

Research Article

The Rheological Property of Potato Starch Adhesives

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Abstract: The main goal of this study was to use potato starch in the production of environmentally sound adhesives. ‘Three-formaldehyde glue’ pollutes the environment and harms to human health strongly, which widely used for wood-based panels preparation. Environment-friendly potato starch adhesives were prepared using method of oxidation-gelatinization, instead of the three formaldehyde glue. The effects of the quality ratio of starch and water, temperature and shear rate on the apparent viscosity of the adhesive were studied. The rheological eigenvalue of apparent viscosity was studied through nonlinear regression. The results showed that the apparent viscosity of potato starch adhesives decreased with the increasing of temperature; the apparent viscosity decreased slowly with the increasing of rotor speed; the phenomenon of shear thinning appeared within potato starch adhesives which was pseudo-plastic fluids. Potato starch adhesives with characteristics of non-toxic, no smell and pollution could be applied in interior and upscale packaging.

Keywords: Apparent viscosity, potato starch adhesives, rheological eigenvalue

INTRODUCTION

Currently, the resin system used in wood-based panel preparation was the three-formaldehyde glue, which mainly consists of Urea-Formaldehyde resin adhesive (UF), Phenolic resin adhesive (PF) and Melamine-Formaldehyde resin adhesive (MF), however, there was a fatal drawback of this type of resin adhesives, such as the release of free formaldehyde which not only polluted the environment but also harmed to humans strongly (Wu *et al.*, 2009; Li *et al.*, 2008; Zhang and Zhang, 2008). Starch had advantages of resource-rich, low-cost, versatile, non-toxic, no smell, pollution etc. What’s more, the starch adhesive with well adhesion and film-forming properties was a class of natural adhesives (Ding, 2008; Chen *et al.*, 2007, 2006).

As a renewable natural polymer materials, the starch which not only has active functional groups, as well as the outstanding characteristics to adapt to the requirements of environmental protection, but also with the advantages of resource-rich, low-cost, non-toxic and biodegradable is paid more and more attention in the field of adhesives. However, as an adhesive, the pure starch has a lot of inadequacies, such as water resistance, fluidity, permeability, storage stability and mechanical properties (Guo and Guo, 2007; Fu and Lu, 2008; Imam *et al.*, 2001; Liu *et al.*, 2008; Santayanon

and Wootthikanokkhan, 2003; Shi *et al.*, 2008), the properties of starch could be improved by physical and chemical methods, for example, it was an effective way to change the solubility, viscosity and related properties to meet the performance requirements of different application areas. In both methods, the chemical modification was an important means of preparation of starch adhesives (Liu *et al.*, 1999; Shi and Wang, 2006; Lin *et al.*, 2007). The starch molecules contained the glycosidic bond and reactive hydroxyl groups could chemically react with many substances, which was the basis of chemically modified starch (Li *et al.*, 2007).

In this study, we reported an easy method to prepare potato starch adhesives through oxidation-gelatinization, instead of the three formaldehyde glue. The aim of this study is to improve the apparent viscosity of potato starch adhesives. Also, the effects of the quality ratio of starch and water, temperature and shear rate on the apparent viscosity of the adhesive were studied. The rheological eigenvalue of apparent viscosity was studied through nonlinear regression.

MATERIALS AND METHODS

The raw materials, reagents and their grades and manufacturers, are listed in Table 1.

Methods: There are many methods to prepare potato starch adhesives and in this test, the method of

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Table 1: The raw materials of experiments

The main raw material	Trademark	Manufacturer
Potato starch	Edible starch	Shandong Jincheng Food Co., Ltd.
30% H ₂ O ₂	AR	Nanjing Chemical Reagent Co., Ltd.
NaOH solution	AR	Nanjing Chemical Reagent Co., Ltd.
Na ₂ S ₂ O ₃	AR	Nanjing Chemical Reagent Co., Ltd.
FeSO ₄ ·7H ₂ O	AR	Nanjing Chemical Reagent Co., Ltd.

Table 2: Formula of preparing potato starch adhesives

The appellation	H ₂ O ₂	Fe ²⁺ solution	NaOH solution	Na ₂ S ₂ O ₃ solution
Concentration	26%	6%	10%	6%
Dosage	0.5 mL	1 mL	18 mL	2 mL
Effect	Oxidizer	Oxidizer	Pasting agent	Blockers

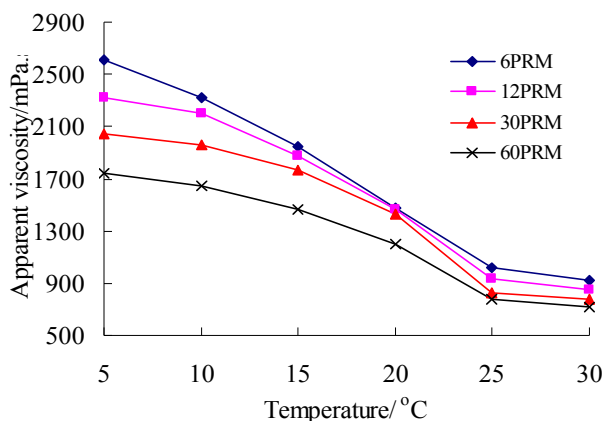
oxidation-gelatinization was used to prepare potato starch adhesives. Table 2 is the formula of preparing starch adhesives.

Analysis methods: In accordance with the national standard GB/T 2794-1995 “the adhesive viscosity measurement”, the NDJ-5S digital viscometer was used to test the starch adhesive viscosity. Before measuring, the viscosity of the liquid to be measured should be estimated firstly and then the suitable rotor and rotational speed of the digital viscometer were selected. To ensure the accuracy, the percentage of the range should be accurately controlled in the range of 10 to 90% and the sample of starch adhesives should be uniformly and without bubbles during the measurement. The samples were measured after half an hour of the temperature converted and the temperature should be reached the set value each time.

Starch adhesives put into the beaker which placed in the bath pot with a constant temperature while measuring the viscosity of starch adhesives. The rotor immersed into the adhesive in depth properly and then selected the appropriate speed by the control panel keys. The average of five measurements of the apparent viscosity of the starch adhesive was considered to be the result.

RESULTS AND DISCUSSION

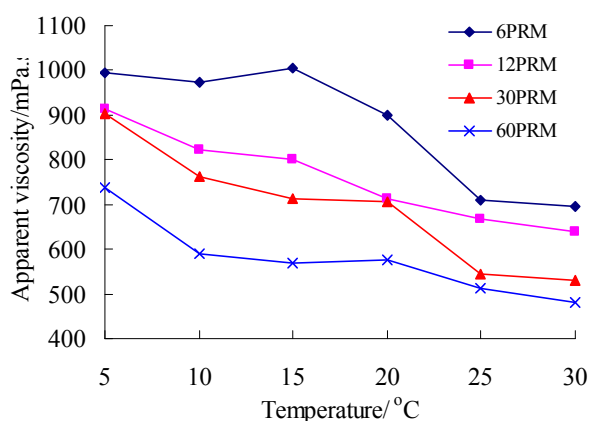
Adhesive viscosity has an important role on the bonding strength, tensile strength and other mechanical



(a) Ratio of 1/6

properties in the composite materials. The starch adhesives apparent viscosity depends on the dispersion of the starch molecules in solution expand capacity, where the starch molecules increase the content area and reinforce mutually during the adhesive preparation process and ultimately enhance the adhesion strength.

Figure 1 shows the effect of temperature on apparent viscosity of potato starch adhesives. As can be seen from the figure, when the ratio of starch and water quality was 1/6, the apparent viscosity of potato starch adhesives decreased with the increase of the temperature. The corresponding maximum value was 2610, 2317, 2047 and 1738 mPa.s, respectively, but the descending of apparent viscosity was quick within 25°C, the decline of the rate of the apparent viscosity decreased gradually after 25°C (Fig. 1a). When the ratio of starch and water was 1/8, the apparent viscosity of potato starch adhesives decreased with the increase of the temperature except at 6 PRM, the maximum value of apparent viscosity was 1007, 914, 903 and 739 mPa.s, respectively and after 25°C, the descending was also slow (Fig. 1b). While the ratio of starch and water was 1/10, the peak values of the apparent viscosity were 450, 378, 362 and 302 mPa.s when speed was 6, 12, 30 and 60 PRM, respectively and the apparent viscosity decreased gradually with the increase of the temperature (Fig. 1c). While the ratio was 1/6, the apparent viscosity of adhesive prepared was significantly higher than the other two adhesive prepared with a ratio of 1/8 and 1/10. As is portrayed in Fig. 1d, when the speed was 30 PRM, the peak values were 2047, 903 and 362 mPa.s when the ratio of starch and water was 1/6, 1/8 and 1/10, respectively, the apparent viscosity decreased with the increase of the temperature, what's more, the higher the temperature was, the smaller the difference between the apparent viscosity of the different adhesives, this may be due to the raise in temperature make the frictional resistance among starch molecules smaller, which manifested as the decrease of the viscosity.



(b) Ratio of 1/8

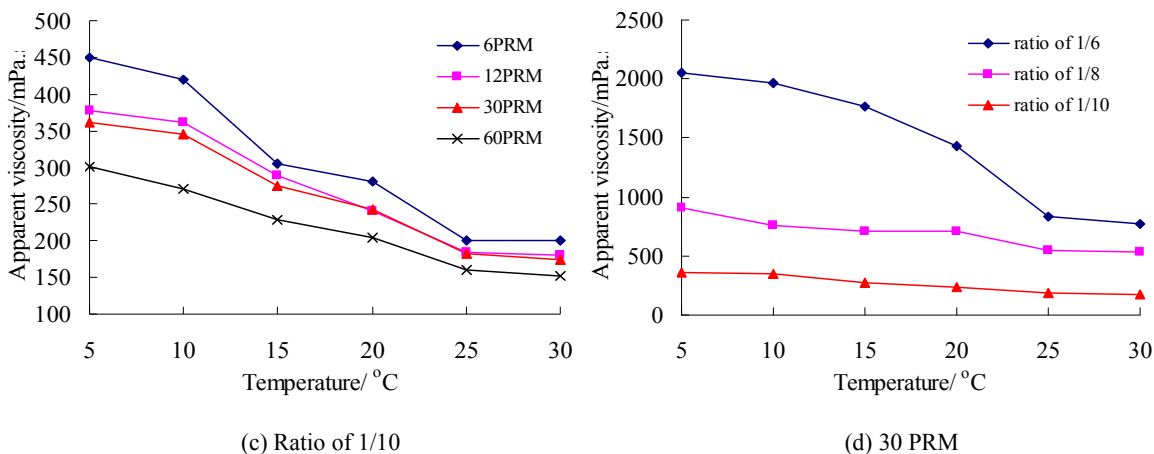


Fig. 1: Effect of temperature on apparent viscosity of potato starch adhesives

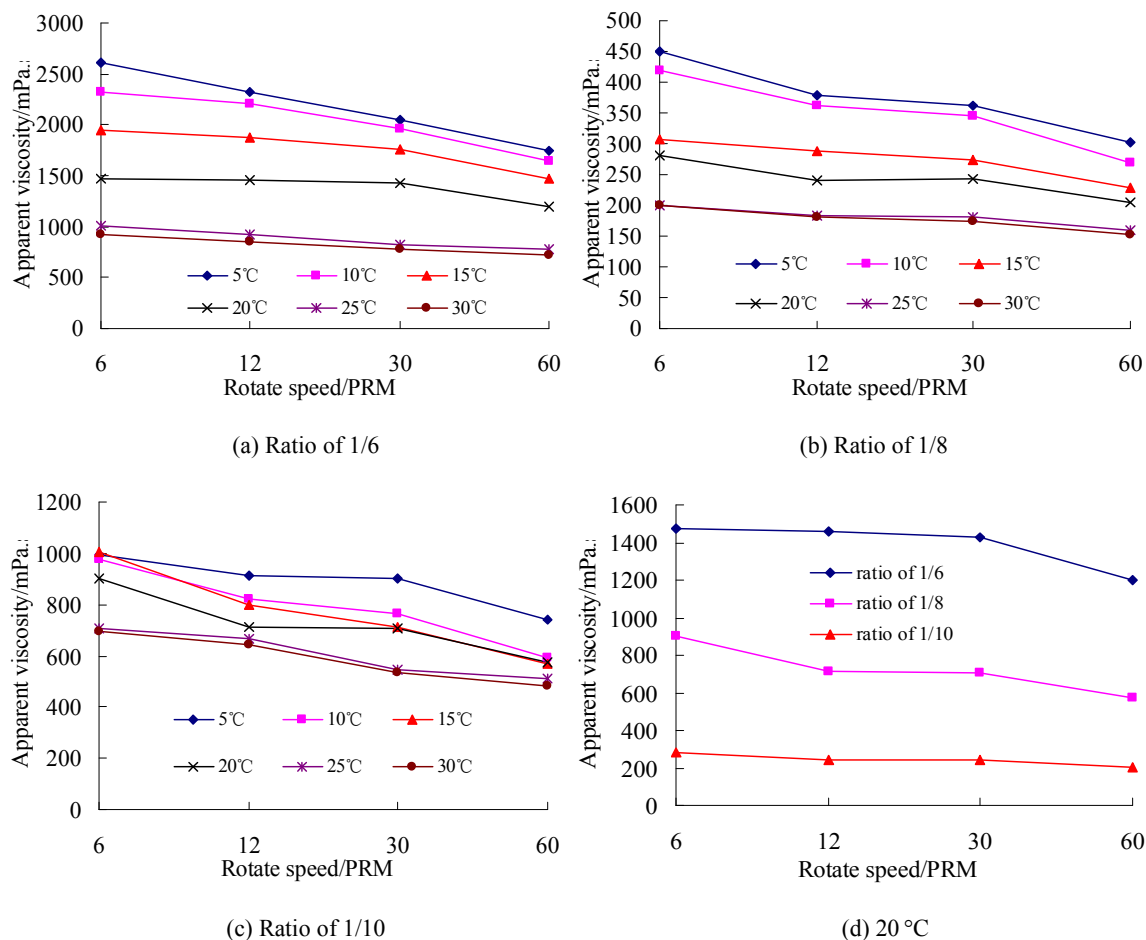


Fig. 2: Effect of rotate speed on apparent viscosity of potato starch adhesives

Figure 2 shows the effect of rotate speed on apparent viscosity of potato starch adhesives. As can be seen from the figure, the apparent viscosity decreased slowly with the increase of the speed of the rotor, that's can be explained that the phenomenon of shear thinning appears in potato starch adhesives, when the ratio of

starch and water was 1/6, the apparent viscosity of adhesives was significantly better than the other two adhesives that was prepared with 1/8 and 1/10 of ratio of starch and water, the peak values (15.9, 12.5 and 12 mPa.s, respectively) were obtained at 20°C.

Table 3: Rheological eigenvalue of potato starch adhesives (ratio of 1/6)

Temperature/°C	k/Pa.s ⁿ	n	Expression	R ²
5	3560.9	-0.1709	$\eta = 3560.9v^{-0.1709}$	0.9878
10	3105.2	-0.1466	$\eta = 3105.2v^{-0.1466}$	0.9459
15	2458.0	-0.1145	$\eta = 2458v^{-0.1145}$	0.8568
20	1764.3	-0.0821	$\eta = 1764.3v^{-0.0821}$	0.7192
25	1251.0	-0.1185	$\eta = 1251v^{-0.1185}$	0.9960
30	1109.4	-0.1067	$\eta = 1109.4v^{-0.1067}$	0.9978

Table 4: Rheological eigenvalue of potato starch adhesives (ratio of 1/8)

Temperature/°C	k/Pa.s ⁿ	n	Expression	R ²
5	1232.40	-0.1134	$\eta = 1232.4v^{-0.1134}$	0.8289
10	1396.40	-0.2001	$\eta = 1396.4v^{-0.2001}$	0.9341
15	1488.10	-0.2299	$\eta = 1488.1v^{-0.2299}$	0.9678
20	1174.70	-0.1689	$\eta = 1174.7v^{-0.1689}$	0.8712
25	943.28	-0.1518	$\eta = 943.28v^{-0.1518}$	0.9677
30	949.03	-0.1669	$\eta = 949.03v^{-0.1669}$	0.9911

Table 5: Rheological eigenvalue of potato starch adhesives (ratio of 1/10)

Temperature/°C	k/Pa.s ⁿ	n	Expression	R ²
5	584.41	-0.1560	$\eta = 584.41v^{-0.156}$	0.9284
10	573.39	-0.1724	$\eta = 573.39v^{-0.1724}$	0.9027
15	385.22	-0.1178	$\eta = 385.22v^{-0.1178}$	0.8811
20	339.13	-0.1175	$\eta = 339.13v^{-0.1175}$	0.8436
25	232.56	-0.0853	$\eta = 232.56v^{-0.0853}$	0.8770
30	241.35	-0.1080	$\eta = 241.35v^{-0.108}$	0.9306

As can be seen from Fig. 1 and 2, with many strongly hydrophilic functional hydroxyl groups in the main chain of the starch molecules, the hydroxyl groups bonded to each other to form hydrogen bonds, so that the starch adhesive would have a certain adhesion force, however, the cohesion of the hydroxyl group with water molecules is much larger than the binding force among the starch molecules, the absorption of hydroxy on glued materials was desorbed by water molecules, as a result, the wet bonding strength of the starch adhesive degraded severely and the effect of temperature on adhesives was greater than the two precious.

The value of k, n and the correlation coefficient R² of adhesives were obtained by using one unknown nonlinear regression to analyze the apparent viscosity and shear rate. Table 3 to 5 show the rheological eigenvalue of potato starch adhesives apparent viscosity with the ratio of 1/6, 1/8 and 1/10, respectively.

As is depicted in Table 3 to 5, potato starch adhesives prepared in this test were pseudo-plastic fluids because all of the n were less than zero. When the rheological curve of potato starch adhesives was described by the pseudo-plastic fluid model, the model could better describe the rheological properties of potato starch adhesives curve if R² was between 0.7192 and 1.

CONCLUSION

- Potato starch adhesives apparent viscosity decreased with the increase of the temperature.
- The apparent viscosity decreases slowly with the increase of the rotor speed and the phenomenon of shear thinning appears in potato starch adhesives.
- Potato starch adhesives are pseudo-plastic fluids.

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