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EFFECT OF CONTROLLED MIXING
ON THE RHEOLOGICAL PROPERTIES OF
DEEP-FAT FRYING BATTERS AT DIFFERENT PERCENT SOLIDS

By

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ABSTRACT

EFFECT OF CONTROLLED MIXING ON THE RHEOLOGICAL PROPERTIES OF DEEP-FAT FRYING BATTERS AT DIFFERENT PERCENT SOLIDS

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Two types of deep-fat frying batters: adhesion and tempura batters were mixed under controlled conditions at different percent solids to study their rheological properties and coating characteristics. Optimum degree of mixing of a batter was defined as the conditions that gave the maximum amount of batter retention on a coated probe. Batters with higher percent solids needed more energy to achieve optimum mixing. In the case of batter retention, batters with higher percent solids required a longer period of time to stabilize dripping. Yield stress and thixotropic behavior were observed in both adhesion and tempura batters. Over time, changes in apparent viscosity and batter retention on the probe did not have practical relevance to the batter and breading industry. When relating batter rheology with fried food quality, it was found that under-mixing a batter had more detrimental effect on fried food quality then over-mixing a batter.

DEDICATION

To my parents,

C.K. Li, V.S. Cheang-Li

and my sister Ella

for their endless support and encouragement.

ACKNOWLEDGMENTS

I would like to express my deepest thanks to Dr. Perry K.W. Ng and Dr. James F. Steffe for their guidance during my master years. I have had a wonderful time in the world of cereal grain and rheology.

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Nomenclature

ρ	Density, kg m^{-3}
$\dot{\gamma}$	Shear Rate, s^{-1}
$\dot{\gamma}_a$	Average shear rate, s^{-1}
σ_0	Yield stress, Pa
n	Flow behavior index, dimensionless
μ	Newtonian viscosity, Pa s
η_a	Apparent viscosity, Pa s
η_0	Limiting viscosity at zero shear rate, Pa s
η_∞	Limiting viscosity at infinite shear rate, Pa s
θ	Angle of inclination, rad
Ω	Angular velocity [2 π (rpm)/60], rad s^{-1}
A	Area, m^2
d	Impeller blade diameter, m
ΔF	Weight percent of coating in final fried food
ΔF_C	Percent increase in weight after coating
F	Weight of food coating, g
F_1	Weight of food before coating, g
F_2	Weight of food after coating, g
F_3	Weight of fried food, g

g	Gravitational acceleration, 9.81 m s^{-1}
h	Thickness of coating, m
K	Consistency coefficient, Pa s^n
k'	Mixer viscometer constant, rad^{-1}
M_a	Average torque, N m
p	Power input to a mixer [M Ω], N m s^{-1}
T	Thickness of coating, mm
T_0	Thickness of food, mm
T_1	Thickness of fried food, mm
t	Time, s
V	Volume of batter retained on the probe, m^3
W	Mass of batter in the mixing cup, kg
w	Weight of batter retained on the probe, kg
X	Coating area of one side of the plate, m^2
x	Total immersed surface area, m^2
y	Distance perpendicular to the inclined plane, m

Chapter 1

Introduction

1.1. Overview and Objectives

Batter coating is not an uncommon technique in the food industry. Many food items found on today's market, such as french fries, chicken nuggets, stuffed mushrooms, fried cheese sticks, fried fish sticks and deep fried shrimp, have batter coatings on them. The practice of battering a food item and then deep-fat frying it was noted ages ago. When this food preparation method actually started is unknown, but it has been adopted by many different cultures. Dairy products, meats, seafood and vegetables can all be prepared with batter coating.

Since the 1970s, researchers have been investigating the functionality of each ingredient in the dry batter mix. Several books (Suderman and Cunningham, 1983; Kulp and Loewe, 1990) have been published to document the role of each ingredient in the batter system. However, the mixing techniques are still based on knowledge gathered with experience rather than hard core science. In addition, very few food scientists dedicate their effort solely to research batter mixing and the related rheological properties. Furthermore, no official methods are established to evaluate the degree of mixing a batter receives, or to measure the extent of batter dripping from the food after coating.

Food rheology is the study of how food products flow and deform under applied stress or strain. Food rheological data are useful information to the batter and breading industry when dealing with process engineering calculations, monitoring product quality during and after production, tracking quality changes within target shelf life and relating food texture with sensory results.

The objectives of this research were:

1. To examine the importance of controlled mixing during the preparation of coating batters, by investigating adhesion and tempura batters of three different commercial brands each.
2. To measure rheological properties of adhesion and tempura batters at different percent solids.
3. To correlate results from the batter stages with the final fried food quality of food items with different batter coatings.

1.2. Definition and Types of Batters

"A semi-fluid substance, usually composed of flour and other ingredients, into which principal components of food are dipped or with which they are coated, or which may be used directly to form bakery foods" is the definition of batter according to the Federal Food, Drug, and Cosmetic Act part 110 (1986). In respect to the batter and breading industry, a more specific definition of deep-fat frying batter is "a liquid mixture comprised of water, flour, starch and seasonings into which food products are dipped prior to cooking (Suderman and Cunningham, 1983)". Other related terms like coatings and pick-up can be described as "the batter and/or breading adhering to a food product after cooking" (Suderman and Cunningham, 1983) and "the amount of coating material adhering to the food product" (Suderman and Cunningham, 1983), respectively. Food products that are prepared with deep-fat frying batter include, but are not limited to, chicken pieces, pork chops, mushrooms, zucchini, cucumber, shrimps, fish sticks and cheese sticks. Generally, coating batter for deep-fat frying can be divided into two subgroups: adhesion batter and tempura batter (Suderman and Cunningham, 1983; Kulp and Loewe, 1990; and Shinsato et al., 1999).

1.2.1. Adhesion Batter

Adhesion batter can be used in conjunction with breading or breadcrumbs. In this case, adhesion batter holds the food substrate and the outside breading together. Chemical leavening agents are usually not included in adhesion batter. Within the category of adhesion batters, there are wheat flour based, corn flour based, starch based and traditional (egg and milk based) batters (Kulp and Loewe, 1990).

1.2.2. Tempura Batter

Tempura/puff batter has a composition similar to that of adhesion batter, but with the addition of chemical leavening agents. Breading or breadcrumbs may also be included in tempura coating applications. Food coated with tempura batter has a puffy, bulky and crispy appearance. On the industrial scale, handling tempura batter requires special care. Common pumping machines used to transfer adhesion batter are not used to transfer tempura batter because pumping may have a detrimental effect on the leavening system. Extra precautions are needed when handling tempura batter.

1.3. Basic Ingredients of Batter

Basic ingredients of adhesion batter and tempura batter include wheat flour, corn flour, sodium bicarbonate, acid phosphate, salt, sugar, flavorings, seasonings and/or other specific ingredients tailored to specific food applications (Suderman and Cunningham, 1983). Functional behaviors of these ingredients have been widely researched and are briefly discussed in the following sections:

1.3.1. Wheat Flour

Wheat flour furnishes both protein and starch to a batter system. Between soft wheat flour and hard wheat flour, a batter coating made with soft wheat flour has better color after frying and requires less water during mixing, because soft wheat flour generally contains a lower level of damaged starch and less protein (Hoseney, 1994). Damaged starch has fractured granules, which swell up more by absorbing more water than undamaged granules, resulting in elevated batter viscosity. Therefore, to maintain a uniform viscosity, more water is needed if hard wheat flour is used in the dry mix.

The other main contribution to a batter system from wheat flour is protein. Commercial batter mixes can contain up to 15.75% of crude protein (Grodner et al., 1991).

Protein functions as a water, fat and flavor binder; it contributes color and textural characteristics to the coating. Gluten proteins found in wheat flour will develop a protein matrix during mixing and maintain structure of the coating after deep-fat frying (Kulp and Loewe, 1990; Novak et al., 1987). This protein matrix is especially important for gas retention in tempura batter to achieve and maintain an aerated and porous texture. Gluten protein also has a high water binding capacity that may contribute to toughness in the fried coating (Kulp and Loewe, 1990). Hard wheat flour, although it contains more gluten protein, is not a preferred choice because it also results in excessive browning, rough coating surface and excessive oil absorption during the deep-fat frying process (Olewnik and Kulp, 1993).

1.3.2. Corn Flour

Corn flour, the second major ingredient in dry batter mix, contains mainly starches and is used to fine-tune the batter viscosity. This in turn affects the pick-up and the amount of coating on the fried food (McGlinchey, 1994). Apart from adjusting the viscosity, corn flour also improves the flavor, color and texture of the fried coating. It is a carrier for spice blends and it also improves crispness and appearance of a fried food. The major component in corn flour is "starch". When compared on a weight-to-weight basis, starch binds significantly less water than protein and therefore, reduces the total water holding capacity of the batter and mellows the toughening effect of the gluten protein. Carotene pigments in yellow corn flour give fried products a natural golden brown color. Corn flour also extends the holding time of the fried product under heat lamps, gives lower greasiness, and improves freeze/thaw stability (Shinsato, 1999).

1.3.3. Leavening Agents

Sodium bicarbonate and acid salts make up the chemical leavening system in batter. A wide selection exists for the acid-leavening agents: tartaric acid, potassium hydrogen tartrate, monocalcium phosphate, sodium acid pyrophosphate, sodium aluminum phosphate, dicalcium phosphate dihydrate and sodium aluminum sulfate (Kulp and Loewe, 1990). Their reaction rates, addition levels and neutralization values determine the efficiency of the leavening systems. More than one acid salt is usually used to ensure carbon dioxide production throughout the lifetime of the batter. It is also important that the leavening system can withstand the temperature stress and agitation stress during the holding period.

1.3.4. Flavorants and Seasonings

Sugar, salt and other seasonings add flavor and visual changes to the coating. Different food substrates need different taste profiles. The choice of flavorants ranges from spices and herbs to liquid/spice extracts to artificial flavors. When choosing what flavor system to use, one has to take into consideration the type of food substrate involved, whether pre-dusting will be used and the cooking temperature (Kulp and Loewe, 1990). Some flavors complement very well with the target food substrates, while others do not result in tasty products. In addition to incorporating flavorants and seasonings in the dry mix, pre-dusting the food with special mixes is another way to add flavor. Cooking temperature is another important aspect in overall flavor development. If the cooking temperature is too high, volatile flavors will flash off easily. Therefore, one needs to make sure the chosen flavor system can withstand the cooking conditions to successfully deliver taste and aroma to the consumers. Other flavor concerns over time include: flavor migration within the food; color leaching by some flavorants like paprika; and settling of larger particulate flavorants during the hydrated state (Suderman, 1993).

1.3.5. Other Specific Ingredients

In commercial batter mixes, starches are modified in four different ways: oxidation, substitution, dextrinization and pre-gelatinizaiton (McGlinchey, 1994; Shinsato, 1999). Batters with oxidized and substituted starches adhere to the food substrates tighter. Dextrins increase crispness of the fried foods. High amylose starches give a more chewy and firm coating texture. Pre-gelatinized starches absorb more water and are used to fine-tune the batter viscosity.

Hydrocolloids are another type of specialty ingredient used in batter mixes. They function similarly to modified starch: control viscosity, control water absorption, form gels/films with other ingredients to resist handling abuse, serve as an oil barrier, and prevent moisture migration (Suderman and Cunningham, 19883; Kulp and Loewe, 1990; Hsia et al. 1992; Dow Chemical, 1997; Balasubramaniam et al, 1997). Examples of hydrocolloids include gelatin, carboxymethylcellulose (CMC), hydroxypropylmethylcellulose, guar gum, agar and xanthan. Hydrocolloids are sometimes preferred over modified starches because they perform well at much lower levels, resulting in a less diluting effect on the protein in the base batter.

1.3.6. Water

Water hydrates the ingredients and facilitates the development of a protein matrix in batter. Both amount and temperature of the water are important to the overall batter development. Batter is made up of one and a half to two parts batter mix with one part water (Suderman and Cunningham, 1983). The amount of water partially determines the viscosity of the batter; temperature of the water affects reaction rate of the leavening systems plus hydration degree of protein, starch and other minor ingredients. Water temperature is recommended to be between 40^0F - 60^0F (4^0C - 16^0C) for optimum batter preparation (Kulp and Loewe, 1990).

1.3.7. Oil and Shortening

Oil and shortening have two roles in batter-coated foods: they are ingredients in the coating, and they also are the heat transfer media during frying. As an ingredient, oil or shortening helps to lubricate the batter and tenderize the fried coating texture. As a frying media, oil transfers heat to set the shape of the coating and cook the food. Several types of oils or shortenings are usually used as frying media: soybean oil, cottonseed oil, corn oil, peanut oil, canola oil, palm oil and tallow (Kulp and Loewe, 1990). Each has its unique fatty acid composition and will produce different flavor, color, and texture characteristics in the final products. Therefore, an oil or shortening should be chosen to complement the target food system. The composition of fatty acids and degree of hydrogenation determine physical properties of an oil system. Oil with a low melting point and low solids content usually gives a cleaner, non-greasy mouthfeel (Kulp and Loewe, 1990). During the frying process, three chemical reactions occur in oil: hydrolysis, oxidation and polymerization (Bennion et al., 1976; Fritsch, 1981; Suderman and Cunningham, 1983). These three reactions cause most of the degradation in oil. Hydrolysis and oxidation result in an off, rancid flavor and foaming of the oil. Polymerization will darken the oil, increase the viscosity, cause foaming and increase oil absorption of the fried food. Therefore, quality of frying oil and the frying conditions need to be monitored carefully. Antioxidants, like polyphenolic compounds from defatted cottonseed flour, can be incorporated in the coating batter to slow down oil degradation (Rhee et al., 1992). As general guidelines, frying temperature should be between 360^0F - 380^0F (182^0C - 193^0C), and depending on the food substrates, the frying time can range from one minute for vegetables to 10 minutes for chicken pieces (Flick et al., 1989; Suderman and Cunningham, 1983).

1.4. Effect of Temperature on Batter Coating

In both commercial and household environments, food substrates for deep-fat frying may be stored in a frozen or cooled state. Temperature of the food substrates is known to affect adhesion of the coating batter (Suderman and Cunningham, 1983; Kulp and Loewe, 1990). Frozen broiler drumsticks can improve batter adhesion slightly (Suderman and Cunningham, 1983; Kulp and Loewe, 1990), as a smaller amount of crumb is lost upon cooling of the fried poultry. In the batter and breading industry, it is well known that the layer of frozen water on the seafood surface, called "ice glaze", will prevent good adhesion of coating batter (Kulp and Loewe, 1990). The smooth ice surface does not allow firm physical or chemical adhesion and results in extensive "blow off" during the frying process. Corrective measures like sprinkling salt onto the seafood surface or increasing the salt content in the predust can melt part of the ice glaze and lower the incidence of "blow off" during deep-fat frying (Kulp and Loewe, 1990).

1.5. Functions of Batter Coating

Coating is primarily used to enhance the appearance and taste profile of the food. It adds bulky appearance and color to the product. With flavors and spices, coating completes the flavor profile of the food. Batter coating gives a crispy texture and enhances the pleasure of eating. Batter coating also functions as a moisture barrier. Batter coating covers the entire food surface and absorbs the natural food juice that leaks out of the food. It also reduces oil uptake during frying (Nakai and Chen, 1986) and reduces dilution or loss of natural flavor volatiles from the food (Nawar et al., 1990). Depending on the choice of special ingredients, coating may also slow down the oxidation process in the frying oil.

1.6. Current Methods of Evaluating Batter Rheology

The batter and breading industry, like many areas in the food science field, is still using empirical means to evaluate properties of their batters. Although these methods serve to characterize the batter, the collective results are not easily compared. The collected measurements are unique to each method and each instrument. This makes cross comparison and transfer of knowledge quite difficult. Within the current batter and breading industry, there are five most commonly use instruments to measure batter viscosity: the Zahn cup, the Stein cup, the Brookfield viscometer, the Bostwick consistometer, and the Brabender Viscoamylograph (Kulp and Loewe, 1990).

1.6.1. Zahn Cup and Stein Cup

The Zahn cup and Stein cup are mostly used for on-line quality checks. The amount of time it takes to empty the batters through a small hole at the bottom of the cup indicates the fluidity of the batter. For thin batters, Zahn cups are preferred because of their smaller hole size, while Stein cups are more suitable for thick batters (Kulp and Loewe, 1990; Steffe, 1996).

1.6.2. Brookfield Viscometer

The Brookfield viscometer is another instrument commonly used to measure the viscosity of fluid material. The company manufactures quite a number of models that can operate with various spindles and revolution per minute (rpm) settings. Since batters exhibit non-Newtonian behavior (Hoseney, 1994), the properties measured by the Brookfield equipment are empirical. In addition, the measurements collected from different spindles have no correlation with each other and therefore interchanging use of models is not advised (Kulp and Loewe, 1990).

1.6.3. Bostwick Consistometer

The Bostwick consistometer is a trough type device. It has two compartments separated by a spring-loaded gate. On the floor of the inclined trough are markings that show the distance traveled by test material over time. When the gate is lowered to form a reservoir, batters are poured in until overflowing. Timing starts when the spring is released; the distance traveled by the batters after 30 seconds is recorded. Although the testing procedures seem simple, many factors exist that can invalidate the final readings. These include obtaining the consistometer level, timing, and reading the marking accurately.

1.6.4. Brabender Viscoamylograph

Brabender Viscoamylograph is another example of an empirical instrument used in the batter and breading industry. It was initially designed to characterize starch solutions during gelatinization. But from time to time, it has also been used to evaluate viscosity of batters. The batter samples in the rotating bowl are heated, held and cooled during the testing cycle. An amylogram with Brabender viscosity units are plotted against time to show the starch quality in the batter samples (Kulp and Loewe, 1990; Steffe, 1996).

1.7. Rheological Measurements and Techniques

1.7.1. Rheological Properties of Semi-Fluid Food

Eugene C. Bingham (1929) defines rheology as the study of flow and deformation. When force is applied, materials are deformed and exhibit either solid or fluid or both kinds of behaviors. Batters are one of those food that exhibit both elastic (solid) and viscous (liquid) behaviors (Baird et al., 1981). Since many fluid foods, including batters, exhibit negligible elastic behavior; the rheological properties are dominated by viscous behavior. Cunningham and Tiede (1981), Hsia et al. (1992), and Lane and Abdel-Ghany (1986) have reported a relationship between apparent viscosity and pick-up (percent coating weight). Hsia et al. (1992) also found batters have time-dependent behavior with apparent viscosity decreasing over time upon continuous mixing. When examining the time-independent behavior of batters, Hsia et al., (1992) and Castell-Perez and Mishra (1995) found that batters have a flow behavior index (n) of less than one and that they are shear-thinning materials.

1.7.2. Models for Shear-Thinning Fluids

Fluid foods can be broadly classified as Newtonian and non-Newtonian. On a rheogram, Newtonian fluids have a linear relation between shear stress and shear rate. Examples of Newtonian fluids are water, glycerol and vegetable oil (Barnes et al. 1989). For non-Newtonian fluids, the relation between shear stress and shear rate is non-linear. When the shear stress increases at an increasing rate with the shear rate, the fluid is known to exhibit shear-thickening or dilatant behavior. Examples for shear-thickening fluids are certain types of honey or a 40% corn starch slurry (Steffe, 1996). On the other hand, when the shear stress increases in a decreasing rate with the shear rate, the fluid is known to exhibit shear-thinning or pseudoplastic behavior. Examples of shear-thinning fluids are applesauce, fruit puree and orange juice concentrate (Steffe, 1996). A shear-thinning rheogram can be divided into three sections (Figure 1.1.): a lower Newtonian region, a middle region and an upper Newtonian region. At very low shear rates, the apparent viscosity, also called the limiting viscosity at zero shear rate (η_0), is constant

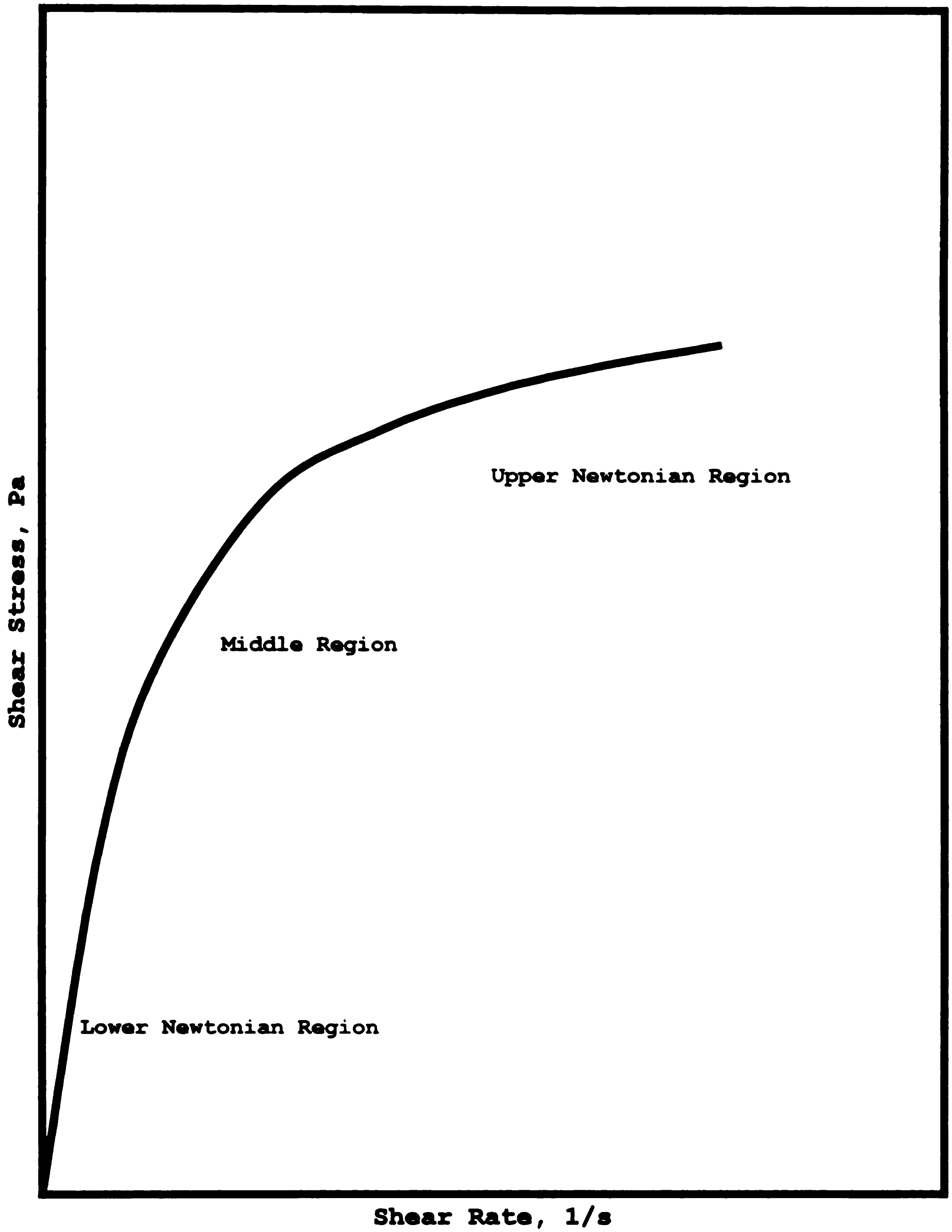


Figure 1.1. Rheogram for Shear Thinning Fluid.

against increasing shear rate (Figure 1.2.). The same phenomenon, but at much higher viscosity is observed again at very high shear rate. The limiting viscosity at infinite shear rate (η_∞) again is constant against increasing shear rate. The middle region of the curve can be mathematically represented with the power law equation:

$$\sigma = K(\dot{\gamma})^n \qquad [1]$$

For shear-thinning fluids, n is between zero and one. The power law equation is a special case of the Herschel-Bulkley Model (Steffe, 1996), which is able to represent many types of fluid behavior:

$$\sigma = K(\dot{\gamma})^n + \sigma_0 \qquad [2]$$

Rotational viscometers are very useful in studying shear-thinning properties of fluid food. These are fundamental testing instruments that shear test materials either under controlled stress or under controlled rate conditions. When choosing the controlled rate method, rheograms with shear stress plotted against shear rate can be generated. If power law trend line is fitted to the

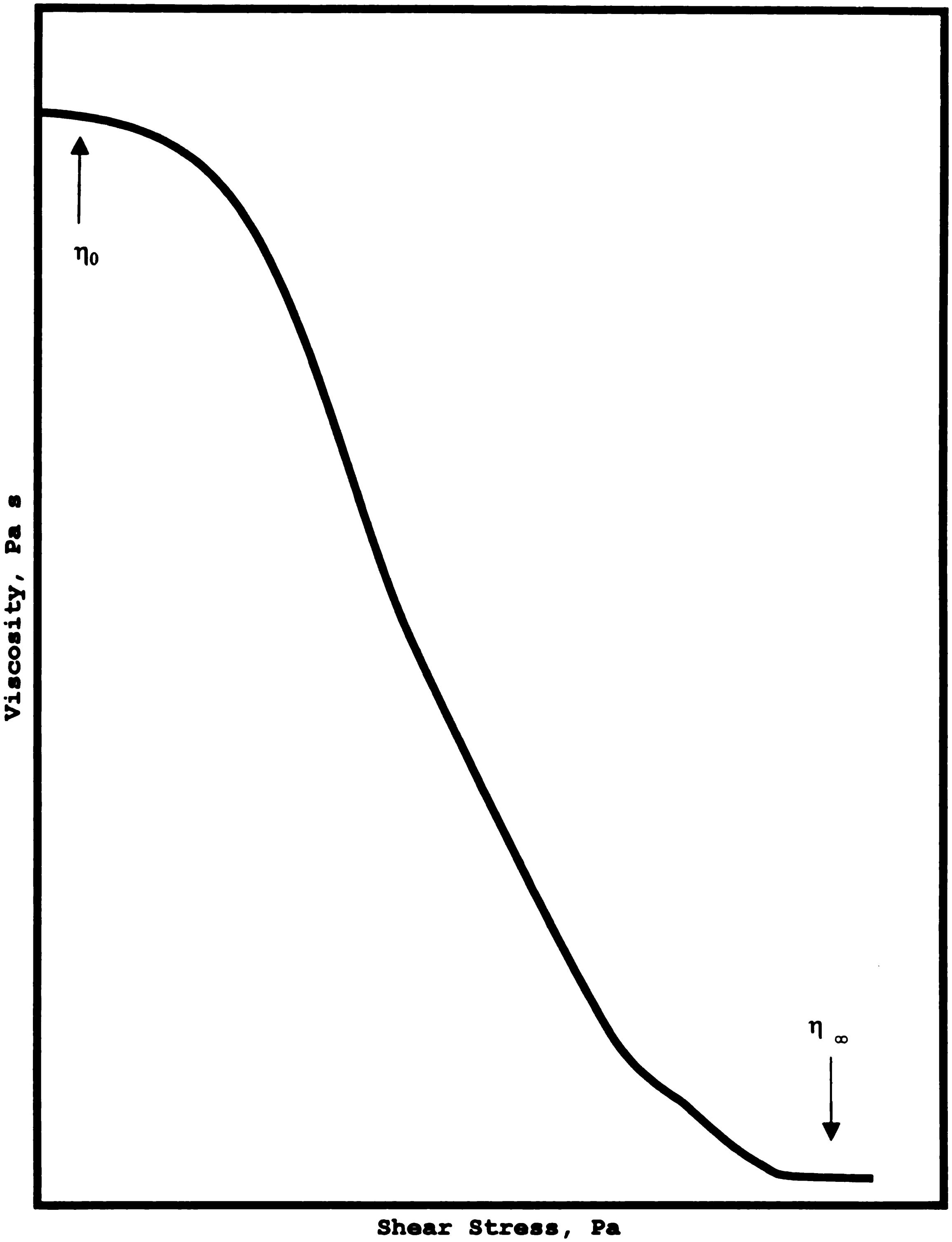


Figure 1.2. Viscosity of Shear-Thinning Fluid.

data, K and n values can then be determined. For batters, a parallel plate setting is preferred because undissolvable particles like spices may exist and generate too much interference when cone and plate sensors are used (Steffe, 1996).

1.7.3. Models for Time-Dependent Fluids

Another type of rheological behavior that non-Newtonian fluids could have is time-dependency. This behavior is caused by changes in the fluid structure over time (Steffe, 1996). Since ideal time-dependent fluids are inelastic, the response to external stress is instantaneous. The observed behavioral changes are not caused by a delayed response as for elastic materials. Within non-Newtonian fluids, there are two kinds of time-dependent behavior: thixotropic and rheopectic (Steffe, 1996). For thixotropic materials, shear stress and apparent viscosity decrease over time at fixed shear rates. This behavior is also described as time-dependent thinning. Rheopexy on the other hand, has increasing shear stress and apparent viscosity over time at constant shear rates, and is also known as time-dependent thickening. Examples of thixotropic fluids are baby food, yogurt and batters

(Steffe, 1996), and an example of rheopectic material is modified waxy corn starch (Rao et al., 1997).

Both thixotropic and rheopectic behaviors may be completely reversible, partially reversible or irreversible. Changes that thixotropic fluids undergo over time can be represented by the "sol-gel" transition as observed in baby food (Steffe, 1996). When the fluids are allowed to rest, they slowly develop three-dimensional networks that act like gel. When an external force, like shear, is applied, the three-dimensional networks are disturbed and the fluids exhibit minimum thickness. They are then referred to as being in the "sol" state. In the case of reversible thixotropic behavior, the three-dimensional network will rebuild and fluids will resume the "gel" state.

Rotational viscometers are very useful for detecting time-dependent behavior. They have the ability to alternately shear then rest the test material at controlled settings. Or the viscometers can ramp shear rate up and down and record behaviors of the materials on a rheogram. If hysteresis loops are generated in rheograms, then the test material exhibits time-dependent behavior (Figure 1.3.). A bigger area between the up and down curves (shaded area in Figure 1.3.) indicates greater time-dependent

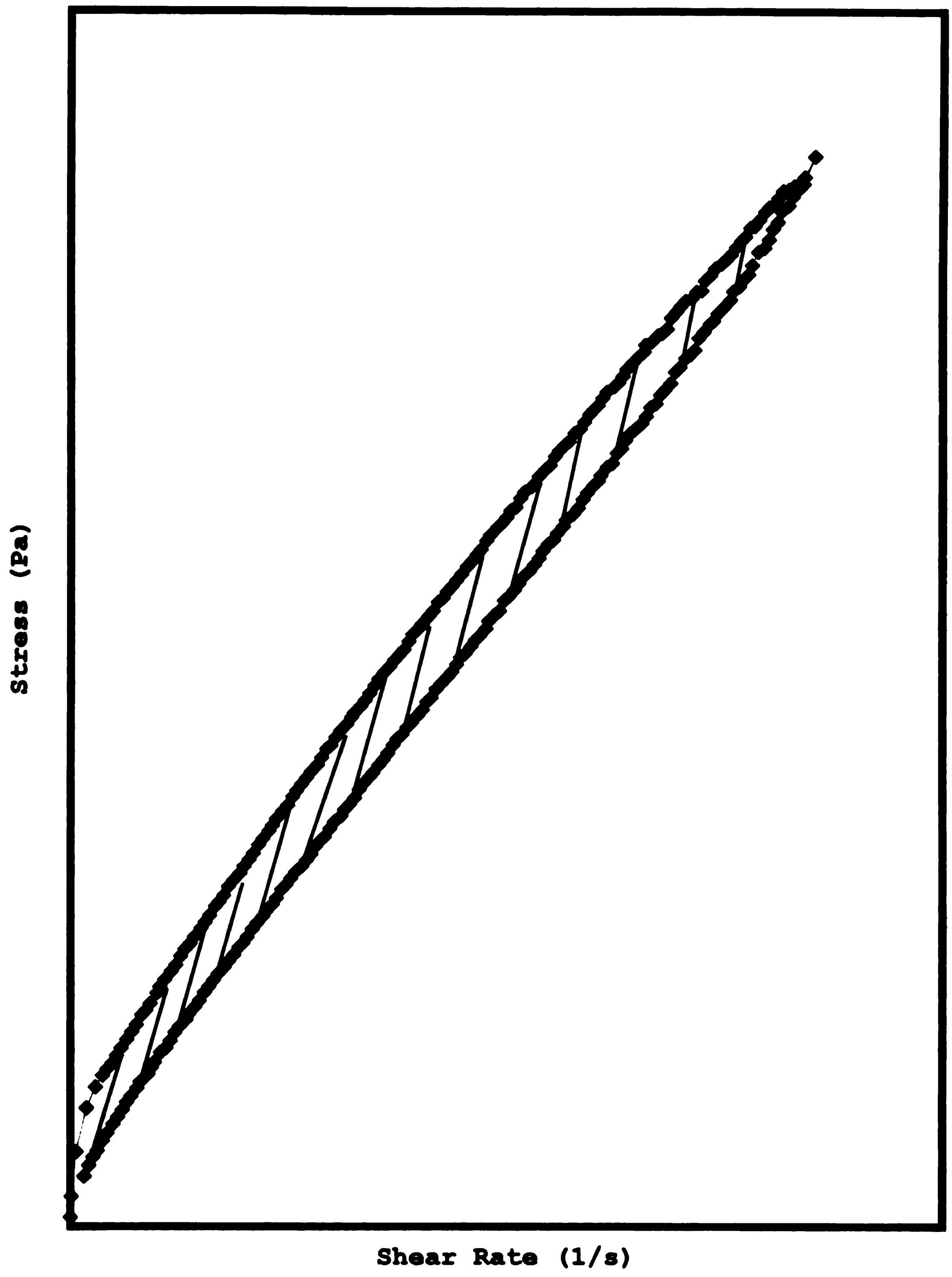


Figure 1.3. Hysteresis Loop.

behavior (Steffe, 1996).

1.7.4. Yield Stress in Coating Batters

Yield stress can be defined as the minimum amount of shear stress required to initiate flow. In fluid suspensions, the major factors causing yield stress are intermolecular hydrogen bonds and molecular entanglement (Heckman, 1977). There are many methods that can be used to evaluate the yield stress of fluid materials: Lang and Rha (1981) reported a comparison of some of them; others like Charm (1962) worked on Casson's equation; Churchill (1988) discussed measuring yield stress on an inclined plate; Kee et al. (1980) mentioned a static technique to measure yield stress; and Kee et al. (1988) proposed a method to measure postwithdrawal drainage of different types of fluids.

The method known as "vertical plate coating" measures the amount of fluid remaining on a plate after plate withdrawal from a sample (Lang and Rha 1981). In this technique, a test plate is fixed to a support to ensure it remains vertical throughout the test period. The plate is then lowered into the sample and raised up at preset rates. After dripping for a fixed period of time, the plate is weighed and the yield stress calculated as:

$$\sigma_0 = 2\rho hg \qquad [3]$$

To conduct this test, the surface of the plate needs to be slip proof and the minimum adhesive force between the plate and the coating material must be greater than the yield stress.

Churchill (1998) modeled shear stress on an inclined plate. The author expressed shear stress as a function of y:

$$\sigma = f(y) = g\rho(h - y)\sin\theta \qquad [4]$$

As y approaches zero, shear stress becomes maximum. If the maximum shear stress is greater than the yield stress, the coating material will flow down the plate due to gravitational pull. When the inclination angle is 90^0, Churchill's equation can provide a simplified expression for the maximum value of h:

$$h_{max} = \frac{\sigma_0}{g\rho} \qquad [5]$$

The above methods, although similar, do not result in identical yield stress values for the same material. Lang and Rha (1981) have reported similar observations. Therefore, when reporting yield stress values, one needs to specify how the yield stress data were collected.

1.8. Importance of Controlled Mixing

Mixing can be defined as "a unit operation that involves the intermingling of two or more dissimilar materials to obtain a desired degree of uniformity (Steffe, 1996)." In batter preparation, the main goal is to blend the dry powder with water until uniform and to keep the undissolved materials, like starch granules and spices, in suspension. The degree of mixing can affect batter performance. Batters not adequately mixed will have lumps of powder within them. This has an adverse effect on the consistency of coating thickness, resulting in poor product quality (Suderman and Cunningham, 1983).

One way to monitor the degree of mixing received by the batter is to calculate the amount of power consumed during mixing. Power consumption in mixing a power law fluid can be described with the following equation:

$$\frac{p}{d^5\Omega^3\rho} = \frac{A\eta}{d^2\Omega\rho} \qquad [6]$$

where :

$$\eta = K(\dot{\gamma}_a)^{n-1} \qquad [7]$$

$$\dot{\gamma}_a = k'\Omega \qquad [8]$$

To apply these equations, a range of experiments need to be done to find the k' value. One way is through the "Slope Method" (Steffe, 1996). The "Slope Method" requires power law fluid standards and is relatively simple. However, the disadvantage of the "Slope Method" is that small errors may become magnified into large errors as the power curve is plotted on a semi-log scale. The "Matching Viscosity Method" (Steffe, 1996) is another means to calculate k'. Fewer power law standard fluids are required but it is more labor intensive and there are more calculations involved.

A simple parameter known as the "Specific Mechanical Energy Input (SME)" can be used to monitor energy input into batters. SME is a popular calculation in the extrusion industry for determining the amount of energy used to mix materials (Onwulata et al., 1998; Choudhury and Gautam, 1998; Gogoi et al. 1996; Schwartzberg et al. 1995 and Lue et al. 1994). It relates energy input with time, speed, average torque, and mass of the test material:

$$SME = \frac{M_a * \Omega * t}{W} \qquad [9]$$

The calculations involved are easier to carry out and the mixing time and mixer speed can be changed during testing.

1.9. Methods Used to Evaluate Deep Fried Food

There are two main ways to evaluate a fried food: subjective evaluations using sensory methods or objective evaluations measuring the chemical and physical properties of the fried food. For sensory methods, a three-point scale or a nine-point hedonic scale is commonly used (Kulp and Loewe, 1990). Both require trained panelists and report results in average numbers. Many aspects of a fried food, like coating adhesion, presence of void, pillowing or blow-off during frying are concerns for evaluations (Suderman and Cunningham, 1983; Kulp and Loewe, 1990). Voids are bare areas on the food substrate not covered by the coating batter. This happens frequently when coating seafood. The problem can be caused by excessive line speed during commercial batter coating, unexposed areas on the seafood substrates, excessive or absence of pre-dusting materials, smooth surface of ice crystals outside the frozen seafood or air pockets trapped between seafood and batter during batter application.

A second defect in fried products is called "blow-off". Blow-off refers to pieces of batter that are ripped off the food during the frying process. The initial contact of wet batter and hot frying oil has a shocking effect on the batter. If there is excessive batter on the food substrate, it will be forced away from the food and fried as a separate entity. These blow-off units sink to the bottom of the fryer, clog the oil recycling systems, or float on the frying oil surface.

Another defect associated with blow-off is presence of air pockets on the fried food surface, called "pillowing". Pillowing is caused by water vaporizing during frying and is first noticed when food exits the fryer. Once cooled, the puffed pockets collapse and result in a wrinkled unappealing appearance. These puffed pockets usually are darker in color than other areas of the food product and are easily broken off during storage and transportation.

There are a number of objective evaluation methods widely used in the batter and breading industry. Each method tackles only a specific quality aspect of the fried products: Hunter and Agtron units measure the coating color; texture analyzer measures the coating compressibility; and specific AOAC methods (Official Methods of Analysis of AOAC International, 2000) analyze different amounts of nutrients present in the food and/or coating. On the aspect of coating adhesion, Suderman and

Cunningham (1983) calculate the percentage breading loss to reflect the degree of adhesion:

$$\%\ \textit{breading loss} = \frac{\textit{weight of lost breading crumb}}{\textit{drumstick weight with predip and breading} - \textit{towel-dried drumstick weight}} * 100 \qquad [10]$$

The US Government has regulations that the batter and breading industry must follow. Frozen battered and/or breaded seafood must meet the Code of Federal Regulations, title 21, chapter I, part 161, subpart B (CFR, 2000). This subpart specifies the minimum weight of seafood in each type of batter and/or breaded product. In addition, the United States Department of Commerce has outlined in its Seafood Inspection Program the standards for grading fishery products (USDC, 2000). The coated seafood products are to be graded in both frozen and cooked states. Final grade of the coated seafood is governed by a two-part inspection. The first part is a score deduction test and the second part is a subjective sensory evaluation. Appearance, uniformity, absence of defects and ease of separation in the frozen state are some areas of concern in the scoring deduction test. There are sub-areas within each area of concern for more detailed evaluation. The initial score of coated seafood is 100; pre-assigned points are deducted from the base score if defects are found. In the subjective sensory evaluation, flavor and odor of the cooked seafood are the main concerns. Results from both parts are then combined and the coated seafood is graded into three different categories: U.S. Grade A, U.S. Grade B and Substandard.

Chapter 2

Materials and Methods

2.1. Batters Tested

The three brand names for adhesion batter dry mixes used in this study were Dorothy Dawson's Batter Mix, Drake's Batter Mix, and Golden Dipt Batter Mix. The three brand names for tempura batter mix were Kikkoman Tempura Batter Mix, Tung-I Tempura Batter Mix, and Newly Wed Tempura Batter Mix. These mixes were either bought from the grocery store or acquired directly from the manufacturer. Out of these six brand names, only Dorothy Dawson's Batter Mix and Kikkoman Tempura Batter Mix were used in the mixing time and impeller speed test. For the frying test, Drake's Batter Mix was chosen to represent the adhesion batter and Kikkoman Tempura Batter Mix was chosen to represent the tempura batter. For the rest of the research, except the deep-fat frying test, all six brands of batter mix were evaluated.

2.2. Sample Preparation

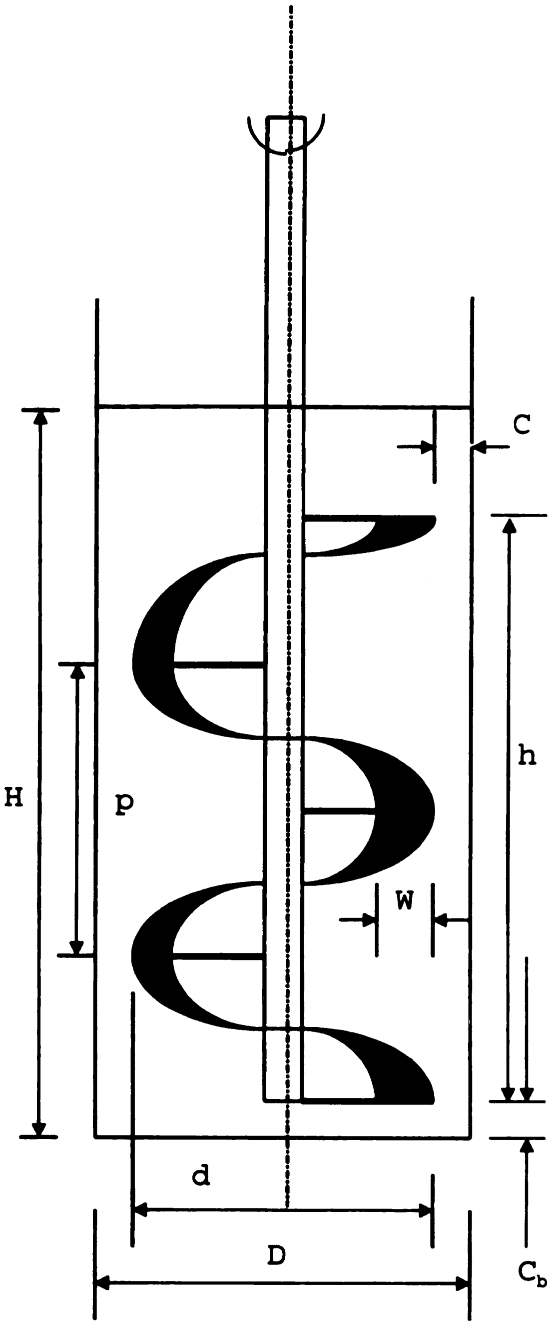
Fresh batter at 45.4%, 50.0% or 55.6% solids was prepared from Dorothy Dawson's Batter Mix and from Kikkoman Tempura Batter Mix. For both mixes, the manufacturers' recommended level was 50.0% solids. The remaining four brands of batter were prepared at two different levels of percent solids: the manufacturers' recommended level and 50.0% solids. Preparing the batter at the manufacturers' recommended level ensured batters were evaluated at the expected consistency. Preparing the batters at 50.0% solids set a common ground for comparison. Table 2.1. provides a detailed breakdown of the batter mix solids and water amounts according to brand name.

A fresh batter sample was mixed for each individual test to eliminate changes in batter properties over time. Batter was prepared by slowly adding mix powder to deionized water during the first two minutes of agitation. Agitation was accomplished with a helical ribbon mixing system (Figure 2.1.). During mixing, the helical screw was turned in a clockwise direction, lifting particles from the side of the mixing cup and circulating them down at the center. A Servodyne mixer head (Cole-Parmer Instrument Company, Model 5000-20) was used to carry out the controlled mixing. Desired mixing time and speed were entered at the control panel to adjust the mixing regimes. Torque, measured by the Servodyne mixer head, was read from the Servodyne mixer head window, and used to calculate the specific mechanical energy input (SME):

Table 2.1. Batter Compositions for the Six Different Brands of Batter Mix

Brand	% Solids	Water (g)	Batter Mix* (g)
Dorothy Dawson's Batter Mix**	45.4	76.4	63.6
	50.0	70.0	70.0
	55.6	62.2	77.8
Drake's Batter Mix**	50.0	70.0	70.0
	57.1	60.0	80.0
Golden Dipt Batter Mix**	50.0	70.0	70.0
Kikkoman Tempura Batter Mix***	45.4	76.4	63.6
	50.0	70.0	70.0
	55.6	62.2	77.8
Tung-I Tempura Batter Mix***	43.8	78.75	61.3
	50.0	70.0	70.0
Newly Wed Tempura Batter Mix***	43.6	79.8	60.2
	50.0	70.0	70.0

* Assume percent moisture in the batter mix is negligible to mimic the actual application.
** Adhesion Batter
*** Tempura Batter



where:

C = 0.40 cm

C_b = 0.25 cm

D = 5.20 cm

d = 4.40 cm

H = 6.25 cm

h = 5.00 cm

p = 2.50 cm

W = 0.80 cm

Figure 2.1. Dimension for Helical Ribbon and Sample Cup.

$$SME = \frac{M_a * \Omega * t}{W} \qquad [9]$$

2.3. Mixing Time and Impeller Speed

One type of adhesion batter mix (Dorothy Dawson's Batter Mix) and one type of tempura batter mix (Kikkoman Tempura Batter Mix) were chosen for this test. Results from this part of the experiment determined the mixing regimes for the remaining tests. Preliminary mixing tests were done on the batters to determine the mixing time and mixing speed used in this experiment. Both batters were mixed in two ways: 1) Constant mixing time with four different mixing speeds (Table 2.2.) and 2) Constant mixing speed with four different mixing times (Table 2.3.).

For Dorothy Dawson's Batter Mix, batter was prepared by mixing at 300 rpm for 2, 3, 4, and 6 minutes. It was also mixed for 4 minutes at 100, 200, 300 and 600 rpm. For the Kikkoman Tempura Batter Mix, batter was mixed at 270 rpm for 2, 2.5, 3 and 5 minutes. It was also mixed for 3 minutes at 70, 170, 270 and 470 rpm.

Immediately after mixing, batters were evaluated with a TA-XT2 Texture Anaylzer (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK). A rectangular Plexiglas probe, attached to the probe

Table 2.2. Constant Mixing Time with Four Different Impeller Mixing Speeds

Type of Batter	Time (min)	Impeller Mixing Speed (rpm)
Adhesion*	4	100
		200
		300
		600
Tempura**	3	70
		170
		270
		470

* Three brands used as adhesion batter samples are Dorothy Dawson's Batter Mix, Drake's Batter Mix and Golden Dipt Batter Mix.

** Three brands used as tempura batter samples are Kikkoman Tempura Batter Mix, Tung-I Tempura Batter Mix and Newly Wed Tempura Batter Mix.

Table 2.3. Constant Impeller Mixing Speed with Four Different Mixing Times

Type of Batter	Time (min)	Impeller Mixing Speed (rpm)
Adhesion*	2	300
	3	
	4	
	6	
Tempura**	2	270
	2.5	
	3	
	5	

* Three brands used as adhesion batter samples are Dorothy Dawson's Batter Mix, Drake's Batter Mix and Golden Dipt Batter Mix.

** Three brands used as tempura batter samples are Kikkoman Tempura Batter Mix, Tung-I Tempura Batter Mix and Newly Wed Tempura Batter Mix.

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carrier of TA-XT2, was lowered into the batter and then removed at a rate of 10mm/s for 100 mm. The plexiglas probe was taken down immediately after the probe carrier of the Texture Analyzer stopped moving (time zero) and the probe coated with batter was weighed on an analytical balance to determine the amount of batter picked up by the probe. The weight of batter picked up by the probe at time zero was plotted against the SME value for that particular batter. The mixing regime resulting in the highest amount of batter retained on the probe at time zero was used to mix that batter type for the remaining tests.

2.4. Batter Retention

All six brands of batter mix were involved in this part of the research. Right after mixing, a fresh sample was evaluated with the Texture Analyzer. A known area of the Plexiglas probe was lowered into the batter and programmed to be withdrawn at a speed of 10 mm/s for 100 mm. After that, the probe was held in position for up to 300 seconds. During this period, the weight of batter retained on the probe was measured and was plotted against time.

Assuming a uniform coating on the Plexiglas probe, yield stress of a batter can be calculated as follows:

First, the volume of batter retained on the Plexiglas probe (V) is calculated by measuring the weight of batter retained on the probe (w) and dividing it by the density of the tested batter (ρ):

$$V = \frac{w}{\rho} \qquad [11]$$

From V, thickness of the coating on the probe (h) can be found with the total immersed surface area (x):

$$h = \frac{V}{x} \qquad [12]$$

Finally, h can then be inputted to calculate yield stress (σ_0) of the batter:

$$\sigma_0 = h\rho g \qquad [13]$$

2.5. Steady Shear Rheological Testing

All six brands of batter mixes were involved in this portion of the research. After mixing, steady shear properties of fresh samples were evaluated with a Haake RS-100 rheometer (Haake Inc., Paramus, N.J.). Since adhesion batters may contain grainy particles, the parallel plate geometry with a 2 mm gap size was used. For tempura batters, gap size was reduced to 1 mm. For the adhesion batters, steady shear properties were tested by ramping shear rate between 0.16 s^{-1} and 50 s^{-1}. Each test was run for 600 seconds with 50 measurement points distributed evenly within the shear rate range. For tempura batters, the steady shear properties between 0.16 s^{-1} and 20 s^{-1} were studied. Each test lasted 120 seconds with 20 measurement points distributed evenly within the shear rate range. Rheogram data and power law properties of batters were collected. Tempura batter was tested up to 20 s^{-1} only, because edge failure was observed beyond 20s^{-1}. Tempura batter at mid-height of the gap started to recess then leak out from the top and bottom surfaces of the parallel plates. This caused a sharp drop in shear stress indicating maximum shear rate for tempura batter in this 1-mm parallel plate setting had been reached.

2.6. Influence of Holding Period on Batter Retention

The Texture Anaylzer and the Haake RS-100 were both used to evaluate the batters during a three-hour holding period. Batter was allowed to rest for 0, 5, 10, 15, 20, 25, 30, 45, 60, 75, 90, 120, 150 and 180 minutes after preparation. At the designated time, a known area of a

Plexiglas probe was lowered into, and removed from, the batter. The amount of batter picked up by the probe at time zero was then weighed. For the studies with the Haake RS-100, steady shear testing, set as ramping up only, was done at 0, 15, 30, 45, 60, 90, 120, 150 and 180 minutes to detect time-independent behavior. The collected shear stress at 15 s^{-1} shear rate is reported as apparent viscosity:

$$\eta = K(\dot{\gamma})^{n-1} \qquad [14]$$

2.7. Deep-Fat Frying

Drake's Batter Mix and Kikkoman Tempura Batter Mix were the two batters used in this test. They were mixed at the manufacturers' recommended levels, 57.1% and 50.0% solids, respectively. Each type of batter was mixed at three different speeds of agitation, with a constant mixing time for each regime. Three kinds of food (Singleton brand frozen cocktail shrimp, Meijer brand string cheese and fresh cucumbers) were used as food substrates for coating. Shrimp were thawed overnight in the refrigerator and cucumbers were cut into ¼ inch slices and blanched for one minute prior to the test. The food substrates were pre-dusted with Golden Dipt Predusts Mix before being dipped into batters. Shrimp and string cheese were coated with adhesion batters while sliced cucumbers and shrimps were coated with tempura batters. All samples were dripped for two minutes before frying. Table 2.4. lists batter mixing and frying conditions. Before the coating was applied, groups of five shrimp or sliced cucumber pieces with similar size and shape were pre-picked. This ensured food substrates having similar weight and coating surface area. Each frying test was repeated three times. Two small deep-fat frying cookers were used to fry the coated food. The frying media was Meijer brand canola oil and the frying temperature was 360^0F - 380^0F (182^0C - 193^0C). New oil was used each day to avoid interference from oxidized oil. Finally, food products were evaluated according to their weight change and appearance. An evaluation sheet (Figure 2.2.) was filled out after cooling to note the observations during coating and frying. The percent increase in weight (ΔF_c) after coating was calculated as:

$$\Delta F_C = \frac{F_2 - F_1}{F_1} * 100 \qquad [15]$$

Table 2.4. Type of Food Substrate, Mixing Regime and Frying Time for Adhesion and Tempura Batters

Batter	% Solids	Food Substrate	Food Piece/ Group	Mixing Time (min)	Mixing Speed (rpm)	Frying Time (min)
Adhesion*	57.1	Shrimp	5	4	100	1.5
					300	
					600	
		String Cheese	4	4	100	1.0
					300	
					600	
Tempura**	50.0	Shrimp	5	3	70	1.5
					270	
					470	
		Sliced Cucumber	5	3	70	1.5
					270	
					470	

* Drake's Batter Mix was used as the adhesion batter.

** Kikkoman Tempura Batter Mix was used as the tempura batter.

Type of Batter: ______________________________

Solids Ratio:

____

Mixing Time: ______________________________

Mixing Speed: ______________________________

Food Substrate: ______________________________

Weight before Coating: ______________________________

Weight after Coating: ______________________________

% Change in Weight: ______________________________

Thickness of Food: ______________________________

Thickness of Fried Food: ______________________________

Thickness of Coating: ______________________________

During Coating:

Void: ______________________________

(If yes) Reason 1: Shape ______________

Reason 2: Air pocket ______________

Reason 3: Batter too thin ______________

During Frying:

Blow off: ______________________________

Pillowing: ______________________________

Color: ______________________________

Texture: ______________________________

After Cooling:

Weight of Fried Food: ______________________________

Weight of Coating: ______________________________

Figure 2.2. Evaluation Form for Deep-Fat Fried Food.

Thickness of coating (T) is calculated as:

$$T = \frac{T_1 - T_0}{2} \qquad [16]$$

Weight percent of coating in final fried food (ΔF) is calculated as:

$$\Delta F = \frac{F}{F_3} * 100 \qquad [17]$$

Chapter 3

Results and Discussion

3.1. Optimum Mixing

Optimum degree of mixing occurs when the maximum amount of batter is retained on the probe. The amount of batter retained is determined by the amount of energy input during mixing. It was found that batters with higher percent solids needed more energy to achieve optimum mixing. When plotting batter retention against specific mechanical energy input (Figure 3.1.), an optimum mixing curve was found. In this study, the part of the optimum mixing curve to the left of the peak was considered as the region of under-mixing while the part of the curve to the right of peak was considered as the region of over-mixing.

As shown in Figure 3.1., Dorothy Dawson's Batter at 55.6% solids received optimum mixing when the SME was between 2,500 and 3,500 N m/kg. For batter at 50.0% solids, optimum mixing occurred when SME was approximately 1,000 N m/kg, and at 45.4% solids, optimum mixing was achieved when SME was approximately 350 N m/kg. Results from Kikkoman Tempura Batter Mix were shown in Figure 3.2. Batter at 55.6% solids received optimum mixing when SME was approximately 1,600 N m/kg. When the batter was at 50.0%

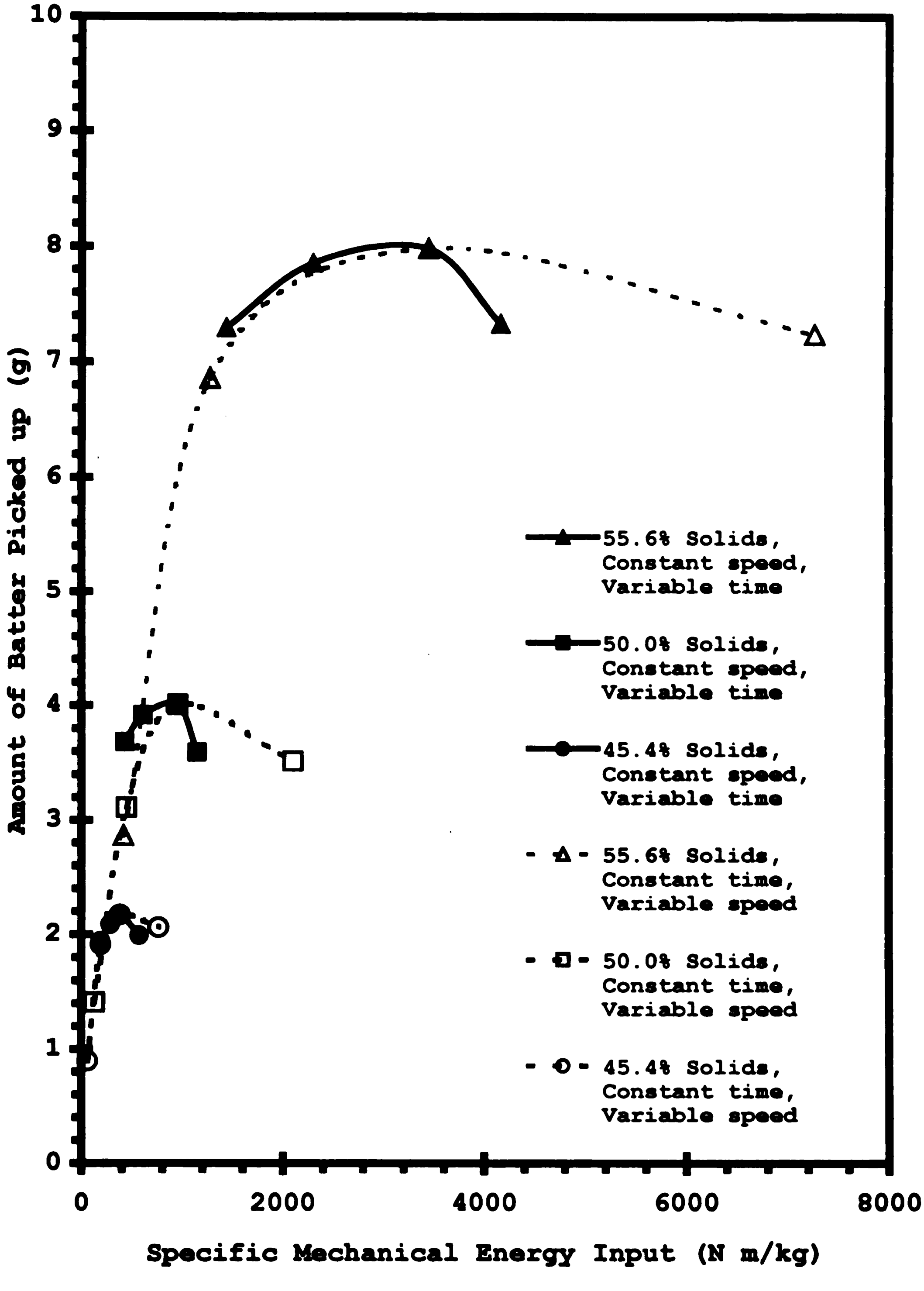

Figure 3.1. Amount of Dorothy Dawson's Batter Picked up by the Probe at Time Zero in Relation to the Specific Mechanical Energy.

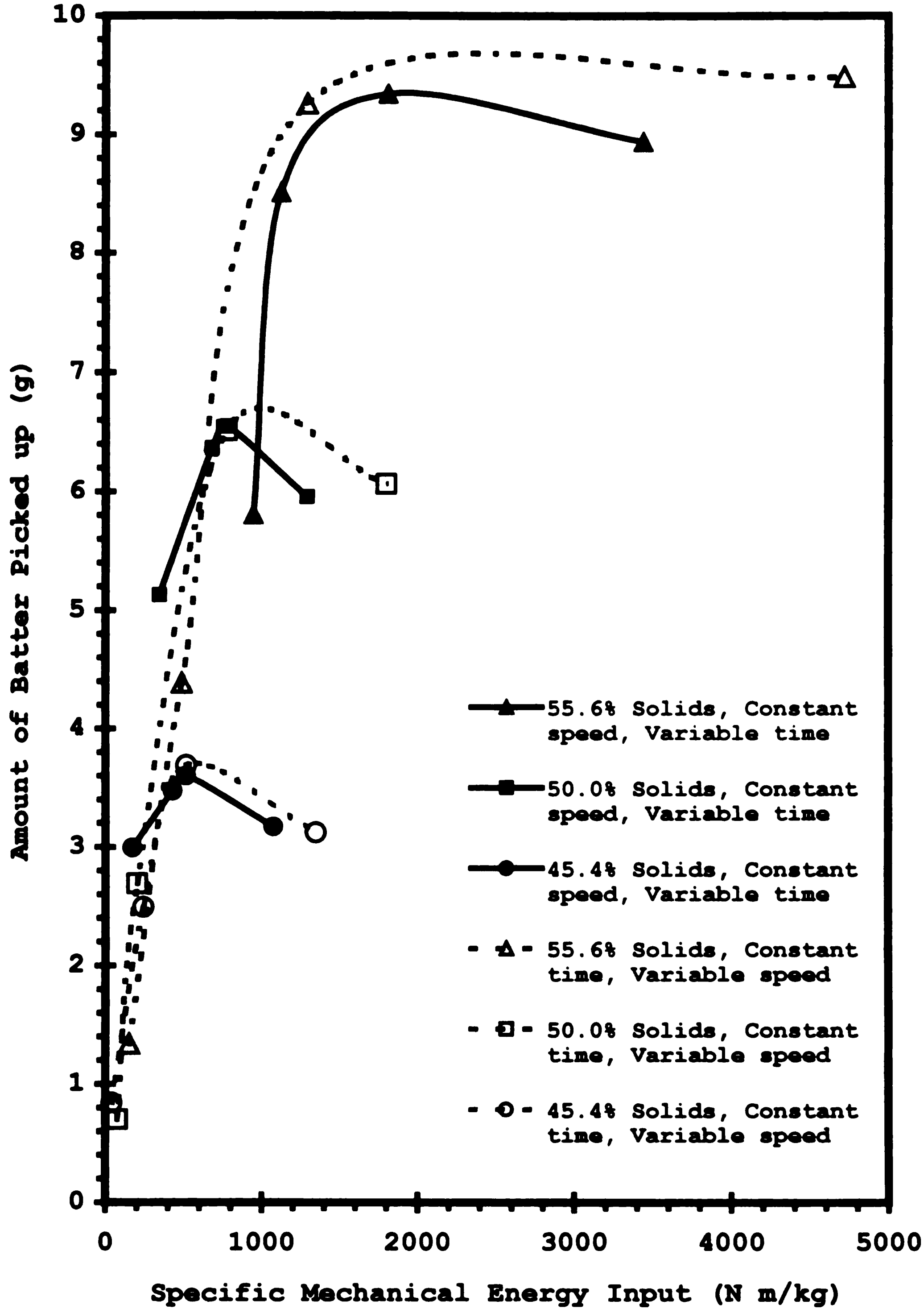

Figure 3.2. Amount of Kikkoman Tempura Batter Picked up by the Probe at Time Zero in Relation to the Specific Mechanical Energy.

solids, optimum mixing was found when SME was between 700 and 1,000 N m/kg; and when batter was at 45.4% solids, the optimum energy input was 600 N m/kg. This shows that for both brands of adhesion batter and tempura batter tested in this part of the studies, the amount of energy needed to obtain optimum-mixing increases with percent solids. Extra energy is needed to blend the additional solids to uniform consistency.

Kikkoman Tempura Batters at different percent solids behaved differently when they were over-mixed. For the 45.4% solids and 50.0% solids batters, the batter amount retained on the probe decreased quickly after the SME exceeded the optimum level of 600 N m/kg and 1,000 N m/kg, respectively. But for batters with 55.6% solids, the batter amount retained on the probe remained fairly constant after the SME amount exceeded the 1,600 N m/kg optimum level. This shows that Kikkoman Tempura Batter at higher percent solids can withstand more over-mixing than batters at lower percent solids. Additional experiments need to be conducted to confirm this behavior.

3.2. Batter Retention over Time

Dripping of most adhesion batters stabilized after two minutes (Figure 3.3.). Drake's Batter Mix at 57.1% solids was the only one that required more than two minutes to stabilize. Viscosity of this batter was so high that dripping did not stabilize within the five-minute test period. This high viscosity was caused by the large amount of solids in the batter. The large quantities of gluten proteins and starches formed more networks during mixing and resulted in a stringy batter. Golden Dipt Batter Mix at 50.0% solids showed a similar dripping curve as Drake's Batter Mix at 57.1% in the beginning, but it quickly stabilized after 120s: with fewer solids in the batter, fewer networks were formed during mixing resulting in a less stringy batter. Generally, batters with lower percent solids need a shorter time period to stabilize dripping. Dorothy Dawson's Batter at 55.6% solids took two minutes to stabilize dripping; at 50.0% solids, it took about one minute; and at 45.4% solids, it took only 40 seconds.

The times required to stabilize dripping of the tempura batters were plotted in Figure 3.4. All tempura batters stopped dripping after three minutes. Kikkoman Tempura Batter at 55.6% solids took three minutes to stabilize dripping; at 50.0% solids, it took two minutes

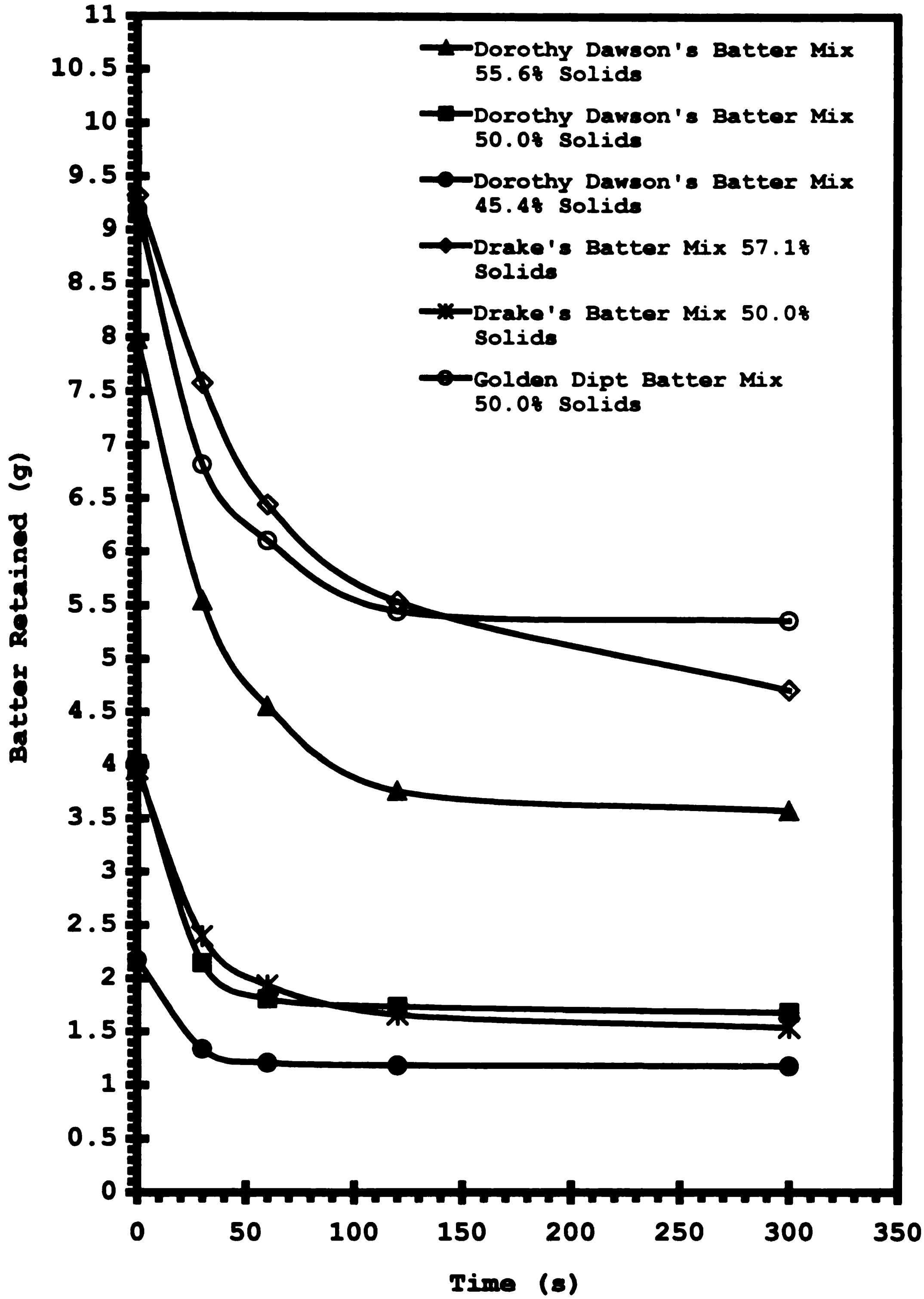

Figure 3.3. Amount of Adhesion Batter Retained over a 5-minute Drip Period at 20°C.

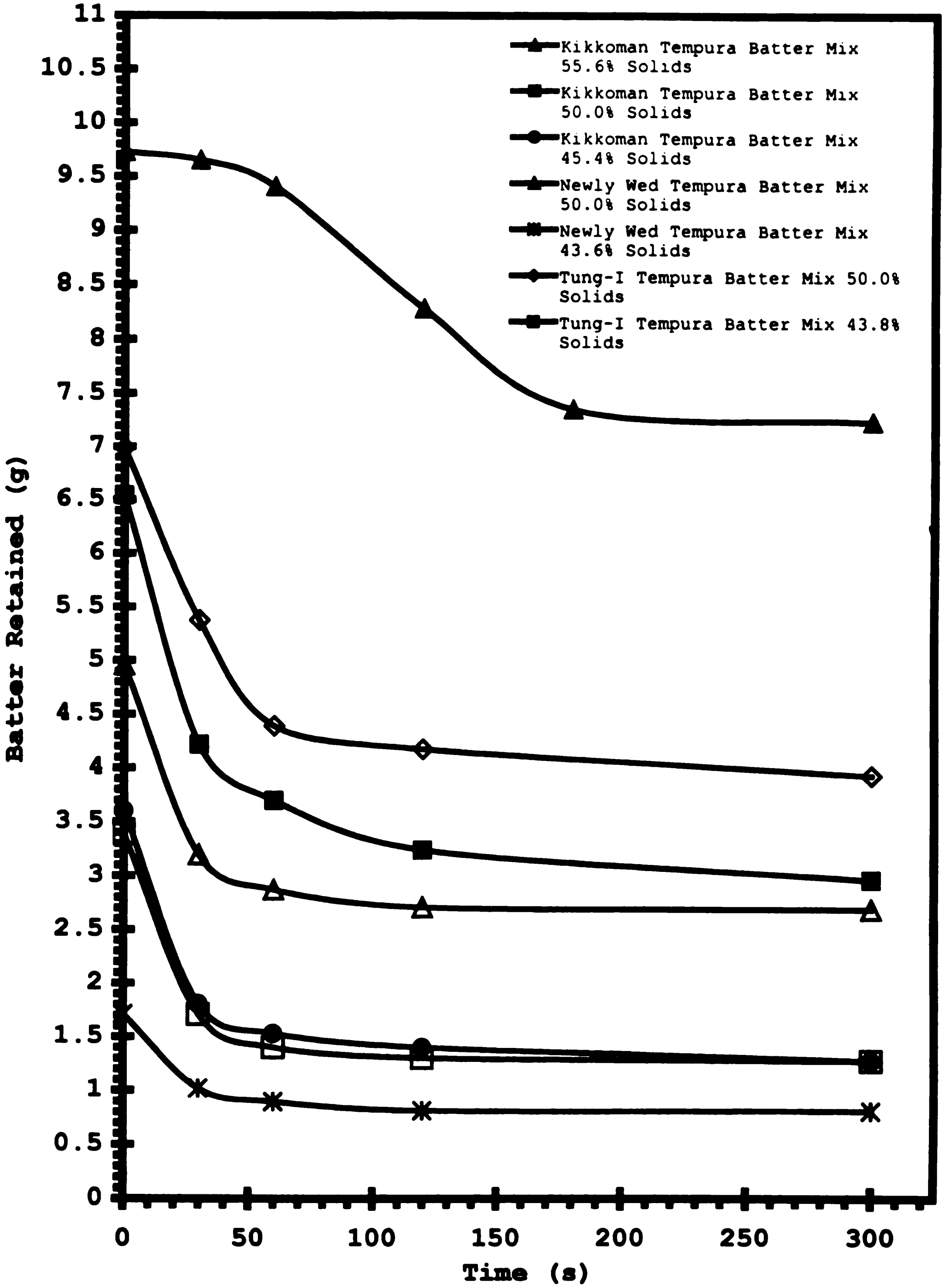

Figure 3.4. Amount of Tempura Batter Retained over a 5-minute Drip Period at 20°C.

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thirty seconds; and at 45.4% solids, it took one minute to stabilize dripping. The same trend in dripping time relative to percent solids was observed for both Kikkoman Tempura Batter and Dorothy Dawson's Batter: the higher the percent solids, the longer the time needed to stabilize dripping.

Another phenomenon observed (Figures 3.3. and 3.4.) was that at the same percent solids, batter mixed from different brands did not result in similar levels of batter retention on the probe after drip stabilization. The greatest difference was noticed for adhesion batters. At 50.0% solids, Dorothy Dawson's Batter Mix and Drake's Batter Mix had around 1.7g of batter retained on the probe. But at the same level, Golden Dipt Batter Mix had 5.4g of batter retained, which was three times more than the amount retained by the other two brands. This reflected the great influence batter ingredients had on the viscosity and adhesion characteristics of the hydrated batter mixes.

Yield stress values of the batters were also determined in this part of the experiment and recorded in Table 3.1. Generally, density of the batters, amount of batter retained at time zero, and yield stress values all increased as percent solids in the batters increased. Dorothy Dawson's Batter Mix at three different percent

Table 3.1. Calculated Yield Stress of Adhesion and Tempura Batters

Brand	% Solids	Density (g/cm^3)	Batter Retained (g)	Yield Stress (Pa)
Dorothy Dawson's Batter Mix	45.4	1.15	2.18	4.99
	50.0	1.16	4.01	9.20
	55.6	1.19	7.98	18.31
Drake's Batter Mix	50.0	1.14	3.96	9.08
	57.1	1.20	9.32	21.39
Golden Dipt Batter Mix	50.0	1.16	9.19	21.08
Kikkoman Tempura Batter Mix	45.4	1.10	3.60	8.26
	50.0	1.14	6.54	15.01
	55.6	1.18	9.73	22.31
Tung-I Tempura Batter Mix	43.8	1.12	3.39	7.78
	50.0	1.15	6.99	16.03
Newly Wed Tempura Batter Mix	43.6	1.07	1.71	3.92
	50.0	1.11	4.96	11.37

solids batters had very close density readings, falling between 1.15 and 1.19 g/cm^3. The amount of batter retained on the probe at time zero for these three different percent solids batters, on the other hand, had a wide range varying from 2.18 g to 7.98 g. This wide range of readings were magnified when the yield stress values were calculated. Hence, yield stress values for the Dorothy Dawson's batter samples ranged from 4.99 to 18.31 Pa. Results similar to those found from the Dorothy Dawson's batter were also observed with the remaining brand batters.

3.3. Thixotropic Behavior and Power Law Fluid

Thixotropic loops of all six brands were plotted in Figures 3.5. to 3.10. Among the three brands of adhesion batter mixes, batters made from Drake's Batter Mix exhibited almost no thixotropic behavior. Batters made from Dorothy Dawson's Batter Mix and Golden Dipt Batter Mix showed some degree of thixotropic behavior. As the percent solids increased in Dorothy Dawson's batter, thixotropic behavior increased. The tested shear rate range for Golden Dipt Batter was between 0.16 s^{-1} and 20 s^{-1} only because beyond this range, the rheometer started to show erratic results: shear stress values increased and decreased randomly and dramatically. Within the 0.16 s^{-1} to 20 s^{-1}

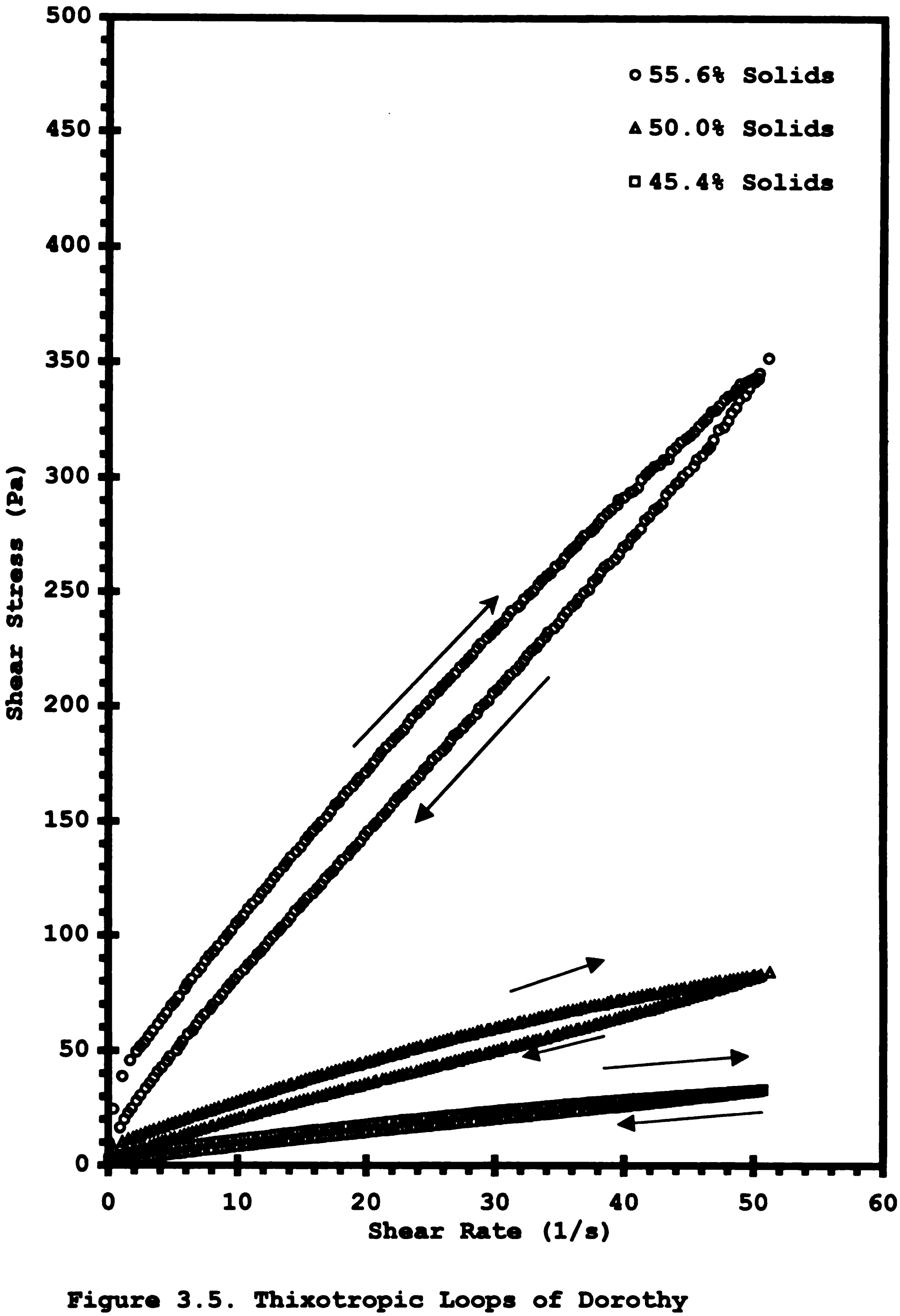

Figure 3.5. Thixotropic Loops of Dorothy Dawson's Batter Samples at 20°C.

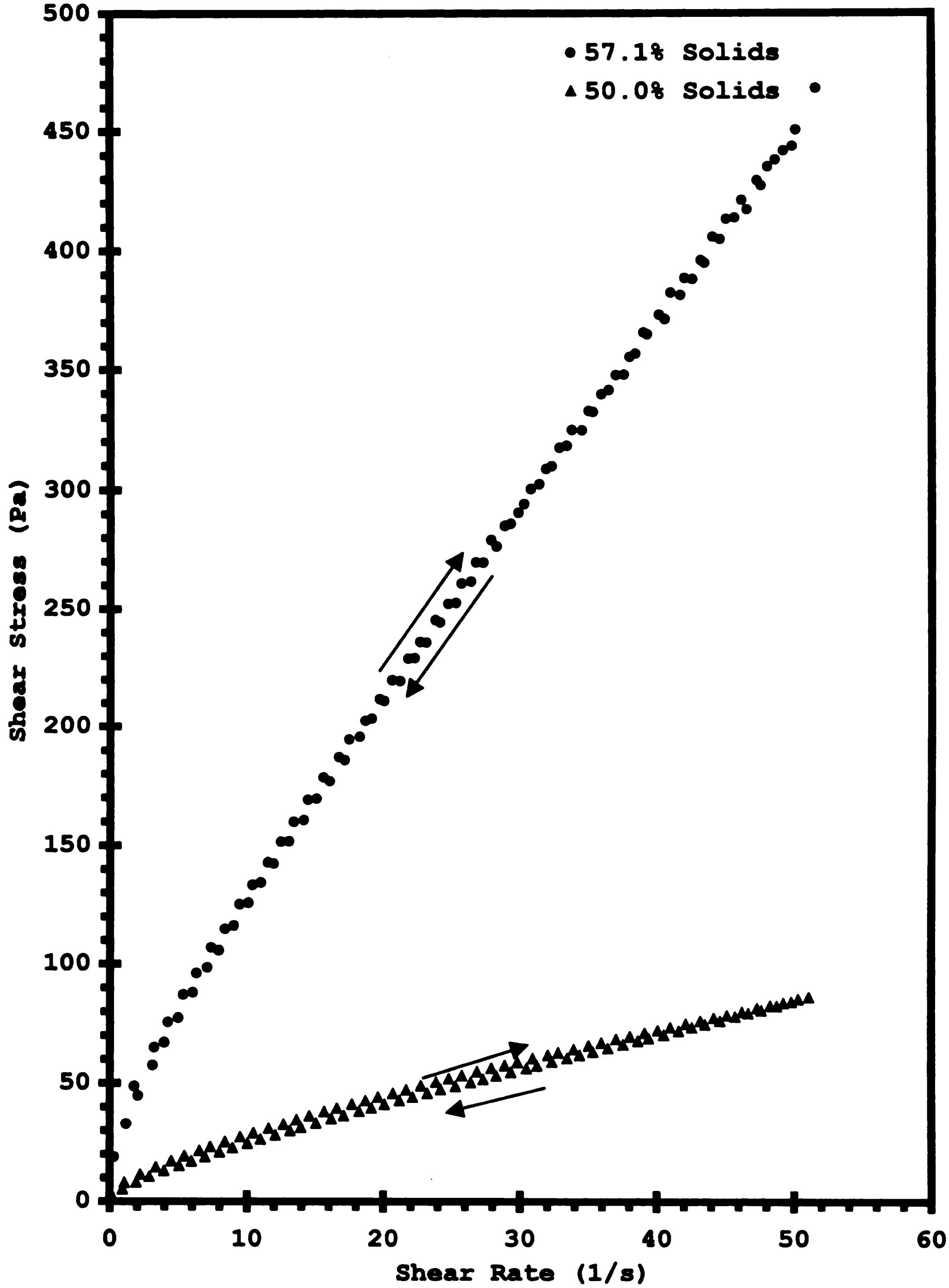

Figure 3.6. Thixotropic Loops of Drake's Batter Samples at 20^{0}C.

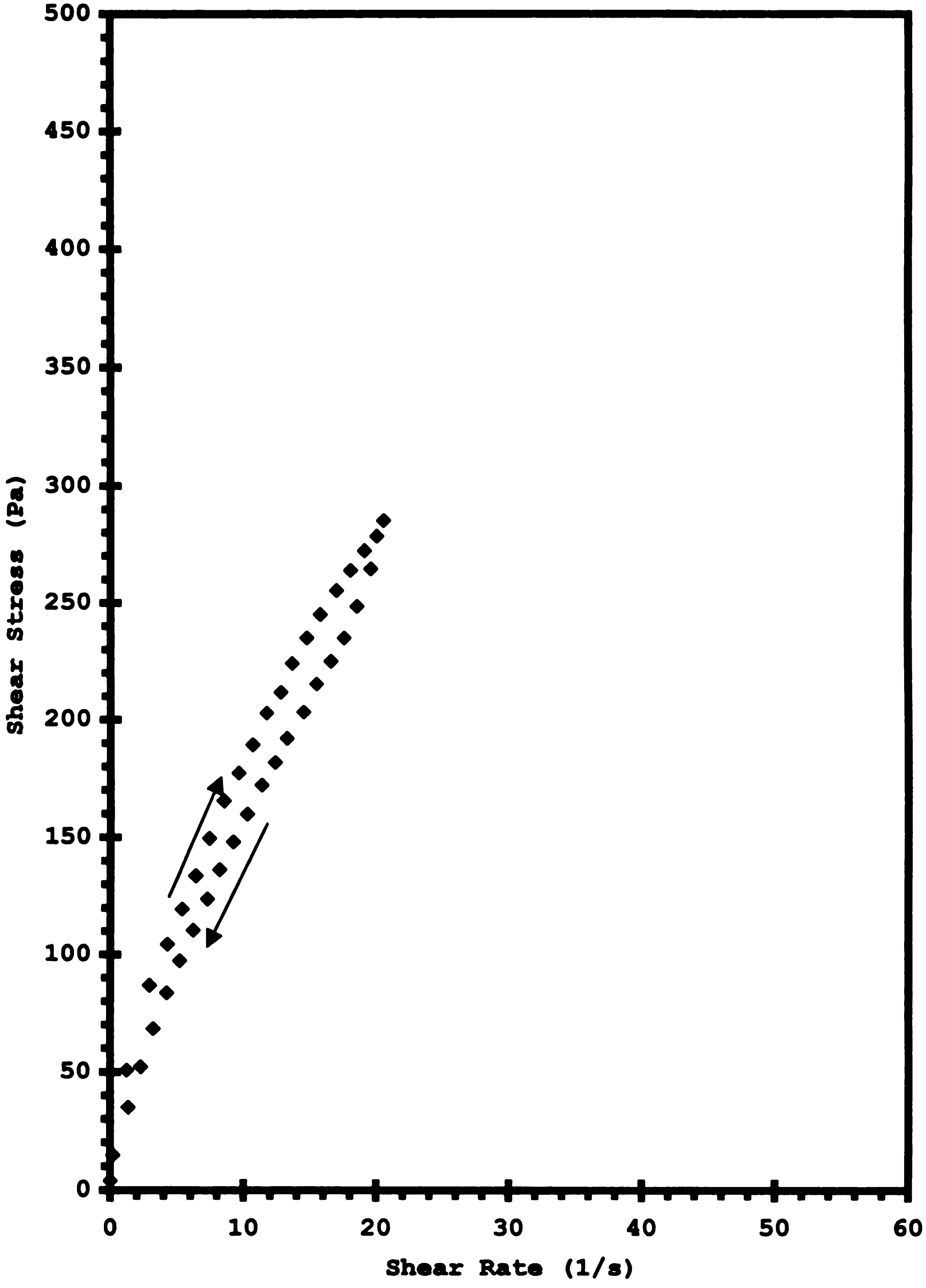

Figure 3.7. Thixotropic Loop of 50.0% Solids Golden Dipt Batter at 20^{0}C.

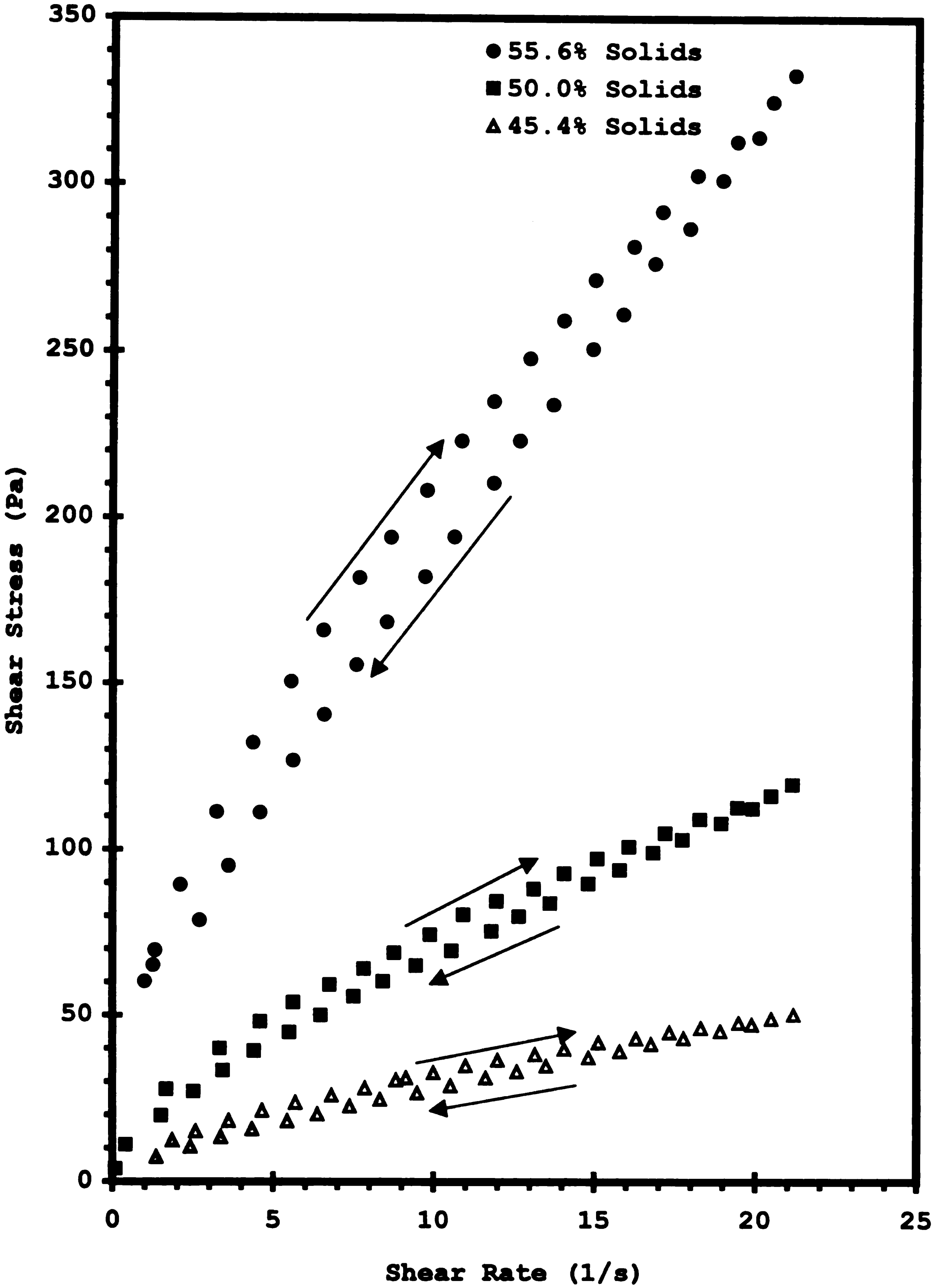

Figure 3.8. Thixotropic Loops of Kikkoman Tempura Batter Samples at 10°C.

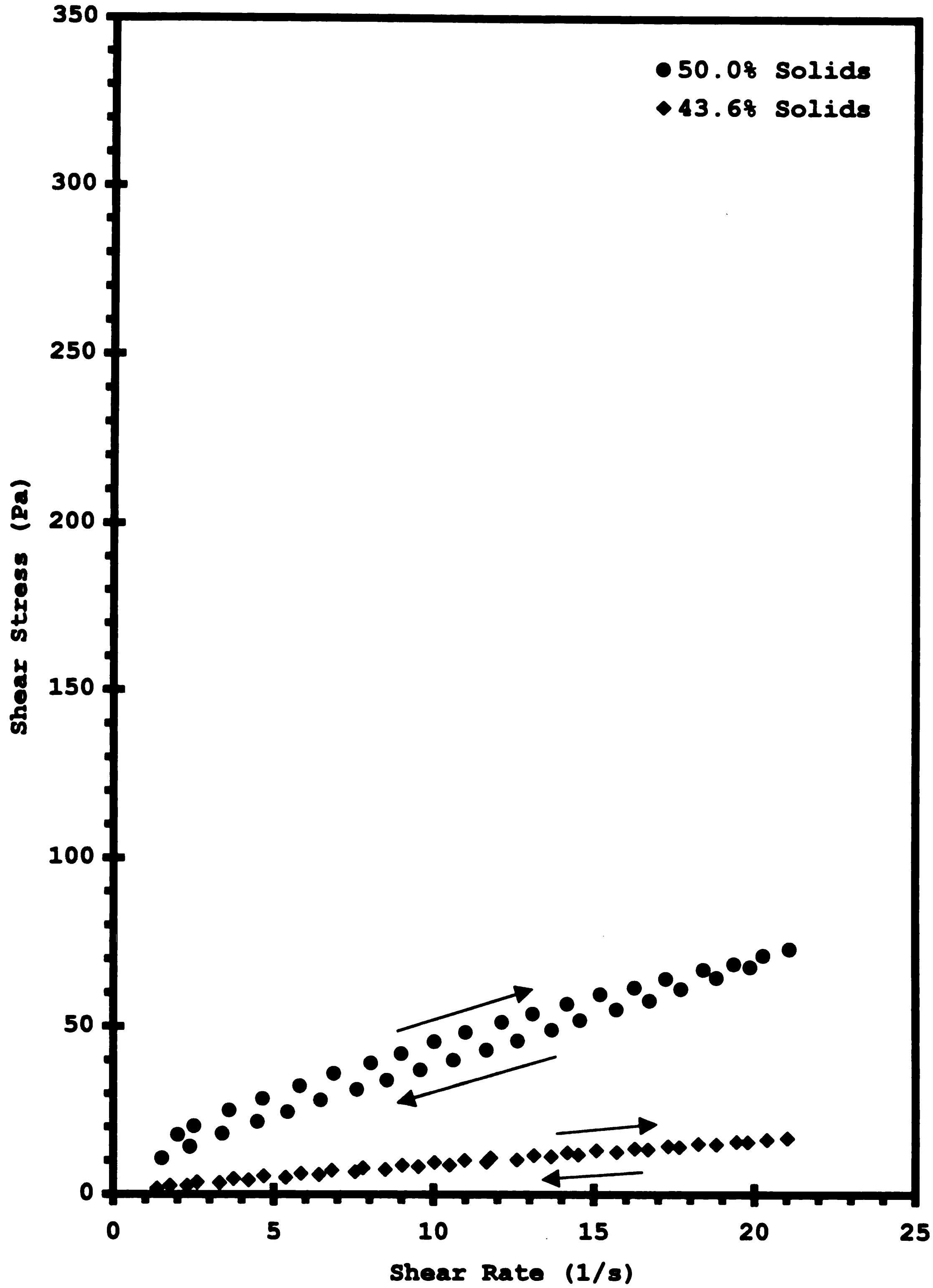

Figure 3.9. Thixotropic Loops of Newly Wed Tempura Batter Samples at 10°C.

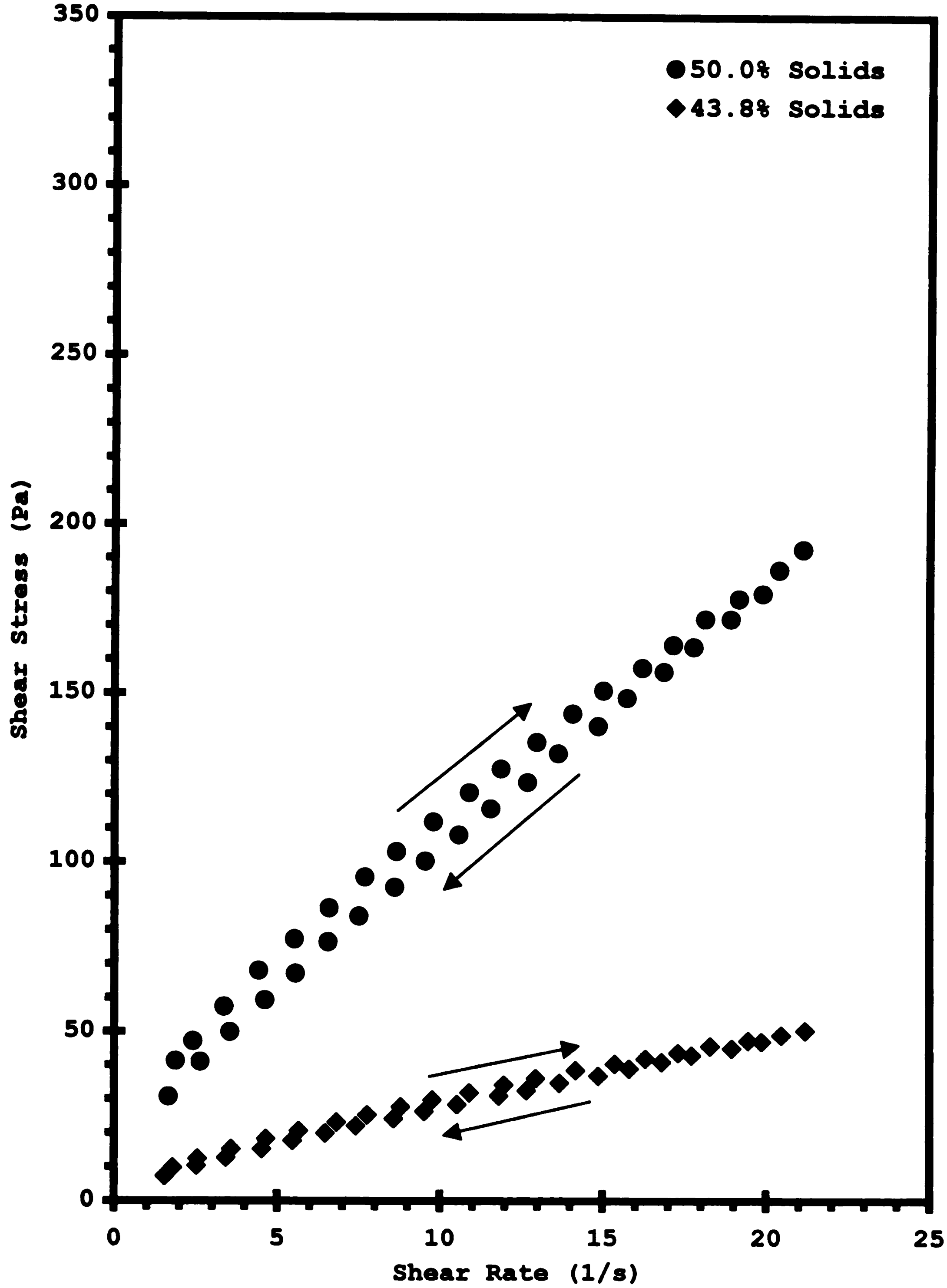

Figure 3.10. Thixotropic Loops of Tung-I Tempura Batter Samples at 10°C.

shear rate range, all three tempura batter mix brands showed some degree of thixotropic behaviors. Like the Dorothy Dawson's batters, degree of thixotropic behavior increased with increase in percent solids.

Power law properties of the six adhesion and tempura batter mix brands are summarized in Table 3.2. All K values were greater than one and all n values were smaller than one. Low n values mean both adhesion and tempura batters exhibit shear-thinning behavior. The K values behaved in the same way for adhesion and tempura batters: increasing as percent solids increased. In Newtonian and Bingham plastic fluids, K is more commonly known as the viscosity (μ) and plastic viscosity (μ_{pl}), respectively. In shear-thinning fluids, although K does not represent the overall viscosity, it can be used to show relative thickness of different fluids. When comparing Figures 3.5. to 3.10., it can be noted that 50.0% solids batters with higher K values have higher rheograms, meaning thicker texture. Other evidence can also be seen in Figures 3.3. and 3.4. Among the 50.0% solids adhesion batters, Golden Dipt batter has the highest K value (44.38 Pa s^n) and the highest amount of batter retained over a 5-minute drip period (Figure 3.3.), followed by Dorothy Dawson's Batter with a K value of 7.20

Table 3.2. Power Law Properties of Adhesion and Tempura Batters Calculated from Ramping Up Steady Shear Rheological Testing

Brand	% Solids	K (Pa s^n)	n (-)	r^2
Dorothy Dawson's Batter Mix*	45.4	2.88	0.61	0.99
	50.0	7.20	0.62	0.99
	55.6	22.32	0.65	0.99
Drake's Batter Mix*	50.0	6.67	0.63	0.99
	57.1	31.14	0.66	0.99
Golden Dipt Batter Mix*	50.0	44.38	0.60	0.99
Kikkoman Tempura Batter Mix**	45.4	7.71	0.61	0.99
	50.0	20.40	0.59	0.99
	55.6	68.09	0.56	0.99
Tung-I Tempura Batter Mix**	43.8	6.94	0.65	0.99
	50.0	29.78	0.63	0.99
Newly Wed Tempura Batter Mix**	43.6	1.71	0.75	0.99
	50.0	14.44	0.54	0.99

* Shear Rate is between 0.16 s^{-1} and 50 s^{-1}

** Shear Rate is between 0.16 s^{-1} and 20 s^{-1}

Pa s^n and medium amount of batter retained. Drake's batter has the lowest K value (6.67 Pa s^n) and lowest amount of batter retained. The same conclusion can be drawn from the three 50.0% tempura batters in Figure 3.4. Tung-I Tempura Batter has the highest K value (29.78 Pa s^n) and highest amount of batter retained. Kikkoman Tempura batter has an intermediate K value (20.40 Pa s^n) and a medium amount of batter retained. Newly Wed Tempura Batter has the lowest K value (14.44 Pa s^n) and least amount of batter retained.

Another important factor that is an indicator of overall viscosity is the flow behavior index, n. For shear-thinning fluids, the closer the flow behavior index is to 1, the straighter the rheogram curve. As mentioned before, all batters tested here had n values lower than one. Adhesion batters had n values between 0.60 and 0.66. Tempura batters had n values between 0.54 and 0.75. Variations in these n values are relatively small. When fitting the K and n values from Table 3.2. into equation 14, apparent viscosity in relation to shear rate can be found. Figures 3.11. and 3.12. show apparent viscosity of adhesion and tempura batters at different percent solids. All batters exhibited very similar downward change in apparent viscosity against increasing shear rate. This means batters in this study exhibited similar degree of

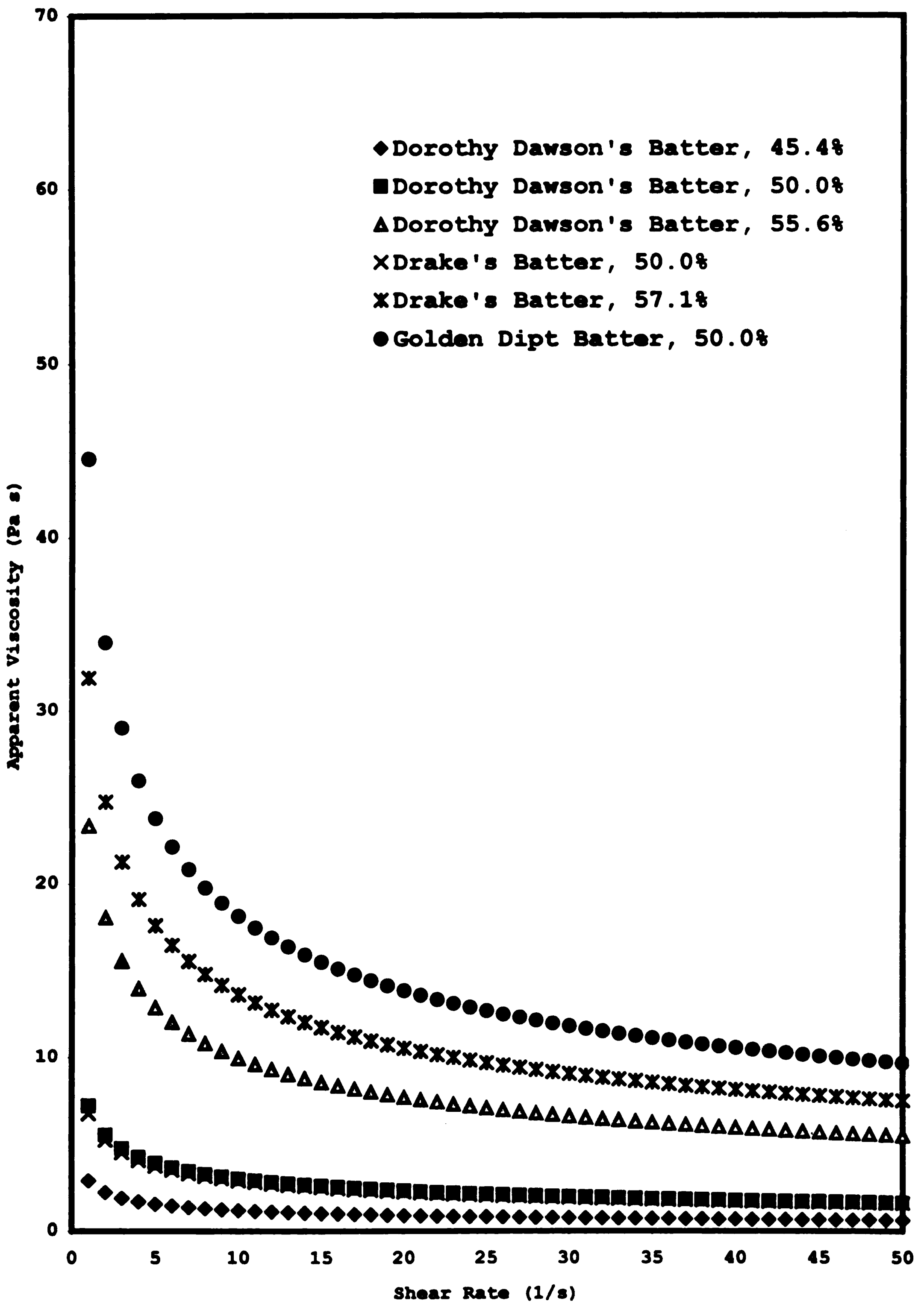

Figure 3.11. Apparent Viscosity of Adhesion Batters.

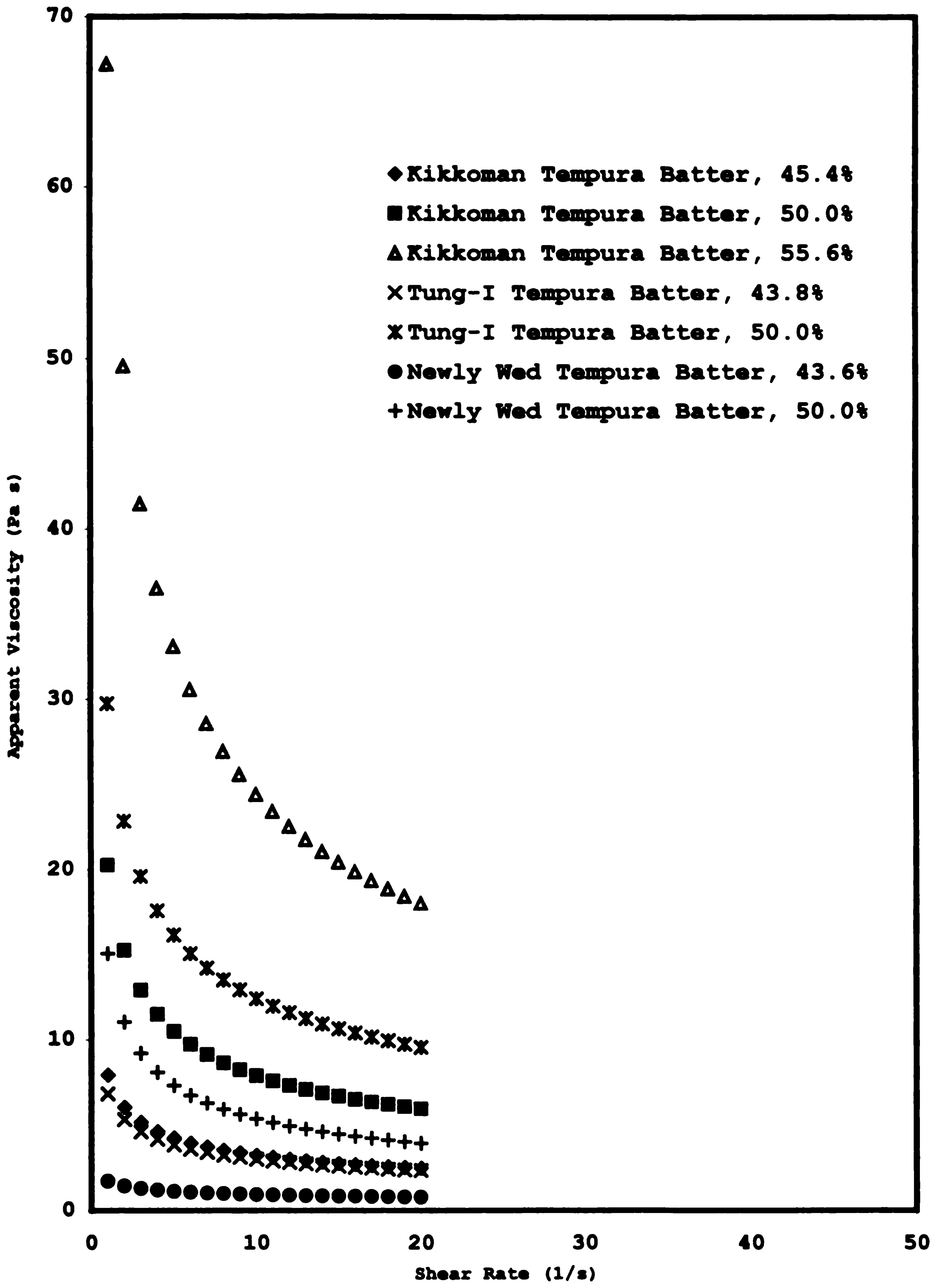

Figure 3.12. Apparent Viscosity of Tempura Batters.

shear-thinning properties regardless as to the type of batter or the amount of solids in the batter.

3.4. Influence of Holding Period on Batter Retention

One would expect the average weight of batter retained on the probe to increase over time because as starches and protein molecules hydrate, they swell in size and cause the batter to increase in viscosity. However, an increase in average weight of batter retained on the probe over time is not observed for the three brands of adhesion batter tested. Tables 3.3. and 3.4. list the collected data. For Dorothy Dawson's Batter at 45.4% solids, the maximum difference in the average weight of batter retained was 0.42g (2.23g - 1.81g). The data collected over the three-hour period were statistically different. At 50.0% solids, the maximum difference increased to 0.73g (4.29g - 3.56g) and data also differed statistically. When Dorothy Dawson's Batter was at 55.6% solids, the maximum difference was 1.22g (8.80g - 7.58g), but no statistically significant differences were found among readings. For Drake's Batter prepared at 50.0% solids, the maximum difference between average batter weight retained on the probe was 0.63g (4.13g - 3.50g) with no significant differences among readings. But at 57.1% solids, the maximum difference

Table 3.3. Average Weight (g) (n=2) of Dorothy Dawson's Batter Retained on the Probe over a Three-Hour Period

Time (minutes)	45.4% Solids	50.0% Solids	55.6% Solids
0	2.03^{c}	3.56^{a}	8.42
5	$2.12^{d,e}$	$3.78^{a,b}$	8.64
10	2.22^{e}	$4.13^{a,b}$	8.30
15	2.23^{e}	4.29^{b}	7.58
20	$2.18^{d,e}$	$4.14^{a,b}$	8.55
25	2.21^{e}	$4.1^{a,b}$	8.80
30	2.18^{d}	$4.15^{a,b}$	8.44
45	$2.12^{d,e}$	$4.09^{a,b}$	8.50
60	$2.11^{d,e}$	$4.04^{a,b}$	8.65
75	$2.11^{d,e}$	$4.11^{a,b}$	8.56
90	1.81^{a}	$4.23^{a,b}$	8.40
120	$1.89^{a,b}$	$4.14^{a,b}$	8.76
150	$2^{b,c}$	$4.14^{a,b}$	8.52
180	$2.07^{c,d}$	$4.18^{a,b}$	8.07

Values in the same column with different letters are significantly different ($P < 0.05$).

Table 3.4. Average Weight (g) (n=2) of Drake's Batter and Golden Dipt Batter Retained on the Probe over a Three-Hour Period

Drake's Batter Mix

Time (minutes)	50.0% Solids	57.1% Solids
0	3.79	$8.07^{c,d}$
5	4.13	$8.10^{c,d}$
10	4.04	$7.84^{b,c,d}$
15	4.32	$8.11^{c,d}$
20	4.04	$7.60^{a,b}$
25	4.11	$7.55^{a,b}$
30	4.09	7.24^{a}
45	4.04	8.25^{d}
60	4.00	8.24^{d}
75	3.70	$8.04^{c,d}$
90	3.65	$7.86^{b,c,d}$
120	3.62	$7.71^{b,c}$
150	3.55	$7.72^{b,c}$
180	3.50	7.27^{a}

Golden Dipt Batter Mix

Time (minutes)	50.0% Solids
0	9.37^{h}
5	$8.88^{e,f}$
10	$8.96^{f,g}$
15	$8.81^{d,e,f}$
20	$8.56^{b,c}$
25	8.38^{b}
30	7.75^{a}
45	$8.67^{c,d,e}$
60	9.12^{g}
75	$8.61^{b,c,d}$
90	9.13^{g}
120	$8.68^{c,d,e}$
150	$8.49^{b,c}$
180	8.42^{b}

Values in the same column with different letters are significantly different ($P < 0.05$).

increased to 1.01g (8.25g - 7.24g) and there were statistical differences among readings. For Golden Dipt Batter prepared at 50.0% solids, the maximum difference was 1.62g (9.37g - 7.75g) with statistical differences among readings.

For tempura batters, the readings are listed in Tables 3.5. and 3.6. The expected trend, i.e., batter weight retained on the probe increasing over time, was also not observed with the tempura data. For Kikkoman Tempura Batter samples at 45.4% solids, there were no significant differences in average weights of batter retained on the probe over the three-hour test period. The maximum difference in the average weight was 0.56g (4.19g - 3.63g). When the percent solids increased to 50.0%, significant differences were found among readings and the maximum difference was 0.88g (7.23g - 6.35g). A similar observation was found when the percent solids were further increased to 55.6%. In this case, statistical differences were found among readings and the maximum difference was 2.59g (10.73g - 8.14g).

For Tung-I Tempura Batter samples at 43.8% solids and 50.0% solids, statistical differences were found among readings and the maximum differences in average weight were 1.07g (4.44g - 3.37g) and 2.01g (9.25g - 7.24g),

Table 3.5. Average Weight (g) (n=2) of Kikkoman Tempura Batter Retained on the Probe over a Three-Hour Period

Time (minutes)	45.4% Solids	50.0% Solids	55.6% Solids
0	3.63	6.35^{a}	$10.36^{e,f}$
5	3.75	$6.73^{b,c}$	$9.61^{c,d,e}$
10	3.92	$7.05^{e,f,g}$	$8.69^{a,b,c}$
15	3.74	$6.97^{d,e,f}$	$8.94^{a,b,c}$
20	3.66	$6.89^{c,d,e}$	$8.80^{a,b,c}$
25	4.01	$7.04^{e,f,g}$	$8.62^{a,b}$
30	4.06	$6.72^{b,c}$	8.14^{a}
45	4.07	$7.14^{f,g}$	$10.2^{d,e,f}$
60	4.19	$7.08^{e,f,g}$	10.73^{f}
75	3.66	7.20^{g}	$10.2^{d,e,f}$
90	4.03	7.23^{g}	$9.24^{b,c}$
120	3.99	$6.97^{d,e,f}$	$9.36^{b,c,d}$
150	3.97	$6.84^{c,d}$	$8.51^{a,b}$
180	3.87	6.55^{b}	$8.71^{a,b,c}$

Values in the same column with different letters are significantly different ($P < 0.05$).

Table 3.6. Average Weight (g) (n=2) of Tung-I Tempura and Newly Wed Tempura Batter Retained on the Probe over a Three-Hour Period

Tung-I Tempura Batter Mix

Time (minutes)	43.8% Solids	50.0% Solids
0	3.37^{a}	$7.3^{a,b}$
5	3.84^{b}	$7.29^{a,b}$
10	$3.75^{a,b}$	$7.58^{a,b,c}$
15	3.95^{b}	7.24^{a}
20	$4.10^{b,c}$	$7.74^{a,b,c}$
25	$4.08^{b,c}$	$7.84^{a,b,c}$
30	$4.16^{b,c}$	$7.35^{a,b}$
45	4.44^{c}	$7.76^{a,b,c}$
60	$4.08^{b,c}$	$8.22^{b,c,d}$
75	4.18^{c}	$9.09^{d,e}$
90	3.92^{b}	$9.07^{d,e}$
120	3.96^{b}	9.25^{e}
150	$4.04^{b,c}$	$8.32^{c,d,e}$
180	3.91^{b}	$8.08^{a,b,c}$

Newly Wed Tempura Batter Mix

Time (minutes)	43.6% Solids	50.0% Solids
0	1.70^{a}	4.85^{a}
5	1.84^{a}	$5.43^{a,b}$
10	1.99^{a}	$5.57^{a,b}$
15	2.29^{a}	$5.46^{a,b}$
20	2.33^{a}	$5.54^{a,b}$
25	2.31^{a}	$5.52^{a,b}$
30	$2.50^{a,b}$	$6.03^{a,b}$
45	$3.49^{b,c}$	$5.95^{a,b}$
60	$4.09^{c,d}$	6.14^{b}
75	3.63^{c}	$5.73^{a,b}$
90	$4.45^{c,d}$	$5.70^{a,b}$
120	4.94^{d}	$5.50^{a,b}$
150	4.70^{d}	$5.35^{a,b}$
180	4.73^{d}	$5.42^{a,b}$

Values in the same column with different letters are significantly different ($P < 0.05$).

respectively. For Newly Wed Tempura Batter samples at 43.6% solids and 50.0% solids, significant differences were also found among readings, and the maximum differences in average weight were 3.24g (4.94g - 1.70g) and 1.29g (6.14g - 4.85g), respectively.

Tables 3.7. and 3.8. list the apparent viscosities of adhesion batters over a three-hour period. The apparent viscosity is expected to increase as time increases, but not all batters showed this trend. For Dorothy Dawson's Batter at 45.4% solids, apparent viscosity increased from 0.98 Pa s to 1.49 Pa s over time. At 50.0% solids and 55.6% solids, the expected trend was not found. For Drake's Batter, apparent viscosity increased over time when the batter was at 50.0% solids but the same trend was not observed with batter at 57.1% solids. For Golden Dipt Batter at 50.0% solids, apparent viscosity remained the same over the three-hour test period.

For tempura batters, results are listed in Tables 3.9. and 3.10. Kikkoman Tempura Batters at all tested solids levels did not have apparent viscosity increases over time. For Tung-I Tempura Batter at 43.8% solids, apparent viscosity increased as holding time increased, but this trend was not found when the percent solids was increased to 50.0%. Results from Newly Wed Tempura Batters were very

Table 3.7. Apparent Viscosity (Pa s) (n=3) for Dorothy Dawson's Batters over a Three-Hour Period at 15 1/s Shear Rate

Time (minutes)	45.4% Solids	50.0% Solids	55.6% Solids
0	0.98[a]	2.54	8.16
15	1.10[a,b]	2.61	7.73
30	1.17[b,c]	2.70	7.55
45	1.20[b,c]	2.73	7.50
60	1.24[b,c]	2.85	7.42
90	1.31[c,d]	2.86	7.71
120	1.48[d,e]	2.86	7.75
150	1.49[e]	2.80	8.16
180	1.46[d,e]	2.92	8.05

Values in the same column with different letters are significantly different ($P < 0.05$).

Table 3.8. Apparent Viscosity (Pa s) (n=3) for Drake's Batters and Golden Dipt Batter over a Three-Hour Period at 15 1/s Shear Rate

Drake's Batter Mix

Time (minutes)	50.0% Solids	57.1% Solids
0	2.05^{a}	7.57^{a}
15	$2.17^{b,c}$	8.08^{b}
30	2.15^{b}	$7.78^{a,b}$
45	$2.19^{b,c,d}$	$7.86^{a,b}$
60	$2.22^{b,c,d}$	$7.87^{a,b}$
90	$2.17^{b,c,d}$	$7.85^{a,b}$
120	$2.21^{b,c,d}$	$7.65^{a,b}$
150	$2.25^{c,d}$	$7.74^{a,b}$
180	2.25^{d}	$7.71^{a,b}$

Golden Dipt Batter Mix

Time (minutes)	50.0% Solids
0	14.98
15	14.13
30	13.61
45	13.42
60	13.73
90	14.14
120	13.73
150	13.62
180	12.95

Values in the same column with different letters are significantly different ($P < 0.05$).

Table 3.9. Apparent Viscosity (Pa s) (n=3) for Kikkoman Tempura Batters over a Three-Hour Period at 15 1/s Shear Rate

Time (minutes)	45.4% Solids	50.0% Solids	55.6% Solids
0	2.70	6.87	20.80
15	2.96	6.51	22.31
30	2.80	6.68	21.68
45	2.97	6.74	21.52
60	2.87	6.35	20.11
90	2.80	6.53	20.06
120	2.76	6.54	20.26
150	2.84	6.06	19.99
180	2.59	5.94	19.20

Values in the same column are not significantly different ($P < 0.05$).

Table 3.10. Apparent Viscosity (Pa s) (n=3) for Tung-I Tempura and Newly Wed Tempura Batters over a Three-Hour Period at 15 1/s Shear Rate

Tung-I Tempura Batter Mix

Time (minutes)	43.8% Solids	50.0% Solids
0	2.52^{a}	10.62
15	$2.85^{a,b,c}$	10.91
30	$2.74^{a,b}$	11.13
45	$2.87^{a,b,c}$	11.32
60	$2.98^{b,c}$	11.32
90	$2.89^{a,b,c}$	11.07
120	$3.07^{b,c}$	10.93
150	$3.06^{b,c}$	10.71
180	3.15^{c}	10.93

Newly Wed Tempura Batter Mix

Time (minutes)	43.6% Solids	50.0% Solids
0	0.90^{a}	4.03
15	1.23^{b}	4.49
30	1.11^{b}	3.84
45	1.15^{b}	4.36
60	1.19^{b}	4.08
90	1.24^{b}	4.10
120	1.19^{b}	4.17
150	1.21^{b}	4.04
180	1.25^{b}	4.23

Values in the same column with different letters are significantly different ($P < 0.05$).

similar to results from Tung-I Tempura Batters. At 43.6% solids, the apparent viscosity of Tung-I Tempura Batter increased over time but the same behavior was not found when the percent solids was increased to 50.0%.

3.5. Relationship Between Batter Rheology and Fried Food Quality

When string cheese was coated with under-mixed adhesion batter, the percent increase in weight between uncoated and coated cheese varied from 0.13% to 8.25%. A very thin layer of coating, 0.05mm, was found on these products that tended to blow off and cause pillowing during frying. When string cheese was coated with batter that had received optimum mixing, the percent increase in weight between uncoated and coated products increased to 29.94%. Also, thicker coatings (0.23mm) were found on the product and no blow off or pillowing was observed during frying. When string cheese was coated with over-mixed batter, the percent increase in weight between uncoated and coated string cheese samples decreased to 28.25%. In this case, thickness of the coating was unchanged at 0.23mm and no blow off or pillowing was found during the frying process.

When under-mixed adhesion batter was applied to shrimp, the percent increase in weight between uncoated and coated shrimp varied from 4.78% to 12.67%. Thickness of the coating could not be measured because shrimp do not have a uniform shape like string cheese. But the under-mixed coating was found to constitute 41.27% of the fried food weight. When optimally mixed batter was applied to shrimp, weights increased by 31.90%. After frying, weight of the coating constituted 60.18% of the total food weight. When shrimp were coated with over-mixed batter, product weight increased by 32.84%, and after frying, 50.36% of the fried food weight was coating. Voids and pillowings were consistently found on the food during and after frying.

As for shrimp coated with under-mixed tempura batter, percent increase in weight before and after coating varied between 5.93% and 22.93%. Neither thickness of coating nor percent of coating in the final fried food product could be determined. That is because the coating was so thin that it could not be separated from the shrimp. But it was observed that shrimp decreased in size after frying. Without a thick layer of coating to absorb the natural juice from the shrimp, it migrated into the frying oil and thus shrimp shrank in size. When shrimp were coated with optimally mixed tempura batter, the percent increase in weight before and after coating was 37.25%. The final coating constituted 55.58% of the fried food product by weight. In the case of over-mixed tempura batter, the coated shrimp increased in weight by 30.87% and, after frying, 41.89% of the final product was coating by weight. Voids were constantly observed in fried shrimp because they have bodies that curve inward and shield the abdomen from batter.

As for cucumber slices coated with under-mixed tempura batter, the percent increase in weight before and after coating was between 7.01% and 11.29%. After frying, 24.28% of the fried food was coating. Excessive blow off was observed during frying mainly because the batter was thin and watery. When coated with optimally mixed batter, cucumber samples increased in weight by 33.14%. After frying, coating constituted 48.86% of the food weight. With over-mixed tempura batter, weight of the cucumber sample increased by 34.13%, and 50.37% of the fried product weight was coating.

3.6. Practical Applications

Every brand and every style of batter comes from a unique formula; it is unrealistic to come up with a universal mixing regime for all batters. It is more useful to provide a method to determine when the optimum mixing of batter is achieved. This is exactly what the optimum mixing test utilizing the Texture Analyzer is doing. By mixing a batter at different speeds and durations while measuring torque, SME may be calculated. By relating SME to the amount of batter retained on a probe, an optimum mixing curve is found. Using this curve, batter mix manufacturers can provide better recommendations to their consumers on how to achieve maximum performance from their mixes. In addition, since the plexiglas probe with fixed dimensions is the customary test probe, characteristics of different brands of batter mix can be compared easily. Variations in formulation from the same brands can also be found without interference from irregular size, shape and varying moisture contents of food substrates.

The batter retention experiments showed there was a batter dripping period after coating. This becomes important cost reduction information for the batter and breading industry. The industry can either design pipes or equipment to collect the drippings or formulate batters with shorter dripping periods to optimize through-put and batter consumption.

Consistency coefficient (K) and flow behavior index (n) are also useful parameters for the batter and breading industry. The K value shows relative thickness of different batters while n reflects the degrees of shear-thinning behavior in a batter. When trying to maintain a constant percent solids and constant viscosity for quality control purposes, steady shear tests can be run on sample batters to evaluate rheological behavior. This information is a good quality control indicator.

Aging influence on batter retention and batter viscosity are not as extreme as one would expect. Over the three-hour test period, although some statistical differences are found in both adhesion and tempura batters, these differences are so small that they are not expected to be relevant in practical applications. As long as batters are kept at the recommended temperature and used within three hours, no practical differences in weight of batter retained on the probe or apparent viscosity of batters are expected.

When relating batter rheology with quality of fried food, it is better to overmix a batter rather than to undermix it. When a batter is undermixed, it is not uniform and the amount of batter picked up by food substrates will vary widely. During frying, natural juice from food substrates will migrate outwards to the frying oil and cause blow off and pillowing. Over-mixing a batter, on the other hand, seems to have a less negative effect on the batter properties. The amount of over-mixed batter picked up by the food substrate does not deviate as much as when the batter is undermixed, and the food has more batter coating to absorb the natural food juice and prevent oil absorption by the food.

Chapter 4

Conclusions and Recommendations

4.1. Summary and Conclusions

For both adhesion and tempura batters, inputting the correct amount of energy during mixing results in maximum level of batter retained on a test probe. Maximum amount of batter retained on the probe was interpreted as optimum degree of mixing. Within the same brand, percent solids in batter had a major influence on the amount of batter retained on the probe, the length of time needed to stabilize dripping, thickness of the batters, and yield stress values of the batters.

Both adhesion and tempura batters were found to be shear-thinning and exhibit thixotropic behavior. In terms of rheological properties, measuring different batters' K values assisted in comparing their relative thicknesses. Double checking consistency of batter samples' n values to 0.6 can serve as a quality control indicator for both adhesion and tempura batters.

Increasing the holding period was hypothesized to increase the apparent viscosity and amount of batter retained on the probe. But the collected apparent viscosity data and batter retention weights did not confirm this assumption. No practical changes in apparent viscosity and weight of batters retained on the probe were observed for adhesion or tempura batters over the three-hour test period.

When string cheese, shrimp and cucumber were coated with either adhesion or tempura batters with different degrees of mixing, it was found that the highest quality fried food were coated with batters that received optimum mixing. Food coated with under-mixed batter had lower quality attributes then those coated with over-mixed batter. Hence, under-mixing a batter had the greatest detrimental effect on final food quality.

4.2. Recommendations for Future Research

Some areas for future research include the following:

1. Compare the industrial mixing system with the laboratory mixing system to determine the scale-up parameters.

2. Perform thorough sensory tests to characterize and distinguish among foods coated with batters that received different degrees of mixing.

APPENDIX

Table A.1. Amount of Dorothy Dawson's Batter Picked up by the Probe at Time Zero Against Amount of Energy Input into Mixing

Mixing Time (Minutes)	SME (N m/kg)	Batter Retained (g)	rpm	SME (N m/kg)	Batter Retained (g)
Percent Solids: 55.6%					
2	1529.705	4.71	100	509.739	1.25
2	1147.279	7.65	100	382.305	3.47
2	1529.705	8.18	100	382.305	2.07
2	1529.705	8.63	100	382.305	4.67
3	2294.558	8.01	200	1274.349	6.35
3	2294.558	7.95	200	509.739	5.25
3	2294.558	7.49	200	1656.653	8.03
3	2294.558	7.97	200	1656.653	7.79
4	4015.476	7.92	300	4015.476	7.92
4	3059.410	8.07	300	3059.410	8.07
4	3441.837	7.87	300	3441.837	7.87
4	3250.623	8.06	300	3250.623	8.06
6	3728.656	7.15	600	7264.943	7.31
6	4302.296	7.40	600	7264.943	7.34
6	4302.296	7.32	600	7264.943	7.18
6	4302.296	7.41	600	7264.943	7.09
Percent Solids: 50.0%					
2	478.033	3.67	100	127.435	1.22
2	382.426	3.84	100	127.435	1.63
2	382.426	3.60	100	127.435	1.73
2	478.033	3.63	100	127.435	1.06
3	573.639	4.15	200	509.739	2.64
3	573.639	3.70	200	509.739	3.86
3	573.639	3.86	200	509.739	3.51
3	717.049	3.97	200	254.870	2.44
4	956.066	4.01	300	956.066	4.01
4	956.066	4.06	300	956.066	4.06
4	956.066	4.13	300	956.066	4.13
4	956.066	3.84	300	956.066	3.84
6	1147.279	3.55	600	1911.827	3.47
6	1147.279	3.55	600	2294.193	3.44
6	1147.279	3.70	600	2294.193	3.66
6	1147.279	3.58	600	1191.827	3.50
Percent Solids: 45.4%					
2	191.213	1.81	100	63.717	1.18
2	191.213	1.98	100	63.717	0.59
2	191.213	1.99	100	63.717	0.81
2	191.213	2.00	100	63.717	1.01
3	286.820	1.98	200	254.870	1.98
3	286.820	2.09	200	254.870	1.86
3	286.820	2.06	200	127.435	1.88
3	286.820	1.87	200	127.435	1.95
4	382.426	2.08	300	382.426	2.08
4	382.426	2.21	300	382.426	2.21
4	382.426	2.24	300	382.426	2.24
4	382.426	2.16	300	382.426	2.16
6	573.639	1.95	600	764.731	2.09
6	573.639	2.01	600	764.731	2.03
6	573.639	1.94	600	764.731	2.03
6	573.639	2.07	600	764.731	2.10

Table A.2. Amount of Kikkoman Tempura Batter Picked up by the Probe at Time Zero Against Amount of Energy Input into Mixing

Mixing Time (Minutes)	SME (N m/kg)	Batter Retained (g)	rpm	SME (N m/kg)	Batter Retained (g)
Percent Solids: 55.6%					
2	1032.259	5.72	70	200.737	1.56
2	860.216	5.99	70	133.825	1.05
2	1032.256	6.30	70	133.825	1.44
2	860.216	5.18	70	133.825	1.31
2.5	1290.324	9.19	170	487.466	5.93
2.5	1290.324	7.22	170	487.466	3.92
2.5	1290.324	8.10	170	487.466	3.77
2.5	1290.324	9.53	170	487.466	3.92
3	1548.388	9.25	270	1290.324	10.14
3	1806.453	8.86	270	1290.324	8.67
3	1806.453	8.20	270	1290.324	8.76
3	2064.518	10.05	270	1290.324	9.46
5	3440.863	8.93	470	5391.699	9.39
5	3440.863	7.97	470	4493.083	9.71
5	3440.863	9.77	470	4493.083	9.20
5	3440.863	9.08	470	4493.083	9.64
			570	6538.613	8.97
			570	5993.729	9.15
			570	5448.844	9.11
			570	5448.844	8.90
Percent Solids: 50.0%					
2	344.086	4.38	70	100.369	0.70
2	344.086	4.89	70	66.912	0.91
2	344.086	5.49	70	66.912	0.65
2	344.086	5.75	70	66.912	0.54
2.5	645.162	6.47	170	324.977	2.40
2.5	860.216	6.39	170	162.489	2.91
2.5	645.162	6.22	170	162.489	2.48
2.5	645.162	6.37	170	162.489	2.97
3	774.194	6.88	270	774.194	6.61
3	774.194	6.01	270	774.194	6.33
3	774.194	6.33	270	774.194	6.56
3	774.194	6.95	270	774.194	6.53
5	1290.324	5.71	470	1797.233	5.98
5	1290.324	5.86	470	1797.233	6.05
5	1290.324	6.17	470	1797.233	6.24
5	1290.324	6.05	470	1797.233	5.96
Percent Solids: 45.4%					
2	172.043	3.09	70	66.912	0.64
2	172.043	2.62	70	33.456	1.03
2	172.043	3.07	70	33.456	1.21
2	172.043	3.20	70	33.456	0.49
2.5	430.108	3.43	170	162.489	2.73
2.5	430.108	3.62	170	162.489	2.09
2.5	430.108	3.26	170	324.977	2.43
2.5	430.108	3.59	170	324.977	2.72
3	516.129	3.45	270	516.129	3.52
3	516.129	3.80	270	516.129	3.52
3	516.129	3.69	270	516.129	3.87
3	516.129	3.47	270	516.129	3.86
5	1290.324	2.83	470	1347.925	3.38
5	1290.324	2.45	470	1347.925	3.24
5	860.216	3.64	470	1347.925	3.59
5	860.216	3.77	470	1347.925	2.28

Table A.3. Amount of Adhesion Batter Retained over a 5-minute Drip Period at 20^{0}C

Batter	% Solids	0s	30s	60s	120s	300s
Dorothy Dawson's Batter	55.6	7.92	5.37	4.56	3.84	3.38
	55.6	8.07	5.64	4.65	3.63	3.30
	55.6	7.87	5.60	4.73	3.82	4.07
	55.6	8.06	5.56	4.28	3.74	3.53
Dorothy Dawson's Batter	50.0	4.01	2.22	1.79	1.67	1.57
	50.0	4.06	2.26	1.89	1.68	1.64
	50.0	4.13	2.01	1.76	1.85	1.62
	50.0	3.84	2.09	1.79	1.74	1.89
Dorothy Dawson's Batter	45.4	2.08	1.42	1.21	1.25	1.12
	45.4	2.21	1.31	1.20	1.20	1.29
	45.4	2.24	1.38	1.23	1.20	1.11
	45.4	2.17	1.25	1.19	1.09	1.18
Drake's Batter	57.1	9.52	7.07	6.06	5.20	4.79
	57.1	9.14	7.48	6.46	5.70	4.84
	57.1	9.51	7.73	6.55	5.52	4.47
	57.1	9.12	8.01	6.66	5.70	4.70
Drake's Batter	50.0	3.94	2.49	1.97	1.55	1.47
	50.0	3.96	2.45	1.93	1.66	1.45
	50.0	4.01	2.27	1.95	1.74	1.63
	50.0	3.92	2.38	1.89	1.69	1.59
Golden Dipt Batter	50.0	9.20	7.08	6.18	5.39	5.28
	50.0	9.38	6.23	6.38	5.39	5.55
	50.0	9.05	6.74	5.57	5.49	5.19
	50.0	9.13	7.21	6.26	5.50	5.38

Table A.4. Amount of Tempura Batter Retained over a 5-minute Drip Period at 10^{o}C

Batter	% Solids	0s	30s	60s	120s	300s
Kikkoman Tempura Batter	55.6	10.05	10.05	10.03	8.69	6.60
	55.6	9.25	9.75	9.55	8.56	7.91
	55.6	10.14	9.48	9.09	8.78	7.65
	55.6	9.46	9.32	8.95	7.07	7.21
Kikkoman Tempura Batter	50.0	6.88	3.79	4.00	3.09	3.13
	50.0	6.01	4.37	3.47	3.48	2.48
	50.0	6.33	4.45	3.43	3.24	3.08
	50.0	6.95	4.26	3.90	3.15	2.83
Kikkoman Tempura Batter	45.4	3.45	2.07	1.45	1.56	1.25
	45.4	3.80	1.97	1.50	1.38	1.32
	45.4	3.69	1.22	1.64	1.40	1.26
	45.4	3.47	1.97	1.53	1.27	1.29
Newly Wed Tempura Batter	50.0	4.65	3.23	2.66	2.81	3.08
	50.0	5.07	3.01	2.90	2.52	2.90
	50.0	5.22	3.34	2.85	2.78	1.90
	50.0	4.88	3.20	3.08	2.72	2.87
Newly Wed Tempura Batter	43.6	1.65	0.82	0.89	0.84	0.81
	43.6	1.71	1.67	0.91	0.82	0.82
	43.6	1.75	0.81	0.89	0.86	0.8
	43.6	1.73	0.76	0.89	0.73	0.81
Tung-I Tempura Batter	50.0	7.01	5.61	3.46	4.22	3.32
	50.0	7.42	5.43	5.09	4.13	4.26
	50.0	6.49	5.32	4.54	4.3	3.01
	50.0	7.03	5.15	4.49	4.05	5.13
Tung-I Tempura Batter	43.8	3.14	1.85	1.44	1.13	1.22
	43.8	3.58	1.54	1.56	1.37	1.30
	43.8	3.44	1.64	1.50	1.40	1.30
	43.8	3.40	1.81	1.42	1.32	1.31

Table A.5. Steady Shear Data of Dorothy Dawson's Batter at 20^0C

45.4% Solids		50.0% Solids		55.6% Solids	
Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
0.063	9.831	0.456	6.902	0.723	3.654
1.1	38.784	1.539	11.406	1.461	4.748
2.199	49.47	2.183	12.681	2.199	5.33
2.827	53.492	2.875	14.242	2.859	5.936
3.456	58.43	3.503	15.561	3.613	6.425
4.194	63.832	4.273	16.903	4.257	6.946
4.885	69.36	4.917	18.101	4.885	7.392
5.466	73.163	5.529	19.365	5.545	7.972
6.11	78.648	6.173	20.762	6.173	8.466
6.896	83.791	6.943	22.12	6.912	8.976
7.54	88.775	7.587	23.476	7.571	9.502
8.2	92.946	8.215	24.563	8.2	9.94
8.954	98.002	8.969	25.895	8.954	10.403
9.55	102.237	9.582	27.063	9.582	10.816
10.194	106.719	10.242	28.155	10.226	11.253
10.838	111.721	10.901	29.531	10.886	11.78
11.624	116.247	11.64	30.727	11.655	12.237
12.268	120.701	12.315	31.839	12.284	12.636
12.912	125.632	12.959	33.166	12.928	13.196
13.65	130.265	13.572	34.295	13.556	13.611
14.153	134.287	14.184	35.385	14.31	14.069
14.938	138.607	14.954	36.494	14.97	14.57
15.551	143.476	15.614	37.831	15.582	14.953
16.226	147.7	16.242	38.888	16.195	15.415
16.996	152.047	16.996	39.992	17.012	15.79
17.64	157.275	17.624	41.269	17.64	16.305
18.253	161.064	18.268	42.312	18.268	16.652
19.007	165.349	18.912	43.402	19.038	17.142
19.509	168.975	19.541	44.342	19.541	17.439
20.279	173.234	20.295	45.392	20.295	17.86
20.954	178.083	20.97	46.589	20.923	18.348
21.583	182.323	21.708	47.735	21.693	18.76

Table A.5. (cont'd)

22.305	186.476	22.337	48.621	22.337	19.156
22.965	189.986	22.934	49.654	22.981	19.642
23.562	194.999	23.64	50.873	23.578	20.026
24.206	198.449	24.253	51.789	24.379	20.371
24.976	202.644	25.007	52.784	25.007	20.762
25.667	206.957	25.683	53.826	25.635	21.136
26.279	210.805	26.311	54.769	26.264	21.535
26.939	214.691	27.081	55.831	27.049	21.916
27.646	218.984	27.677	56.681	27.677	22.277
28.274	222.796	28.306	57.35	28.306	22.665
28.918	227.475	28.934	58.513	28.95	23.079
29.704	231.515	29.61	59.27	29.578	23.427
30.316	235.436	30.348	60.185	30.332	23.802
30.976	239.469	31.008	61.261	30.976	24.132
31.777	243.459	31.793	62.036	31.604	24.512
32.248	246.77	32.264	62.816	32.233	24.823
33.002	250.342	33.05	63.72	33.018	25.136
33.631	254.986	33.646	64.59	33.662	25.499
34.322	258.214	34.322	65.426	34.306	25.866
35.092	262.359	35.076	66.349	35.076	26.235
35.736	267.197	35.673	67.4	35.704	26.657
36.317	270.088	36.333	67.684	36.333	26.881
36.914	274.579	36.945	68.911	37.118	27.258
37.699	277.678	37.715	69.569	37.573	27.561
38.28	282.148	38.39	70.106	38.359	27.815
39.019	285.887	39.003	71.355	39.003	28.121
39.553	290.251	39.663	71.857	39.631	28.481
40.432	293.352	40.417	72.572	40.417	28.713
41.061	295.515	41.061	73.291	41.029	29.129
41.689	301.177	41.736	74.184	41.658	29.312
42.317	304.688	42.302	74.783	42.302	29.574
43.056	307.689	43.103	75.642	43.056	29.917
43.637	311.327	43.715	76.116	43.7	30.155
44.344	315.344	44.391	76.897	44.328	30.582
45.098	318.217	45.113	77.637	45.098	30.85
45.773	322.279	45.757	78.338	45.757	31.038
46.386	325.729	46.386	79.085	46.386	31.335
47.045	329.289	47.03	79.97	47.03	31.579
47.736	333.881	47.799	80.369	47.627	31.852

Table A.5. (cont'd)

48.428	336.189	48.412	81.082	48.396	32.126
48.962	340.829	49.087	81.798	49.056	32.456
49.716	342.32	49.873	82.473	49.684	32.678
50.438	345.312	50.501	83.059	50.454	32.899
50.36	343.066	50.297	82.382	50.297	32.677
49.621	338.875	49.653	81.349	49.669	32.18
48.852	334.064	48.852	80.145	48.899	31.714
48.271	328.19	48.271	78.554	48.271	31.224
47.705	322.005	47.595	77.503	47.627	30.766
46.873	316.417	46.998	76.416	46.998	30.284
46.386	312.214	46.37	75.035	46.37	29.833
45.569	307.863	45.616	74.094	45.6	29.491
44.925	302.576	44.956	73.075	44.956	28.968
44.218	298.031	44.202	71.684	44.171	28.579
43.574	294.559	43.574	70.682	43.542	28.193
42.946	288.532	42.93	69.728	42.93	27.733
42.302	285.798	42.317	68.494	42.286	27.48
41.595	281.298	41.658	67.597	41.658	26.875
40.872	275.243	40.888	66.544	40.888	26.501
40.275	270.746	40.244	65.3	40.228	26.081
39.615	266.534	39.631	64.384	39.631	25.688
38.861	262.273	38.861	63.279	38.83	25.323
38.186	258.533	38.217	62.262	38.202	24.96
37.605	254.419	37.668	61.176	37.573	24.601
36.929	249.701	36.961	60.139	36.929	24.125
36.317	245.185	36.317	59.224	36.317	23.748
35.579	241.338	35.579	58.279	35.531	23.421
34.95	236.359	34.872	57.044	34.903	22.98
34.102	232.429	34.133	56.192	34.149	22.612
33.505	228.001	33.505	55.016	33.631	22.293
32.892	224.521	32.94	54.18	32.877	21.864
32.264	219.947	32.264	53.242	32.233	21.573
31.62	215.792	31.62	52.206	31.604	21.063
30.866	211.603	30.819	51.357	30.819	20.734
30.206	207.458	30.222	50.096	30.191	20.277
29.547	202.638	29.562	49.3	29.562	19.933
28.793	199.293	28.824	48.374	28.934	19.592
28.164	194.363	28.149	47.321	28.306	19.254
27.567	190.881	27.536	46.448	27.536	18.816

Table A.5. (cont'd)

26.861	187.431	26.923	45.55	26.876	18.424
26.264	182.52	26.295	44.465	26.279	18.036
25.525	178.68	25.478	43.588	25.478	17.653
24.834	174.021	24.85	42.464	24.85	17.254
24.237	170.013	24.253	41.513	24.206	16.86
23.483	165.859	23.483	40.605	23.593	16.53
22.839	162.013	22.855	39.738	22.808	16.145
22.211	158.464	22.211	38.881	22.164	15.765
21.536	153.713	21.551	37.764	21.551	15.279
20.813	149.34	20.766	36.842	20.75	14.947
20.153	145.756	20.185	35.843	20.138	14.601
19.556	141.085	19.525	34.745	19.494	14.134
18.85	137.252	18.881	33.919	18.881	13.763
18.143	133.127	18.143	32.909	18.237	13.362
17.467	128.272	17.514	31.805	17.467	12.985
16.855	125.124	16.87	31.072	16.855	12.631
16.211	120.532	16.226	30.027	16.195	12.149
15.472	116.673	15.472	28.872	15.441	11.791
14.844	112.402	14.828	27.919	14.797	11.39
14.153	107.902	14.184	26.857	14.153	10.919
13.446	103.547	13.43	25.841	13.399	10.52
12.802	99.681	12.818	24.845	12.912	10.172
12.142	95.064	12.158	23.658	12.111	9.758
11.561	91.699	11.53	22.685	11.514	9.339
10.116	83.016	10.132	20.67	10.1	8.434
9.488	78.776	9.472	19.657	9.456	7.994
8.844	74.138	8.828	18.486	8.844	7.502
8.105	69.769	8.09	17.353	8.058	7.076
7.461	65.618	7.446	16.355	7.414	6.644
6.817	60.865	6.817	15.055	6.77	6.134
6.173	57.078	6.189	14.025	6.189	5.69
5.561	52.165	5.561	12.863	5.576	5.242
4.775	47.416	4.822	11.706	4.775	4.764
4.147	42.648	4.147	10.591	4.115	4.263
3.534	38.146	3.519	9.248	3.487	3.782
2.906	33.487	2.78	7.909	2.733	3.233
2.199	28.036	2.121	6.602	2.121	2.722
1.555	22.788	1.539	5.362	1.492	2.183
0.927	16.382	0.895	3.697	0.848	1.482

Table A.6. Steady Shear Data of Drake's Batter and Golden Dipt Batter at 20^{o}C

Drake's Batter				Golden Dipt Batter	
50.0% Solids		57.1% Solids		50.0% Solids	
Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
0.157	2.423	0	2.799	0	3.955
1.068	7.859	0.314	18.952	0.209	14.788
2.215	11.341	1.791	48.679	1.236	50.794
3.362	14.331	3.236	65.064	2.932	86.918
4.492	16.981	4.225	75.601	4.294	104.423
5.435	19.113	5.341	87.1	5.383	119.507
6.535	21.447	6.315	96.142	6.409	133.72
7.32	23.035	7.398	106.928	7.435	149.481
8.404	25.092	8.404	114.856	8.524	165.493
9.519	27.214	9.456	125.301	9.634	177.431
10.493	28.904	10.399	133.424	10.681	189.451
11.592	30.862	11.53	142.882	11.729	202.949
12.692	32.554	12.488	151.56	12.818	211.921
13.635	34.409	13.43	159.991	13.655	224.246
14.577	35.967	14.467	169.242	14.765	235.15
15.661	37.861	15.598	178.625	15.792	245.136
16.603	39.285	16.729	187.169	17.027	255.252
17.703	41.018	17.483	194.586	18.075	263.692
18.692	42.503	18.677	202.58	19.122	272.023
19.604	43.984	19.729	211.69	20.064	278.125
20.703	45.59	20.64	219.737	20.567	284.722
21.661	46.992	21.803	228.852	19.604	264.346
22.745	48.689	22.682	235.832	18.556	248.535
23.845	50.243	23.813	245.042	17.593	235.148
24.787	51.647	24.74	251.869	16.588	225.224
25.73	52.962	25.714	260.252	15.499	215.446
26.845	54.586	26.782	269.106	14.535	203.448
27.913	56.125	27.882	278.447	13.278	192.221
28.871	57.238	28.887	284.281	12.378	181.931
29.814	58.55	29.861	289.919	11.373	172.195
30.929	60.107	30.788	299.704	10.283	159.871

Table A.6. (cont'd)

32.029	61.492	31.887	308.056	9.236	148.076
32.798	62.503	32.861	316.973	8.189	136.215
33.913	63.876	33.788	324.379	7.288	123.856
35.013	65.466	35.013	332.423	6.22	110.414
35.956	66.63	35.94	339.449	5.194	97.369
37.024	68.173	36.992	347.487	4.231	83.705
38.029	69.321	38.013	355.239	3.225	68.459
39.097	70.812	39.019	365.578	2.283	52.17
40.055	71.857	40.165	373.038	1.361	35.025
40.982	73.037	40.998	382.346		
42.097	74.526	42.003	388.381		
43.165	75.814	43.197	395.864		
44.124	77.027	44.061	405.749		
45.082	78.163	45.019	413.19		
46.181	79.528	46.166	421.109		
47.265	81.084	47.265	429.416		
48.223	82.114	48.051	435.173		
49.166	83.242	49.197	441.919		
50.25	84.789	50.093	450.746		
51.019	85.798	51.538	468.331		
49.747	83.741	49.841	443.826		
48.695	81.979	48.6	438.118		
47.579	80.147	47.564	427.331		
46.637	78.997	46.527	417.191		
45.679	77.549	45.632	413.804		
44.595	75.813	44.579	404.735		
43.495	74.353	43.448	394.762		
42.537	73.035	42.584	387.983		
41.579	71.603	41.705	381.261		
40.495	70.021	40.574	371.093		
39.396	68.497	39.286	364.711		
38.61	67.356	38.437	356.571		
37.542	65.904	37.589	347.769		
36.427	64.309	36.49	341.216		
35.327	62.813	35.327	332.055		
34.369	61.49	34.51	324.288		
33.442	60.105	33.411	317.871		
32.327	58.698	32.311	309.208		
31.243	57.086	31.4	301.803		

Table A.5. (cont'd)

30.458	56.011	30.285	293.537
29.342	54.329	29.311	285.217
28.259	52.852	28.29	275.76
27.3	51.467	27.3	269.023
26.389	50.066	26.421	261.065
25.274	48.446	25.306	252.188
24.19	47.123	24.159	244.018
23.216	45.521	23.138	235.599
22.148	43.948	22.29	229.003
21.174	42.5	21.221	219.364
20.075	40.859	20.059	210.959
19.132	39.343	19.148	203.438
18.237	37.978	18.253	195.707
17.106	36.169	17.169	185.935
16.179	34.72	16.038	177.087
15.08	32.913	15.095	169.697
13.964	31.129	14.169	160.751
13.163	29.819	13.069	151.744
12.095	27.973	11.954	142.344
10.996	26.115	11.027	134.291
10.053	24.489	10.116	125.804
8.954	22.504	9.032	116.196
8.011	20.782	7.917	105.797
6.959	18.674	7.1	98.548
5.953	16.823	6.032	88.029
5.058	14.983	4.995	77.379
3.958	12.747	3.974	67.113
2.875	10.259	3.126	57.567
1.932	7.937	2.058	44.69
0.927	4.99	1.21	32.817

Table A.7. Steady Shear Data of Kikkoman Tempura Batter at 10°C

45.4% Solids		50.0% Solids		55.6% Solids	
Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
9.142	31.14	1.257	65.186	0.094	3.856
1.854	12.365	1.319	69.695	0.408	11.029
2.576	15.08	2.105	89.44	1.665	27.706
3.613	18.227	3.236	111.415	3.33	40.041
4.65	21.318	4.367	132.225	4.587	48.166
5.686	23.74	5.561	150.648	5.623	53.961
6.817	25.951	6.566	166.077	6.754	59.301
7.854	28.085	7.697	182.005	7.823	64.109
8.828	30.521	8.671	194.112	8.765	68.867
9.99	32.73	9.802	208.14	9.896	74.356
10.996	34.848	10.87	223.048	10.933	80.463
12.001	36.505	11.875	235.002	11.969	84.476
13.163	38.203	13.006	247.909	13.132	88.215
14.074	39.788	14.043	259.381	14.074	92.804
15.142	41.88	15.017	271.532	15.111	97.266
16.305	43.092	16.211	281.592	16.085	100.834
17.342	44.879	17.09	292.009	17.216	104.926
18.315	46.169	18.158	302.794	18.284	109.155
19.478	47.715	19.384	312.972	19.446	112.673
20.483	48.944	20.483	325.044	20.483	116.249
21.174	50.224	21.174	333.096	21.143	119.609
19.886	47.275	20.043	314.401	19.918	112.355
18.912	45.273	18.944	301.391	18.944	107.908
17.781	43.123	17.938	287.032	17.75	102.995
16.776	41.374	16.87	276.454	16.839	98.991
15.802	39.203	15.896	261.331	15.802	93.86
14.828	37.243	14.954	250.772	14.828	89.762
13.509	34.76	13.729	233.999	13.635	83.882
12.598	33.062	12.692	223.122	12.661	79.885
11.624	31.193	11.875	210.392	11.812	75.427
10.524	28.806	10.65	194.25	10.556	69.566
9.488	26.693	9.739	182.342	9.456	65.142
8.325	24.687	8.545	168.603	8.419	60.369
7.383	22.671	7.603	155.663	7.508	55.711
6.377	20.287	6.597	140.748	6.472	50.058
5.435	18.185	5.623	126.935	5.498	44.886
4.335	15.751	4.587	111.257	4.398	39.302
3.362	13.381	3.613	95.125	3.424	33.32
2.419	10.534	2.702	78.786	2.513	27.073
1.351	7.41	1	60.258	1.508	19.795

Table A.8. Steady Shear Data of Newly Wed Tempura Batter at 10^{0}C

43.6% Solids		50.0% Solids	
Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
12.975	9.373	5.812	37.487
1.759	2.542	2.011	17.661
2.608	3.576	2.513	20.311
3.738	4.629	3.613	25.051
4.681	5.404	4.65	28.576
5.843	6.218	5.812	32.372
6.817	7.156	6.88	36.067
7.791	7.869	8.042	39.238
9.016	8.618	8.985	42.011
10.022	9.49	10.022	45.609
10.964	10.166	10.996	48.333
11.781	10.929	12.127	51.351
13.132	11.624	13.1	53.812
14.169	12.408	14.169	56.742
15.08	13.048	15.205	59.638
16.273	13.67	16.273	61.598
17.31	14.343	17.247	64.223
18.253	15.052	18.41	66.904
19.446	15.704	19.352	68.573
20.389	16.313	20.263	71.096
21.017	16.778	21.08	72.988
19.792	15.629	19.855	67.715
18.818	14.905	18.818	64.499
17.656	14.146	17.719	61.171
16.682	13.408	16.745	57.673
15.708	12.591	15.708	55.083
14.514	11.849	14.577	51.915
13.666	11.225	13.697	49.051
12.598	10.315	12.629	45.839
11.655	9.62	11.655	43.095
10.493	8.72	10.619	40.098
9.519	8.238	9.582	37.216
8.482	7.393	8.545	34.107
7.54	6.683	7.603	31.303
6.409	5.903	6.472	28.112
5.372	5.029	5.435	24.593
4.21	4.2	4.492	21.675
3.299	3.448	3.393	18.105
2.293	2.506	2.388	14.226
1.351	1.698	1.508	10.703

Table A.9. Steady Shear Data of Tung-I Tempura Batter at 10^{0}C

43.8% Solids		50.0% Solids	
Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
8.985	26.172	2.985	62.188
1.791	9.786	1.885	41.289
2.545	12.431	2.419	47.15
3.581	15.264	3.362	57.419
4.65	18.288	4.43	68.091
5.655	20.657	5.529	77.381
6.817	23.179	6.597	86.5
7.76	25.315	7.697	95.608
8.796	27.727	8.671	103.152
9.77	29.776	9.802	111.991
10.901	31.929	10.901	120.709
11.969	34.247	11.875	127.777
12.943	36.122	12.975	135.748
14.169	38.534	14.074	144.146
15.362	40.406	15.017	150.95
16.305	41.943	16.211	157.663
17.31	43.705	17.153	164.525
18.284	45.67	18.127	172.128
19.446	47.376	19.164	178.163
20.452	48.944	20.389	186.765
21.174	50.259	21.112	192.848
19.855	47.039	19.886	179.705
18.944	45.075	18.912	172.128
17.719	42.963	17.781	163.883
16.808	40.966	16.87	156.596
15.802	39.02	15.739	148.806
14.86	36.857	14.86	140.506
13.666	34.76	13.635	132.392
12.661	32.534	12.692	123.855
11.812	30.949	11.561	115.985
10.524	28.469	10.587	108.224
9.519	26.394	9.55	100.388
8.577	24.258	8.608	92.663
7.414	22.056	7.508	84.114
6.472	19.964	6.566	76.467
5.466	17.74	5.561	67.277
4.524	15.282	4.618	59.302
3.424	12.699	3.55	49.886
2.513	10.291	2.639	41.1
1.539	7.233	1.665	30.713

Table A.10. Steady Shear Data for Calculating Power Law Properties for Dorothy Dawson's Batter at 45.4% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
0.487	2.198	0.456	2.165	0.628	1.624
1.398	4.332	1.319	4.798	1.304	3.17
2.435	5.351	2.388	6.117	2.325	4.397
3.534	6.172	3.503	7.218	3.456	5.552
4.65	6.922	4.602	8.158	4.571	6.576
5.592	7.544	5.545	8.95	5.529	7.366
6.566	8.103	6.519	9.619	6.613	8.29
7.634	8.752	7.603	10.465	7.587	9.017
8.592	9.314	8.545	11.145	8.498	9.719
9.692	9.968	9.66	11.96	9.598	10.554
10.493	10.371	10.587	12.638	10.571	11.284
11.718	11.141	11.702	13.422	11.53	11.844
12.661	11.633	12.629	14.071	12.598	12.619
13.76	12.267	13.713	14.827	13.697	13.367
14.687	12.768	14.828	15.585	14.797	14.086
15.645	13.227	15.629	16.058	15.582	14.606
16.745	13.871	16.713	16.849	16.698	15.359
17.86	14.459	17.829	17.541	17.797	16.055
18.802	14.931	18.787	18.126	18.881	16.769
19.745	15.392	19.713	18.742	19.682	17.24
20.829	16.033	20.797	19.453	20.782	17.961
21.944	16.57	21.928	20.135	21.897	18.636
22.902	17.039	22.839	20.677	22.824	19.198
23.829	17.534	23.798	21.249	23.782	19.811
24.929	18.099	24.881	21.941	24.866	20.457
26.028	18.631	25.997	22.645	25.981	21.113
26.955	19.13	26.939	23.174	26.751	21.557
27.913	19.572	27.866	23.757	27.85	22.209
28.997	20.084	28.981	24.372	28.95	22.848
30.112	20.647	30.081	24.994	30.049	23.52
31.055	21.085	30.992	25.551	30.992	24.084
32.013	21.506	31.981	26.041	31.919	24.583
33.097	22.067	33.081	26.685	33.002	25.184
34.023	22.475	34.165	27.236	33.976	25.695
35.139	22.956	34.966	27.666	35.076	26.334
36.081	23.397	36.065	28.227	36.018	26.781
37.181	23.935	37.134	28.873	37.118	27.41
38.265	24.385	38.108	29.316	38.233	27.994
39.066	24.719	39.05	29.736	39.003	28.404
40.165	25.2	40.118	30.346	40.134	28.974
41.108	25.613	41.233	30.881	41.202	29.496
42.207	26.128	42.192	31.394	42.144	30.024
43.307	26.523	43.118	31.775	43.071	30.503
44.265	26.972	44.218	32.324	44.186	31.04
45.365	27.425	45.302	32.822	45.286	31.554
46.307	27.831	46.26	33.212	46.244	31.854
47.25	28.24	47.202	33.717	47.202	32.431
48.318	28.678	48.302	34.283	48.271	32.985
49.433	29.146	49.402	34.71	49.354	33.545
50.203	29.407	50.344	35.112	50.171	33.855

Table A.11. Steady Shear Data for Calculating Power Law Properties for Dorothy Dawson's Batter at 50.0% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
0.251	3.131	0.314	5.795	0.581	4.849
1.21	8.229	1.272	10.918	1.225	8.636
2.309	11.042	2.34	13.398	2.278	12.281
3.44	13.588	3.471	15.674	3.424	15.561
4.398	15.673	4.43	17.517	4.54	18.45
5.498	17.979	5.529	19.598	5.498	20.763
6.613	20.175	6.629	21.402	6.597	23.198
7.556	21.759	7.414	23.058	7.43	24.9
8.482	23.663	8.529	24.971	8.514	27.115
9.598	25.723	9.629	26.937	9.613	29.375
10.54	27.415	10.571	28.567	10.556	31.241
11.655	29.425	11.671	30.459	11.655	33.392
12.739	31.13	12.613	32.085	12.598	35.127
13.666	32.886	13.713	33.925	13.729	37.235
14.624	34.436	14.656	35.472	14.813	39.195
15.739	36.317	15.755	37.322	15.582	40.614
16.698	37.89	16.698	38.796	16.698	42.537
17.781	39.59	17.797	40.674	17.797	44.377
18.724	41.111	18.928	42.439	18.865	46.257
19.651	42.502	19.698	43.659	19.682	47.534
20.782	44.308	20.782	45.359	20.782	49.31
21.693	45.788	21.865	47.025	21.865	51.086
22.824	47.429	22.839	48.517	22.839	52.608
23.782	48.791	23.782	49.826	23.766	53.973
24.881	50.416	24.881	51.47	24.866	55.613
25.981	52.07	25.965	53.07	25.965	57.353
26.892	53.464	26.798	54.223	26.923	58.705
27.85	54.84	27.897	55.683	27.882	60.035
28.965	56.309	28.965	57.275	28.934	61.729
30.034	57.835	30.081	58.777	30.049	63.133
30.992	59.079	31.023	60.222	30.992	64.514
31.919	60.49	32.123	61.608	31.934	65.589
33.018	61.957	33.065	62.815	33.018	67.282
34.102	63.482	33.992	63.995	34.133	68.463
34.919	64.311	35.092	65.506	34.935	69.325
36.003	65.946	36.034	66.63	36.003	70.941
37.118	67.277	37.134	67.969	37.149	72.155
38.029	68.622	38.092	69.238	38.06	72.998
39.019	69.857	39.034	70.105	39.16	74.401
40.102	71.228	40.134	71.815	40.087	75.645
41.061	72.15	41.092	72.91	41.233	76.77
42.113	73.8	42.144	74.269	42.302	78.078
43.213	74.996	43.244	75.469	43.087	78.736
44.202	75.986	44.186	76.462	44.249	79.751
45.302	77.2	45.302	77.899	45.317	80.818
46.213	78.557	46.276	79.085	46.213	81.892
47.171	79.748	47.218	80.059	47.14	82.882
48.255	81.038	48.333	81.172	48.192	83.834
49.386	82.338	49.449	82.338	49.244	85.111
50.124	82.924	50.344	83.332	50.344	86.26

Table A.12. Steady Shear Data for Calculating Power Law Properties for Dorothy Dawson's Batter at 55.6% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
0.707	21.811	0.016	2.814	0.408	17.904
2.121	36.509	0.534	17.163	2.011	38.45
3.33	45.943	2.073	34.28	3.299	48.575
4.288	53.023	3.314	44.133	4.445	56.819
5.419	60.867	4.304	51.388	5.404	63.162
6.535	68.29	5.404	58.995	6.409	69.482
7.477	74.353	6.535	66.02	7.493	76.202
8.435	80.104	7.351	70.891	8.404	81.846
9.566	87.002	8.435	77.331	9.503	88.586
10.477	92.943	9.535	83.879	10.477	94.485
11.592	99.533	10.493	89.241	11.561	101.03
12.692	105.74	11.608	95.259	12.535	106.459
13.65	112.087	12.582	100.878	13.587	113.464
14.577	117.809	13.65	107.076	14.546	119.004
15.677	124.401	14.577	112.138	15.504	124.568
16.619	129.863	15.692	118.079	16.588	131.118
17.75	136.785	16.588	123.454	17.687	137.254
18.692	142.515	17.75	129.349	18.661	142.874
19.792	148.243	18.881	135.21	19.761	149.525
20.703	154.21	19.635	139.486	20.703	154.708
21.693	160.108	20.719	145.574	21.818	161.186
22.792	165.989	21.693	150.688	22.777	166.312
23.829	172.045	22.761	156.516	23.656	172.045
24.85	177.744	23.75	161.629	24.803	178.145
25.745	183.403	24.787	167.28	25.902	184.082
26.829	189.774	25.934	172.766	26.798	189.291
27.787	195.696	26.813	177.808	27.756	194.644
28.903	201.639	27.725	182.993	28.903	200.713
29.861	206.446	28.871	188.53	29.955	207.168
30.976	212.702	29.939	194.081	30.913	211.969
32.029	219.128	30.929	199.149	31.871	217.271
32.845	223.166	31.84	204.499	32.924	224.295
33.913	230.21	32.971	210.068	34.055	229.675
35.029	236.204	34.1	215.198	34.887	233.966
36.003	240.165	34.903	218.604	35.971	239.541
37.024	246.527	36.018	223.463	37.039	245.895
37.982	250.655	36.961	229.596	38.202	250.097
39.176	254.98	38.233	232.501	39.003	254.899
40.087	260.56	38.94	238.137	39.992	262.598
40.982	267.438	40.165	242.664	41.123	267.108
42.129	272.073	41.171	248.582	42.082	272.988
43.275	277.924	42.239	251.928	43.15	276.329
44.234	283.159	43.024	258.77	44.108	284.944
44.925	290.417	44.186	262.512	45.27	289.043
46.181	295.942	45.365	272.4	46.229	293.604
47.281	300.121	46.071	275.739	47.108	299.422
48.192	304.329	47.092	278.844	48.239	303.713
49.15	309.454	48.223	282.56	49.244	308.921
50.25	312.834	49.276	289.553	50.25	313.638
		50.265	292.822		

Table A.13. Steady Shear Data for Calculating Power Law Properties for Drake's Batter at 50.0% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
0.188	2.629	0.157	2.423	0.503	4.399
1.084	7.549	1.068	7.859	1.131	7.768
2.356	11.484	2.215	11.341	2.372	11.436
3.33	13.993	3.362	14.331	3.346	13.886
4.461	16.571	4.492	16.981	4.461	16.416
5.419	18.593	5.435	19.113	5.309	18.142
6.503	20.806	6.535	21.447	6.377	20.283
7.477	22.643	7.32	23.035	7.477	22.483
8.435	24.3	8.404	25.092	8.451	24.063
9.519	26.29	9.519	27.214	9.519	26.067
10.493	28.154	10.493	28.904	10.509	27.847
11.561	29.874	11.592	30.862	11.42	29.295
12.676	31.756	12.692	32.554	12.519	31.185
13.462	32.942	13.635	34.409	13.603	32.914
14.546	34.722	14.577	35.967	14.734	34.665
15.645	36.434	15.661	37.861	15.504	35.878
16.588	37.8	16.603	39.285	16.588	37.62
17.703	39.467	17.703	41.018	17.719	39.192
18.645	41.048	18.692	42.503	18.677	40.548
19.761	42.502	19.604	43.984	19.745	42.183
20.687	43.918	20.703	45.59	20.703	43.593
21.787	45.622	21.661	46.992	21.818	45.127
22.745	46.856	22.745	48.689	22.745	46.387
23.845	48.379	23.845	50.243	23.703	47.801
24.771	49.686	24.787	51.647	24.787	49.306
25.698	50.976	25.73	52.962	25.902	50.73
26.845	52.425	26.845	54.586	26.813	52.105
27.772	53.679	27.913	56.125	27.756	53.391
28.903	55.095	28.871	57.238	28.84	54.839
29.814	56.345	29.814	58.55	29.939	56.234
30.788	57.647	30.929	60.107	30.913	57.459
31.856	58.964	32.029	61.492	31.871	58.699
32.94	60.489	32.798	62.503	32.924	60.182
33.913	61.684	33.913	63.876	33.913	61.413
34.997	63.088	35.013	65.466	35.013	62.774
35.956	64.191	35.956	66.63	35.971	63.795
37.024	65.664	37.024	68.173	37.039	65.383
38.139	66.951	38.029	69.321	38.202	66.466
38.924	67.844	39.097	70.812	38.924	67.64
40.04	69.113	40.055	71.857	40.04	68.825
41.108	70.477	40.982	73.037	40.935	70.103
42.082	71.561	42.097	74.526	42.082	71.268
42.993	72.654	43.165	75.814	43.213	72.527
44.108	73.883	44.124	77.027	44.124	73.627
45.05	75.037	45.082	78.163	45.05	74.694
46.166	76.33	46.181	79.528	46.15	76.114
47.265	77.503	47.265	81.084	47.092	76.98
48.161	78.686	48.223	82.114	48.239	78.115
49.323	79.878	49.166	83.242	49.292	79.435
50.077	80.678	50.25	84.789	50.234	80.678
51.192	82.336	51.019	85.798	50.957	81.303

Table A.14. Steady Shear Data for Calculating Power Law Properties for Drake's Batter at 57.1% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
0.314	20.117	0.314	18.952	0.298	19.182
1.963	51.744	1.791	48.679	1.775	50.199
3.236	66.185	3.236	65.064	3.22	67.357
4.383	77.336	4.225	75.601	4.21	78.255
5.341	87.425	5.341	87.1	5.341	90.047
6.299	96.435	6.315	96.142	6.299	99.49
7.414	106.003	7.398	106.928	7.398	110.044
8.545	115.66	8.404	114.856	8.435	118.468
9.488	123.019	9.456	125.301	9.456	128.338
10.462	131.813	10.399	133.424	10.43	136.385
11.357	139.083	11.53	142.882	11.545	146.552
12.456	147.583	12.488	151.56	12.613	156.466
13.603	155.964	13.43	159.991	13.383	162.854
14.514	163.748	14.467	169.242	14.498	172.056
15.519	171.07	15.598	178.625	15.614	181.248
16.572	179.294	16.729	187.169	16.556	189.717
17.687	187.786	17.483	194.586	17.656	199.377
18.645	195.777	18.677	202.58	18.598	207.037
19.509	203.08	19.729	211.69	19.713	215.88
20.703	211.25	20.64	219.737	20.625	223.707
21.74	219.736	21.803	228.852	21.567	231.754
22.714	227.103	22.682	235.832	22.682	240.259
23.656	233.979	23.813	245.042	23.798	250.035
24.834	242.368	24.74	251.869	24.74	256.931
25.792	251.308	25.714	260.252	25.683	264.333
26.845	256.364	26.782	269.106	26.766	273.84
27.756	264.576	27.882	278.447	27.85	281.822
28.84	273.254	28.887	284.281	28.73	287.436
30.002	280.551	29.861	289.919	29.767	295.875
30.866	288.203	30.788	299.704	30.929	305.407
31.997	296.133	31.887	308.056	31.856	313.57
33.034	302.151	32.861	316.973	32.892	322.022
33.929	308.94	33.788	324.379	33.898	327.933
35.092	316.79	35.013	332.423	34.919	337.872
35.924	324.922	35.94	339.449	36.128	345.048
37.087	330.492	36.992	347.487	36.851	351.732
38.029	338.61	38.013	355.239	37.982	359.625
39.034	346.733	39.019	365.578	39.144	367.412
39.945	354.572	40.165	373.038	39.977	377.63
40.982	358.953	40.998	382.346	41.029	388.084
42.019	370.314	42.003	388.381	42.05	392.464
43.165	377.234	43.197	395.864	43.056	402.206
44.077	384.514	44.061	405.749	44.092	408.494
45.16	388.476	45.019	413.19	45.003	416.987
46.134	395.861	46.166	421.109	46.197	421.626
47.407	401.898	47.265	429.416	47.218	431.087
48.082	412.47	48.051	435.173	48.192	436.224
48.946	419.764	49.197	441.919	49.166	443.932
50.171	422.449	50.093	450.746	50.25	448.078
51.601	439.697	51.538	468.331	51.459	472.26
49.763	415.748	49.841	443.826	49.779	442.448

Table A.14. (cont'd)

48.522	411.14	48.6	438.118	48.648	435.908
47.595	400.787	47.564	427.331	47.469	429.938
46.621	391.261	46.527	417.191	46.621	420.799
45.679	387.284	45.632	413.804	45.789	413.394
44.658	378.801	44.579	404.735	44.626	403.013
43.48	371.283	43.448	394.762	43.48	395.563
42.584	364.129	42.584	387.983	42.553	389.275
41.563	357.425	41.705	381.261	41.532	384.121
40.589	349.555	40.574	371.093	40.479	371.968
39.411	342.519	39.286	364.711	39.411	363.075
38.642	334.907	38.437	356.571	38.5	355.714
37.479	328.02	37.589	347.769	37.542	351.258
36.458	318.948	36.49	341.216	36.395	341.123
35.327	312.138	35.327	332.055	35.327	332.607
34.448	303.818	34.51	324.288	34.479	327.567
33.489	297.609	33.411	317.871	33.489	318.321
32.39	288.973	32.311	309.208	32.358	309.829
31.29	281.226	31.4	301.803	31.4	302.943
30.473	275.339	30.285	293.537	30.285	294.142
29.39	268.442	29.311	285.217	29.358	287.008
28.321	259.356	28.29	275.76	28.274	277.773
27.316	252.426	27.3	269.023	27.332	270.098
26.389	245.276	26.421	261.065	26.217	262.206
25.321	236.99	25.306	252.188	25.29	253.791
24.222	228.849	24.159	244.018	24.206	244.806
23.232	222.277	23.138	235.599	23.091	236.837
22.18	213.74	22.29	229.003	22.321	229.613
21.206	206.456	21.221	219.364	21.19	220.782
20.075	198.453	20.059	210.959	20.106	211.982
19.117	191.099	19.148	203.438	19.179	204.012
18.253	183.208	18.253	195.707	18.237	196.762
17.106	174.891	17.169	185.935	17.122	187.512
16.022	167.226	16.038	177.087	16.022	178.156
15.048	158.725	15.095	169.697	15.237	171.53
14.169	150.758	14.169	160.751	14.153	162.214
13.053	142.343	13.069	151.744	13.053	152.917
12.142	134.696	11.954	142.344	12.064	144.14
11.153	127.151	11.027	134.291	11.043	134.755
10.069	118.303	10.116	125.804	10.1	126.308
9.016	108.79	9.032	116.196	9.001	116.519
8.027	100.684	7.917	105.797	7.901	106.207
7.147	92.516	7.1	98.548	7.147	98.993
6.048	82.931	6.032	88.029	6.079	88.216
4.948	72.403	4.995	77.379	4.964	77.03
4.021	63.675	3.974	67.113	4.021	67.804
3.094	54.287	3.126	57.567	3.126	57.604
2.042	41.95	2.058	44.69	2.042	44.461
1.084	28.733	1.21	32.817	1.225	32.679

Table A.15. Steady Shear Data for Calculating Power Law Properties for Golden Dipt Batter at 50.0% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
0.209	18.414	0.021	3.856	0.272	17.542
1.424	56.009	0.209	14.733	1.361	56.935
3.142	84.298	1.026	55.311	3.079	92.092
4.335	99.842	2.932	96.293	4.377	110.311
5.424	113.529	4.273	114.649	5.508	125.028
6.472	126.034	5.362	129.252	6.576	136.625
7.54	137.737	6.409	143.609	7.582	147.651
8.566	149.174	7.477	157.792	8.629	160.633
9.613	162.35	8.524	171.409	9.634	175.168
10.744	171.801	9.488	183.697	10.828	185.946
11.812	180.514	10.66	196.774	11.854	195.999
12.818	191.596	11.666	209.66	12.901	205.316
13.907	199.811	12.65	219.974	13.865	213.974
14.87	206.685	13.907	236.93	15.101	222.141
15.896	213.825	14.954	245.057	16.064	229.092
17.027	219.672	16.001	255.334	17.216	232.838
18.137	223.64	17.09	262.549	18.2	236.539
19.227	227.796	18.137	269.204	19.31	240.815
20.127	230.996	18.975	275.61	20.274	243.086
20.525	235.222	20.127	278.294		

Table A.16. Steady Shear Data for Calculating Power Law Properties for Kikkoman Tempura Batter at 45.4% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
0.314	3.543	10.022	26.444	0.314	3.62
0.88	9.28	1.759	9.815	0.817	7.486
2.011	16.44	2.608	12.199	2.105	13.696
3.55	22.036	3.613	14.676	3.424	17.882
4.587	24.954	4.681	17.043	4.555	21.274
5.843	28.524	5.686	18.824	5.561	23.646
6.629	30.898	6.817	20.678	6.692	26
7.854	34.079	7.885	22.442	7.665	28.137
9.016	36.772	8.828	23.527	8.671	30.79
9.959	39.298	10.022	24.782	9.896	33.092
10.901	41.472	11.027	26.443	10.901	34.905
12.189	44.162	11.969	28.032	11.875	37.126
13.132	46.172	13.132	29.537	13.038	39.266
14.169	49.051	14.137	30.598	13.98	40.749
15.142	51.314	15.111	31.817	15.017	43.029
16.336	52.947	16.054	33.032	16.022	44.454
17.279	54.353	17.342	34.729	17.247	46.637
18.284	56.147	18.284	35.682	18.221	48.158
19.164	58.649	19.478	36.884	19.384	49.704
20.515	60.746	20.452	38.018	20.295	50.994
21.269	61.711	21.206	38.986		

Table A.17. Steady Shear Data for Calculating Power Law Properties for Kikkoman Tempura Batter at 50.0% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
4.178	48.064	1.979	34.025	0.126	3.874
1.854	28.037	1.571	29.072	0.314	10.796
2.482	32.651	2.388	36.216	1.382	28.915
3.487	39.21	3.456	44.102	3.142	44.461
4.587	45.744	4.587	51.673	4.461	53.709
5.623	51.425	5.718	58.431	5.466	59.72
6.723	57.081	6.723	63.873	6.597	66.105
7.791	62.654	7.791	70.147	7.603	71.313
8.796	66.184	8.796	75.3	8.671	76.987
9.896	70.81	9.896	80.464	9.833	82.075
10.996	76.551	10.996	86.359	10.776	86.452
11.969	79.929	12.158	90.993	11.844	91.516
13.1	83.974	13.069	94.974	13.038	95.8
14.137	87.842	14.137	100.236	13.949	99.589
15.111	91.752	15.111	103.858	15.017	104.112
16.273	95.312	16.273	108.117	15.991	107.444
17.185	98.694	17.216	111.249	17.216	111.829
18.441	102.894	18.473	116.358	18.19	115.123
19.415	106.462	19.415	119.774	19.289	119.173
20.452	110.146	20.483	123.628	20.326	122.576
21.3	113.255	21.269	127.264		

Table A.18. Steady Shear Data for Calculating Power Law Properties for Kikkoman Tempura Batter at 55.6% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
1.948	9.64	9.142	31.14	0.314	3.62
1.539	8.418	1.854	12.365	0.817	7.486
2.545	11.438	2.576	15.08	2.105	13.696
3.581	13.959	3.613	18.227	3.424	17.882
4.681	16.554	4.65	21.318	4.555	21.274
5.686	18.637	5.686	23.74	5.561	23.646
6.817	20.722	6.817	25.951	6.692	26
7.885	22.9	7.854	28.085	7.665	28.137
8.828	24.615	8.828	30.521	8.671	30.79
9.99	26.493	9.99	32.73	9.896	33.092
11.058	28.547	10.996	34.848	10.901	34.905
11.969	30.199	12.001	36.505	11.875	37.126
13.163	31.927	13.163	38.203	13.038	39.266
14.137	33.623	14.074	39.788	13.98	40.749
15.142	35.104	15.142	41.88	15.017	43.029
16.305	36.768	16.305	43.092	16.022	44.454
17.216	38.17	17.342	44.879	17.247	46.637
18.284	39.785	18.315	46.169	18.221	48.158
19.415	41.436	19.478	47.715	19.384	49.704
20.483	42.705	20.483	48.944	20.295	50.994
21.206	43.702	21.174	50.224		

Table A.19. Steady Shear Data for Calculating Power Law Properties for Tung-I Tempura Batter at 43.8% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
1.759	10.052	1.791	9.786	1.665	10.473
2.576	12.8	2.545	12.431	2.513	13.486
3.613	15.563	3.581	15.264	3.581	16.555
4.681	18.473	4.65	18.288	4.65	19.794
5.655	20.832	5.655	20.657	5.686	22.375
6.817	23.248	6.817	23.179	6.786	24.929
7.76	25.339	7.76	25.315	7.854	27.702
8.828	27.829	8.796	27.727	8.796	29.909
9.99	30.041	9.77	29.776	9.99	32.314
10.933	31.956	10.901	31.929	10.996	34.848
11.969	34.218	11.969	34.247	11.969	36.829
13.163	36.298	12.943	36.122	13.132	38.93
14.106	38.051	14.169	38.534	14.074	40.718
15.142	40.158	15.362	40.406	15.111	42.772
16.242	41.848	16.305	41.943	16.116	44.258
17.373	43.899	17.31	43.705	17.247	46.003
18.284	45.405	18.284	45.67	18.535	48.158
19.446	47.174	19.446	47.376	19.478	49.531
20.452	48.703	20.452	48.944	20.452	51.029
21.143	49.911	21.174	50.259	21.174	52.337

Table A.20. Steady Shear Data for Calculating Power Law Properties for Tung-I Tempura Batter at 50.0% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
2.231	50.934	2.482	65.746	5.372	85.717
2.45	53.927	1.885	48.509	2.231	45.812
3.33	64.231	2.388	55.237	2.293	47.827
4.461	76.252	3.393	66.671	3.424	60.065
5.498	86.501	4.43	78.565	4.43	70.855
6.597	95.95	5.655	89.862	5.623	81.539
7.665	105.494	6.66	99.096	6.629	90.144
8.671	114.487	7.697	109.369	7.697	99.741
9.802	123.08	8.671	118.201	8.671	107.707
10.87	132.049	9.802	127.948	9.833	116.309
11.844	139.325	10.901	137.678	10.901	125.585
12.975	147.955	12.064	146.68	11.938	132.795
14.043	155.347	13.006	154.538	13.006	140.567
14.985	163.244	14.074	163.821	14.043	148.015
16.116	170.098	15.048	170.949	15.048	156.034
17.122	176.696	16.211	178.366	16.211	163.18
18.41	185.534	17.185	184.92	17.122	169.053
19.321	191.18	18.19	192.849	18.378	177.428
20.452	199.102	19.384	199.67	19.321	183.014
21.112	205.748	20.42	207.264	20.358	190.624

Table A.21. Steady Shear Data for Calculating Power Law Properties for Newly Wed Tempura Batter at 43.6% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
1.602	2.542	1.445	2.015	1.225	2.272
2.639	3.576	2.608	2.996	2.545	3.662
3.676	4.738	3.738	3.908	3.581	4.958
4.712	5.64	4.618	4.678	4.869	5.948
5.906	6.461	5.906	5.456	5.781	6.815
6.88	7.406	6.849	6.275	6.786	7.817
8.137	8.146	7.823	6.947	7.823	8.605
8.828	8.798	9.079	7.583	8.922	9.433
10.022	9.563	9.99	8.171	9.927	10.242
10.933	10.422	10.996	8.964	10.933	11.07
12.189	11.179	12.252	9.619	12.127	11.85
13.132	11.915	13.195	10.376	13.1	12.575
14.043	12.592	14.074	10.85	14.106	13.306
15.048	13.357	15.08	11.51	15.048	14.165
16.273	13.987	16.242	12.044	16.211	14.724
17.279	14.687	17.247	12.657	17.185	15.611
18.19	15.442	18.158	13.442	18.158	16.238
19.446	16.122	19.478	13.932	19.384	16.936
20.389	16.72	20.389	14.486	20.326	17.57
20.923	17.211	21.017	14.849		

Table A.22. Steady Shear Data for Calculating Power Law Properties for Newly Wed Tempura Batter at 50.0% Solids

Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]	Shear Rate [1/s]	Shear Stress [Pa]
0.88	18.951	2.325	20.376	1.854	19.307
1.445	22.881	2.482	22.127	2.482	22.172
2.639	26.126	3.581	27.603	3.519	27.299
3.77	29.568	4.618	31.741	4.65	30.792
4.869	32.927	5.718	35.951	5.749	34.052
5.843	35.922	6.786	39.915	6.817	37.099
6.849	39.423	7.791	43.387	7.728	39.453
7.76	42.712	8.922	47.012	8.954	42.36
9.173	46.475	9.99	50.545	9.896	44.817
9.99	49.053	10.933	53.453	10.933	47.89
11.027	51.917	12.095	56.78	12.127	50.683
12.127	55.158	13.069	59.449	13.038	53.596
13.132	58.013	14.106	62.533	14.106	56.186
14.137	60.75	15.268	65.418	15.237	58.501
15.142	63.513	16.211	67.473	16.179	61.095
16.305	66.179	17.247	70.515	17.185	63.669
17.185	68.862	18.221	72.82	18.19	65.656
18.158	72.104	19.415	75.423	19.101	67.716
19.415	74.265	20.389	78.335	20.295	70.056
20.452	76.763	21.08	80.191		
21.08	79.216				

Table A.23. Weight (g) of Adhesion Batters Retained on the Probe over a Three-Hour Period

Time (minutes)	Dorothy Dawson's Batter			Drake's Batter		Golden Dipt Batter
	45.4% Solids	50.0% Solids	55.6% Solids	50.0% Solids	57.1% Solids	50.0% Solids
0	2.01	3.74	8.78	3.03	8.00	9.05
	2.04	3.37	8.06	2.65	8.13	9.69
5	2.15	3.73	9.15	3.27	8.14	8.76
	2.09	3.82	8.12	2.21	8.06	9.00
10	2.17	4.15	8.71	2.39	7.77	8.84
	2.28	4.11	7.89	1.50	7.91	9.07
15	2.20	4.20	7.56	1.16	8.10	8.70
	2.26	4.38	7.59	0.95	8.12	8.91
20	2.14	4.14	9.31	3.03	7.63	8.47
	2.22	4.13	7.79	1.44	7.57	8.65
25	2.18	4.12	9.84	3.54	7.55	8.27
	2.24	4.08	7.75	1.43	7.55	8.49
30	2.20	4.18	8.65	2.27	7.15	7.79
	2.16	4.12	8.22	1.94	7.32	7.71
45	2.10	3.99	8.90	2.81	7.92	8.23
	2.13	4.18	8.09	1.78	8.58	9.11
60	2.06	3.96	9.27	3.25	8.11	8.81
	2.16	4.11	8.03	1.76	8.36	9.43
75	2.11	4.13	9.19	2.95	7.88	8.47
	2.10	4.09	7.93	1.74	8.20	8.74
90	1.55	4.39	8.84	2.90	7.70	9.09
	2.07	4.06	7.95	1.82	8.01	9.17
120	1.67	4.13	9.15	3.35	7.63	8.71
	2.10	4.14	8.37	2.13	7.79	8.64
150	1.99	4.14	9.14	3.01	7.40	8.70
	2.00	4.13	7.89	1.76	8.04	8.27
180	2.11	4.23	8.20	1.86	7.26	8.44
	2.02	4.13	7.93	1.78	7.27	8.40

Table A.24. Weight (g) of Tempura Batters Retained on the Probe over a Three-Hour Period

Time (minutes)	Kikkoman Tempura Batter			Tung-I Tempura Batter		Newly Wed Tempura Batter	
	45.4% Solids	50.0% Solids	55.6% Solids	43.8% Solids	50.0% Solids	43.6% Solids	50.0% Solids
0	3.25	6.64	9.92	3.23	7.39	1.72	4.81
	4.01	6.05	10.79	3.51	7.21	1.67	4.89
5	3.26	6.47	9.28	3.62	7.58	1.83	5.47
	4.23	6.99	9.93	4.05	6.99	1.85	5.38
10	3.29	7.03	8.77	3.62	7.31	1.85	5.72
	4.54	7.06	8.60	3.87	7.85	2.13	5.41
15	3.07	6.92	9.23	3.73	7.01	2.31	5.59
	4.41	7.01	8.64	4.17	7.47	2.26	5.33
20	2.90	6.94	8.58	4.02	7.76	2.22	5.52
	4.42	6.83	9.02	4.18	7.71	2.43	5.56
25	3.51	7.11	8.66	3.84	7.19	2.36	5.55
	4.50	6.96	8.57	4.32	8.49	2.26	5.49
30	3.46	6.97	7.29	3.84	6.95	2.36	5.82
	4.65	6.48	8.98	4.47	7.74	2.64	6.23
45	3.00	7.46	10.00	4.25	8.12	4.20	6.35
	5.15	6.82	10.39	4.63	7.40	2.78	5.55
60	3.46	6.94	10.08	4.25	7.79	4.81	6.67
	4.92	7.22	11.38	3.90	8.64	3.37	5.61
75	3.25	7.22	10.63	4.44	9.25	4.30	6.28
	4.07	7.18	9.76	3.92	8.92	2.95	5.18
90	3.55	7.39	9.15	3.89	9.41	4.10	5.90
	4.51	7.06	9.33	3.94	8.72	4.80	5.49
120	3.37	6.89	9.31	3.86	9.84	5.05	5.77
	4.60	7.05	9.41	4.05	8.66	4.83	5.23
150	3.53	6.98	9.07	4.00	8.50	4.64	5.50
	4.41	6.70	7.94	4.08	8.15	4.75	5.19
180	3.69	6.50	8.51	3.70	7.96	4.75	5.57
	4.04	6.60	8.91	4.12	8.21	4.71	5.27

Table A.25. Shear Stress Measurements of Adhesion Batters over a Three-Hour Period at 15 1/s Shear Rate

Time (minutes)	Dorothy Dawson's Batter			Drake's Batter		Golden Dipt Batter
	45.4% Solids	50.0% Solids	55.6% Solids	50.0% Solids	57.1% Solids	50.0% Solids
0	13.227	36.317	124.401	29.763	111.136	206.685
	16.058	37.322	118.079	31.426	116.458	245.057
	14.606	40.614	124.568	30.938	113.196	222.141
15	15.528	35.703	115.383	32.385	123.067	204.524
	17.624	39.194	113.249	32.717	118.459	215.521
	16.326	42.634	119.003	32.440	121.962	215.816
30	17.166	38.555	111.136	32.634	113.249	195.575
	18.252	39.072	111.452	31.780	117.483	205.531
	17.444	43.729	117.159	32.385	119.384	211.481
45	17.285	41.020	114.687	33.135	119.548	192.777
	20.207	39.317	107.693	32.912	117.375	199.172
	16.500	42.602	115.329	32.606	116.673	212.066
60	18.581	42.061	117.159	32.745	116.458	191.664
	19.248	41.492	102.937	33.304	120.862	210.750
	18.150	44.904	113.834	33.697	116.835	215.373
90	18.395	39.901	121.907	32.137	114.634	192.081
	19.971	41.777	107.125	33.332	118.568	222.666
	20.359	47.100	118.079	32.385	120.095	221.616
120	21.682	41.083	117.646	34.378	112.825	193.894
	22.956	41.586	109.251	32.968	116.350	207.915
	21.862	45.895	121.631	32.164	115.222	215.890
150	21.258	40.459	125.853	34.179	113.621	194.523
	24.554	42.188	114.848	34.179	117.483	202.660
	21.059	43.535	126.358	32.856	117.267	215.742
180	19.269	42.698	121.686	34.407	115.920	188.069
	22.634	44.281	114.634	34.150	118.513	211.115
	23.678	44.510	126.078	32.717	112.349	183.760

Table A.26. Shear Stress Measurements of Tempura Batters over a Three-Hour Period at 15 1/s Shear Rate

Time (minutes)	Kikkoman Tempura Batter 45.4% Solids	Kikkoman Tempura Batter 50.0% Solids	Kikkoman Tempura Batter 55.6% Solids	Tung-I Tempura Batter 43.8% Solids	Tung-I Tempura Batter 50.0% Solids	Newly Wed Tempura Batter 43.6% Solids	Newly Wed Tempura Batter 50.0% Solids
0	43.029	104.112	297.205	33.061	170.949	13.357	65.418
	41.564	100.734	306.494	40.065	151.012	14.165	57.337
	36.798	104.112	332.272	40.220	156.034	13.168	58.501
15	41.470	93.620	284.000	44.258	178.367	21.090	65.658
	48.741	94.730	359.470	40.873	154.475	17.017	74.267
	42.932	104.469	360.332	43.093	158.104	17.334	62.026
30	40.313	96.189	291.666	37.243	176.763	16.626	60.864
	39.941	93.475	345.551	43.673	162.031	17.714	57.300
	45.606	110.830	338.368	42.389	162.095	15.782	54.755
45	45.045	99.141	301.743	40.873	184.036	17.916	70.974
	42.516	95.070	341.251	43.868	167.949	18.282	67.028
	46.004	109.261	325.502	44.454	157.475	15.707	58.312
60	47.042	98.498	271.615	45.209	183.017	19.723	62.532
	40.096	91.276	326.778	44.030	166.201	17.235	61.096
	42.071	95.848	306.758	44.749	160.188	16.723	60.135
90	40.561	97.561	265.914	42.804	179.238	18.611	64.382
	39.173	97.512	333.837	43.157	158.104	19.575	62.845
	46.071	98.943	303.059	44.291	160.632	17.394	57.263
120	39.357	101.837	302.357	48.160	172.986	17.613	62.532
	41.722	96.043	292.442	44.356	154.475	19.090	60.864
	43.125	96.482	316.913	45.540	164.526	16.743	64.422
150	39.787	92.611	303.586	43.028	175.433	16.645	65.658
	48.126	93.909	298.336	47.785	150.152	19.809	57.674
	39.910	86.311	297.814	47.075	156.221	17.956	58.501
180	39.142	95.070	275.450	54.064	167.754	19.300	65.400
	38.141	90.281	291.752	45.407	157.161	18.756	61.560
	39.387	82.162	296.770	42.102	166.718	18.283	63.198

Table A.27. Weight (g) and Thickness (mm) Measurements of Food Substrates before and after Frying

Food Substrate:	String Cheese with adhesion batter coating			Shrimp with adhesion batter coating		
	Undermixed Batter	Optimum-mixed Batter	Over-mixed Batter	Undermixed Batter	Optimum-mixed Batter	Over-mixed Batter
F_1 (g)	29.82	28.68	258.12	32.94	36.23	34.85
	26.96	31.72	28.62	34.74	37.04	36.04
	27.69	28.52	28.70	33.93	39.43	36.30
F_2 (g)	29.86	40.37	39.15	37.72	52.35	49.60
	27.25	45.68	40.52	38.73	53.02	54.94
	30.18	40.91	39.44	35.63	60.45	55.33
F_3 (g)				37.72	53.02	49.60
				38.73	52.35	54.94
				35.63	60.45	55.33
F (g)				15.90	32.35	28.13
				16.57	29.62	32.41
				13.85	38.06	33.18
T_0 (mm)	1.76	1.76	1.76			
	1.76	1.76	1.76			
	1.76	1.76	1.76			
T_1 (mm)	1.866	2.25	2.23			
	1.878	2.22	2.22			
	1.846	2.41	2.19			

F = Weight of Food Coating (g)

F_1 = Weight of Food before Coating (g)

F_2 = Weight of Food after Coating (g)

F_3 = Weight of Fried Food (g)

T_0 = Thickness of Food (mm)

T_1 = Thickness of Fried Food (mm)

Table A.28. Weight (g) Measurements of Food Substrates before and after Frying

Food Substrate:	Sliced Cucumber with tempura batter coating			Shrimp with tempura batter coating		
	Undermixed Batter	Optimum-mixed Batter	Over-mixed Batter	Undermixed Batter	Optimum-mixed Batter	Over-mixed Batter
F_1 (g)	47.31	48.07	47.57	29.47	31.52	30.98
	50.64	49.05	46.75	30.34	31.41	31.19
	49.18	47.64	47.66	30.13	31.94	30.61
F_2 (g)	41.97	75.91	70.60	27.82	50.48	47.07
	47.09	70.02	70.35	24.68	49.56	45.77
	44.20	70.89	74.71		51.17	41.69
F_3 (g)	42.00	73.71	68.54		48.18	44.57
	45.68	67.52	68.32		47.44	43.06
	43.49	68.64	72.62		49.14	39.30
F (g)	10.31	38.24	34.57		26.39	22.70
	9.58	30.86	35.28		26.44	23.83
	11.87	33.63	35.61		27.65	18.90

F = Weight of Food Coating (g)

F_1 = Weight of Food before Coating (g)

F_2 = Weight of Food after Coating (g)

F_3 = Weight of Fried Food (g)

BIBLIOGRAPHY

BIBLIOGRAPHY

Baird, D.G. 1981 Dynamic viscoelastic properties of soy isolate doughs. Journal of Texture Studies. 12: 1-16.

Balasubramanian, V.M., Chinnan, M.S., Mallikarjunan, P. and Phillips, R.D. 1997. The Effect of Edible Film on Oil Uptake and Moisture Retention of a Deep-fat Fried poultry Product. Journal of Food Process Engineering. 20: 17-29.

Barnes, H.A., Hutton, J.F. and Walters, K. 1989. An Introduction to Rheology. Elsevier Science Publishers Co., New York.

Bennion, M., Stirk, K.S. and Ball, B.H. 1976. Changes in Frying Fats with Batters Containing Egg. Journal of The American Dietetic Association. 68(3): 234-236.

Bingham, E.C. 1929. Fluidity and Plasticity. Mc Graw-Hill Book Co., New York.

Bourne, M.C. 1982. Food Texture and Viscosity: Concept and Measurement. Academic Press. New York.

Castell-Perez, M.E. and Mishra, A.K. 1995. Research Note: Flow Behavior of Regular and Peanut-Fortified Idli Batters. Journal of Texture Studies. 26: 273-279.

Charm, S.E. 1963. The Direct Determination of Shear Stress-Shear Rate Behavior of Foods in the Presence of a Yield Stress. Journal of Food Science. 28: 107-113.

Choudhury, G.S. and Gautam, A. 1998. Comparative Study of Mixing Elements During Twin-Screw Extrusion of Rice Flour. Food Research International. 31(1): 7-17.

Churchill, S.W. 1988. Viscous Flows: The Practical Use of Theory. Butterworths, Boston.

Code of Federal Regulations, 2000. Requirements for specific standardized fish and shell fish. Title 21, Chapter I, Part 161, Subpart B, Sections 161.175 and 161.176.

Cunningham, F.E., and Tiede, L.M. 1981. A Research Note: Influence of Batter Viscosity on Breading of Chicken Drumsticks. Journal of Food Science. 46: 1950, 1952.

Dow Chemical 1997. Methocel Food Gums: Fried Food/Batters. Brochure 194-01290-497GW. The Dow Chemical Co., Midland, MI.

Flick, G.J., Gwo, Y., Ory, R.L., Baran, W.L., Sasiela, R.J., Boling, J., vinnett, C.H., Martin, E. and Arganosa G.C. 1989. Effects of Cooking Conditions and Post-preparation Procedures on the Quality of Battered Fish Portions. Journal of Food Quality. 12: 227-242.

Fritsch, C.W. 1981. Measurement of Frying Fat Deterioration: A Brief Review. Journal of American Oil Chemist Society. 58: 272.

Gogoi, B.K., Oswalt, A.J., Choudhury, G.S. 1996. Reverse Screw Eelment(s) and Feed Composition Effects During Twin-Screw Extrusion of Rice Flour and Fish Muscle Blends. Journal of Food Science. 61(3): 590-595.

Gogoi, B.K., Choudhury, G.S., Oswalt, A.J. 1996. Effects of Location and Spacing of Reverse Screw and Kneading Element Combination During twin-Screw Extrusion of Starchy and Proteinaceous Blends. Food Research International. 29(5/6): 505-512.

Grodner, R.M., Andrews, L.S. and Martin, R.E. 1991. Chemical Composition of Seafood Breading and Batter Mixes. Cereal Chemistry. 68(2): 162-164.

Heckman, E. 1977. Starch and its Modifications for the Food Industry. In Food Colloids (H. Graham, ed.) pp464-477. AVI Publishing Co., Westport, CT.

Hoseney, R.C. 1994. Principles of Cereal Science and Technology. 2nd Edition. American Association of Cereal Chemists, Inc., St. Paul. Minnesota.

Hsia, H.Y., Smith, D.M. and Steffe, J.F. 1992. Rheological Properties and Adhesion Characteristics of Flour-Based Batters for Chicken Nuggests as Affected by Three Hydrocolloids. Journal of Food Science. 57(1): 16-18, 24.

Kee, D.D., Schlesinger, M. and Godo, M. 1988 Postwithdrawal Drainage of Different Types of Fluids. Chemical Engineering Science. 43(7): 1603-1614.

Kee, D.D. Turcotte, G., Fildey, K and Harrison. 1980. Research Note: New Method for the Determination of Yield Stress. Journal of Texture Studies. 10:281-288.

Kulp, K and Loewe, R. (ed.) 1990. Batters and Breadings in Food Processing. American Association of Cereal Chemists, Inc., St. Paul, Minnesota.

Lane, R.H. and Abdel-Ghany, M. 1986. Viscosity and Pick-up of a Fish and Chip Batter: Determinants of Variation. Journal of Food Quality. 9: 107-113.

Lang, E.R. and C. Rha. 1981. Determination of Yield Stresses of Hydrocolloid Dispersions. Journal of Texture Studies. 12: 47-62.

Lue, S., Hsieh, F., Huff, H.E. 1994. Modeling of Twin-screw Extrusion Cooking of Corn Meal and Sugar Beet Fiber Mixtures. Journal of Food Engineer. 21(3): 263-289.

McGlinchey, N. 1994. Batter By Far - Speciality Starches in Battered and Breaded Foods. Food Technology Europe. 1(5): 96, 98, 100.

Nakai, Y. and Chen, T.C. 1986. Effects of Coating Preparation Methods on yields and Compositions of Deep-Fat Fried Chicken Parts. Poultry Science 65: 307-313.

Nawar, W., Hultin, H., Li, Y., Xing, Y., Kelleher, S. and Wilhelm, C. 1990. Lipid Oxidation in Seafoods Under Conventional conditions. Food Reviews International 6(4): 647-660.

Novak, F., Olewnik, M. and Kulp, K. 1987. Functionality of Flour in Batter Systems. (Abstract.) Cereal Foods World. 32: 659.

Official Methods of Analysis of AOAC International. 2000. 17^{th} Edition. Baithersburg. Maryland.

Olewnik, M. and Kulp, K. 1993. Factors Influencing Wheat Flour Performance in Batter Systems. Cereal Food World. 38(9): 679-684.

Onwulata, C.I., Konstance, R.P., Smith, P.W., Holsinger, V.H. 1998. Physical Properties of Extruded Products as Affected by Cheese Whey. Journal of Food Science. 63(5): 814-818.

Rao, M.A., Okechukwu, P.E., Silva, P.M.Sda., Oliveira, J.C. 1997. Rheological Behavior of Heated Starch Dispersions in Excess Water: Role of Starch Granule. Carbohydrate Polymers. 33(4):273-283.

Rhee, K.S., Housson, S.E. and Ziprin, Y.A. 1992. Enhancement of Frying Oil Stability by a Natural Antioxidative Ingredient in the Coating System of Fried Meat Nuggests. Journal of Food Science. 57(3): 789-791.

Schwartzberg, H.G., Wu, J.P.C., Nussinovitch, A., Mugerwa, J. 1995. Modelling Deformation and Flow During Vapor-induced Puffing. Journal of Food Engineer. 25(3): 329-272.

Shinsato, E., Hippleheuser, A.L. and Van Beirendonck, K. 1999. Products for Batter and Coating Systems. The World of Ingredients. January/February: 38-49,42.

Steffe, J.F. 1996. Rheological Methods in Food Process Engineering. 2nd edition. Freeman Press. East Lansing, MI.

Suderman, D.R. 1993. Selecting Flavorings and Seasonings for Batter and Breading Systems. Cereal Food World. 38(9): 689-694.

Suderman, D.R. and Cunningham, F.E. (ed.) 1983. Batter and Breading Technology. AVI Publishing Company, Inc., Westport, Connecticut.

United State Department of Commerce. 2000. Seafood Inspection Program. U.S. Standards for Grades of Fishery Products. [Online] Available http://www.seafood.nmfs.gov/standard.html,January 1, 2000