4-1983

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Recommended Citation

Munce, Martin E., "The Use of Ultrasonic Frequencies as a Mechanism for Refining" (1983). *Paper Engineering Senior Theses*. 316.
https://scholarworks.wmich.edu/engineer-senior-theses/316

The Use of Ultrasonic Frequencies
As a Mechanism for Refining

by

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

Western Michigan University
Kalamazoo, Michigan
April 17, 1983

Abstract

The objective of this thesis was to explore the use of ultrasonic frequencies as a mechanism for refining. Through cooperation with the Intex Corporation, an ultrasonic cleaning apparatus, that was easily adaptable to use as a refiner, was borrowed. The experimental procedure indicated that ultrasonic refining coupled with mechanical refining produced a sheet with improved tear, tensil, fold and opacity characteristics. The burst, however, was slightly lower. An interesting phenomenon that occurred was the plateauing effect that is observed, most distinctly on the graphs of burst and tensil vs. freeness. this plateau seems to be a phenomenon where the maximum value of a test is held relatively constant over a wide freeness range. The peaking, and quick fall off that occurs with mechanical refining is not present with ultrasonic refining. One problem that exists is that the ultrasonic power requirements appear to be relatively high.

Key Words;

Ultrasound
Refining
Fibrillation
Plateau Effect
High Frequency

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Introduction

Ultrasonic waves are elastic waves that require a medium for propagation. Mechanical waves ranging between sixteen and twenty thousand hertz are audible to the human ear. Those frequencies that are above twenty thousand hertz are inaudible and are termed ultrasonic frequencies. The features of ultrasound that make them applicable to industrial applications are classified as first order or second order.[1] The first order effects are particle displacement, velocity and acceleration. The secondary effects are acoustic streaming, radiation pressure, interfacial instability and cavitation. When considering a fiber suspension, it is the secondary effects that have the greatest influence on the properties of the suspension.

When ultrasonic waves pass through a medium, a flow of matter occurs which is termed acoustic streaming. The liquid medium has inherent properties which inhibit the ability of the medium to modify itself to the advancing motion of the ultrasonic waves. Specifically, these properties are viscosity and the ability to absorb acoustic energy.

At the phase boundaries an interfacial instability is created, due to the back and forth motion of the particles in suspension. The actual displacement of the particles in suspension results in a secondary pressure termed radiation pressure. One fact that produces a problem in this area of research, is the tendency of a heterogeneous suspension, such as a pulp slurry, to separate into distinct groups in the presence of high frequencies.[1] Particles in suspension will oscillate with frequencies dependent on the mass of the particle. Lighter particles will be able to follow the acoustic streaming earlier and to a higher frequency than the heavier particles. Particles of similar mass will coalesce and begin to travel as a group. This results in a distinct separation of the particles by mass. By maintaining a turbulent flow or through agitation this occurence can be avoided.

The property of cavitation is the most important to the application of ultrasound to refining. Cavitation is characterized by the formation of small bubbles flowing through the medium. These bubbles (often referred to as cavities) are not empty, and are described by the nature of their contents, vaporous or gaseous. Gaseous cavities occur mainly at the low frequencies and moderate intensities in the early stages of cavitation. The contents of these cavities consist of only the types of gasses that are dissolved in the medium. Vaporous cavities occur in the advanced stages of cavitation, and consist of the vaporized medium. These cavities quickly collapse upon formation, and the contents are compressed to very high pressures. The collapsing of these cavities produce shock waves in the medium. The shock waves not only produce more of these cavities but also contain a high level of mechanical energy. The amplitude of the shock waves depend on the contents of the cavities. Vaporous cavitation produces waves of greater amplitude that the corresponding gaseous cavities. Due to the greater amplitude a higher level of mechanical energy to the system.

The development of cavitation depends greatly on the intensity of the ultrasonic energy applied to the system. As shown in fig. 1 there exists a threshold intensity (usually about .2-.4 watts/cm^2)[1] which is relatively constant at the lower frequencies, but markedly increases at about ten thousand hertz. This threshold must be exceeded before the phenomenon of cavitation can occur. When a medium contains dissolved gasses the threshold energy required is lower that a deaerated sample. The formation of gaseous cavities is more easily accomplished than the vaporous cavities and therefore the aerated sample requires a lower threshold for formation.

The mechanical energy released by the cavities create shear waves in the medium. Among other things the shear forces initiates a fiber to fiber rubbing action which contributes to the mechanism of ultrasonic refining. The degree of this refining is governed by the amplitude of the shock waves.

History of Ultrasonics

In 1833 Galton laid the groundwork for future research and development of ultrasound when he produced oscillation frequencies up to twenty five thousand hertz by exciting a pipe to high frequencies through the use of an air flow.[2] In 1905 Koenig found that frequencies in the supersonic region, up to ninety thousand hertz, could be produced by means of a small tuning fork type of device.[3] In 1919 Hartman further improved the attainable frequency level with a supersonic pipe operated with hydrogen that produced frequencies up to five hundred thousand hertz. One draw back of these devices used to produce ultrasound, was that the power delivered by these units was very low.[2] In work between 1934 through 1948 Takeuchi and Sato used a rotary siren which chopped compressed air currents at high frequencies and resulted in a supplied power of nearly thirty five killowatts.[2] All of these devices are classified as mechanical as they rely on the production of the ultrasound through non-electric methods.[4] The majority of investigative work with the mechanical generators was in the navigation and military fields, in the area of distance measurement.[4] In 1914 Langevin developed the piezo-electric crystal oscillator.[2] Much of his work was drawn from work done in the 1880's by the Curie brothers, who reported on their discovery of the piezo-electric effect. Langevin's oscillator along with a piezo-electric crystal was able to create frequencies of up to five hundred mega hertz, when excited with a high frequency a.c. current.[2] This means of electrical high frequency generation has served as the primary means for research in the paper industry.

Work in the Paper Industry

The first work in the paper industry involving the effects of sound waves on a pulp slurry was by Buckingham in 1936.[1] He utilized a high intensity sound to produce a beating effect on the fiber suspension. Though he used a relatively low frequency a definite effect was seen on the characteristics of the fiber suspension. This experiment laid down the framework for future investigation. Frey-Wissling in 1947, Simpson and Mason in 1950 and Algar and Giertz in 1951 expanded on the work of Buckingham by maintaining a high intensity signal at the ultrasonic frequency. This resulted in significant effects produced on individual fibers (Algar & Giertz) as well as on the fiber suspension (Simpson & Mason and Frey-Wissling.) More in depth work was then carried out by Iwasaki in 1962, Labosky & Martin in 1969, and Laine & Goring in 1977 and 1979.

Effect of Ultrasound on Cellulose Fibers

As mentioned earlier the shock waves produced through cavitation create a shearing action in the medium. The shearing action in turn has a beating effect on the fibers. The frequencies introduced to the system also result in the resonance of the individual fibers or building units of the fibers. Since the frequencies used correspond to wave lengths much greater than needed to bring a whole fiber into resonance, it can be concluded that the cavitation effect is the major factor influencing the beating action. Thepulsating shock waves produced through cavitation, work on the fiber structures weak points.[5] The ultrasonic beating breaks the lateral "secondary valence" bonds between the longitudinal structural units of the fiber, such as between fibrils and micellar strings.[6] However the work also occurs along the faults of a fiber that are the result of a non-uniform attack of the pulping chemicals.[6] The photographs show that fibers with a high hemi-cellulose content swell more when treated ultra sonically than mechanically.[6] This is because the hemi-cell ulose fraction is relatively amorphous when compared to the cellulose fraction, and therefore will swell greatly. However the hemi fraction is situated in the fiber in such a way that the swelling is restricted by the fiber structure itself.[7] The ultrasonic treatment of pulp weakens the fiber structure by breaking the lateral forces holding the fiber together. This allows the hemi's to swell freely and, depending on the amount of swelling, leads to the dispersion of the structure into fibrils and finally to micellar strings.[5] The progression of the action on cellulose fibers can be put into four categories; 1) cell wall deformation, 2) removal of S_1, 3) swelling, and 4) fibrillation.[6]

In the cell wall deformation stage it can be seen that (see photographs) some dislocations exist in untreated fibers. As the treatment progresses the dislocations become more distinct and new dislocations occur at remarkable regular intervals. When observed under polarized light, at 800x, the deformations become quite obvious. The deformations are classified into three catagories, types I, II, III (see diagram). Types I and II are mainly produced through the beating process. Type III appeared frequently before beating, but was apparently not produced through the beating process.

In the early stages of beating the restricting outer layers of the fiber, primary and S_1, are disrupted and in part removed. The mechanical energy released to the system through cavitation, work at the disruptions in the S_1 to begin the peeling of the layer. Also this action forms dislocations in the S_2. The dislocations are primarily formed by rearrangement of the microfibrils on the S_2.[6] These dislocations allow for water penetration into the S_2, however the S_1 is still present as a barrier to the swelling of the S_2, and the dislocation swelling is limited. The swelling that does occur is very important in making the fiber more flexible, and also in the rupture of the S_1 wall.

The second stage of the process is termed S_1 wall removal. The combined effects of the cavitation energy and the pressure due to swelling of the S_2 layer act on the fiber in such a way that the S_1 layer begins to peel off. Because of the crossed fibrillar structure of the S_1 layer, the layer peels off in flakes rather than fibrillating. Since only very limited swelling is present prior to the S_1 removal, the major effect of the first stage is to increase the flexibility of the fiber. Once the removal of the S_1 has occurred, the S_2 layer becomes saturated with water to cause swelling to the greatest possible degree. The deformations of the S_2 now serve as weak points for the structure and the internal swelling results in an external fibrillation of the structure.

Effect of Slurry Parameters

Other than the type of pulp used, which was discussed somewhat earlier, the major factors influencing the behavior of the slurry to ultrasonic irradiation are consistency, temperature, and to some extent the nature of the fiber.[8] By the nature of the ultrasonic refining, a fiber that is as inelastic as possible is desired. Just as a branch will break more easily than a blade of grass when a force is applied at both ends, so will a stiff fiber as opposed to a flexible fiber when a wave propagates through the structure. The stiffer fiber will then be more likely to sustain the dislocations of the walls. In this respect a stiffer, shorter hardwood fiber would be desired. Another factor that is very important to the fiber stiffness is the temperature of the fiber suspension. At lower temperatures the system will be more resistant to the wave motion and will more easily form the dislocations than at the higher temperatures. This is why ultrasonic refining has been reccomended to take place at approximately 80 degrees F.[9]

Consistency is a complicated variable when considered in ultrasonic refining. Theoretically, since the ultrasound propagates through the refining chamber as waves filling the entire chamber, a sample of stock should be treated equally at any point in the chamber.[2] However, some significant interactions are taking place within the slurry. At high consistencies a flocculation of the fibers occur. This results in fibers that move together as agglomerates, which in turn cuts down on the relative motion of the fibers to each other, which decreases the effect of the fiber rubbing as a contribution to refining. Also these agglomerates hinder the shock waves from creating the dislocations as completely as possible. The major disadvantage of high consistency refining is the drop in the intensity of the ultrasonic energy due to the fibers absorbing and scattering of the ultrasonic energy.[8] The onset of cavitation is determined by the amount of dissolved gasses in a substance as well as the actural intensity of the applied ultrasound. Due to the decrease in intensity at higher consistencies, it is obvious that the refining effects become less at the higher consistencies. Other factors such as filler content have a relatively small effect on the ultrasonic refining of pulp.[2]

Results of Ultrasonic Refining on the Sheet

The major difference in an ultrasonically and mechanically refined sheet is the fact that the Ultrasonically refined sheet contains a very low fines content.[10] Because of the fibrillation, as a result of fiber to fiber action and inter fiber swelling, the fiber is almost completely fibrillated with very little fines production. The small amount of fines that are present are a result of the rubbing off of small fibrils on the S_2 layer.[5] This can be shown through the use of a fiber classification. Labosky and Martin used a Bauer-McNett classifier to compare the two types of refining (see table I) at 700,585,440, and 250 C.S.F. The table shows that at each freeness level (except 700, where a very small amount of fines is present) the ultrasonic refining produced significantly lower fines content, an average of 45% lower.[10] The greater fines formation in the mechanical refining is due mainly to the cutting action on the fiber by the tackle used in mechanical refining.[11] Ultrasonics tend to work gently from the outside inward. The primary and S_1 layers that remain after pulping are peeled away by the ultrasound after which fibrillation occurs. The remaining primary and S_1 layers are removed mechanically by the abrasive action of the beaters. In addition the microfibrils existing on the surface of the S_2 layer tend to be torn off which also contributes to a greater fines production.

The fiber length distribution difference between the two pulps provides a justification for comparison of the two pulps.

Bulk- The ultrasonically refined pulp has been found to have a higher bulk than the mechanically refined pulp. This is because the fines present from the mechanical method serve as small particles to fill the small voids in the sheet structure. The ultrasonic refining does not have the same fines production, therefore a smaller amount of fines are present to serve as the filling for the voids, which results in a higher bulk (lower density.) Another factor is the stiffness of the ultrasonically refined sheet. Since the action starts from the outside and gradually progresses inward, at any given C.S.F. value the mean wall thickness for the ultrasound sheet is greater than for the mechanical refining. This is because the ultrasonic beating has not progressed to the inner cell wall layers as greatly as the mechanical refining has at any given C.S.F. level. The flexibility is dependent on the thickness of the cell wall present. The lower flexibility of the ultrasound sheet results in fibers that do not conform as well to the hills and valleys, therefore more of the small voids are present.

Tear- Both types of beating result in a sheet that follows some form of the theoretical graph of tear versus beating time. The two major differences are that the ultrasonic sheet reached the maximum point later in the beating process (about 600 C.S.F.) than the mechanical refining which peaked about 700 C.S.F. Secondly the slope of the curve after the maximum has been reached is much less steep for the ultrasound sheet (see graph for tear versus freeness), which results in tear values that are higher at nearly all freenesses for the ultrasonic sheet. Theoretically the tear varies directly with fiber length and indirectly with fiber to fiber bonding, only after a mimimum level of bonding has occurred. Since it has been shown that the fiber length reduction is negligible, therefore the decreasing values for the tear are strictly due to the development of fiber to fiber bonding.

Tensil & Burst- Much discrepancy is involved in the discussion of the effect of ultrasound on sheet tensil and burst. Work previously done has indicated a nearly even split on the sheet properties. As an example, Carter in his thesis reported a 28-39% increase in the tensil. Martin and Labosky reported a substantially lower tensil when using the same methods. Theoretically it would be expected that the tensil and burst would be lower ultrasonically. The fines generation in mechanical refining adds a substantially greater surface area available for bonding. Although the fibrillation occurring in the ultrasonic refining does increase the available surface area, it does not increase the area to the same extent that the fines do, and the fiber to fiber bonding is promoted more slowly.

Economics

The major factor regarding the economics of a system such as this is the power consumption. Previous work has indicated that the power requirements are higher for the ultrasonic refining. However, most of this work as done 15-20 years ago, since then many advancements have been made in efficiencies of these systems. The most recent work indicated that highly efficient mechanical systems (upwards of 75% efficient) and improved electrical systems make the use of ultrasound more economically feasible. Other factors that must also be considered are the effect of reduced load on the recirculating system. The longer fiber, due to the lower level of fines, in the ultrasonic system results in better retention, which in turn relates to a lower fiber requirement.

Experimental Design

All previous work done in this area has utilized exclusively ultrasonic refining. The objective of this thesis is to combine the use of ultrasonic and mechanical refining to achieve a sheet of superior quality. By incorporating an ultrasonic refining method into the conventional mechanical refining, the resulting pulp should consist of well fibrillated fiber, along with a level of fines that should help to develop the burst and tensil properties.

Stock- Ideally, a pulp consisting of 100 % softwood in the unbleached form should be used, to eliminate the effects of degradation due to bleaching. However, because I could not obtain an unbleached sample, bleached softwood was substituted.

Equipment- The conventional mechanical refining was done using the Claflin refiner at a 40 Kw. setting.

An ultrasonic device used as a cleaning system was borrowed from the Intex Corporation. This unit is easily adaptable to use as a refining apparatus. It consists of a frequency generator, a power supply, a signal filter and a transducer (diagram #6.) The unit delivers 1000 watts of power at a frequency of approximately 20000 hertz. The transducer converts the electrical input signal from the power supply, to a mechanical sound wave through the use of a magneto restrictive core. This core consists of ferro-magnetic material which changes dimension in a varying magnetic field. The purpose of the filtering unit is simply to prevent the signal from transferring back into the public utility power lines and causing radio interference problems. The unit is well suited to serve as a flow through refining unit.

Procedure- The first step in the process was to determine the optimum consistency for the ultrasonic refining. This was done through batch trials. A 400 ml. sample of pulp was placed in the chamber, and exposed to the ultrasound for varying time intervals to develope a "beater curve". This was done for pulps at 1,1.5,2,3.4, and 1.4 percent consistencies. Once the optimum consistency was determined the next step was to carry out the combined refining of the pulp.

Due to the low power supplied by the ultrasonic equipment, the pulp would have to be exposed to the ultrasound for a relatively long period of time. To do this two alternatives were available, either the pulp could be passed many times through the refining chamber, at short exposure times. The second option would be to retain the pulp in the chamber for longer periods of time, thereby requiring fewer passes. The term passes refers to the number of times the pulp that is being passed through the chamber, though this does not mean that each fiber is necessarily being passed through that number of times since the pulp is recirculated back to a mixing chest and is kept constantly agitated. I reasoned that the longer exposure time would actually transfer more of the energy to the fiber system, wheras many passes at short exposures would result in a large amount of the energy being di sipated in the energy transfer through the water, therefore a method using long exposure times was developed.

To obtain long exposure times in the refining chamber, a very low flow rate must be maintained. To do this the ultrasonic device was mounted, with a gate valve to control the flow rate, on an electromagnetic flowmeter. The flowmeter served, basically as a bypass element, to relieve the back pressure on the valve, allowing the valve to control low flow rates precisely. The lowest flow rates that could be maintained was 3-4 gal per minute. This flow results in a pulp exposure time of approximately 8.7 seconds.

Stock samples were then passed through the system with varying degrees of initial mechanical refining. The procedure consisted of four trials, the first was soley ultrasonic refining, the second was mechanical refining to 458 freeness followed by three passes of the pulp volume through the ultrasonic refiner. The third sample consisted of mechanical refining to 512 C.S.F. followed by the volume of pulp passed through ultrasonic system three times. The fourth sample was used as a control and consisted of mechanical refining to 628,484,444,399,and 338 C.S.F.

Testing- Handsheets were made from each of the freeness samples and tested for tear, burst, tensil, opacity, and fold. In addition, a fiber classification using the Bauer-M^{c}Nett apparatus was done on each of the freeness levels. This was done to determine the degree of fiber shortening that has occurred. A comparison of the resulting strength properties was used as a measure of the effectivness of the ultrasonic refining method when compared to that of mechanical refining.

Discussion of Results

Consistency- As stated earlier, the first step in this experiment was to determine the optimum consistency for refining pulp ultrasonically. As seen in graph #1, the consistency producing the greatest freeness drop with time was at about 1.4% consistency. Samples at 1,2,3.4% all produced significantly lower curves. To verify this result a sample at 1.5% was tested. The resulting curve was much higher than the other three, confirming that the optimum consistency for ultrasonic refining is apparently 1.5 %.

Fiber Classification- The results of the fiber classification studies presented some differences from the literature data. Whereas the literature indicated that ultrasound produced lower fines content than mechanical over a freeness range from 700 to 250 C.S.F., the experimental data indicated that the combined mechanical and ultrasonic refining resulted in a lower fines content until a freeness value of about 360 C.S.F. The graph of fines vs. freeness is interesting to analyze (see graph #2.) While the mechanical refining of pulp resulted in a relatively smooth curve, with increasing fines content at lower freenesses, the combined refining resulted in very low fines production from 512 to 370 C.S.F. At this point the production of fines increased dramatically. This can be explained by examining the mechanism of ultrasonic refining. As explained earlier, the ultrasound causes a great degree of fibrillation on the fiber, the longer the exposure to the ultrasound, the greater the fibrillation becomes, to a point where the lateral secondary valence bonds between longitudinal elements of the fiber disrupt and fibrillation occurs. Eventually the swelling becomes so great that the fibers dispers into smaller fibers. This action proceeds, until it is happening on such small fibers that the dissolution causes fines to be formed. At about 370 C.S.F. there is a great amount of very small fiber present, and any further work on the fiber results in its' dissolution into particles known as fines.

Tear- As stated in the literature the ultrasonic refining of pulp results in higher tear values for a given sheet of paper. Graph #3 is a plot of tear factor (tear/grammage) vs. freeness. It is clear that the ultrasound method of refining has resulted in significantly higher tear values at a given freeness. Since the tear test is affected directly by fiber length, and indirectly by fiber to fiber bonding (after a small amount of initial bonding), the longer fiber present, at a given freeness level, results in higher tear value

Tensil- The graph of tensil vs. freeness (graph #4) illustrates a phenomenon that will be observed throughout much of the testing. This phenomenon will be reffered to as the plateauing effect.

Theoretically, the tensil test is dependant on fiber to fiber bonding, and to a lesser degree the individual fiber strength. Therefore, with increased bonding the tensil value should increase, to a point where the fines production is such that the individual fiber strength deteriorates to such a degree that the tensil test decreases. The curve for mechanical refining follows this theory, as there appears to be a distinct peak, followed by a rapid strength drop ff. The combined mechanical and ultrasonic refining indicates a very broad plateau at a strength value approximately equal to the maximum value of the strength. From earlier discussion, the fines level produced is very small, therefore the increase and holding of the value over a wide plateau must be attributed to the bondin area available through fibrillation. Evidently the increased fibrillation at lower freenesses must be offsetting any decrease in fiber strength that might be occurring.

Burst- The graph of burst vs. freeness (graph #5) again illustrates this plateauing effect produced by ultrasonic refining. The bursting strength of a sheet is dependant, not only on fiber bonding, but also on the extensibility of the fibers. The combined refining results in values that are slightly higher while reaching the plateau. While this plateau maintains a relatively constant value, the mechanical refining exceeded the combined in the areas of the peak that occurs with mechanical refining. The reason that mechanical refining values exceed the combined is that the dependance of the burst test on the extensibilty allows the more extensible mechanically refined fibers (as literature indicated) to hold or withstand the bursting pressure to a greater degree, therefore higher burst values were observed for the mechanically refined pulp in the peak area. Outside the peak, the combined refining was significantly higher. This is mainly due to the plateauing effect that is occurring.

Fold- The graph of fold vs. freeness (graph #6) resulted in curves that were, again, higher for the combined refining than with mechanical refining. Once again the plateauing effect seems to be present, though it appears to be plateauing at a later point then with the tensil and burst. This could possibly be due to the interrelationship of tensil and fold.

The fold test is heavily dependant on the fiber length, and to a lesser degree the fiber bonding. Because of the greater amount of long fiber present in the combined refining of pulp, the likelyhood of fibers spanning the folding zone is increased, and therefore the fold test is more likely to be higher. At a given freeness the fibers of the ultrasonic method are generally longer than the mechanically refined pulp, and therefore the individual fiber strength is greater, and therefore the folding strength is greater. One caution, the fold test is greatly dependant on many factors including the tensil. These interrelationships, and the nature of the fold test result in a test that is greatly variable, and the data should be judged accordingly.

Opacity- A graph opacity vs. freeness (graph #7) indicates that the combined refining produced a sheet that is slightly more opaque than a refined mechanically pulp. This again, is due to the fines production of the two refining methods. Initially, the well fibrillated fibers of an ultrasonic refining method will fill in more of the voids in the fiber structure, refracting the light, and allowing less to pass through. At a corresponding freeness the mechanically refined pulp is less fibrillated, and more light passes through. As refining increases, the large fines generation in the mechanical method also fill in the voids, however the eventual fiber bonding that takes place results in less refration and more light passing. The freeness drop with ultrasonic refining correspond to a greater fibrillation of the fibers, which refrect the light to a greater degree when bonding begins to occur, resulting in a higher opacity. This creates a plateauing effect, which has the effect of maintaining the opacity of the ultrasonic pulp at a higher level, up to the point of about 380 C.S.F. At this point the fines production is increased greatly and the fines increase the bonding. This increased bonding then decreases the opacity. Though the curves are similar in shape, the major difference is due to the plateauing effect, which creates a flatter curve in the middle freeness range.

Economic Considerations

As the literature indicated, I found that the use of ultrasonic refining resulted in a relatively high power consumption. It appears that the ultrasonic method requires approximately two times the amount of power reqired in mechanical refining at a 100 ml. freeness drop. However there are three factors which must be considered. First, the equipment was not designed for this type of work, low power supply and low frequencies coupled with an inefficient design for refining, result in a greater power consumption. Secondly, referring to table #2, it can be seen that the dissolved gasses in the pulp produce cavitation of a lower intensity, namely gaseous cavitation. If the medium could be degassed the formation of vaporous cavities would create a more violent release of energy to the system, and therefore a greater refining effect. Third, the tradeoffs that exist must be taken into consideration. For example, the improved sheet quality would have some increased value. Also, the ability to run a given sheet quality at a higher freeness would result in the ability to run the machine much faster, and also a fiber savings would be realized through increased retention due to longer fiber at that freeness, and therefore a lower load on the recirculation system.

Concusion

The use of ultrasonic frequencies combined with mechanical refining has been shown to have many desirable effects on a resulting sheet of paper. The most attreactive of these seems to be the ability of the ultrasound to create a low, almost constant fines level over a wide freeness range. In turn, the tensil, fold, tear, and opacity are not only improved over this freeness range, but also a plateauing effect seems to occur regularly. This plateauing effect refers to the extended length of the maximum values of the curve over a wide freeness range. There are no distinct peaks and dropoffs as is the case with mechanical refining. This effect is very desirable in that by maintaining the overall strength of the sheet over a wide range, the papermaker has great flexibility in machine operating speed (due to drainage through the wire) without losing much of the sheet strength.

A comparison of sheet properties at a given strength was also considered to be of interest. In evaluating the overall sheet quality, the graphs of tensil, burst, fold, and opacity vs. tear (graphs 8-11) give a good indication of the quality of the sheet. The graphs indicate that at a given tear strength, the ultrasonically refined sheet resulted in better tensil, fold, and opacity. While the mechanically refined sheet was slightly better in the bursting strength. This is again probably due to the difference in fiber extensibility. Although the power requirements appear to be higher for the ultrasonic method, the increased strength and opacity of the sheet justify the need for further work in this area.

Suggestions for Further Study

An interesting related area of study would be to compare the effects of ultrasound on differing fiber fractions. A classification could be used to establish the different fractions which could then be used for a strength study. to determine if the increased strength properties found here are actually do to the fibrillation of longer fibers as assumed. In addition, some sort of microscopy would be interesting, to observe the effects on a microscopic basis. The effect of varying frequecies on pulp refining would also be a good area to look into, for this is possibly one way to cut down on the power requirements as the refining action may be significantly different at different frequencies.

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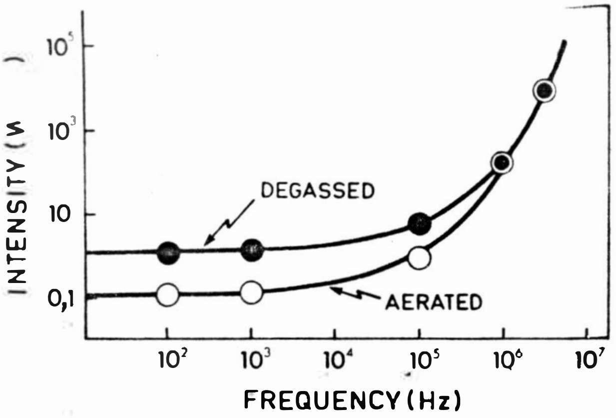
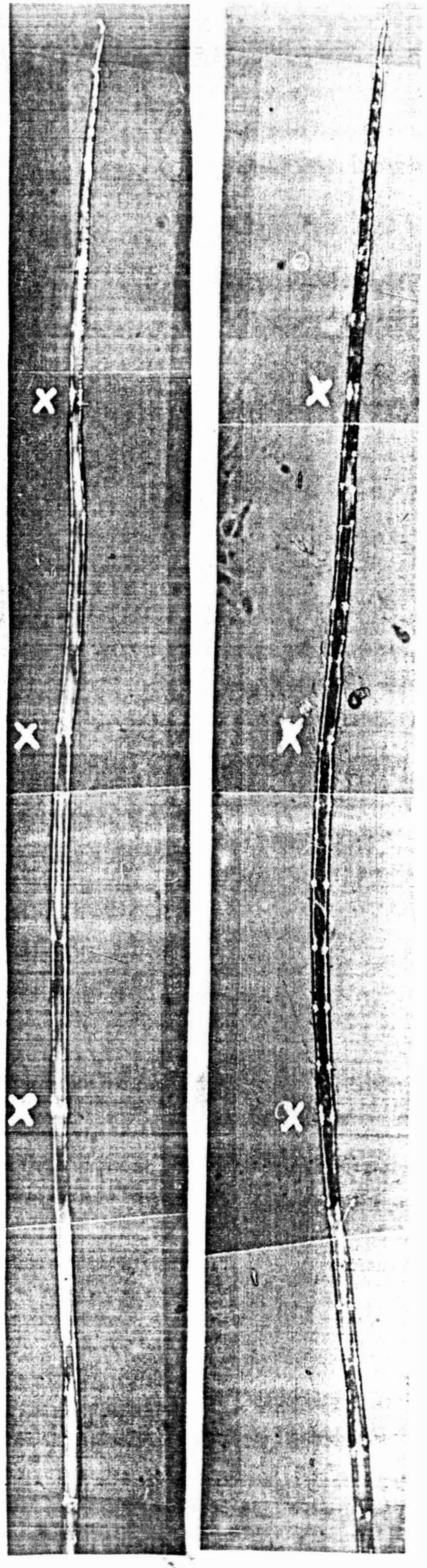


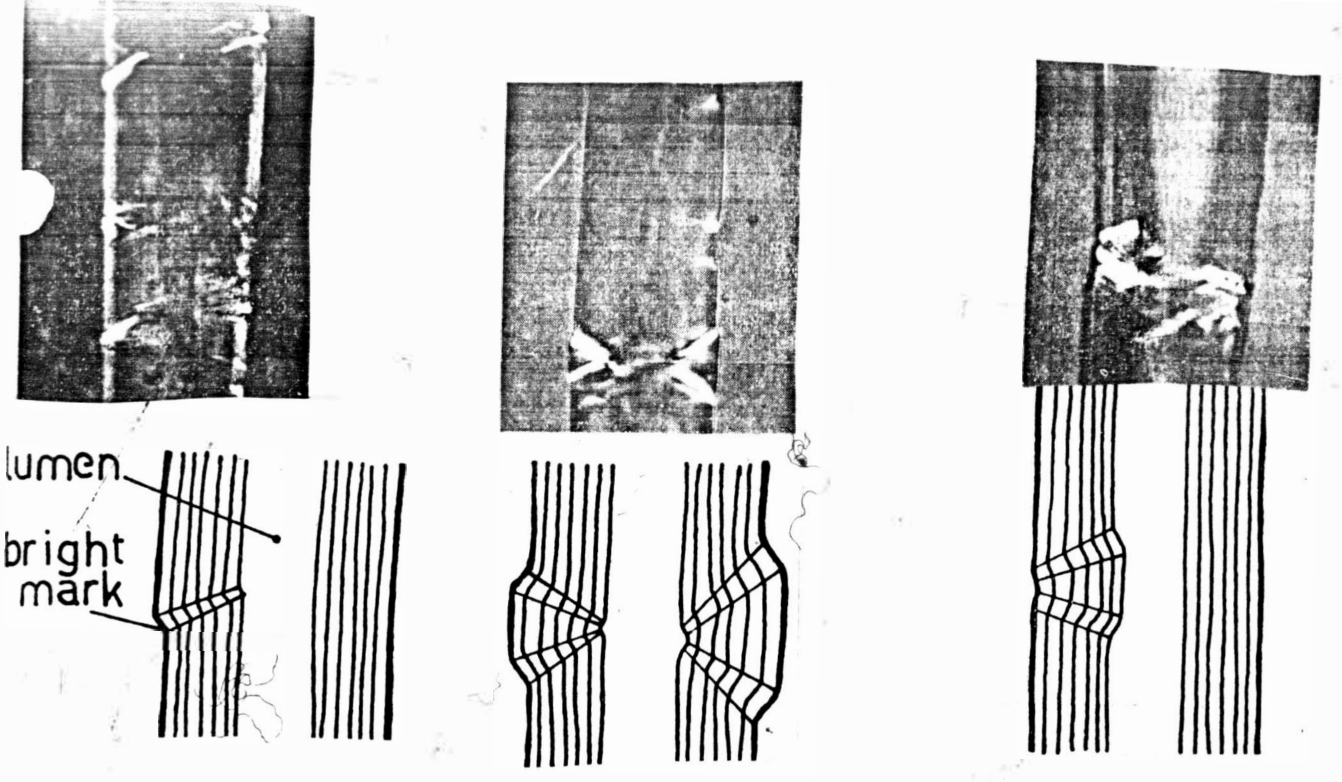
Figure I
a graph illustrating
the intensity threshold
for cavitation in
aerated and deaerated
samples



A.

B.

Figure 2
polarized light x75
a) untreated
b) 60 sec. treatment
(note regularity of
dislocations in b)



A. B. C.

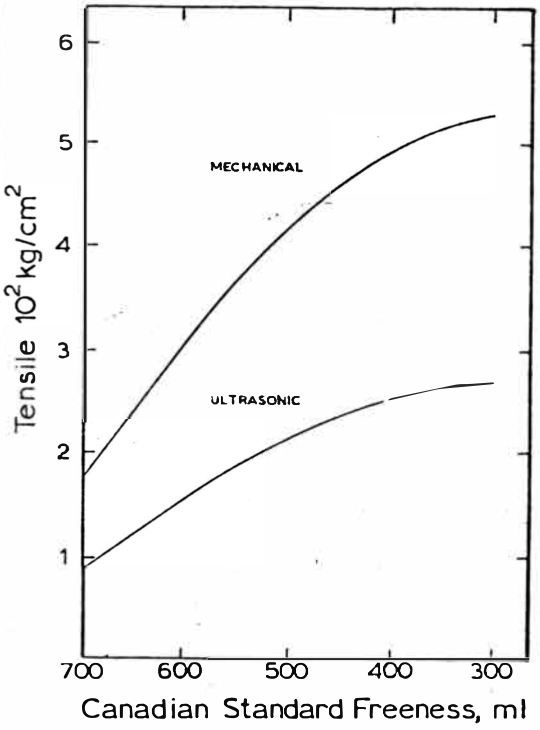
Figure 3
dislocations
a) Type I
b) Type II
c) Type III

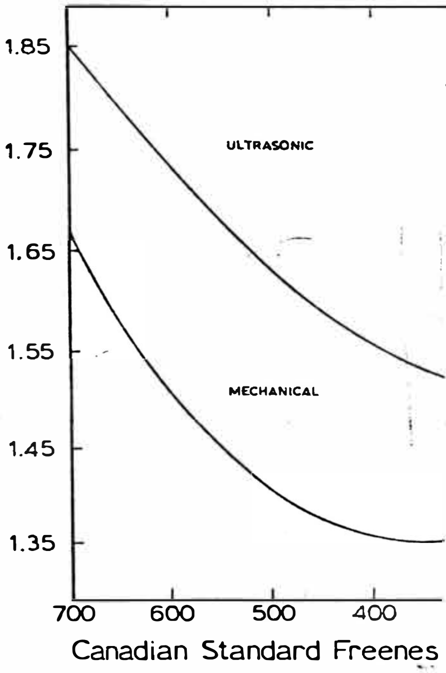
Trends of Ultrasonic Beating versus Mechanical

Figure #5

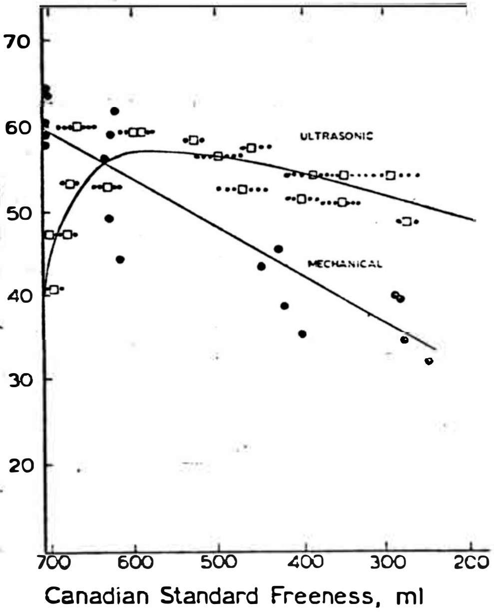
ble 1. — PULP CLASSIFICATION ON BAUER-McNETT CLASSIFIER. THE VALUES REPRESENT PERCENT ENTION OF THE PULP ON VARIOUS SIZE SCREENS AFTER BEATING TO A GIVEN FREENESS LEVEL.

		Ultrasonic Beaten Pulp	Mechanical Beaten Pulp	Unbeaten Pulp
Canadian Standard Freeness (ml)		670	696	731
			% Retention	
Screen size	20	63.4	53.0	65.3
	38	12.1	14.3	18.2
	65	8.3	11.2	8.3
	200	8.2	12.4	8.2
	Fines	8.0	9.1	0.0
Canadian Standard Freeness (ml)		583	586	
Screen size	20	58.0	34.6	
	38	13.8	8.3	
	65	8.6	11.8	
	200	9.1	14.3	
	Fines	10.5	31.0	
Canadian Standard Freeness (ml)		443	436	
Screen size	20	57.6	32.0	
	38	11.7	27.7	
	65	7.5	7.9	
	200	7.9	9.4	
	Fines	15.3	23.0	
Canadian Standard Freeness (ml)		243	272	
Screen size	20	55.6	30.6	
	38	11.7	11.9	
	65	8.9	13.2	
	200	8.9	22.4	
	Fines	14.9	21.9	



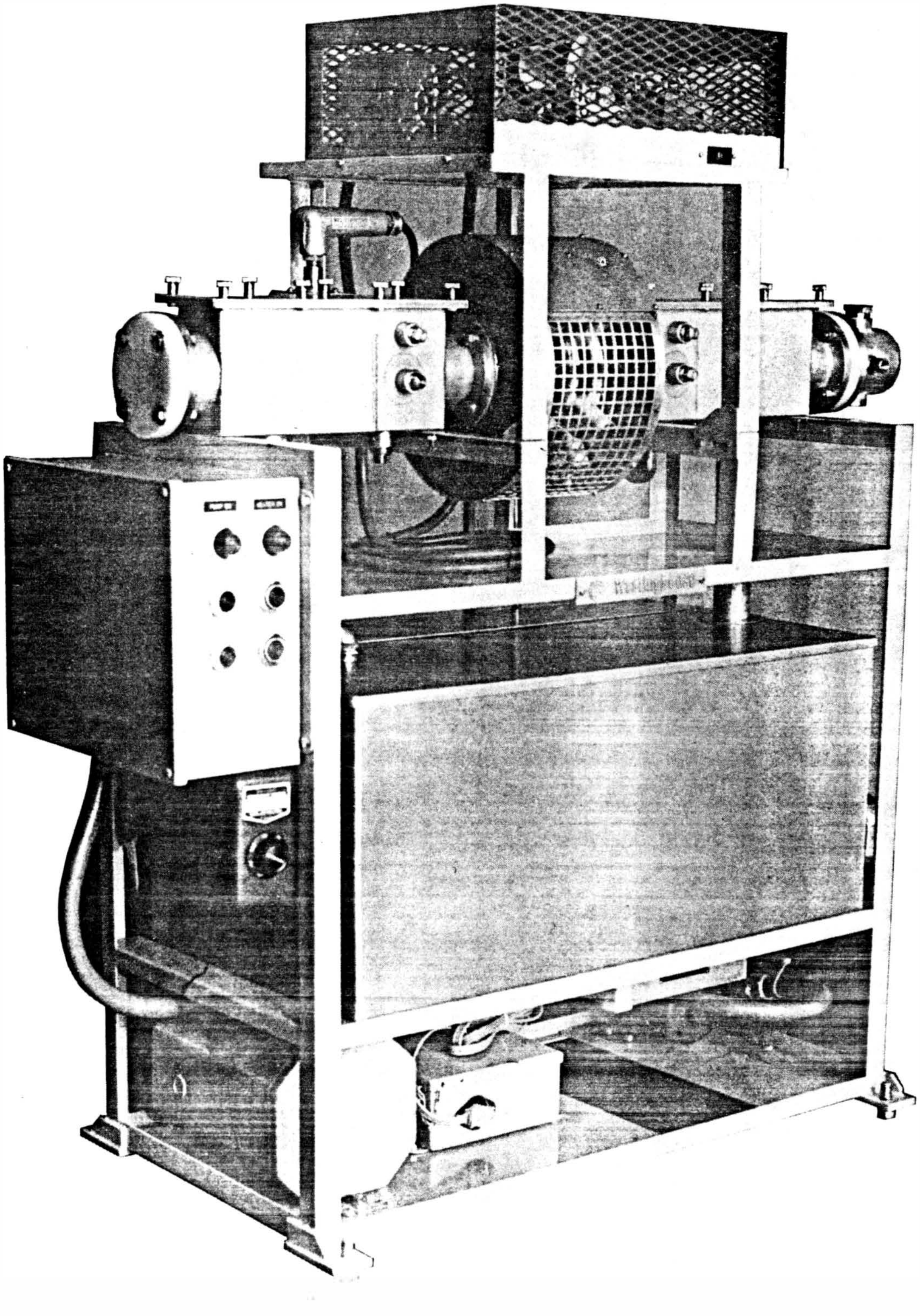


Bulk vs. Freeness

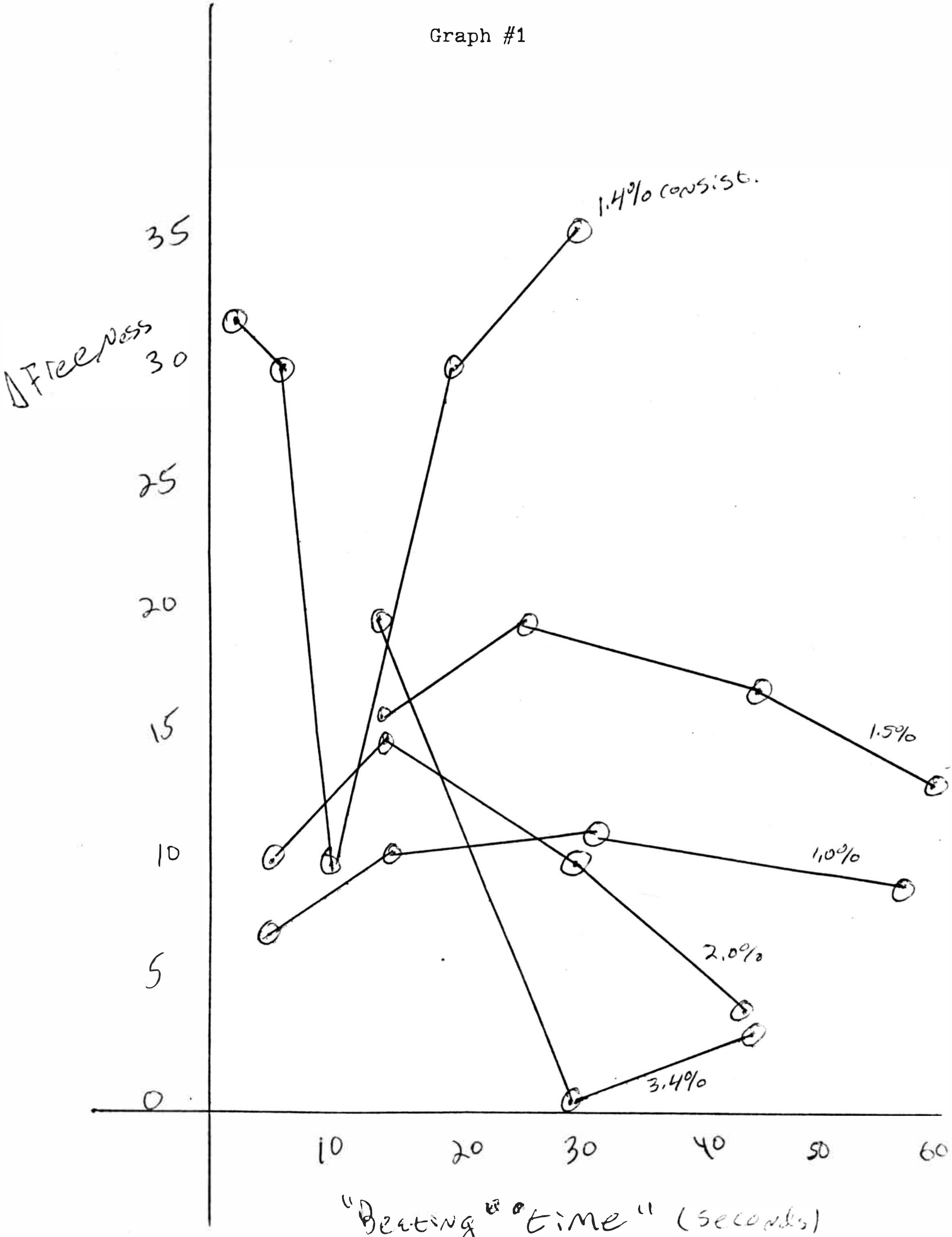


Tear vs. Freeness

Diagram #6



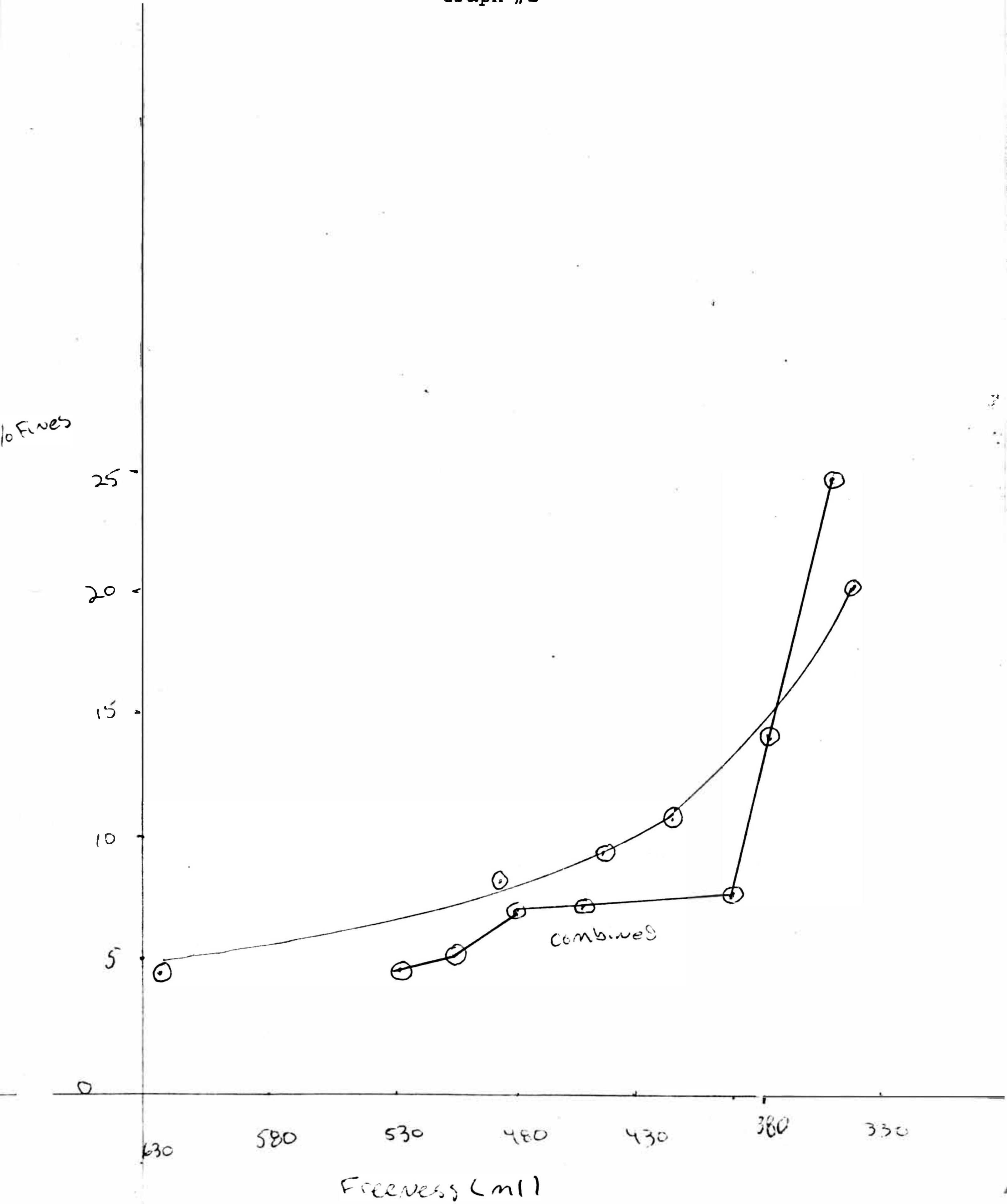
Graph #1



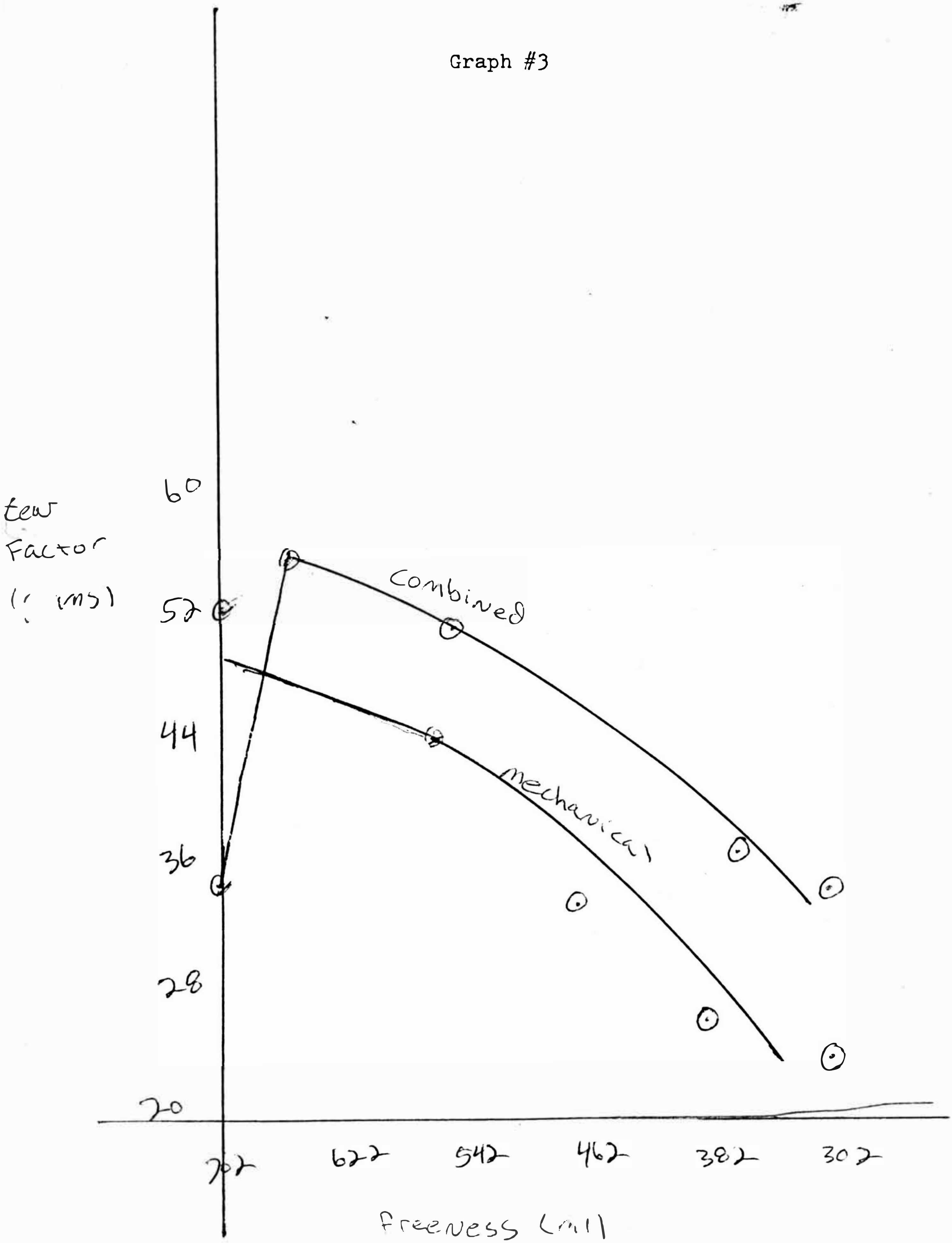
ΔFreeness
35
30
25
20
15
10
5
0
10
20
30
40
50
60
"Beating" "time" (seconds)
1.4% consist.
1.5%
1.0%
2.0%
3.4%

(a-6)

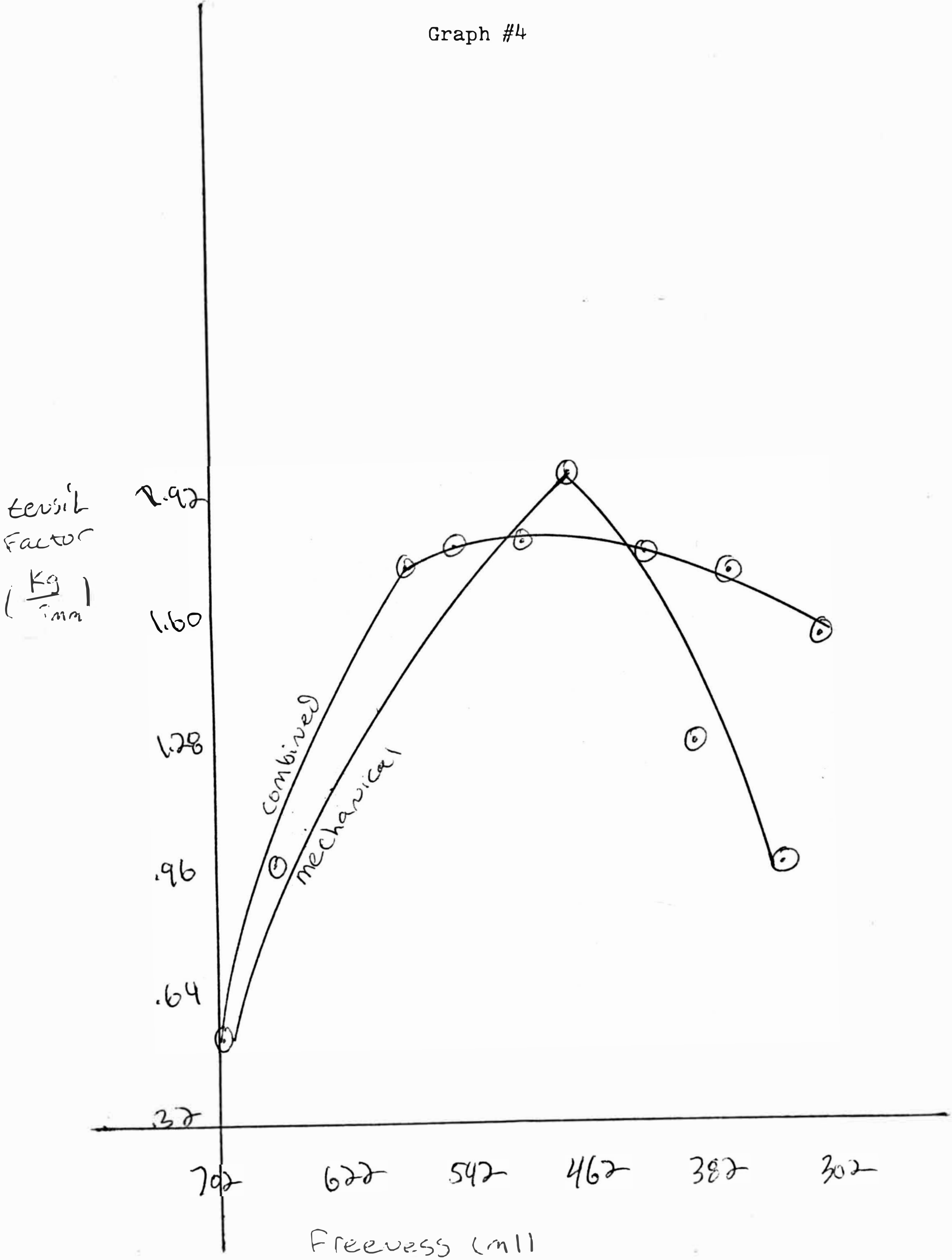
Graph #2


% Fines
25
20
15
10
5
0
combined
630
580
530
480
430
380
330
Freeness (ml)

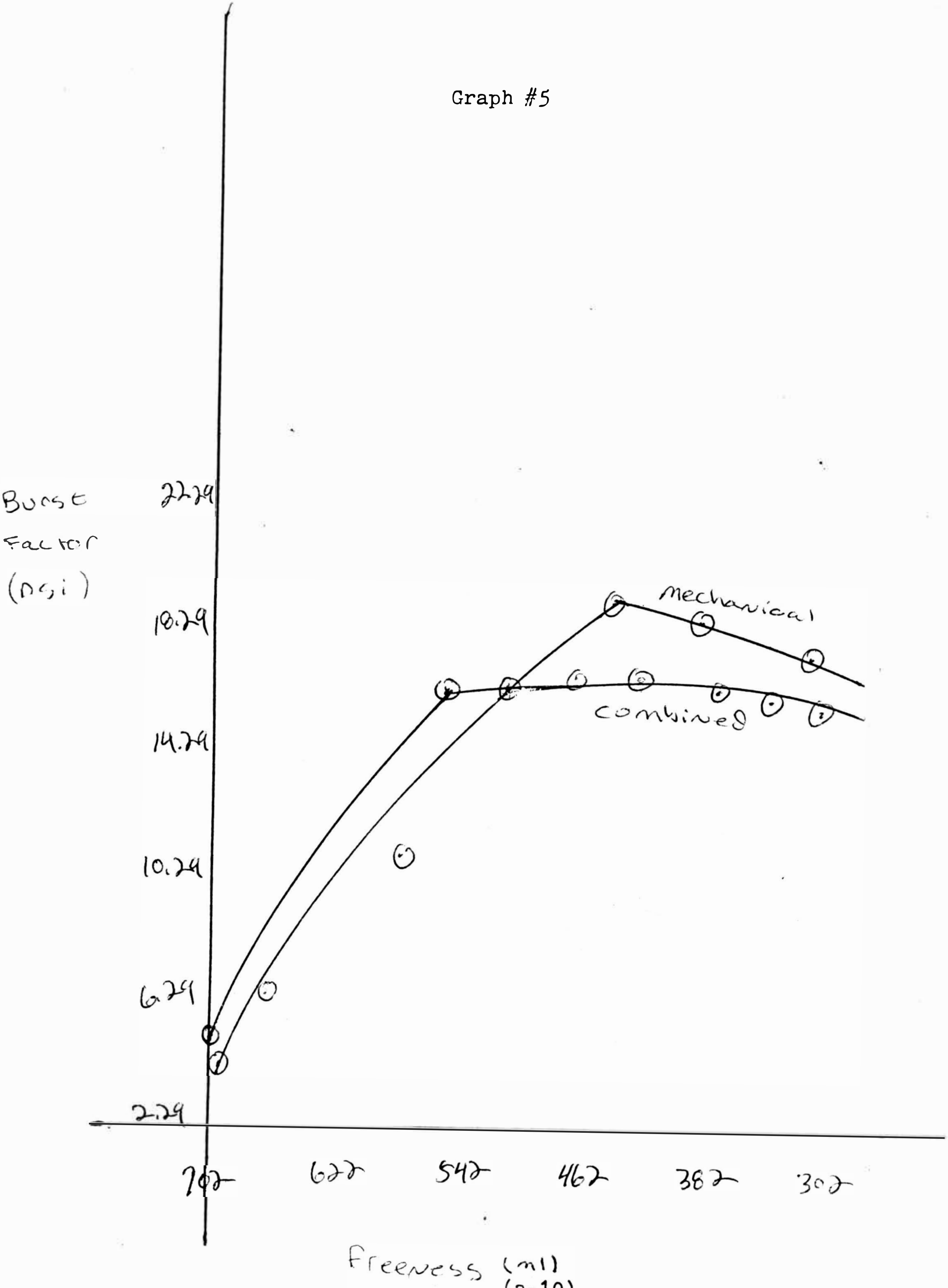
Graph #3


tear
Factor
(gms)
60
52
44
36
28
20
combined
mechanical
702
622
542
462
382
302
freeness (ml)

Graph #4

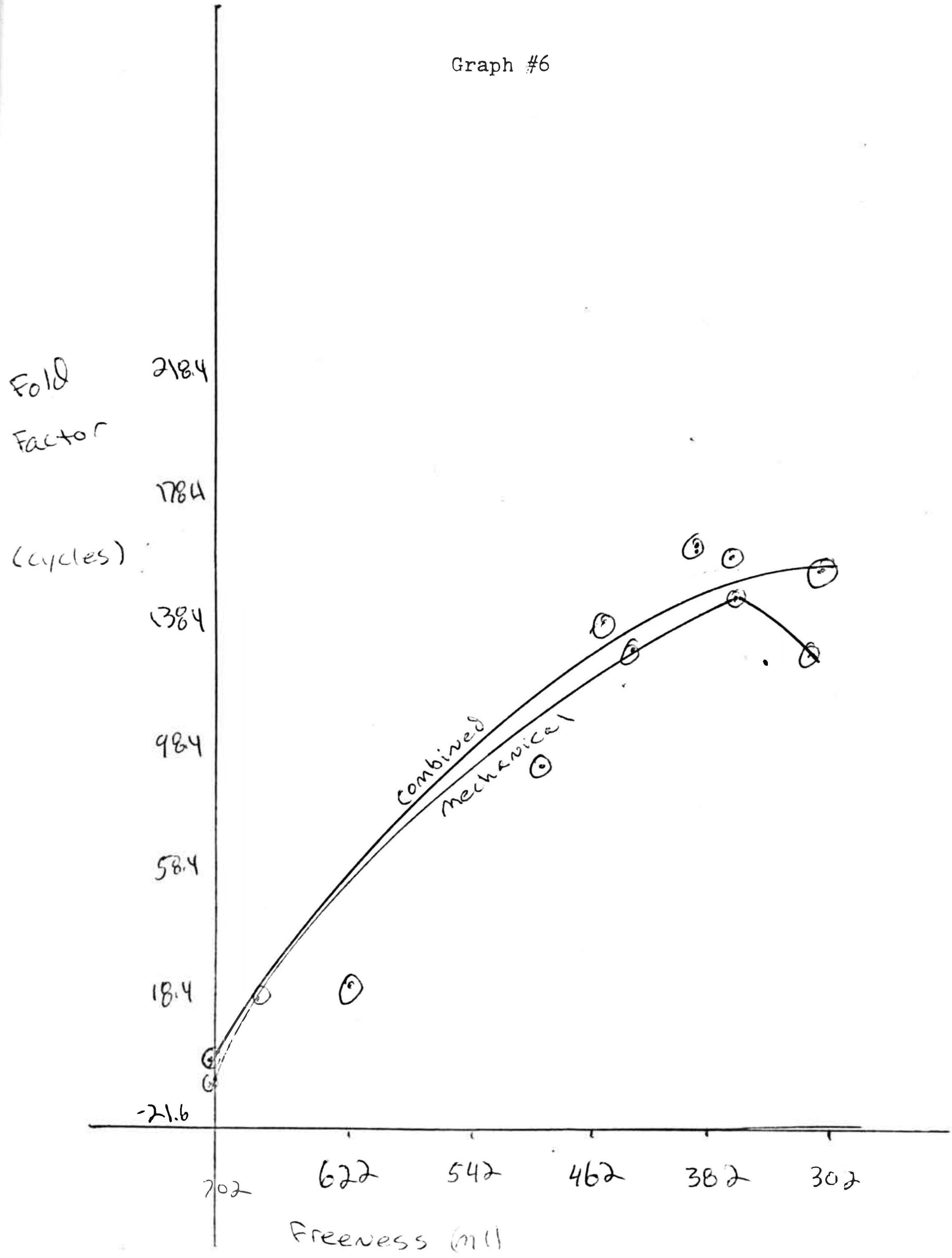

tensil Factor (Kg/mm)
1.92
1.60
1.28
.96
.64
.32
combined
mechanical
702
622
542
462
382
302
Freeness (ml)

Graph #5


Burst Factor (psi)
22.29
18.29
14.29
10.29
6.29
2.29
702
622
542
462
382
302
Freeness (ml)
mechanical
combined

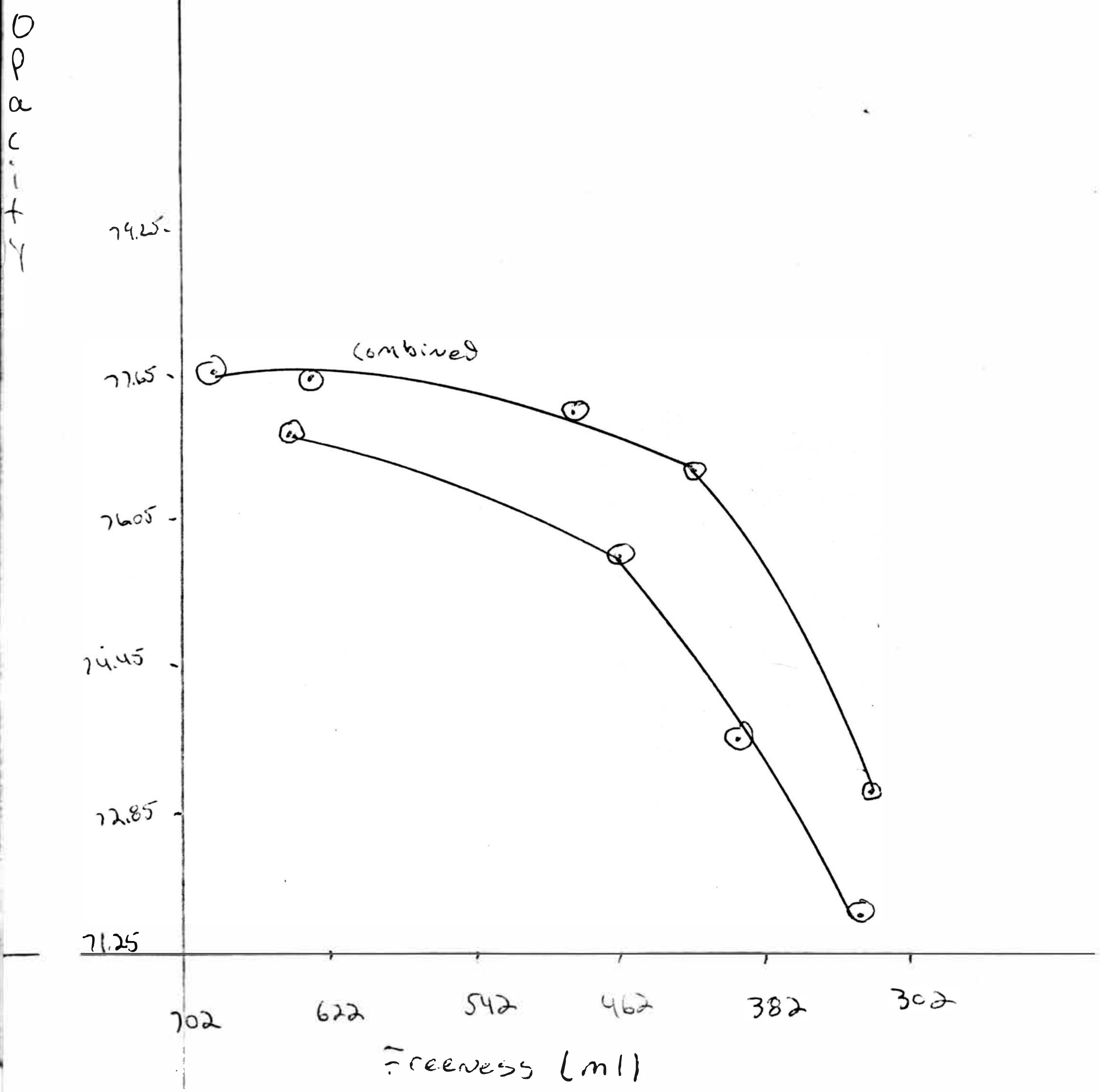
(a-10)

Graph #6



Fold Factor (cycles)
218.4
178.4
138.4
98.4
58.4
18.4
-21.6
combined
mechanical
702
622
542
462
382
302
Freeness (ml)

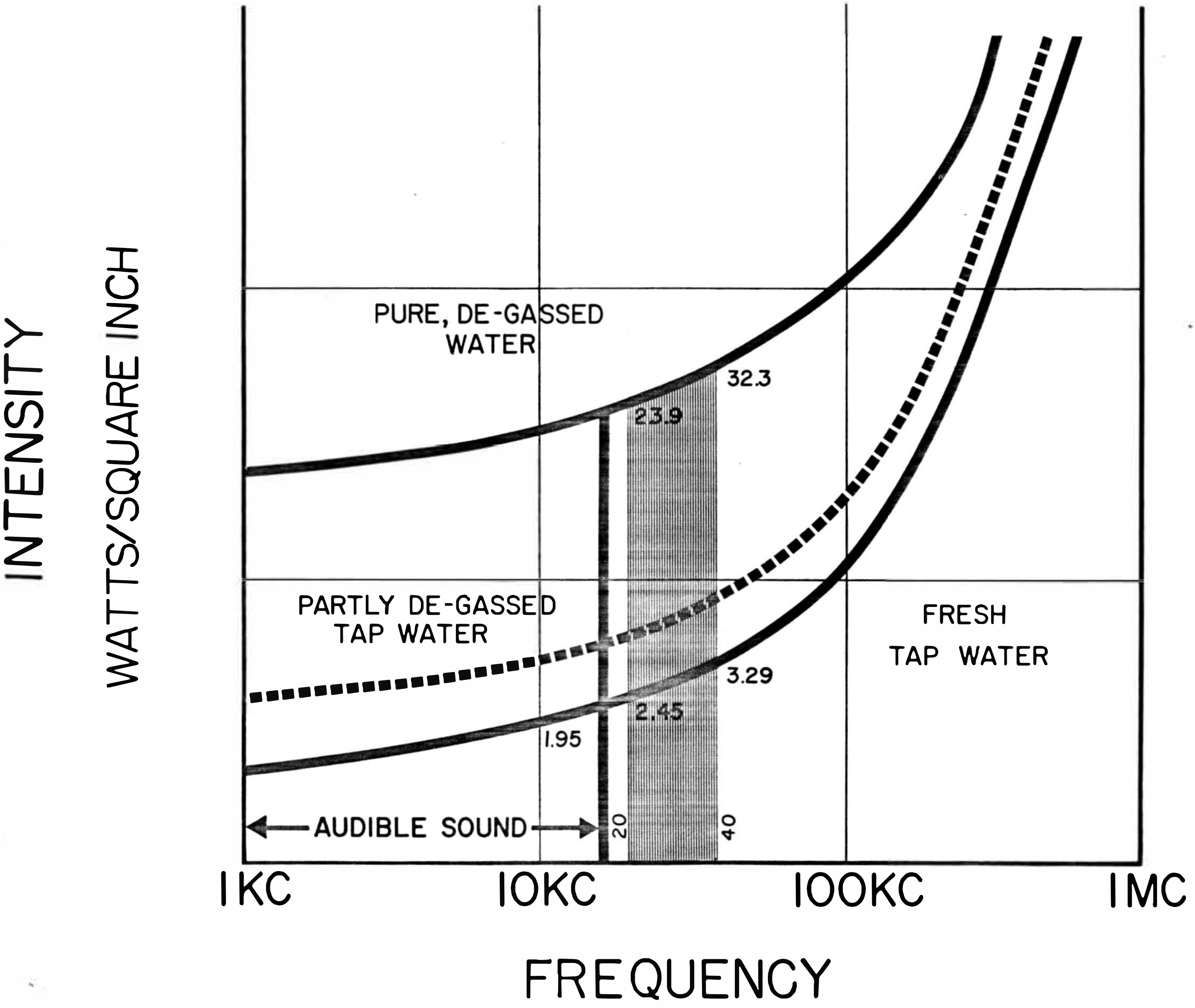
Graph #7


Opacity
79.25
77.65
76.05
74.45
72.85
71.25
combined
702
622
542
462
382
302
Freeness (ml)

(a-12)

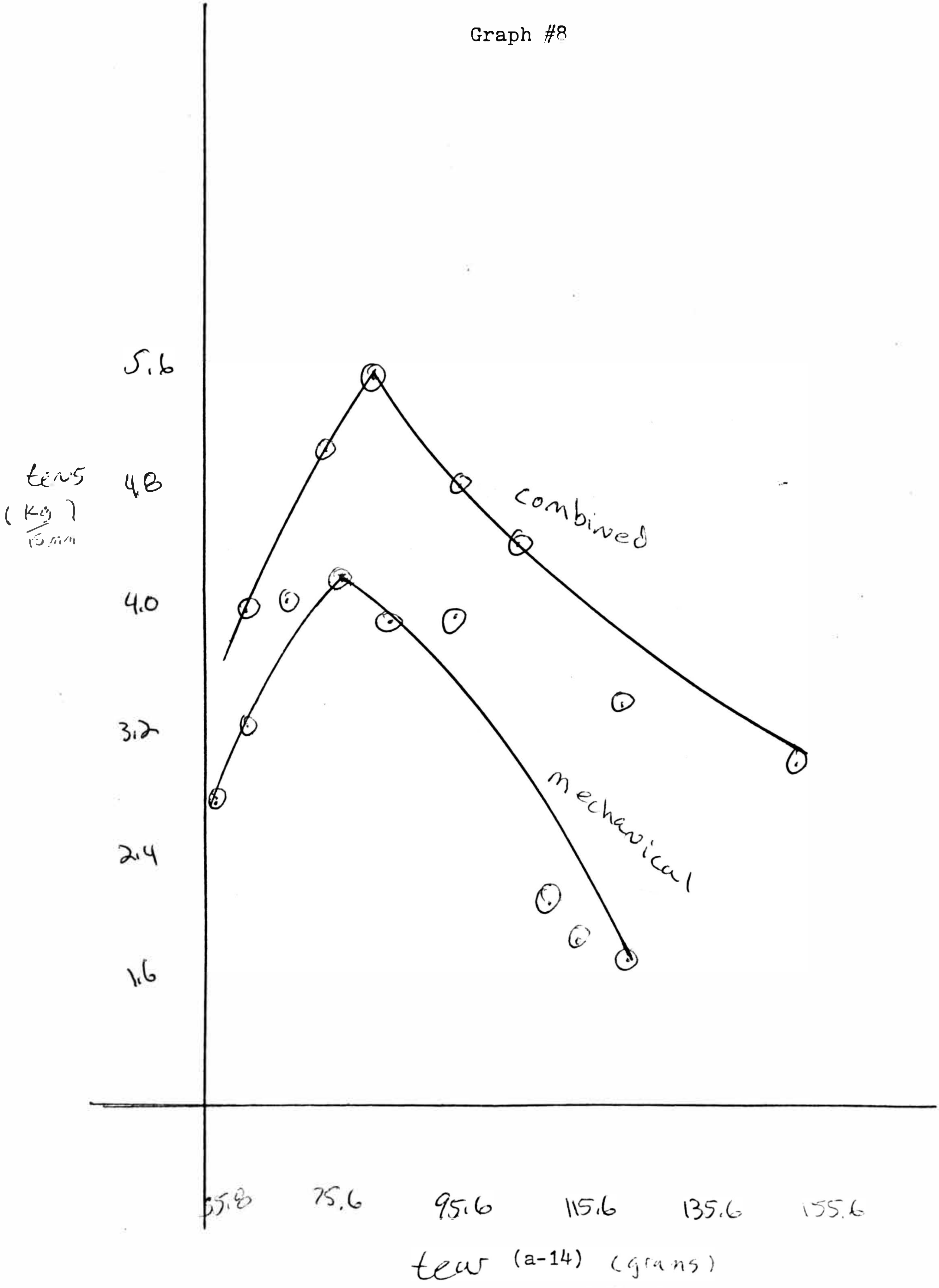
Table #2

THRESHOLD OF CAVITATION



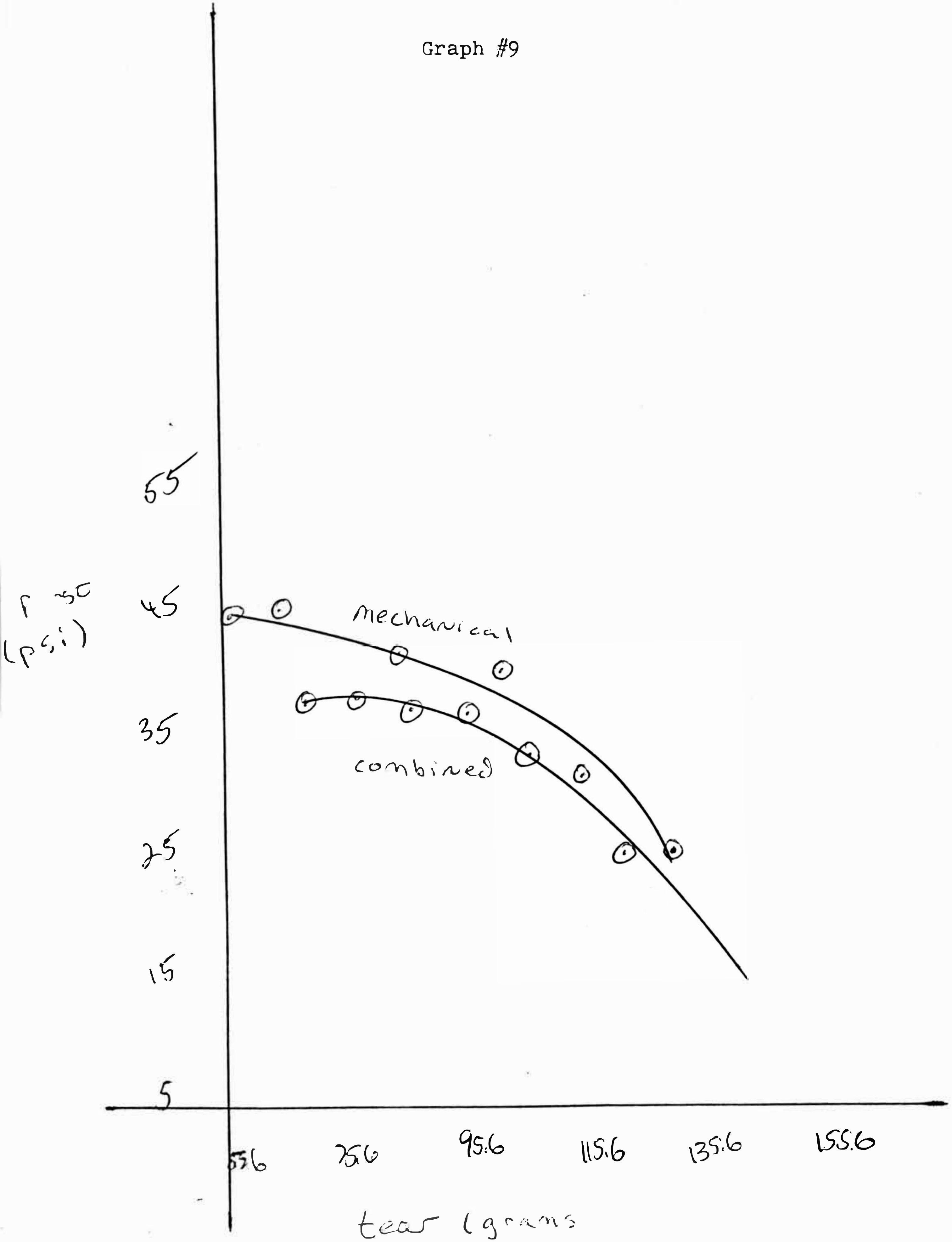
(a-13)

Graph #8

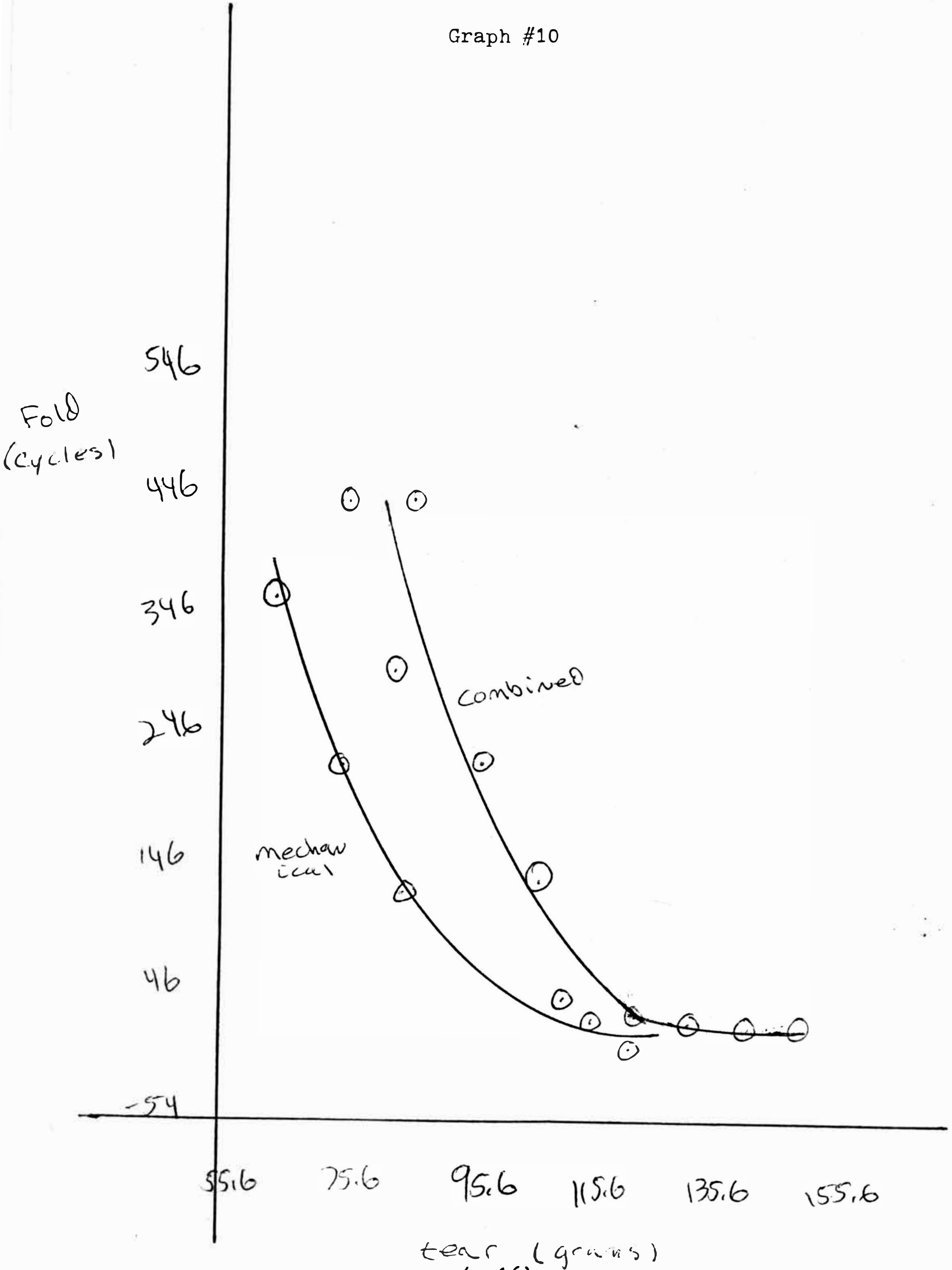


5.6
4.8
4.0
3.2
2.4
1.6
tens (Kg) / 15mm
combined
mechanical
55.8
75.6
95.6
115.6
135.6
155.6
tear (a-14) (grams)

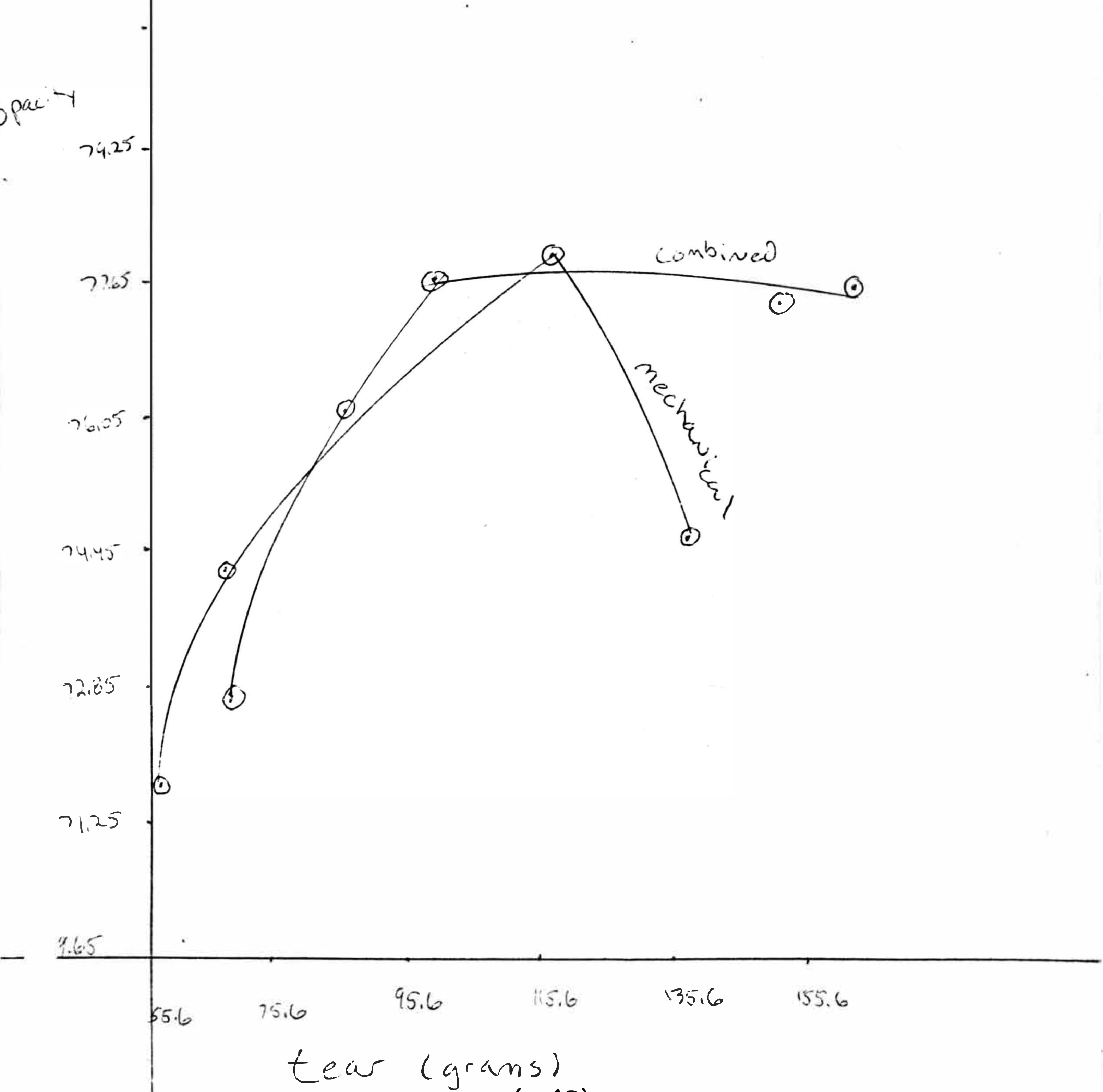
Graph #9


55
45
35
25
15
5
(psi)
mechanical
combined
55.6
75.6
95.6
115.6
135.6
155.6
tear (grams

Graph #10


Fold
(cycles)
546
446
346
246
146
46
-54
combined
mechanical
55.6
75.6
95.6
115.6
135.6
155.6
tear (grams)

Graph #11


pac ty
79.25
77.65
76.05
74.45
72.85
71.25
9.65
combined
mechanical
55.6
75.6
95.6
115.6
135.6
155.6
tear (grams)