

Effects of Foamers and Stabilizers on Foaming Ability and Stability of Oxidized Starch/Polyacrylic Acid Size Liquor in Foam Sizing

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ABSTRACT

Foam sizing has been studied as a low-add-on technology. Foam properties of size liquor, including foaming ability and foam stability, can directly affect the quality of sized yarns. Different foamers and stabilizers were added to oxidized starch/polyacrylic acid size liquor to prepare foaming size liquor. This paper reports the foam properties of the foaming size liquor the optimized mixed proportions of foamers and stabilizers. Foaming ratio and foam half-life time were measured to characterize the foaming ability and foam stability. The experimental results revealed that foam properties of the composite foamer and stabilizer were greater than those of each individual agent. The foam properties achieved optimum levels when the ratio of lauryl sodium sulfate to dodecyl dimethyl betaine was 80:20 and the foamer concentration was 6g/L. It was also found that the composite stabilizers of dodecanol and guar gum at a ratio of 60:40 exhibited a synergistic effect, achieving optimal foam properties at a stabilizer concentration of 4g/L. Yarn properties of the foam sizing were better than those of conventional sizing at optimum conditions.

Keywords: Foam sizing; foamer; foaming ratio; half-life time; synergistic effect.

INTRODUCTION

Foam technology such as foam dyeing [1-4] and foam finishing [5-8] developed rapidly in the textile industry. Foam sizing has been studied for over 30 years. In 1980, Perkins and Walker showed that the properties of warps sized using foam were equivalent or superior to those of similar warps sized conventionally [9, 10]. Namboodri indicated that energy savings and increased production speed were realized and less bridging of warps and reduced warp hairiness were benefits [11]. Some

other researchers also discussed the differences between foam sizing and conventional technology and the influences of size concentration on the quality of warp sizing, and showed that energy consumption using foam sizing is almost half that of conventional sizing approach but the sizing qualities of the two methods showed no appreciable differences. In addition, the researchers stated that the warp quality using foam depended on the stability of the size and compared the differences of energy consumption between the devices used to apply foam and conventional sizing and illustrated foam-sizing technology. Foam sizing results in a more stable size film on the warp surface and reduces the hairiness [12-16]. In 1988, Xiong Yan studied the foaming performance of sizing materials and analyzed the main factors influencing foamability of the size liquor [17]. In 1999, Zhou Xiaohong studied the foam-sizing process through quantification theory and general design. She found out the selection of adhesive and foaming agent and the adhesive concentration were critical to foam-sizing technology [18]. In 2014, Weidong Gao [19, 20] of Jiangnan University developed foam sizing for industrial application, studied sizing effects of the combined foam-sizing and warp pre-wetting processes. The combined process is superior to the conventional process, saving gas, desizing waste water and desizing agent. In addition, the warp strength increases, the elongation decreases, the wear resistance increases, the hairiness decreases, and the weaving efficiency are not significantly affected with the combined process.

Previously, there has been no research on effects of foamers and stabilizers on foaming ability and foam stability of size liquor. The main factors influencing foaming ability and foam stability of the size liquor,

including foamer, stabilizer and their concentrations, were measured and discussed in this paper. The foaming size liquor should possess a good foaming ratio and the resulting foams should have good stability. In this paper, oxidized starch and polyacrylic acid, which are commonly used in the sizing mills, were selected to prepare the size liquor. According to previous studies of conventional sizing, the yarn performance was optimal when the ratio of oxidized starch to polyacrylic acid was 50:50 and the size concentration was 10 percent. Anionic foamers lauryl sodium sulfate (SDS) and sodium lauryl polyoxyethylene ether sulfate (AES), cationic surfactants lauryl dimethyl amine oxide (OB-2), nonionic surfactant Tween-80 (T-80) and zwitterionic surfactant dodecyl dimethyl betaine (BS-12) were selected as foamers. Foam properties of composite SDS/AES, SDS/OB-2, SDS/T-80, and SDS/BS-12, and optimal concentration of composite foamers were investigated. Stabilizers were important auxiliary components of the foaming size liquor. Dodecanol and guar gum were chosen as stabilizers. This paper also studied foam properties of composite stabilizers and their optimal concentrations. To verify the foam properties at the optimal foaming conditions, greige cotton yarns were processed by foam and conventional sizing. Yarn properties were then tested and compared.

EXPERIMENTAL PROCEDURE

Materials

Lauryl sodium sulfate (SDS), sodium lauryl polyoxyethylene ether sulfate (AES), Tween-80 (T-80) and dodecanol were all 100% purity and purchased from Sinopharm Chemical Reagent Co., Ltd. Lauryl dimethyl amine oxide (OB-2), Tween-80, Dodecyl dimethyl betaine (BS-12) and guar gum were 100% purity and obtained from Qingdao Uoslf chemical technology co., LTD. Oxidized starch as a white powder with 11.06% moisture, 0.45% protein, 0.16% ash and 0.75% fat and polyacrylic acid (XP-C) was obtained from Fengyang Co., Ltd (China). The pH value of the size liquor was 6.5. Cotton 19.4 tex single ring spun yarns were purchased from Yancheng Yueda cotton spinning co., LTD.

Methods

Foams were produced by a high speed mechanical agitator (RW20, IKA, German) for three minutes and rapidly poured into a graduated cylinder (100mL). Then total weight was precisely measured to calculate the weight of the foams. Foaming ratio

(X), defined as the ratio of the weight of an equal volume of foam [24] indicates the foaming ability of foaming size liquor. Higher values of X reflect greater foamability. In the experiments, the density of foaming size liquor (ρ_l) was approximately $1\text{g}\cdot\text{L}^{-1}$. The foaming ratio was calculated by Eq. (1):

$$X = \frac{V_b}{V_l} = \frac{V_b}{m_l / \rho_l} = \frac{V_b}{m_l} = \frac{V_a}{m_b} \quad (1)$$

where V_a , V_b and V_l represent volume of graduated cylinder, foams and foaming size liquor respectively. m_l and m_b which denoted weight of foaming size liquor and foams, and the values were identical.

The foam half-life time reflected foam stability and defined as the time required for one-half of the liquid in the initial foam to separate from the foam by self-drainage [22, 23].

RESULTS AND DISCUSSION

This section presents the results of the investigation of effects of composite foamers and stabilizers on foam properties. Size liquor was prepared by blending oxidized starch and polyacrylic acid at a ratio of 50:50 at size concentrations of 10 percent. Different foamers and stabilizers were added to the size liquor to produce foaming size liquors. The weight coefficient method was proposed to optimize the ratios of the composite foamers and stabilizers. Optimal concentrations of composite foamers and stabilizers were determined.

Effects of Composite Foamers on Foam Properties

Foamer concentration was fixed at $10\text{g}\cdot\text{L}^{-1}$. Foam properties of lauryl sodium sulfate and sodium lauryl polyoxyethylene ether sulfate, lauryl dimethyl amine oxide, tween-80 and dodecyl dimethyl betaine are shown in *Table I*.

TABLE I. Foam properties of different foamers.

Foamer	Foaming ratio	Foam half-life time
SDS	4.5	2.35
AES	4.35	2.29
OB-2	4.42	2.1
T-80	4.34	2.15
BS-12	4.39	2.11

As seen from *Table I*, the foam properties of SDS were the greatest among the five foamers. SDS was

selected to compound with other foamers in order to investigate the foam properties of SDS/AES, SDS/OB-2, SDS/T-80, and SDS/BS-12 composite systems. Foam properties of the four composite foamers are shown in *Figure 1*. $W_1\%$, $W_2\%$, $W_3\%$ and $W_4\%$ respectively are the mass fractions of AES, OB-2, T-80 and BS-12 in the composite foamers.

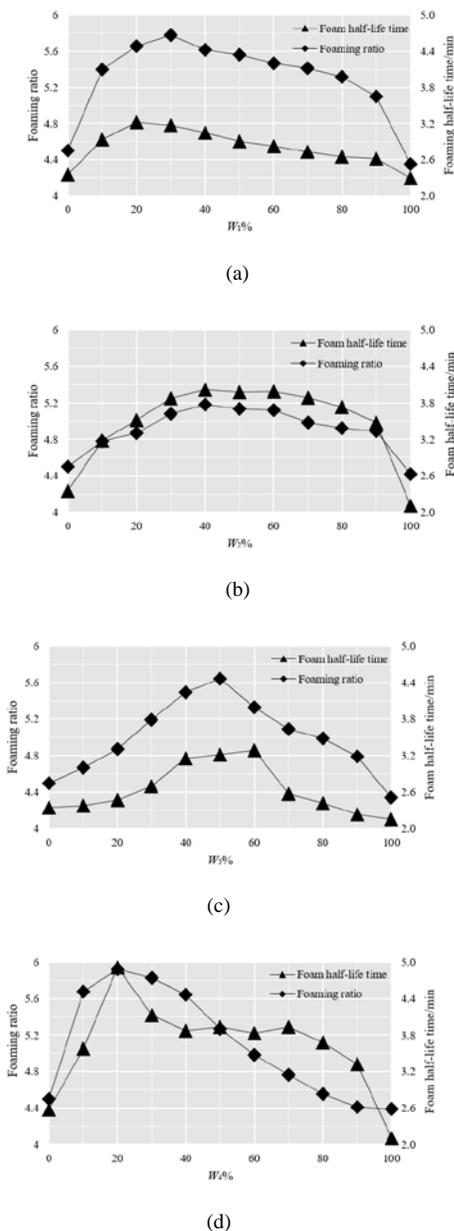


FIGURE 1. Foam properties of (a) SDS/AES, (b) SDS/OB-2, (c) SDS/T-80 and (d) SDS/BS-12 composite foamers.

From *Figure 1*, the foam properties of the four composite foamers were higher than those of a

single foamer and the composite foamers demonstrated synergistic effects. With an increase of the mass fractions of AES, OB-2 and BS-12, the foaming ability of all composite systems increased. Foam properties gradually declined after achieving maximum at critical micelle concentration. Similarly, the change in foam stability was same as that of foaming ability.

In *Figure 1(a)*, the synergistic effects in SDS/AES composite system were mainly due to the polyoxyethylene groups of the AES molecules, which formed hydrogen bonds which are weakly electropositive in aqueous solution. When AES molecules are interact with SDS, the electrostatic repulsion between the SDS molecules decreased and the surface tension was reduced. This enhanced the foaming ratio. On the other hand, the increase of the surfactant adsorption quantity increased the surface viscosity of the solution, which is conducive to the stability of foams, thus and increasing the foam half-life time.

From *Figure 1(b)*, the SDS/OB-2 composite foamers showed obvious synergistic effects. Due to the strong charge interaction of anionic/cationic composite system, the surface activity of the mixture was improved and the foaming ratio increased. The surfactant adsorption on the surface of the liquid film was increased and the intensity of film strength rose, leading to increased foam stability.

As shown in *Figure 1(c)*, the SDS/T-80 composite system had good synergy. As the mass fraction of tween-80 increased, the foaming ratio also gradually increased and the initial growth changed more gradually. This is because the intermolecular interaction of composite foamers becomes weak and the synergistic effects tend to be insignificant. When the mass fraction of tween-80 reached a certain value, the foaming ratio increased rapidly and achieved maximum value at critical micelle concentration. As the mass fraction of tween-80 decreased, the molecular interactions of the composite foamers were enhanced and the surface tension was reduced, increasing the foaming ratio and foam half-life time.

The foam properties of the SDS/BS-12 composite system in *Figure 1(d)* showed excellent synergy. A small amount of SDS solution BS-12 increased the foam properties rapidly and achieved a maximum at

critical micelle concentration. As the mass fraction of BS-12 continued to increase, the foam properties were slightly reduced. Due to the positive charge of the zwitterion surfactant molecules, there was strong electrostatic attraction between BS-12 and SDS. The hydrocarbon chains of BS-12 and SDS also have hydrophobic interactions and the surfactant molecules in the liquid-gas interface thus became significantly compacted.

Proportion Optimization of Composite Foamers

Greater foaming ratio and half-life time results from higher synergy between composite foamers. In this research, the method of weight coefficient was proposed to calculate the optimal proportion of composite foamers. The weigh coefficients are shown in Eq. (2):

$$F_i(x) = w_i f_i(x) + w'_i g_i(x) \tag{2}$$

Where x denotes mass fraction of SDS in composite foamers, $f_i(x)$ and $g_i(x)$ respectively denoted the foaming ratios and foam half-life times of different mixed proportions of surfactant, i takes the values of 1,2,3, and 4, denoting SDS/AES, SDS/OB-2, SDS/T-80 and SDS/BS-12, respectively, and w_i and w'_i denote the weights of foaming ratio and half-life time respectively. The variation coefficient method was used to calculate the weight of w_i and w'_i . The standard deviation of foaming ratio is calculated by:

$$\sigma_i = \sqrt{\frac{\sum_{j=1}^n (f_i(x_j) - v_i)^2}{n}} \tag{3}$$

$$v_i = \frac{\sum_{j=1}^n f_i(x_j)}{n} \tag{4}$$

Where σ_i denoted the standard deviation of $f_i(x_j)$, v_i denoted the mean value of $f_i(x_j)$, j values are positive integers of 1-10 and n is the number of data points. The coefficient of variation of the foaming ratio was calculated by:

$$V_i = \frac{\sigma_i}{v_i} \tag{5}$$

The weight of foaming ratio is calculated by:

$$w_i = \frac{V_i}{V_i + V'_i} \tag{6}$$

Likewise, w'_i is obtained in accordance with w_i .

The relationship between $F_i(x)$ and ratios of the components of the 4 foamers are shown in Figure 2.

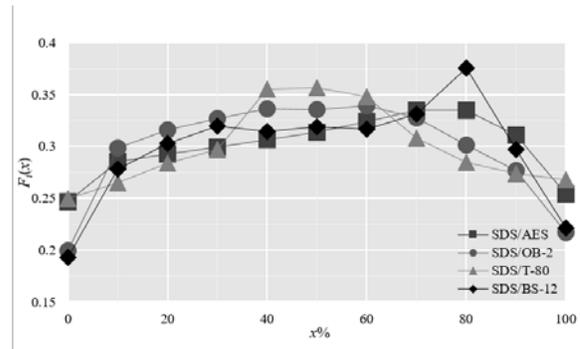


FIGURE 2. Results of $F_i(x)$

As seen in Figure 2, when the proportion of SDS and BS-12 was 80:20, $F_i(x)$ was maximized.

Effects of Foamer Concentration On Foam Properties

The influence of concentration of components of the SDS/BS-12 composite system on foam properties aishown in Figure 3.

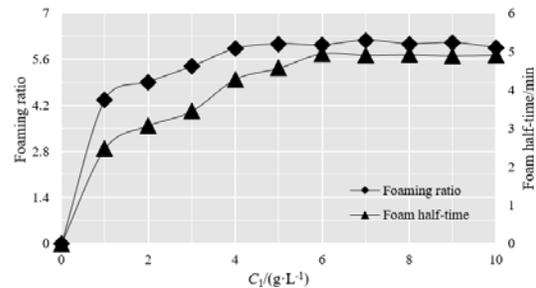


FIGURE 3 Foam properties at different concentrations of SDS/BS-12.

From *Figure 3*, the foaming ratio and half-life time improved as the concentration of composite foamer increases. As this occurs, the adsorption of foamer at the solution interface increases, the surface tension is decreased and the foaming ratio and half-life time increase. The adsorption of foamers reached a maximum at the solution interface at critical micelle concentration. Both foaming ratio and half-life time tended to be constant when the concentration of composite foamers was $6\text{g}\cdot\text{L}^{-1}$.

Effects of Composite Stabilizers on Foam Properties

Composite stabilizers of dodecanol/guar gum were tested. Concentration of composite foamers and stabilizers were fixed at $6\text{g}\cdot\text{L}^{-1}$ and $4\text{g}\cdot\text{L}^{-1}$. Foam properties of composite stabilizers are shown in *Figure 4*; $w\%$ denotes mass fraction of guar gum.

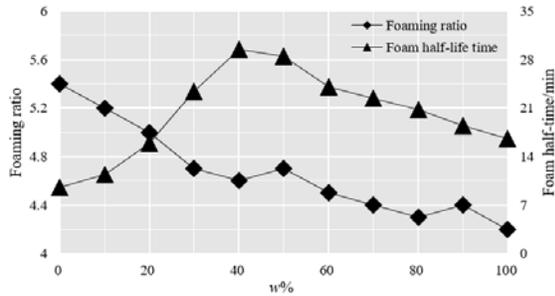


FIGURE 4 Foam properties of composite stabilizers.

From *Figure 4*, as the mass fraction of guar gum increased, the foaming ratio trended to decrease, while the half-life time first increased and then decreased. A composite film was formed by the molecules of stabilizers and the viscoelasticity of foam film was enhanced. Since the main component of guar gum is galactomannan, which contains hydroxyl groups, hydrogen bonds were formed with

the alcoholic hydroxyl group of dodecanol, enhancing the space structure of foam film. The higher strength of the foam film made liquor made drainage more difficult.

Similarly, the weight coefficient $G(w)$ of composite stabilizers was calculated as Eq. (7):

$$G(w) = \alpha_k s(w) + \alpha'_k t(w) \tag{7}$$

Where w denoted mass fraction of guar gum in the composite stabilizers, $s(w)$ and $t(w)$ denote foaming ratio and foam half-life time, respectively and α_k and α'_k denote weight of foaming ratio and half-life time. The relationship between $G(w)$ and mass fraction of guar gum is shown in *Figure 5*.

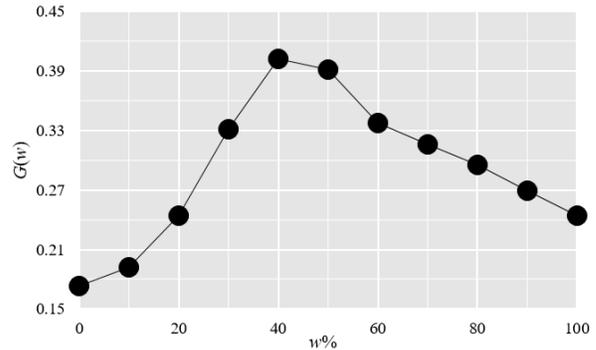


FIGURE 5 Results of $G(w)$.

In *Figure 5*, when the ratio of dodecanol and guar gum was 60:40, $G(w)$ was maximized.

Effects of Stabilizer Concentrations on Foam Properties

The influence of concentration of dodecanol/guar gum on foam properties is shown in *Table II*.

TABLE II. Foam properties of dodecanol/guar gum.

Concentration (g/L)	0	2	4	6	8	10
Foaming ratio	5.92	5.1	4.6	3.9	3.7	3.5
Foam half-life time	4.91	12.7	29.4	61.1	109.1	158.4

In *Table II*, the foaming ratio decreased while half-life time greatly increased with an increase in concentration. The stabilizers caused the viscosity of the liquor to increase, leading to lower foaming ability. According to Reynolds [25], an increase in the viscosity of the liquor results in slower liquor drainage and higher foam stability. When the concentration of composite stabilizer reached $6\text{g}\cdot\text{L}^{-1}$, the foaming ratio was less than 4. Thus $4\text{g}\cdot\text{L}^{-1}$ was the most appropriate concentration.

Comparison of Foam Sizing and Conventional Sizing

Oxidized starch and polyacrylic acid were blended at a 50:50 ratio and 10% and conventionally sized to cotton yarns. Cotton yarns were also foam-sized using this composite.

Comparison of size pick-up, breaking strength, elongation, abrasion resistance and hairiness of foam-sized and conventional yarn are shown in *Table III*.

TABLE III. Test results of yarns.

Description	Size pick-up (%)	Breaking strength (cN/tex)	Elongation (%)	Abrasion resistance (times)	Hairiness (piece/m)
Unsize	0.00%	14.94	8.74	70.13	19.49
Conventional-sized	8.02%	21.48	5.97	139.27	7.55
Foam-sized	5.06%	20.85	6.26	129.75	7.45

In *Table III*, the breaking strength of foam-sized yarns increased by about 40% with as little as 5.06% size pick-up, while strength of conventional sized yarn was increased by 45% at 8.02% size pick-up. The abrasion resistance of foam-sized yarns was lower than that of conventionally sized yarns. The elongation, hairiness and abrasion resistance were almost same for foam-sized and conventional yarns.

CONCLUSION

This paper investigated foam properties of foaming size liquor in order to optimize the proportions of foamers and stabilizers. The foam properties were optimal when the ratio of SDS and BS-12 was 80:20 at a concentration of $6\text{g}\cdot\text{L}^{-1}$. The optimum ratio of dodecanol and guar gum was 60:40 at a concentration of $4\text{g}\cdot\text{L}^{-1}$. Compared with conventional sizing, foam sizing improves properties with less size pick-up. Effects of foam sizing on weaving efficiency and economics of foam sizing will be studied in the future research.

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