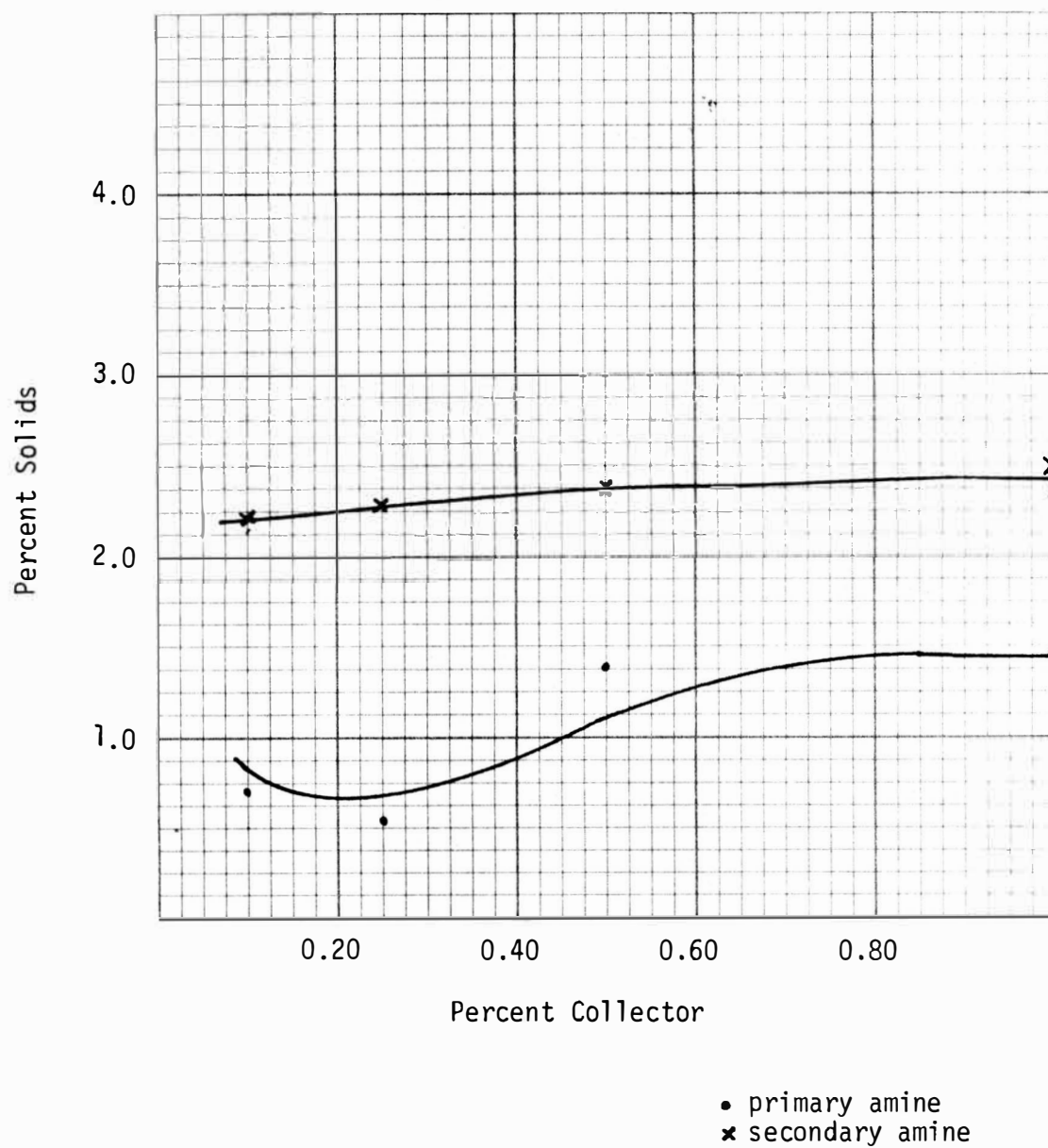


Figure 10a

pH-7

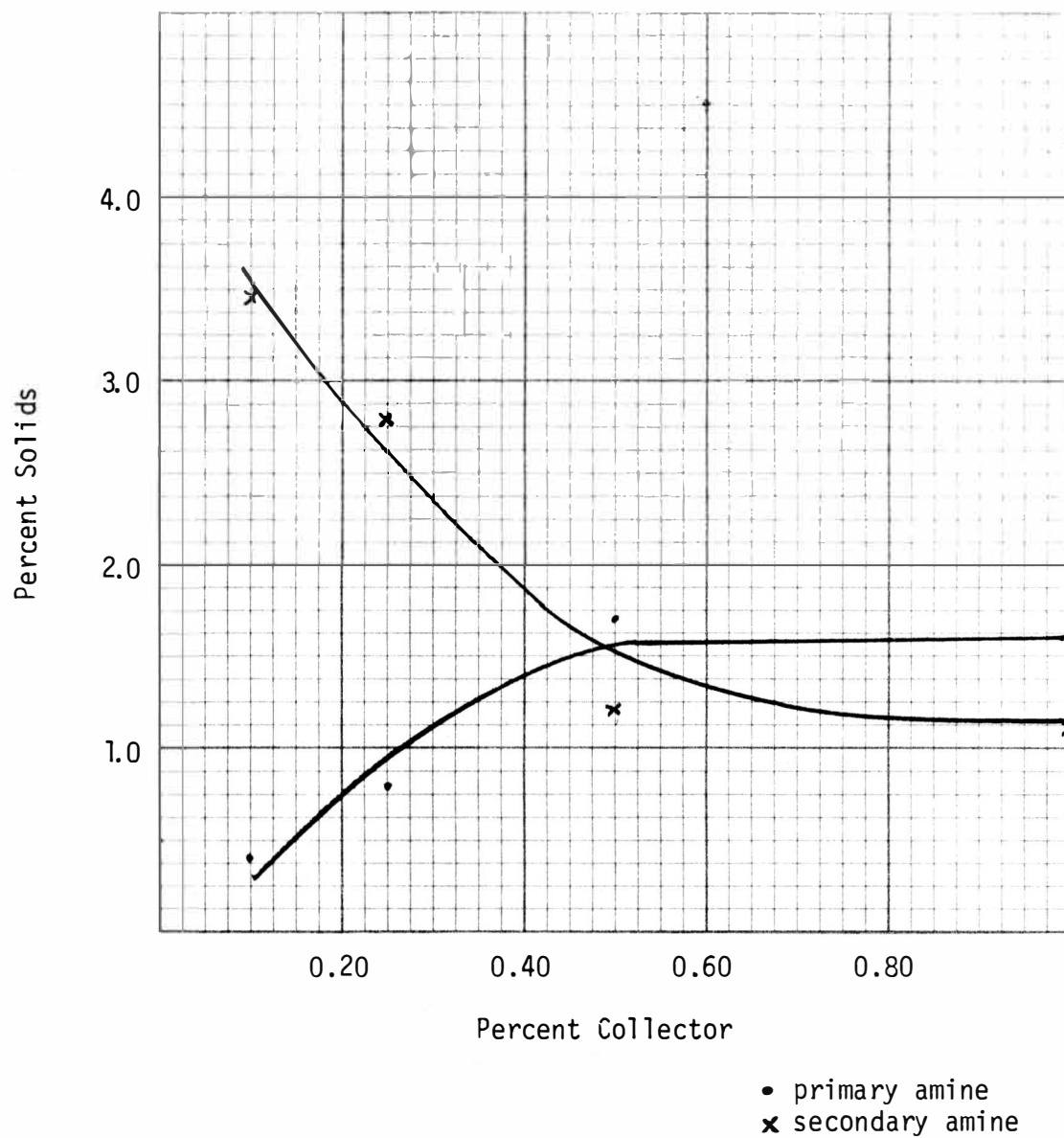


Figure 11a

pH-9

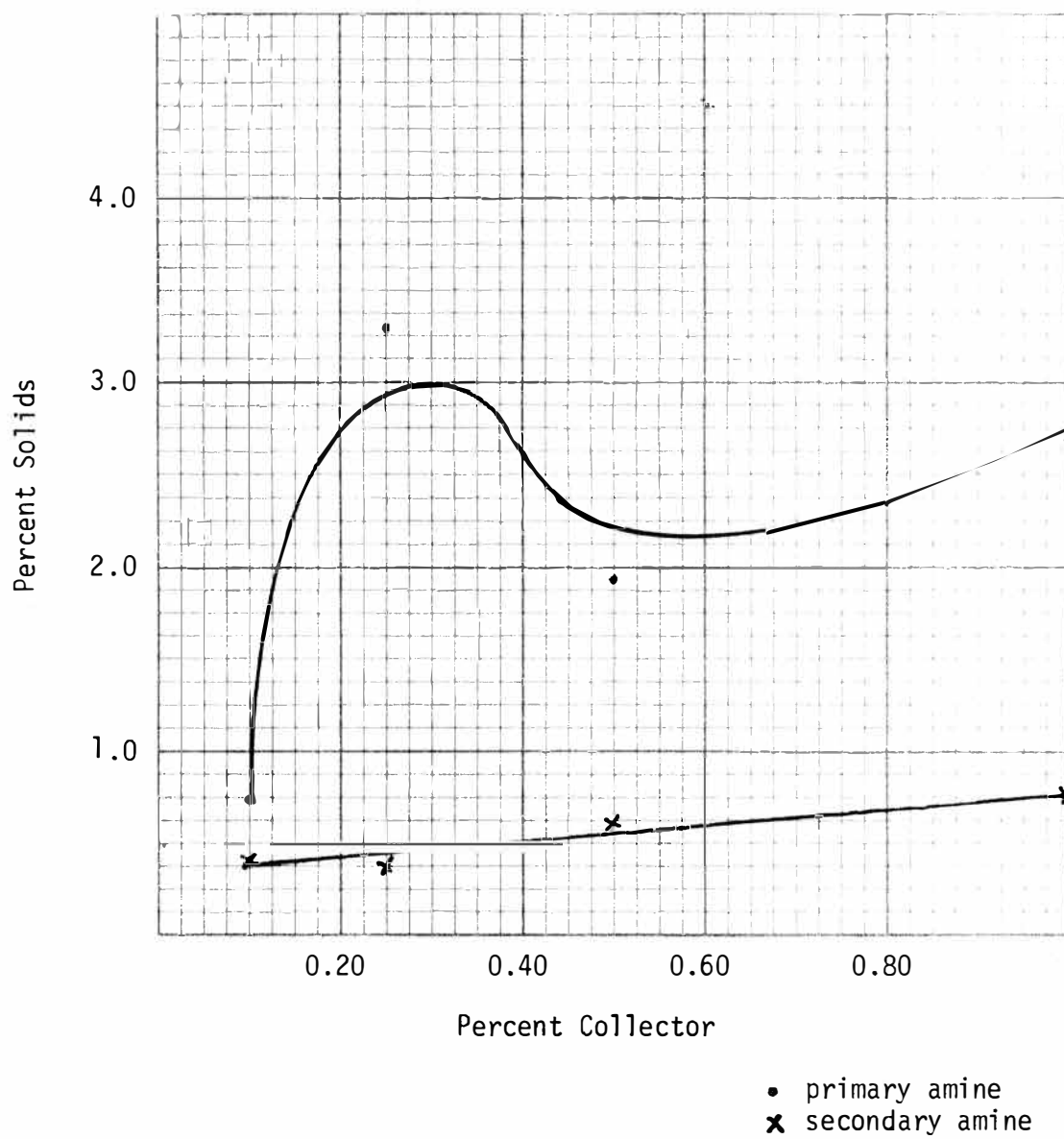


Figure 12a
Primary Amine

-36-

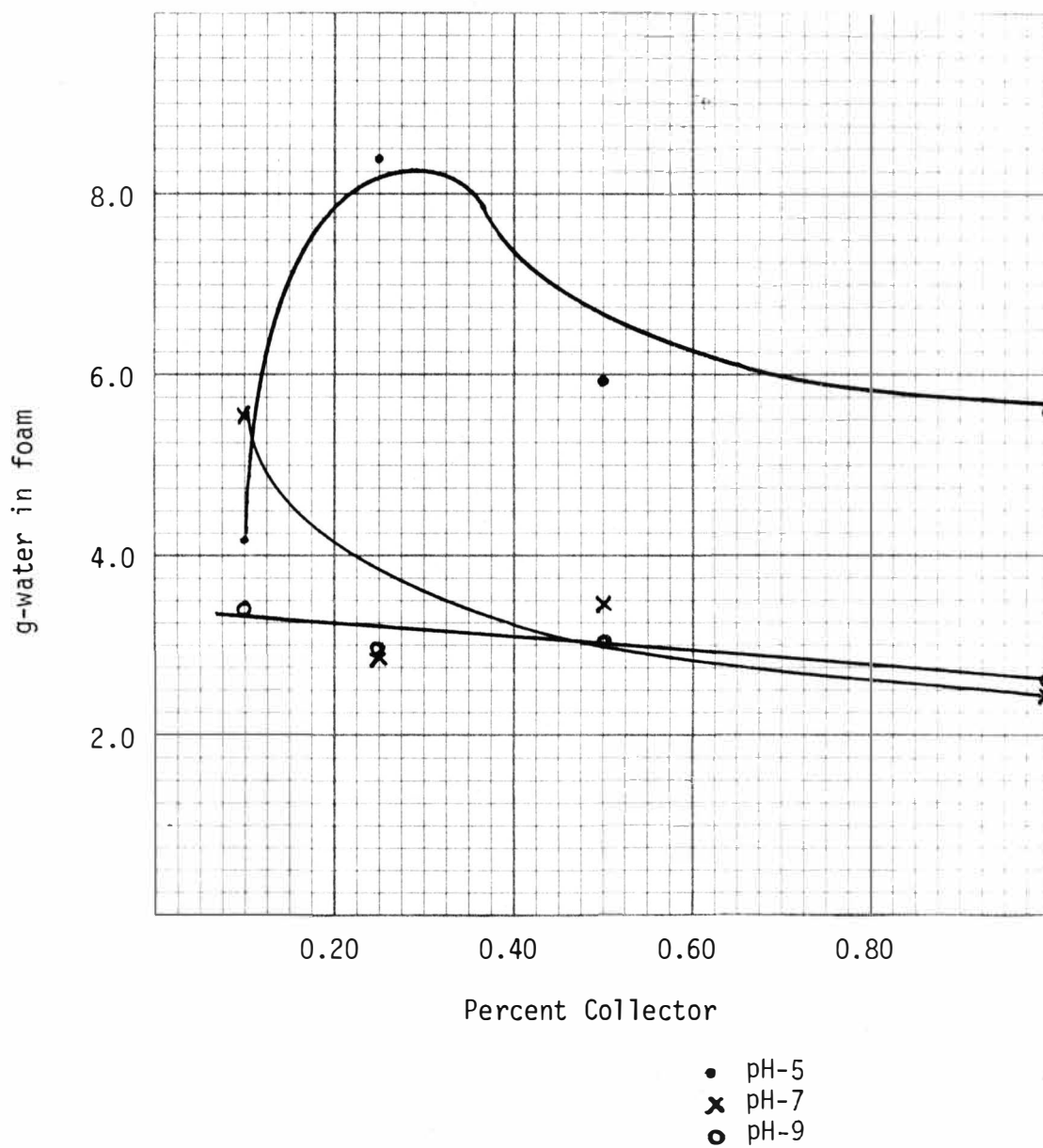


Figure 13a
Secondary Amine

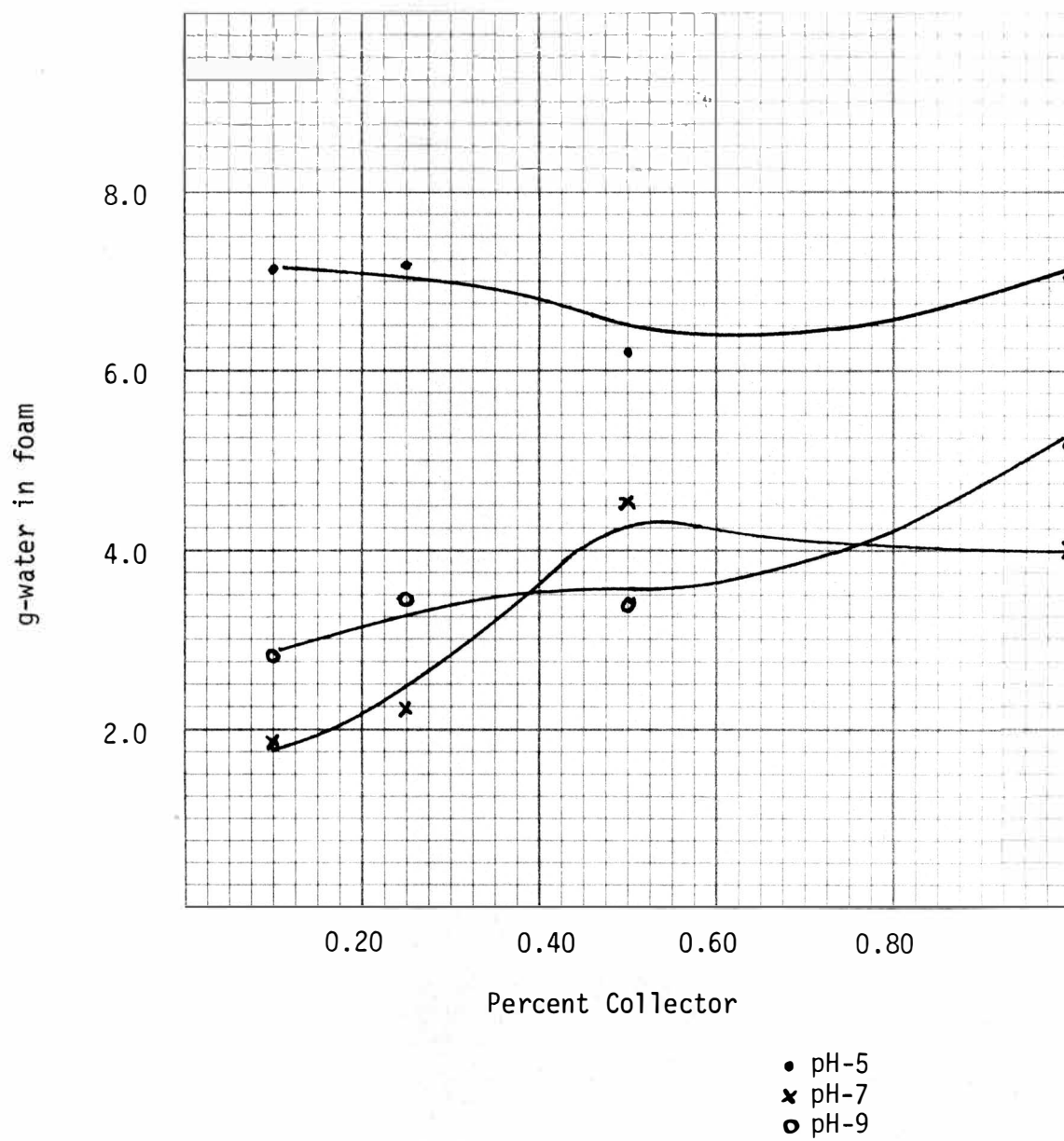
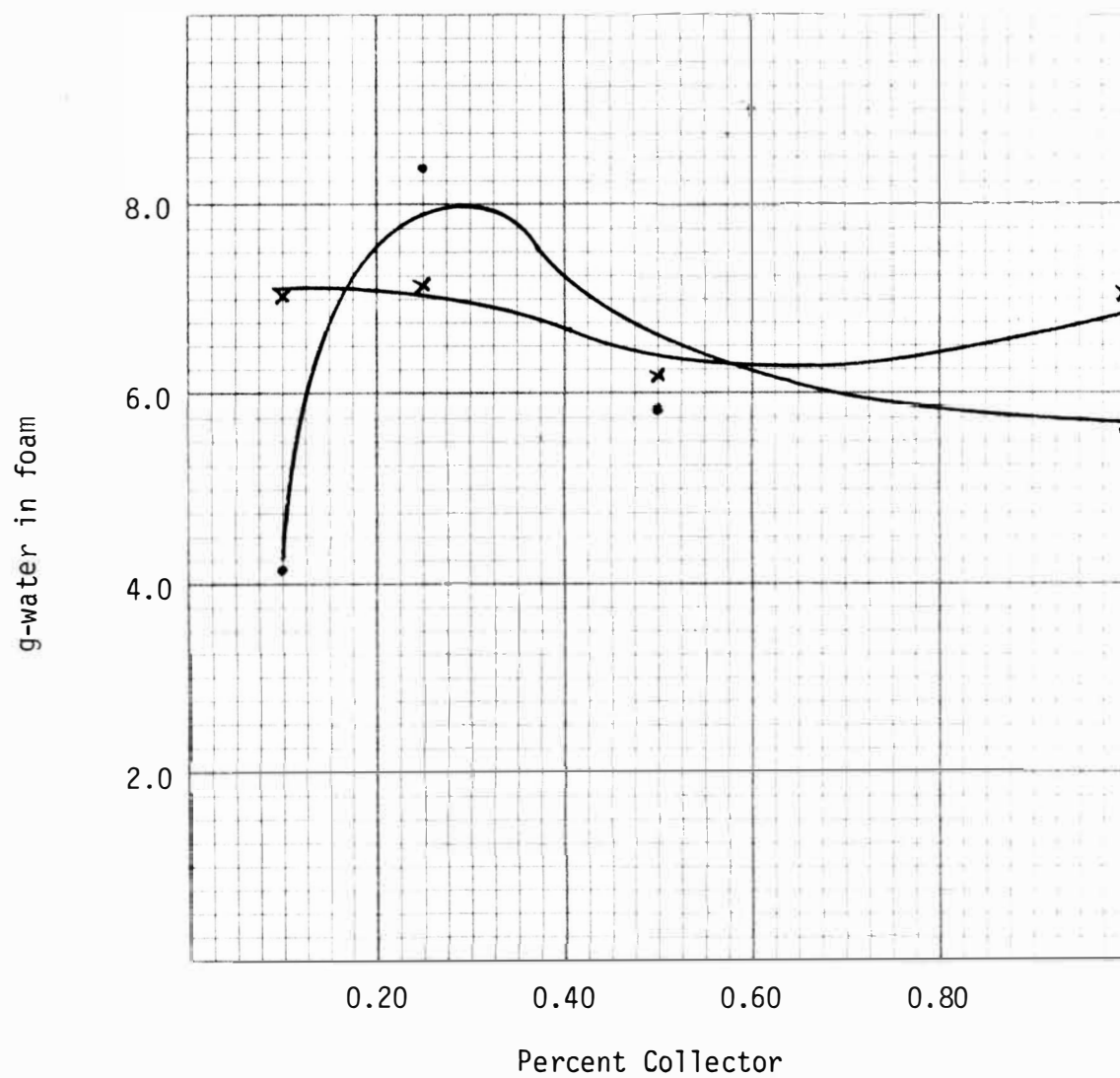


Figure 14a

-38-

pH-5



• primary amine
x secondary amine

Figure 15a

-39-

pH-7

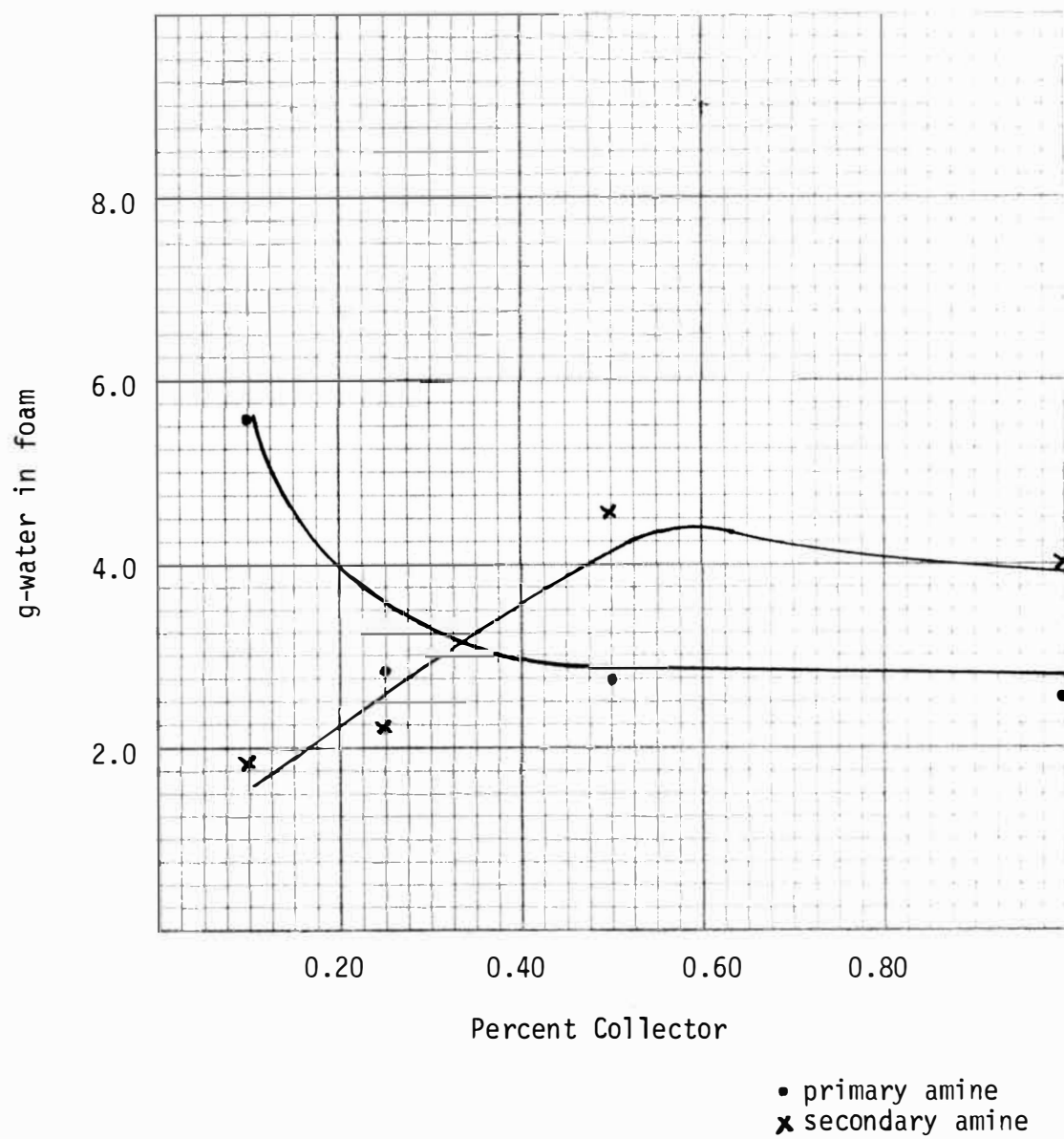
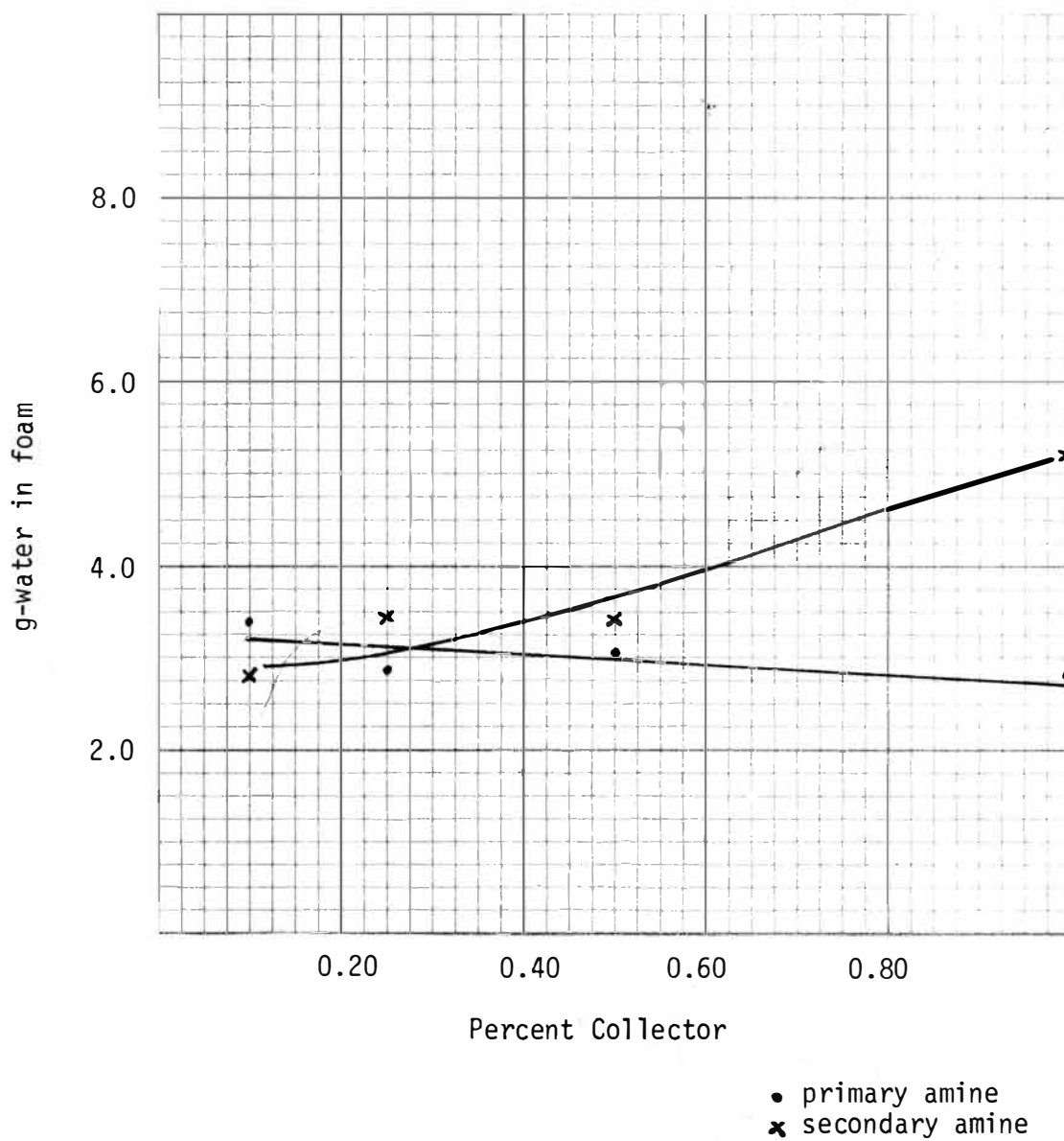


Figure 16a

-40-

pH-9



DISCUSSION

Many hours were spent in constructing and operating the flotation device with considerable efficiency. Ways of improving technique include: a water-tight fit between the collection cup and flotation chamber preventing water and foam leakage, a glass collection cup allowing less foam to adhere on the inner cup surface, and a more discreet way of determining the water-froth line during collection into the cup.

In the procedure ash content of the collected solids was overlooked. Had it been included a more in depth analysis might have shown the relative amount of fiber and clay collected. Also sedimentation should have been tested at all three pH levels, since fibers will agglomerate at lower pH values. This would have been important in comparison to the tests with collectors at the same pH.

In this study, a great range of suspended-solids samples were used raising a question of the effect of the solids count toward collection. Figure 1a shows a decrease in solids collected as the suspended solids concentration increased. The collector might have been weakened (diluted) by the presence of many more particles. With the higher concentration the collector would attach onto a heavier group and perhaps being of relatively small chain length lose a battle in bringing up the added weight. Because of such solids dependency absolute comparisons cannot be made between the various phases of this study. However, a comparison of trends is instructive.

Correlation of the grams of collector with grams of solid collected at each pH, illustrated by Figure 4a through Figure 6a, suggests that the secondary amine's effectiveness declines rapidly with an increase in pH, while the primary amine only slightly increases in collection. The greater variation in the performance of the secondary amine may be attributed to its greater ease of ionization in comparison to the primary amine. At a low pH where collection is high the secondary amine apparently attracts the readily available Hydrogen ions, forming a positively charged end that will adsorb onto the negatively charged particles. As the pH increases the secondary amine is competing with the OH^- groups present for the free H^+ ions.

While the secondary amine solid collection varied slightly at different concentrations for each pH, the primary amine showed poor collection properties at 0.10 and 0.25%, while 0.50 and 1.0% were much better. The occurrence at pH 5 and 7 could be attributed to the H^+ ion competing with the primary collector at the lower concentrations while at higher concentrations the effect was dampened.

In froth flotation a foam with low water content and high solids recovery is desired. As the pH decreased the weight of the foam increased. This may be attributed to increased hydrogen bonding between collector, frother, and suspended particulate. As the pH increased the excess H^+ ions were diminished causing breaks in bonding and lower water content in the foam. It should be noted that between 0.5% and 1.0% concentration of

collector little change occurred in water content.

Results from tests run with no collector showed low results. However, the said values were not lower than the lowest collector values. The tests of collection without collector produced generally lower values at the give pH7.

The comparison of the flotation device with sedimentation showed higher consistency than nearly every flotation value. The sedimentation duration was an hour compared to ten minutes in the flotation cycle.

According to the graphs, best collection with little foam would be at all concentrations in range pH5 for a secondary amine and pH9 at 0.25% concentration collector for the primary amine.

CONCLUSION

Paper mill effluents must be removed in the near future to sustain aquatic life. One possible answer being, froth flotation, still has much to be learned. The major problem in removing suspended particles is first in identifying them. Much more must be known about the surface chemistry of white water constituents.

This paper has shown with an increase in pH a decrease in water content of the foam and a decrease in collection by a secondary amine on white water, while collection increased for a primary amine. Also, the curves showed a definite similarity between the solids collected and the consistency of the foam. Analysis of these results showed no major breakthrough for froth flotation but perhaps showed that at certain conditions flotation techniques are more efficient than sedimentation. It is my hope that questions raised in this paper mill will be answered in the interest of a cleaner environment.

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