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Preparation and stability of zinc ferrite nano-particle suspension of ammonia-water solution

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Abstract: In order to apply nano-particles to the ammonia-water absorption refrigeration, the zinc ferrite nano-particles suspension of ammonia-water solution with the mixed surfactants of sodium dodecyl benzene sulfonate (SDBS) and cetyl trimethyl ammonium bromide (CTAB) is prepared. A series of experiments is performed to investigate the stability of the prepared nanofluid with different contents and proportions of surfactants, different durations of ultrasonic wave vibration and different durations of illumination. The optimal dispersion conditions are 1.5% SDBS, 0.015% CTAB (mass fraction), 30 min of ultrasonic vibration and over 72 h of illumination. Finally, based on double electrode layer theory, the influences of the content of the surfactants on the stability of nanofluid are analyzed. The existence of the optimal surfactant content is proved, which is in accordance with the experimental results.

Key words: nanofluid; stability; surfactant; ammonia water

Nanofluid, or nano-particle suspension, was proposed first by Choi[1]. Many experiments have been performed on the application of nanofluid in the ammonia-water absorption. Kim et al.[2] defined binary nanofluid as the binary mixture, in which nano-particles were evenly distributed, and the effects of binary nanofluid on the ammonia-water bubble absorption performance were studied. It is found that the absorption rates of the ammonia-water nanofluid adding nano-particles and the nanofluid adding both nano-particles and surfactants are 3.21 times and 5.32 times higher than those of ammonia water, respectively. Kang et al.[3] found that the absorption rate and the heat transfer rate of the ammonia-water nanofluid with 0.001% CNT particles are 20% and 29.4% higher than those of the ammonia-water without nano-particles, and the ammonia-water nanofluid with 0.001% CNT particles is the optimal candidate for ammonia-water absorption performance enhancement.

The absorption is critical to the performance of ammonia-water absorption refrigeration. Further studies should be performed on the heat and mass transfer characteristics of ammonia-water nanofluid with different varieties of nano-particles. In the previous research, aluminum oxide and carbon black nano-particles are used in the ammonia-water nanofluid, and the results are satisfying[4]. However, no existing literature on the ammonia-water nanofluid with zinc ferrite nano-particles is found.

In this paper, zinc ferrite nano-particles containing two metallic elements are dispersed stably in the ammonia-water solution, and the effects of illumination on the nano-particles dispersion process are studied. A method of using mixed surfactants including anionic and cationic surfactants as dispersants is proposed and studied quantitatively. The influences of the content of the surfactants on the stability of nanofluid are analyzed based on double electrode layer theory.

1 Preparation of Zinc Ferrite Nano-Particle Suspension of Ammonia-Water Solution

The nanofluids in this study are prepared by mixing zinc ferrite and a surfactants mixture with an ammonia-water solution in a thermostated container at a temperature of 20 ℃ at atmospheric pressure. The mean size of the zinc ferrite particles produced by the precipitation method is less than 30 nm (see Fig. 1). The content of the ammonia-water base fluid is 25%. The surfactants selected in this study are sodium dodecyl benzene sulfonate (SDBS) and cetyl trimethyl ammonium bromide (CTAB), respectively.

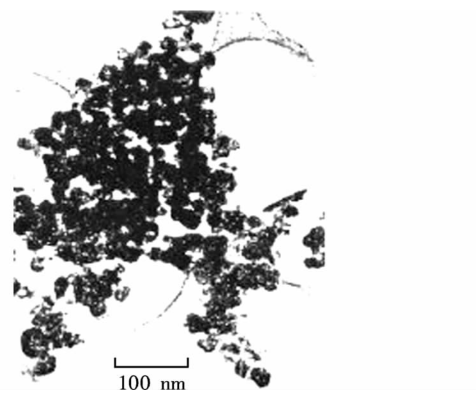

Fig. 1 The SEM image of zinc ferrite nano-particles

The experiments show that the surfactants play an important role in the dispersion stability of nanofluids, and nano-particles cannot be dispersed stably without surfactants. The left tube in Fig. 2 shows that the sediments of zinc ferrite particles appear at the bottom of the tube without surfactants just 2 h after ultrasonic vibration. Under the same condition, the dispersion stability of the nanofluid with proper SDBS is superior to that of the nanofluid without surfactants (see the left tube in Fig. 2). After mechanical agitation, ultrasonic vibration and illumination, the nanofluid maintains stable for more than two months without stratification.

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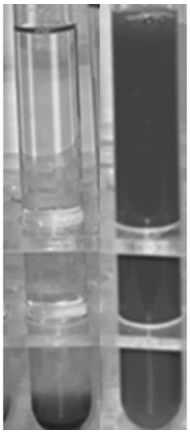


Fig. 2 The influence of SDBS on dispersion of zinc ferrite nano-particles in ammonia-water solution(w(SDBS) $=1.5\%$)

2 Influence of Different Contents of Mixed Surfactants on Stability of Nanofluid

For the base nanofluid of a 25% ammonia-water solution with 0.1% zinc ferrite, when SDBS and CTAB are added to it, respectively, together with different mass contents of orthogonal combinations, the stability of the nanofluid is various.

1) When different contents of SDBS are added separately, in the case of adding a small amount ($<0.1\%$), the suspending time of the nanofluid decreases: 20 min after ultrasonic vibration in the suspension with 0.015% SDBS, the sediments of zinc ferrite particles appear at the bottom of the test tube. Under the same conditions, sediments appear after 1 h in the nanofluid with 0.05% SDBS, and sediments appear after 2 h in the solution without surfactants. It is shown that the smaller amount of SDBS exacerbates the stability of the nano-particles of zinc ferrite. In the case of adding a little greater amount of SDBS($>0.1\%$), the suspension time of the nanofluid increases with the increase in the content of SDBS, and the reunion of nano-particles weakens with the increase in the content of surfactants (see Fig. 3). From left to right, the contents of SDBS are 0.015%, 0.05%, 0.15%, 0.5%, 0.75%, 1.5%, 2.25%, 3%, 3.75%.

2) When the content of SDBS is 1.5%, the effect of the dispersion of nano-particles is superior to that with other contents, and when 0.015% CTAB is added, the nanofluid is the most stable (see Fig. 4). From left to right, the contents of CTAB are 0, 0.015%, 0.05%, 0.15%, 0.5%, 0.75%. Furthermore, it can be concluded from the experiments that, for the dispersion of zinc ferrite nano-particle suspension of the ammonia-water solution, the order of surface activity of the surfactants is as follows: SDBS with minute CTAB > SDBS > CTAB with minute SDBS.

3) When the content of SDBS is equal to or close to that of CTAB, a great amount of reunion of zinc ferrite particles appears immediately, and the surface activity and other functions of the nanofluid disappear. From left to right in Fig. 5, the contents are 0.015%, 0.05%, 0.15%, 0.5%, 1.5%. In fact, when the content difference between SDBS and CTAB reaches three times, floccules appear in the nanofluid. This phenomenon accords with the description in Ref. [5], which indicates that, when the anionic surfactants dominate, the ratios of anionic surfactants to cationic surfactants should be from 4 to 50.

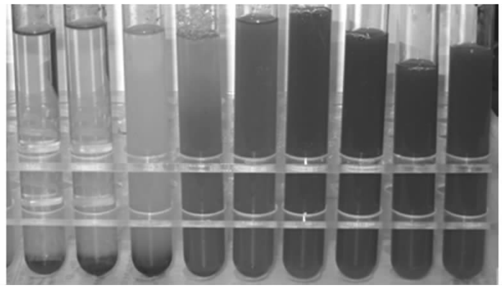


Fig. 3 Influence of different contents of SDBS on stability of nanofluids

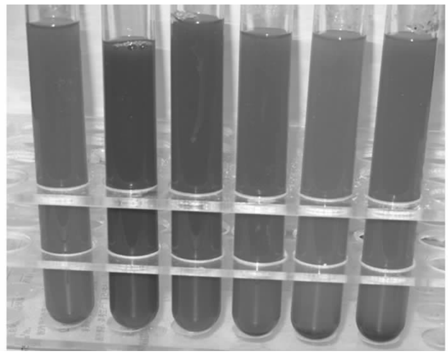


Fig. 4 The nanofluid with different contents of CTAB and 1.5% SDBS

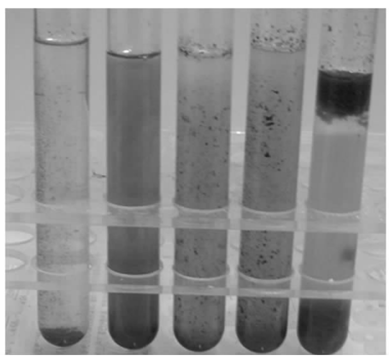


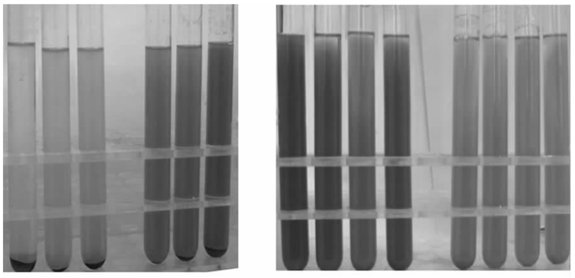
Fig. 5 The nanofluid with the same content of CTAB and SDBS

3 Influence of Ultrasonic Vibration and Illumination on Stability of Nanofluid

3.1 Influence of ultrasonic vibration on stability of nanofluid

When the content of added SDBS is low($<0.5\%$), the effect of dispersion of nano particles is deteriorated after ultrasonic vibration (40 kHz) for half an hour (see Fig. 6 (a)). When the content of SDBS added is above 1.5%, the effect of dispersion of nano-particles is improved after ultrasonic vibration (see Fig. 6(b)). It can be explained as follows:

When less SDBS is added, there are small amounts of surfactant molecules adsorbed on the solid surface and the repulsion among the nano-particles is weak. The nano-particles are accelerated by the resonance vibration induced by ultrasonic waves, which increase the collision of nano-particles. While SDBS are added in the nanofluid solution with higher contents, there are more surfactant molecules adsorbed on the solid surface and the repulsion among nano-particles is intensified, so the nanofluid is dispersed stably due to the effect of the strong cavitation of ultrasonic vibration. The nanofluids are ultrasonically vibrated for 30, 60, 90 and 120 min to show the differences with the nanofluid without ultrasonic vibration. The results show that 30 min is an optimal ultrasonic time for the surfactant mixture with optimal contents of 1.5% SDBS and 0.015% CTAB.



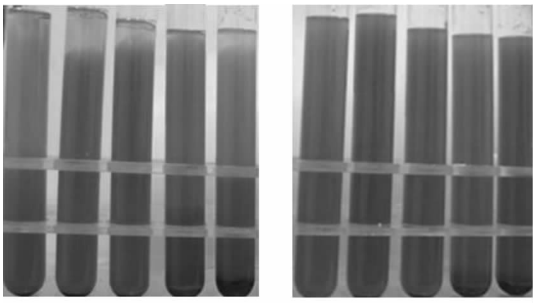
(a) (b)

Fig. 6 Comparisons between after and before ultrasonic vibration of 30 min with different contents of SDBS. (a) The contents of SDBS are 0.05%, 0.15%, 0.5%; (b) The contents of SDBS are 1.5%, 2.25%, 3%, 3.75%

3.2 Influence of illumination on stability of nanofluid

Experiments show that the dispersion of nano-particles is improved after illumination. When the stratified nanofluid is exposed to sunshine for 4 h, the stratification disappears and the nano-particles are dispersed more uniformly (see Fig. 7). From left to right in these two figures, the contents of SDBS are 0.75%, 1.5%, 2.25%, 3%, 3.75%. It is shown that the nanofluid with 72 h of illumination can be dispersed more stably over a longer period without any stratification. The effects of illumination on the improvement of the dispersion can be explained as follows:

First, the nano-particles are ionized and excited as a result of the interaction and energy transfer between high-energy light and nano-particles. A variety of effects arouses subsequently, such as chemical reactions, heat effects, charge effects generated by various types of radiation defects and free radicals, and changes the surface properties of those illuminated. Therefore, the illumination can be used for the modification of the surface properties of nano-particles[6]. Secondly, the zinc oxide of the zinc ferrite absorbs the UV of light and the nanofluid is heated, and the change in temperature will induce the change in the solubility of the ammonia-water and convection in solution, which leads to a more uniform dispersion in the nanofluid[7].



(a) (b)

Fig. 7 Influence of illumination on the stability of nanofluids. (a) Before illumination; (b) After illumination

4 Theoretical Analysis of Zinc Ferrite Nano-Particle Suspension of Ammonia-Water Solution

The mechanism of the effects of anionic surfactants on nano-particles is shown in Fig. 8. Zinc ferrite nano-particles are positively charged after adsorbing Fe^{3+} and Zn^{2+}. The particles suspended in the ammonia-water solution are dispersed due to the electrostatic repulsion among them. According to the Gibbs adsorption theory, the stable dispersion of nano-particles cannot be maintained unless the thickness of the interfacial films of nano-particles is more than 10 nm[6]. However, the thickness of the interfacial films formed by Fe^{3+} and Zn^{2+} is far less than 10 nm. Thereby, the nano-particles are deposited at the bottom of the test tubes after 2 h.

1) When a small amount of SDBS (< 0.1 %) is added to the solution, the suspension time of the nano-particles decreases and the stability of the nanofluid is exacerbated. This phenomenon can be explained in the following way: When the anionic surfactants with lower contents are added in the solution, the positive charges of particles can be eliminated by anions, which leads to the reunion of nano-particles in the ammonia-water solution. Moreover, SDBS is composed of

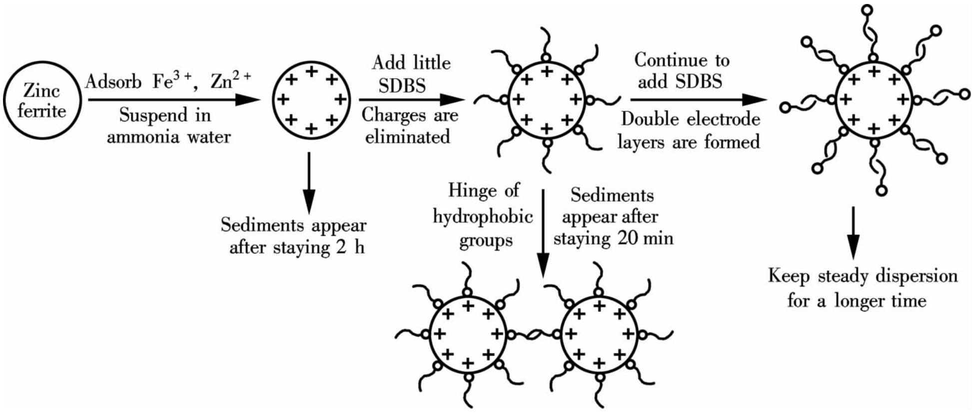


Fig. 8 Reaction of anionic surfactants to the nano-particles

the hydrophilic ion-head and the hydrophobic carbon chain, and the hinge of hydrophobic groups can also induce reunion[8].

2) When a little greater amount of SDBS (> 0.1%) is added, the suspension time of nano-particles increases with the increment in the content of SDBS, and the stability of the nano-particles is improved with the increase in the content of the surfactant. The reason for such a phenomenon is that the excessive anionic surfactants after balance between positive charges and anion charges are adsorbed on the surface, and the thickness of the double electrode layer, formed by the hinge of hydrophobic groups, is more than 10 nm[8]. The hydrophilic ion-head of SDBS inserts the aqueous phase and the nano-particles are charged again, and the negative charge of the double electrode layer can maintain the nano-particles dispersion stable for a long time.

3) When too much SDBS (higher than the content of adsorption saturation) is added, there is oversaturated adsorption on the surface of the nano-particles. The hinge of organics causes the decrease in the hydrophilicity of the nano-particles[5]. Therefore, too much SDBS will also lead to a reunion among the nano-particles. There must be an optimal content of surfactants. For the zinc ferrite nano-particle suspension of the ammonia-water solution in the present experiments, the optimal content of SDBS is 1.5%.

5 Conclusions

1) SDBS leads to the reunion among nano-particles first and then promotes the stability of nanofluid with the increase in content. The turning point is 0.05%. The optimal combination of contents of surfactants is 1.5% SDBS and 0.015% CTAB.

2) Ultrasonic vibration plays contrary roles with different contents of surfactants of ammonia-water nanofluids. The effects of the dispersion of nano-particles deteriorate after ultrasonic vibration with lower contents of SDBS, but are promoted with higher contents.

3) Illumination is applied to the nano-particles dispersion process and the nanofluid after illumination can be dispersed stably for a longer time without stratification.

4) The stability of the nanofluid is exacerbated first and then is improved, and is exacerbated again with the increase in the content of ionic surfactants. The existence of optimal surfactant content is proved by experimental results and theoretical analysis based on double electrode layer theory.

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铁酸锌-氨水纳米流体的制备及稳定性

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摘要:为了将纳米颗粒的强化传热吸收作用应用于氨水吸收制冷中,提出了在氨水溶液中添加铁酸锌纳米颗粒和复配阴/阳离子表面活性剂 SDBS 和 CTAB 的纳米流体的配制方法,并对其稳定性进行了实验研究. 研究了阴阳离子活性剂质量分数、复配比例及超声分散和光照对稳定性的影响,确定了铁酸锌-氨水纳米流体分散的最佳工艺为:SDBS 质量分数为 1.5%,CTAB 质量分数为 0.015%,超声时间为 30 min,光照时间 72 h 以上. 最后根据双电层原理分析了活性剂质量分数对悬浮液稳定性的影响,表明存在最佳活性剂质量分数,并与实验结果相符.

关键词:纳米流体;稳定性;表面活性剂;氨水

中图分类号:TB61[+1]