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The Influence of Locust Bean Gum on the Strength Characteristics of Handsheets Under Varying pH Conditions. A study of the Effect of Alum or Hydrogen Ion Concentration

Robert J. Witters
Western Michigan University

THE INFLUENCE OF LOCUST BEAN GUM ON THE STRENGTH CHARACTERISTICS OF HANDSHEETS UNDER VARYING pH CONDITIONS. A STUDY OF THE EFFECT OF ALUM OR HYDROGEN ION CONCENTRATION.

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By Robert J. Witters

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INTRODUCTION

A literature survey concerning the addition of locust bean gum to beaten pulp and the resulting strength characteristics imparted to handsheets through the addition of the gum has been undertaken. Although much literature can be found, hardly any detailed information can be extracted on the effect of alum or hydrogen ion concentration. Therefore, the aim of this paper is to draw some conclusion, through laboratory work, as to any possible change, due to pH or alum, in the strength characteristics of handsheets containing locust bean gum.

The first part of this thesis will be a brief review of work that has already been carried out concerning the use of locust bean gum in papermaking, while parts two and three will show the planning of experiments and results of the laboratory work.

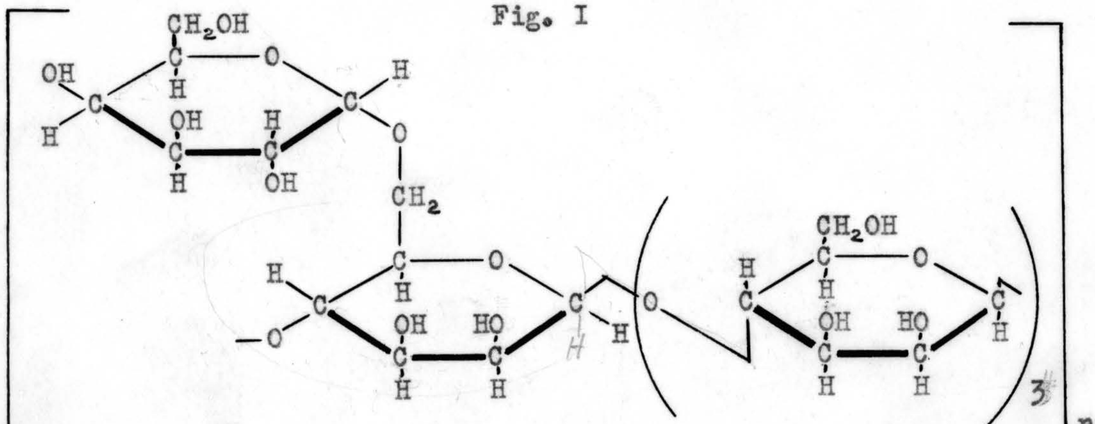
WHAT IS LOCUST BEAN GUM ?

Locust bean gum, also known as Carob gum, is the product obtained from the seeds of the locust bean tree (Ceratonia Siliqua, L.). This tree is native to Spain and Palestine but also is grown and cultivated along the entire coastal Mediterranean section. The trees begin to bear fruit when they are about four years of age and about three feet high. They produce a blossom in late summer or early autumn and then ripen into smooth long pods, which contain about twelve red seeds.

The pods are gathered and spread out in the sun to dry, after which the seeds are removed either by hand or machine and are packed for shipment. These seeds contain the valuable gum, and removal of it is the subject of many patents, all of which involve the removal of the outside skin and ovarium by passage between rollers which turn in opposite directions. Usually the gum is sold in the powdered form or in the form of a four per cent water dispersion (8). It is said (2) that 1,000 pounds of beans yield 100 pounds of seed, from which only thirty five pounds of gum is obtained. At present, locust bean gum is being imported into this country in fair quantity and papermaking grades can be purchased for about twenty five cents per pound (3).

The chemical constitution of locust bean gum as determined by Smith (5) is shown to be composed of d-galactose (about twenty per cent) and d-mannose (about eighty per cent). The simplest structure for the repeating unit of locust bean gum is shown by the formula in Fig. I.

Fig. I



It can be readily seen that locust bean gum is a mannogalactan polysaccharide and the molecule consits of a chain of d-mannopyranose units joined by 1,4,glycosidic bonds. Attached to this mannose chain are side chains of d-galactopyranose units. This side chain is joined to a primary alcohol group of a mannopyranose unit by a 1,6 glycosidic bond. The ratio of galactose to mannose seems to be determined by the frequency of galactose side chains in terms of mannopyranose units.

Tables I,II,III, and IV show some of the properties and composition of the gum. Its chemical and physical properties indicate that it should be classed with the starches, and cellulose, but because of its source and background it continues to be sold by gum merchants and classified by the trade along with vegetable gums.

PROPERTIES OF LOCUST BEAN GUM (8)	
Moisture	12.08%
Ash	2.78%
Solubility in water . . .	Complete
Reaction	Neutral
Preservative .	Phenol & derivatives
Fehling solution . . .	No reduction

TABLE I

COMPOSITION OF LOCUST BEAN GUM	
Galactan	29.18 %
Mannan	58.42 %
Pentosans	2.75 %
Nitrogen	0.83 %
Cellular Tissue	3.64 %
Ash	0.82 %

TABLE II

PROPERTIES OF AQUEOUS DISPERSIONS (8)	
Addhesion	Poor
Water Dispersability	4% solids usable.
Mineral acids	Decrease viscosity
Boric acid	Increase viscosity
Borax	" "
Caustic alkalies	" "
Tannin . . .	Increases viscosity, then precipitate forms which dissolves upon heating

TABLE III

VISCOSITIES OF LOCUST BEAN GUM SOLUTIONS (2)	
Concentration of gum	Viscosity (18-20 C.) in Sec.
0.00%	14
0.25%	20
0.50%	62
0.75%	500
1.00%	Very thick
5.00%	Solid

TABLE IV

Being an irreversible colloid when dispersed in water, this gum is very sensitive to heavy metal salts, which cause coagulation and precipitation in a concentrated solution of the gum. However, this may be avoided by adding other irreversible colloids such as glucose and glycerol. As indicated in table III, mineral acids and oxidizing agents lessen the viscosity of the dispersions while alkalies increase this property. However, alkalies and alkaline salts often result in a darkening of the product (8). The viscosities in table IV were prepared by letting the solutions of various concentrations, after being boiled and allowed to stand overnight, pass through a twenty-five ml. pipette (2). It can be seen from this table that a one per cent concentration of the gum gives a very thick solution, and a five per cent solution is practically solid. This makes it necessary to convert or partially degrade the gum to a suitable viscosity if one wants to use it at a four to five per cent concentration.

It was found(4) that an aqueous borax solution provided a suitable conversion medium. This procedure is an application of the property of mannogalactans to form a water insoluble gel in the presence of borax. In this case, the small particles of mucilage do not dissolve because each particle is presumably surrounded with a layer of the borax gel, thereby preventing the penetration of a sufficient amount of water to disperse the mucilage. Following the conversion reaction, the mucilage may be filtered off, washed with dilute borax solution, and dried. This gives a fine white product having a much lower viscosity than the original product.

THE USE OF LOCUST BEAN GUM IN PAPERMAKING

One of the steps in the manufacture of many papers is the beating of the pulp mixture which consists essentially of cellulose and water (3). Cellulose fibers, when treated this way, are said to become "hydrated," a term which does not indicate hydration in the chemical sense. The outstanding property of such beaten cellulose fibers is their ability to form strong addhesive bonds when dried in contact with one another.

Although paper made from beaten stock may be stronger, such paper shrinks more upon drying, becomes more dense, more translucent, less opaque, less compressible, and less oil receptive. These trends are to be avoided if a good printing paper is desired.

The further importance of beating is emphasized by the appreciable amounts of power required by the conventional beating and refining engines. Although beating and refining are necessary in many papermaking operations, these processes are costly and have certain disadvantages. For these reasons papermakers have long sought a means of "hydrating" cellulose fibers by chemical rather than mechanical methods. This means that a beater or headbox additive has been sought which will give the surface of relatively unbeaten cellulose fibers characteristics similar to those provided by mechanical beating.

Beside saving power, such an additive would conserve the natural fiber structure, and papers could be made which have high tearing strength as well as higher porosity, higher opacity, better formation, better compressibility for printing, lower hygroexpansivity, and less tendency to curl and cockle (6). In addition, treating pulps in this manner would make the fiber drain more rapidly, making faster machine speeds possible. Many of the above stated properties of paper are incompatible with high strength as developed by mechanical beating processes. (3) Furthermore, higher percentages of inert fillers and weak, short fibered filler pulps could be used if chemical "hydrating" agents are employed. This would conserve the increasingly scarce supply of long-fibered pulps.

It was found that locust bean gum possessed many of the desirable properties necessary to chemically "hydrate" cellulose fibers. Each fiber becomes coated with a film of highly swollen mucilage which gives the pulp many of the same characteristics as mechanical beating. It has been shown that the addition of such a small quantity of gum as 0.1 per cent, based on fiber weight, will give appreciable improvements in both sheet formation quality and strengh properties. Larger quantities of the gum bring about proportionally larger improvements in these strength properties, up to a certain point(3).

EFFECT OF LOCUST BEAN GUM ON PROPERTIES OF PAPER

One-half per cent of locust bean gum (based on weight of pulp) increased the bursting strength of a coniferous sulphite pulp beaten for fifteen minutes to that of a pulp beaten for 50 minutes. This represents a saving of 70 per cent of beating time and an increase in bursting strength of 32 percent over the original pulp. Similarly, one and five per cent additions of the gum gave 40 and 64 per cent increases in bursting strength respectively. According to Swanson (3), when gum is added to an unbeaten pulp, very little strength improvement is realized. It appears that beating is first necessary

to roughen the surface of the cellulose fibers in order to increase the surface area so that the gum can be adsorbed in sufficient amounts. Casey (7) claims that in order to realize an appreciable strength increase, the locust bean gum must be added before beating.

The addition of one per cent locust bean to pulp produced a tearing strength that was about 50 per cent less than handsheets prepared from pulp with no gum added, while 2 per cent of gum (based on dry weight pulp beaten 20 minutes) gave a 33 per cent increase in tensile trength, thereby producing tensile strength equal to those sheets prepared from pulps beaten forty to fifty minutes. (3)

The effect of the addition of 5 per cent of locust bean gum upon the relationship between bursting strength and apparent density is that the bursting strength properties of sheets having an apparent density of twelve may be equalled at an apparent density of 10.5 with a less highly beaten stock. This should provide a sheet having better printing properties and with less tendency to curl and cockle. Also, papers of high porosity and high strength can be produced by decreasing the mechanical beating and adding locust bean gum to obtain desired strength (3).

It was stated earlier in this paper that chemical "hydration" would permit higher machine speeds because of faster drainage while on the wire and better pulp deflocculation. A furnish prepared from a lightly beaten pulp with one per cent locust bean gum added has a freeness of 800 ml. and a burst equal to that of a mechanically beaten pulp having a freeness of 400 ml. Paper mill experience has already shown that the addition of 0.5 per cent to one per cent of mannogalactan gum to a practically unbeaten kraft furnish affords a ten per cent increase in machine speed with improved sheet properties from the standpoints of strength and increased porosity (3). Also, it is indicated that papers of lower hygroexpansivity or better dimensional stability

may be made by decreasing the mechanical beating and refining and adding locust bean gum.

It was found during early stages of study that locust bean gum possessed a marked fiber dispersing ability (7). In general, these gums have shown best results in furnishes containing little or no alum. However, the addition of fifteen per cent alum did not decrease the formation quality of the gum to a point as low as did the fiber alone. Locust bean gum also has an effect on opacity. By use of locust bean gum a sheet may be produced having an opacity of 62 per cent with a burst of 74, whereas a less highly refined pulp containing one per cent mannogalactan yields a sheet having a 70 per cent opacity. Similar improvements have been observed with kraft pulp (3).

Today, the paper industry is facing the problem of a decreasing supply of coniferous pulps. However, the large response of the coniferous pulps to the action of locust bean gum enables the papermaker to mix larger quantities of hardwood pulp with softwood pulp and, by means of the gum, maintain the same strength properties as coniferous pulp alone. For example, the percentage of hardwood pulp in a softwood-hardwood mixture can be increased from 10 per cent to 45 percent and the strength held constant by the addition of 3 per cent locust bean gum (based on weight of total furnish) (1).

REASONS FOR STRENGTH INCREASES DUE TO LOCUST BEAN GUM

It has been said (6) that the strength of a sheet of paper is primarily dependent upon four factors. These are: (1) the strength of the fibers, (2) the strength of the fiber bonds, (3) the number of bonds, (4) formation (distribution of fibers and bonds). To bring about increases in paper strength, one or more of these factors must be affected.

It has been demonstrated (6) that locust bean gum increases paper strength by improving formation, increasing the bonded area, and by increasing the bonding strength. The increase in bonding strength is seen to have the

greatest effect. The use of even 0.5 per cent of locust bean doubles the bonding strength. The increased bonding strength, in turn, may be due to one of several factors. If there is truly an increase in the strength of the individual bonds, then it is probable that this strength increase is brought about by the formation of bonds involving the gum molecules. Such bonds would be more flexible than bonds between two cellulose molecules which are ridgidly held in the crystalline structure of the fibers. However, it is to be pointed out that the strength properties do not continue to increase linearly with increasing bonding strength. It is felt (6) that at higher values of strength properties the strength of the individual fibers becomes much more important.

As would be expected from the theories of bonding, bursting strength and tensile strength are increased by an increase in the bonded area, whereas the tearing strength will decrease with increasing bonded area. This is in accordance with the theory of the tear test. The presence of a large number of bonds can decrease the tearing strength by causing a rupture of the fibers instead of by separation of the fibers intact. Elongation would appear to be almost independent of bonded area (6).

Burst and tensile also show increases with improved formation. This is to be expected because both tests are tests of the weakest parts of the paper. Higher values of elongation also appear to be obtained with papers having better formation. According to Casey (7), the improved formation is due to the fact that certain hydrophilic colloids, such as locust bean gum, act as a powerfull dispersing agent for pulp fibers. The most favorable effect being obtained when the gum is used in the absence of alum. Tearing strength appears to be a weaker function of formation due to the fact that tearing strength represents the average force to tear the sheet.

Thus it is shown that the improvements in the strength of a paper obtained with locust bean gum can be partially attributed to increases in bonded area,

increases in bonding strength and improved formation. The increases in strength properties have been estimated to be approximately as shown in table V (6).

STRENGTH INCREASES DUE TO	CONTRIBUTION (%)
Increased bonded area	15
Improved formation	25
Increased bonding strength	60
Increased fiber strength	0

TABLE V

Many suggestions have been made to explain the beneficial effect of beater adhesives such as locust bean gum. Musser and Engel (9) list increased swelling and actuation of fibrillation as possible reasons, while Horsey (10) and Rowland (11) proposed that the free hydroxyl groups on the adhesive promote additional bonding. Improvement of formation by deflocculation is also mentioned. Dixson (12) and Swanson (3) emphasize the importance of colloidal phenomena. Cobb (13) and Musser and Engel (9) proposed that the adhesive may improve fiber bonding by a cementing action. Some attribute the strength increase entirely to improved formation.

The water soluble mannogalactans of which locust bean gum is an example are not only excellent inter-fiber bonding agents, but rendered insoluble by means of a mild alkali such as calcium metaborate will produce a wet strength paper. This type of wet strength is particularly desirable in paper towels and certain tissues (14) (3) as it is only temporary (2). Moreover, the recovery and repulping of waste papers containing locust bean gum and borax present no technical problems (3).

Thus it can be seen that mannogalactan beater additives such as locust bean gum have a very prominent place in the paper industry, if they can be made to work at full efficiency. However, mill trials have shown that the strength increases in the paper containing the gum have not been as great as expected. As stated earlier, the object of this paper is to determine if alum or pH might be responsible for this ineffectual addition of the gum.

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The Influence of Locust Bean Gum on the Strength Characteristics of Handsheets Under Varying pH Conditions. A Study of the Effect of Alum or Hydrogen Ion Concentration.

EXPERIMENTAL PROCEDURE

It was decided to carry on the experimentation for this thesis in the following manner: The laboratory work was divided into two parts, the first of which consisted of adding varying amounts of alum and sodium aluminate to stock containing varying amounts of locust bean gum, cooked over a steam bath, at 200° F for 45 minutes at 1 per cent concentration, and recording the pH of each formulation. The second part consisted of duplicating the pH conditions obtained in Part I with sulphuric acid instead of alum and caustic soda in place of sodium aluminate. Handsheets of each formulation in Parts I and II were made and tested for bursting strength, tensile strength, tearing resistance, and ash content, thus providing a means for studying the effect of alumina and pH on the strength characteristics of handsheets containing locust bean gum.

PART I

The variables involved, as dictated by the thesis, were the per cent of locust bean gum added, the per cent alum and sodium aluminate added (all percentages based on fiber weight, a.d.) and the recorded pH at each formulation. The fixed conditions were the type of pulp used and the length of heating time.

The pulp for this work was an unbleached Canadian sulphite pulp and was beaten for fifteen minutes to a freeness of approximately 590 ml. (C. S. F.) at a consistency of 1.57 per cent.

Although locust bean gum can be added at both the beater and headbox under different pH conditions, it was decided that for this investigation only beater conditions would be used.

After the pulp was beaten at a consistency of 1.57 per cent for the desired time, thirty grams (a.d. pulp) were placed in a 3000 ml. beaker. Next, the desired amount of cooked locust bean gum was added, and the pulp-gum mixture was agitated for ten minutes. The desired quantity of alum or sodium aluminate was added at the end of this time and the mixture of pulp-gum-alum or aluminate was agitated for two minutes. At this point the pH was taken by means of a Beckman pH meter and recorded. The pulp was then put into the mixing box of a Noble & Wood sheet machine and handsheets were made, pressed, and dried, the drying being done on a steam heated rotary drier maintained at 250° F.

			PER CENT ADDITIVE				
		pH	0.0	0.1	0.25	0.5	1.0
Per Cent Sod. Alum.	5.0	9.7	1 Set	1 Set	1 Set	1 Set	1 Set
	2.5	9.4	1 Set	1 Set	1 Set	1 Set	1 Set
Blank	0.0	7.2	1 Set	1 Set	1 Set	1 Set	1 Set
Per Cent Alum	2.5	6.0	1 Set	1 Set	1 Set	1 Set	1 Set
	5.0	4.9	1 Set	1 Set	1 Set	1 Set	1 Set

TABLE VI

Table VI shows the varying amounts of alum, sodium aluminate, and locust bean gum used, with the resulting pH values. It can be seen from this table that there were twenty-five sets of handsheets made containing 0, 0.1, 0.25, 0.5, 1.0 per cent of locust bean gum in a stock containing 0, 2.5, 5.0 per cent alum (based on fibre weight a.d.); each set contained nine sheets, of which the six most representative were tested for bursting strength, tensile strength, and tearing resistance after conditioning at 73° F. and 50 per cent relative humidity for 24 hours.

PART II

In order to determine if the effects obtained in the experiment outlined in Part I were due to the alum or sodium aluminate or the pH resulting from the addition of these chemicals, it was decided to duplicate the pH conditions encountered in Part I by adjusting the acidity of the stock with sulphuric acid and the alkalinity with caustic soda. Twenty-five more sets of handsheets were made using the same pulp and the same varying amounts of gum at the same pH as in the first part. These sheets were produced by adding locust bean gum to the thirty grams of pulp (a.d.), and after agitating for ten minutes the pH was adjusted to the desired conditions by adding the sulphuric acid or caustic soda. These sheets, in turn, were tested for bursting strength, tensile strength, and tearing resistance the same as in part I.

RESULTS OF EXPERIMENTATION

Before describing the observed effects of alumina and pH on the strength characteristics of the handsheets containing locust bean gum, it is well to mention the results of ash tests taken on the handsheets. For these ash tests, it was decided to work with the sheets containing 0.0 per cent and 1.0 per cent gum and 2.5 and 5.0 per cent alum and sodium aluminate. Blank tests were also run with 0.0 and 1.0 per cent gum and no alum or sodium aluminate.

It was decided that any excessive quantities of ash found present in sheets would be due to precipitation of the calcium bicarbonate from the water used to make the sheets. From Table VII it is seen that there was no significant change in the tests of the zero or blank series, and the ash present is mainly pulp ash. If the other tests containing alum are compared with the blank or zero

series, it is noticed that all sets containing alum had a slightly increased ash, approximately 1.1 per cent, with no appreciable difference between 0.0 and 1.0 per cent locust bean gum, or 2.5 and 5.0 per cent alum. Likewise, all sheets containing sodium aluminate had an increased ash content, with higher aluminate yielding a higher ash. However, in this case, the higher percentage of locust bean gum seemed to result in a decreased ash content.

SAMPLE		% ASH
0.0 % Chem.	0.0 % Gum	0.57
0.0 % Chem.	1.0 % Gum	0. 63
2.5 % Alum	0.0 % Gum	0.93
2.5 % Alum	1.0 % Gum	1.00
5.0 % Alum	0.0 % Gum	1.22
5.0 % Alum	1.0 % Gum	1.21
2.5 % Aluminate	0.0% Gum	1.80
2.5 % Aluminate	1.0% Gum	1.68
5.0 % Aluminate	0.0% Gum	3.20
5.0 % Aluminate	1.0% Gum	2.20

TABLE VII

The maximum ash content found was 3.2 per cent and occurred in the sets containing 5.0 per cent sodium aluminate and 0.0 per cent locust bean gum. Knowing that ash remained in only limited quantities, it was decided to rule it out as a major contributing factor to any strength variations which might occur.

The first strength characteristic to be discussed in connection with the experimental work is bursting strength . From the graphs in figure 2, which are plots of absolute values, the following conclusions may be drawn.

There was a consistent increase in bursting strength due to the addition of higher quantities of locust bean gum. This increase was maintained throughout the entire pH range (4.9-9.7) and was always conspicuous with all concentrations of alum, aluminate, acid, and caustic.

The family of curves that were obtained were due to the presence of alum, aluminate, acid, and caustic which influenced the bursting strength found in the blank, or zero series tests.

Sheets made in the alkaline range with sodium aluminate or caustic soda at a pH of 9.4 or 9.7 were always weaker than the blank series, the weakest being the ones containing 2.5 per cent (50#/ton) and 5.0 per cent (100#/ton) sodium aluminate. Both series of sets containing caustic soda showed less loss in strength than the corresponding ones with sodium aluminate.

It was found that the smaller portion of alum, 2.5 per cent (50#/ton) resulting in a pH of 6.0 and the corresponding quantity of sulphuric acid yielding a pH of 6.0, improved the bursting strength consistently under the conditions of the experiment. This effect was noticed in the absence of locust bean gum as well as in the presence of it.

In the pH range of 4.9 where large quantities of alum were used, 5.0 per cent (100#/ton), the situation was different. In this case, the alum turned out to be slightly detrimental, whereas a corresponding quantity of sulphuric acid (pH 4.9) improved the strength of the sheet slightly and consistently.

At this point it is interesting to note the effect produced in the tensile strength of the handsheets tested for this experiment.

A study of the graphs in figure 3 results in the following observations.

The effect of sodium aluminate and caustic soda at pH values of 9.4 and 9.7 followed the pattern of bursting strength in every respect. That is, sheets made in the alkaline range with sodium aluminate and caustic soda were weaker than the blank series .

The smaller quantity of alum, 2.5 per cent (50#/ton), turned out to be beneficial. The degree of improvement was higher for alum than for sulphuric acid, an observation which was not in conformity with the findings for bursting strength.

At a pH of 4.9 the observations were quite inconsistent in the presence of sulphuric acid, whereas a small increase in tensile strength over the blank test was observed in the presence of 100#/ton (5.0 per cent) of alum.

In studying the graphs in figure 4, of the tearing resistance of the handsheets, the following conclusions were reached.

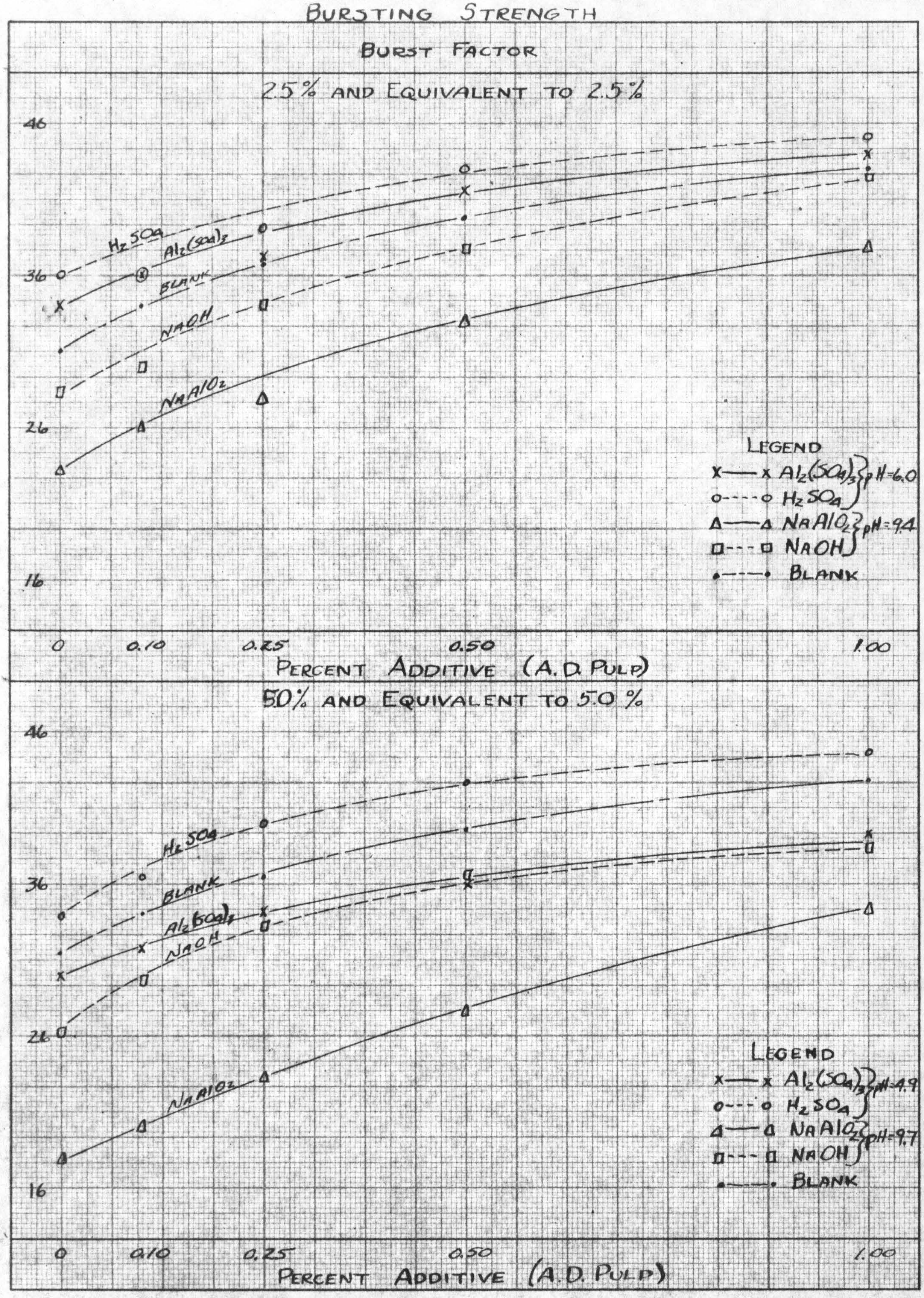
Adding locust bean gum resulted in a definite but moderate decrease in the tearing resistance in the case of the blank sets run without adding acid or alkaline chemicals.

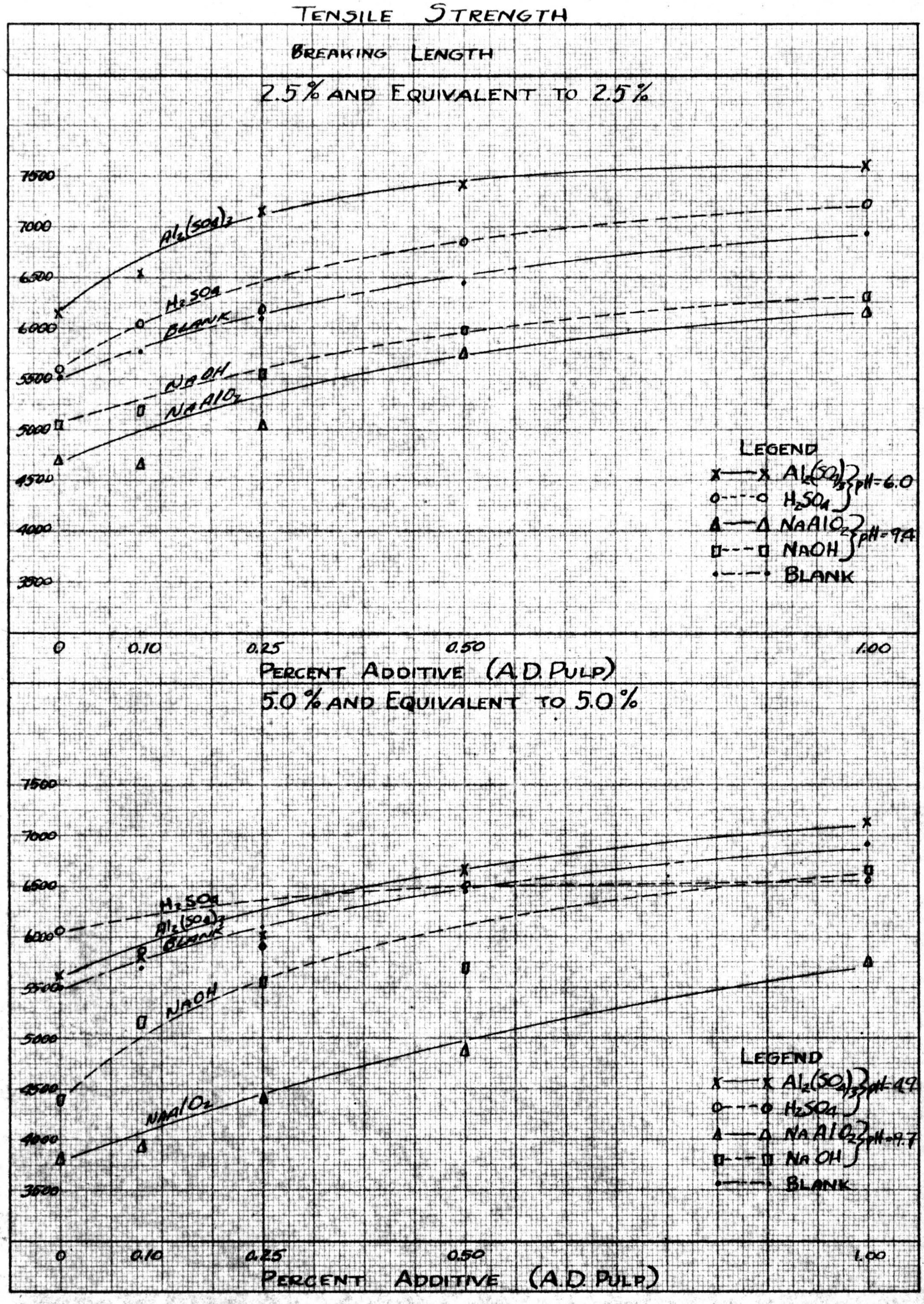
The relative position of the tear curves for sets containing alkaline and acid chemicals followed as expected, inversely, the pattern set by bursting strength and breaking length. That is, a larger quantity of locust bean gum in the presence of alum, sulphuric acid, sodium aluminate, and caustic soda, showed a greater decrease in the tearing resistance.

In the case of the sheets formed in the presence of 2.5 per cent sodium aluminate (pH 9.4), the results were not sufficiently consistent to permit the plotting of a smooth curve which would fit into the family of curves established by the results of the experiment.

SUMMARY

To briefly summarize the results of this study, it can be said that under the conditions of this experiment locust bean gum consistently improved the sheets in all cases. It helped remedy strength losses caused by excessive alkalinity due to the addition of sodium aluminate or caustic, and was equally effective in the acid range where it helped remedy the effect of excessive quantities of alum, added under the experimental conditions.


BURSTING STRENGTH
BURST FACTOR
2.5% AND EQUIVALENT TO 2.5%
46
36
26
16
H2SO4
Al2(SO4)3
BLANK
NaOH
NaAlO2
LEGEND
x—x Al2(SO4)3 } pH=6.0
o----o H2SO4
Δ—Δ NaAlO2 } pH=9.4
□---□ NaOH
•---• BLANK
0
0.10
0.25
0.50
1.00
PERCENT ADDITIVE (A.D. PULP)
5.0% AND EQUIVALENT TO 5.0%
46
36
26
16
H2SO4
BLANK
Al2(SO4)3
NaOH
NaAlO2
LEGEND
x—x Al2(SO4)3 } pH=4.9
o----o H2SO4
Δ—Δ NaAlO2 } pH=9.7
□---□ NaOH
•---• BLANK
0
0.10
0.25
0.50
1.00
PERCENT ADDITIVE (A.D. PULP)



TENSILE STRENGTH
BREAKING LENGTH
2.5% AND EQUIVALENT TO 2.5%
7500
7000
6500
6000
5500
5000
4500
4000
3500
Al2(SO4)3
H2SO4
BLANK
NaOH
NaAlO2
LEGEND
Al2(SO4)3 pH-6.0
H2SO4
NaAlO2 pH-9.4
NaOH
BLANK
0
0.10
0.25
0.50
1.00
PERCENT ADDITIVE (A.D. PULP)
5.0% AND EQUIVALENT TO 5.0%
7500
7000
6500
6000
5500
5000
4500
4000
3500
H2SO4
Al2(SO4)3
BLANK
NaOH
NaAlO2
LEGEND
Al2(SO4)3 pH-4.9
H2SO4
NaAlO2 pH-9.7
NaOH
BLANK
0
0.10
0.25
0.50
1.00
PERCENT ADDITIVE (A.D. PULP)

FIGURE IV

TEARING RESISTANCE