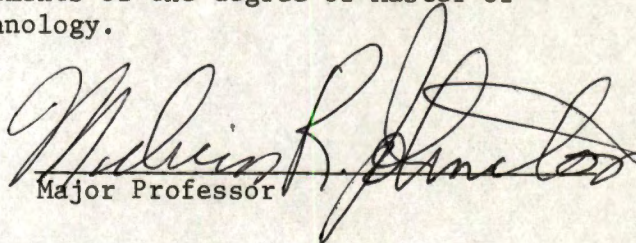


July 29, 1970

To the Graduate Council:

I am submitting herewith a thesis written by José Roberto Gutiérrez entitled "Rheological Properties of Tomato Catsup." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements of the degree of Master of Science, with a major in Food Technology.

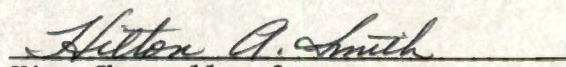

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RHEOLOGICAL PROPERTIES OF TOMATO CATSUP

A Thesis

Presented to

the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by

José Roberto Gutiérrez

August 1970

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ABSTRACT

The objectives of this investigation was to determine the effect of certain compositional factors such as total solids content and alcohol-insoluble solids, and the effect of some physical factors such as particle size distribution and shear rate on the consistency of catsup.

In this investigation, four different brands of catsup were examined, and three treatments were used. The treatments used were:

1. Catsup plus 5 percent by weight of water added.
2. Catsup plus 10 percent by weight of water added.
3. Catsup plus 15 percent by weight of water added.

The control used was pure catsup, without any amount of water added. Each treatment was replicated three times. The percentage of total solids, percentage of alcohol-insoluble solids, particle size, particle concentration, specific gravity and consistency of each sample were measured.

Under the condition of this experiment, the following results were found:

1. As the particle size is enlarged, keeping all other variables constant, the consistency of catsup increases.
2. As the particle concentration is increased, keeping all other variables constant, the consistency of catsup also increases.
3. As solids (both total and alcohol-insoluble) are increased, keeping all other variables constant, the consistency of catsup increases.

4. As the shear rate increases, keeping all other variables constant, the consistency of catsup decreases.



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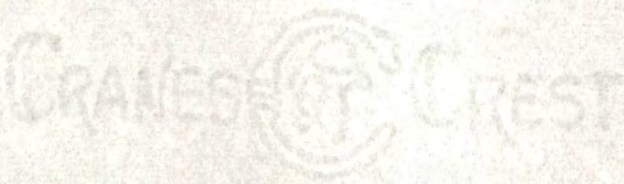
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CHAPTER I

INTRODUCTION

Catsup is the favorite condiment in the United States with an annual per capita consumption of about 3.1 pounds. Ketchup, catsup or catchup is the clean product made from properly prepared strained tomatoes with spices, salt, sugar and vinegar with or without onions and garlic and contains not less than 12 percent of solids (25).¹ Catsup may be prepared from cycloned juice or from canned pulp; however, the most common practice is to prepare it from fresh tomatoes so that it can be manufactured in a single operation during the growing season. Less color is lost due to less heat exposure of catsup when it is prepared in a single operation.

Consistency, which generally refers to the viscosity of the product and the tendency to hold its liquid portion in suspension, is a factor of primary concern in determining the quality of catsup. Consistency accounts for 25 percent of the factors of quality used in grading catsup. The other factors, color, absence of defects and flavor, account for the remaining 75 percent of the total score (38).

The importance of the study of rheology of foodstuffs is the gaining of an understanding of the principles underlying their behavior under the influence of applied stresses. The rheological properties of

¹The numbers in parenthesis represent similarly numbered references in the Bibliography.

a suspension cannot be fully understood by consistency measurements at constant shearing rate. Rheology has been defined as "the science devoted to the study of deformation and flow of matter." Therefore, when forces result in deformation and flow, the mechanical properties are referred to as rheological properties or behavior of a semi-solid fluid and is expressed in terms of three parameters: force, deformation and time.

The purpose of this investigation was to find the relationship between fluidity and such factors as total solids content, alcohol-insoluble solids, particle size distribution, and the effect of shear rate on the apparent viscosity of catsup.

CHAPTER II

REVIEW OF LITERATURE

I. INTRODUCTION

Viscosity or consistency is an appearance factor of great importance with such foods as catsup, fruit purees, jams, oils, syrups, et al. Measurement of this quality factor may be made not only to indicate the consistency of the finished product, but also as a quality control tool on the raw products, or on the product at various stages of the process, for predicting final consistency (18).

II. METHODS OF MANUFACTURE

Tomatoes, which are the major ingredient in the manufacture of catsup, contain 7 to 8.5 percent total solids of which 1 percent is due to skins, and seeds. The strained tomatoes obtained by cycloning ordinarily have the following composition (25):

Insoluble Solids - 1 percent.

Sugar (practically all invert sugar) - 2 to 3 percent.

Acid (calculated as citric) - 0.3 to 0.5 percent.

Soluble Protein - 0.8 to 1.2 percent.

Mineral Constituents - 0.3 to 0.6 percent.

Salt (sodium chloride) - 0.05 to 0.1 percent.

The percentage of solids in tomatoes varies. This may be due to part to the variety of the tomato, character of the soil and amount of rainfall during the growing and harvesting season.

Inasmuch as tomato products, such as pulp catsup, are evaporated to a definite specific gravity, consistency or solids content, the yield per ton of tomatoes varies with the composition of raw tomatoes used. The yield is also influenced by the equipment and adjustment of the cyclone and the details of its operation.

Catsup is a more highly concentrated product than puree. The tomatoes used in the manufacture of catsup are usually high quality tomatoes; they are sorted carefully and the requirements for such tomatoes are usually similar to the requirements for U. S. No. 1 (5). The tomatoes are then washed and crushed or cut by machine. Heating to at least 190 F in a continuous heat exchanger is advisable in order to inactivate pectic enzymes that would otherwise destroy the pectin and reduce the consistency of the catsup (5). The next step is pulping, which is accomplished by a machine commonly known as a "cyclone" or pulper. This machine usually consists of a heavy money or stainless-steel perforated sheet in the form of a half-cylinder which forms the lower half of its cylinder. The upper half of the cylinder is made of heavy sheet metal. Monel metal paddles revolve at a high rate of speed within the cylinder. The tomatoes are broken by the impact of the paddles or by the impact received when thrown against the walls of the pulper. The pulp and juice pass through the screen into the tank, and the skins, seeds and fibers pass through an opening at the lower end of the pulper. The

pulped product is passed through a finisher to give it a smooth texture. The pulp is then concentrated to about 1.060 specific gravity by boiling in an open tank or by evaporating in vacuum pans. At this stage, the product is ready to mix with other ingredients and final cooking. The usual ingredients are salt, sugar, vinegar, onion powder and certain spices (5, 25). The cooking process is continued to the desired consistency. Finally the catsup is bottled and sealed at 180 F (25).

III. THE CONCEPT OF VISCOSITY

Viscosity is that property of all real fluids which distinguishes them from ideal (nonviscous) fluids. The viscosity of a fluid is a measure of its resistance to flow. This resistance is measured as a total shear force.

For many years, the motion of fluids has been treated under various specialized headings such as hydraulics, aeronautics and acoustics with the result that many engineers have failed to understand some of the underlying principles for describing both Newtonian and non-Newtonian flow phenomena (14). As now known, consideration of fluid motion is not strictly confined to external forces, but also to internal forces such as those caused by viscosity. All existing fluids are known to exhibit this physical property, which is related to existing tangential shearing stresses within the fluid.

Before continuing with the discussion of this physical property of fluids, it is necessary to classify fluids according to their response to external forces (stresses). Wilkinson (44) classified them into two

groups, Newtonian and non-Newtonian. He subdivided the non-Newtonian group into three subdivisions:

1. Fluids for which the shear stress depends only on the shear rate, and although the relationship between them is nonlinear, it is independent of the time of application of the shear stress.

2. Fluids for which the shear stress depends not only upon the shear rate, but also upon the time the fluid has been sheared or upon its previous history.

3. Viscoelastic fluids, which exhibit characteristics of both elastic solids and viscous fluids.

Another well-known classification is that of Metzner (26). He classified fluids into four general categories:

1. Purely viscous fluids. These include Newtonian fluids and non-Newtonian fluids for which the shear stress depends only upon shear rate and is independent of time.

For Newtonian fluids:

$$\tau = \mu \left(\frac{du}{dy} \right)$$

where

τ = the force per unit area or shear stress;

μ = a constant known as the coefficient of viscosity.

$\left(\frac{du}{dy} \right)$ Shear rate, velocity gradient or the change of velocity with respect to the distance between the planes of liquid.

For non-Newtonian fluids included in this category, a number of equations have been developed to describe their behavior. Among these

equations the better known are;

The power-law equation:

$$\tau = K \left(\frac{du}{dy} \right)^n$$

where "K" is a consistency index and "n" is a flow behavior index.

The Bingham equation:

$$\tau = \tau_1 + \mu_B \left(\frac{du}{dy} \right)$$

which describes those fluids that act as solids when submitted to shear stresses lower than τ_1 .

The Ellis equation:

$$\left(\frac{du}{dy} \right) = \frac{\tau_1}{\mu_0} + \left(\frac{\tau}{K} \right)^{1/n}$$

which corrects for the inaccuracy of the power-law equation at low shear rates.

2. Time-dependent fluids. Fluids for which the apparent viscosity decreases with time under a constant shear rate are called thixotropic; those for which the apparent viscosity increases with time are called rheopectic.

3. Viscoelastic fluids. Materials which exhibit characteristics of both elastic solids and viscous fluids.

4. More complex rheological systems. These are systems that exhibit characteristics of all three types 1, 2 and 3. (See Figure 1.)

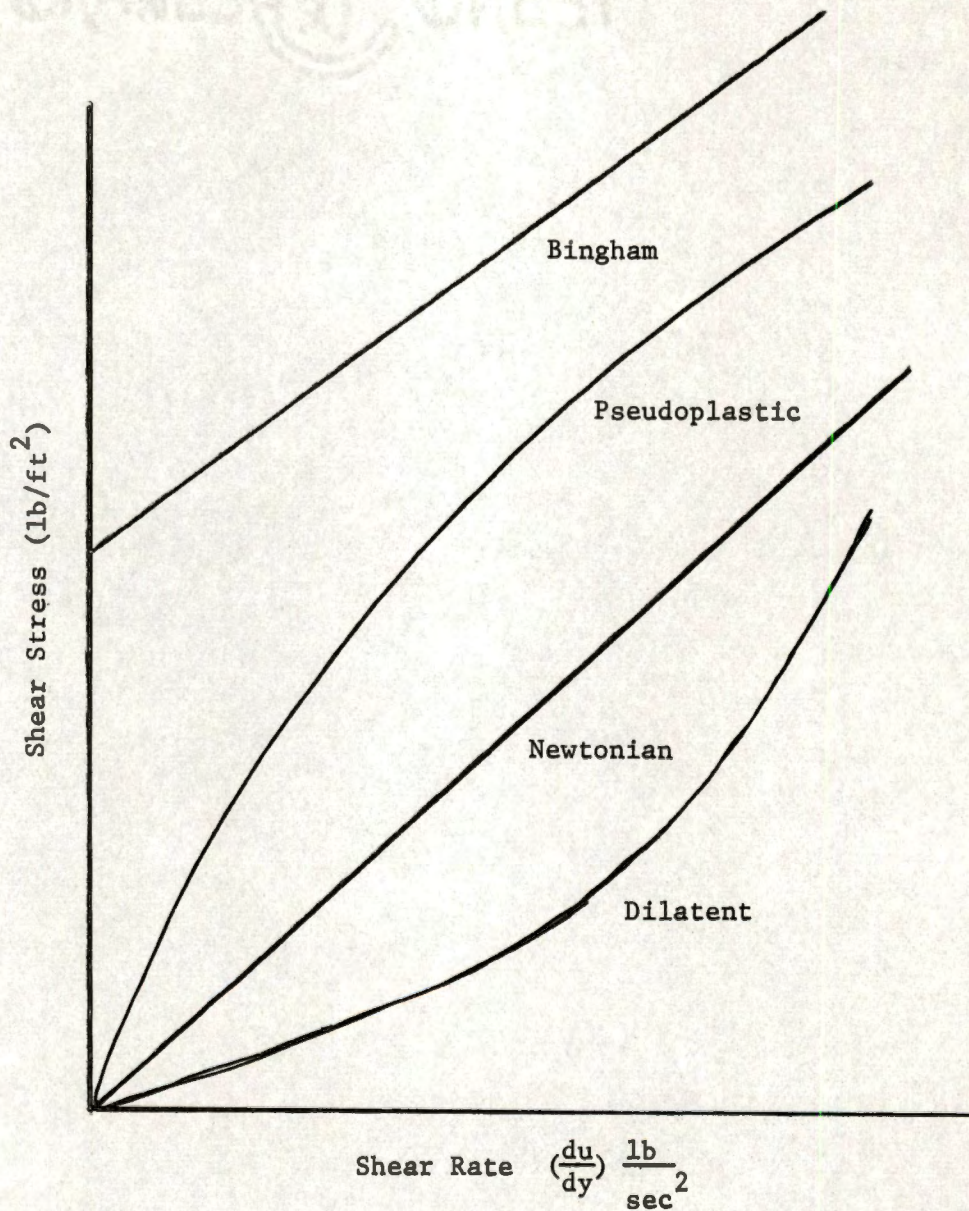


Figure 1. Viscous behavior of fluids.

Catsup may be classified as a diphasic suspension system; wherein a high proportion of suspended solid particles are dispersed in a serum, which within itself, is a colloidal system. Catsup is a thixotropic system because its shear stress is time dependent. At constant shear rate, the apparent viscosity of catsup decreases with time. With such complexity, many chemical and physical properties may be expected to influence consistency (19).

IV. PROPERTIES AFFECTING CONSISTENCY

Among the compositional factors affecting the consistency of catsup, the most important are solids and pectic substances. In a study by Kramer and Twigg (19), it was found that pH had a negative relationship with consistency, and that pectic substances, structural solids and nonstructural solids had a positive relationship with consistency. In this study it was also found that pectic substances had a greater influence on consistency than any other factor. It is obvious that no one component is totally responsible for the consistency of catsup, and that consistency cannot be explained or understood on the basis of a single component; moreover, the real effect of a single component on the consistency cannot be measured due to the interdependency existing among all factors that affect that property.

Consistency and the tendency of catsup to hold its liquid portion in suspension are evaluated under the single heading of consistency in the U. S. standards for grading catsup. It has been implied that these

two factors are not necessarily related, i.e., thick or thin catsups may have either high or low degree of serum separation (20).

The effect of pH on consistency of tomato products is a useful tool in controlling the consistency of these products. It has been postulated that the increase in consistency of catsup with decrease in pH results from increases in consistency of the low ester pectic substances dissolved in catsup. Tomatoes can be processed to the desired consistency--thin juice or firm gell, and practically any product between these extremes--by adjusting the acidity when the tomatoes are crushed. Wagner and Miers (39) have developed and refined the controlled acidity technique for this purpose. It gives better control over a wider range of product consistency than the heat treatment now used in commercial processing plants.

Low methoxyl pectic substances have been found in tomato products (19). Schultz, et al. (32) found that enzymatically deesterified pectinic acid reacted with pH more like low methoxyl pectic acid than the pectinic acid deesterified by the action of acid or alkali. They explained this fact by hypothesizing that esterase deesterifies entire portions of the galacturonide chain, while acid or alkali acts in a random manner. With the presence of such pectic constituents, the proposed reaction is possible since the pH of catsup is within the necessary range.

The preheat temperature of the tomatoes is very important in tomato puree, catsup and other concentrates. Heat inactivates pectin-esterase (PE) and polygalacturonase (PG) enzymes present in fresh tomatoes that affect consistency of tomato products. To obtain inactivation,

it is the common practice in the processing industry to heat the tomatoes to 190 F or higher before, during or immediately after the chopping or crushing operation (39).

CHAPTER III

MATERIALS AND METHODS

I. MATERIALS

Four different brands of commercially prepared catsup were examined during this investigation. They had been packed in commercial No. 10 cans at four different locations. Previous to their examination, they had been stored at room temperature for about two months. Each can contained approximately seven pounds and two ounces of catsup.

II. EQUIPMENT

The following apparatus were used in this investigation:

Bostwick Consistometer. This instrument is frequently used to measure consistency of flowable foods, such as catsup, tomato paste and purees. The sample is held in one end of the metal trough, fixed in a horizontal plane by a vertical gate. The gate is withdrawn rapidly and the sample flows under its own weight along the trough. The distance traveled in a prescribed time is a measure of consistency.

Adams Consistometer. This instrument uses the same flow principle as the Bostwick consistometer. The only difference is that in the Adams consistometer the flow pattern is circular rather than linear in a trough as in the Bostwick.

Brookfield Synchro-Lectric Viscometer. This viscometer rotates a cylinder or a disc in a fluid and measures the torque necessary to

overcome the resistance to the induced movement. This is accomplished by driving the immersed element, which is called "spindle," through a beryllium copper spring. The degree to which the spring is wound indicated by the position of a pointer in the viscometer's dial, is proportional to the viscosity of the fluid. The viscometer is applicable over a wide range of viscosities.

The Abbe Refractometer. The Abbe Refractometer utilizes the principle of reflected light from a mirror passing into an illuminating prism, the upper surface of which is rough ground. This rough surface acts as a source of an indefinite number of rays which pass through the layer of liquid in all directions. The rays then strike the surface of a polished prism and are refracted (for both prisms and the refractive indices is 1.75). This instrument permits the determination of a wide range of refractive indices (1.3000 to 1.7000). The refractive index can be read quickly and easily to an accuracy of 0.0002. The refractive index or the percent solids can be read directly from the scale.

III. METHOD OF PREPARATION

Preliminary work pointed out that the use of 1000 ml. beakers was advisable when determining consistency with the Brookfield Synchronic Electric Viscometer because they reduced the walls' shear stress and that mechanical mixing at high speed induced the formation of bubbles when mixing catsup and water. Another fact observed from the preliminary work was that in making readings with both the Adams Consistometer and the Bostwick Consistometer, it was advisable to let the catsup set for at

least ten minutes in order to enable entrapped air to escape and to let the sample level itself by its own weight.

IV. TREATMENTS

Control. Eight hundred gms. of catsup was weighted into a 1000 ml. beaker. They were allowed to set for thirty minutes at room temperature.

Treatment I. Seven hundred sixty-five gms. of catsup was weighted into a 1000 ml. beaker. Thirty-eight gms. (5 percent w/w) of distilled water was added to the catsup. The sample was gently stirred, using a large spoon, for ten minutes and finally was allowed to set at room temperature for thirty minutes.

Treatment II. Seven hundred thirty gms. of catsup was weighted into a 1000 ml. beaker. Seventy-three gms. (10 percent w/w) of distilled water was added to this catsup and were mixed by stirring with a spoon for ten minutes. The mixture was then allowed to set at room temperature for thirty minutes.

Treatment III. Six hundred ninety-five gms. of catsup was weighted into a 1000 ml. beaker. One hundred four (15 percent w/w) of distilled water was added and mixed by stirring with a spoon for ten minutes. The mixture was then allowed to set at room temperature for thirty minutes.

V. METHODS OF ANALYSIS

Soluble Solids Content

The percent soluble solids was ascertained from readings obtained with the Abbe Refractometer using the Brix scale. A drop of the sample

was placed between the two prisms. Light from a lamp was passed through the sample and a reading was obtained from the Brix scale when the angle of incidence had been increased enough to make the angle of refraction 90° (25).

Alcohol Insoluble Solids

In determining the alcohol insoluble solids content, the A.O.A.C. method was used (1, 25). A 20 gm. aliquot of catsup was weighted into a 600 ml. beaker. Three hundred ml. of 80 percent ethyl alcohol were added to the sample. The mixture was then heated and boiled for thirty minutes and filtered through a Buchner's funnel using filter paper No. 1, which had been previously heated in an oven at 100 C for thirty minutes and weighted. The weight of the paper was recorded. After filtering, the filtrate and paper were placed in an oven at 100 C for two hours. After this period, they were weighted and the percentage of insoluble solids was calculated using the following formula:

$$\text{Percent insoluble solids} = \frac{\text{weight of the filtrate}}{\text{weight of the sample}} \times 100.$$

Specific Gravity

The specific gravity was determined by using the refractometer's method (25). From the percent of total solids, the specific gravity of the sample was obtained by referring to Schoenrock's tables (25).

Particle Size and Particle Concentration

Particle size distribution was studied under the microscope using the high power lens with a magnification of 440 times their real size.

The concentration of the particles was estimated by counting those particles whose diameters exceeded one-fourth of the radius of the field being observed. Ten fields were observed for each sample and the average was recorded. The average size in microns was estimated and recorded.

Consistency

The consistency was studied using three different consistometers.

Adams Consistometer. The Adams Consistometer was used in the standard manner (25, 37). The cup of the Adams was filled with the sample being analyzed. The sample was allowed to set for ten minutes. The cup was released rapidly and the sample allowed to flow for ten seconds. The average distance flow was obtained and recorded.

Bostwick Consistometer. The Bostwick Consistometer was also used in its standard manner (25, 37). The cup of the consistometer was filled with the sample. The sample was allowed to set for ten minutes. The gate was then lifted rapidly and the fluid allowed to flow. A reading was obtained after ten seconds of flow and recorded.

Brookfield Synchro-Lectric Viscometer. One thousand ml. beakers containing 780 gms. of the sample were analyzed with the Brookfield Viscometer. The spindle of the viscometer was immersed into the fluid. The shear rate was varied by changing the speed and the thickness of the spindle. Readings were taken with two spindles No. 3 and No. 4 and at four different speeds--6, 12, 30 and 60 revolutions per minute. The

readings were recorded when the pointer in the scale of the viscometer fixed in the scale for at least five revolutions.

Statistical Analysis

All data were analyzed by the analysis of variance method using the ANOVAR computer program modified by The University of Tennessee Computing Center. Significant difference between means were determined by using Duncan's Multiple Range Test. All treatments were replicated three times. The correlation analysis was done by using the BMD Program of Correlation and Transgeneration.



CHAPTER IV

RESULTS AND DISCUSSION

I. SOLUBLE SOLIDS

The soluble solids content for the control and treatments are shown in Table I. It can be seen that there was significant variation in the soluble solids content among brands, but not within a brand. Since consistency was the principal factor of concern in this investigation, the consistency of the different brands of catsup at different dilutions (different contents of solids) is shown in Table II. The soluble solids content was controlled within a brand, but it was not controlled among brands.

Approximately one-half of the total solids present in whole tomato cycloned juice is sugar, since sugar is added to the cycloned juice in manufacturing catsup. Most of the soluble solids present in catsup are sugar. The ratio of total solids to insoluble solids in cycloned juice is fairly constant, likewise the ratio of sugar to acid.

The amount of onions, salt and spices for the same volume of catsup are always the same (for each brand). The proportion of sugar and acid in the raw stock used may vary somewhat in different varieties of tomatoes. Slight changes in the amounts of added sugar and vinegar in the batch formula may be necessary from time to time. It is necessary

TABLE I
SOLUBLE SOLIDS CONTENT OF THE CONTROL AND TREATMENTS
WITH THEIR RESPECTIVE REPLICATIONS

Replication	Treatments			
	C	T1	T2	T3
	Degree Brix			
Brand "A"				
1	37.13	35.22	33.52	32.25
2	37.16	35.14	33.50	32.26
3	37.14	35.18	33.50	32.22
4	37.09	35.14	33.54	32.28
Mean	37.13	35.17	33.51	32.35
Brand "B"				
1	33.84	32.16	30.82	29.47
2	33.86	32.32	30.83	29.43
3	33.83	32.21	30.74	29.44
4	33.86	32.22	30.76	29.43
Mean	33.85	32.22	30.79	29.44
Brand C				
1	34.59	33.10	31.44	29.99
2	34.63	33.13	31.45	29.94
3	34.67	33.14	31.40	29.97
4	34.63	33.10	31.44	29.94
Mean	34.63	33.11	31.43	29.96

TABLE I (continued)

Replication	Treatments			
	C	T1 Degree Brix	T2	T3
Brand D				
1	32.61	31.06	29.63	28.42
2	32.64	31.06	29.67	28.46
3	32.60	31.12	29.64	28.46
4	32.63	31.09	29.67	28.50
Mean	32.62	31.08	29.65	28.46

Note: C = Control (pure catsup); T1 = Treatment I (catsup plus 5 percent w/w of water); T2 = Treatment II (catsup plus 10 percent w/w of water); T3 = Treatment III (catsup plus 15 percent w/w of water).

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TABLE II
CONSISTENCY OF CATSUP AT DIFFERENT SOLUBLE SOLIDS CONTENT

Soluble Solids Degree Brox	Consistency		
	Adams cms.	Bostwick cms.	Brookfield sp4-6rpm poises
Brand "A"			
37.13	9.32	4.42	541.62
35.17	10.29	4.88	473.37
33.51	10.49	5.21	327.75
32.25	12.49	5.71	265.37
Brand "B"			
33.85	9.95	6.20	275.62
32.22	11.21	6.80	255.25
30.79	12.44	7.41	192.12
29.44	13.83	7.80	122.25
Brand "C"			
34.63	12.11	6.27	308.50
33.11	13.43	7.32	235.00
31.43	14.85	8.11	135.37
29.96	16.21	8.68	125.37
Brand "D"			
32.62	11.06	5.97	255.75
31.08	12.62	6.80	184.25
29.65	14.04	7.77	122.62
28.46	15.04	8.02	77.35

Note: Soluble Solids--degree Brix; Adams--cms. flown in ten seconds; Bostwick--cms. flown in ten seconds; Brookfield--poises.

to have a high concentration of total solids in the final product so that it will keep after being opened for the consumer's use.

The summary of the analysis of variance of the results of soluble solids content for all brands, dilutions and their interaction are shown in Table III. Highly significant differences were noted in brand dilution and their interaction. The results of Duncan's Multiple Range Test, as shown in Table IV, indicated that the soluble solids content of brand "A" were significantly higher than all other brands at the 0.01 level of probability. The differences in treatments (dilutions) are shown by the results of the Duncan's Multiple Range Test in Table V.

II. ALCOHOL INSOLUBLE SOLIDS

The alcohol insoluble solids content of all brands and treatments, expressed as w/w percentage is shown in Table VI. It can be seen that the ratio of total solids to insoluble solids remains approximately constant. The variation of insoluble solids content from brand to brand is very small and practically none within brand. The difference of insoluble solids content from brand to brand is partially due to different formulas used by the processors and to the different varieties of tomatoes used in the manufacture of catsup.

Since the primary concern of this investigation was to observe the effect of certain variables such as soluble solids, alcohol insoluble solids and particles size distribution on the consistency of catsup, the consistency of catsup at different contents of alcohol insoluble solids is shown in Table VII.

TABLE III
SUMMARY OF A O V FOR THE EFFECT OF BRANDS ON SOLUBLE SOLIDS

Source	D. F.	M. S.	F-Ratio
Brand	3	190.153	94989.625 ^a
Dilution	3	246.380	123077.688
B x D	9	0.368	183.713
Error	240	0.002	

^aStatistical significance at 0.001 level of probability.

TABLE IV
RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT
OF BRAND ON THE SOLUBLE SOLIDS CONTENT

Brand		Mean		Significance
Large	Small	Large	Small	
1	3	34.526	32.290	a
1	2	34.526	31.577	a
1	4	34.526	30.437	a
3	2	32.290	31.577	a
3	4	32.290	30.437	a
2	4	31.577	30.437	a

^aStatistical significance at 0.01 level of probability.

Note: Brand A = 1; Brand B = 2; Brand C = 3; Brand D = 4.

TABLE V
RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT
OF DILUTION ON THE SOLUBLE SOLIDS CONTENT

Dilution		Mean		Significance
Large	Small	Large	Small	
1	2	34.560	32.883	a
1	3	34.560	31.340	a
1	4	34.560	30.023	a
2	3	32.883	31.340	a
2	4	32.883	30.023	a
3	4	31.340	30.023	a

^aStatistical significance at 0.01 level of probability.

Note: Nondiluted catsup = 1; 5 percent diluted = 2; 10 percent diluted = 3; 15 percent diluted = 4.

TABLE VI

ALCOHOL INSOLUBLE SOLIDS CONTENT OF THE CONTROL AND TREATMENTS
WITH THEIR RESPECTIVE REPLICATIONS

Replication	Treatment			
	C	T1	T2	T3
Percentage				
Brand "A"				
1	4.22	4.02	3.81	3.68
2	4.19	4.03	3.83	3.67
3	4.20	4.02	3.86	3.63
4	4.22	4.04	3.82	3.65
Mean	4.21	4.03	3.83	3.66
Brand "B"				
1	3.83	3.62	3.40	3.30
2	3.84	3.63	3.43	3.28
3	3.83	3.62	3.42	3.25
4	3.87	3.63	3.43	3.22
Mean	3.83	3.62	3.42	3.26
Brand "C"				
1	3.14	3.02	2.86	2.75
2	3.16	3.04	2.85	2.74
3	3.17	3.04	2.81	2.74
4	3.15	3.03	2.84	2.74
Mean	3.15	3.03	2.84	2.74

TABLE VI (continued)

Replication	Treatment			
	C	T1	T2	T3
	Percentage			
	Brand "D"			
1	3.26	3.11	2.97	2.75
2	3.26	3.11	2.97	2.77
3	3.22	3.12	2.95	2.73
4	3.24	3.13	2.94	2.75
Mean	3.24	3.12	2.96	2.75

TABLE VII
CONSISTENCY OF CATSUP AT DIFFERENT CONTENTS OF
ALCOHOL INSOLUBLE SOLIDS

Insoluble Solids Percentage	Adams cms.	Bostwick cms.	Brookfield sp4-6 rpm poises
Brand "A"			
4.19	9.32	4.42	541.62
4.02	10.29	4.88	473.37
3.83	10.49	5.21	327.75
3.65	12.49	5.71	265.37
Brand "B"			
3.85	9.95	6.20	275.62
3.63	11.21	6.80	255.25
3.42	11.44	7.41	192.12
3.26	13.83	7.80	122.25
Brand "C"			
3.45	12.11	6.27	308.50
3.29	13.43	7.32	235.00
3.10	14.85	8.11	135.37
3.00	16.21	8.68	125.37
Brand "D"			
3.24	11.06	5.97	255.75
3.11	12.62	6.80	184.25
2.96	14.04	7.77	122.62
2.75	15.04	8.02	77.35

Note: Insoluble Solids--w/w percentage; Adams--cms. flown in ten seconds; Bostwick--cms. flown in ten seconds; Brookfield--poises.

The summary of analysis of variance of the result of alcohol insoluble solids content for control and treatments are tabulated in Table VIII. Very little difference between brands, treatment and their interaction was indicated. Therefore, the Duncan's Multiple Range Test was not conducted.

III. SPECIFIC GRAVITY

The specific gravity for all brands and treatments and control with their respective replications are shown in Table IX. As it can be seen from this table, the agreement of measurements is good and there is difference from brand to brand but none within brands.

The summary for the analysis of variance of the results of specific gravity for brand, treatments and their interaction is shown in Table X. Highly significant differences were noted in brand, dilution and the interaction of brand and dilution. The results of Duncan's Multiple Range Tests, as shown in Tables XI and XII indicated that there was significant differences at 0.01 level of probability for brand and dilution, respectively.

IV. PARTICLES SIZE DISTRIBUTION

The concentration of particles expressed in number of particles per field is shown in Table XIII, and the effect of particle concentration on the consistency of catsup is shown in Table XIV.

The particle size expressed as the average of ten fields observed under the microscope with the high power lens with a magnification of

TABLE VIII
SUMMARY OF A O V FOR THE EFFECT OF BRAND ON THE
ALCOHOL INSOLUBLE SOLIDS

Source	D.F.	M.S.	F-Ratio
Brand	3	4.073	1.110 ^a
Dilution	3	4.620	1.259
B x D	9	3.688	1.005
Error	176	3.669	

^aStatistical significance at 0.1 level of probability.

TABLE IX

SPECIFIC GRAVITY OF THE CONTROL AND TREATMENTS WITH THEIR
RESPECTIVE REPLICATION

Replication	Treatments			
	C	T1	T2	T3
	(gm/ml)			
	Brand "A"			
1	1.17	1.16	1.15	1.14
2	1.16	1.16	1.15	1.14
3	1.17	1.16	1.15	1.14
4	1.17	1.16	1.15	1.14
Mean	1.17	1.16	1.15	1.14
	Brand "B"			
1	1.15	1.14	1.14	1.13
2	1.15	1.14	1.14	1.13
3	1.15	1.14	1.14	1.13
4	1.15	1.14	1.14	1.13
Mean	1.15	1.14	1.14	1.13
	Brand "C"			
1	1.16	1.15	1.14	1.13
2	1.16	1.15	1.14	1.13
3	1.16	1.15	1.14	1.13
4	1.16	1.15	1.14	1.13
Mean	1.16	1.15	1.14	1.13

TABLE IX (continued)

Replication	Treatments			
	C	T1	T2	T3
		(gm/ml)		
		Brand "D"		
1	1.15	1.14	1.13	1.12
2	1.15	1.14	1.13	1.12
3	1.15	1.14	1.13	1.12
4	1.15	1.14	1.13	1.12
Mean	1.15	1.14	1.13	1.12

TABLE X
SUMMARY OF A O V FOR THE EFFECTS OF BRAND ON
THE SPECIFIC GRAVITY

Source	D.F.	M.S.	F-Ratio
Brand	3	0.000	4145.434 ^a
Dilution	3	0.005	7702.008
B x D	9	0.009	103.601
Error	240	0.000	

^aStatistical significance at 0.001 level of probability.

TABLE XI
RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT
OF BRAND ON THE SPECIFIC GRAVITY

Brand		Mean		Significance
Large	Small	Large	Small	
1	3	1.154	1.145	n.s.
1	2	1.154	1.139	n.s.
1	4	1.154	1.135	a
3	2	1.145	1.139	n.s.
3	4	1.145	1.135	n.s.
2	4	1.139	1.135	n.s.

^aStatistical significance at 0.01 level of probability.

Note: Brand A = 1; Brand B = 2; Brand C = 3; Brand 4 = 4.

TABLE XII
RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT
OF DILUTION ON THE SPECIFIC GRAVITY

Dilution		Mean		Significance
Large	Small	Large	Small	
1	2	1.157	1.147	n.s.
1	3	1.157	1.139	a
1	4	1.157	1.132	a
2	3	1.147	1.139	n.s.
2	4	1.147	1.132	n.s.
3	4	1.139	1.132	n.s.

^aStatistical significance at 0.01 level of probability.

Note: Nondiluted catsup = 1; 5 percent dilution = 2; 10 percent dilution = 3; 15 percent dilution = 4.

TABLE XIII

PARTICLE CONCENTRATION OF CATSUP FOR ALL TREATMENTS AND CONTROL,
EXPRESSED IN PARTICLES PER FIELD

Replication	Treatments			
	C	T1	T2	T3
Count				
Brand "A"				
1	7.8	7.5	7.5	6.9
2	8.6	7.9	7.1	7.2
3	8.4	7.3	7.1	6.8
4	7.9	7.8	7.3	7.0
Mean	8.2	7.6	7.3	7.0
Brand "B"				
1	7.9	7.6	7.6	6.7
2	8.3	7.7	7.3	6.9
3	8.1	7.5	6.9	6.8
4	8.2	7.9	6.9	7.0
Mean	8.1	7.7	7.3	6.9
Brand "C"				
1	8.7	8.0	7.3	7.4
2	8.0	7.6	7.4	6.6
3	8.0	7.2	7.0	6.9
4	8.2	7.5	7.2	6.7
Mean	8.2	7.6	7.2	6.9

TABLE XIII (continued)

Replication	Treatments			
	C	T1	T2	T3
	Count			
	Brand "D"			
1	8.0	8.2	7.5	7.1
2	8.2	7.6	7.3	7.3
3	7.9	7.9	7.8	7.0
4	8.4	8.1	7.1	7.5
Mean	8.2	7.9	7.4	7.2

TABLE XIV

EFFECT OF PARTICLE CONCENTRATION ON THE CONSISTENCY OF CATSUP

Particle Concentration Count	Consistency		
	Adams cm.	Bostwick cm.	Brookfield sp4-6rpm poises
Brand "A"			
8.2	9.32	4.42	541.62
7.6	10.29	4.88	473.37
7.3	10.49	5.21	327.75
7.0	12.49	5.71	265.37
Brand "B"			
8.1	9.95	6.20	275.62
7.7	11.21	6.80	255.25
7.3	11.44	7.41	192.12
6.9	13.83	7.80	122.25
Brand "C"			
8.2	12.11	6.27	308.50
7.6	13.43	7.32	235.00
7.2	14.85	8.11	135.37
6.9	16.21	8.68	125.37
Brand "D"			
8.2	11.06	5.97	255.75
7.9	12.62	6.80	184.25
7.4	14.04	7.77	122.62
7.2	15.04	8.02	77.35

440 times their real size and expressed in microns is shown, for all brands and treatments, in Table XV. The effect of particle size on the consistency of catsup for all brands, treatments and control is shown in Table XVI.

The summary of analysis of variance for the combined effect of particle size and particle concentration is shown in Table XVII. There was significant difference at 0.01 level of probability for brand, dilution and their interaction. The results of Duncan's Multiple Range Test for brand and dilution are shown on Tables XVIII and XIX.

V. CONSISTENCY

The consistency measurements obtained with the Adams Consistometer for all brands and treatment are shown on Table XX. The effect of dilution on the consistency of catsup determined with the Adams Consistometer are shown in Figure 2.

The analysis of variance for the consistency measurements done with the Adams Consistometer for all brands, dilution and their interaction is shown in Table XXI. Highly significant differences in brand, dilution and the interaction of brand and dilution were observed from the results of the analysis of variance. The results of Duncan's Multiple Range Tests, for brand and treatment are shown in Tables XXII and XXIII, respectively, show that there were significant differences at 0.01 level of probability for both brand and dilutions.

From Figure 2, it can be seen that as dilution increases the fluidity of catsup also increases. In other words, total solids

TABLE XV

PARTICLES SIZE OF CATSUP FOR ALL TREATMENTS AND THE CONTROL

Replication	Treatments			
	C	T1	T2	T3
	microns			
Brand "A"				
1	12.5	8.0	14.2	10.0
2	8.0	11.6	12.5	5.5
3	10.0	12.5	11.0	12.5
4	5.5	12.5	8.0	12.5
Mean	8.7	11.1	11.4	10.1
Brand "B"				
1	18.6	15.7	8.6	6.8
2	13.2	17.3	11.9	16.7
3	10.7	11.1	12.5	5.2
4	8.2	17.6	5.5	5.5
Mean	12.7	15.4	9.6	8.5
Brand "C"				
1	11.6	13.6	9.8	11.8
2	14.9	8.0	11.9	11.8
3	9.5	7.8	12.5	8.6
4	7.8	11.6	7.8	7.8
Mean	10.9	10.2	10.5	10.0

TABLE XVI
EFFECT OF PARTICLE SIZE ON THE CONSISTENCY OF CATSUP

Particle Size microns	Consistency		
	Adams cms.	Bostwick cms.	Brookfield sp4-6rpm poises
Brand "A"			
8.7	9.32	4.42	541.62
11.1	10.29	4.88	473.37
11.4	10.49	5.21	327.75
10.1	12.49	5.71	265.37
Brand "B"			
12.7	9.95	6.20	275.62
15.4	11.21	6.80	255.25
9.6	11.44	7.41	192.12
8.5	13.83	7.80	122.25
Brand "C"			
10.9	12.11	6.27	308.50
10.2	13.43	7.32	235.00
10.5	14.85	8.11	135.37
10.0	16.21	8.68	125.37
Brand "D"			
14.9	11.06	5.97	255.75
10.4	12.62	6.80	184.25
10.1	14.04	7.77	122.62
12.3	15.04	8.02	77.35

Note: Particle size in microns²; Adams in cms. flown in 10 seconds; Bostwick in cms. flown in 10 seconds; Brookfield in poises.

TABLE XVII

SUMMARY OF A O V FOR THE EFFECT OF BRAND, DILUTION AND THEIR
INTERACTION ON PARTICLE SIZE DISTRIBUTION

Source	D.F.	M.S.	F-Ratio
Brand	3	246127.36	95642.75 ^a
Dilution	3	174214.30	74276.28
B x D	9	5216.47	1901.70
Error	112	2.074	

^aStatistical significance at 0.001 level of probability.



TABLE XVIII

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT
OF BRAND ON PARTICLE SIZE DISTRIBUTION

Brand		Mean		Significance
Large	Small	Large	Small	
4	2	91.50	86.64	a
4	3	91.50	77.70	a
4	1	91.50	77.72	a
2	3	86.64	77.70	a
2	1	86.64	77.62	a
3	1	77.70	77.62	n.s.

^aStatistical significance at 0.01 level of probability.

Note: Brand A = 1; Brand B = 2; Brand C = 3; Brand D = 4.

TABLE XIX

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT
OF DILUTION ON PARTICLE SIZE DISTRIBUTION

Dilution		Mean		Significance
Large	Small	Large	Small	
1	2	96.56	90.70	a
1	3	96.56	76.98	a
1	4	96.56	71.57	a
2	3	90.70	76.98	a
2	4	90.70	71.57	a
3	4	76.98	71.57	a

^aStatistical significance at 0.01 level of probability.

Note: Dilution 1 = no water added; Dilution 2 = 5 percent water added; Dilution 3 = 10 percent water added; Dilution 4 = 15 percent water added.

TABLE XX

CONSISTENCY MEASUREMENTS WITH THE ADAMS CONSISTOMETER OF THE CONTROL
AND TREATMENTS WITH THEIR RESPECTIVE REPLICATIONS

Replication	Treatments			
	C	T1	T2	T3
	cms.			
	Brand "A"			
1	9.31	10.24	11.18	12.50
2	9.32	10.25	11.23	12.46
3	9.29	10.28	10.30	12.48
4	9.35	10.25	10.23	12.52
Mean	9.32	10.29	10.49	12.49
	Brand "B"			
1	10.02	11.25	12.48	13.83
2	9.97	11.17	12.44	13.87
3	9.90	11.17	12.40	13.87
4	9.90	11.24	12.45	13.75
Mean	9.95	11.21	12.44	13.83
	Brand "C"			
1	12.07	13.43	14.87	16.20
2	12.10	13.47	14.83	16.18
3	12.11	13.41	14.89	16.19
4	12.16	13.41	14.81	16.27
Mean	12.11	13.43	14.85	16.21

TABLE XX (continued)

Replication	Treatments			
	C	T1	T2	T3
		cms.		
		Brand "D"		
1	11.10	12.56	14.06	15.02
2	11.01	12.58	14.04	15.02
3	11.07	12.64	14.04	15.10
4	11.02	12.72	14.02	15.03
Mean	11.06	12.62	14.04	15.04

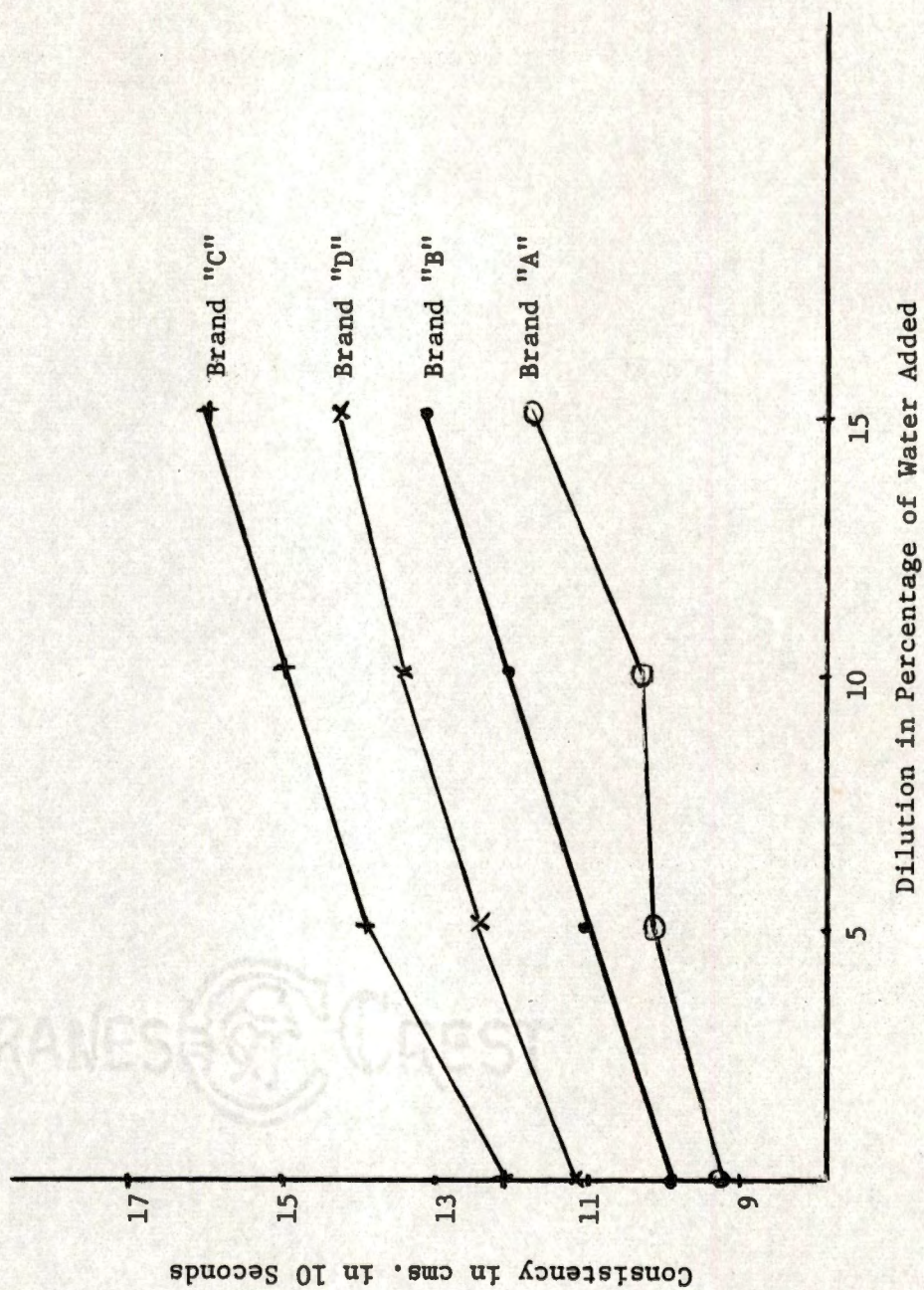


Figure 2. Consistency measurements with the Adams Consistometer as a function of dilution. 8

TABLE XXI

SUMMARY OF A O V FOR THE EFFECT OF BRAND ON CONSISTENCY
MEASUREMENTS WITH THE ADAMS CONSISTOMETER

Source	D.F.	M.S.	F-Ratio
Brand	3	74.960	5063.676 ^a
Dilution	3	82.510	5573.684
B x D	9	0.975	65.839
Error	112	0.015	

^aStatistical significance at 0.001 level of probability.

TABLE XXII

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF BRAND ON
THE CONSISTENCY MEASUREMENTS OBTAINED WITH
THE ADAMS CONSISTOMETER

Brand		Mean		Significance
Large	Small	Large	Small	
3	4	14.151	13.193	a
3	2	14.151	11.860	a
3	1	14.151	10.652	a
4	2	13.193	11.860	a
4	1	13.193	10.652	a
2	1	11.860	10.652	a

^aStatistical significance at 0.01 level of probability.

Note: Brand A = 1; Brand B = 2; Brand C = 3; Brand D = 4.

TABLE XXIII

RESULT OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF DILUTION ON
THE CONSISTENCY MEASUREMENTS OBTAINED WITH
THE ADAMS CONSISTOMETER

Dilution		Mean		Significance
Large	Small	Large	Small	
4	3	14.396	11.957	a
4	2	14.396	11.890	a
4	1	14.396	10.612	a
3	2	11.957	11.890	n.s.
3	1	11.597	10.612	a
2	1	11.890	10.612	a

^aStatistical significance at 0.01 level of probability.

Note: Dilution 1 = no water added; Dilution 2 = 5 percent water added; Dilution 3 = 10 percent water added; Dilution 4 = 15 percent water added.

decreases the consistency of catsup also decreases. This relationship is almost linear.

The consistency measurements obtained with the Bostwick Consistometer for all brands and treatments are shown in Table XXIV and expressed in cms. flown in ten seconds. The effect of dilution on the fluidity of catsup is illustrated in Figure 3. It can be seen that as dilution increases the fluidity of catsup also increases and that this relationship is almost linear.

The analysis of variance for the consistency measurements obtained with the Bostwick Consistometer for all brands, dilutions and their interactions are shown in Table XXV. Highly significant differences were observed from the results of the analysis of variance for brand, dilution and the interaction of brand and dilution. The results of Duncan's Multiple Range Tests, for brand and treatment, are shown in Tables XXVI and XXVII, respectively. These results showed that there were significant differences at 0.01 level of probability for both brands and dilutions.

The consistency measurements obtained with the Brookfield Synchronic Viscometer at different shear rates for the different brands and dilutions are shown in Tables XXVIII and XXIX. The consistency is expressed in poises, which is the c.g.s. unit for viscosity:

$$\text{poise} = \frac{\text{gm.}}{\text{cm. sec.}} = \frac{\text{dyne}}{\text{sec. cm}^2}.$$

Figures 4, 5, 6 and 7 show the effect of shear rate in revolution per minute on the apparent viscosity of the different brands and treatment of catsup.

TABLE XXIV

CONSISTENCY MEASUREMENTS WITH THE BOSTWICK CONSISTOMETER FOR
CONTROL AND TREATMENTS AND THEIR
RESPECTIVE REPLICATION

Replication	Treatments			
	C	T1	T2	T3
	cms.			
	Brand "A"			
1	333 4.40	4.88	5.23	5.77
2	4.45	4.87	5.20	5.68
3	4.42	4.89	5.22	5.68
4	4.42	4.89	5.19	5.70
Mean	4.42	4.88	5.21	5.71
	Brand "B"			
1	6.22	6.87	7.45	7.82
2	6.17	6.75	7.40	7.77
3	6.20	6.75	7.40	7.83
4	6.20	6.82	7.41	7.77
Mean	6.20	6.80	7.41	7.80
	Brand "C"			
1	6.27	7.35	8.05	8.65
2	6.22	7.30	8.10	8.70
3	6.30	7.35	8.15	8.70
4	6.30	7.30	8.10	8.70
Mean	6.27	7.32	8.10	8.69

TABLE XXIV (continued)

Replication	Treatments			
	C	T1	T2	T3
		cms.		
		Brand "D"		
1	5.95	6.80	7.41	7.85
2	6.00	6.75	7.43	7.85
3	6.00	6.80	7.41	7.75
4	6.00	6.85	7.39	7.75
Mean	5.99	6.80	7.41	7.80

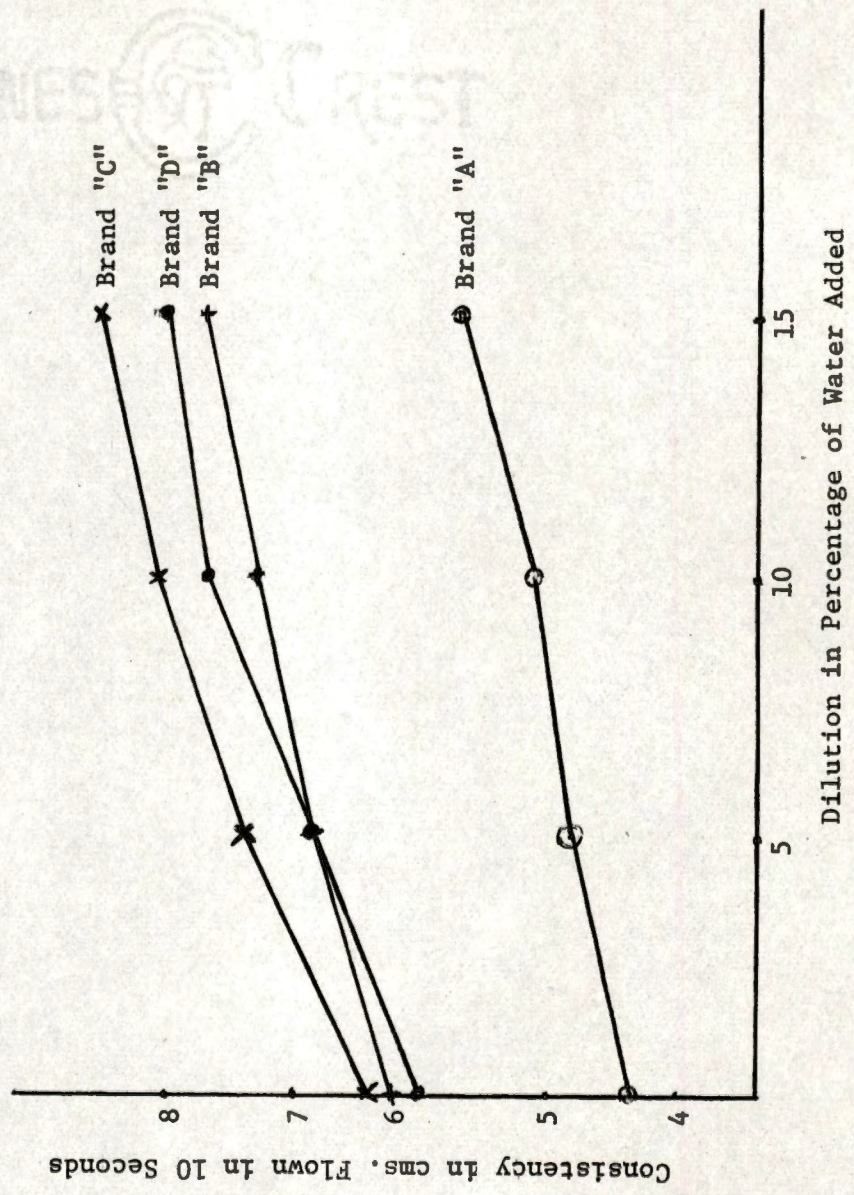


Figure 3. Consistency measurements with the Bostwick Consistometer as a function of dilution.

TABLE XXV

SUMMARY OF A O V FOR THE EFFECT OF BRAND ON CONSISTENCY
MEASUREMENTS WITH THE BOSTWICK CONSISTOMETER

Source	D.F.	M.S.	F-Ratio
Brand	3	40.773	28102.297 ^a
Dilution	3	20.688	14258.777
B x D	9	0.479	330.073
Error	112	0.001	

^aStatistical significance at 0.001 level of probability.

TABLE XXVI

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF BRAND ON
THE CONSISTENCY MEASUREMENTS OBTAINED WITH
THE BOSTWICK CONSISTOMETER

Brand		Mean		Significance
Large	Small	Large	Small	
3	4	7.600	7.143	a
3	2	7.600	7.053	a
3	1	7.600	5.069	a
4	2	7.143	7.052	a
4	1	7.143	5.069	a
2	1	7.053	5.069	a

^aStatistical significance at 0.01 level of probability.

Note: Brand A = 1; Brand B = 2; Brand C = 3; Brand D = 4.

TABLE XXVII

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF DILUTION ON
THE CONSISTENCY MEASUREMENTS OBTAINED WITH
THE BOSTWICK CONSISTOMETER

Dilution		Mean		Significance
Large	Small	Large	Small	
4	3	7.556	7.128	a
4	2	7.556	6.453	a
4	1	7.556	5.718	a
3	2	7.128	6.453	a
3	1	7.128	5.718	a
2	1	6.453	5.718	a

^aStatistical significance at 0.01 level of probability.

Note: Dilution 1 = no water added; Dilution 2 = 5 percent water added; Dilution 3 = 10 percent water added; Dilution 4 = 15 percent water added.

TABLE XXVIII
CONSISTENCY MEASUREMENTS WITH BROOKFIELD VISCOMETER USING
SPINDLE FOUR AT DIFFERENT SHEAR RATES

Brand	Dilution	Shear Rate in rpm.			
		6	12	30	60
		poises			
1	1	541.62	344.75	196.32	81.90
1	2	473.37	261.00	123.02	70.92
1	3	327.75	187.33	104.27	66.71
1	4	265.37	170.25	97.72	
2	1	275.62	203.27	107.55	68.52
2	2	255.25	154.28	81.61	47.33
2	3	192.12	116.92	55.87	34.63
2	4	122.25	75.17	52.43	32.26
3	1	308.50	178.71	88.65	53.71
3	2	235.00	138.56	84.61	51.35
3	3	135.37	84.38	55.36	37.33
3	4	125.37	80.36	53.56	41.87
4	1	255.75	170.68	84.38	52.75
4	2	184.25	121.53	52.28	38.51
4	3	122.62	77.90	46.32	26.60
4	4	77.35	50.75	31.55	20.53

TABLE XXIX

CONSISTENCY MEASUREMENTS WITH THE BROOKFIELD VISCOMETER USING
SPINDLE THREE AND DIFFERENT SHEAR RATES

Brand	Dilution	Shear Rate in rpm.			
		6	12	30	60
		poises			
1	1	--	--	--	--
1	2	198.90	--	--	--
1	3	178.35	--	--	--
1	4	142.77	91.40	--	--
2	1	161.80	--	--	--
2	2	135.06	87.82	--	--
2	3	97.13	57.23	33.06	--
2	4	87.80	54.63	31.57	--
3	1	121.87	73.80	--	--
3	2	110.52	72.70	--	--
3	3	107.53	70.11	35.51	--
3	4	67.40	40.85	17.50	--
4	1	129.50	81.61	--	--
4	2	104.62	59.68	34.27	--
4	3	84.93	54.40	30.83	--
4	4	78.68	45.88	23.50	16.32

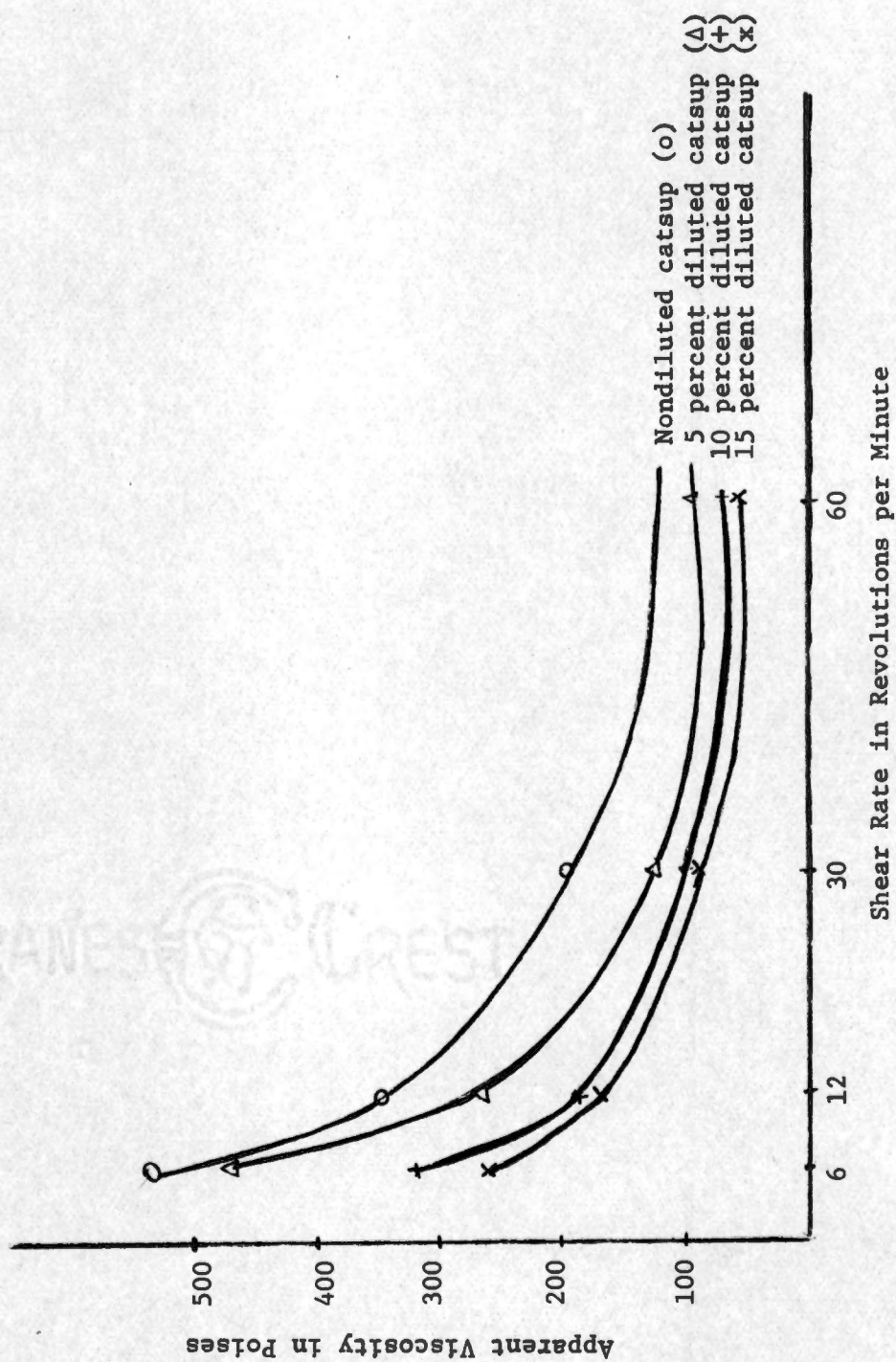


Figure 4. Apparent viscosity of brand "A" catsup as a function of shear rate.

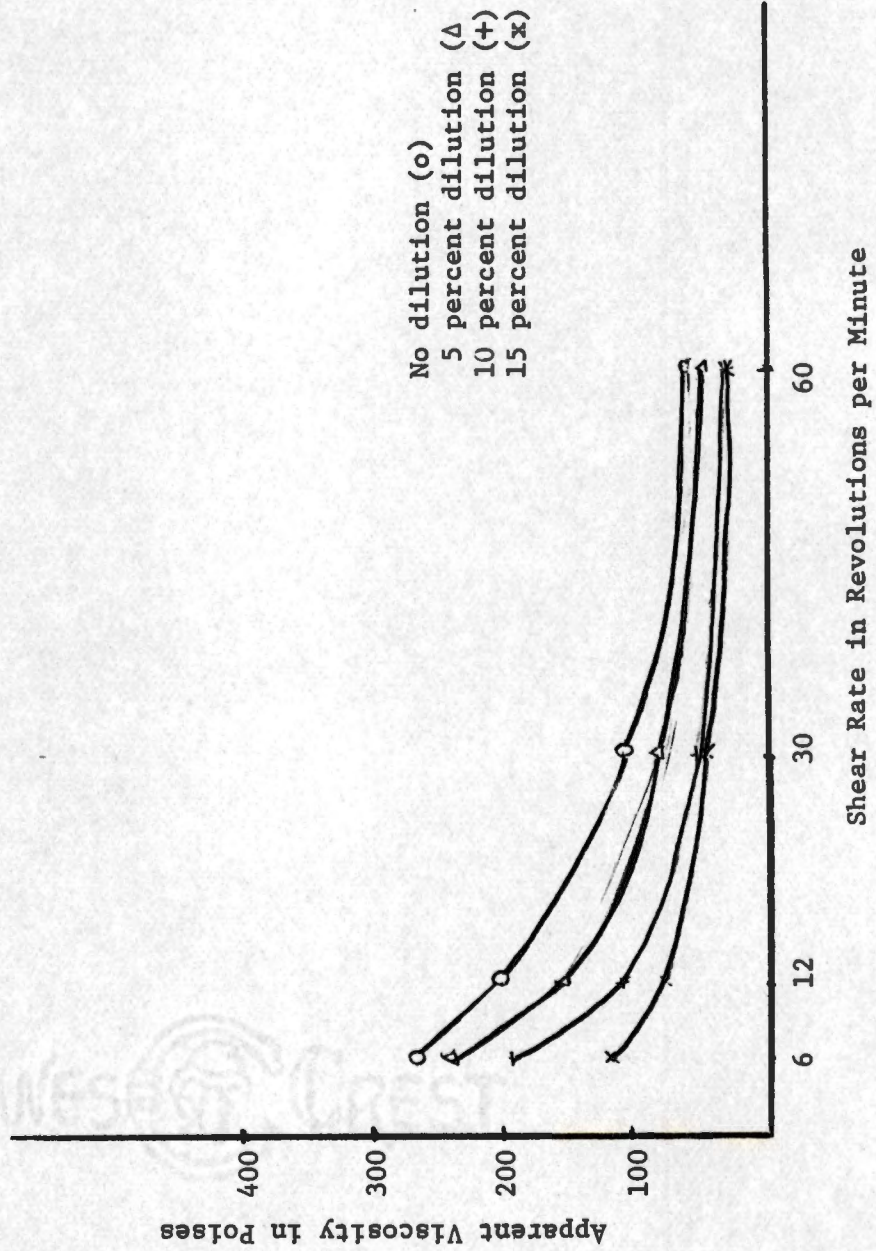


Figure 5. Apparent viscosity of brand "B" catsup as a function of shear rate.

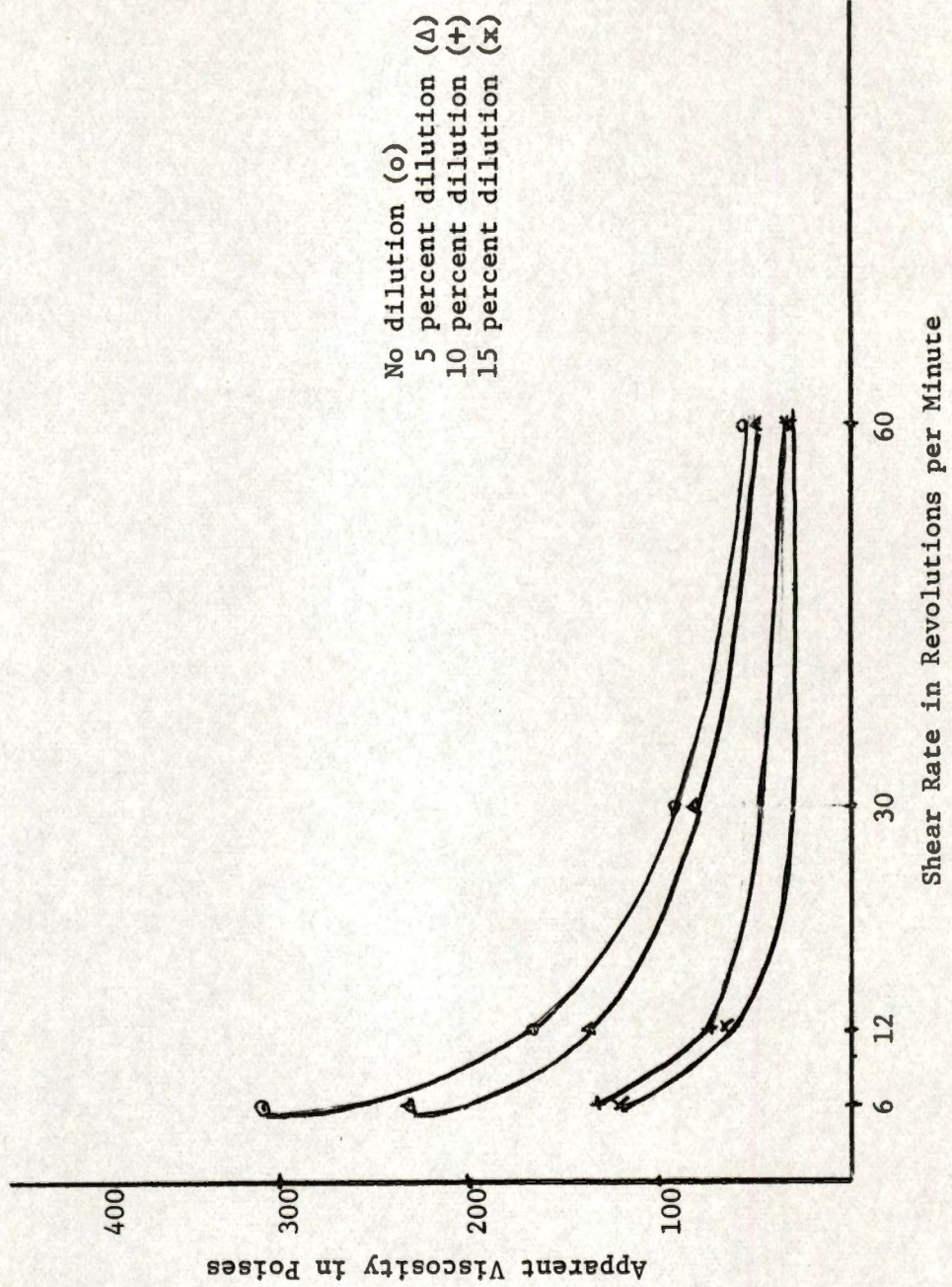


Figure 6. Apparent viscosity of brand "C" catsup as a function of shear rate.

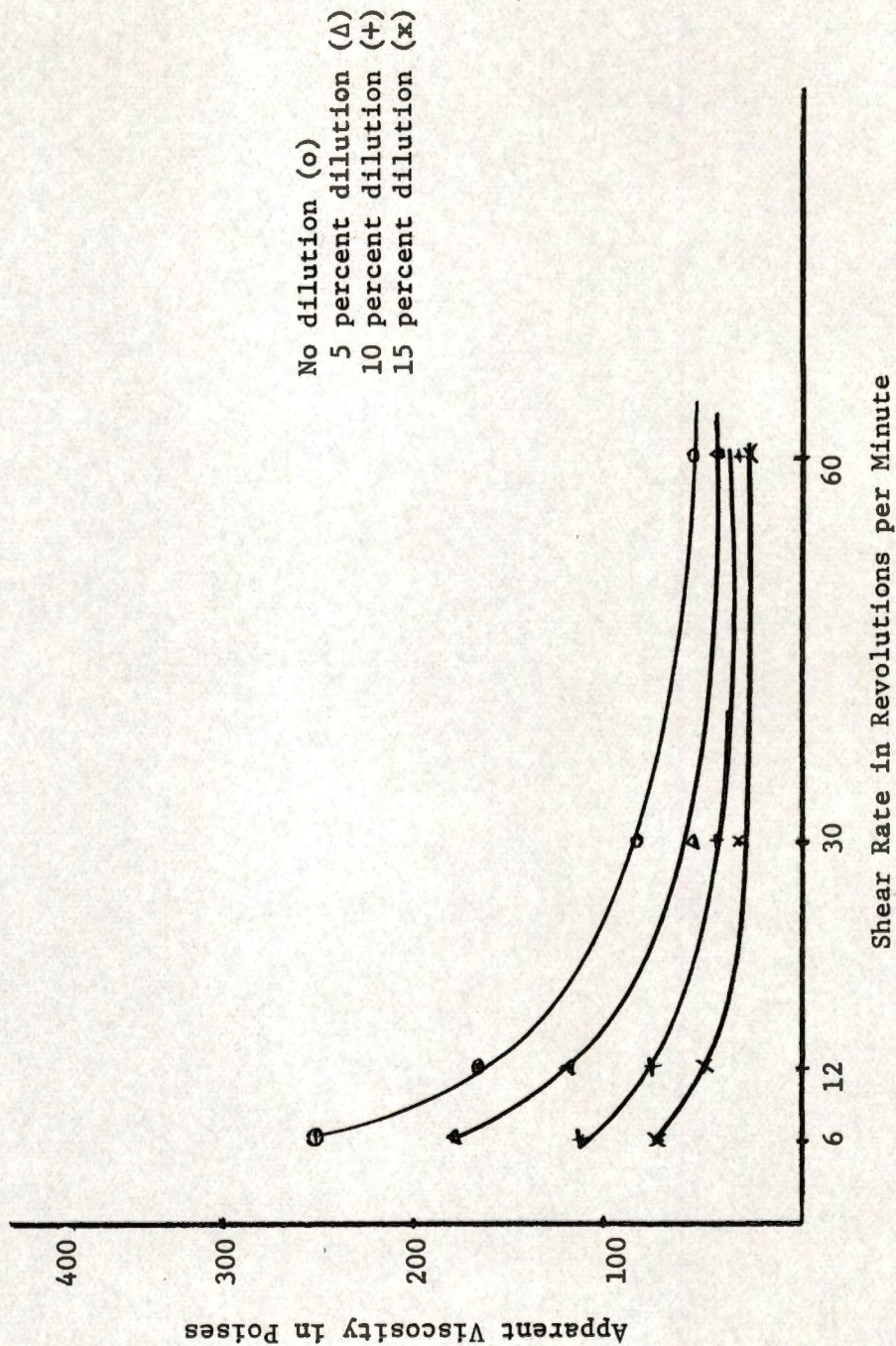


Figure 7. Apparent viscosity of brand "D" catsup as a function of shear rate.

The analyses of variance for the different measurements at different shear rates are shown in Tablex XXX, XXXI, XXXII for 6, 12 and 30 revolutions per minute, respectively, using spindle No. 4. Significant differences were observed in every analysis for brand, dilution, and the interaction of brand and dilution. The results of Duncan's Multiple Range Tests for the different shear rates showed significant differences at 0.01 level of probability. These results are shown in Tablex XXXIII, XXXIV and XXXV for shear rates of 6, 12 and 30 revolutions per minute, respectively, for the effect of brand and on Tables XXXVI, XXXVII and XXXVIII for the effect of dilution. For all other shear rates it was not possible to run the analysis of variance because of insufficient data.

TABLE XXX

SUMMARY OF A O V FOR THE EFFECT OF BRAND ON CONSISTENCY
MEASUREMENTS WITH THE BROOKFIELD VISCOMETER
FOR SPINDLE FOUR AT SIX RPM.

Source	D.F.	M.S.	F-Ratio
Brand	3	372715.312	125283.938 ^a
Dilution	3	254625.563	85589.438
B x D	9	7442.477	2501.703
Error	112	2.975	

^aStatistical significance at 0.001 level of probability.

TABLE XXXI

SUMMARY OF A O V FOR THE EFFECT OF BRAND ON CONSISTENCY
 MEASUREMENTS WITH THE BROOKFIELD VISCOMETER
 FOR SPINDLE FOUR AT TWELVE RPM.

Source	D.F.	M.S.	F-Ratio
Brand	3	120324.938	73214.375 ^a
Dilution	3	107882.813	65643.688
B x D	9	2137.054	1300.338
Error	112	1.643	

^aStatistical significance at 0.001 level of probability.

TABLE XXXII

SUMMARY OF A O V FOR THE EFFECT OF BRAND ON CONSISTENCY
MEASUREMENTS WITH THE BROOKFIELD VISCOMETER
FOR SPINDLE FOUR AT THIRTY RPM.

Source	D.F.	M.S.	F-Ratio
Brand	3	35521.312	216669.688 ^a
Dilution	3	23553.375	143668.750
B x D	9	1624.693	9910.156
Error	112	0.164	

^a Statistical significance at 0.001 level of probability.

TABLE XXXIII

RESULTS OF THE DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF BRAND
ON THE CONSISTENCY MEASUREMENTS OBTAINED WITH THE BROOKFIELD
SYNCHRO-ELECTRIC VISCOMETER USING
SPINDLE NO. FOUR AT SIX RPM.

Brand		Mean		Significance
Large	Small	Large	Small	
1	2	403.03	211.31	a
1	3	403.03	201.06	a
1	4	403.03	159.99	a
2	3	211.31	201.06	a
2	4	211.31	159.99	a
3	4	201.06	159.99	a

^aStatistical significance at 0.01 level of probability.

Note: Brand A = 1; Brand B = 2; Brand C = 3; Brand D = 4.

TABLE XXXIV

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF DILUTION
ON THE CONSISTENCY MEASUREMENTS OBTAINED WITH THE BROOKFIELD
SYNCHRO-ELECTRIC VISCOMETER USING
SPINDLE NO. FOUR AT SIX RPM.

Dilution		Mean		Significance
Large	Small	Large	Small	
1	2	345.37	286.96	a
1	3	345.37	194.46	a
1	4	345.37	147.58	a
2	3	286.96	194.46	a
2	4	286.96	147.58	a
3	4	194.46	147.58	a

^aStatistical significance at 0.01 level of probability.

Note: Dilution 1 = no water added; Dilution 2 = 5 percent water added; Dilution 3 = 10 percent water added; Dilution 4 = 15 percent water added.

TABLE XXXV

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF BRAND ON
THE CONSISTENCY MEASUREMENTS OBTAINED WITH THE BROOKFIELD
SYNCHRO-ELECTRIC VISCOMETER USING
SPINDLE NO. FOUR AT TWELVE RPM.

Brand		Mean		Significance
Large	Small	Large	Small	
1	2	240.83	137.41	a
1	3	240.83	120.50	a
1	4	240.83	105.21	a
2	3	137.41	120.50	a
2	4	137.41	105.21	a
3	4	120.50	105.21	a

^aStatistical significance at 0.01 level of probability.

Note: Brand A = 1; Brand B = 2; Brand C = 3; Brand D = 4.

TABLE XXXVI

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF DILUTION
ON THE CONSISTENCY MEASUREMENTS OBTAINED WITH THE BROOKFIELD
SYNCHRO-ELECTRIC VISCOMETER USING
SPINDLE NO. FOUR AT TWELVE RPM.

Dilution		Mean		Significance
Large	Small	Large	Small	
1	2	224.35	168.84	a
1	3	224.35	116.63	a
1	4	224.35	94.13	a
2	3	168.84	116.63	a
2	4	168.84	94.13	a
3	4	116.63	94.13	a

^aStatistical significance at 0.01 level of probability.

Note: Dilution 1 = no water added; Dilution 2 = 5 percent water added; Dilution 3 = 10 percent water added; Dilution 4 = 15 percent water added.

TABLE XXXVII

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF BRAND ON
CONSISTENCY MEASUREMENTS WITH THE BROOKFIELD VISCOMETER
USING SPINDLE FOUR AND THIRTY RPM.

Brand		Mean		Significance
Large	Small	Large	Small	
1	2	130.33	74.36	a
1	3	130.33	70.14	a
1	4	130.33	53.63	a
2	3	74.36	70.14	a
2	4	74.36	53.63	a
3	4	70.14	53.63	a

^aStatistical significance at 0.01 level of probability.

Note: Brand A = 1; Brand B = 2; Brand C = 3; Brand D = 4.



TABLE XXXVIII

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST FOR THE EFFECT OF DILUTION
ON THE CONSISTENCY MEASUREMENTS WITH THE BROOKFIELD
VISCOMETER USING SPINDLE FOUR AND THIRTY RPM.

Dilution		Mean		Significance
Large	Small	Large	Small	
1	2	120.22	85.38	a
1	3	120.22	65.44	a
1	4	120.22	58.81	a
2	3	85.38	65.44	a
2	4	85.38	58.81	a
3	4	65.44	58.81	a

^aStatistical significance at 0.01 level of probability.

Note Dilution 1 = no water added; Dilution 2 = 5 percent water added; Dilution 3 = 10 percent water added; Dilution 4 = 15 percent water added.

CHAPTER V

SUMMARY

This investigation was undertaken to study the effect of soluble solids content, alcohol-insoluble solids, particle size distribution and shear rate on the apparent viscosity of catsup.

Under the condition of this experiment, the following conclusions were reached:

1. Catsup is a very complex rheological system in which the apparent viscosity is time dependent.
2. The soluble solids content of commercial processed catsup varies according to the specifications of the processor. The range of soluble solids studied in this investigation were from 37.1 to 28.4; however, the amount of solids in the original samples ranged from 37.1 to 32.6. As the soluble solids increases the consistency of catsup also increases.
3. The alcohol-insoluble solids of the catsups examined varies from 4.2 to 2.7; however, in the original samples without any dilution, the alcohol-insoluble solids content ranged from 4.2 to 3.2. The consistency of catsup increases as the alcohol-insoluble solids content increases.
4. Particle size distribution and concentration influence consistency of catsup in the same manner as the solids influence consistency:

As the particles are enlarged and the concentration increased, the consistency of catsup also increases. The uniformity in size and distribution also plays a very important role in determining the consistency of the product.

5. The consistency of catsup depends greatly upon the stress at which it has been submitted. The range of consistencies studied in this investigation was 541.2 to 16.3 poises.

6. Dilution has a great influence on consistency. As the dilution is increased the consistency of catsup decreased. Dilution also affects the rheological behavior of catsup: As dilution increases the pseudo-plastic behavior increased.

7. From the summary of the correlation analysis (Table XXXIX) it can be seen that soluble solids, alcohol-insoluble solids and specific gravity have a positive relationship with the consistency measurements obtained with the Brookfield Viscometer at 6, 12 and 30 revolutions per minute, respectively, and negative relationships with the measurements obtained with Adams and Bostwick Consistometers.

8. The soluble solids content was highly correlated with the consistency measurements obtained with the Brookfield Viscometer at 6, 12 and 30 revolutions per minute and with the specific gravity measurements.

9. Alcohol-insoluble solids content was highly correlated with consistency measurements obtained with Adams, Bostwick and Brookfield at 6, 12 and 30 revolutions per minute.

TABLE XXXIX

SUMMARY OF THE CORRELATION ANALYSIS

S.S.	I.S.	S.Gr.	Adams	Bostwick	Brookfield				
					6 rpm.	12 rpm.	30 rpm.		
1	*	.8786	.9792	-.8134	-.8563	.9480	.9490	.9242	S.S.
	*	.8207	-.9050	-.8959	.9208	.9208	.9288	.9068	I.S.
	*		-.7854	-.8821	.9141	.9141	.9099	.8720	S.Gr.
			*	.9091	-.8447	-.8447	-.8716	-.7977	Adams
			*		-.9221	-.9221	-.9221	-.8669	Bostwick
				*		*	.9842	.9499	6 rpm.
							*	.9744	12 rpm.
								*	30 rpm.

Note: I.S. = insoluble solids; S.S. = soluble solids; S.Gr. = specific gravity.

10. The consistency measurements obtained with the Brookfield Viscometer at different shear rates were highly correlated with each other.

11. The consistency measurements obtained with the Adams Consistometer were highly correlated to the consistency measurements obtained with the Bostwick Consistometer.



LIST OF REFERENCES

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LIST OF REFERENCES

1. A. O. A. C. 1965. "Official Methods of Analysis." 10th ed. Assoc. Offic. Agr. Chemists, Washington, D. C.
2. Becker, R., J. R. Wagner, J. C. Miers, D. W. Sanshuck and W. C. Dietrich. 1967. Consistency of Tomato Products III. Food Technol. 22, 159.
3. Charm, S. E. 1961. The Nature and Role of Fluid Consistency in Food Engineering Applications. Advances in Food Research 11, 356.
4. _____. 1963. "The Fundamentals of Food Engineering." The AVI Publishing Co., Ltd., Westport, Conn.
5. Cruess, W. V. 1958. Tomato products. In "Commercial Fruit and Vegetable Products." McGraw-Hill Book Co., Inc., New York.
6. Daniels, F. and R. A. Alberty. 1967. Irreversible processes in solution. In "Physical Chemistry." John Wiley and Sons, Inc., New York.
7. Elder, A. L. and R. J. Smith. 1968. Food Rheology Today. Food Technol. 23, 639.
8. Ezell, A. L. 1958. Viscosity of Concentrated Orange and Grapefruit Juice. Food Technol. 13, 9.
9. Fredrickson, A. G. 1964. Principles and Applications of Rheology. Prentice Hall Inc., Englewood Cliffs, N. J.
10. Giedt, W. H. 1961. Viscous fluid flow. In "Principles of Engineering Heat Transfer." D. Van Nostrand Co., Inc., New York.
11. Goose, P. G. and R. Binsted. 1964. Tomato Paste, Puree, Juice and Powder. Food Trade Press Ltd., London.
12. Hermans, J. J. 1963. Flow Properties of Disperse Systems. Interscience Publishers Inc., New York.
13. Holman, J. P. 1963. Viscous flow. In "Heat Transfer." McGraw-Hill Book Co., New York.
14. Honeycutt, E. H. 1965. Rheological Properties of Aqueous Solutions of Milling Yellow Dye. Master's Thesis. The University of Tennessee, Knoxville, Tenn.

15. Hutchings, J. B., F. W. Wood and R. Young. 1968. An Objective Colour Method for the Determination of Tomato Maturity. Journal of Food Technol. 4, 45.
16. Joslyn, M. A. and J. L. Heid. 1964. Pumps and pumping. In "Food Processing Operations." v. 3. The AVI Publishing Co., Inc., Westport, Conn. (X)
17. Kramer, A. and B. A. Twigg. 1966. Quality Control. The AVI Publishing Co., Westport, Conn. ✓
18. _____. 1959. Principles and Instrumentation for Physical Measurements of Food Quality with Special Reference to Fruit and Vegetable Products. Advances in Food Research 9, 153.
19. _____. 1959. Relative Influence of Certain Compositional Factors on the Consistency and Degree of Serum Separation of Catsup. Maryland Processors' Report 5, 7.
20. _____. 1959. Effect of Certain Manufacturing Variables on the Consistency, Serum Separation and Other Chemical and Physical Properties of Catsup. Maryland Processors' Report 5, 8.
21. Matz, S. A. 1962. Food Texture. The AVI Publishing Co., Westport, Conn. (X)
22. Miers, J. C., J. R. Wagner and D. W. Sanshuck. 1966. Consistency of Tomato Products II. Food Technol. 21, 117.
23. Mohsenin, N. N. 1968. Physical Properties of Plants and Animal Materials. Part I, Department of Agriculture Engineering. The Pennsylvania State University.
24. Muller, H. G. 1968. Routine Rheological Test in the British Food Industry. Journal of Food Technol. 4, 83. ✓
25. National Canners Association Research Laboratory. 1950. Tomato Products. Bulletin No. 27-L. Washington, D. C.
26. Olson, R. M. 1966. Essentials of Engineering Fluid Mechanics. International Textbook Company, Scranton, Pennsylvania. X
27. Pefley, R. K. and R. I. Murray. 1966. Thermofluid Mechanics. McGraw-Hill Book Co., New York.
28. Perry, J. H. 1968. Chemical Engineers' Handbook. 4th ed. McGraw-Hill Book Co., New York.

29. Peters, G. L., H. D. Brown, W. A. Gould and R. B. Dairs. 1954. Effect of Added Calcium Chloride and Sodium Hexametaphosphate on the Pectic Content and Serum Viscosity of Tomato Puree. Food Technol. 8, 91.
30. Reiner, M. 1949. Deformation and Flow. H. K. Lewis and Co., Ltd., London.
31. Saravacos, G. D. 1968. Tube Viscometry of Fruit Purees and Juices. Food Technol. 22, 1585.
32. Schultz, T. H., H. Lotzkar, H. S. Owens and W. D. Maclay. 1945. Influence of Method of Deesterification on the Viscosity and Acid Behavior of Pectinic Acid Solutions. Journal of Physical Chemistry 49, 554.
33. Scott Blair, G. W. 1957. Rheology in Food Research. Advances in Food Research 8, 1.
34. Shaheen, E. I. 1967. Rheological Studies on Viscosity and Pipeline Flow of Concentrated Slurries. Ph.D. Dissertation. The University of Tennessee. Knoxville, Tenn.
35. Smit, G. J. and B. K. Norge. 1958. Observations of the Consistency of Tomato Paste. Food Technol. 12, 554.
36. Tressler, D. K. and M. A. Joslyn. 1961. Tomato juice. In "Fruit and Vegetable Juice Processing Technology." The AVI Publishing Co., Inc., Westport, Conn.
37. Twigg, B. A. 1959. Consistency and Serum Separation of Catsup. Ph.D. Dissertation. The University of Maryland, College Park. Maryland.
38. U. S. Department of Agriculture. 1953. U. S. Standards for Grades of Catsup. Agriculture Marketing Service, Washington, D. C.
39. Wagner, J. R. and J. C. Miers. 1966. Consistency of Tomato Products I. Food Technol. 21, 114.
40. Wagner, J. R., J. C. Miers, D. W. Sanshuck and R. Becker. 1968. Consistency of Tomato Products V. Food Technol. 22, 1484.
41. _____. 1968. Consistency of Tomato Products IV. Food Technol. 23, 113.
42. Ware, G. W. and J. P. McCollum. 1968. Tomatoes. In "Producing Vegetables Crops." The Interstate Printers and Publishers Inc., Danville, Illinois.

43. White, G. W. 1969. Rheology in Food Research. Journal of Food Technology 5, 1. X
44. Wilkinson, W. L. 1960. Non Newtonian Fluids. Pergamon Press, New York.
45. York, J. K., M. O'Brien, D. Trombopoulos, F. H. Winter and S. J. Leonard. 1963. Relation of Fruit Damage to Quality and Consistency of Tomato Concentrates. Food Technol. 21, 69.



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