



Optimized Synthesis of Lignosulphonate-g-poly(acrylic acid-co-acrylamide) Superabsorbent Hydrogel Based on the Taguchi Method

Yuxiong Wu^{1*}, Jinhua Zhou², Cuiceng Ye², Hanzhou Sun², and Renjie Zhao¹

(1) School of Material Science and Engineering, Central South University of Forestry and Technology, Changsha-410004, P.R. China

(2) School of Science, Central South University of Forestry and Technology, Changsha-410004, P.R. China

Received 23 August 2009; accepted 26 January 2010

A B S T R A C T

A method for inclusion of lignosulphonate into superabsorbent hydrogels by graft copolymerization of partially neutralized acrylic acid and acrylamide onto lignosulphonate was developed. The Taguchi method, a robust experimental design, was employed for the optimization of synthetic conditions for the hydrogels based on water absorbency. The Taguchi L_{16} (4^5) orthogonal array was selected for experimental design. Concentrations of cross-linker *N,N'*-methylene-bisacrylamide (C_{NMBA}), initiator potassium persulphate (C_{KPS}) and magnesium lignosulphonate (C_{MgLS}), neutralization degree of acrylic acid (N_{AA}) and molar ratio of acrylamide to acrylic acid ($R_{AM/AA}$) were chosen as five factors. From the analysis of variance of the test results, the optimal conditions were obtained as follows: C_{NMBA} 7.5×10^{-4} mol/L, C_{KPS} 4.0×10^{-3} mol/L, C_{MgLS} 2.5 g/L, N_{AA} 60 and $R_{AM/AA}$ 1:1. The confirmed maximum water absorbency of the optimized final hydrogel is found to be 1156 g/g. The hydrogel also shows high physiological saline absorbency (122 g/g) and high Pb^{2+} adsorption capacity (332 mg/g). FTIR analysis confirmed the graft copolymerization of lignosulphonate with acrylic acid and acrylamide. SEM Photograph showed a hydrogel of porous sponge structure with increased surface area. The thermogravimetric analysis indicated the hydrogel has good thermal stability with initial decomposition temperature of about 320°C and maximum decomposition temperature of about 360°C.

Key Words:

superabsorbent hydrogel;
lignosulphonate;
lignin;
Taguchi method;
synthesis.

INTRODUCTION

Superabsorbent hydrogel (SAH) [1] can absorb a large amount of water and even retain the absorbed water under some pressures. SAH is widely used in many fields such as hygiene products, agriculture and soil conditioning. They can also be used in controlled drug delivery systems, artificial snow, swelling rubber, coal dewatering where water absorbency or water retention is important [2-5]. Most

of these hydrogels are prepared from non-renewable chemical raw materials, which are not in accordance with the global resource-conservation tendency and make them more expensive. Fortunately, much attention has been paid to the renewable natural resources gradually. Starch [6-9], chitosan [10,11], cellulose [12-14], carrageenan [15], pectin [16], protein [5,17,18], collagen [19],

(*) To whom correspondence to be addressed.

E-mail: sandywyx@126.com

alginate [20], etc. are employed in the preparation of SAHs. However, few studies on lignin (and/or lignosulphonate) as a natural source of SAHs are reported [21,22].

Lignin (and/or lignosulphonate) is a waste discharged from paper mills in large quantities and poses huge disposal problem [23]. At the same time, lignin is the second most abundant natural raw material [24]. Inappropriate disposal of lignin will cause heavy environmental pollution and it is also a great waste of renewable resource. Lignin features high surface area (180 m²/g) [25] and it has a potential to be used as a possible adsorption material to remove heavy metals from waste waters [26]. Suhas et al. [27] reviewed the published work about lignin being employed as adsorbent resin to remove metallic pollutants from waste waters.

Although the chemical reactivity of lignin is not good, lignin can graft-copolymerize with vinyl monomers such as acrylic acid, acrylamide and styrene [28,29]. In our laboratory, in studying the acrylic SAH, it is found that the inclusion of a "useless" but abundant and renewable source such as lignin to acrylic SAH networks through graft copolymerization can improve acrylic SAHs' salt-resistance and impart SAHs with high metal ion adsorption capacities.

Taguchi method [30,31] is a powerful design of experiments tool developed by G. Taguchi. It can provide a simple, efficient and systematic approach to optimize designs for performance, quality and cost. In this study, magnesium lignosulphonate (MgLS) graft-copolymerized with partially neutralized acrylic acid and acrylamide to produce a new kind of SAH, lignosulphonate-g-poly(acrylic acid-co-acrylamide) (LS-g-P(AA-co-AM)) and the Taguchi orthogonal experimental design was applied to optimize the operational conditions for the synthesis of LS-g-P(AA-co-AM). Introduction of lignosulphonate to acrylic SAHs not only lowers the cost of SAH, but also improves their practical properties. The optimized LS-g-P(AA-co-AM) hydrogels show good water absorbency (1156 g/g), good physiological saline absorbency (122 g/g) and high metal ion adsorption capacities (Pb²⁺ adsorption capacity achieves 332 mg/g). At the same time, a new way to utilize lignin has been developed.

EXPERIMENTAL

Materials

Magnesium lignosulphonate (MgLS) was purchased from Jiangmen Ganhua Group Co., Ltd. (Jiangmen, China). Other materials used in the study including acrylic acid (AA), acrylamide (AM), *N,N'*-methylene-bisacrylamide (NMBA, cross-linker), sodium hydroxide (NaOH), sodium chloride (NaCl), potassium persulphate (KPS, initiator), lead nitrate and ethanol (95%, v/v) were purchased from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China) and they were of reagent analytical grades. All the materials were used as received.

Instrumental Analysis

FTIR Spectra of samples were taken in KBr pellets using a Nicolet Avatar 330 FTIR spectrophotometer (Thermo Electron Corporation, USA). Morphology of the dried SAH was studied by scanning electron microscopy. Dried SAH powders were coated with a thin gold layer and imaged by SEM instrument (JSM-6380LV, Jeol Ltd., Japan). Perkin Elmer Pyris 6 TGA (PerkinElmer Inc., USA) was used for thermogravimetric analysis (TGA) under nitrogen atmosphere. The heating rate was 15°C/min with sample of 7.0 mg weight. Concentrations of Pb²⁺ were determined by an atomic absorption spectrophotometer (AA-7003, East & West Analytical Instruments, Inc., China).

Experimental Design

The Taguchi orthogonal experimental design was applied to minimize the number of experiments and optimize the synthetic conditions for LS-g-P(AA-co-AM). Distilled water absorbency (Q_W) of LS-g-P(AA-co-AM) was selected as the response. The following factors were determined to be the most effective in the synthesis of LS-g-P(AA-co-AM) based on our preliminary experiments and literature [32,33]: concentration of cross-linker NMBA (C_{NMBA}), concentration of initiator KPS (C_{KPS}), concentration of MgLS (C_{MgLS}), neutralization degree of AA (N_{AA}) and molar ratio of AM to AA ($R_{AM/AA}$).

Based on the examples introduced by Zou [4] and our preliminary laboratory research trials on

Table 1. Various levels of each factor.

Factor	Level 1	Level 2	Level 3	Level 4
C_{NMBA} (mol/L), A	2.5×10^{-4}	5.0×10^{-4}	7.5×10^{-4}	1.0×10^{-3}
C_{KPS} (mol/L), B	1.0×10^{-3}	2.0×10^{-3}	3.0×10^{-3}	4.0×10^{-3}
C_{MgLS} (g/L), C	2.5	5.0	7.5	10.0
N_{AA} , D	60	70	80	90
$R_{\text{AM/AA}}$, E	1:1	1:2	1:3	1:4

Table 2. Experimental design (according to L_{16} (4^5)) and the responses.

Run	A	B	C	D	E	Q_W (g/g)
1	1	1	1	1	1	773.9
2	1	2	2	2	2	137.6
3	1	3	3	3	3	125.3
4	1	4	4	4	4	81.0
5	2	1	2	3	4	176.2
6	2	2	1	4	3	1016.0
7	2	3	4	1	2	94.2
8	2	4	3	2	1	972.2
9	3	1	3	4	2	364.1
10	3	2	4	3	1	504.8
11	3	3	1	2	4	786.7
12	3	4	2	1	3	952.6
13	4	1	4	2	3	129.0
14	4	2	3	1	4	900.5
15	4	3	2	4	1	791.1
16	4	4	1	3	2	925.2

hydrogels, four levels were determined for each selected factor (Table 1). Thus, the Taguchi L_{16} (4^5) orthogonal array was selected for experimental design. Based on the L_{16} orthogonal array, 16 syntheses were conducted and each one was repeated three times. For each synthesis, mean value of the three replications was the response of this synthesis. Table 2 shows the experimental design and the responses (Q_W).

Preparation of LS-g-P(AA-co-AM)

For each run, the total concentration of AA and AM was 3 mol/L and the respective concentration for AA and AM depended on $R_{\text{AM/AA}}$ according to Tables 1 and 2. AA was pre-neutralized to designated neutralization degree according to Tables 1 and 2 by drop-wise addition of 9 mol/L NaOH solution in an

ice-water bath. NMBA, MgLS, KPS and AM were prepared as solutions and stored in a refrigerator. Reaction duration and temperature were programmed as 55°C for 2.5 h, then 65°C for 2.5 h and followed by 75°C for 3 h to guarantee complete copolymerization and therefore, good products.

For some radical polymerizations, at the beginning of an isothermal reaction, due to the higher concentrations of initiator and other raw materials, one would expect higher reaction rate, and thus, the reaction may release a large amount of heat and even may lead to uncontrollable situation. However, towards the middle-late period, the reaction rate would fall with decreasing initiator and raw materials. Thus, temperature step-increasing mode could be employed to keep a relatively uniform reaction rate and to avoid wide distribution

of molecular weight of the product which may result from the non-uniform rates of the reaction system [34]. At the same time, high temperature at the later period may be good for the perfection of the products.

Based on Tables 1 and 2, the pre-neutralized AA was carefully and completely transferred into a 50 mL scaled tube. Predetermined AM, NMBA, MgLS and KPS solutions were in turn added into the tube by pipettes. Immediately, the volume was set by distilled water and then the tube was shaken thoroughly to guarantee all the reaction materials to be homogeneously mixed.

Subsequently, the fully mixed reaction material system was transferred into the 100 mL three-necked flask of the polymerization device. The copolymerization was progressed according to the programmed reaction temperature and duration with agitation (achieved by JB50-D electric agitator, Shanghai Leigu Instrument Ltd., China) in a hot-water bath until the viscosity of the polymerization system increased to some extent but the system was still flowable. Then, the polymerization system was transferred into a 100 mL beaker immediately and continued to finish the copolymerization along the same programmed reaction temperature and duration. Absence of air (usually achieved by replacement of nitrogen) is no need for the whole synthesis process. After reaction, the product was cut into small pieces and immersed into ethanol overnight. Then, the product was dried in vacuum oven at 50°C until its mass was constant. Finally, the dried product was ground thoroughly. The particle sizes for all samples used in the following experiments were in the range of 80-100 mesh.

Determination of Q_W and Q_{PS} (Physiological Saline Absorbency)

An accurately weighed LS-g-P(AA-co-AM) sample (about 0.2 g) was immersed into a certain amount of distilled water (or physiological saline, 0.9 wt% NaCl) and allowed to soak at ambient temperature until maximum swelling. The swollen polymer was filtered through an 80-mesh sieve to remove non-absorbed water (or physiological saline) and weighed again to find the amount of water (or

physiological saline) absorbed thereby [32]. The distilled water absorbency, Q_W , and physiological saline absorbency, Q_{PS} , were calculated by the following equations, respectively:

$$Q_W = \frac{W_1 - W_0}{W_0} \quad (1)$$

$$Q_{PS} = \frac{W_2 - W_0}{W_0} \quad (2)$$

where Q_W and Q_{PS} indicate the water and physiological saline absorbency, respectively (g/g); W_0 , W_1 and W_2 denote the weights of the LS-g-P(AA-co-AM) sample, the water swollen hydrogel and the physiological saline swollen hydrogel (g), respectively.

Determination of $q(\text{Pb}^{2+})$ (Pb^{2+} Adsorption Capacity)

Pb^{2+} adsorption capacities of LS-g-P(AA-co-AM) were also determined at ambient temperature [35]. About 0.2 g LS-g-P(AA-co-AM) sample was accurately weighed into a conical flask and then 200 mL of 2.00 mmol/L Pb^{2+} solution (prepared from lead nitrate) was carefully added into the flask. The flask was gently shaken for several minutes before it was statically placed for 24 h to allow the Pb^{2+} adsorption saturation of the LS-g-P(AA-co-AM) sample to be achieved. Subsequently, the adsorption solution was filtered and part of the filtrate was diluted to a certain concentration for determination by an atomic absorption spectrophotometer. Therefore, the Pb^{2+} adsorption capacities of LS-g-P(AA-co-AM) were calculated by eqn (3).

$$q(\text{Pb}^{2+}) = \frac{(c_0 - c) \times V \times M}{W} \quad (3)$$

where $q(\text{Pb}^{2+})$ is Pb^{2+} adsorption capacity of LS-g-P(AA-co-AM) (mg/g), c_0 and c are the metal ion concentrations of Pb^{2+} solution before and after adsorption (mmol/L), respectively, V is the solution volume (L), M is the relative molecular weight of Pb^{2+} (here is 207.19 g/mol) and W is the weight of LS-g-P(AA-co-AM) sample (g).

Determination of Soluble Fraction for Gels

The soluble fraction for certain gels, w_{sol} , which indirectly reflects the gel content (as a measure of the cross-linking polymerization reaction), was determined according to the method reported by Unal et al. [36].

RESULTS AND DISCUSSION

IR Spectra

The grafting was confirmed by comparing the FTIR spectrum of lignosulphonate with that of the grafted products LS-g-P(AA-co-AM). Figure 1a shows the FTIR spectrum of lignosulphonate. The band at about 3412 cm^{-1} is due to the -OH stretching vibrations. The band at $1620\text{-}1627\text{ cm}^{-1}$ is assigned to carbonyl stretching conjugated with the aromatic ring. Absorption at 1463 cm^{-1} indicates the C-H deformations (asymmetric in $-\text{CH}_3$ and $-\text{CH}_2-$). Aromatic ring vibrations in the lignin fractions are assigned at 1515 cm^{-1} and 1427 cm^{-1} . The bands at 1188 cm^{-1} and 1047 cm^{-1} are the characteristic vibrations of the sulphonic group. The band at 1116 cm^{-1} indicates lignin's aromatic C-H in-plane deformation. Aromatic out-of-plane bending appears at 837 cm^{-1} . In comparison to the spectrum of lignosulphonate, hydrogels (Figure 1b) show new absorption bands at 2946 , 1670 , 1562 , 1453 , 1405 and 1319 cm^{-1} . The bands at 1405 and 1319 cm^{-1} are two strong bands of

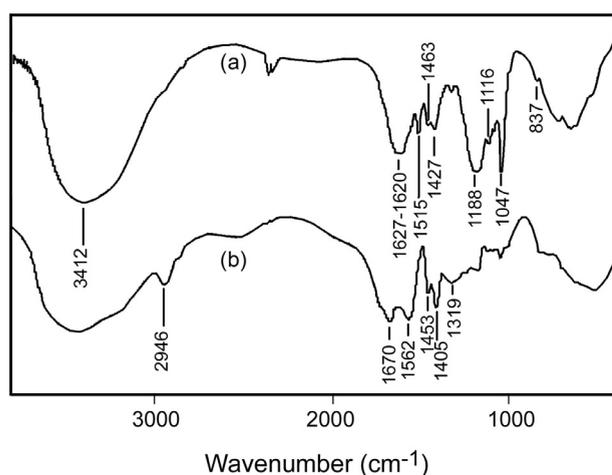


Figure 1. FTIR Spectra of: (a) lignosulphonate and (b) LS-g-P(AA-co-AM) hydrogel.

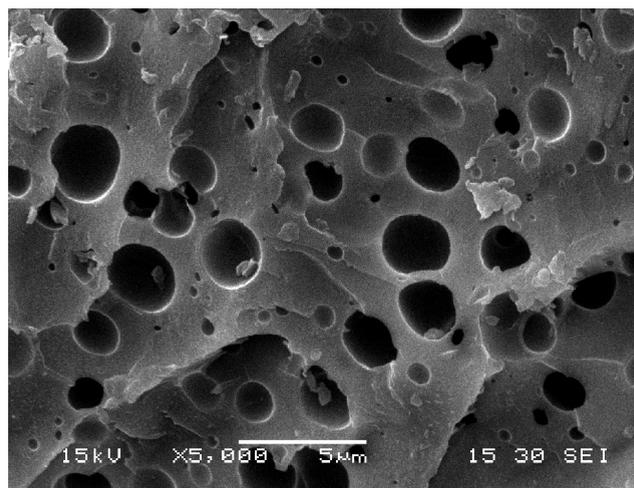


Figure 2. SEM Photograph of LS-g-P(AA-co-AM) hydrogel surface at a magnification of 5,000 and the scale bar is $5\text{ }\mu\text{m}$.

carboxy (and/or carboxylate anion) while 1562 cm^{-1} is due to asymmetric stretching in carboxylate anion that is reconfirmed by another peak at 1453 cm^{-1} which is related to the symmetric stretching mode of the carboxylate groups [19]. The band at 1670 cm^{-1} may be due to carbonyl $\text{C}=\text{O}$ absorption for primary amides. The band at 2946 cm^{-1} may indicate the $-\text{CH}_2-$ stretching vibrations of AA and AM after graft onto the aromatic ring of MgLS.

Morphological Analysis

Figure 2 shows the SEM photograph of LS-g-P(AA-co-AM) hydrogel. The picture verifies that the grafted copolymers have porous sponge structure. The pores might be induced into the hydrogel by water evaporation resulting from high temperature at the later reaction period [37]. This kind of porous sponge structure brings about an increased surface area and capillary effect which are of great importance to the hydrogels' water absorbency, retention rate and metal ion adsorption capability. It is supposed that these pores are the regions of water permeation and interaction sites of external stimuli with the hydrophilic groups of the grafted copolymers [19].

Thermogravimetric Analysis

TG and DTG curves of LS-g-P(AA-co-AM) hydrogel are presented in Figure 3. DTG shows that the initial

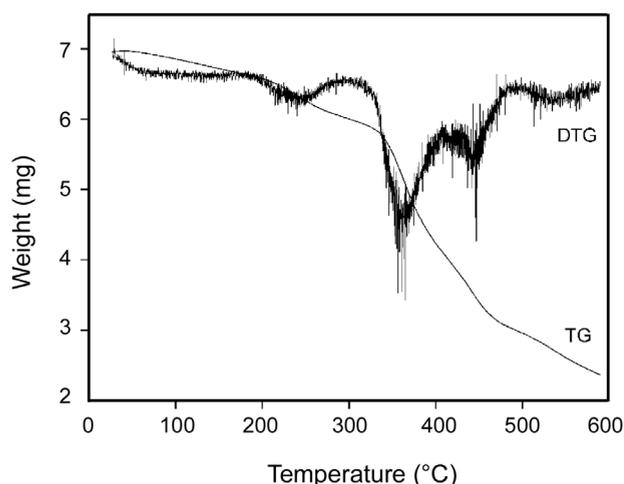


Figure 3. TGA Curves of LS-g-P(AA-co-AM) hydrogel, heating rate at 15°C/min, under N₂.

decomposition temperature of the hydrogel is about 320°C with maximum decomposition at about 360°C. It seems that the hydrogel has good thermal stability.

Statistical Analyses of Q_W

The mean value of three replications of each Q_W response was considered as the result for each run and is listed in Table 2. All statistical analyses were conducted by Minitab software (version 15). S/N ratio (signal to noise ratio) is a very useful parameter to reflect the relative effects of factors since it takes both mean and variance into consideration in the mean time and it is strongly suggested by Taguchi experimental design method. The above larger S/N ratio indicates stronger effects of the above factors. S/N ratio is given by:

$$S/N = -\log \left[\frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \right] \quad (4)$$

Tables 3 and 4 demonstrate the response table for means and for S/N ratios, respectively. Δ for each factor in the two tables are given by eqn (5) for Table 3, and eqn (6) for Table 4, respectively:

$$\Delta_{factor(mean)} = response_{max} - response_{min} \quad (5)$$

$$\Delta_{factor(S/N)} = S/N_{max} - S/N_{min} \quad (6)$$

The significant ranking factors given by Tables 3 and 4 are consistent. Both are C_{MgLS}, C_{NMBA}, R_{AM/AA}, C_{KPS} and N_{AA}. Figure 4 is the main (reflected by S/N ratio) graph of each effective factor. The optimal levels of factors indicated by S/N ratios (based on Table 4 or Figure 4) are shown in Table 5. The optimal levels of factors indicated by mean responses (according to Table 3) are 4(C_{NMBA}), 4(C_{KPS}), 1(C_{MgLS}), 1(N_{AA}) and 1(R_{AM/AA}) and they are inconsistent with those given by S/N ratios. Since S/N ratio has considered both response and variance, the optimal levels given by S/N ratio are recommended.

Figure 4 also shows that C_{NMBA}, C_{MgLS} and R_{AM/AA} have significant influence on S/N ratio. This is in accordance with the result of ANOVA (Analysis of Variance, Table 6). In Figure 4, Q_W decreases by concentration of MgLS. This is due to the large size of lignin molecule. Lignin molecule's big steric effect derived from its large size may impair LS-g-P(AA-co-AM), the SAH's lightly cross-linked net-like structure, which is crucial to the water absorbency of SAH. Another factor that influences the cross-linked

Table 3. Response table for Q_W (g/g) means.

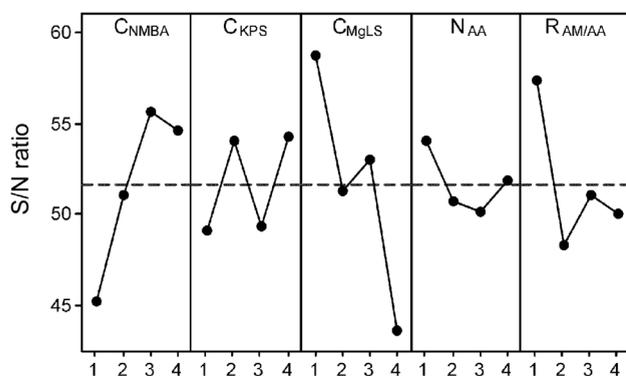
Level	C _{NMBA}	C _{KPS}	C _{MgLS}	N _{AA}	R _{AM/AA}
1	279.5	360.8	875.5	680.3	760.5
2	564.6	639.7	514.4	506.4	380.3
3	652.0	449.3	590.5	432.9	555.7
4	686.5	732.8	202.3	563.1	486.1
Δ	407.0	371.9	673.2	247.4	380.2
Rank	2	4	1	5	3

Table 4. Response table for signal to noise ratios (for Q_W); the larger the better.

Level	C_{NMBA}	C_{KPS}	C_{MgLS}	N_{AA}	$R_{AM/AA}$
1	45.17	49.03	58.79	53.98	57.39
2	51.07	54.02	51.31	50.66	48.20
3	55.70	49.33	53.01	50.07	50.97
4	54.65	54.21	43.48	51.87	50.02
Δ	10.53	5.17	15.31	3.91	9.19
Rank	2	4	1	5	3

net-like structure is the concentration of cross-linker. As the concentration of cross-linker NMBA increases, the swelling capacity of the copolymer increases up to a certain level. However, with higher cross-linker concentration the swelling capacity decreases. This is due to reduced space between the copolymer chains as cross-linking increases in LS-g-P(AA-co-AM) [38]. $R_{AM/AA}$, the molar ratio of acrylamide to acrylic acid reflects the ratio of non-ionic hydrophilic group $-\text{CONH}_2$ to anionic hydrophilic group $-\text{COOH}$ (and/or $-\text{COONa}$). Water absorbency of $-\text{CONH}_2$ is lower than that of $-\text{COOH}$ (and/or $-\text{COONa}$) [39]. Thus, in general water absorbency of LS-g-P(AA-co-AM) is decreased by $R_{AM/AA}$.

Table 6 is the result of ANOVA for S/N ratios. Since C_{KPS} and N_{AA} have insignificant influence on S/N ratios, they have been pooled into errors. The F-value gives the value of statistical test and P-value reflects the level of insignificance of each factor while confidence reflects the level of significance of each factor (Confidence = 1-P).

**Figure 4.** Main effect (reflected by S/N ratio) of each factor for Q_W .**Table 5.** Optimal level of each factor for Q_W based on Table 4 or Figure 4.

Factor	Rank	Optimal level	Corresponding Q_W (g/g)
C_{NMBA}	2	3	652.0
C_{KPS}	4	4	732.8
C_{MgLS}	1	1	875.5
N_{AA}	5	1	680.3
$R_{AM/AA}$	3	1	760.5

Based on Taguchi method, if only the significant factors (C_{NMBA} , C_{MgLS} and $R_{AM/AA}$) are considered, Q_W (the response) can be predicted as follows:

$$\begin{aligned} \text{Predicted } Q_W &= Q_{W1} + [Q_W(C_{NMBA}, 3) - Q_{W1}] + \\ &[Q_W(C_{MgLS}, 1) - Q_{W1}] + [Q_W(R_{AM/AA}, 1) - Q_{W1}] = \\ &545.65 + (652.0 - 545.65) + (875.5 - 545.65) + \\ &(760.5 - 545.65) = 1196.7 \text{ g/g} \end{aligned} \quad (7)$$

where Q_{W1} is the mean value of Q_W for 16 runs in Table 2, $Q_W(C_{NMBA}, 3)$, $Q_W(C_{MgLS}, 1)$ and $Q_W(R_{AM/AA}, 1)$ are the corresponding Q_W means of the significant factors at their optimal levels (Table 5).

Experiments were conducted to confirm the predicted Q_W . Three replications were made to give the confirmed Q_W :

$$Q_W = 1156 \text{ g/g} \quad (8)$$

Table 6. Analysis of variance for S/N ratios (for Q_{WV}), using adjusted SS for tests.

Source	Degree of freedom	Sequential sum of squares	Adjusted sum of squares	F	P	Confidence	Significant*
C_{NMBA}	3	270.76	90.25	4.06	0.068	93.2%	Yes
C_{MgLS}	3	478.56	159.52	7.18	0.021	97.9%	Yes
$R_{AM/AA}$	3	191.75	63.92	2.88	0.125	87.5%	Yes
C_{KPS}	Pooled						No
N_{AA}	Pooled						No
Error	6	133.31	22.22	-	-	-	-
Total	15	1074.38	* Note: at least 75% confidence				

The sol fraction of the optimized hydrogel was 0.03, and the soluble parts may be unreacted raw materials, homopolymers, and/or uncross-linked copolymers.

Q_{PS} and $q(Pb^{2+})$ of LS-g-P(AA-co-AM) Hydrogel

For many applications, it is more important to know the absorbency in a physiological saline which is simulated by 0.9% aqueous NaCl solution. The physiological saline absorbency, Q_{PS} , of LS-g-P(AA-co-AM) hydrogel prepared under optimized synthetic conditions is 122 g/g which is much lower than its distilled water absorbency (1156 g/g). The water absorption properties are thought to result from osmotic pressure and interaction through hydrogen-bonding of the groups of hydrogels with water molecules. When physiological saline is used as a swelling agent, the osmotic pressure outside the hydrogel decreases drastically and therefore, the absorption is lowered [21].

SEM photograph of LS-g-P(AA-co-AM) hydrogel suggests that the hydrogel has formed porous sponge structure with increased surface. Higher porosity and larger surface would be very helpful for the adsorption of metal ions. Moreover, the introduction of lignosulphonate to the hydrogel has brought about a number of functional groups such as phenolic, hydroxyl, carboxyl, benzyl alcohol, methoxyl, aldehyde and sulphonic acid groups [40] which would interact with, and then capture the metal ions. Thus, the special porous sponge structure and the introduction of lignosulphonate have endowed LS-g-P(AA-co-AM) hydrogel with high adsorption

capacity for metal ions. Here $q(Pb^{2+})$ of LS-g-P(AA-co-AM) hydrogel reaches 332 mg/g.

CONCLUSION

A method for grafting lignosulphonate into a superabsorbent hydrogel was developed. The synthetic conditions of superabsorbent hydrogel were optimized by Taguchi method. The maximum water absorbency (1156 g/g) was achieved under the optimized synthetic conditions with physiological saline absorbency (122 g/g). The hydrogel also shows high Pb^{2+} adsorption capacity (332 mg/g), which may attribute to the hydrogel's special porous sponge structure and the introduction of lignosulphonate into the hydrogel.

SYMBOLS AND ABBREVIATIONS

AA	Acrylic acid
AM	Acrylamide
C_{KPS}	Concentration of potassium persulphate
C_{MgLS}	Concentration of magnesium lignosulphonate
C_{NMBA}	Concentration of <i>N,N'</i> -methylene-bisacrylamide
KPS	Potassium persulphate
LS-g-P(AA-co-AM)	Lignosulphonate-g-poly(acrylic acid-co-

	acrylamide)
MgLS	Magnesium lignosulphonate
N_{AA}	Neutralization degree of acrylic acid
NaCl	Sodium chloride
NaOH	Sodium hydroxide
NMBA	<i>N,N'</i> -Methylene-bisacrylamide
$q(\text{Pb}^{2+})$	Pb^{2+} adsorption capacity
Q_{PS}	Physiological saline absorbency
Q_W	Distilled water absorbency
$R_{AM/AA}$	Molar ratio of acrylamide to acrylic acid
SAH	Superabsorbent hydrogel
S/N ratio	Signal to noise ratio
w_{sol}	Soluble fraction of hydrogel

ACKNOWLEDGEMENT

This research was supported by Science and Technology Planning Project of Hunan Province, China (2009FJ3100) and Scientific Research Fund of Central South University of Forestry & Technology (2008025B).

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