



A Scaling-up Synthesis from Laboratory Scale to Pilot Scale and to near Commercial Scale for Paste-Glue Production

Johnner P. Sitompul¹, Hyung Woo Lee¹, Yook Chan Kim² & Matthew W. Chang³

¹Department of Chemical Engineering, Faculty of Industrial Technology,
Institute of Technology Bandung, Jalan Ganesha No. 10, Bandung 40132, Indonesia

²PT. Garuda Twin Jaya, Jalan Sultan Iskandar Muda No. 8, Jakarta 12240, Indonesia

³School of Chemical and Biomedical Engineering,
Nanyang Technological University, Singapore 637459, Singapore
E-mail: sitompul@che.itb.ac.id

Abstract. This paper concerns on developing a synthesis method of paste-glue production for gummed tape using a corn-based starch as an alternative feedstock from laboratory-scale to pilot-scale and to near commercial scale. Basically, two methods of synthesis were developed to produce paste-glue in laboratory scale. Based on the two methods, we then scale-up the earlier laboratory scale data to pilot-scale and near commercial-scale for developing a large scale process production of paste-glue. Scaling up production from 1,000 ml reactor to 500 L pilot-scale reactor and 1,500 L near commercial scale reactor, we monitored pathway of temperature increase during reaction as well as adjustment of operating condition conducted for laboratory experimental data in order to produce a good quality of paste-glue. Some scaling up parameters have been found as well as critical parameters for a good product quality such as viscosity and ceiling temperature of the reaction which are very crucial in order to give optimum operating condition. We have selected synthesis method of paste-glue production and found the range of the parameters in order to produce a very good quality of paste-glue in pilot scale and near commercial scale.

Keywords: *scale-up; process development; paste glue; gummed tape; polymerization; lab scale; pilot scale; near commercial scale.*

1 Introduction

The synthesis of paste-glue, also known as starch-polymer adhesive, is a determining step for making gummed tape. In order to be used as gummed tape, the paste-glue will be coated on special paper and then dried. The coated paste-glue on paper, so called gummed tape, will be then contacted with water and the glue will be activated and ready to be used in packing and sealing boxes and for making plywood. In order to be used for the plywood manufacturing, the gummed tape must have special characteristics depending on various characteristic of wood [1-5]. For this purpose, special processed starch is mainly

used in paste-glue production for the gummed tape [1]. The gummed tape is a starch based adhesive on a paper backing which becomes sticky when moistened. The gummed tape is usually used for packing and sealing boxes, and the specific gummed tape is also used for the plywood industry. Recently, due to efficiency reason in production cost of the plywood manufacturing industry, the related industries including gummed tape manufacturing have faced difficulties as a whole. Therefore, these industries require efforts for cost reduction and they have tried to find a method in replacing the previous higher cost special processed starch. In order to substitute the previous feedstock with low cost starch, we try several synthesis approaches or methods from laboratory scale to pilot scale and near commercial scale in order to produce specified paste-glue which is commercially accepted by the user in plywood industries.

Nauman [6,7] has recently discussed concept of similarity and residence time distribution for scaling-up method in process development of chemical reactors, however, his approach is quite difficult to apply for polymerization reactor, such as paste-glue production, as the later is mostly batch operated and has strong effect on mass, heat and hydrodynamic phenomena. Furthermore, polymerization processes are highly nonlinear and crucially depending on product-based properties. Nauman further suggested scaling up method for polymerization processes but more studies and development are required. Maschio, *et al.* [8] have proposed an integrated calorimetric approach for scaling reactor of methylmethacrylate polymerization from from 0.1 L to 100 L. They found scaling up parameters, such as heat transfer, stirrer power and safety data. Hoogenboom, *et al.* [9] later proposed an alternative method for scaling polymerization reaction by applying microwave-assited synthesis for polymerization batch-mode and they found direct scaling without any heat and mass transport issues from scaling up 1 ml to 250 ml reactor volume, however, further studies are needed for scaling up the polymerization reactor from laboratory scale to pilot or commercial scale.

With regard to scaling up of polymerization reactors, Meyer [10] has given detailed review on the difficulty during development of polymerization processes. Discrimination of alternative synthesis or process synthesis is required or applied during the stages of process development. Further, iterative processes are required during the whole process development as well as delicate or accurately understanding of necessary parameters during production from bench scale to pilot scale and to commercial scale. The same properties at both bench and large scale are crucial in the polymerization process such as the paste-glue production. Based on these heuristic, we then apply a scaling-up synthesis from laboratory-scale to pilot-scale for paste-glue production before commercial scale initiated in the factory or plant. The scale of paste-glue polymerization reactor ranges from 1,000 ml laboratory scale to 500 L pilot

scale and to 1,500 L near commercial scale reactor. Note that the commercial scale is within the range of 2,000 L to 2,500 L.

In this research, we developed two methods of synthesis of paste-glue production for gummed tape using a common starch, corn-based starch as an alternative feed stock for paste-glue production, in the laboratory scale. With these two methods we then characterized the product, mainly viscosity and polymer quality. We tried to adjust and modify experimental conditions at the laboratory scale and adopted them to pilot scale and then to near commercial scale before full scale or commercial scale initiated. In brief, from a set of laboratory- or bench-scale data we have tried to scale-up experiments in order to establish pilot scale and near commercial scale synthesis process.

2 Synthesis Method and Experimental Reactors

In the first experiments, two methods of synthesis for paste glue production were carried out. Synthesis method 1 consists of 3 steps, preparation of starch decomposition by dissolving an edible starch with water and enzyme, followed by preparation of polymer in a separate reactor by adding acrylic monomer with water and commercial catalyst and finally followed by mixing process of the decomposed starch with the polymer, where copolymerization presumably taking place in the reactor. Regarding Synthesis method 2, monomer and catalyst with specified amount are directly poured into a reactor containing the decomposed starch slurry, hydrolyzed by enzyme and then polymerization would be taking place. During the course of synthesis, for lab scale, the heating of the reactor was conducted by the use of controlled temperature water bath while for the pilot and near commercial scale it was conducted by utilizing steam passed through jacketed reactors. The temperature of the reactors was controlled by using thermocontroller.

3 Laboratory Scale Reactor

The laboratory scale reactor for decomposition, polymerization and reactor for mixing of decomposed starch polymer was designed to accomplish the aforementioned two methods of synthesis. A 1,000 ml capacity glass reactor was used and placed in a water bath with temperature controller. A multi propeller type impeller attached with double wings was used for mixing of reactants. Figure 1 shows schematically the experimental set up for laboratory scale of a typical reactor paste-glue production. The reactor, placed in a temperature controlled water bath, is externally heated by hot water and equipped with propeller type impeller for accommodating good mixing of the mixture.

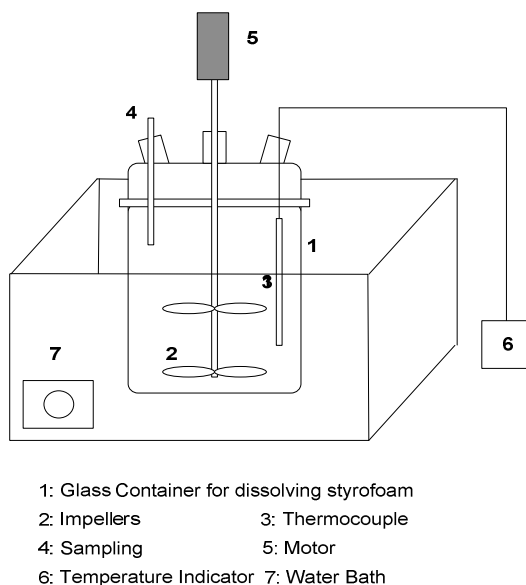


Figure 1 Schematic experimental set up and a typical reactor for producing paste-glue in laboratory scale.

4 Pilot Scale and Near Commercial Reactors

After laboratory experiments conducted, we then followed the two methods of synthesis for pilot scale and near commercial scale experiment with two reactors, a 3,000 L capacity stainless steel reactor with steam-heated jacket type of reactor for dissolving of starch and a 3,000 L capacity stainless reactor with steam-heated jacket type for synthesis method 1 or 2. These reactors were built with different impeller. The scale of production are prepared for 2 sets of experiments, one set for approximately 10-20% of its capacity, here after so called pilot scale, around 300-500 L. We also increase the volume of the pilot of experiment with 3 times pilot scale volume, 1,500 L, here after so called near commercial scale. The near commercial scale experiments were conducted in order to make sure whether commercial scale will be put into reality in the future. The reactor for pilot and near commercial scale is basically quite similar with the schematic for laboratory scale as previously shown in Figure 1, except the method of reactor heating. Figure 2 shows a typical pilot or near commercial scale reactor for paste-glue production. The total volume of the jacketed reactor is 3,000 L and heated by steam and equipped with impeller. Note that both experimental systems for laboratory scale and pilot scale were designed to enable measurements of viscosity of glue and it were measured using Brokerfield viscometer at temperature 60 °C and mixing at 10 rpm.

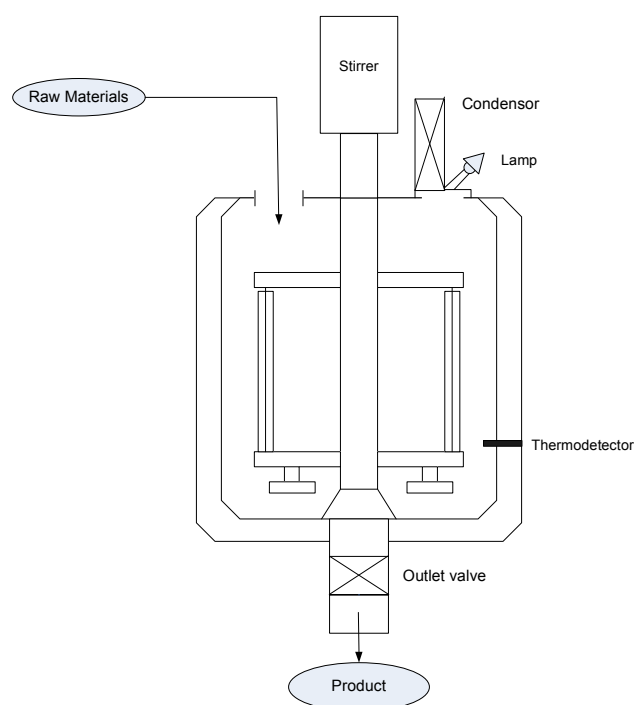


Figure 2 Schematic experimental set up of a typical reactor for producing paste-glue in pilot and near commercial scale.

5 Results and Discussion

5.1 Paste-Glue Production at Lab Scale and Pilot Scale with Synthesis Method 1

The glue was produced by mixing of dissolved starch and polymer. The optimal synthesis conditions were found in the glass reactor with 1,000 ml volume and these were applied to pilot scale experiment of 1,000 times. Table 1 shows the reaction conditions and result. The result in the table shows a viscosity of synthesized glues and shows effect for following gummed tape production or coating process. In order to manufacture the actual gummed tape, this glue should satisfy various characteristics such as a viscosity, initial adhesion, and durability of adhesive strength etc., however, in this paper we only focused on finding the process variables and problems that can be occurred during scale-up, and on overcoming these problems. So the result of experimental data just shows viscosity value of produced glue and whether the glue produced good or poor quality for the next processes of making gummed tape. The most

appropriate viscosity value for following coating operations is within the range of 10,000 cps to 35,000 cps.

Table 1 Summarized reaction conditions and results of glue synthesis for lab Scale and Pilot scale with synthesis method 1.

Scale	Starch Decomposition			Polymerization				Copolymerization (Mixing) Result	
	Water (ml)	Starch (g)	Enzyme (g)	Water (ml)	Mono mer (g)	Heating (°C)	Cat. (g)	Viscosity (cps)	Quality product
L-01	165	165	0.1	190	110	50	0.7	25,000	Good
L-02	150	100	0.07	150	65	95	0.28	19,000	Good
Pilot Scale	Water (L)	Starch (kg)	Enzyme (kg)	Water (L)	Mono mer (kg)	Heating (°C)	Cat. (kg)	Viscosity (cps)	Quality product
P-01	165	165	0.1	190	110	50	0.7	70,000	Poor
P-02	330	325	0.2	400	213	50	1.4	20,000	Poor*)
P-03	300	200	0.15	300	130	100	0.56	31,000	Good

*) Even though the viscosity was good, however, the polymer was not good after further processed to make paste-glue

L-01 at the Table 1 shows reaction conditions and result from laboratory-scale experiment. At the first step, water 165 ml and starch 165 g were mixed in a 1:1 ratio and heated to 100°C for dissolving of starch. At the second step, monomer 110 g was mixed with water 190 ml in the other reactor, and then heated to 50 °C and after injecting of the catalyst, polymerization started without supply of additional heat, and the polymer was ultimately formed. At third step, the prepared dissolved starch slurry was transferred to the reactor of prepared polymer and these were mixed entirely. The final synthesized glue was tested for viscosity and was observed during following process for making gummed tape in the laboratory scale. The synthesized glue from these reaction conditions had a viscosity of 25,000 cps and showed appropriate characteristics during the next process. The reaction conditions of L-01 were then applied straightforward to pilot scale with 1,000 times (500 L volume of reactant) larger in a 3,000 L capacity reactor (P-01). As a result, the obtained glue has high viscosity of 70,000 cps and then showed poor characteristics for next manufacturing process of making gummed tape.

During lab-scale synthesis of polymer (L-01) as the second step of glue production, the change or course of temperature in the reactor according to reaction times was studied in detail and shown in Figure 3. Figure 3 shows that the reactants were heated to 50 °C and catalyst injected to start reaction, and then the polymerization proceed steadily without any additional heat supply due to exothermic reaction.

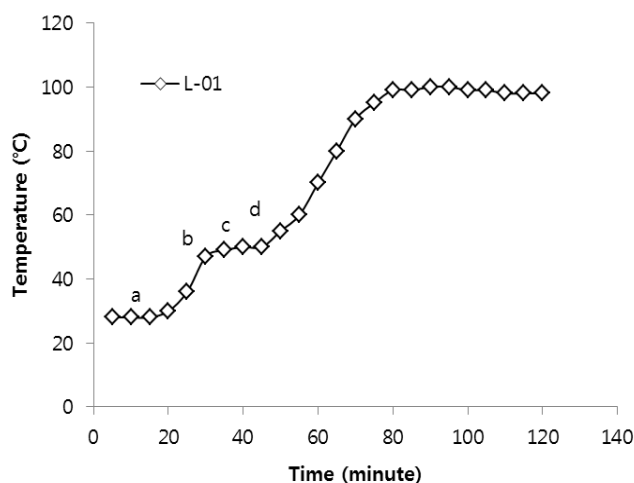


Figure 3 Graph of reaction temperature changes over reaction time during polymerization stage with lab-scale (L-01); a: heating supplied, b: heating stopped, c: catalyst injected, d: polymerization started.

Figure 4 shows a graph on the change of reactor temperature over times during the polymerization in 1,000 times larger (P-01) than that of L-01, however, it shows difficulty in controlling the reactor temperature. At room temperature, 28 °C, heating was supplied to the reactor (a) and heat supply was stopped at 45 °C (b) but the reactor temperature continued to increase until 71 °C and then decreased slightly. The catalyst was then injected at 50 °C (c) but the polymerization was not occurred and temperature was further decreasing. As the reactor was re-heated at 39 °C (d), the reactor temperature rose to 75 °C and heat supply was stopped (e). However, the polymerization did not take place and temperature was decreased again. Re-heat supply was conducted (f) and the polymerization occurred at 79 °C, and then the heat supply was stopped (g). The glue obtained from applying the reactor temperature control has quite high viscosity and it led to difficulties in the coating process. In particular, the produced polymer was gel chunk, and the final synthesized glue from mixing of dissolved starch and polymer also contained polymer beads of approximately 1 mm in diameter. During the synthesis of polymers, failure of temperature control in the reactor took place at the high temperature (79 °C) and it led to gelation due to the rapid exothermal heat in the polymerization reaction. In fact, the final gummed tape obtained from glue of P-01 showed a very low quality product. Usually when the dissolved starch and the polymer are mixed, the starch chains may fuse with polymer chains and link together. However, sudden exothermal heat during polymerization formed a cross-linked gel and the starch chains could not be mixed well to produce polymer chains. Then it might lead

to the decline of product quality when the polymer mixed with decomposed starch during copolymerization process.

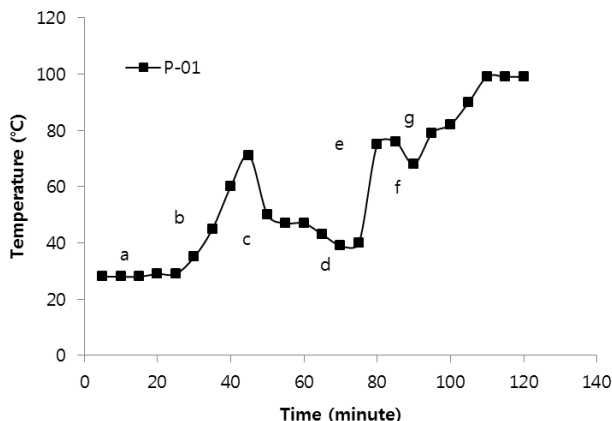


Figure 4 Graph of reaction temperature changes over reaction time during polymerization stage with pilot-scale (P-01); a: heating supplied, b: heating stopped, c: catalyst injected, d: heating supplied, e: heating stopped, f: heating supplied, g: heating stopped & polymerization started

In the pilot-scale experiments, the reactants were used in the range of 1/10 to 1/6 scale with a reactor volume of 3,000 L capacity. The established optimal reaction conditions in the laboratory scale (L-01) were further tested for 1,000-fold (P-02), 2,000-fold (P-03) scale-up in the 3,000 L capacity reactor system with different reactant condition for starch decomposition stage and polymerization stage, respectively.

In the beginning, we considered that a using of relatively small amounts of mixture would enable on controlling the overall reactor temperature. So by doubling the volume of reactants in the case of P-01 the experiments were then carried out for pilot scale experiment (P-02). Figure 5 shows reactor temperature changes over time for copolymerization of P-03. The heating was supplied at the room temperature (a) and heat supply was stopped at 43 °C (b). After the heat supply was stopped to the reactor, temperature was increased up to 61 °C and then decreased. The catalyst was then injected at 50 °C (c). However, the temperature was continuously decreasing and the re-supply heat was resumed from 42 °C (d) to 50 °C (e). Ten minutes later, the polymerization started (f) and the temperature increased dramatically. Note that P-02 used twice amount of reactants than in P-01 and it was slightly easier for controlling temperature during polymerization of reactants than that of P-01. The produced glue has a proper viscosity value of 20,000 cps for next coating process, but it

contained a small amount of polymer beads with 0.5 mm in diameter as in P-01 and there were difficulties of process during making of gummed tape including the coating process with this glue. The quality of the final product was better than the case of P-01, but was lower compared to available commercial products.

During the polymerization process with method 1, the temperature control was difficult which led to the deterioration in product quality. In order to solve a difficulty of controlling reactor temperature during scaling-up process, we tried to find other optimal reaction conditions by reducing the amount of catalyst and by supplying heat up to 95 °C during copolymerization in the laboratory scale (L-02). Applying the condition of L-02 to pilot scale production using the 3,000 L-capacity reactor (P-02), the supplying of heat was slowly transferred to the reactants, but the reaction proceeded faster after the heat was delivered evenly to the reactants, and then more heating occurred from exothermal reaction, reaching 100 °C quickly (see Figure 6). Therefore, the effect of rapid heat generation during copolymerization of the product need to be investigated more detail in the future.

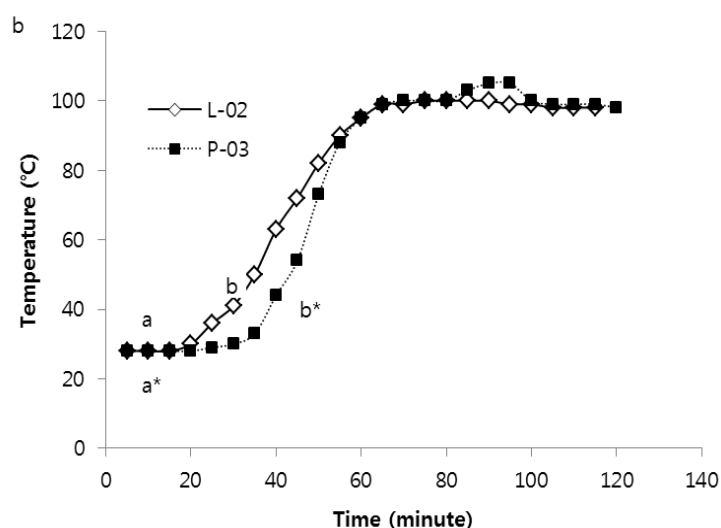


Figure 5 Graph of reaction temperature changes over reaction time during polymerization stage with lab-scale (L-02) and pilot-scale (P-03); a&a*: heating supplied, b&b*: catalyst injected.

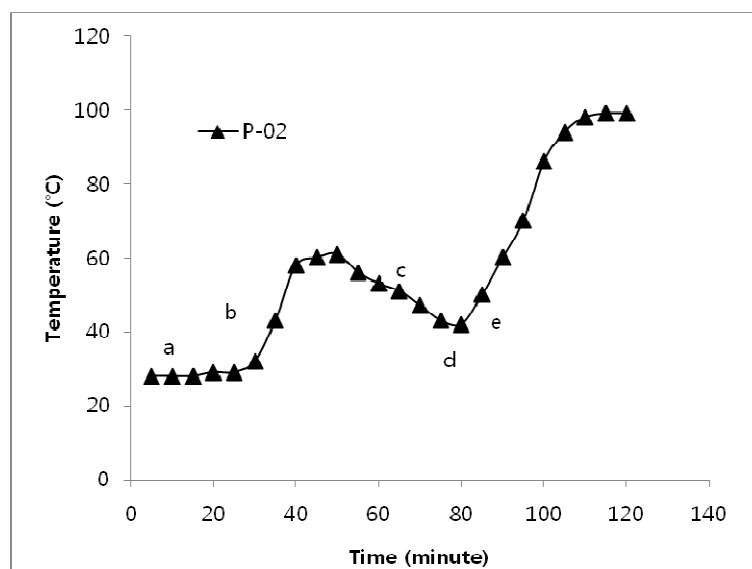


Figure 6 Graph of reaction temperature changes over reaction time during polymerization stage with pilot-scale (P-02); a: heating supplied, b: heating stopped, c: catalyst injected, d: heating supplied, e: heating stopped.

5.2 Glue Synthesis at Lab and Pilot Scale with Synthesis Method 2

Unlike the previous glue which was made by mixing the dissolving starch and polymer, we developed another synthesis, called method 2, that monomer was introduced into slurry of dissolved starch and then polymerization proceeded in the starch slurry. With regard to discovered problem in the previous process, we established synthesis method 2 and found optimal conditions and they are showed at Table 2 below.

Table 2 Summarized reaction conditions and results of glue synthesis for lab scale and pilot scale with synthesis method 2.

	Starch Decomposition			Monomer and Catalyst Injected			Polymerization Result	
	Water (ml)	Starch (g)	Enzyme (g)	Monomer (g)	Heating (°C)	Cat. (g)	Viscosity (cps)	Quality product
Lab Scale								
L-03	290	145	0.1	66.5	95	0.3	21,000	Good
L-04	290	145	0.1	66.5	no	0.6	10,700	Good
Pilot Scale	Water (L)	Starch (kg)	Enzyme (kg)	Monomer (kg)	Heating (°C)	Cat. (kg)	Viscosity (cps)	Quality product
P-04	300	150	0.1	70	100	0.35	25,000	Good
P-05	300	150	0.1	70	No	0.67	11,000	Good

In the case of L-03 laboratory scale experiment, the starch was dissolved with enzyme to 100 °C and was cooled down 70 °C and then monomer was introduced into the starch slurry. The catalyst was injected at temperature approximately 50 °C and then heating was supplied to 95 °C. As a result, there was prepared glue which has the viscosity of 21,000 cps, and this showed proper characteristics for the next process of coating process. These reaction conditions were scaled up to 1,000 times (P-04), and the glue from the pilot scale polymerization has a viscosity of 25,000 cps and also showed an appropriate attribute for the following process. Figure 7 shows the reactor temperature changes according to the reaction time on L-03 of lab scale and P-4 of pilot scale. The case of P-04 was that the temperature rising was late start compared with that of L-03, but these different size reactors showed similar heat characteristics during polymerization. The experimental results showed similar result as found by other researchers [7] that there would be an existence of ceiling temperature and intrinsic limitation on the temperature increase during polymerization process as to give a good quality product.

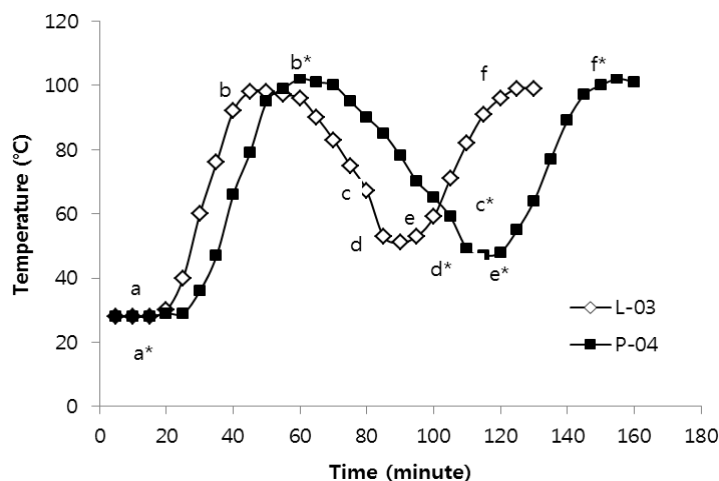


Figure 7 Graph of reaction temperature changes over reaction time during glue synthetic reaction with lab-scale (L-03) and pilot-scale (P-04); a&a*: heating supplied, b&b*: heating stopped, c&c*: monomer injected, d&d*: catalyst injected, e&e*: heating supplied, f&f*: heating stopped.

In the case of L-03 and P-04 was that the catalyst was injected into a mixture of starch slurry and monomer at a temperature of 50 °C and then the mixture was heated to 95 °C for inducing rapid reaction. In a separate run of experiment, we increased amount of catalyst twice and the catalyst was injected into the reactants at 60 °C without any external heat supply in order to induce the

reaction proceeds with slow rate. Laboratory-scale L-05 and pilot-scale P-04, which is 1,000 times scale-up from L-04, would produce glue with viscosities of 10,700 cps and 11,000 cps, respectively, and these glues showed good characteristics for the next processes of making gummed tape. In Figure 8, lab scale L-04 and pilot-scale P-05 show a similar trend on temperature changes over the reaction time. So we found that the reaction conditions established at the laboratory was well adapted to 1,000-fold scale-up process.

On the other hand, the glues obtained under different conditions would have different viscosity values. When the catalyst was injected and the heating was supplied (L-03, P-04), the viscosity of produced glue is two times than that of glue which obtained with slow reaction rate under double amount of catalyst without external heat supply (L-04, P-05).

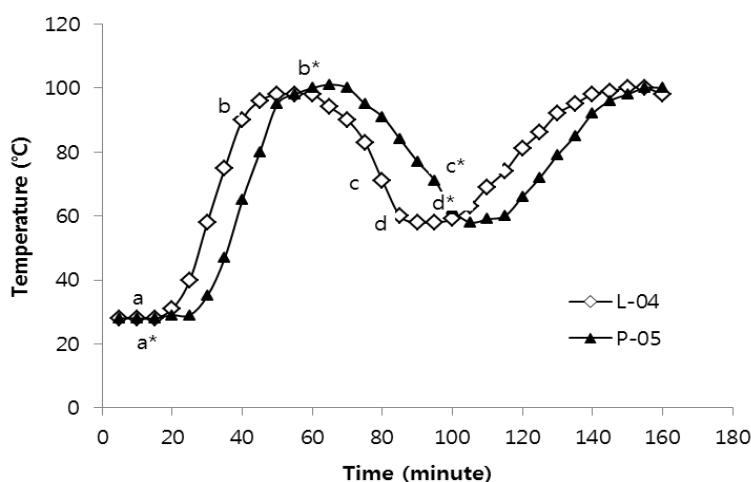


Figure 8 Graph of reaction temperature changes over reaction time during glue synthetic reaction with lab-scale(L-04) and pilot-scale (P-05); a&a*: heating supplied, b&b*: heating stopped, c&c*: monomer injected, d&d*: catalyst injected.

This is the reason that the external heat supply leads to the faster polymerization rate and this might cause more back-bone from radical polymerization during growing of polymer chain. The back-bone makes more branched or cross-linked chains and then the viscosity of glue can be increased.

The case of producing glue when introducing a monomer into slurry of dissolved starch (Table 2) produced a more stable reaction and also produced glue with proper characteristics compared with the case of producing glue by

mixing dissolved starch slurry with polymer (Table 1). Hence, based on the reaction condition laboratory scale (L-04) that can be scaled up to 1,000-fold (P-04 and P-05) as well as considering product quality given, and more importantly, slow reaction over temperature changes during polymerization process for production, the synthesis method 2 becomes the best option to paste-glue production using corn-starch as an alternative feed stock. Note that condition and parameter for P-04 and P-05 are similar except no heating during polymerization for the later.

5.3 Comparison of Glue Synthesis for Pilot Scale and near Commercial Scale with Synthesis Method 2

After finding the optimum reaction conditions with respect to method of synthesis for pilot scale (Table 2), we then tried to apply for near commercial scale, about 3 times (1,500 L) of aforementioned pilot scale reactor with reaction condition P-04 and P-05. Similar method 2 for near commercial reactor A and B, with different impeller, would be conducted throughout this experiments.

In the earlier experiments, the glue production is alternately synthesized at the reactor A and reactor B using the condition of experiment P-04. However, despite the same conditions, when the reactor A was used, the viscosity of synthesized glue was very high around 82,500 cps and the glue showed poor properties during next processing, but when the reactor B was used with same reaction conditions, the produced glue has proper viscosity of 28,000 cps and this was used in the next process and gave good quality of gummed tape production. This phenomenon can be seen more clearly through the reactor temperature changes over reaction time during the synthesizing process of glue (Figure 9). In the case of C-01 with the reactor A shows that after the catalyst was added and the external heating was supplied, the start of temperature rising is a quite late but the increasing rate of temperature was higher than the case of C-02 with the reactor B. This phenomenon might be due to possibility of reactor A, embedded with propeller-type impeller, needs more time for diffusing equally the heat coming from outside into the reactant mixture compared with reactor B, embedded with flat blade turbine type impeller. However, once the reaction is started in the reactor A, it proceeded more intensely. These differences in heat transfer of the reactors may be caused from the difference in the structure of a stirrer of the reactors embedded in the pilot scale reactor. This hydrodynamic phenomenon will be studied in the future.

Therefore, in order to produce the optimal production, appropriate or optimum reaction conditions should be established for each reactor. When the reactor B was used, the established reaction conditions of P-04 could be applied, but

when the reactor A was used, new developed reaction conditions were needed. The condition of experiment C-03 shows that during the polymerization in reactor A, the amount of water was increased and the external heating was supplied up to 85 °C, and then the reactor A could produce glue with viscosity of 33,000 cps.

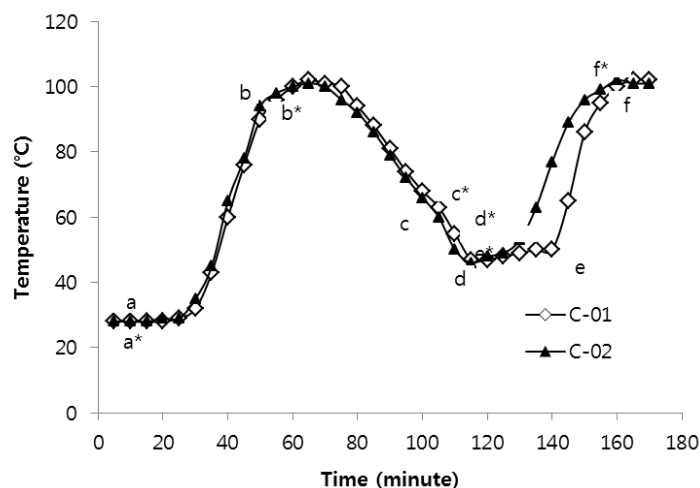


Figure 9 Graph of reaction temperature changes over reaction time during glue synthetic reaction at reactor A (C-01) and reactor B (C-02) with near commercial scale; a&a*: heating supplied, b&b*: heating stopped, c&c*:monomer injected, d&d*:catalyst injected, e&e*: heating supplied, f&f*:heating stopped.

From the synthesis approach with two different synthesis method, we have developed the optimum reaction conditions of scaling from laboratory scale L-04 and to pilot scale P-05 with method 2 that the catalyst be added to mixture of dissolved starch and monomer. With the synthesis method 2 we proceed to near commercial scale of production (C-01 to C-05, as shown in the Table 3). Note that the synthesis method 2 was applied for near commercial scales, however, for C-04 and C-05 without any external heat supply, following condition P-05. After the synthesis process in reactor A with optimum reactant condition P-05, the reactant condition of C-03 was applied for making glue (C-04) while at the reactor B, the reactant condition of C-02 was applied for C-05. The each glue from C-04 and C-05 had viscosity value of 10,200 cps and 12,000 cps, respectively. An interesting experimental result shows that as in the case of the previous result in the Table 3, the case of no further external heat supply in the near commercial scale process will produce glue with good viscosity compared with the case of further external heat supply to the reactor. The earlier case was

presumably caused by large heat of reaction during polymerization and enough to supply heating during the course of paste-glue production.

Table 3 Summarized reaction conditions and results of glue synthesis for near commercial scale with synthesis method 2 based on P-04 and P-05 parameters.

Near commercial Scale	Reactor	Starch Decomposition			Monomer and Catalyst Injected			Polymerization Result	
		Water (L)	Starch (kg)	Enzyme (kg)	Monomer (kg)	Heating (°C)	Cat. (kg)	Viscosity (cps)	Quality product
C-01	A	1,460	600	0.5	280	95	2.66	82,500	Poor
C-02	B	1,460	600	0.5	280	95	2.66	28,000	Good
C-03	A	1,550	600	0.5	280	85	2.66	33,000	Good
C-04	A	1,550	600	0.5	280	No	5.2	10,200	Good
C-05	B	1,460	600	0.5	280	No	5.2	12,000	Good

6 Conclusion

We have carried out a scaling-up approach for paste glue synthesis in a laboratory scale to a pilot scale and to near commercial scale. Monitoring the pathway of reaction temperature changes, especially ceiling temperature and viscosity, over reaction time during glue synthetic reaction were crucial in order to produce good quality of paste glue, as the prior requirement of making good quality of gummed tape. Further, the glue quality was determined by the viscosity of product, within the range 10,000-30,000 cps at various scale experimental study for glue synthesis from 1,000 ml laboratory scale to 300 L pilot scale and to 1,500 L near commercial scale reactor. The synthesis method 2 which was conducted by introducing monomer into slurry of dissolved starch and then polymerization proceeded in the starch slurry gave good quality of glue product for bench or laboratory scale to pilot scale to near commercial scale. However, synthesis method 1 by mixing the dissolving starch and polymer, gave poor glue product. It was found that the synthesis method 2 presumably give good polymerization and produce rather consistent and good quality product of glue throughout the scale of reactor compared with synthesis method 1. For the future work, we will apply the synthesis method for commercial scale production as well as determine the correlations suitable for scaling up the paste-glue production from laboratory scale to commercial scale.

Acknowledgement

Dr. Lee is a distinguished visiting scholar from TPC consultant, funded and supported by National Research Funding of Korea and he is assigned at the Department of Chemical Engineering, Faculty of Industrial Technology,

Institute of Technology Bandung, Indonesia. We also acknowledge PT. Garuda Twin Jaya for permission of publishing some data in this paper as well as for financial support during the course of the project.

References

- [1] ASTM D5749-01, *Standard Specification for Reinforced and Plain Gummed Tape for Sealing and Securing*, 2006.
- [2] Benedek, I., *Development and Manufacture of Pressure-Sensitive Products*, Marcel Dekker Inc., NY 1999.
- [3] An Article from http://en.wikipedia.org/wiki/Adhesive_tape (26 September 2012)
- [4] JIS Z 0218, *Gummed Tape-Testing Methods for Adhesive Strength*, 2002.
- [5] Jung, H.S. & Kim, K.H., *Characteristics of Gummed Tape for Plywood Manufacture*, *Wood Engineering*, **1**, pp.10-12, 1973.
- [6] Nauman, E.B., *Chemical Ractor Design, Optimization and Scale up*, McGraw Hill, New York, 2002.
- [7] Nauman, E.B., *Chemical Ractor Design, Optimization and Scale up*, 2nd Ed., Wiley, New York, 2008.
- [8] Hoogenboom, R., Paulus, R.M., Pilotti, A. & Schubert, U.S., *Scale-up of Microwave-Assisted Polymerizations in Batch Mode: The Cationic Ring-Opening Polymerization of 2-Ethyl-2-oxazoline*, *Macromolecular Rapid Communication*, **27**, pp. 1556-1560, 2006.
- [9] Maschio, G., Ferrara, I., Bassani, C. & Nieman, H., *An Integrated Calorimetric Approach for the Scale-up of Polymerization Reactors*, *Chemical Engineering Science*, **54**, pp. 3273-3282, 1999.
- [10] Meyer, T., *Scale-up of Polymerization Process: A Practical Example*, *Organic Process Reserach & Development*, **7**, pp. 297-302, 2003.