Rheological Property of Mayonnaise Processed by High Pressure

Zhao Hongxia[1], Zhang Shouqin[1], Wu Hua[1], Ma Chenglin[1], Lü Chaohui[1], Liu Zhixia[2]
(1. College of Biological and Agricultural Engineering, Jilin University, Changchun 130025, China;
2. College of Agricultural Engineering, Shenyang Agricultural University, Shenyang 110161, China)

Abstract: The rheological property of mayonnaise under different pressures is measured using AR2500 rheometer at low shear rate. The results show that Mayonnaise processed by high pressure is shear thinning fluid and takes on pseudoplastic characteristics. Taking the minimum standard error as the standard for best fit, the mathematic model of mayonnaise under different high pressure processing is obtained by using the constitutive equation of non2Newtonian flow and measured data to fit curves, and the reason of viscosity variety in terms of pressure is analyzed tentatively. This is due to the protein molecule disassociated and unfolded with treatment of less than or equal to 500 MPa, while small molecule disassociated with the continuous increase of pressure may be associated over again, and increase of salad oil particle size in mayonnaise results in decrease of energy dissipation using slippage and friction beyond 500 MPa.

Key words: high hydrostatic pressure (HHP); mayonnaise; rheological property; viscosity
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1 Introduction

Egg is one of the most important nutrition ingredients to people. The yolk of an egg consists of protein, sugar, multivitamin, and mineral, etc, especially its protein nutrition value is higher than that of any other animal foodstuff and plant foodstuff. Most important of all, it also contains such indispensable substance as lecithin, cephalin and other ingredients to people's brain and nervous system [1]. But egg is not easy to transport due to its brittle eggshell and is likely to be influenced by circumstances during the process of stockpile. Therefore, egg is usually manufactured into kinds of goods, and mayonnaise is one instance of those. Mayonnaise is a sort of emulsifying semisolid, high nutrition value and distinctive flavor condiment. It is made of yolk, edible vegetable oil and other condiments. It cannot be sterilized by heating because mayonnaise structure will be destroyed[2], while it is easily corruptive by microorganism at normal temperature. High pressure processing can sterilize at normal or lower temperature and gain new food with distinguished quality. Mayonnaise processed by high pressure takes on steady quality, abundant nutrition, safety, convenience, and longer storage life. So mayonnaise market potential is huge.

Food rheology plays a more and more important role in food processing industry along with its development. Mayonnaise rheological property may vary largely as its categories, producing areas, test instrument precision and processing methods, and moreover, mayonnaise viscosity has a direct effect on taste and edible quality[3, 4]. In this paper static rheological property of mayonnaise treated with high pressure at low shear rates and the mathematical models of its viscosity are discussed.

2 High Pressure Processing

In our experiments, the maximum working pressure of high pressure equipment is 700 MPa. The equipment mostly consists of a high pressure vessel and its closure, a pressure2generation

Received date: 2001207220
Biography: Zhao Hongxia, female, doctoral student. Email: zhxjlu@263.net

system, and assistant parts High pressure is generated by indirect compression. Supercharger produces high pressure through pumping the pressure medium from the reservoir into the closed vessel and thus samples are processed. The process has four steps: 1) Samples sealed in vacuum2packed bags are placed into the high pressure vessel, then the vessel is closed and sealed; 2) To start high pressure pump, high pressure is generated and reaches the desired pressure for a certain time; 3) After the high pressure treatment, the valve which controls high pressure oil route is opened and the pressure is released; 4) To take out samples from the vessel, experimental samples are gained after removing its packing.

Experimental pressure of pressurized samples is from 100MPa to 600MPa, each processing time (holding time) is 5 min, and control sample is unpressurized samples. Thus there are 7 experimental samples. All experiments are carried out at room temperature.

3 Rheological Property Experiment

Samples in this experiment are KEWPIE mayonnaise. Mayonnaise rheological property is measured using AR2500 rheometer of TA Instruments, shear rate is less than 1715 s^{-1}, experimental temperature is 20 ℃, and all experimental samples are in steady state flow. Relation curve of viscosity and shear rate is shown in Fig. 1 (Viscosity is a function of shear rate in rheology, namely, $S = G \times \dot{C}$), and relation curve of shear stress and shear rate is shown in Fig. 2.

4 Flow Model

In order to perform a quantitative comparison of materials, it is generally required fitting the experimental data to some forms of best2fit mathematical equation or model[5]. The model is used to predict the viscosity of a flow as a function of shear stress or shear rate, it is named also constitutive equation of a flow. The most popular flow models are as follows.

① Power Law Equation

Since most materials are non2Newtonian, non2

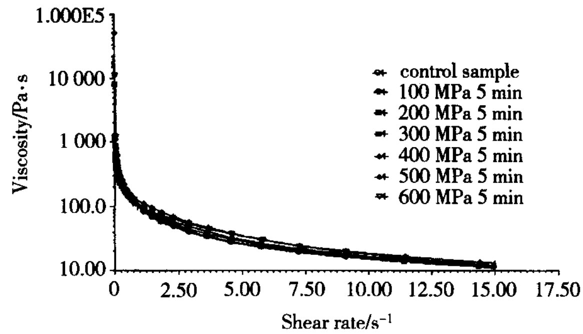

Fig. 1 The curve of viscosity vs. shear rate
(Note: The scale of y2axis is logarithm of viscosity value in order to make the relationship clear)

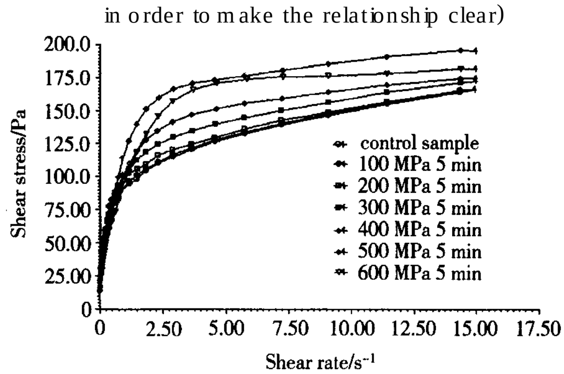

Fig. 2 The curve of shear stress vs. shear rate

linear models are needed to describe the change in viscosity as a function of shear. The power law equation is the simplest one among the models available. Characteristic equation of power law mode is as follows

$$S = K \times \dot{C}^n \quad (1)$$

where S—— shear stress, Pa; $\dot{C}$—— shear rate, s^{-1}; K —— consistency coefficient, the higher K is, the thicker flow is, Pa · s^n; n —— rate index, is degree measurement of non2Newtonian flow, the farther n is depart from 1, the more distinct the property of non2Newtonian behavior is.

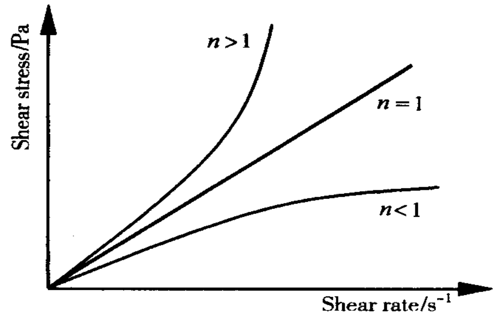

Fig. 3 The power law curve of relationship between shear stress and shear rate

According to the value of n (Fig. 3), the power law model can be divided into three basic types of flow: 1) When n is less than 1, apparent viscosity reduces with the increase of shear rate, curvature of S2$\dot{C}$ is downwards, which is called shear thinning fluid or pseudoplastic. 2) When n is larger than 1, apparent viscosity increases with the increase of shear rate, curvature of S2$\dot{C}$ is upwards, which is called shear thickening flow or dilatancy. 3) When n is equal to 1, it is called Newtonian behavior.

Most materials are shear thinning and can be represented by the power law over a limited range of shear, but it may not accurately describe the materials behavior and more complex models must be used.

② Bingham Equation

Bingham takes on different mechanics behavior compared with Newtonian behavior. It has enough rigid structure of three dimensions to resist any outside force, which is under yield stress. If outside force exceeds yield stress, this kind of structure will decompose and generate flow. The Bingham equation describes the shear stress ö shear rate behavior of many shear2thinning materials at low shear rates. Its characteristic equation is as follows

$$S = S_y + K \times \dot{C} \qquad (2)$$

where S_y —— yield stress, Pa.

③ Newtonian Equation

This model describes the simplest type of flow behavior, namely where the viscosity of a material is constant: the stress is proportional to the flow rate. Its characteristic equation is as follows

$$S = K \times \dot{C} \qquad (3)$$

④ Herschel2Bulkley Equation

This model incorporates the elements of the Newtonian, Power law and Bingham equations

$$S = S_y + K \times \dot{C}^n \qquad (4)$$

Newtonian　Yield stress = 0　$n = 1$

Power law　Yield stress = 0　n = power law index

Bingham　Yield stress value　$n = 1$

It can often be used as a general2purpose model for shear thinning materials.

⑤ Casson Equation

This model can be used for materials that tend to Newtonian behavior only at shear stresses considerably higher than their yield stresses

$$\sqrt{S} = \sqrt{S_0} + \sqrt{K} \times \sqrt{\dot{C}} \qquad (5)$$

⑥ Sisko Equation

The Sisko model can often be used with data generated at high shear rates

$$G = G_\infty + K \times \dot{C}^{n-1} \qquad (6)$$

where G_∞ —— infinite rate viscosity, Pa·s

⑦ Williamson Equation

This model can often be used with data generated at low shear rates

$$G = \frac{G_0}{1 + (K \times \dot{C})^n} \qquad (7)$$

where G_0 —— zero2rate viscosity

⑧ Cross Equation

To obtain a model for a general flow curve, over a wide range of shears, requires a model with at least four parameters. The Cross model is a good example of this type of equation.

The Cross model uses shear rate as the independent variable. Constitutive equation of non2linear flow proposed by Cross which includes 4 constants is as follows

$$\frac{G - G_\infty}{G_0 - G_\infty} = \frac{1}{1 + (K \times \dot{C})^n} \qquad (8)$$

⑨ Ellis Equation

This model is equivalent to the Cross model, but using shear stress rather than shear rate.

$$\frac{G - G_\infty}{G_0 - G_\infty} = \frac{1}{1 + (K \times S)^n} \qquad (9)$$

5 Flow Model of Mayonnaise Processed by Different High Pressures

A series of discrete date points are acquired using AR2500 Rheometer. The flow equation of mayonnaise processed by different high pressures is developed through curve fitting using known constitutive equations of non2Newtonian flow and measured data. The model fitting software will calculate and display the standard error of the fit, defined in Equation 10. The best fit is explained by standard error. The greater the standard error, the worse the fit; a reasonable fit gives a value of standard error less than about 20.

$$\text{Standard error}=\frac{\left[\frac{\sum (X_n - X_c)^2}{n-2}\right]^{1ö2}}{Range}\times 1\ 000 \tag{10}$$

where X_m is the measured value and X_c the calculated value of X for each data point, n is the number of data points, and the $Range$ is the difference between maximum value of X_m and its minimum value.

Fitting equations of mayonnaise treated with different pressures are showed in Table 1.

Table 1 Fitting flow equation of mayonnaise treated with high pressure

Sample (Pressure and holding time)	Fitting model	Flow equation	Standard errors
control sample	Williamson	$G=\frac{475\ 500}{1+(233\ 300\dot{C})^{01700\ 6}}$	14. 35
100 MPa, 5 min	Williamson	$G=\frac{756\ 500}{1+(527\ 800\dot{C})^{01692\ 2}}$	18132
	Cross	$\frac{G-01000\ 001\ 092}{654\ 800-01000\ 001\ 092}=\frac{1}{1+(427\ 400\dot{C})^{01692\ 3}}$	18132
200 MPa, 5 min	Williamson	$G=\frac{368\ 700}{1+(196\ 800\dot{C})^{01688\ 0}}$	19137
	Cross	$\frac{G-01000\ 002\ 477}{381\ 500-01000\ 002\ 477}=\frac{1}{1+(207\ 100\dot{C})^{01687\ 9}}$	19137
300 MPa, 5 min	Williamson	$G=\frac{22\ 400\ 000}{1+(84\ 110\ 000\dot{C})^{01684\ 3}}$	19116
400 MPa, 5 min	Williamson	$G=\frac{49\ 260\ 000}{1+(218\ 800\ 000\dot{C})^{01688\ 9}}$	18. 61
500 MPa, 5 min	Williamson	$G=\frac{108\ 900\ 000}{1+(227\ 100\ 000\dot{C})^{01720\ 2}}$	18156
600 MPa, 5 min	Williamson	$G=\frac{78\ 340\ 000}{1+(397\ 800\ 000\dot{C})^{01689\ 9}}$	17165
	Cross	$\frac{G-01038\ 32}{31\ 860\ 000-01038\ 32}=\frac{1}{1+(107\ 500\ 000\dot{C})^{01690\ 2}}$	17165

6 Discussion

1) From Figure 1, it can be concluded that mayonnaise is shear thinning flow and its viscosity reduces sharply with the increase of shear rate in a steady shear flow.

2) Mayonnaise viscosity becomes larger along with the increase of pressure in the range of 500 MPa, while becomes gradually smaller beyond 500 MPa. This is due to the protein molecule disassociated and unfolded[6] with pressure less than or equal to 500 MPa, while small molecule disassociated may be associated over again with the continuous increase of pressure, and increase of salad oil particle size results in decrease of energy dissipation using slippage and friction with pressure beyond 500 MPa.

3) From Figure 2, we can conclude that the n value is less than 1 and this shows that mayonnaise takes on pseudoplastic characteristics under condition of 20 ℃.

4) When G_∞ tends to 0, Cross model can be simplified as Williamson model. From Table 1, we can draw conclusion that super2high pressure processing has no marked change on the type of mayonnaise flow model within range of experiment pressure, but the constants of equation are not the same.

5) Protein particle size becomes small and its surface area increases, global protein molecule folds and intensities mutual action with water, and the texture of mayonnaise becomes thinner after high pressure processing. At different high pressures, these changes are various, so the constants of equation are different.

6) A lot of experiments should be done in

order to find out the influence of time-pressure on the flow model of mayonnaise.

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高压加工对蛋黄酱流变特性的影响

赵红霞[1], 张守勤[1], 吴 华[1], 马成林[1], 吕朝辉[1], 刘志侠[2]

(1. 吉林大学生物与农业工程学院, 长春 130025; 2. 沈阳农业大学农业工程学院, 沈阳 110161)

摘 要: 在低剪切速率下, 采用AR2500 流变仪测定了不同压力下蛋黄酱的流变特性, 结果表明, 高压处理后的蛋黄酱是剪切稀化流体, 具有假塑性特征。利用已知非牛顿流体本构方程对测量值进行曲线拟合的方法, 以标准差最小作为最佳拟合, 得到了不同高压处理条件下蛋黄酱的数学模型, 并初步分析了粘度随压力变化的原因。在 500 MPa 范围内, 超高压处理使得蛋白质分子发生了一定程度的解聚、伸展; 超过 500 MPa 以后, 虽然可能造成蛋白质颗粒的进一步解聚和伸展, 但解聚的小分子又可能部分重新缔合, 而且此时蛋黄酱中的油滴颗粒也会增大, 使得由于颗粒间滑移和摩擦而耗散的能量减少。

关键词: 超高静压; 蛋黄酱; 流变特性; 粘度