THE RELATIONSHIP BETWEEN WHEAT HARDNESS AND MILLING AND BAKING CHARACTERISTICS.

by

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TABLE OF CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURES

Page

Page

Introduction

Wheat hardness is not easily defined, and the relationship between this property and the end use of wheat, primarily breadmaking, has not been adequately studied. Generally, "hard wheats", except for durum, are prized for breadmaking purpose while "soft wheats" are chosen for production of many types of sweet goods.

Within a class of wheat, for example Hard Red Winter (HRW), considerable variations may exist in the hardness of different varieties. Recent trends in wheat breeding are leading to even greater differences in hardness, as breeders increasingly draw upon soft wheat parents to evolve new HRW lines.

It is now important to obtain more information on the relationship between wheat hardness and wheat functionality, for at least two reasons:

(1)Much research is being expended on developing new tests for wheat grading based on hardness. Is hardness a truly valid criteria for milling and baking functionality?

(2)Wheat breeders consider hardness in their programs for new varieties. Again, is hardness a critical factor in HRW functionality?

Literature Review

Measurement of Hardness

There is no generally recognized objective method to measure wheat hardness. Each method or test is influenced by variables peculiar to the equipment used. No serious attempt has been made to standardize equipment and procedure.

Testing wheat for kernel hardness dates back almost to the beginning of milling. In early milling literature, the primitive test of chewing the wheat was described as a method of determination of kernel hardness. The first attempt was made by H.F.Roberts (1910) who studied the hardness of wheat as measured by the weight required to crush an individual kernel. Unfortunately, this test was tedious, at least 300 kernels were necessary, and the kernels had to be oven dried for seven days at 100 C (212 F). Jelinek (1927) in Russia developed a test based on the cutting resistance of the kernels. He found a good relationship between kernel hardness and yield of flour.

Presently, we can divide the wheat hardness test into two categories; one is an individual kernel method and the other is a bulk sample method.

(a) Individual kernel methods.

Gradually, as knowledge of the fundamentals of milling and baking quality expanded, screening of wheat for quality became much more sophisticated. Several methods have been developed to evaluate the hardness of wheat kernels (Obuchowski and Bushuk 1980).

Barlow et al (1973) used a micropenetrometer to measure the strength of purified wheat proteins and starch granules. Katz et al (1959) investigated the penetration of the Barcol cmpressor (a small spring-loaded stylus) into a kernel section.

Smeets et al (1956) used the Smeetar micro-hardness tester (a penetrometer that produces an indentation) to determine the degree of softness of conditioned wheat.

Wingfield (1985) used the Ogawa Seiki O.S.K. grain hardness tester (Tokyo, Japan) to measure the maximum force required to fracture a kernel undergoing compression between a plane surface and a moving cylindrical plunger. Lai et al (1985), after preliminary compression, shear, and puncture tests, designed a continuous automatic single kernel hardness tester. This tester was used to measure stress-strain relations during the crushing of single kernel. Among the six parameters determined from the stress-strain curve, the ratio of the first valley to the first peak was reported to be the most important predictior in wheat hardness.

Mattern (1985) used image analysis method to estimate kernel hardness. By a pair of rolls, with fixed roll gap, wheat kernel was crushed, and the crushed kernel apperance was observed by microscope connecting with a computer to make an image analysis. Image analysis is a relatively new technique and that is currently receiving increased attention.

The practical application of the single kernel hardness measurement is still, however, limited because of the low reproducibility of results, due to the structual variability among kernels and among various parts of a single kernel (Blum et al 1960).

(b) Bulk sample methods

For research purposes hardness is often measured objectively by determing "pearling index", usually defined as the percentage of material "pearled-off" from a sample of wheat of prescribed weight in a laboratory barley pearler operated for a prescribed period of time. This test was developed by Taylor et al (1939). With increasing moisture contents, especially after tempering, pearling index increases. This phenomenon is due to an increase in toughness of the bran, which makes the bran more resistant to abrasion (Meppelink 1971). Beard and Poehlman (1954), in studying segregation produced from crossing hard and soft wheats, found wide differences in pearling indexes and showed that with such material, visual classification according to hardness was frequently faulty. The amount of material "pearled-off" is influenced by the following: kernel size (length and diameter), toughness, and brittleness of the grain. These factors cannot be separated from each other and yet must be taken into consideration in interpreting the pearling values of wheats.

Cutler and Brinson (1935) developed a particle size index (PSI) to rank wheats, based on their relative hardness. Symes (1961) used PSI in routine tests of grain. For the PSI test, a weighed sample of grain is ground and sifted under standard conditions and the weight of sample passing through the sieve is measured. Grinding of a soft wheat produces a distribution of relatively small particles leading to a high value for the PSI, whereas a low value for PSI signifies a hard wheat. There was little kernel size effect on the particle size index (Meppelink 1971). In general, the PSI has been the most widely accepted test (Yamazaki and Donelson 1983).

Williams (1979) introduced near infrared reflectance spectroscopy (NIR) to measure the hardness. He used the principle that analysis of NIR was markedly affected by the mean particle size (MPS) of the ground material (Williams 1975, Williams and Thompson 1978). In 1984, the AACC Physical Testing Methods Subcommittee initiated a collaborative study to verify the integrity of NIR spectroscopy as a rapid method for hardness measurement (Williams and Sobering 1986).

Grinding time of 4 g wheat sample by a Brabender Automatic Microhardness Tester was also used to measure the hardness (Miller et al 1981 and 1984).

Theory of Grain Hardness

Currently, at least three theories have been suggested to explain grain hardness.

Simmonds (1971), Simmonds et al (1973), and Barlow et al (1973) from Australia undertook the first study to determine what causes hardness in wheat. Using a micropenetrometer, Barlow and co-workers (1973) were able to show that there was no difference in the hardness of either the starch or the protein between the types of wheats. However, they also showed that the binding between the protein and the starch appeared to be stronger in hard wheat than it was in soft wheat. They suggested that this was what was responsible for the difference in hardness. Hoseney and Seib (1973) reached similar conclusions, based on scanning electron microscopic observations of cut kernels.

This theory suggests that something controls the binding of the protein and starch. Recent work with corn, grain sorghum, and pearl millet have shown that an alcohol-soluble protein is responsible for the binding of the protein and the starch (Abdelrahman and Hoseney 1984). Similar work with wheat has not yet been reported.

The second theory, proposed by Stenvert and Kingswood (1977), is essentially one of a filled versus unfilled matrix. Many hard wheats are vitreous and, thus, have a filled matrix. The theory holds that in such a filled matrix, the strength of the kernel would be greater simply because of more surface interaction, even if the strength of the protein-starch bond were the same. Although the theory is reasonable at first glance, several factors argue against it. For instance, cultivars of excellent soft wheat when grown under the right conditions can have a vitreous (filled) grain but remain quite soft. The reverse is also true: Certain hard wheat can have an unfilled matrix (opaque or floury) and still be quite hard. Thus, this theory does not appear to be true.

Recently, the Dutch researcher Doekes has proposed a third theory (1985). This theory suggests that hardness is caused by the protein fractions of the wheat. The protein fraction that is responsible for the difference is charged, and if the net charge of those proteins is high, the proteins will repel each other and the grain will be soft. If the net charge is low, there is no such repulsion and the grain is hard.

More recently, Greenwell and Schofield (1986) have reported that soft wheat starch contains a protein on the surface of its granules that is either missing or found in only very low levels on hard wheat starch. They made this observation on more than 300 cultivars, and suggested that this protein interferes with the interaction of the protein and starch, which fits nicely with the protein starch binding theory. It also agrees with the observation of Abdelrahman and Hoseney (1984) that starch from different sources affected the hardness of pellets made from isolated starch and protein. It may be premature to assume that this explains hardness, but it certainly is an attractive theory that needs to be studied more.

Influence of Genetical & Environmental Factors

It is generally recognized that hardness is a varietal characteristic greatly influenced by environmental factors, but we are not sure which factor has the greatest influence.

Working on wheat, Parish and Halse (1968) reported that temperature and relative humidity during ripening have an effect on grain hardness. They also found that altering the drying conditions during grain maturation produced wide variation in the proportion of vitrous kernels. Hard wheat became harder with a more humid atmosphere during the later stages of ripening, while all wheat became harder if the temperatures during this period were higher.

Trupp (1976) stated that hardness was mainly conditioned by environmental factors. Katz et al (1961) reported that the hardness of a kernel section of hard red winter, soft white winter and durum wheat decreased with increasing moisture content. Miller et al (1982) pointed out that irrigation of wheat decreased its hardness as measured by the time of grinding.

On the other hand, Hoseney (1987) mentioned that hardness was not materially affected by environment but was determined almost entirely by genetics. Baker

(1977) found that hardness was governed by two major genes and one or more minor genes.

At first glance, these theories look controversial, but actually they are not. Hardness is pretty much governed by genetic factors. For example, durum wheat cannot be as soft as soft red winter wheat. However, within a certain range, hardness is greatly influenced by environment factors. ✓

Sandtstedt and Fortmann (1944) studied eight hard red winter wheats and concluded that environment markedly affected protein content, absorption, handling properties, mixing requirement and loaf volume of wheat flours, although not all varieties were affected to the same degree.

Harris and co-workers (1944 and 1945), who studied North Dakota spring wheat, found that protein content, loaf volume and crumb color were significantly affected by both cultivar and environment, with the latter exerting the major influence. They also stated that variety had more effect than environment in influencing physical dough properties.

Finney and Fryer (1958) provided evidence that the quality of wheat for bread production could be influenced by high temperatures during the fruiting period. They reported that temperature above 32 C

(90 F) consistently decreased loaf volume and mixing time.

The importance of the environmental effect on wheat quality was also emphasized by Johnson and co-workers (1972). Working with hard red winter wheat cultivars grown in different localities in Kansas, they reported that environment had the greatest effect on all quality characteristics studied (protein, farinograph mixing time, loaf volume) except for bakery mixing time which was influenced to a greater extent by genetic factors.

Very little is reported in the literature on the effect of environment and the variety on milling quality of wheat. Harris (1955) investigated the relation between wheat variety and location of growth with flour particle size. He reported that environment was more influential than the variety for flour particle size distribution. He also found that flour ash content varied significantly among the locations.

Material and Methods

Each year, the Kansas Agricultural Experiment Station breeds wheat cultivars in replicated drill strips of varying size in different locations of the state. Qualities analysis are made on entries from all of those locations annually. The grain samples are composites of all replications of each entry from each location.

For this study, we received 172 samples from the 1986 crop. The wheat samples consisted of 30 different varieties grown in 8 different locations in Kansas. After test weight was measured, we eliminated wheat samples which had low test weights (below 56 lb/bushel). We used 18 samples of wheat with acceptable test weights for the tests described in this report.

A. Wheat Analysis

Method of Cleaning

All the wheat samples were cleaned using a Carter Dockage Tester. The clean wheat was then submitted for analysis.

Test Weight

Test weight is the weight per Winchester bushel with weight expressed to the nearest tenth of a pound. Determinations were made according to the standard method outlined by the USDA (1953).

Proximate Analysis of Wheats

Moisture, ash, and protein test were done by AACC methods (1983).

(1) Moisture

We used the air-oven method. Using a Udy-mill (1.00-mm screen), grind 30-40 g wheat sample, take 2-3 g portion to the moisture dish , dry at 130 C for one hour. Remove dishes from oven, cover rapidly, and transfer to desiccator as quickly as possible. Weigh dishes after they reach room temperature (45-60 min usually). Determine loss in weight as moisture. Before using, moisture dishes should be dried for one hour at 130 C, cooled in a desiccator, and obtained tare weight.

(2) Ash

We used the basic method. Weigh 3-5 g (14 % moisture basis) of well-mixed ground sample into an ashing dish which has been ignited, cooled in a desiccator, and weighed soon after attaining room temperature. Place in a muffle furnace at 575-590 C for hard wheat flours. Incinerate until light gray ash is obtained or to constant weight. The sample must not be allowed to fuse. Cool in desiccator and weigh soon after room temperature is attained.

(3) Protein

We used the improved Kjeldahl method.

1. Place weighed sample (0.7-2.2 g; 14 % moisture basis) in digestion flask. Add 40 ml H_2SO_4 containing 2 g salicyclic acid. Shake until thoroughly mixed and let stand, with occasional shaking, for 30 min or more; then add 5 g $Na_2S_2O_4.5H_2O$ or 2 g zinc dust. Shake and let stand 5 min; then heat over low flame until frothing ceases. Turn off heat.

2. Add 0.7 g HgO or 0.65 g metallic Hg, 15 g powdered K_2SO_4 or anhyd. Na_2SO_4, and 25 ml H_2SO_4. Place flask in inclined position and heat gently until frothing ceases; boil briskly until solution clears and then for at least 30 min longer.

3. Cool, add approx. 200ml water, cool below 25 C, add 25 ml sulfide or thiosulfate solution, and mix to ppt mercury. Add few zinc granules to prevent bumping, tilt flask, and add layer of NaOH without agitation.

4. Immediately connect flask to bulb on condenser and, with tip of condenser immersed in 25 ml std. acid in receiver, rotate flask to mix contents thoroughly; then heat until all ammonia has distilled.

5. Titrate excess standard acid in distillate with standard alkaline solution, using methyl red indicator.

6. Correct for blank determinations on reagents.

Wheat Hardness

(1) Pearling Index

20 g of clean sound wheat was pearled in a Strong Scott laboratory barley pearler (Fig.1) for 60 sec. The remaining grain was handsifted on a 20 wire Tyler standard sieve, weighed and recorded as a percentage of the original sample and expressed as pearling value or pearling index. The higher the value, the harder the grain.

(2) Particle Size Index (PSI)

Using a Udy-mill with 1.00-mm screen (Fig.2), approximately 200 g of wheat was ground into whole flour. Feed rate of Udy-mill was set at minimum.

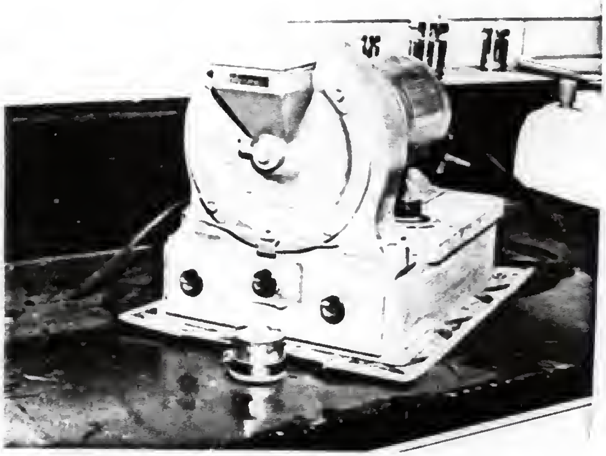


Fig. 1 Barley Pearler.

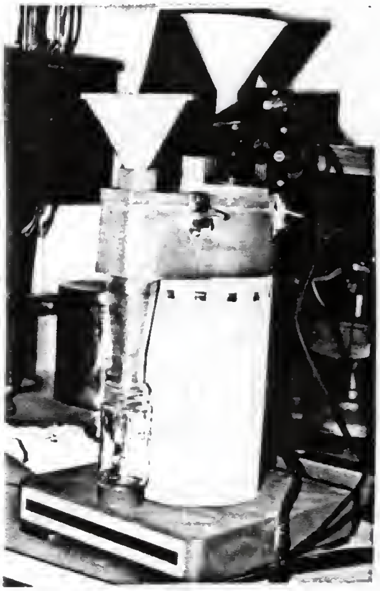


Fig. 2 Udy-mill.

Take 100 g ground sample, use Alpine air sifter (Fig.3) for 5 min with #200 mesh. Weigh the sample which has remained on the sieve (Williams 1979). The more ground wheat that remains, the harder the wheat.

(3) NIR

Technicon Infra Analyzer 300 was used for the hardness test. Wheat samples ground by a Udy-mill were used for NIR testing.

(4) Image Analysis

Microscopic techniques (Mattern 1985) available at The University of Nebraska were used. Statistical information and video recordings of the microscopic images of samples were provided. Wheat samples were crushed by fixed gap rolls, and the crushed samples were provided for this test.

B. Milling Test

Tempering of Wheat

Motomco Dickey-John grain moisture tester (Fig.4) was used. All of the samples were tempered for about 24 hours to approximately 16 % moisture.

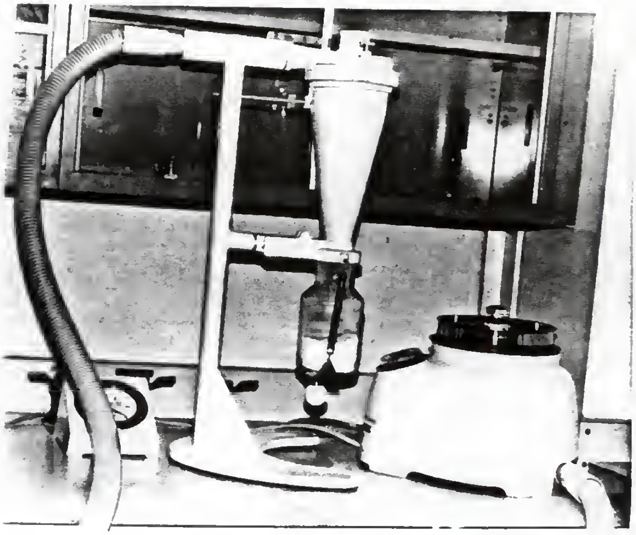


Fig. 3 Alpine air sifter.

Fig. 4 Motomco Dickey-John grain moisture tester.

Milling

The samples were milled by the Ross Experimental Mill with a Great Western lab. sifter (Fig.5). The differential of the break rolls was 2.5 : 1. The pitch of 1 & 2 BK was 14. The pitch of 3, 4, & 5 BK was 24. Grinding action was dull : dull.

Suggested break release are as follows:

1BK	30 % thru 20 L.W.
2BK	40 % thru 20 L.W.
3BK	35 % thru 20 L.W.
4BK	20 % thru 24 L.W.
5BK	Clean-up

The differential of the smooth rolls was 1.6 : 1. The flow sheet (Fig.6) consisted of five break rolls, two sizing rolls, five reduction rolls, and one tailing roll. Each stream was collected and blended for straight grade flour. Some portion of each stream was used to draw an ash curve. The extraction rate was approximately 70 %.

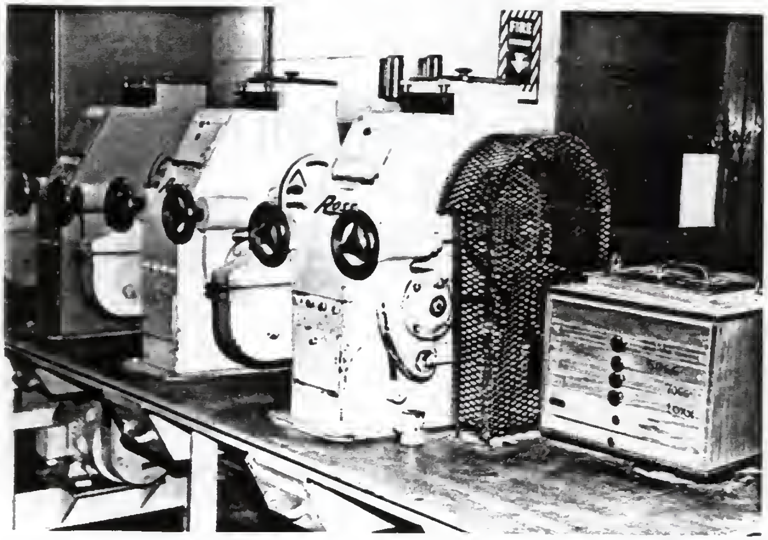
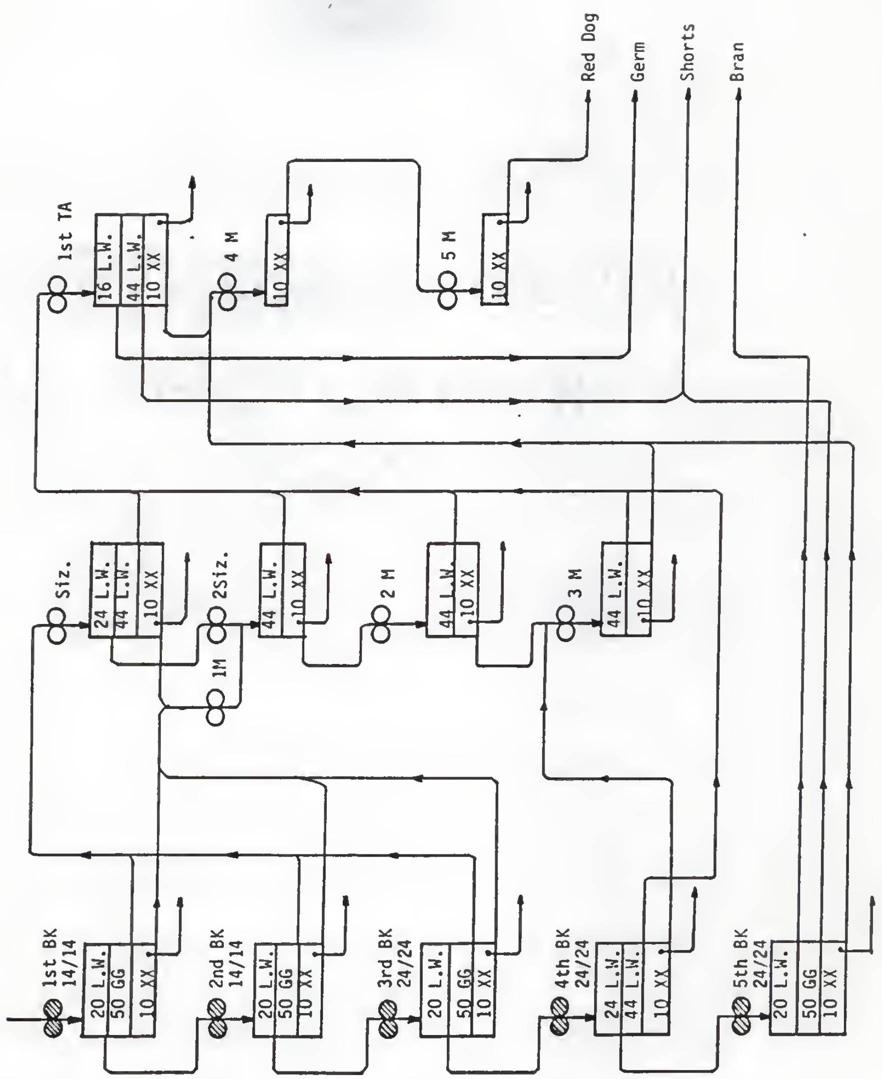


Fig. 5 Ross Experimental Mills with Great Western laboratory sifter.

Fig. 6 Flow sheet for Milling Test.


1st BK
14/14
20 L.W.
50 GG
10 XX
2nd BK
14/14
20 L.W.
50 GG
10 XX
3rd BK
24/24
20 L.W.
50 GG
10 XX
4th BK
24/24
24 L.W.
44 L.W.
10 XX
5th BK
24/24
20 L.W.
50 GG
10 XX
Siz.
24 L.W.
44 L.W.
10 XX
1M
2Siz.
44 L.W.
10 XX
2 M
44 L.W.
10 XX
3 M
44 L.W.
10 XX
1st TA
16 L.W.
44 L.W.
10 XX
4 M
10 XX
5 M
10 XX
Red Dog
Germ
Shorts
Bran

C. Flour & Dough Tests

Proximate Analysis

Moisture, ash, and protein of each flour were measured by AACC methods (1983).

Gluten Determination

This was done with the Glutomatic gluten washer (Model 2200) manufactured by The Falling Number Company. The Glutomatic is an automatic apparatus which develops the gluten from a wheat flour; subsequent separation of starch and other solubles from the dough takes place in the same test chamber under controlled, standardized conditions.

The system consists of three separate components:

(1) The combined dough mixer and washer(2200).
(2) The centrifuge(2012).
(3) The Glutork dryer(2020).

(a) Wet gluten

10 g of flour were introduced in the Glutomatic test chamber and 5.2 ml of 2% sodium chloride solution were added by means of a built-in pipette. During the first 20 sec, the dough was mixed, the Glutomatic then switched automatically to the washing sequence which lasted 5 min and separation of gluten and soluble

starch products was obtained. The gluten ball was then divided and placed in the centrifuge for one min to remove excess water. The weight of the centrufuged gluten x 10 = percent of wet gluten.

(b) Dry gluten

To remove the bound water from wet gluten, the gluten ball was placed between two teflon-coated heated plates for 4 min. The weight of the dry gluten x 10 = percent dry gluten.

Mixograph

The Swanson-working recording dough mixer or mixograph is an instrument that measures changes in the combined effects of elasticity, plasticity, and viscosity as functions of continuous mixing. Its most recently modified version uses only 10 g of flour. In the mixograph, the mixing effect is obtained by four vertical pins attached to a rotating head which revolves through the dough in a planetary motion around three other fixed pins in the mixing bowl. As the dough consistency increases, a gradually increasing amount of force is required to push the revolving pins through the dough. This increased dough resistance imparts a twisting motion to the mixing bowl which is placed in the center of a lever system. The degree of twist produced is measured and recorded by means of a stylus on a chart traveling at a uniform rate of speed. A detailed description of a 10 gram mixograph is provided by Finney and Shogren (1972). A ten gram mixograph was done following the AACC methods (1983).

(1)Ten grams of flour (14 % moisture basis) was weighed out and transferred into the mixograph mixing bowl.

(2)A hole was formed in the middle of the flour and water needed was added into the hole with a pipette.

(3)The ink pen was released and placed on the base line of the chart.

(4)The mixing head was released and locked down into the mixing bowl.

(5)Timer was adjusted and the mixer and chart paper switches turned on.

Falling Number

Since the level of diastatic or amylolytic activity in the flour exerts a major effect on both dough properties and final product quality, it is an important flour quality characteristic related to baking performance. The substrates for cereal alpha and beta amylases are amylose and amylopectin of the starch molecules, or the products of their hydrolytic degradation. Beta-amylase, an exoenzyme, hydrolyzes the alpha-1,4-glucosidic bonds of outer chains of the starch molecule starting from the nonreducing end and producing maltose and limit dextrins. Ultimately, free linear chains such as amylose can be completely converted into maltose. Alpha-amylase hydrolyzes alpha-1.4-glucosidic bonds within the starch molecule in a random fashion producing additional free starch chains for conversion into maltose by beta-amylase. Yeast in the dough converts each maltose into two glucose units by a complex mechanism, thus utilizing the glucose units in the fermentation process.

Ungerminated, sound wheat contains an abundance of beta-amylase and a low, variable level of alpha-amylase (Pomeranz 1978). Therefore, it is a common practice to supplement flour with a source of alpha-amylase during milling and/or baking processes. The sources of alpha-amylase activity are fungal, bacterial, and cereal alpha-amylases in the form of cereal malts, of which barley malt is probably the most common. A reliable method to measure diastatic activity and alpha-amylase supplementation enables the baker to optimize accurately the amylolytic activity according to the desired product characteristics. In addition, a method in determining diastatic activity is of importance among millers who are concerned with incoming grain quality. During germination of wheat kernels, alpha-amylase activity increases drastically, and a high percentage of sprout-damaged kernels always indicates strong damage to baking properties (Standt and Ziegler 1973).

Amylolytic activity can be measured directly by measuring the increase in amount of the product or a decrease in the amount of substrate as a result of the amylase action. Also, amylolytic activity can be assayed indirectly by using such instruments as a gasograph, amylograph, and the falling number. In this experiment, the Falling Number method was utilized to measure alpha-amylase activity. This method is based on the rapid gelatinization of a flour suspension and the subsequent measurement of the degradation of the starch paste by alpha-amylase. As a suspension of flour or starch is heated, the individual starch granules swell by taking up water and cause the suspension to become more viscous. The reduction of the swollen gelatinized starch granules into dextrins and maltose by alpha-amylase causes a drop in the viscosity of the suspension. In this method, the level of enzyme action is defined as the time in seconds required to stir and allow the stirrer to fall a measured distance through the hot aqueous gel undergoing liquifaction (Doty 1981). Strict control of temperature and stirring action (shearing) is required in order to compare the alpha-amylase activity of different flours. As indicated by Hoseney et al (1982), the Falling Number method is a simple, reliable viscometric method of determining alpha-amylase activity in wheat flours, provided the experimental conditions are closely controlled.

The falling number test was done following the AACC methods (1983).

(1)Weigh 7.00 g (14 % moisture basis) of flour into a dry tube. Add 25 ml water. Insert rubber stopper and shake tube in uptight position 10 times, making sure all flour is suspended.

(2)Scrape down upper part of tube with viscometer-stirer.

(3)Set the tube in the Falling Number equipment.

(4)Press start switch.

(5)After the buzzer is activated, stop the test by turning the small top knob, which controls the contact wire, counterclockwise.

(6) Record time in seconds.

(7) Quickly remove test tube from bath, hold tube under running water, and remove viscometer-stirer. Starch gel is easily removed from tube by means of a spatula with extended handle. Clean viscometer-stirrer with test-tube brush.

If the falling number is above 220, add malt and adjust the falling number to 220-250 for the baking test.

D. Baking Test

While various methods such as gluten washing, amylograph, farinograph, mixograph, alveograph, and extensigraph tests provide valuable information on flour quality, the baking test in which flour is actually worked up into a dough and baked into product is considered as the ultimate final criterion of the flour quality.

Basically, the analytical bread baking methods utilize the straight-dough process and can be divided into one pound loaf bake test, pup loaf bake test (based on 100 g flour), and micro loaf bake test (based on 10 g flour), and modifications of these. The one pound loaf test is probably the easiest to determine the quality of flour. However, since a relatively large amount of flour is consumed in this test and especially if a large number of loaves are to be produced in the test, the availability of flour may be a limiting factor. The pup loaf procedure is also fairly simple and it allows more loaves to be produced in laboratory conditions. The micro loaf process, if properly done, produces accurate results. The micro loaf bake test is especially suitable for fractionation and reconstitution studies where small amounts of flour and flour components are available.

The baking test was done according to the KSU Pup Loaf Test Baking Procedure.

Formula	Flour (14% m.b.)	100
	NFDM	4
	Shortening	3
	Salt	1.5
	Sucrose	6
	Pottassium bromate	opt.
	Water	opt.
	Yeast(Instant dry yeast)	0.76

(1) Add dry ingredients to lightly greased mixing bowl.

(2) Add sugar/salt solution, yeast suspension, remainder of water (bromate solution included).

(3) Mix to optimum consistency as determined by smoothness and stretch-ability (film forming ability) of dough. Note time.

(4) Remove dough from bowl and use approximately four stretching manipulations to form a smooth ball.

(5) Place dough ball in lightly greased, suitable bowl (S.S., 45 mm diam. X 63 mm high), cover with plexiglass and place in cabinet at 30 C and 86-90 % R.H.

(6) After 105 min. measure and record height of dough ball from top of bowl.

(7) First punch: through sheeting rolls with 4.8 mm (3/16") gap.

(8) Fold dough strip in half twice (bookfold) so that outside skin of fermented ball remains outermost.

(9) Return to covered bowl and cabinet for 50 min.

(10) Second punch: through 3/16" sheeting rolls, maintaining rectangular dough piece shape.

(11) Fold twice as before ensuring that previous outer skin remains outermost.

(12) Return to covered bowl and cabinet for 25 min.

(13) Sheet through rolls set at 7.9 mm (5/16") gap and roll into a tight cylinder ensuring that outside layer is maintained. Pinch ends to seal gaps.

(14) Place roll in lightly greased pan (140 x 80 x 60 mm), (one side greased to only half way) so that the seam is on the bottom and faces away from the half greased side. Label for identity.

(15) Proof 55 min and measure height to nearest mm, or proof to constant height (76 mm) and note time.

(16) Bake 25 min, 218 C (425 F).

(17) Remove from pan, weigh and measure volume by rapeseed displacement immediately.

(18) Allow to cool, cut with sharp knife or electric knife and evaluate crust texture and color, crumb texture and color, odor and flavor.

Fig.7, 8, and 9 show the mixer, sheeting rolls for punching, and molder for pup loaf test.

In those procedure, optimum water absorption was determined by feel of dough at mixing, and the use of mixograph absorption as a guide. Optimum mixing time was determined by smoothness and film forming ability of dough using the mixograph as a guide. Generally, the mixing time is increased from the mixograph mixing time by 30-45 seconds because of salt, NFDM in the formula and since the mixer has one less mixing pins than the mixograph. Optimum mixing time is considered very essential for the test as shown by Finney and Barmore (1945). The importance of optimum oxidation was also noted by them. Flours that have short to medium-short mixing times basically require higher oxidant level than flours that have medium to medium-long mixing times. When potassium bromate is used, the amount must be optimized for each flour and possible overoxidation is bufferd by NFDM.

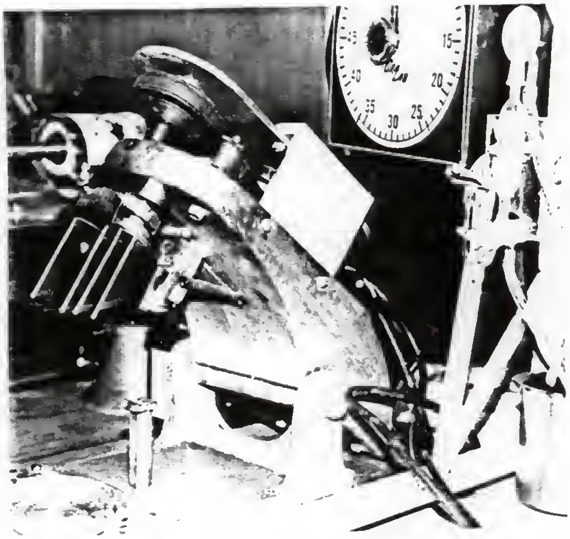


Fig. 7 Mixer for Pup Loaf Test.

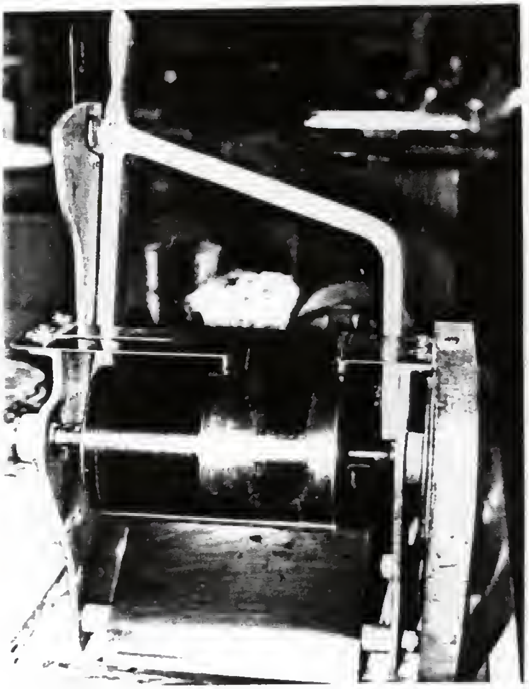


Fig. 8 Sheeting rolls for punching.

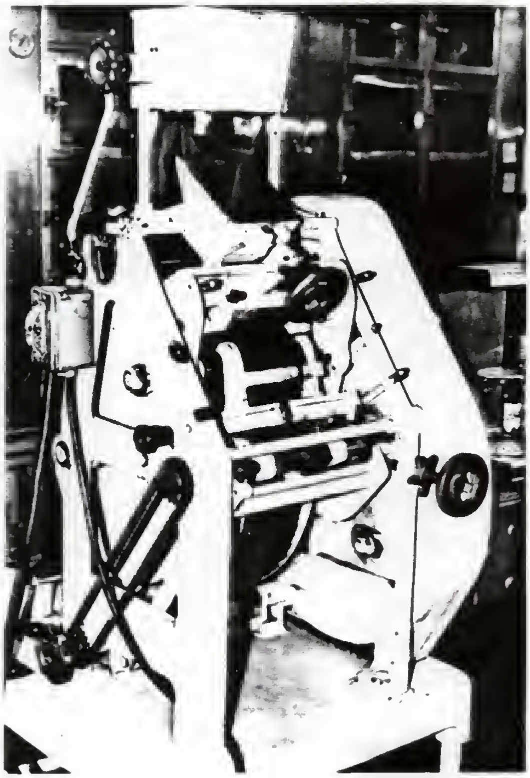


Fig.9 Molder for Pup Loaf Test.

Results and Discussion

(1)Wheat Data

Table 1 outlines the test results of the wheats we used for this study. Moisture was 11-12.3 %, protein content was 12.8-14.8 %, and test weight was 56-63 lb/bushel.

Moisture is an important factor which affects the hardness of wheat. When water is added to the wheat, the outer layer of wheat absorbs the moisture quickly and bran becomes tough. This phenomenon affects pearling value (PV) drastically. And as time goes by, water penetrates into an inner layer, diffuses into the endosperm, and makes the endosperm mellower. This affects particle size index (PSI). According to AACC approved methods (1983), moisture should be 11-13 % for hardness test. As we can see in Table 1, all of the moisture data fit within this range.

Protein content is important to baking quality. If protein content varies too much, the baking test will be affected, and it may become impossible to see the influence of hardness on baking characteristics.

Test weight is an important factor for a milling test. Niernberger et al (1975) mentioned that test ✓ weight is related to flour yield, milling rating, and milling value significantly. That is the reason we

Table 1

WHEAT DATA

Variety (location)	Moisture (%)	Ash (%)	Protein (%)	Test Wt. (lb/bu.)
Arkan (Kingman)	11.9	1.28	14.3	59.4
Arkan (Dickinson)	11.2	1.58	13.6	58.2
Colt (Kingman)	11.8	1.55	14.1	59.0
Colt (Logan)	12.1	1.69	13.8	57.0
Larned (Kingman)	12.1	1.26	12.9	60.2
Larned (Logan)	12.1	1.58	13.7	57.0
Garst HR64 (Kingman)	11.5	1.45	13.3	58.6
Garst HR64 (Rush)	11.0	1.69	13.3	63.0
Garst HR64 (Logan)	12.1	1.41	13.4	57.1
Mustang (Kingman)	12.0	1.34	12.8	60.5
Mustang (Logan)	12.0	1.46	13.4	57.0
Pioneer 2157 (Kingman)	11.7	1.48	13.7	59.8
Pioneer 2157 (Pawnee)	11.1	1.63	14.8	57.7
Tam 107 (Kingman)	12.2	1.38	14.7	59.4
Tam 107 (Pawnee)	11.5	1.33	14.7	57.4
Probrand 830 (Kingman)	12.3	1.41	13.6	60.6
Probrand 830 (Pawnee)	11.2	1.73	14.6	57.4
Probrand 830 (Cloud)	11.0	1.47	12.8	57.0

eliminated wheat samples which had test weights less than 56 lb/bushel.

(2) Hardness Test.

Table 2 shows the hardness of wheat samples. Arkan (Kingman) and Pioneer 2157 (Pawnee) had smaller PV than other samples. However, compared to the difference of PV, the difference of PSI, NIR, and IA was relatively small. This result indicated the toughness of bran of those two wheat samples was less than others.

As we can see from Table 2, the difference in hardness among the wheat samples was apparently not great. This was confirmed by statistical analysis, which is shown in Table 3.

(3) Correlation of Hardness Test.

Table 3 shows the correlation coefficients among the hardness tests. PSI and NIR values had a significant correlation coefficient ($r = 0.61$, $p = 0.007$). The rest of the test values were insignificantly correlated.

Williams et al (1986) made a comparison of PSI and NIR using samples of Soft Red Winter, Soft White Winter, Hard Red Winter, Hard Red Spring, and Durum Wheats.

Table 2

HARDNESS TEST

Variety (Location)	PV (%)	PSI (%)	NIR (%)	IA (%)
Arkan (Kingman)	54.5	48.5	262.5	5.77
Arkan (Dickinson)	62.5	44.1	262.5	5.77
Colt (Kingman)	66.5	45.3	248.0	5.13
Colt (Logan)	65.5	48.1	249.5	5.35
Larned (Kingman)	67.0	47.3	260.6	5.82
Larned (Logan)	63.5	49.0	258.9	5.29
Garst HR64 (Kingman)	68.0	49.0	268.9	5.44
Garst HR64 (Rush)	67.5	46.7	245.2	5.17
Garst HR64 (Logan)	64.0	47.8	260.3	5.11
Mustang (Kingman)	63.0	51.2	267.5	5.82
Mustang (Logan)	63.0	48.3	267.3	5.46
Pioneer 2157 (Kingman)	63.0	44.8	248.3	5.28
Pioneer 2157 (Pawnee)	55.5	42.0	238.9	5.12
Tam 107 (Kingman)	63.0	48.7	282.0	5.10
Tam 107 (Pawnee)	59.5	45.5	273.1	5.19
Probrand 830 (Kingman)	70.5	49.0	267.5	5.76
Probrand 830 (Pawnee)	64.5	46.5	257.6	5.32
Probrand 830 (Cloud)	71.0	48.1	268.5	5.74

PV: pearling value.
PSI: particle size index.
NIR: near infrared reflectance spectroscopy.
IA: image analysis.

Table 3

CORRELATION COEFFICENTS OF HARDNESS TESTS

	PV	PSI	NIR	IA	1BK	2BK	3BK
PV		0.360 (0.142)	0.147 (0.562)	0.185 (0.463)	0.411 (0.121)	0.239 (0.401)	0.188 (0.611)
PSI	0.360 (0.142)		0.606 (0.007)	0.396 (0.104)	0.589 (0.010)	0.618 (0.006)	0.502 (0.019)
NIR	0.147 (0.562)	0.606 (0.007)		0.306 (0.217)	0.424 (0.118)	0.264 (0.399)	0.265 (0.398)
IA	0.185 (0.463)	0.396 (0.104)	0.306 (0.217)		0.151 (0.554)	0.232 (0.411)	0.357 (0.189)
1BK	0.411 (0.121)	0.589 (0.010)	0.424 (0.118)	0.151 (0.554)		0.613 (0.012)	0.548 (0.014)
2BK	0.239 (0.401)	0.618 (0.006)	0.264 (0.399)	0.232 (0.411)	0.613 (0.012)		0.529 (0.017)
3BK	0.188 (0.611)	0.502 (0.019)	0.265 (0.398)	0.357 (0.189)	0.548 (0.014)	0.529 (0.017)	

* The number inside of ( ) is probability (p-value).

** When p-value is less than 0.05, it is significant.

According to his results, the correlation coefficient between PSI and NIR was 0.93. The difference between our study and his study must be due to the difference in hardness range. The hardness of the samples he used had a wide variation; on the other hand, hardness of the samples we used was within a narrow range. This may explain the difference in results of the two studies.

Table 3 also shows the significant correlation coefficients between PSI and milling test; the stream from 1-3BK to sizing. Table 4 shows the percentage of stock from 1-3 BK to sizing streams which were used for statistical analysis in Table 3.

No significant correlation between protein content and wheat hardness was found. The correlation coefficients between each hardness test and protein content were as follows; PV ($r = 0.360$, $p = 0.152$), PSI ($r = 0.483$, $p = 0.08$), NIR ($r = 0.084$, $p = 0.74$), IA ($r = 0.185$, $p = 0.47$).

Table 4

MILLING TEST

Variety (Location)	1BK to Siz. (%)	2BK to Siz. (%)	3BK to Siz. (%)
Arkan (Kingman)	25.13	38.52	22.98
Arkan (Dickinson)	25.32	35.50	21.45
Colt (Kingman)	21.64	30.37	18.68
Colt (Logan)	25.91	33.22	20.36
Larned (Kingman)	23.64	35.03	23.33
Larned (Logan)	24.96	35.35	23.74
Garst HR64 (Kingman)	25.02	36.09	23.47
Garst HR64 (Rush)	21.67	30.50	17.81
Garst HR64 (Logan)	22.51	30.64	19.89
Mustang (Kingman)	23.82	37.25	24.47
Mustang (Logan)	23.31	34.73	23.14
Pioneer 2157 (Kingman)	26.33	34.97	19.93
Pioneer 2157 (Pawnee)	23.17	32.67	15.76
Tam 107 (Kingman)	22.34	31.84	24.50
Tam 107 (Pawnee)	21.58	31.88	24.18
Probrand 830 (Kingman)	22.48	34.70	22.86
Probrand 830 (Pawnee)	22.80	30.10	19.05
Probrand 830 (Cloud)	22.09	33.75	21.74

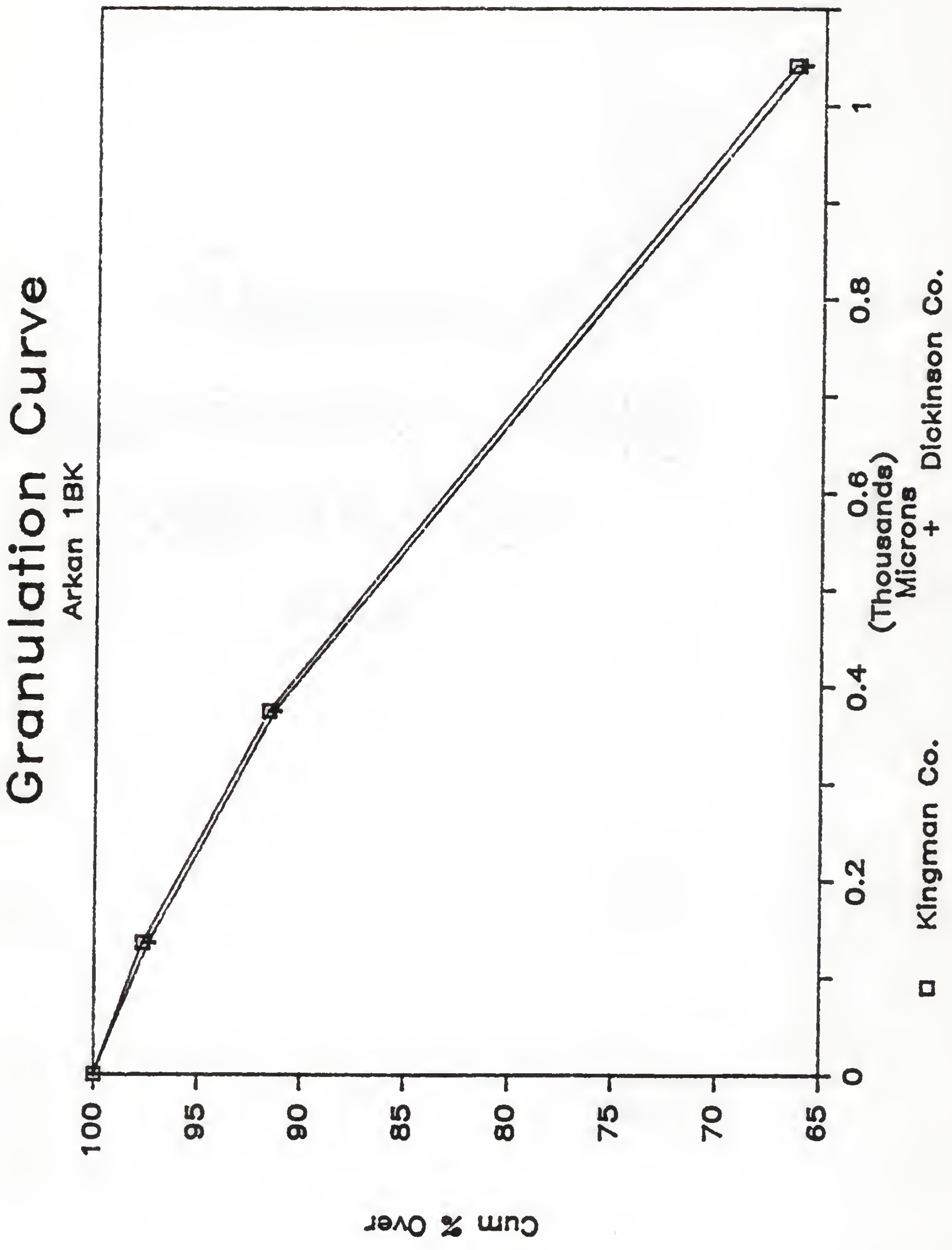

Granulation Curve
Arkan 1BK
Cum % Over
100
95
90
85
80
75
70
65
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
□ Kingman Co.
+ Dickinson Co.

Fig. 10

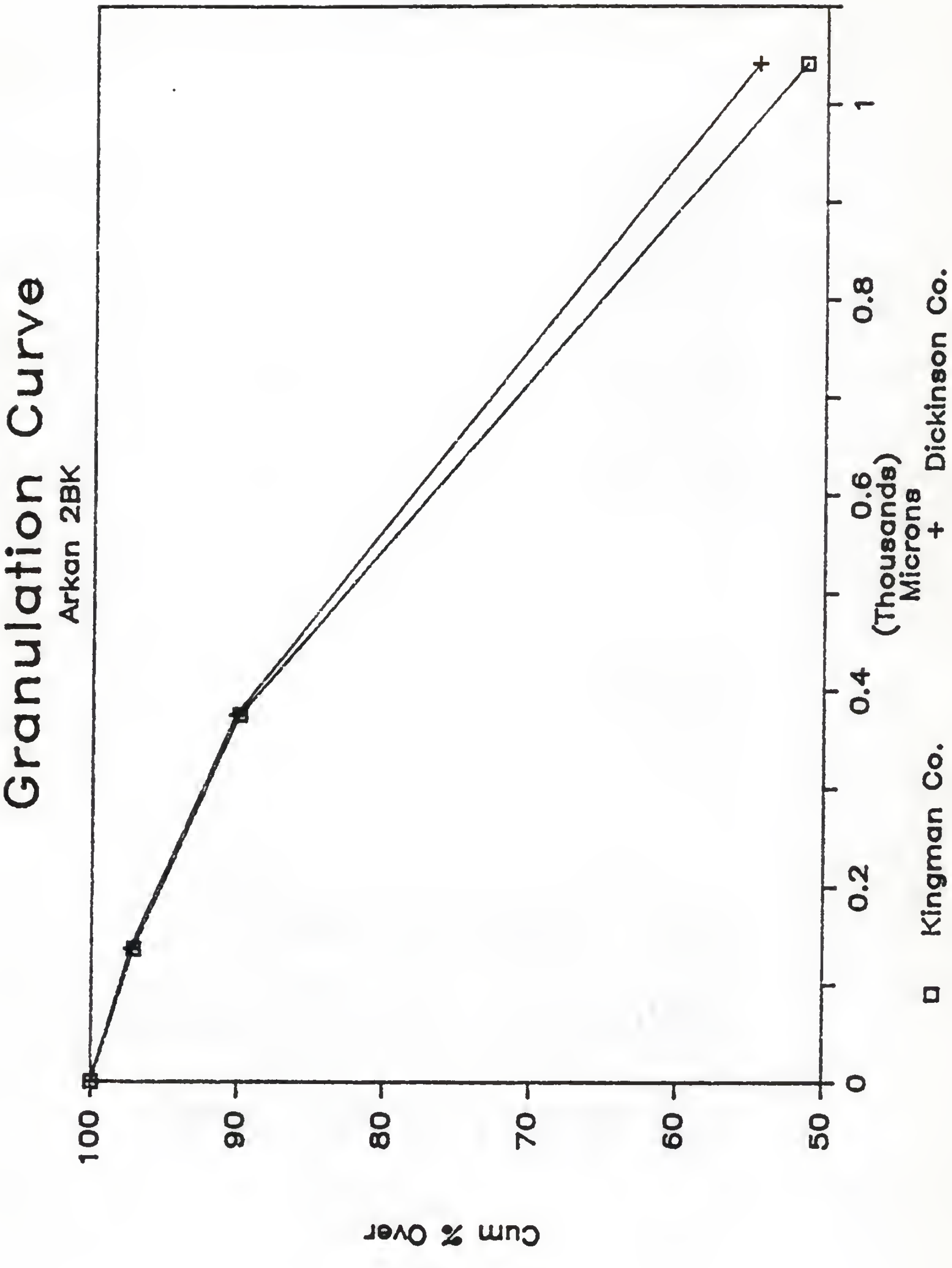

Granulation Curve
Arkan 2BK
Cum % Over
100
90
80
70
60
50
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
□ Kingman Co.
+ Dickinson Co.

Fig. 11

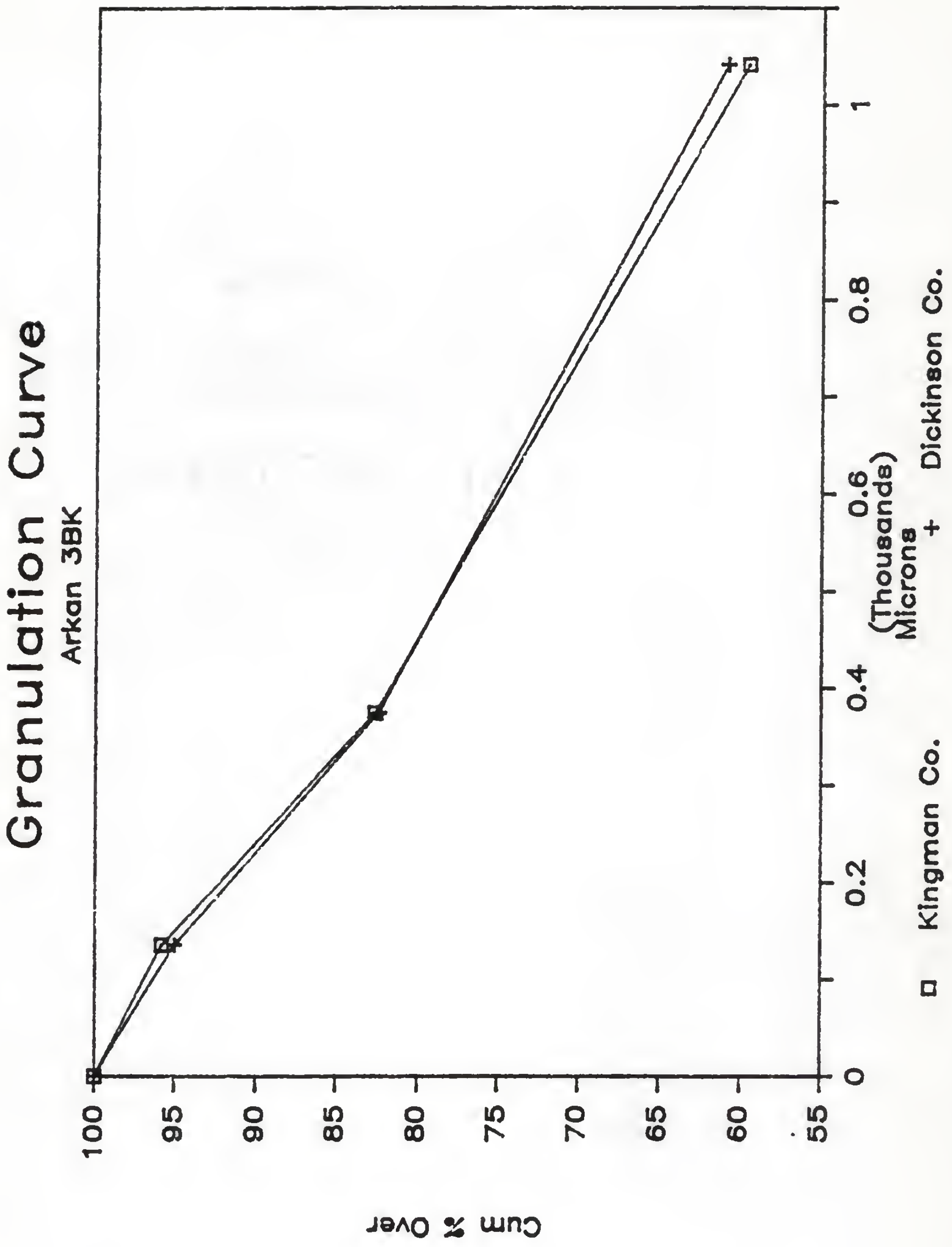

Granulation Curve
Arkan 3BK
Cum % Over
100
95
90
85
80
75
70
65
60
55
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Dickinson Co.

Fig. 12

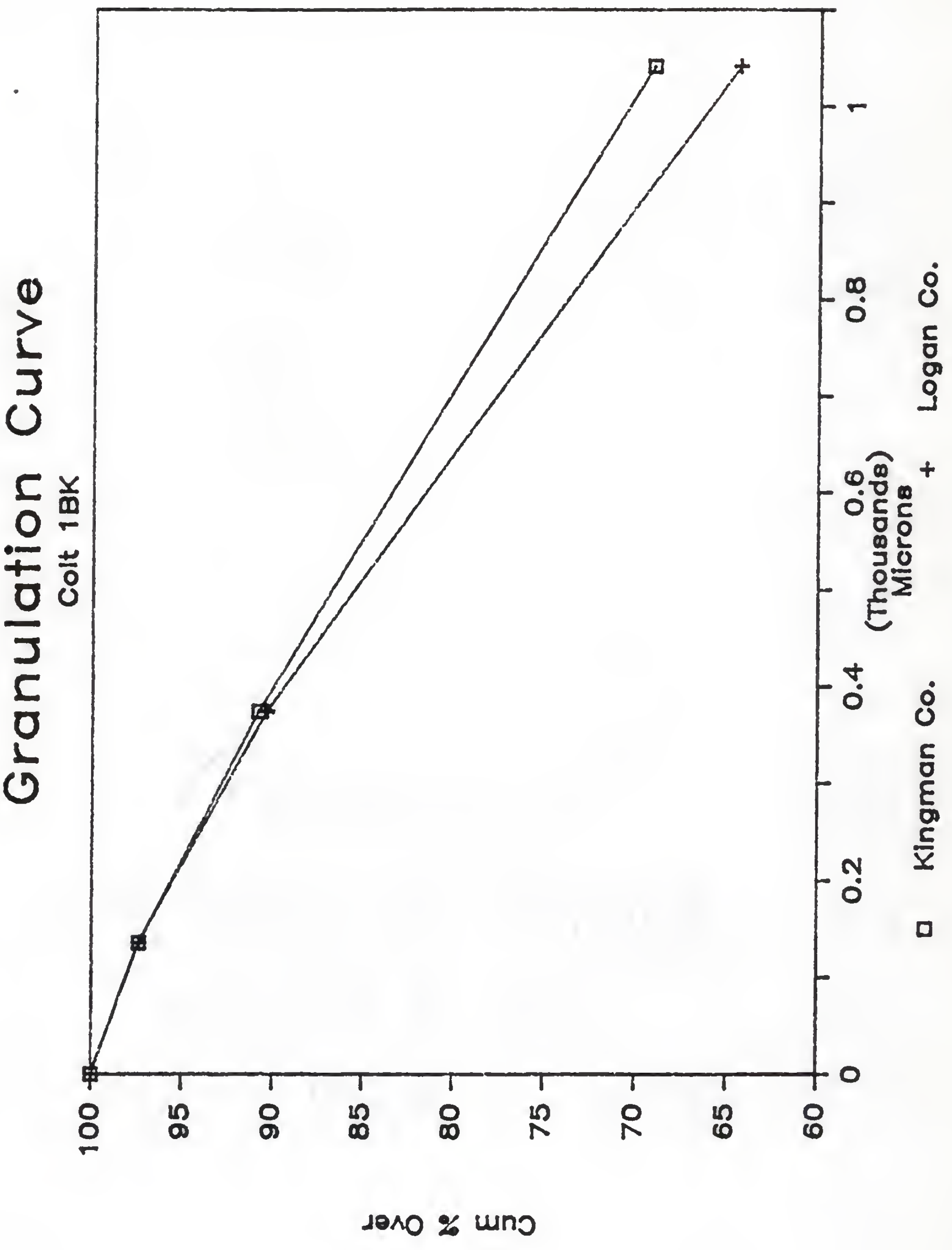

Granulation Curve
Colt 1BK
Cum % Over
100
95
90
85
80
75
70
65
60
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
□ Kingman Co.
+ Logan Co.

Fig. 13

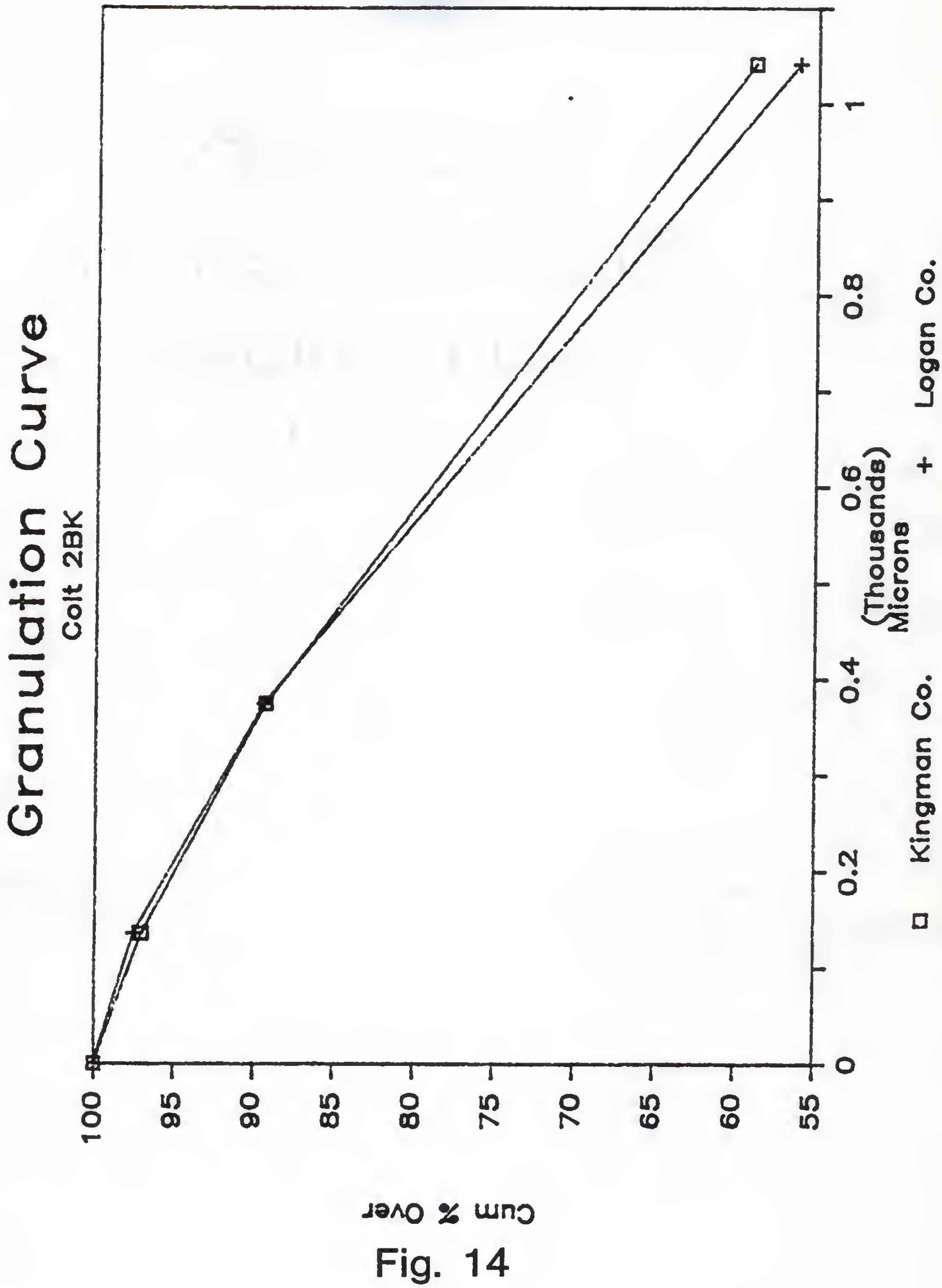

Granulation Curve
Colt 2BK
Cum % Over
100
95
90
85
80
75
70
65
60
55
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Logan Co.

Fig. 14

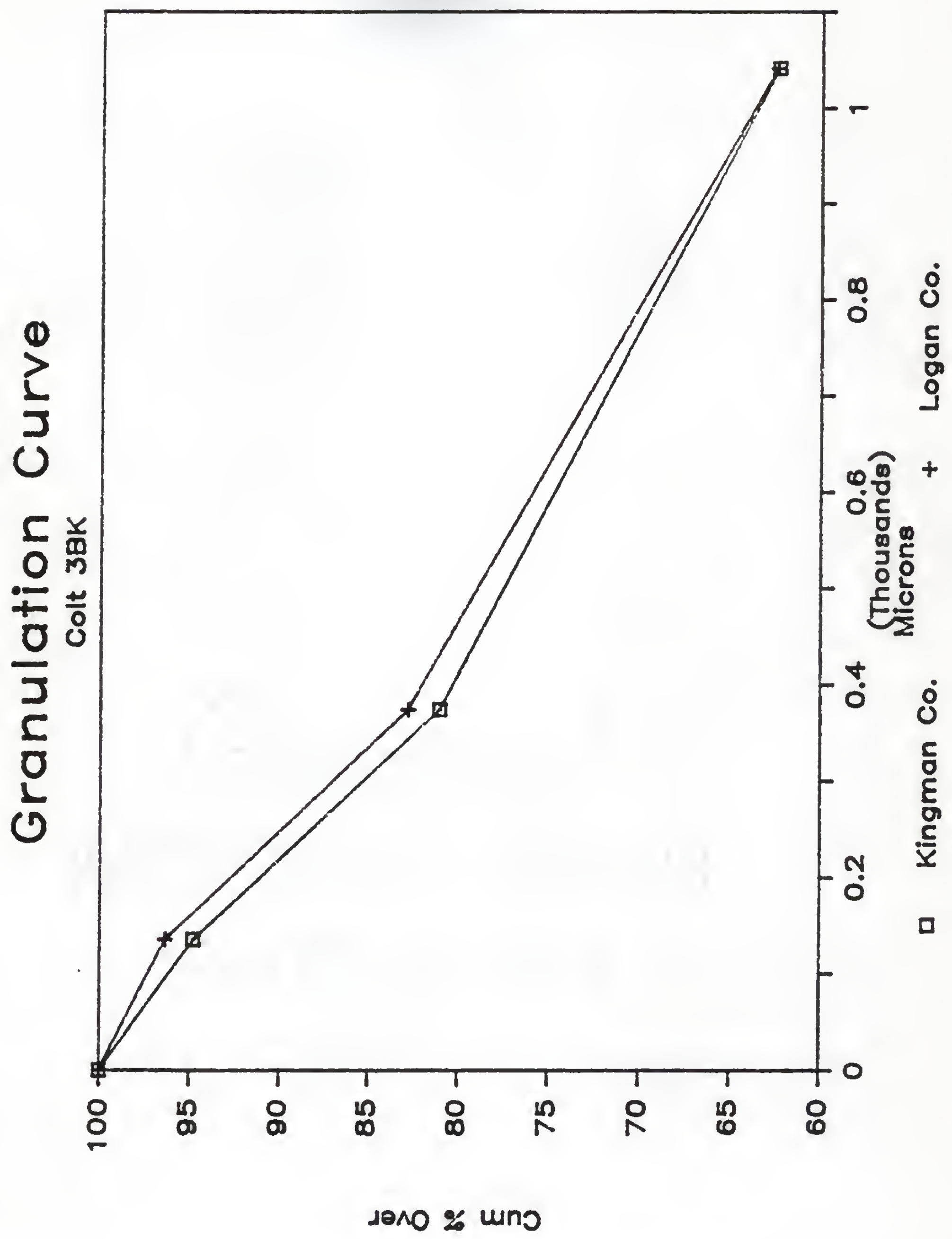

Granulation Curve
Colt 3BK
Cum % Over
100
95
90
85
80
75
70
65
60
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Logan Co.

Fig.15

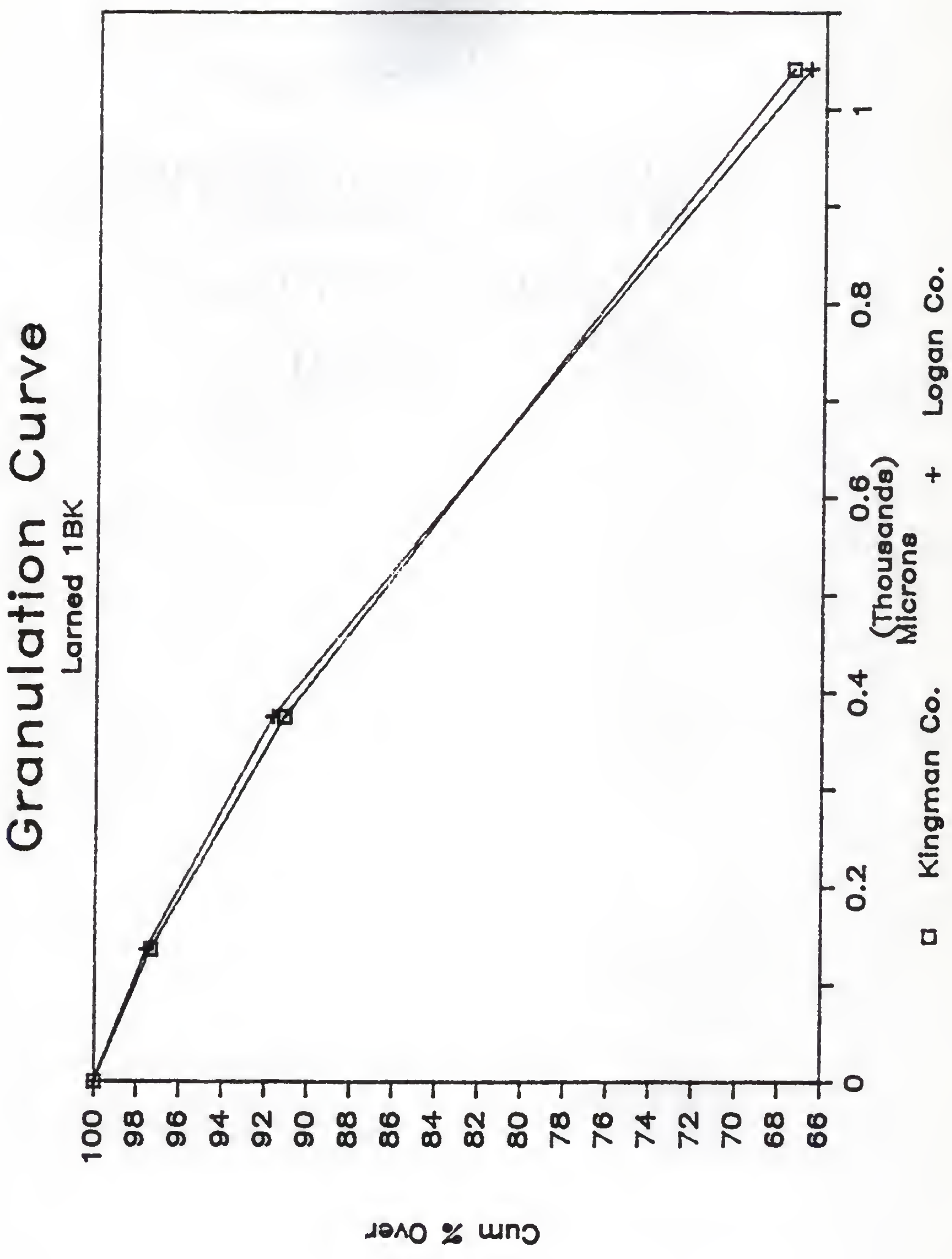

Granulation Curve
Larned 1BK
100
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
68
66
Cum % Over
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Logan Co.

Fig. 16

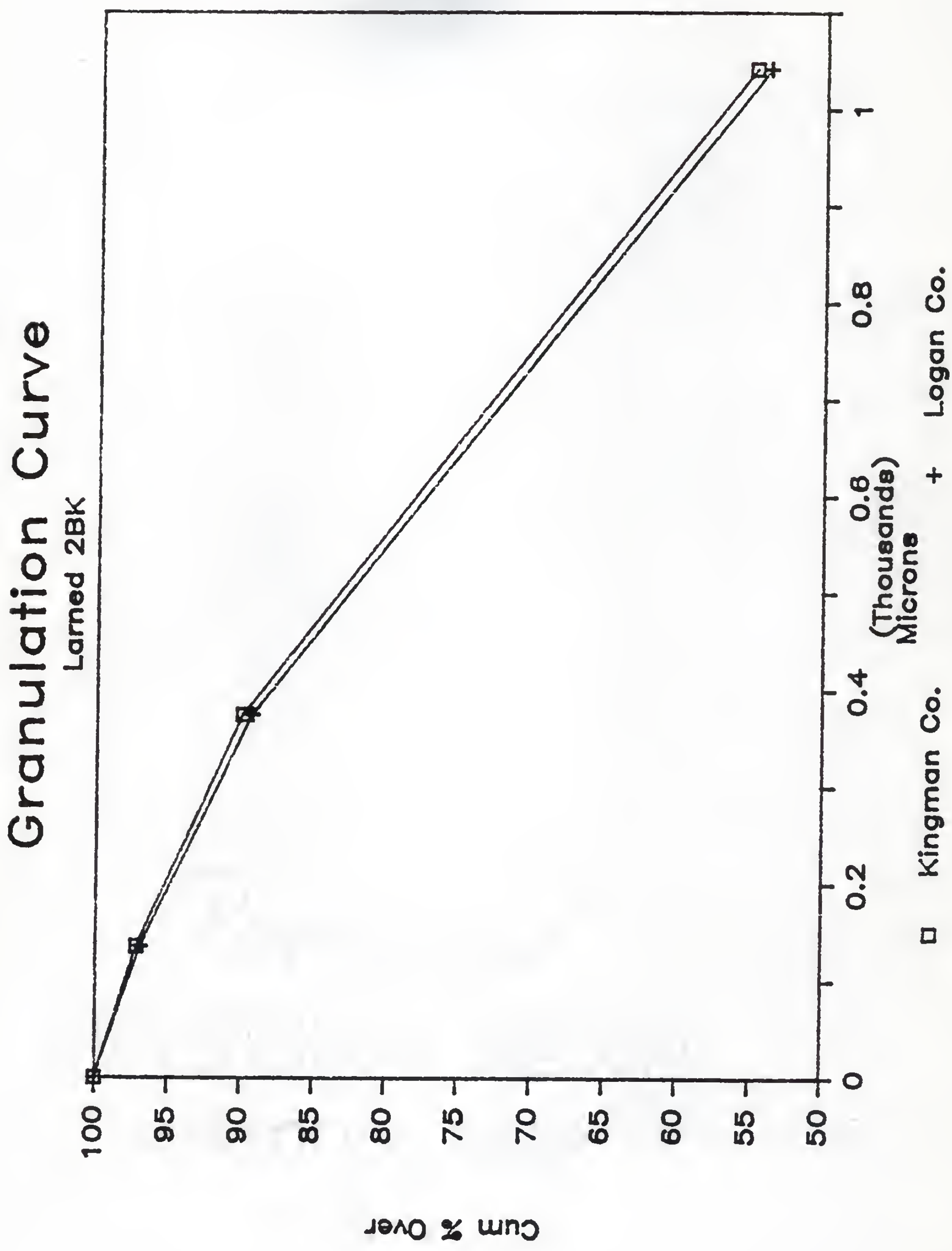

Granulation Curve
Larned 2BK
Cum % Over
100
95
90
85
80
75
70
65
60
55
50
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Logan Co.

Fig. 17

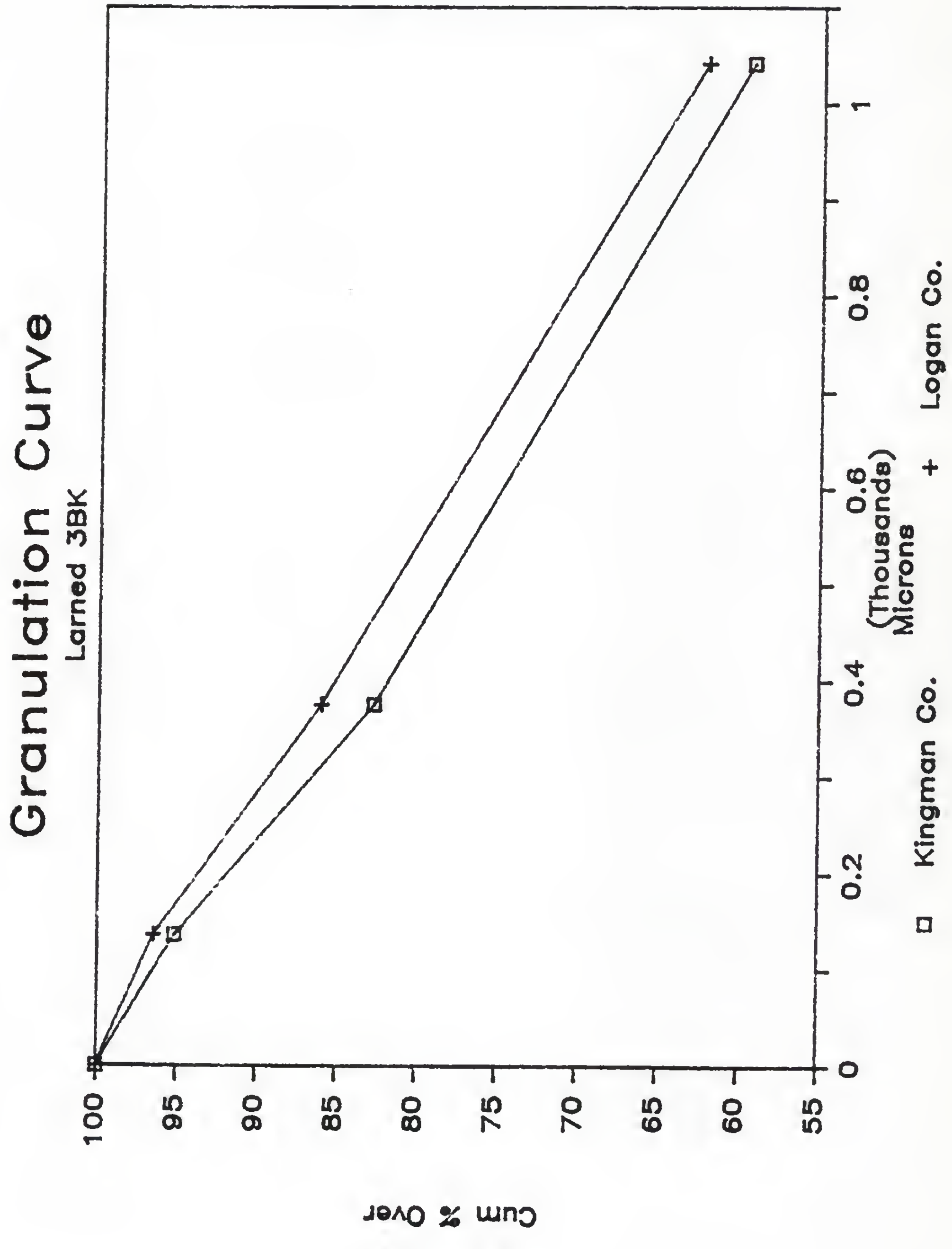

Granulation Curve
Larned 3BK
Cum % Over
100
95
90
85
80
75
70
65
60
55
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Logan Co.

Fig. 18

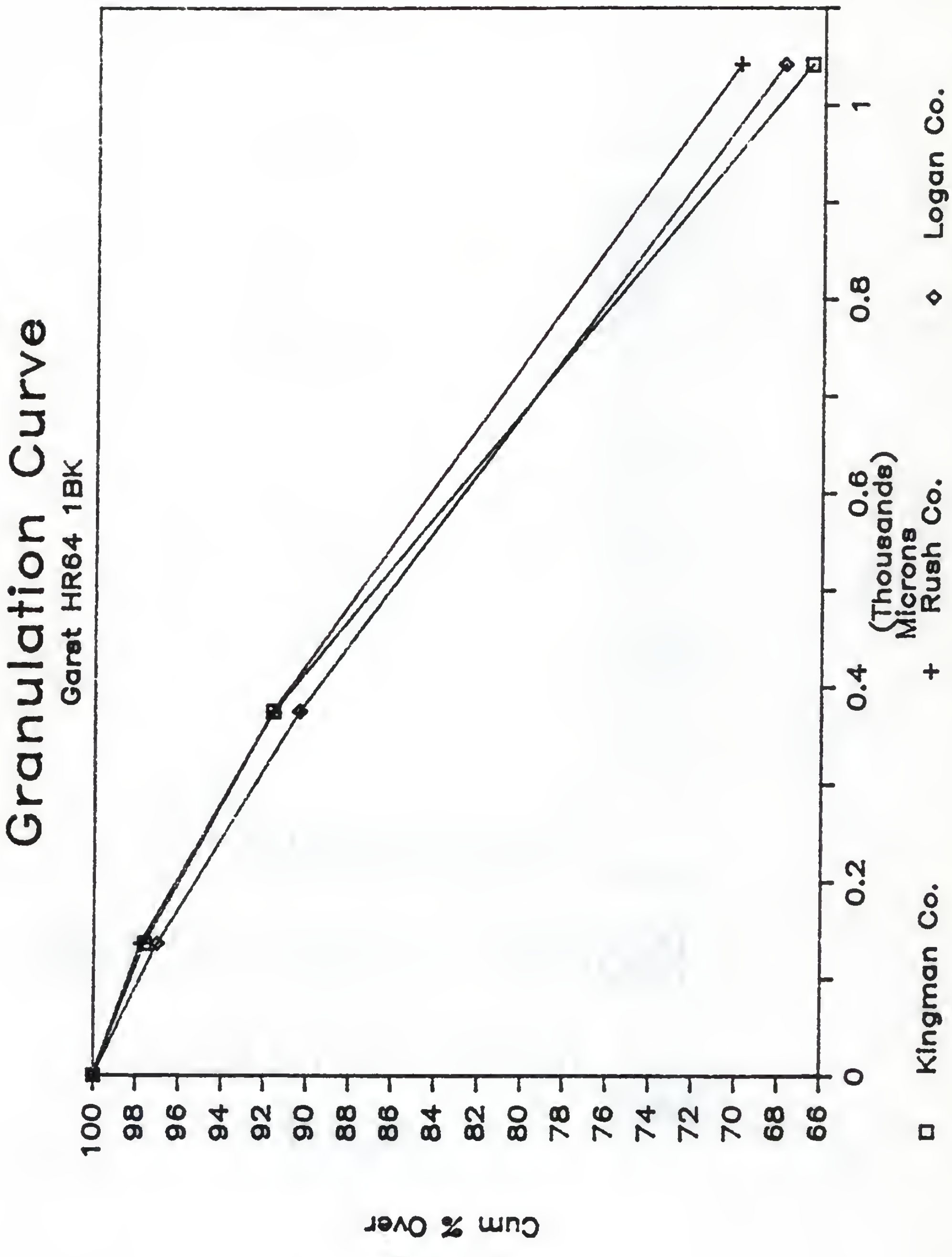

Granulation Curve
Garst HR64 1BK
Cum % Over
100
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
68
66
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Rush Co.
◇ Logan Co.

Fig. 19

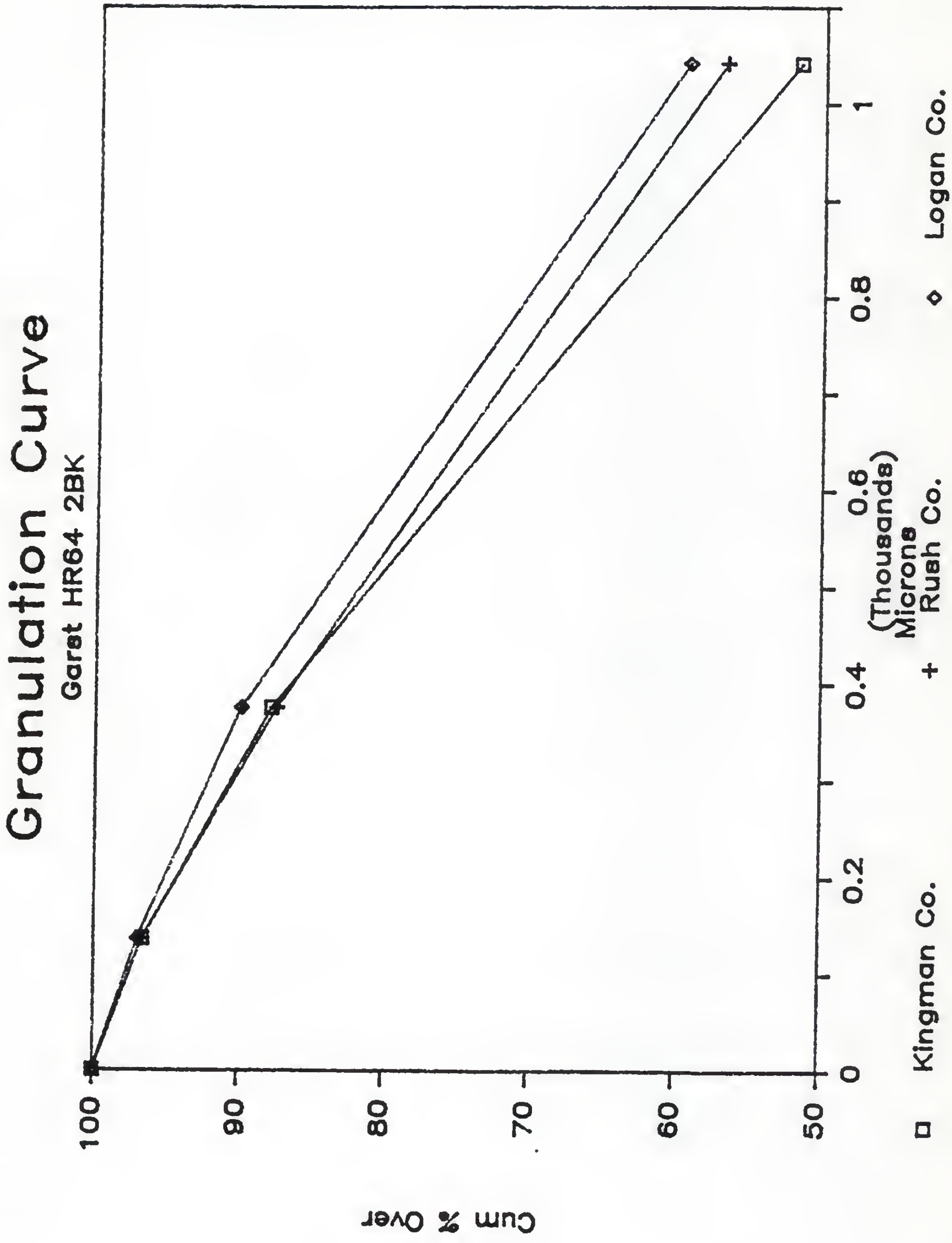

Granulation Curve
Garst HR64 2BK
Cum % Over
100
90
80
70
60
50
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Rush Co.
◇ Logan Co.

Fig. 20

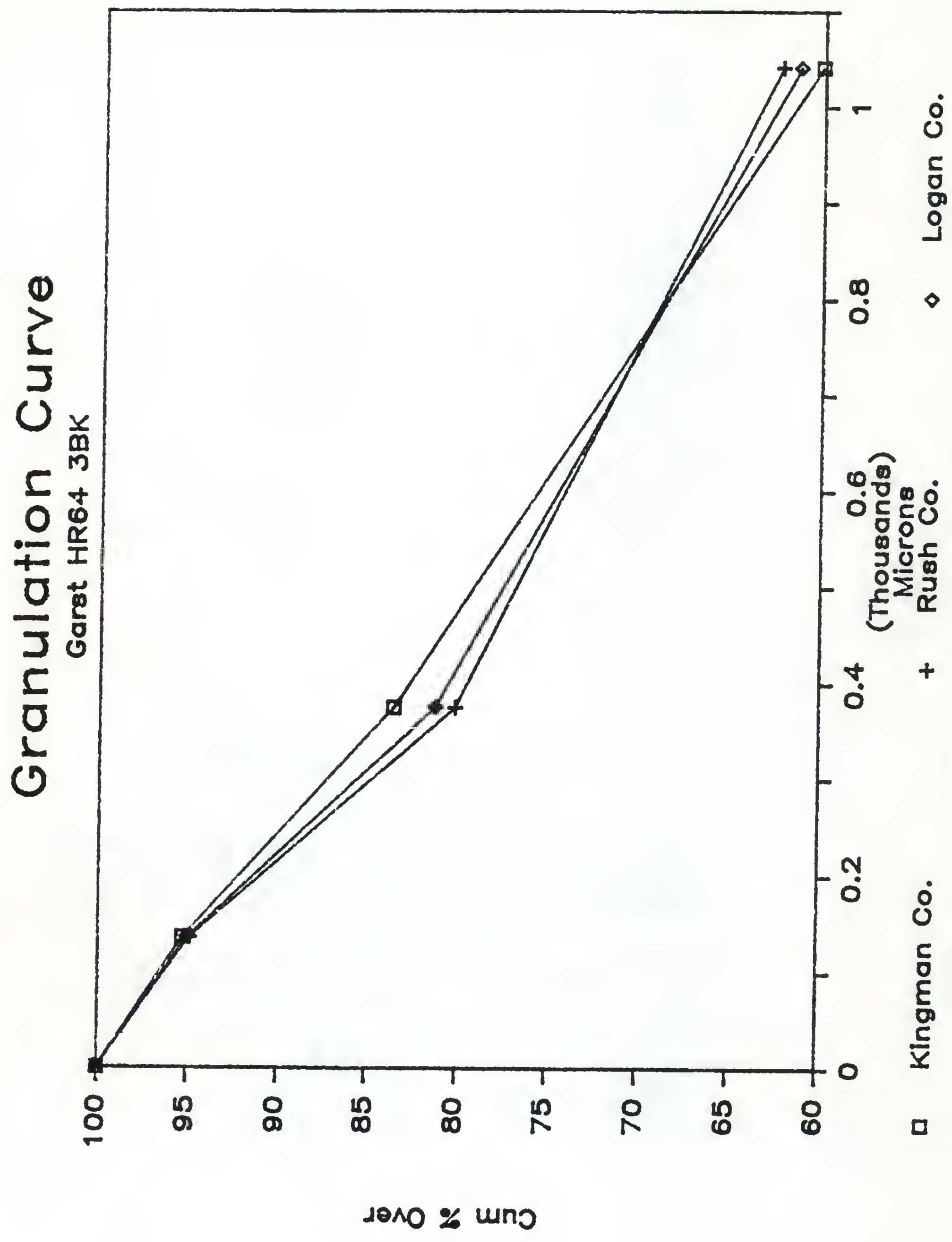

Granulation Curve
Garst HR64 3BK
Cum % Over
100
95
90
85
80
75
70
65
60
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
□ Kingman Co.
+ Rush Co.
◇ Logan Co.

Fig. 21

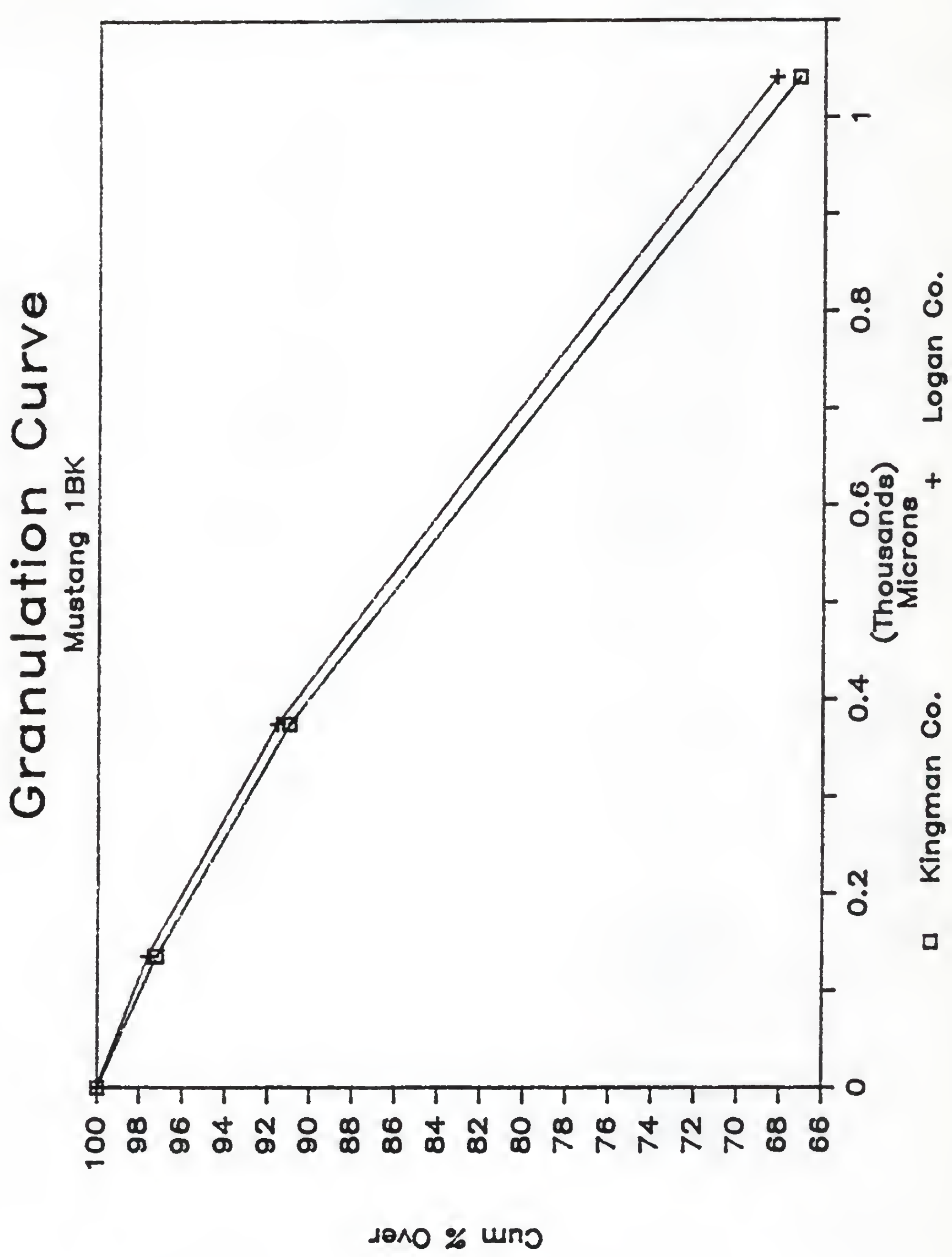

Granulation Curve
Mustang 1BK
Cum % Over
100
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
68
66
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
□ Kingman Co.
+ Logan Co.

Fig. 22

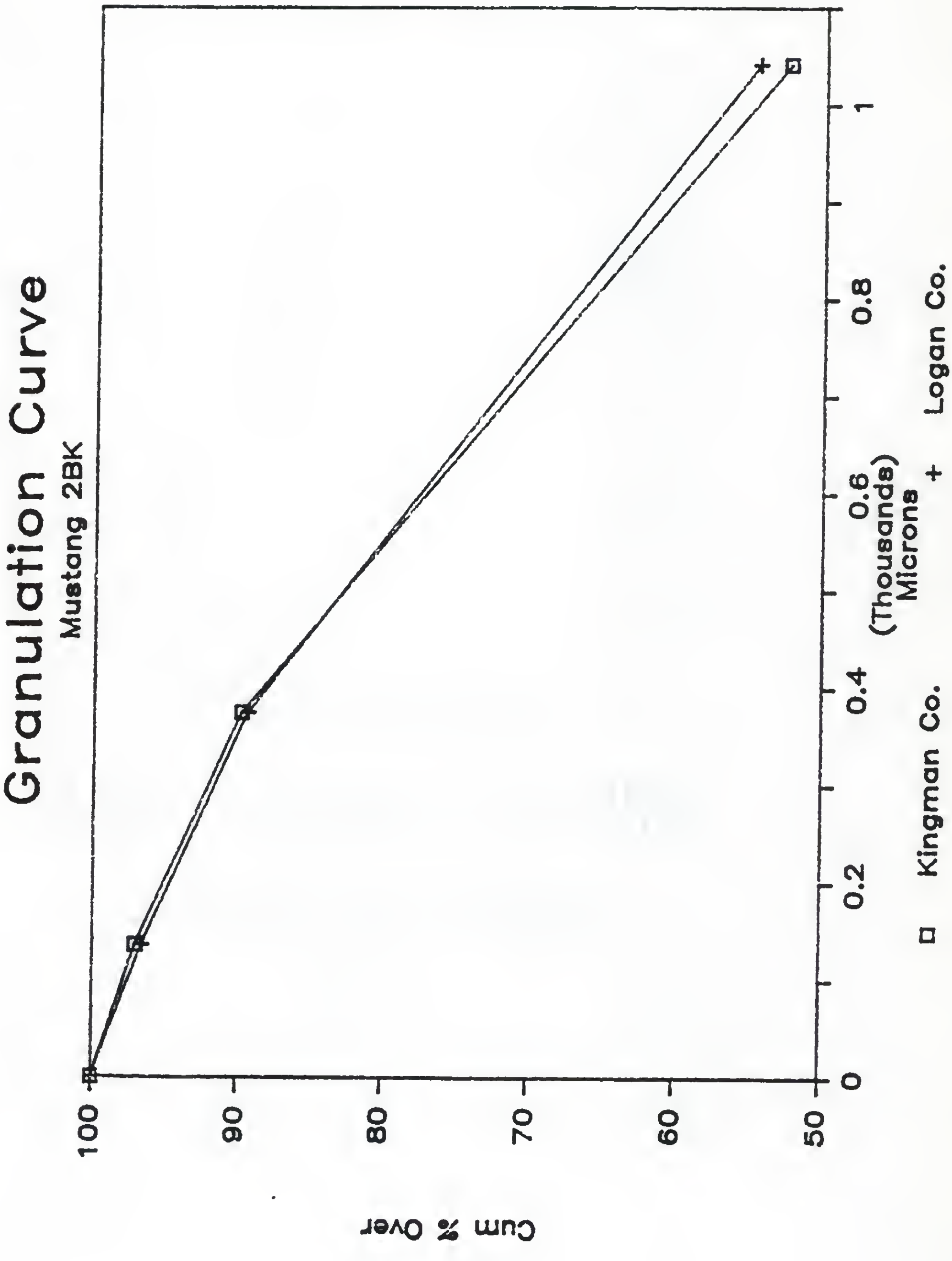

Granulation Curve
Mustang 2BK
Cum % Over
100
90
80
70
60
50
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
☐ Kingman Co.
+ Logan Co.

Fig. 23

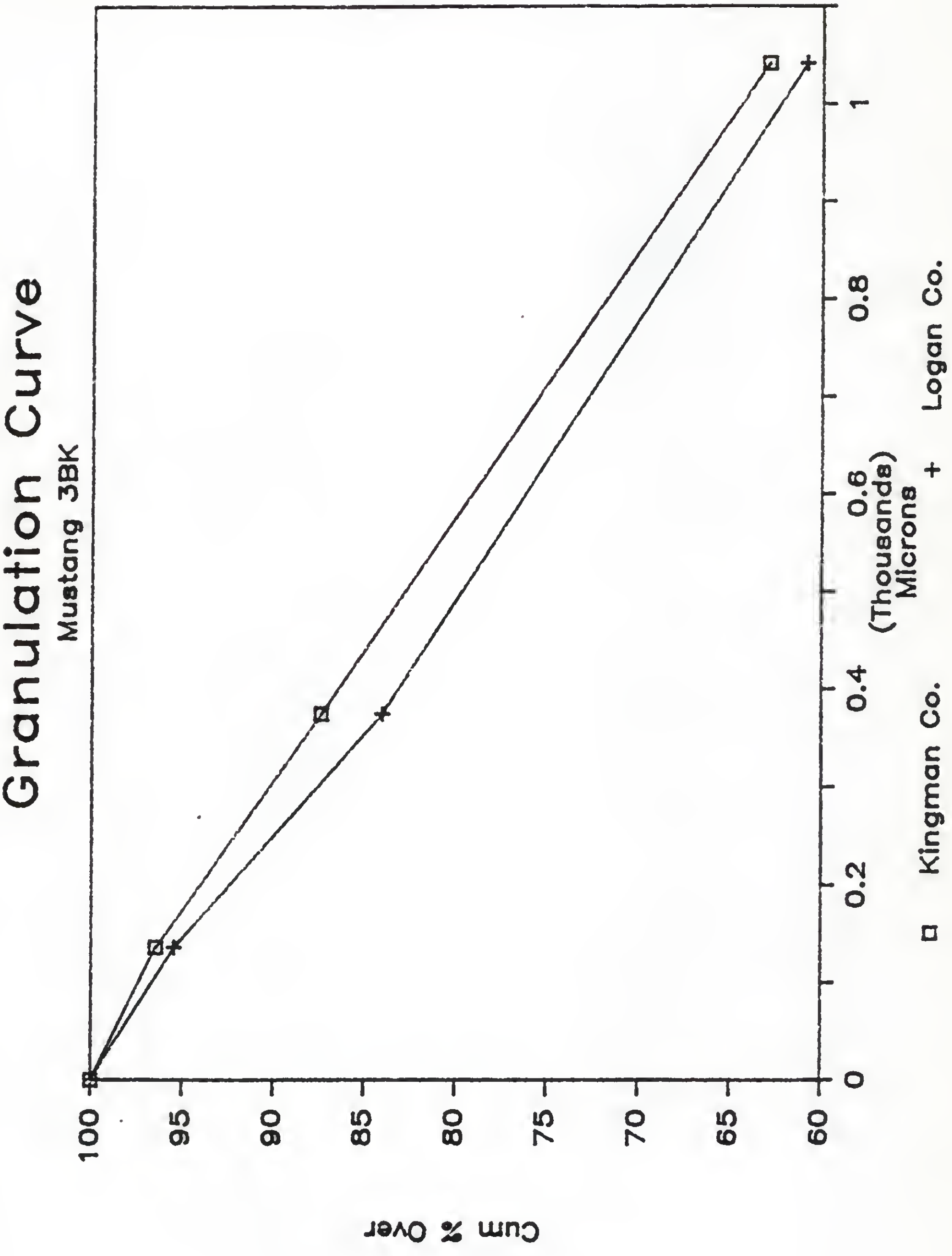

Granulation Curve
Mustang 3BK
100
95
90
85
80
75
70
65
60
Cum % Over
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
Kingman Co.
Logan Co.

Fig. 24

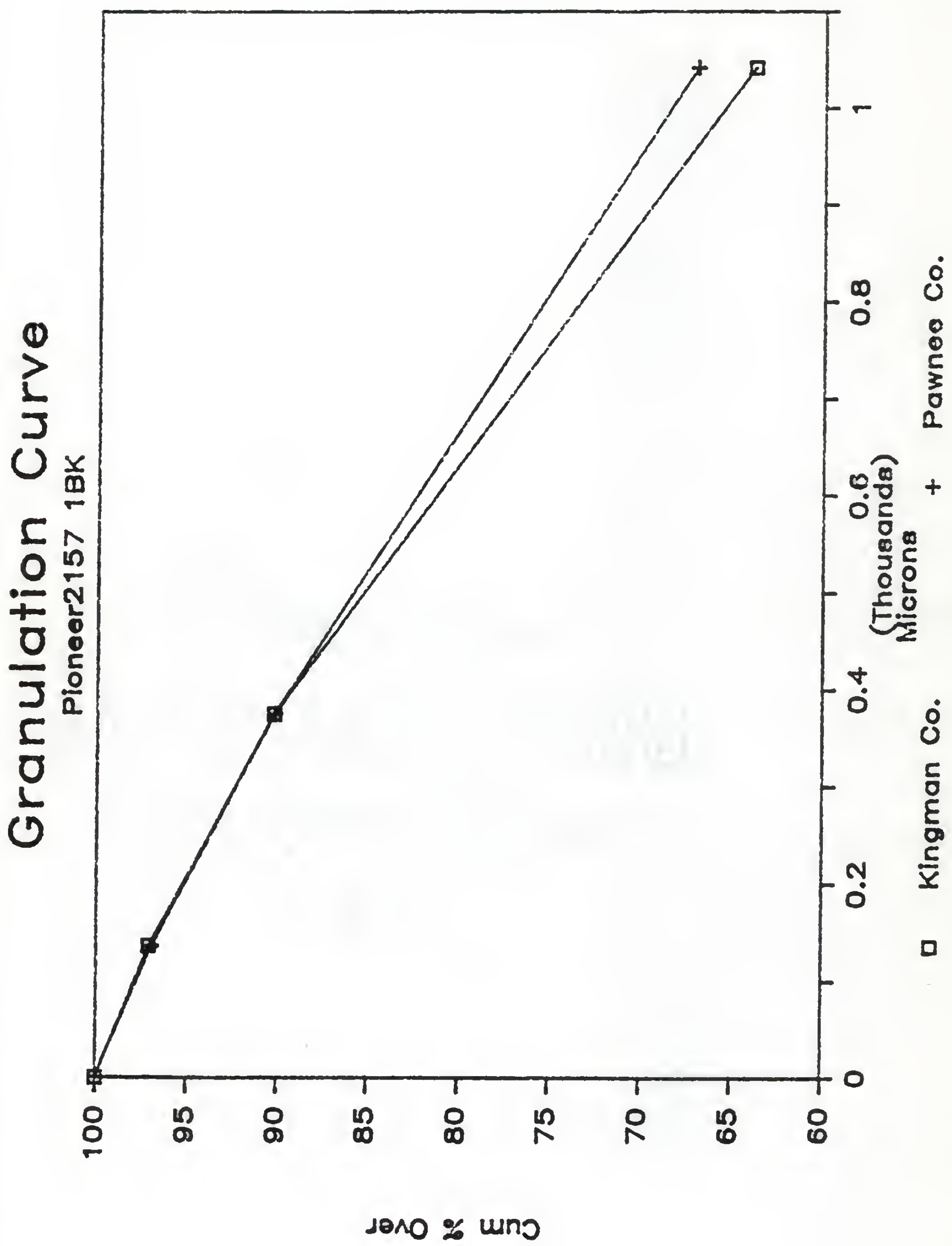

Granulation Curve
Pioneer2157 1BK
Cum % Over
100
95
90
85
80
75
70
65
60
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Pawnee Co.

Fig. 25

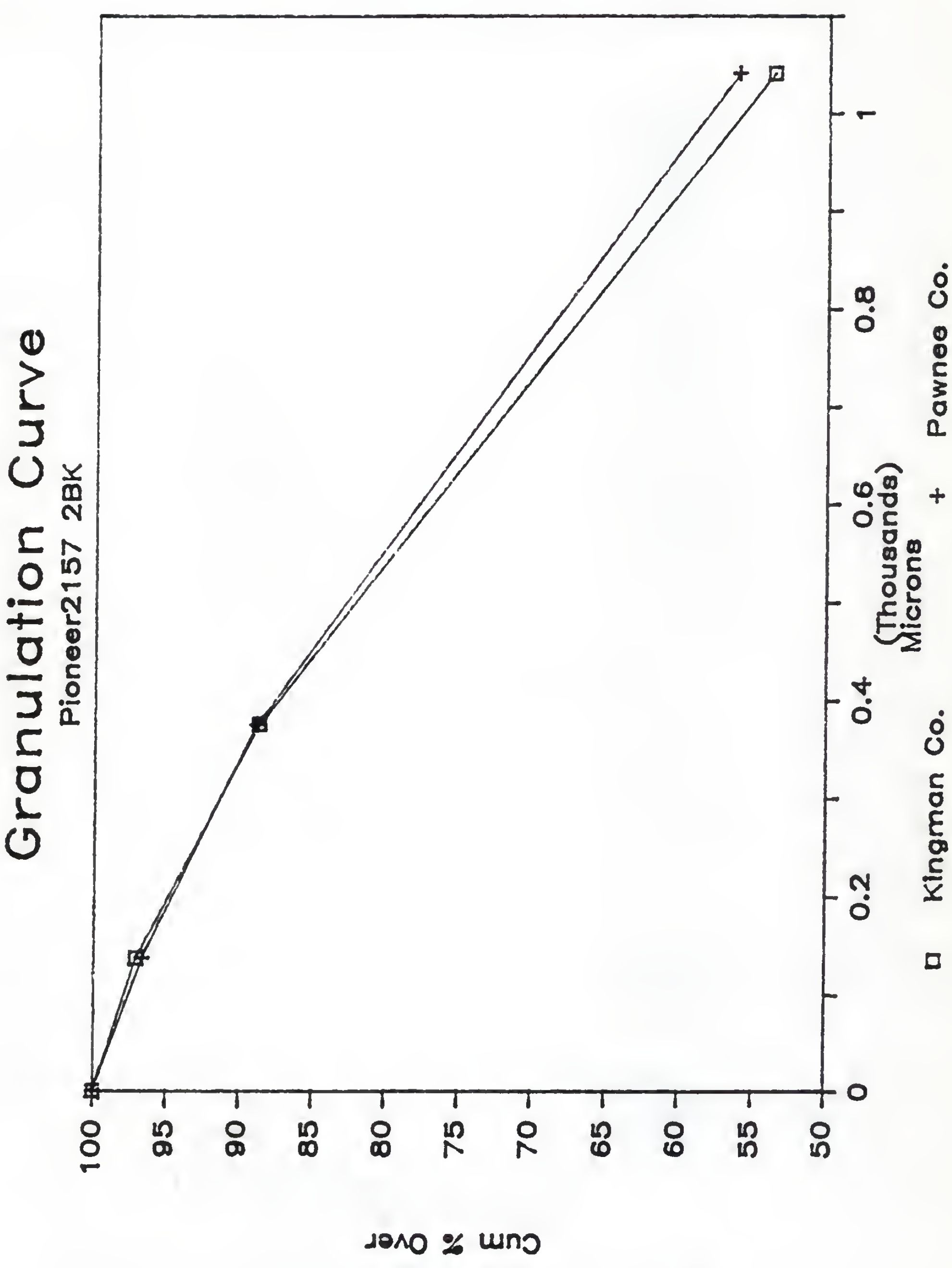

Granulation Curve
Pioneer2157 2BK
Cum % Over
100
95
90
85
80
75
70
65
60
55
50
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Pawnee Co.

Fig. 26

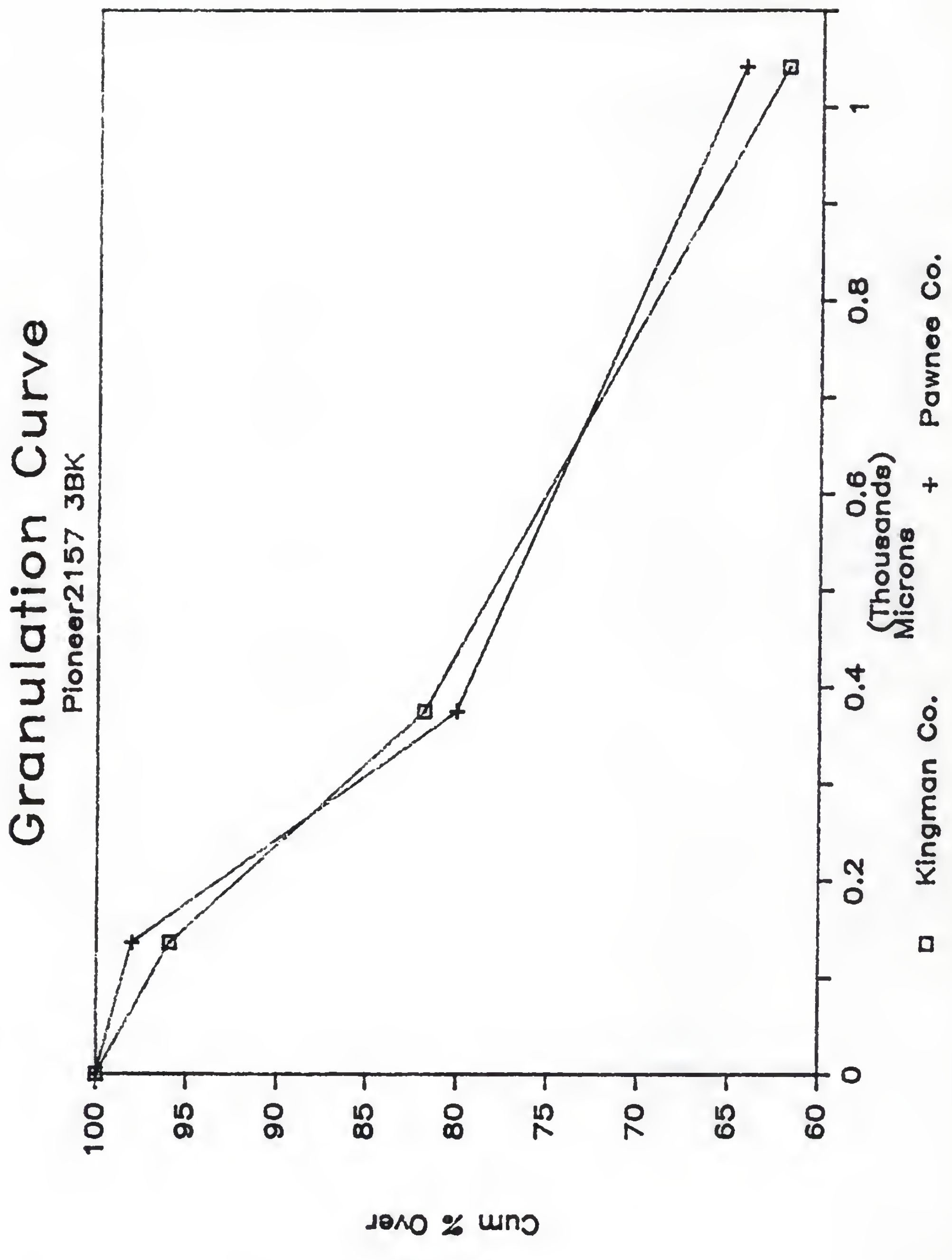

Granulation Curve
Pioneer2157 3BK
100
95
90
85
80
75
70
65
60
Cum % Over
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Pawnee Co.

Fig. 27

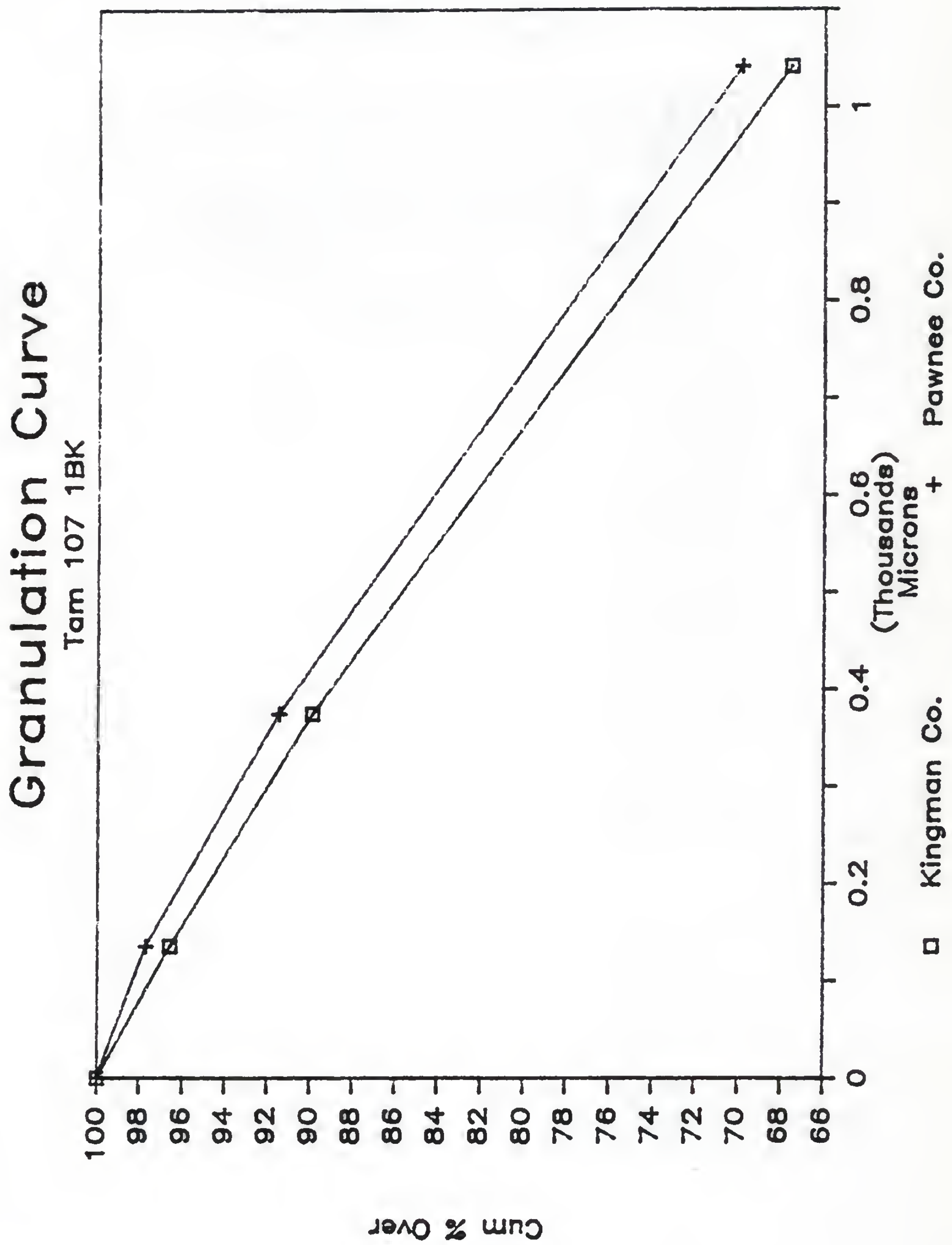

Granulation Curve
Tam 107 1BK
Cum % Over
100
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
68
66
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
□ Kingman Co.
+ Pawnee Co.

Fig. 28

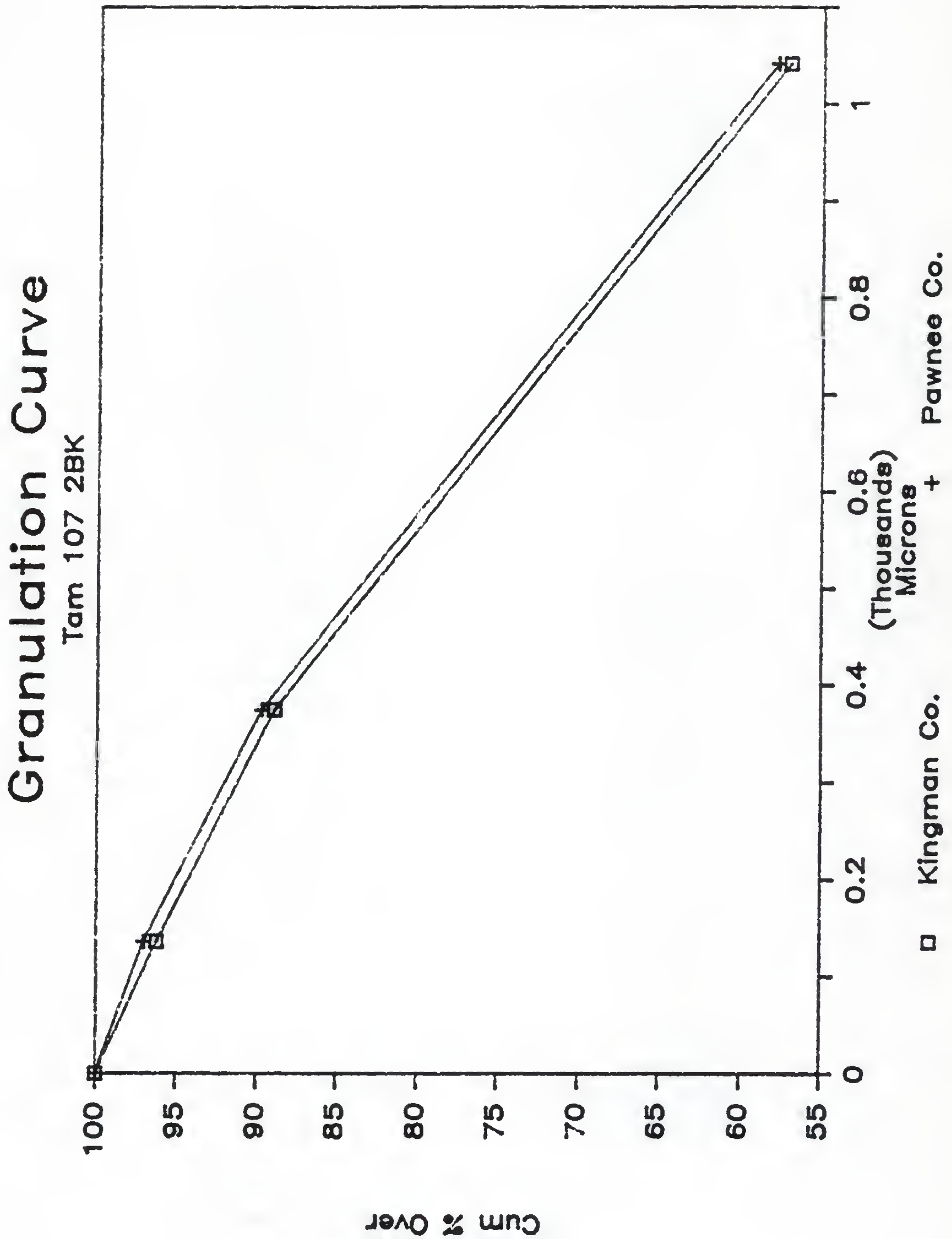

Granulation Curve
Tam 107 2BK
Cum % Over
100
95
90
85
80
75
70
65
60
55
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
□ Kingman Co.
+ Pawnee Co.

Fig. 29

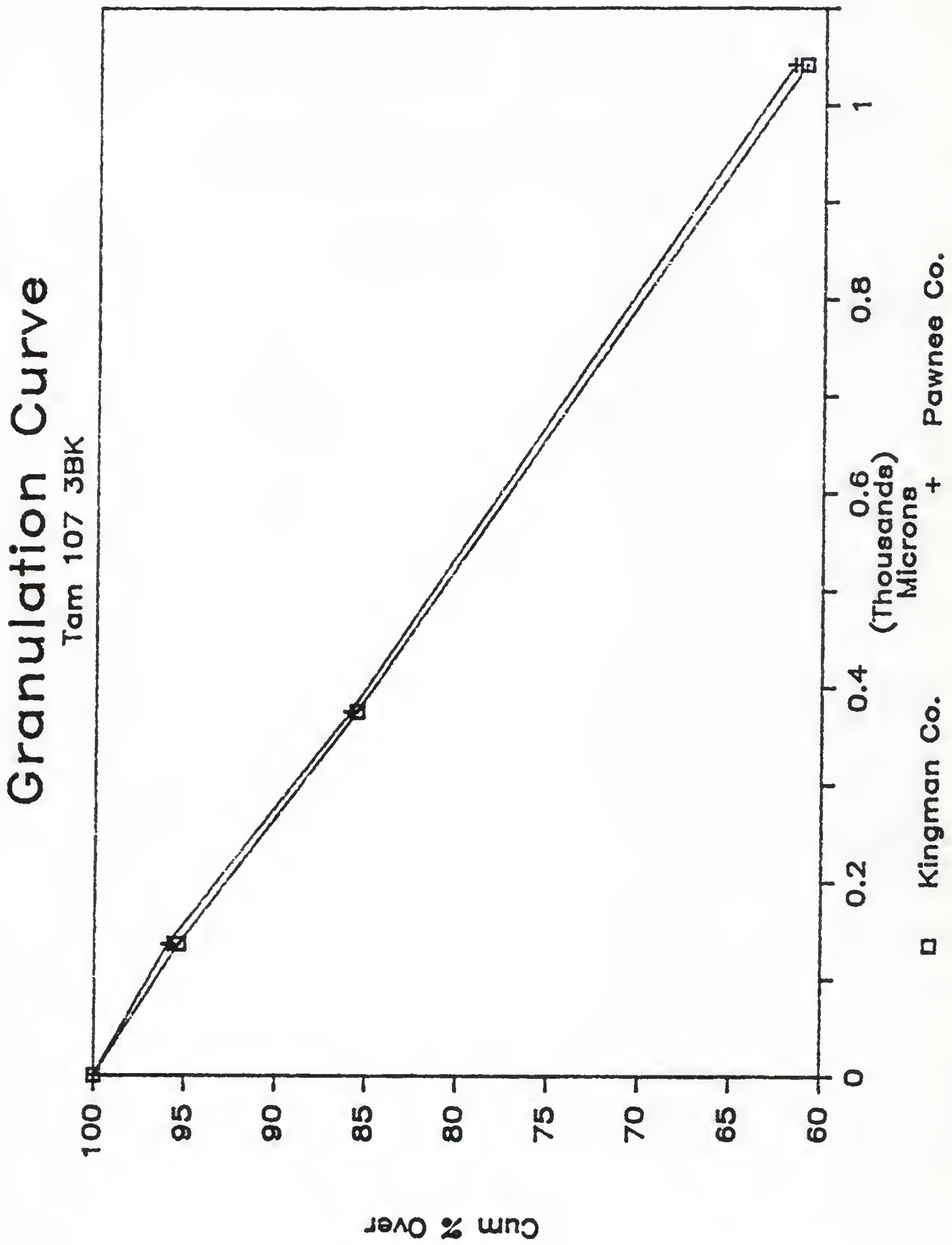

Granulation Curve
Tam 107 3BK
Cum % Over
100
95
90
85
80
75
70
65
60
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
□ Kingman Co.
+ Pawnee Co.

Fig. 30

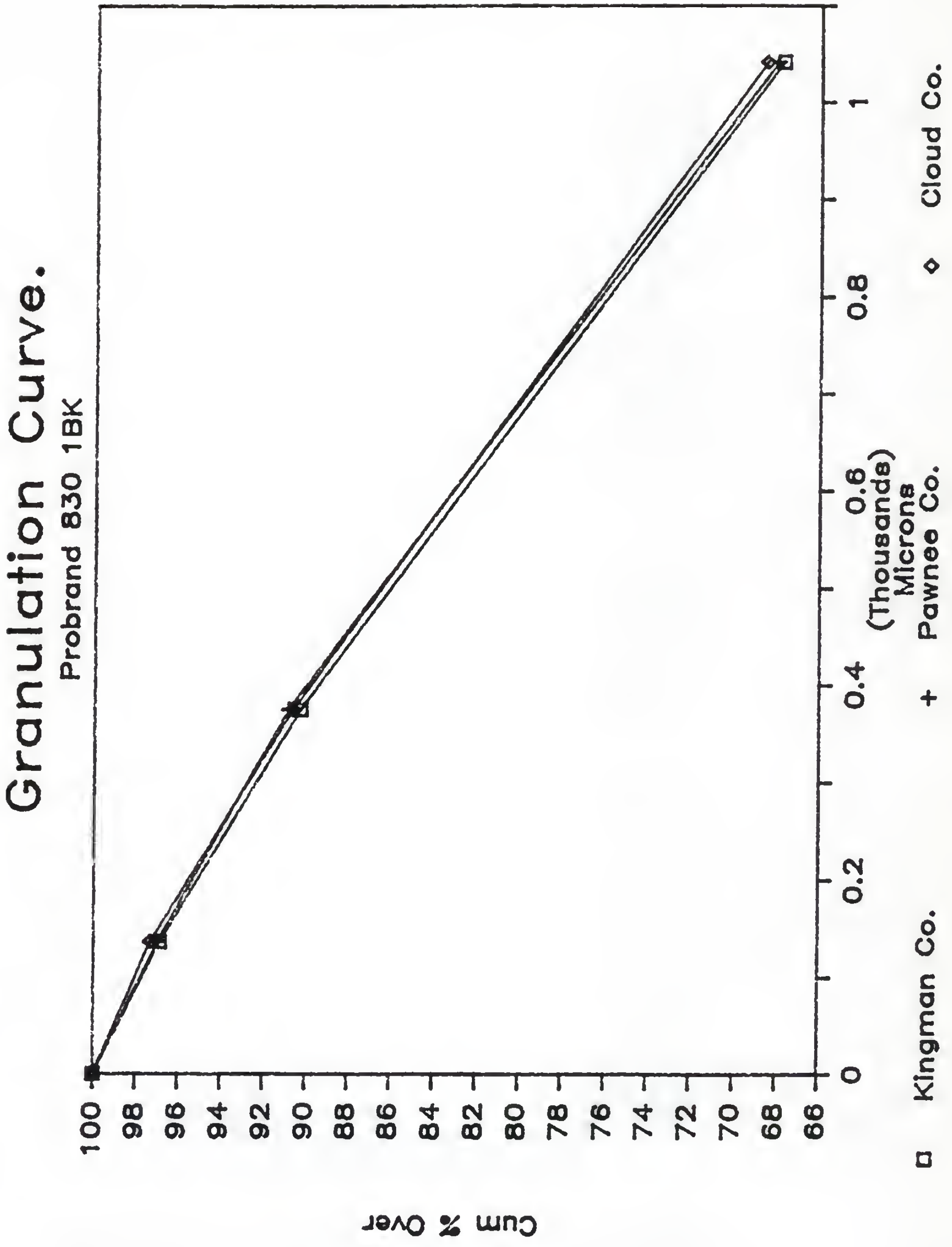

Granulation Curve.
Probrand 830 1BK
Cum % Over
100
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
68
66
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
□ Kingman Co.
+ Pawnee Co.
◇ Cloud Co.

Fig. 31

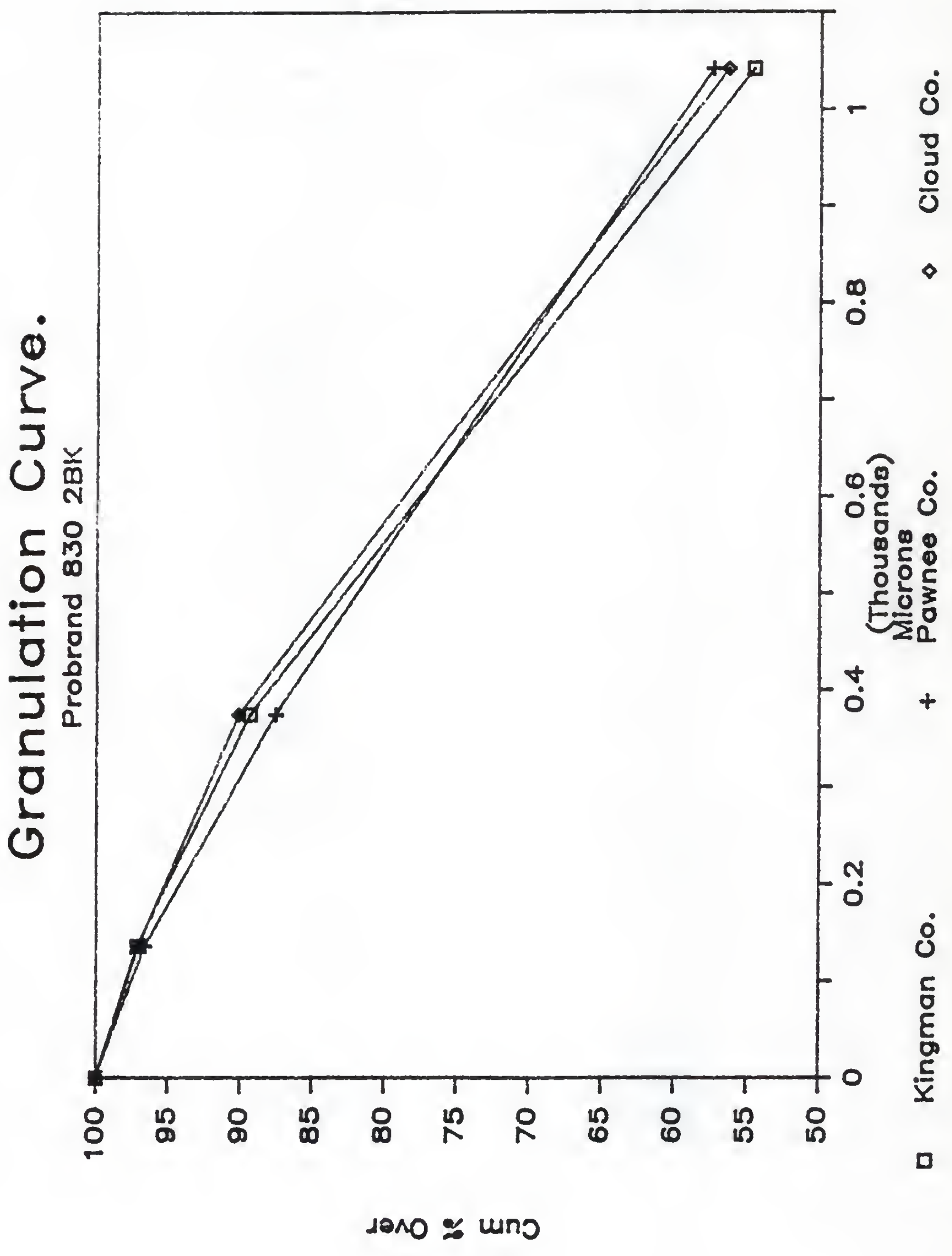

Granulation Curve.
Probrand 830 2BK
Cum % Over
100
95
90
85
80
75
70
65
60
55
50
0
0.2
0.4
0.6
0.8
1
(Thousands)
Microns
□ Kingman Co.
+ Pawnee Co.
◇ Cloud Co.

Fig. 32

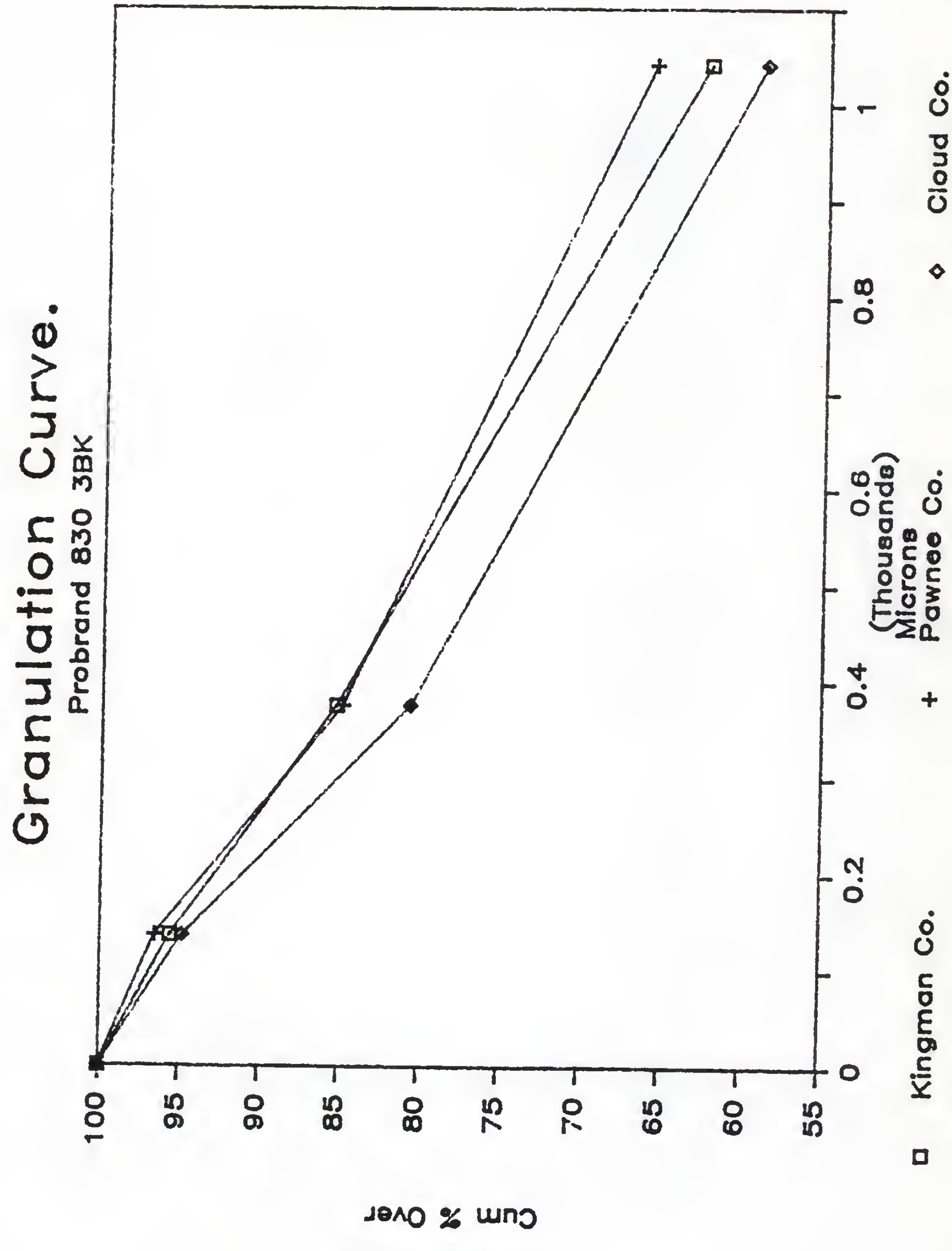

Granulation Curve.
Probrand 830 3BK
Cum % Over
100
95
90
85
80
75
70
65
60
55
0
0.2
0.4
0.6
0.8
1
Microns
(Thousands)
□ Kingman Co.
+ Pawnee Co.
◇ Cloud Co.

Fig. 33

(4) Milling Test.

(a) Particle Size Distribution.

Fig. 10-33 shows the granulation curves obtained from 1-3BK fractions of 18 wheat samples. The ordinates are marked off in microns. The abcissas are marked off in cumulative percent of material over each sieve having the aperature opening indicated. The plots were made with 100 % of all material being over 0 microns in size. The amount of material left on each sieve was obtained from the test results and cumulatively substracted, starting with 100 %. The stream fractions were as follows:

0-136 microns: Flour stream
136-375 microns: Middling stream
375-1041 microns: Sizing stream

From 1BK to 3 BK, Fig. 10-33 shows different rates of production in certain size ranges; less sizing and more middlings. As shown on the flow sheet (Fig.6, p.22), the number of corrugations per inch of roll surface increased from 14/inch to 24/inch. When run at the same rpm, this gave the effect of producing more corrugation contacts as the break stock progressed thru the mill. In addition to this, the corrugations also had less depth as the number of corrugations per inch increased. This combination of factors, number of corrugations and depth of corrugations, affected the size of the middlings produced with smaller middlings increasing as the number of corrugations per inch increased, at a given release rate.

Arkan

Fig. 10 shows the results of 1BK release of Arkan (Kingman and Dickinson Co.). Those two granulation curves were identical. Fig.11 shows the result of 2BK release. Kingman had 38.52 % of sizing stock, and Dickinson had 35.50 %. Both middling and flour streams were identical. When one wheat is harder than the other, the harder wheat tends to have larger particle size. Therefore, we can see that Kingman is harder than Dickinson because of higher portion of sizing stream. Fig. 12 shows the 3BK release. Kingman had more percentage in both sizing and middling stream, and less percentage in flour stream than Dickinson. These data fit well with the results of PSI shown in Table 2.

Colt

Fig. 13 shows the result of 1BK release of Colt (Kingman and Logan Co.). Logan had a higher percentage in sizing and middling stream than Kingman. The flour streams were identical. Fig. 14 also shows a higher percentage from Logan in sizing and middling stream and less flour than Kingman. Fig. 15 shows the same result as Fig. 14. These data fit well with P.S.I. data.

Larned

Fig. 16-18 shows the 1-3BK release of Larned (Kingman and Logan Co.). In 1 & 2 BK, Logan showed a little more sizing stream than Kingman, but the difference was not large. For 3BK, Logan showed less middling and flour streams than Kingman. The sizing streams were identical.

Garst HR 64

Fig. 19-21 shows the result of 1-3BK release of Garst HR 64 (Kingman, Rush, and Logan Co.). For the 1BK granulation curve, Kingman showed higher amounts of sizings. When comparing Rush to Logan, there was more sizings in Logan, and also more flour.

For 2BK, Kingman showed a greater percentage in sizings than Rush and Logan. Both Rush and Logan were identical in sizings, but Rush had more middlings than Logan. The flour was identical for three of them.

For 3BK data, the amount of sizings were as follows; Kingman>Logan>Rush. This data fits well with PSI data.

Mustang

Fig. 22-24 shows 1-3BK release of Mustang (Kingman and Logan Co.). We can not see much difference in 1BK. 2BK showed that Kingman had more sizings than Logan. For 3BK, Kingman had less middlings and flour than Kingman.

Pioneer 2157

Fig. 25-27 shows 1-3 BK release of Pioneer 2157 (Kingman and Pawnee Co.). 1 & 2BK data showed more sizings from Kingman than Pawnee. Middlings and flour streams were identical. For 3BK data, Kingman showed more sizings and less middlings than Pawnee, but more flour than Pawnee.

Tam 107

Fig.28-30 shows 1-3BK release of Tam 107 (Kingman and Pawnee Co.). 1BK data showed that Pawnee had less of flour, but middlings and sizings were not much different. In 2 & 3BK, granulation curves were identical.

Probrand 830

Fig. 31-33 shows 1-3BK of Probrand 830 (Kingman, Pawnee, and Cloud Co.). For 1BK data, the three samples were identical. In 2BK data, the amount of sizings were as follows; Kingman>Cloud>Pawnee. Middlings were as follows; Pawnee>Kingman>Cloud. Flour showed little difference. For 3BK, the sizings were as follows; Kingman>Cloud>Pawnee.

Over all, as we can see from Table 3, particle size distribution (sizing stream) seemed to have a significant relation with PSI wheat hardness test.

(b)Ash

A comparison of Fig. 34-41 shows differences in the ash distribution of the break release products. Table 5-12 shows the calculation to make ash curve.

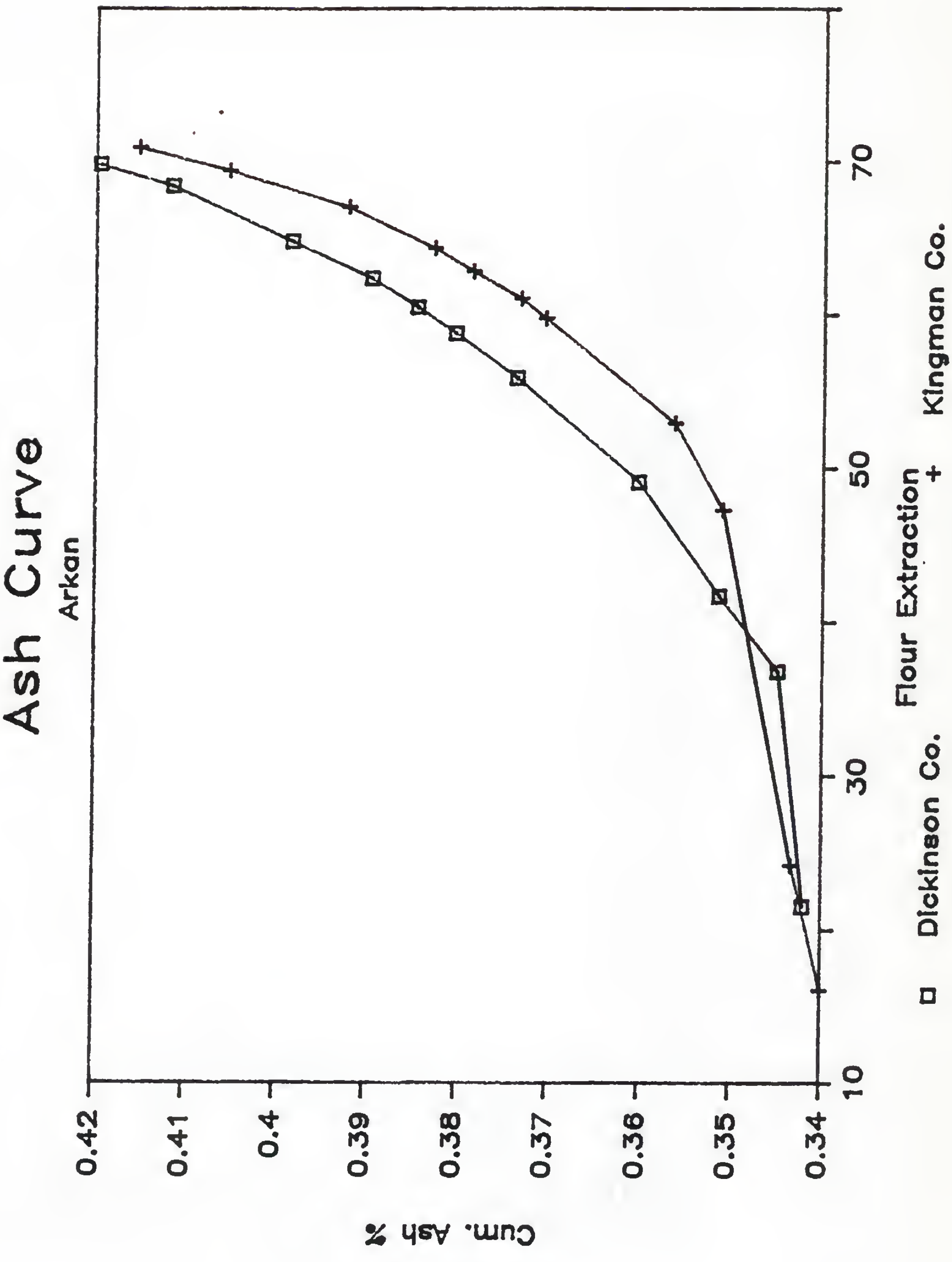

Ash Curve
Arkan
Cum. Ash %
0.42
0.41
0.4
0.39
0.38
0.37
0.36
0.35
0.34
10
30
50
70
Flour Extraction
□ Dickinson Co.
+ Kingman Co.

Fig. 34

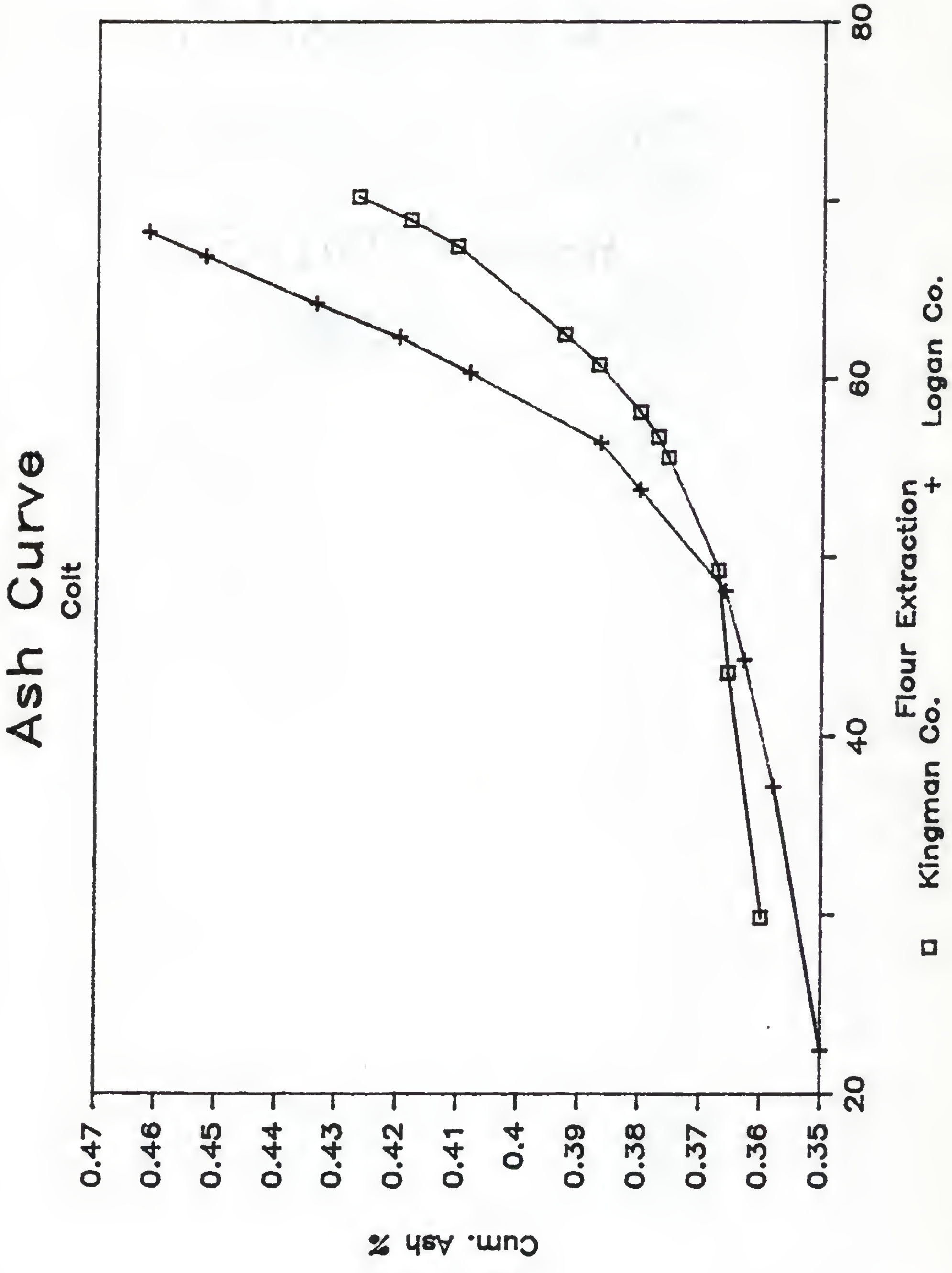

Ash Curve
Colt
Cum. Ash %
0.35
0.36
0.37
0.38
0.39
0.4
0.41
0.42
0.43
0.44
0.45
0.46
0.47
20
40
60
80
Flour Extraction
□ Kingman Co.
+ Logan Co.

Fig. 35

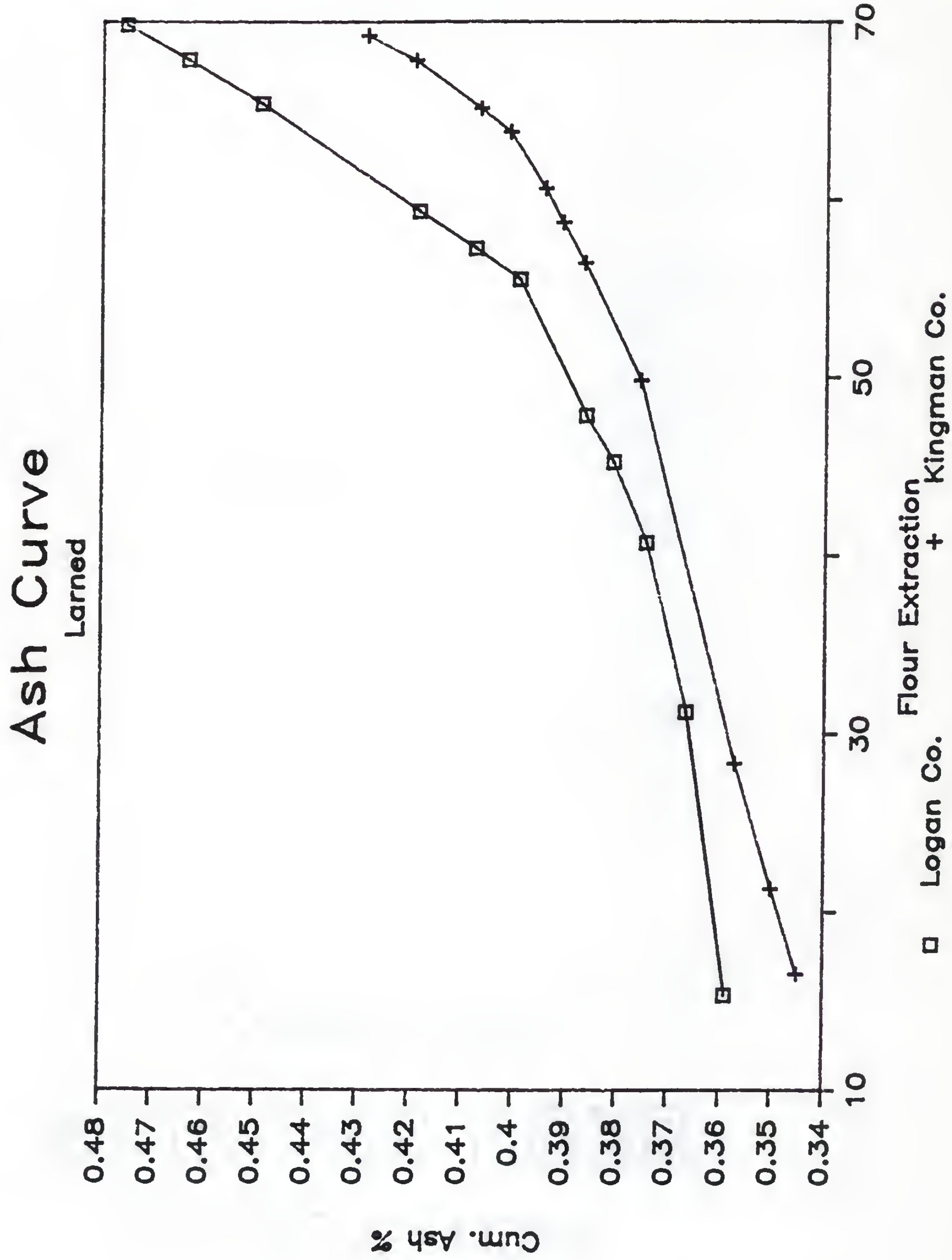

Ash Curve
Larned
Cum. Ash %
0.48
0.47
0.46
0.45
0.44
0.43
0.42
0.41
0.4
0.39
0.38
0.37
0.36
0.35
0.34
10
30
50
70
Flour Extraction
□ Logan Co.
+ Kingman Co.

Fig. 36

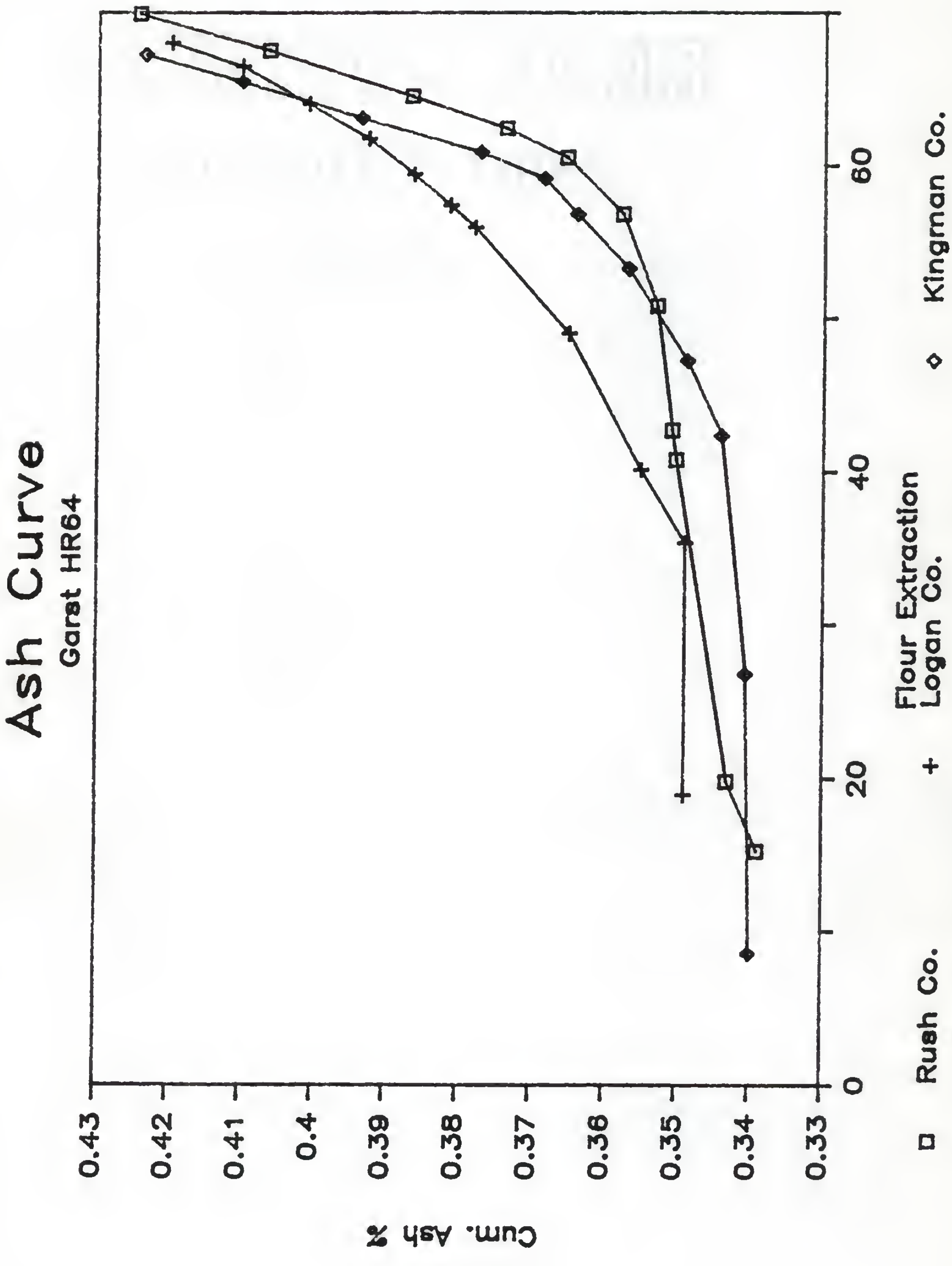

Ash Curve
Garst HR64
Cum. Ash %
0.43
0.42
0.41
0.4
0.39
0.38
0.37
0.36
0.35
0.34
0.33
0
20
40
60
Flour Extraction
□ Rush Co.
+ Logan Co.
◇ Kingman Co.

Fig. 37

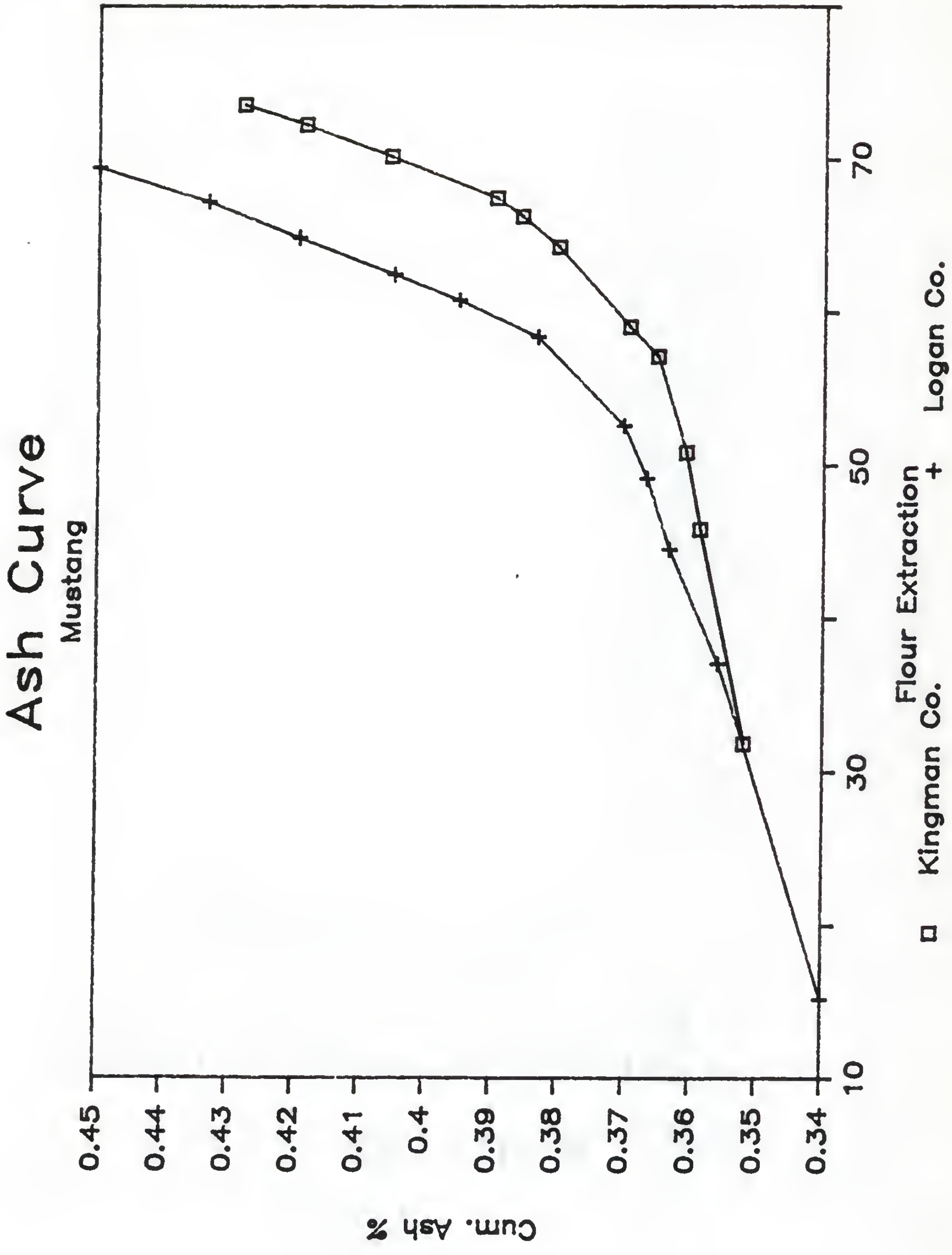

Ash Curve
Mustang
Cum. Ash %
0.45
0.44
0.43
0.42
0.41
0.4
0.39
0.38
0.37
0.36
0.35
0.34
10
30
50
70
Flour Extraction
□ Kingman Co.
+ Logan Co.

Fig. 38

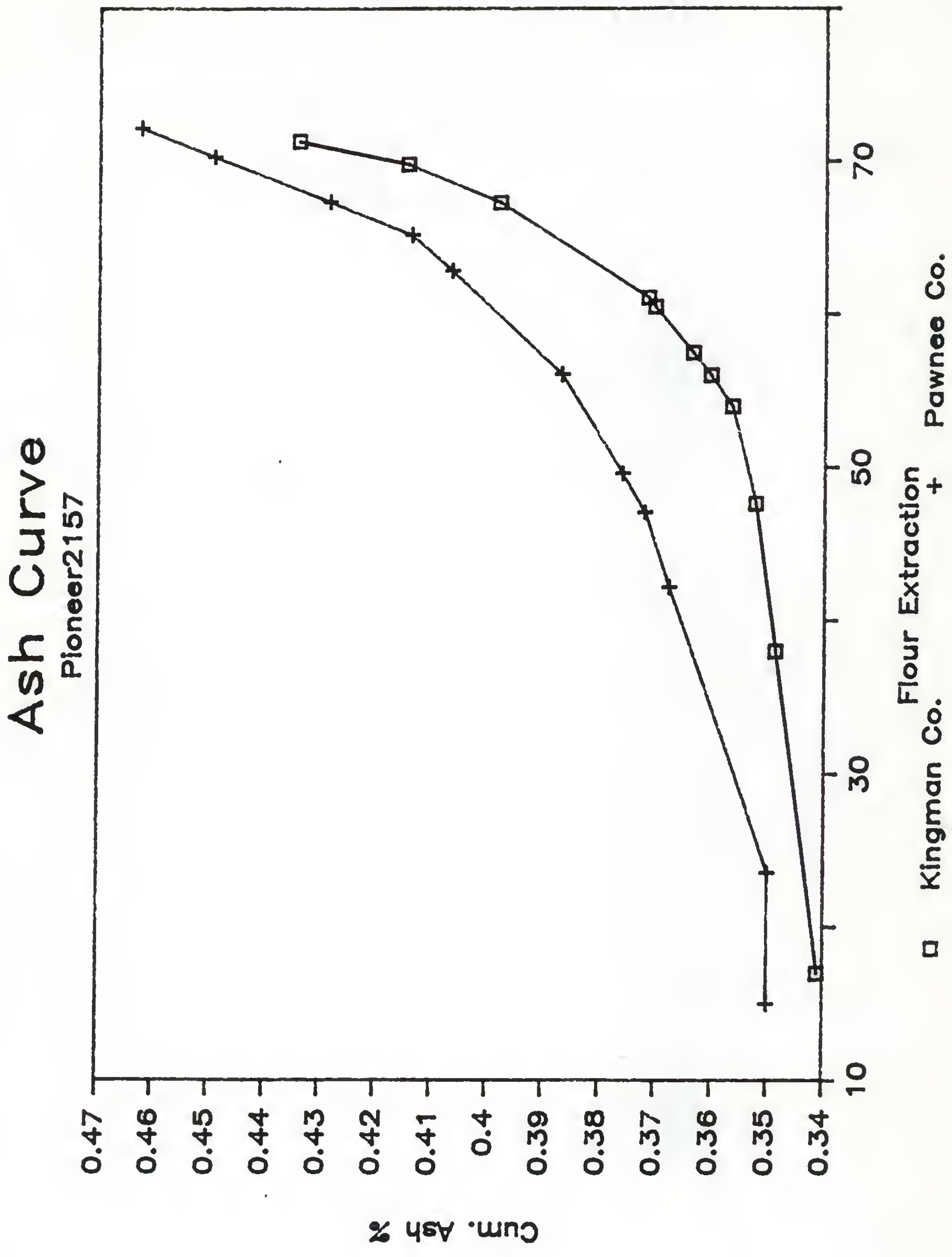

Ash Curve
Pioneer2157
Cum. Ash %
0.47
0.46
0.45
0.44
0.43
0.42
0.41
0.4
0.39
0.38
0.37
0.36
0.35
0.34
10
30
50
70
Flour Extraction
□ Kingman Co.
+ Pawnee Co.

Fig. 39

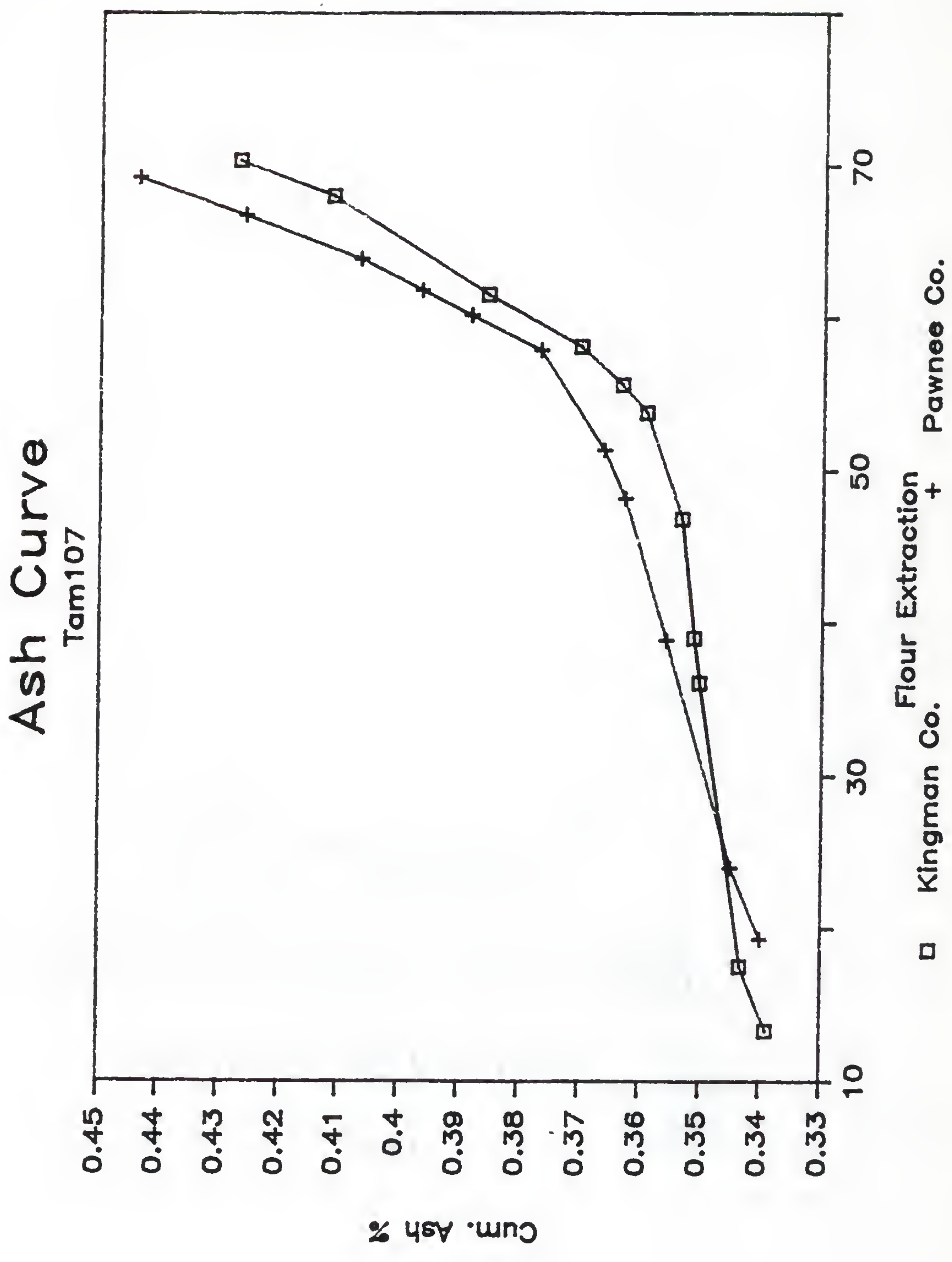

Ash Curve
Tam107
Cum. Ash %
0.45
0.44
0.43
0.42
0.41
0.4
0.39
0.38
0.37
0.36
0.35
0.34
0.33
10
30
50
70
Flour Extraction
□ Kingman Co.
+ Pawnee Co.

Fig. 40

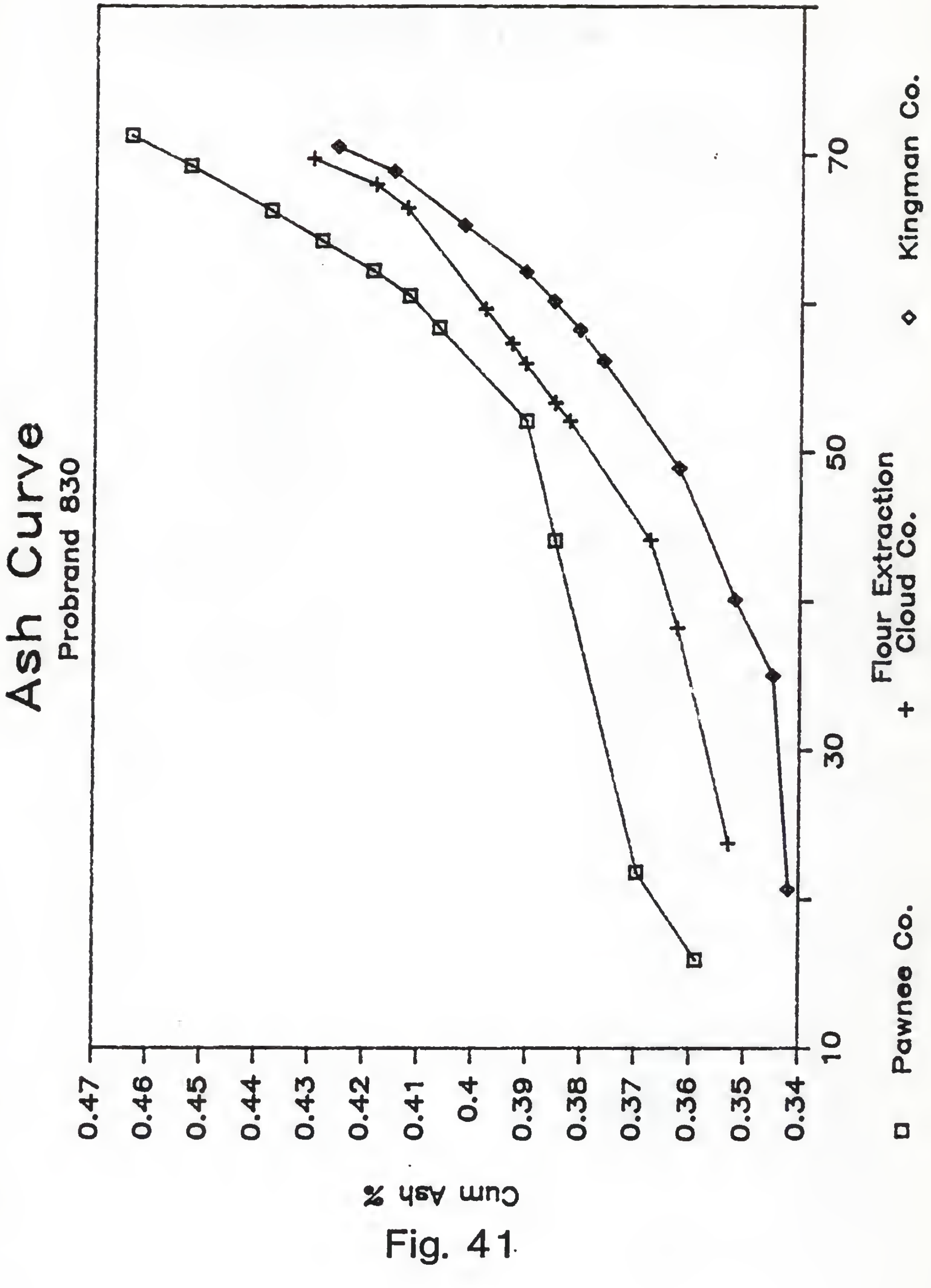

Ash Curve
Probrand 830
Cum Ash %
0.47
0.46
0.45
0.44
0.43
0.42
0.41
0.4
0.39
0.38
0.37
0.36
0.35
0.34
10
30
50
70
Flour Extraction
□ Pawnee Co.
+ Cloud Co.
◇ Kingman Co.

Fig. 41

Table 5

CUMULATIVE ASH CALCULATIONS

A = Ash % (14 % moisture basis)
Q = Quantity (% of flour extraction)
S = Summation

Arkan (Kingman)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
1M	0.342	21.5	21.5	7.35	7.35	0.34
2M	0.349	15.3	36.8	5.34	12.69	0.34
Siz	0.400	4.9	41.7	1.96	14.65	0.35
3M	0.410	7.4	49.1	3.03	17.96	0.36
4M	0.470	6.8	55.9	3.20	20.88	0.37
1T	0.510	2.9	58.8	1.48	22.36	0.38
3BK	0.529	1.7	60.5	0.90	23.26	0.38
2BK	0.550	1.9	62.4	1.05	24.31	0.39
1BK	0.629	2.4	64.8	1.51	25.82	0.40
5M	0.649	3.6	68.4	2.34	28.15	0.41
4&5BK	0.811	1.4	69.8	1.14	29.29	0.42

Arkan (Dickinson)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
2M	0.340	16.1	16.1	5.46	5.46	0.34
3M	0.350	8.1	24.2	2.83	8.29	0.34
1M	0.359	23.1	47.3	8.29	16.58	0.35
Siz	0.400	5.7	53.0	2.28	18.86	0.36
4M	0.480	6.8	59.8	3.28	22.14	0.37
1T	0.500	1.3	61.1	0.65	22.79	0.37
2BK	0.559	1.8	62.9	0.99	23.79	0.38
3BK	0.559	1.5	64.4	0.84	24.63	0.38
1BK	0.619	2.7	67.0	1.65	26.28	0.39
5M	0.779	2.4	69.4	1.85	28.13	0.41
4&5BK	0.877	1.5	70.9	1.32	29.44	0.42

Table 6

CUMULATIVE ASH CALCULATIONS

A = Ash % (14 % moisture basis)
Q = Quantity (% of flour extraction)
S = Summation

Colt (Kingman)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
1M	0.340	29.9	29.9	10.16	10.16	0.34
2M	0.360	13.7	43.5	4.92	15.08	0.35
Siz	0.380	5.7	49.3	2.17	17.25	0.35
3M	0.439	6.3	55.6	2.78	20.03	0.36
1T	0.460	1.2	56.7	0.53	20.56	0.36
3BK	0.500	1.4	58.1	0.70	21.26	0.37
1BK	0.540	2.7	60.8	1.43	22.69	0.37
2BK	0.540	1.7	62.5	0.91	23.60	0.38
4M	0.559	4.9	67.4	2.76	26.35	0.39
5M	0.680	1.5	68.9	1.00	27.35	0.40
4&5BK	0.700	1.3	70.2	0.92	28.28	0.40

Colt (Logan)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
1M	0.350	22.4	22.4	7.85	7.85	0.35
2M	0.370	14.7	37.2	5.45	13.30	0.36
3M	0.389	7.1	44.3	2.76	16.06	0.36
Siz	0.403	3.9	48.1	1.55	17.61	0.37
4M	0.499	5.7	53.8	2.82	20.43	0.38
1T	0.520	2.7	56.4	1.38	21.81	0.39
5M	0.719	3.9	60.3	2.82	24.63	0.41
3BK	0.779	2.0	62.3	1.53	26.16	0.42
2BK	0.881	1.9	64.2	1.67	27.83	0.43
1BK	0.899	2.7	66.8	2.38	30.22	0.45
4&5BK	0.923	1.4	68.2	1.26	31.48	0.46

Table 7

CUMULATIVE ASH CALCULATIONS

A = Ash % (14 % moisture basis)
Q = Quantity (% of flour extraction)
S = Summation

Larned (Kingman)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
2M	0.345	16.5	16.5	5.69	5.69	0.35
Siz	0.368	4.8	21.3	1.77	7.46	0.35
3M	0.379	7.0	28.3	2.65	10.11	0.36
1M	0.400	21.5	49.8	8.60	18.71	0.38
4M	0.469	6.6	56.4	3.10	21.81	0.39
1T	0.494	2.3	58.7	1.14	22.94	0.39
2BK	0.500	1.9	60.6	0.95	23.89	0.39
5M	0.530	3.2	63.8	1.70	25.59	0.40
3BK	0.687	1.3	65.1	0.89	26.48	0.41
1BK	0.724	2.7	67.8	1.95	28.44	0.42
4&5BK	0.879	1.4	69.2	1.23	29.67	0.43

Larned (Logan)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
1M	0.339	15.3	15.3	5.19	5.19	0.34
2M	0.340	15.9	31.2	5.41	10.60	0.34
3M	0.360	9.5	40.7	3.42	14.03	0.34
Siz	0.439	4.5	45.2	1.98	16.01	0.35
1T	0.479	2.6	47.8	1.25	17.26	0.36
4M	0.479	7.7	55.5	3.68	20.93	0.38
3BK	0.681	1.7	57.2	1.18	22.11	0.39
2BK	0.761	2.1	59.3	1.58	23.69	0.40
5M	0.781	6.1	65.4	4.72	28.42	0.43
1BK	0.839	2.5	67.8	2.07	30.49	0.45
4&5BK	1.000	2.0	69.8	1.97	32.46	0.47

Table 8 (I)

CUMULATIVE ASH CALCULATIONS

A = Ash % (14 % moisture basis)
Q = Quantity (% of flour extraction)
S = Summation

Garst HR64 (Kingman)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
1M	0.349	18.9	18.9	6.60	6.60	0.35
2M	0.349	16.4	35.3	5.73	12.33	0.35
Siz	0.400	4.7	40.1	1.92	14.24	0.36
3M	0.410	8.9	49.0	3.64	17.88	0.37
4M	0.470	6.9	55.9	3.26	21.14	0.38
1T	0.510	1.5	57.4	0.74	21.88	0.38
3BK	0.529	2.0	59.4	1.07	22.95	0.39
2BK	0.550	2.4	61.7	1.29	24.24	0.39
1BK	0.629	2.3	64.0	1.42	25.66	0.40
5M	0.649	2.5	66.5	1.60	27.25	0.41
4&5BK	0.849	1.5	68.0	1.29	28.54	0.42

Garst HR64 (Rush)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
3M	0.340	8.5	8.5	2.90	2.90	0.34
1M	0.341	18.2	26.8	6.21	9.11	0.34
2M	0.350	15.6	42.3	5.45	14.57	0.34
Siz	0.390	4.9	47.2	1.90	16.47	0.35
4M	0.420	6.0	53.2	2.53	19.00	0.36
5M	0.470	3.6	56.8	1.67	20.67	0.36
1T	0.479	2.4	59.1	1.13	21.79	0.37
3BK	0.679	1.7	60.9	1.17	22.96	0.38
2BK	0.839	2.2	63.1	1.87	24.83	0.39
1BK	0.849	2.4	65.5	2.02	26.85	0.41
4&5BK	0.922	1.8	67.2	1.61	28.46	0.42

Table 8 (II)

CUMULATIVE ASH CALCULATIONS

A = Ash % (14 % moisture basis)
Q = Quantity (% of flour extraction)
S = Summation

Garst HR64 (Logan)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
3M	0.340	8.5	8.5	2.90	2.90	0.34
1M	0.341	18.2	26.8	6.21	9.11	0.34
2M	0.350	15.6	42.3	5.45	14.57	0.34
Siz	0.390	4.9	47.2	1.90	16.47	0.35
4M	0.420	6.0	53.2	2.53	19.00	0.36
5M	0.470	3.6	56.8	1.67	20.67	0.36
1T	0.479	2.4	59.1	1.13	21.79	0.37
3BK	0.679	1.7	60.9	1.17	22.96	0.38
2BK	0.839	2.2	63.1	1.87	24.83	0.39
1BK	0.849	2.4	65.5	2.02	26.85	0.41
4&5BK	0.922	1.8	67.2	1.61	28.46	0.42

Table 9

CUMULATIVE ASH CALCULATIONS

A = Ash % (14 % moisture basis)
Q = Quantity (% of flour extraction)
S = Summation

Mustang (Kingman)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
1M	0.352	31.8	31.8	11.19	11.19	0.35
2M	0.374	14.0	45.8	5.24	16.43	0.36
3M	0.380	5.0	50.8	1.91	18.34	0.36
Siz	0.400	6.3	57.1	2.51	20.85	0.37
2BK	0.498	1.9	59.0	0.96	21.81	0.37
4M	0.501	5.2	64.3	2.62	24.43	0.38
1T	0.567	2.0	66.2	1.12	25.55	0.39
3BK	0.599	1.2	67.5	0.73	26.28	0.39
1BK	0.800	2.7	70.2	2.18	28.46	0.41
4&5BK	0.855	2.1	72.3	1.78	30.23	0.42
5M	0.960	1.3	73.5	1.23	31.46	0.43

Mustang (Logan)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
2M	0.340	15.1	15.1	5.14	5.14	0.34
1M	0.367	21.9	37.0	8.04	13.18	0.36
3M	0.400	7.5	44.5	2.98	16.16	0.36
Siz	0.400	4.7	49.1	1.86	18.02	0.37
1T	0.420	3.4	52.5	1.43	19.45	0.37
4M	0.501	5.8	58.4	2.92	22.37	0.38
5M	0.680	2.4	60.8	1.65	24.02	0.40
3BK	0.761	1.7	62.5	1.28	25.30	0.40
1BK	0.800	2.4	64.9	1.90	27.20	0.42
2BK	0.819	2.3	67.2	1.91	29.11	0.43
4&5BK	0.959	2.2	69.4	2.11	31.22	0.45

Table 10

CUMULATIVE ASH CALCULATIONS

A = Ash % (14 % moisture basis)
Q = Quantity (% of flour extraction)
S = Summation

Pioneer 2157 (Kingman)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
2M	0.341	17.0	17.0	5.80	5.80	0.34
1M	0.355	21.0	38.0	7.46	13.25	0.35
3M	0.367	9.6	47.6	3.52	16.78	0.35
Siz	0.389	6.4	54.0	2.49	19.26	0.36
2BK	0.462	2.0	56.0	0.92	20.19	0.36
3BK	0.481	1.5	57.5	0.72	20.91	0.36
1BK	0.499	3.0	60.5	1.50	22.41	0.37
1T	0.499	0.6	61.1	0.30	22.71	0.37
4M	0.659	6.2	67.3	4.09	26.79	0.40
5M	0.860	2.5	69.8	2.15	28.94	0.41
4&5BK	1.343	1.5	71.3	2.02	30.96	0.43

Pioneer 2157 (Pawnee)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
2M	0.350	15.0	15.0	5.25	5.25	0.35
3M	0.350	8.6	23.6	2.99	8.24	0.35
1M	0.390	18.6	42.2	7.26	15.50	0.37
Siz	0.410	4.9	47.0	2.00	17.50	0.37
1T	0.450	2.6	49.6	1.16	18.66	0.38
4M	0.470	6.5	56.1	3.05	21.70	0.39
5M	0.570	6.8	62.9	3.86	25.56	0.41
3BK	0.609	2.3	65.2	1.43	26.99	0.41
2BK	0.871	2.2	67.4	1.87	28.86	0.43
1BK	0.930	2.9	70.3	2.72	31.58	0.45
4&5BK	0.950	1.9	72.2	1.80	33.37	0.46

Table 11

CUMULATIVE ASH CALCULATIONS

A = Ash % (14 % moisture basis)
Q = Quantity (% of flour extraction)
S = Summation

Tam 107 (Kingman)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
2M	0.339	13.3	13.3	4.51	4.51	0.34
Siz	0.357	4.2	17.5	1.50	6.01	0.34
1M	0.357	18.6	36.1	6.64	12.65	0.35
1T	0.363	2.9	39.0	1.05	13.70	0.35
3M	0.364	7.8	46.8	2.84	16.54	0.35
4M	0.399	7.0	53.8	2.79	19.33	0.36
3BK	0.483	1.8	55.6	0.87	20.20	0.36
2BK	0.523	2.5	58.1	1.31	21.51	0.37
1BK	0.649	3.4	61.5	2.21	23.72	0.39
5M	0.654	6.5	68.0	4.25	27.97	0.41
4&5BK	0.889	2.3	70.3	2.04	30.31	0.43

Tam 107 (Pawnee)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
1M	0.340	19.3	19.3	6.56	6.56	0.34
Siz	0.366	4.7	23.9	1.71	8.26	0.35
2M	0.373	14.9	38.9	5.57	13.83	0.36
3M	0.392	9.3	48.2	3.64	17.47	0.36
1T	0.420	3.2	51.3	1.34	18.81	0.37
4M	0.460	6.5	57.9	3.00	21.81	0.38
1BK	0.678	2.3	60.2	1.55	23.36	0.39
3BK	0.699	1.6	61.8	1.15	24.51	0.40
2BK	0.711	2.1	63.9	1.46	25.97	0.41
5M	0.852	2.9	66.7	2.46	28.43	0.43
4&5BK	0.921	2.5	69.2	2.27	30.71	0.44

Table 12 (I)

CUMULATIVE ASH CALCULATIONS

A = Ash % (14 % moisture basis)
Q = Quantity (% of flour extraction)
S = Summation

Probrand 830 (Kingman)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
1M	0.342	20.7	20.7	7.07	7.07	0.34
2M	0.349	14.3	35.0	5.00	12.07	0.34
Siz	0.400	5.1	40.1	2.05	14.11	0.35
3M	0.410	8.8	48.9	3.62	17.73	0.36
4M	0.470	7.2	56.2	3.39	21.12	0.38
1T	0.501	2.1	58.3	1.05	22.18	0.38
3BK	0.529	1.9	60.2	1.02	23.19	0.39
2BK	0.550	2.0	62.1	1.07	24.26	0.39
1BK	0.629	3.1	65.2	1.96	26.23	0.40
5M	0.649	3.6	68.9	2.36	28.58	0.42
4&5BK	0.849	1.7	70.5	1.42	30.00	0.43

Probrand 830 (Pawnee)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
2M	0.359	16.0	16.0	5.73	5.73	0.36
Siz	0.399	5.9	21.8	2.34	8.06	0.37
1M	0.400	22.3	44.1	8.91	16.98	0.39
3M	0.420	8.0	52.1	3.36	20.33	0.39
4M	0.540	6.3	58.4	3.40	23.73	0.41
1T	0.560	2.2	60.5	1.21	24.94	0.41
3BK	0.660	1.7	62.2	1.11	26.05	0.42
2BK	0.720	2.0	64.2	1.45	27.50	0.43
4&5BK	0.739	2.0	66.2	1.48	28.98	0.44
1BK	0.779	3.0	69.3	2.36	31.34	0.45
5M	0.839	2.0	71.3	1.69	33.03	0.46

Table 12 (II)

CUMULATIVE ASH CALCULATIONS

A = Ash % (14 % moisture basis)
Q = Quantity (% of flour extraction)
S = Summation

Probrand 830 (Cloud)

Stream	A	Q	S of Q	A*Q	S of A*Q	S of A
1M	0.353	23.7	23.7	8.38	8.38	0.35
2M	0.378	14.5	38.2	5.47	13.85	0.36
Siz	0.400	5.9	44.1	2.36	16.21	0.37
3M	0.465	8.0	52.1	3.71	19.91	0.38
1T	0.499	1.2	53.3	0.61	20.53	0.39
1BK	0.500	2.7	56.0	1.33	21.86	0.39
3BK	0.500	1.3	57.3	0.66	22.53	0.39
2BK	0.519	2.3	59.6	1.21	23.74	0.40
4M	0.540	6.8	66.4	3.66	27.40	0.41
4&5BK	0.660	1.6	68.0	1.05	28.44	0.42
5M	0.880	1.7	69.7	1.52	29.97	0.43

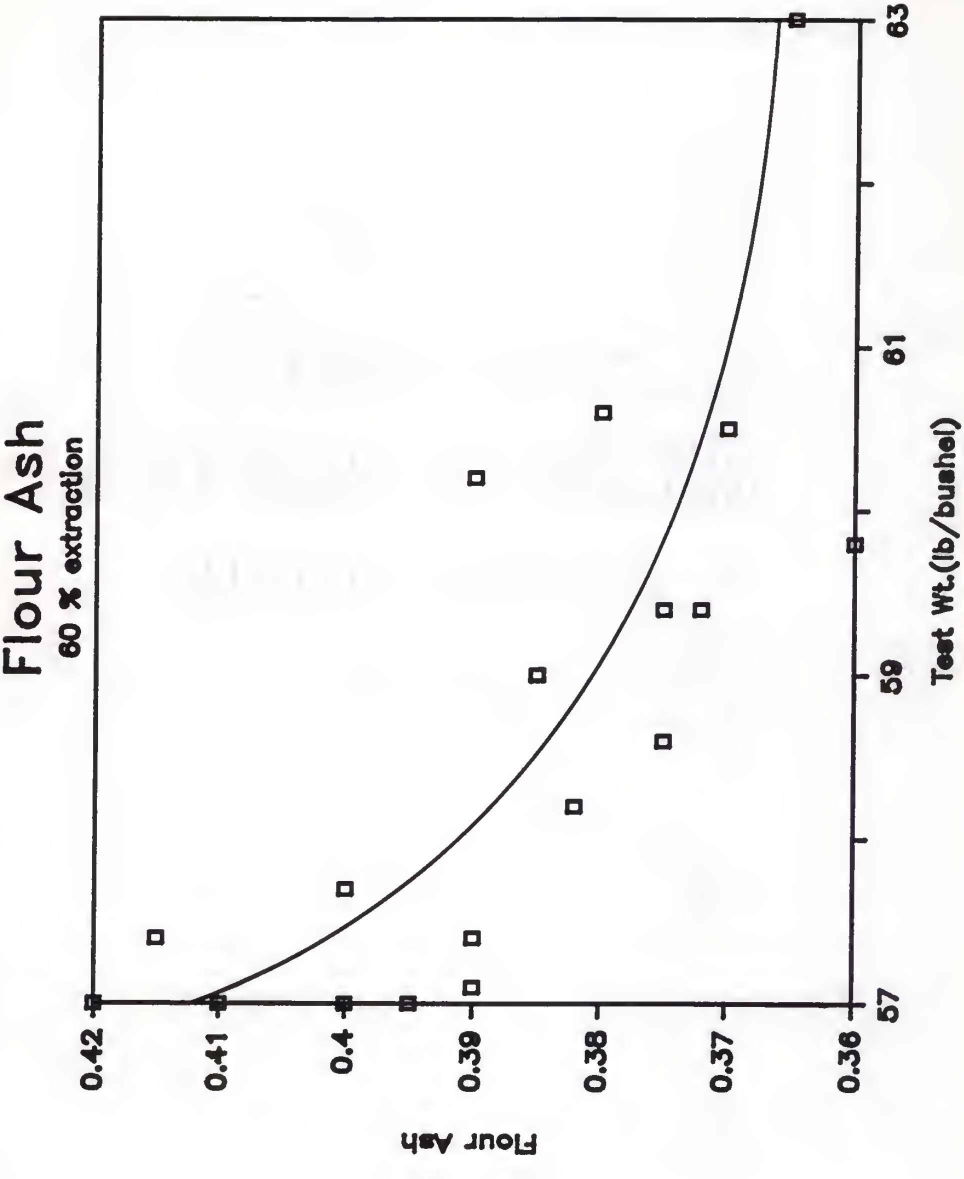

Flour Ash
60 % extraction
0.42
0.41
0.4
0.39
0.38
0.37
0.36
57
59
61
63
Test Wt.(lb/bushel)
Flour Ash

Fig. 42

At the 60 % flour extraction, cumulative ash is as follows;

Variety(location)	Ash(%)
Arkan(Kingman)	0.372
Arkan(Dickinson)	0.382
Colt(Kingman)	0.385
Colt(Logan)	0.410
Larned(Kingman)	0.390
Larned(Logan)	0.420
Garst HR64(Kingman)	0.375
Garst HR64(Rush)	0.365
Garst HR64(Logan)	0.390
Mustang(Kingman)	0.370
Mustang(Logan)	0.395
Pioneer 2157(Kingman)	0.360
Pioneer 2157(Pawnee)	0.400
Tam 107(Kingman)	0.375
Tam 107(Pawnee)	0.390
Probrand 830(Kingman)	0.380
Probrand 830(Pawnee)	0.415
Probrand 830(Cloud)	0.400

Fig. 42 shows the relationship between ash (60 % extraction) and test weight. When test weight was low, flour ash was high. From this figure, we could tell that 58 lb/bushel was a critical point. When test weight was lower than this point, ash content increased siginificantly with decreasing test weight. Over 58 lb/bushel, ash content of flour did not change much.

(5) Flour Data.

Table 13 summarizes characteristics of flour from the 18 wheat samples. Flour ash seemed not to correlate with wheat ash content (Table 1, p 37). It is well known that it is impossible to make low ash flour from high ash content wheat. However, the aim of milling is to separate endosperm from bran cleanly, to avoid migration of minerals from bran to endosperm. If the endosperm is rich in minerals, even though we can separate endosperm from bran well, the final product would be high ash content flour. In other words, unless the endosperm is rich in minerals, it may be possible to make low ash flour although wheat ash is not so low.

On the other hand, flour protein is well correlated with wheat protein. Flour protein is about 1 % less than wheat protein content.

The Falling Numbers of all samples ranged from 317-422. Barley malt was added to adjust falling number to 220-250 for baking tests.

Fig. 43 and 44 shows the mixographs of straight grade flour from the wheat samples. Mixograph is an important guide for baking tests, providing information on water absorption and mixing time.

Table 13

FLOUR DATA

Variety (Location)	Moist. (%)	Ash (%)	Pro. (%)	Falling# (sec.)	W.Glu. (%)	D.Glu (%)
Arkan (Kingman)	15.3	0.44	13.2	353	31.4	11.9
Arkan (Dickinson)	15.3	0.44	12.7	348	30.1	11.0
Colt (Kingman)	14.7	0.43	13.0	340	32.1	12.2
Colt (Logan)	14.8	0.47	12.8	377	34.2	12.7
Larned (Kingman)	15.2	0.42	12.0	317	29.8	10.9
Larned (Logan)	15.3	0.47	12.6	367	28.4	10.3
Garst HR64 (Kingman)	14.6	0.45	12.0	338	26.3	10.4
Garst HR64 (Rush)	14.9	0.43	12.2	373	29.7	11.3
Garst HR64 (Logan)	14.9	0.44	12.3	366	2.85	10.3
Mustang (Kingman)	14.5	0.42	11.9	396	26.5	11.0
Mustang (Logan)	14.3	0.45	12.4	338	29.2	10.5
Pioneer 2157 (Kingman)	14.8	0.44	12.8	361	32.4	12.1
Pioneer 2157 (Pawnee)	14.5	0.48	13.6	394	33.4	12.4
Tam 107 (Kingman)	15.2	0.44	13.7	360	25.4	9.7
Tam 107 (Pawnee)	15.3	0.44	13.7	386	29.4	10.8
Probrand 830 (Kingman)	14.6	0.43	12.6	409	27.4	11.0
Probrand 830 (Pawnee)	15.3	0.47	13.5	391	32.4	12.5
Probrand 830 (Cloud)	14.8	0.43	11.9	422	24.1	9.2

* Ash & Protein: 14 % moisture basis.

Fig. 43 and 44 Mixograph of straight grade flour.

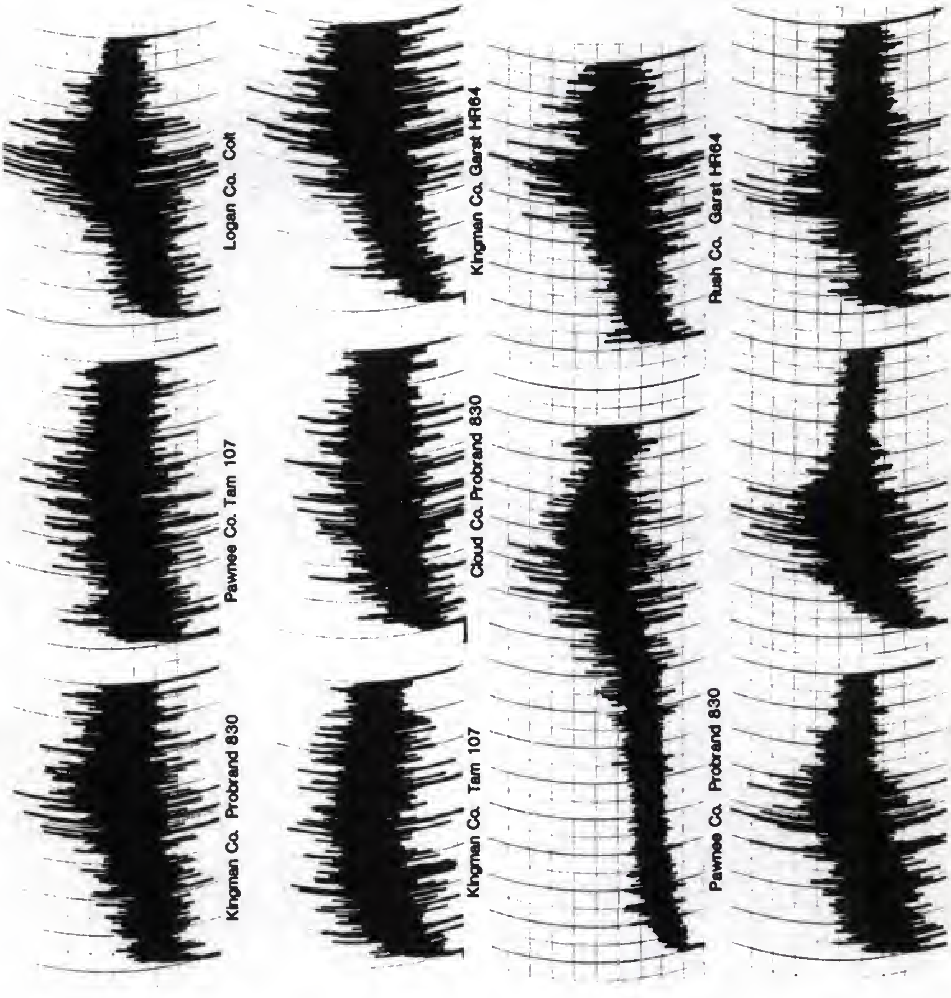

Logan Co. Colt
Kingman Co. Garst HR64
Rush Co. Garst HR64
Kingman Co. Larned
Pawnee Co. Tam 107
Cloud Co. Probrand 830
Dickinson Co. Arkan
Kingman Co. Probrand 830
Kingman Co. Tam 107
Pawnee Co. Probrand 830
Kingman Co. Pioneer 2157

Fig. 43

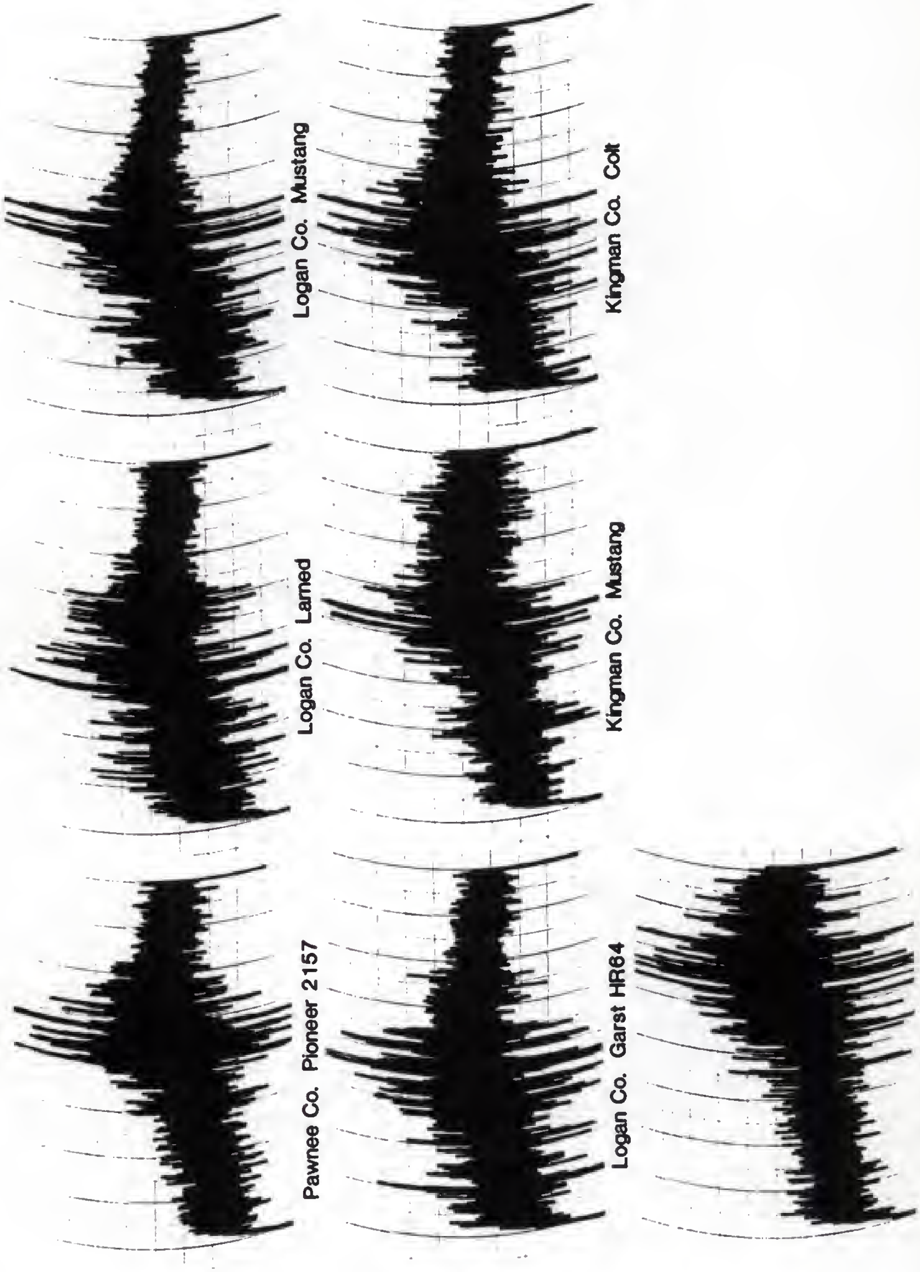

Logan Co. Mustang
Kingman Co. Colt
Logan Co. Larned
Kingman Co. Mustang
Pawnee Co. Pioneer 2157
Logan Co. Garst HR64
Kingman Co. Arkan

Fig. 44

Mixograph water absorptions and mixing times obtained were as follows:

Variety (Location)	W. Abs. (%)	Mix. Time (min.)
Arkan (Kingman)	58 %	6'
Arkan (Dickinson)	54 %	3'
Colt (Kingman)	63 %	3' 30"
Colt (Logan)	62 %	4' 30"
Larned (Kingman)	58 %	3' 30"
Larned (Logan)	58 %	4'
Garst HR 64 (Kingman)	58 %	5' 30"
Garst HR 64 (Rush)	59 %	5'
Garst HR 64 (Logan)	56 %	4'
Mustang (Kingman)	61 %	4' 30"
Mustang (Logan)	61 %	4'
Pioneer 2157 (Kingman)	59 %	4' 30"
Pioneer 2157 (Pawnee)	62 %	4' 30"
Tam 107 (Kingman)	51 %	4'
Tam 107 (Pawnee)	58 %	5'
Probrand 830 (Kingman)	60 %	5' 30"
Probrand 830 (Pawnee)	68 %	11' 30"
Probrand 830 (Cloud)	52 %	5'

(6)Baking Test

While varrious physical and dough tests provide valuable information on flour quality, the baking test is considered the ultimate final criterion of flour quality.

Table 14 shows the result of the baking tests. According to analysis of variance, no significant difference was found in specific volume and grain of bread among the 18 samples. Therefore, as far as our

Table 14 (I)

BAKING TESTS

Variety (Location)	KBrO3 (ppm)	Water Abs. (%)	Mix. Time (min.)	Proof Height (mm)
Arkan (Kingman)	10	54.7	5'30"	77
Arkan (Dickinson)	10	51.7	3'15"	76
Colt (Kingman)	10	55.7	3'50"	76
Colt (Logan)	10	58.2	4'40"	76
Larned (Kingman)	10	54.7	4'40"	76
Larned (Logan)	10	54.7	4'10"	77
Garst HR64 (Kingman)	10	54.7	5'25"	77
Garst HR64 (Rush)	10	54.7	5'15"	76
Garst HR64 (Logan)	10	53.7	4'20"	78
Mustang (Kingman)	10	54.7	5'	76
Mustang (Logan)	10	54.7	4'10"	77
Pioneer 2157 (Kingman)	10	54.7	5'10"	76
Pioneer 2157 (Pawnee)	10	54.7	4'15"	76
Tam 107 (Kingman)	10	51.7	4'30"	77
Tam 107 (Pawnee)	10	57.7	5'50"	76
Probrand 830 (Kingman)	10	51.7	4'40"	76
Probrand 830 (Pawnee)	10	61.7	9'10"	77
Probrand 830 (Cloud)	10	51.7	4'40"	77

Table 14 (II)

BAKING TESTS

Variety (Location)	Loaf vol. (cc)	Loaf wt. (g)	Spec. vol. (cc/g)	Crumb Grains
Arkan (Kingman)	800	140	5.71 (0.02)	9.0
Arkan (Dickinson)	785	138	5.69 (0.03)	9.0
Colt (Kingman)	810	142	5.70 (0.02)	9.0
Colt (Logan)	815	143	5.70 (0.03)	9.0
Larned (Kingman)	800	140	5.71 (0.03)	9.0
Larned (Logan)	790	138	5.72 (0.02)	9.0
Garst HR64 (Kingman)	805	141	5.71 (0.03)	9.0
Garst HR64 (Rush)	798	140	5.70 (0.03)	9.0
Garst HR64 (Logan)	801	141	5.68 (0.02)	9.0
Mustang (Kingman)	812	143	5.68 (0.02)	9.0
Mustang (Logan)	799	140	5.71 (0.03)	9.0
Pioneer 2157 (Kingman)	795	140	5.68 (0.03)	9.0
Pioneer 2157 (Pawnee)	800	140	5.71 (0.02)	9.0
Tam 107 (Kingman)	789	139	5.71 (0.03)	9.0
Tam 107 (Pawnee)	769	135	5.70 (0.04)	9.0
Probrand 830 (Kingman)	833	147	5.67 (0.04)	9.0
Probrand 830 (Pawnee)	799	141	5.67 (0.03)	9.0
Probrand 830 (Cloud)	802	140	5.73 (0.04)	9.0

* Specific volume shows mean and standard deviation of 6 loaves.

** Analysis of variance showed no difference of specific volume and crumb grain.

*** Crumb grains: min. 1 to max. 10, worst to best.

samples were concerned, there was no significant difference between wheat hardness and baking quality.

Doekes et al (1976) made the similar conclusion that no relationship existed between kernel hardness and dough-making and baking properties. Using chromosome substitution lines of Cappelle Desprez, Cheyenne, Hope, and Timstein into the recipient variety Chinese Spring, he made an attempt to identify the chromosomal location of genetic control of a few components of wheat quality.

Doekes et al (1976) mentioned that major factors for kernel hardness and increased baking absorption were found on chromosomes 5D of Cheyenne and Hope, and on 3B, 5D and 7D of Timstein. In Timstein, the presence of one of these chromosomes sufficed to make the wheat kernels hard. However, factors for favorable dough properties were identified on a few other chromosomes, different in various varieties. These were 1A of Cappelle Desprez and Cheyenne, 3B od Hope, and 2D of Timstein. All but one of these chromosomes showed an increase in loaf volume to a level in-between those of the recipient variety Chinese Spring and the donor varieties. Therefore, it was assumed that wheat quality is due to a combination of kernel hardness and favourable dough-making properties.

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THE RELATIONSHIP BETWEEN WHEAT HARDNESS AND MILLING AND BAKING CHARACTERISTICS.

by

KIMIO TSUCHIYA

B.S., Tohoku University, 1983

AN ABSTRACT OF A MASTER'S THESIS

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1988

ABSTRACT

The relationship between wheat kernel hardness and milling and baking characteristics for 1986 Hard Red Winter wheat (18 samples) were investigated. The samples comprised 8 varieties from 6 Kansas counties.

Four hardness tests were utilized: pearling value (PV), particle size index (PSI), near infrared reflectance (NIR), and image analysis (IA). We found that the PSI and NIR were significantly correlated. The PSI test was also significantly correlated with milling test. As far as our sample were concerned, none of the hardness tests, however, was significantly correlated with bread baking characteristics.

Wheat protein content did not show any correlation with kernel hardness. Wheat protein content was correlated, of course, with flour protein content.

Ash content of flour was significantly related with test weight of wheat. When test weight was below 58 lb/bushel, ash content of straight grade flour increased drastically.