Preparation of Uniform Poly(glycidyl methacrylate) Porous Microspheres by Membrane Emulsification–Polymerization Technology

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ABSTRACT: Uniform poly(glycidyl methacrylate-divinylbenzene) (P(GMA-DVB)) and poly(glycidyl methacrylate-ethylene dimethacrylate) (P(GMA-EGDMA)) porous microspheres with several 10 μm were successfully prepared by membrane emulsification–polymerization technology. Conventional suspension polymerization method was first investigated by examining the effects of recipe components on the morphologies of P(GMA-DVB), including stabilizer, diluent, and crosslinker to select a optimum recipe. The membrane emulsification–polymerization process was developed to prepare uniform PGMA porous microspheres as the following: the oil phase composed of monomer, diluent and initiator was pressed through membrane pores into the aqueous phase to form uniform droplets, and subsequent suspension polymerization was carried out. GMA and 4-methyl-2-pentanol in the selected recipe were relatively hydrophilic, and therefore oil phase could wet the hydrophilic glass membrane and bring about polydispersed droplets. However, when isooctane was added as a component of diluents, the uniform droplets could be prepared by membrane emulsification method. In the membrane emulsification–polymerization, the coagulation between microspheres obviously decreased while yield of microspheres slightly increased. To extend the application of PGMA, as a trail, uniform P(GMA-EGDMA) porous microspheres were also successfully prepared by membrane emulsification–polymerization with a isooctane contained diluent, even though EGDMA was more hydrophilic than DVB. Therefore, recipe was found the important factor to prepare uniform PGMA porous microspheres using membrane emulsification–polymerization method. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 102: 5018–5027, 2006

Key words: glycidyl methacrylate; microsphere; membrane emulsification; polymerization; isooctane

INTRODUCTION

Reactive polymer microspheres with the diameter of several micrometers to 100 μm have a number of applications, especially in chromatography and bioreactor fields. In these cases, uniform size is usually preferred. For suspension polymerization method, the uniformity of microspheres depends on the uniformity of emulsion droplets before polymerization. Conventional process is particularly suitable for the production of larger polymer microsphere with the diameter ranging from 5 to 1000 μm.[1] Since the emulsion droplets are produced by shearing component phases with strong agitation, which bring about a very broad size distribution of droplets, so that obtained microspheres are polydispersed. So increasing interest is now devoted to the development of technologies to prepare polymer microspheres with narrow size distribution.

Membrane emulsification is such a new technology to prepare uniform emulsion droplets.[2] SPG membrane is a special glass membrane with uniform pore size distribution and hydrophilic pore wall composed of SiO_2-Al_2O_3. The fabricated process of SPG membrane was developed by Nakashima et al.[3] and the pore sizes from 0.1 to 18 μm is commercially available. Uniform oil droplets can be obtained by pressing oil phase through the membrane pores into aqueous phase with a stabilizer under a controlled pressure. Then, uniform microspheres can be prepared by subsequent suspension polymerization. More details of the schematic diagram of the apparatus and the membrane emulsification process were shown elsewhere.[4,5]

Yuyama et al. demonstrated that the monodispersity of the droplets is controlled by the wettability of oil phase to the thin layer of aqueous phase on the membrane surface.[6] For this reason, the polar or hydrophilic monomer cannot be used to prepare uniform droplets by hydrophilic membrane emulsification technology. In the previous studies, the preparation of the uniform emulsion droplets with hydrophilic or polar substance

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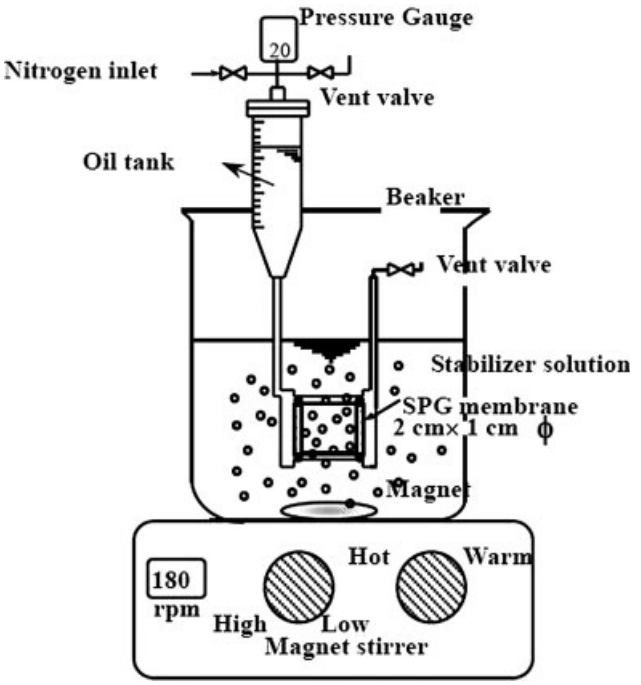

Figure 1 Schematic diagram of a miniature apparatus kit for membrane emulsification.

was carried out by a two-step emulsification technology.[7,8] First, a hydrophobic component of oil phase was used to prepare uniform seed droplets by membrane emulsification, and the relatively hydrophilic ones were prepared to be smaller secondary emulsion droplets by conventional homogenizer or sonification. Then, the two emulsions were mixed under mild agitation. The secondary emulsion would diffuse into the aqueous phase and be adsorbed by the hydrophobic seed droplets to form uniform swollen droplets. After swelling process, suspension polymerization of swollen droplets was carried out to obtain uniform microspheres containing the hydrophilic units. Uniform microspheres with high content of 2-hydroxyethyl methacrylate (HEMA) or methyl methacrylate (MMA) have been successfully prepared by this two-step emulsification technology. However, it is more desirable to obtain uniform droplets composed of polar monomer only by a single step.

Alkane is a useful additive in oil phase to affect interfacial tension between oil phase and aqueous phase, and then the wettability of the oil phase to the thin layer of the aqueous phase on the membrane surface. It was reported that the uniformity of the droplet sizes was significantly improved by adding hexadecane (HD) as an additive.[6] To synthesizing porous copolymer microspheres, there is a wide range of diluents to select. So it was assumed that a suitable diluent could also work as nonpolar additive to change interfacial tension between oil phase and aqueous phase, and uniform droplets containing polar/hydrophilic substances could be prepared by a single step membrane emulsification other than multistep methods.

Poly(glycidyl methacrylate) (PGMA) microspheres are very useful reactive polymer. Covered with many epoxy groups, PGMA is easily derived to multifunctional material and has potential applications in the protein separation and enzyme immobilization.[9–11] Suspension polymerization is an conventional method to prepare PGMA microsphere, with the major disadvantage of broad size distribution. Seeded swelling-polymerization method has been developed to overcome this problem.[12,13] In this method, seeds were prepared by emulsion polymerization or dispersion polymerization; then seeds were swollen by GMA and other components; finally suspension polymerization was carried out. However, this method was time-consuming and effective only in the preparation of microspheres with several micrometer diameters, while it was difficult to prepare uniform microspheres with diameter of 20–30 μm, which were commonly used in industrial-scale bioseparation by low-pressure chromatography.[14]

To obtain porous PGMA microspheres, alcohol such as lauryl alcohol or cyclohexanol was usually used as

TABLE I
Standard Recipe to Prepare P(GMA-DVB) Microsphere

	Recipe no.						
	R100	R101	R102	R103	R104	R105	R106
Oil phase							
GMA (g)	8.0	8.0	8.0	8.0	6.0	5.0	4.0
DVB (g)	2.0	2.0	2.0	2.0	4.0	5.0	6.0
4-Melthyl-2-pentanol (g)	–	6.0	10.0	6.0	6.0	6.0	6.0
Isooctane (g)	10.0	4.0	–	4.0	4.0	4.0	4.0
BPO (g)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Aqueous phase							
Gelatin (g)	–	0.4	–	–	–	–	–
PVA (g)	2.0	–	2.0	2.0	2.0	2.0	2.0
SDS (g)	0.07	0.07	0.07	0.07	0.07	0.07	0.07
$NaNO_2$ (g)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Deionized water (g)	200	200	200	200	200	200	200

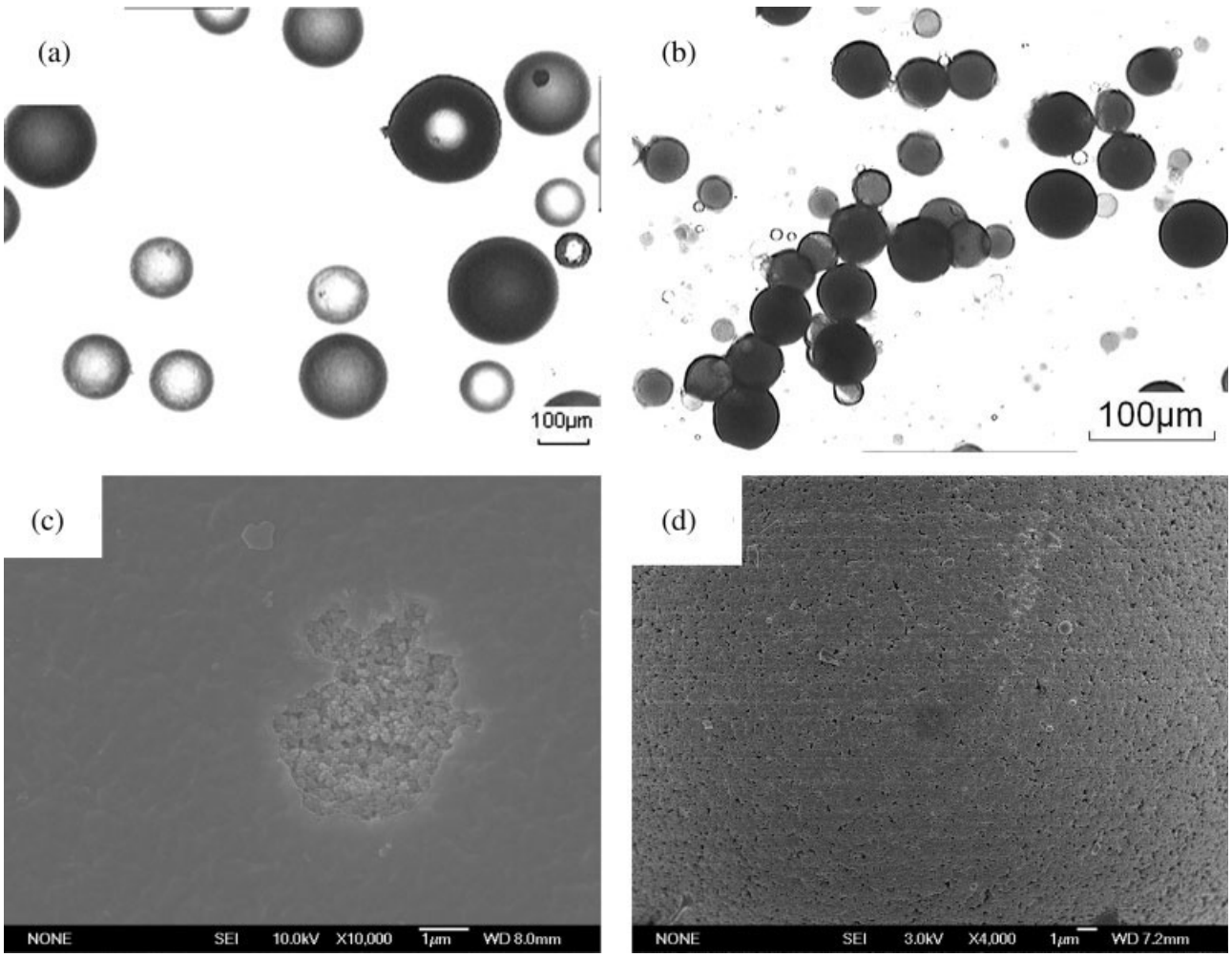

Figure 2 Typical optical micrograph (OM) and SEM photos of P(GMA-DVB) microspheres of R101 and R103. (a) OM image of R101; (b) OM image of R103; (c) surface SEM image of R101; (d) surface SEM image of R103.

the diluent.[15–17] Kuroda et al. studied 16 substances in the preparation of P(GMA-DVB) microsphere with high crosslinking degree (GMA/DVB = 1/3, wt/wt) and found 4-methyl-2-pentanol was the most efficient diluent for building up the highest porosity microspheres. In their research, the porous P(GMA-DVB) microspheres with larger specific surface area and pore volume could be prepared in the presence of an alcohol, while smooth skin layer was formed on the surface of the microspheres when a hydrocarbon was used as the diluent. Otherwise, when ester such as dioctyl phthalate or butyl stearate was used as the diluent, microsphere showed many cracks on the surface.[18]

In this study, a mixture of isooctane and 4-methly-2-pentanol was used as diluent to prepare porous P(GMA-DVB) microspheres. Interestingly, isooctane also worked as a hydrophobic additive and ensured the uniformity of the droplets in membrane emulsification technology, which was important for the following uniformity of porous P(GMA-DVB) microspheres. To optimize the recipe, the effects of the stabilizer, the diluent and crosslinker on the morphology of microspheres were investigated by the conventional suspension polymerization. Based on the above-mentioned results, membrane emulsification–polymerization technology was used to prepare P(GMA-DVB) microspheres and the uniform-sized microspheres with the diameter over 20 μm were obtained. Given the relative hydrophilicity of GMA and 4-methyl-2-pentanol were comparatively hydrophilic, it was speculated that isooctane was an essential component worked both as diluent and hydrophobic additive.

The effect of the membrane pore size on the uniformity of the emulsion droplets was also investigated. With the increase of the size of membrane pore, smaller droplets occurred besides desired uniform size. In addition, compared with the conventional suspension polymerization, the coagulation of microspheres decreased and the yield of microspheres slightly increased when the droplets were prepared by membrane emulsification.

The crosslinker, such as DVB or ethylene dimethacrylate (EGDMA), played an important roles in the applica-

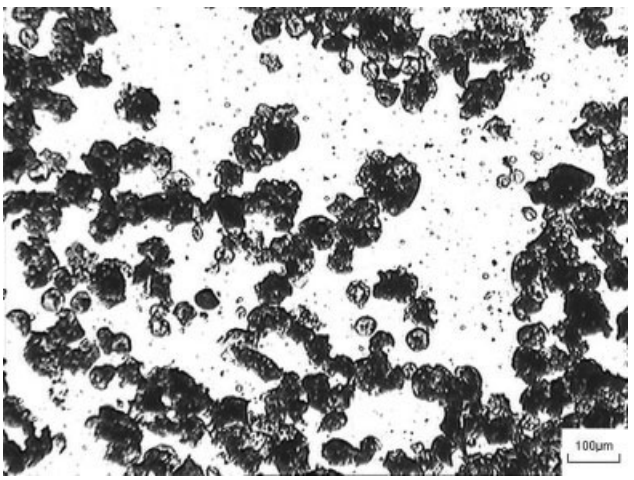

Figure 3 OM image of P(GMA-DVB) copolymer obtained when isooctane was alone used as diluent (R100).

tions of the PGMA porous microspheres.[19,20] Alternatively, EGDMA was more hydrophilic than DVB. To extend the application, the PGMA porous microspheres were also prepared with EGDMA as crosslinker to replace DVB. It was also found that when isooctane was employed, uniform P(GMA-EGDMA) porous microspheres could be prepared even though using EGDMA will increase hydrophilicity of oil phase.

EXPERIMENTAL

Materials

Glycidyl methacrylate (GMA, Fluka) and ethylene glycol dimethacrylate (EGDMA, Sigma-Aldrich) were distilled under reduced pressure. Divinylbenzene (DVB, 55 wt %, Sigma) was washed with 5 wt % aqueous sodium hydroxide solution and deionized water, and dried using anhydrous sodium sulfate. Sodium dodecyl sulfate (SDS, biochemical grade) was purchased from Merck. Benzoyl peroxide (BPO) with 25 wt % moisture content (reagent grade), sodium nitrite ($NaNO_2$, analytical grade), 4-methyl-2-pentanol (reagent grade), and isooctane (analytical grade) were purchased from Beijing Chemical Reagents Company and were used as received. Poly(vinyl alcohol) (PVA GH20, 87.7 mol % of hydrolyzation degree; viscosity is 43.7 mPa s) was provided by Nippon Synthetic Chemical Industry. Gelatin (photo grade) was provided by Anhui Changjiang Gelatin Factory.

In membrane emulsification technology, the membrane was hollow columniform microporous glass with size of 10 ϕ $\times$20 L mm and the average pore size was 1.4, 5.2, 7.0, and 9.5 μm. The apparatus of SPG membrane emulsification used to prepare PGMA microspheres was a miniature kit. Figure 1 shows a schematic diagram of this kit.[8]

TABLE II
Effects of DVB Content in Monomer on Pore Size and Specific Surface Area on P(GMA-DVB) Microsphere

	Recipe no.			
	R103	R104	R105	R106
Specific surface area (m^2/g)	29.97	61.88	168.91	312.72
Average pore size (nm)	36.59	25.80	22.56	13.79

Preparation of uniform PGMA microsphere

Optimization of recipe by conventional suspension polymerization

The standard recipe to prepare P(GMA-DVB) microsphere is shown in Table I. Sodium nitrite (0.05 wt %) was added into the aqueous solution to prevent the secondary nucleation in the aqueous phase because hydrophilic GMA would diffuse into the aqueous phase. The polymerization was carried out in a flask with a semicircular anchor-type blade (300 rpm), a N_2 inlet, and a condenser at 80°C for 16 h. The obtained

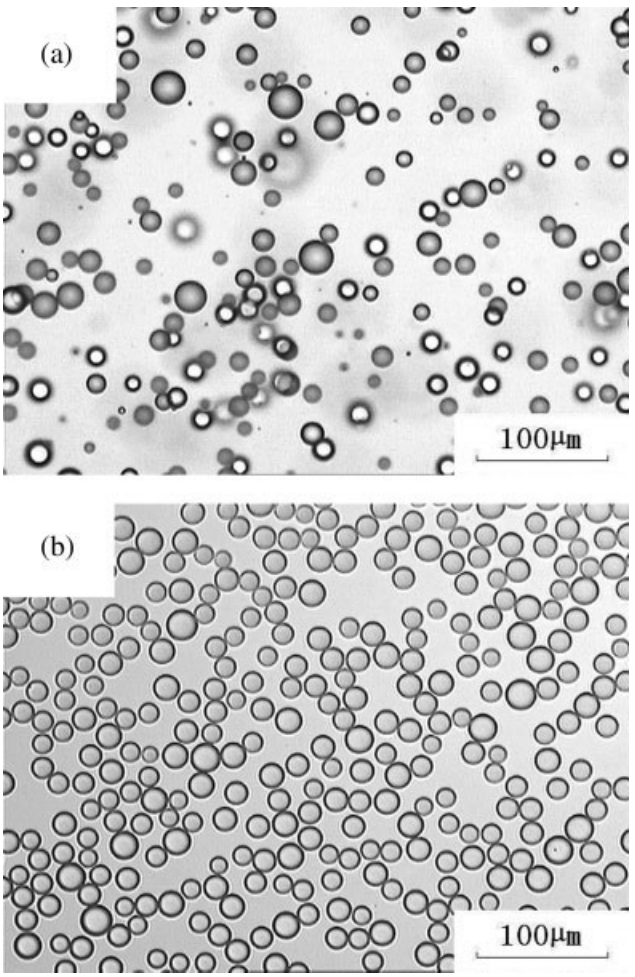

Figure 4 Optical micrograph (OM) of droplets prepared by membrane emulsification (membrane pore size = 5.2 μm). (a) $R_{ME}102$, average size = 13.9 μm, CV = 26.9%; (b) $R_{ME}103$, average size = 21.0 μm, CV = 12.0%.

TABLE III
Effects of DVB Content in Monomer on Size Distributions of Droplet and P(GMA-DVB) Microsphere (Membrane Pore Size = 5.2 μm)

	Recipe no.			
	$R_{ME}103$	$R_{ME}104$	$R_{ME}105$	$R_{ME}106$
DVB content in oil phase (wt %)	10	20	25	30
Critical pressure (kPa)	2.1	2.2	2.3	2.8
Emulsion droplet average size (μm)	21.2	21.2	22.9	23.4
CV% (droplets)	12.0	11.7	11.5	11.5
Microsphere average size (μm)	20.8	20.6	21.8	22.0
CV% (microspheres)	13.4	13.1	12.3	12.1

microspheres were washed with water and extracted with acetone in a Soxhlet apparatus to remove diluent and unreacted monomer. The microspheres were finally dried in vacuum at 40°C for 24 h.

Preparation of PGMA microspheres with membrane emulsification–polymerization

The recipe of R102–106 was used to prepare uniform P(GMA-DVB) porous microspheres by membrane emulsification–polymerization, named $R_{ME}102$–106 correspondingly. As shown in Figure 1, the oil phase was pressed by nitrogen gas through the pores of SPG membrane into the aqueous phase under a controlled pressure, which is slightly above the critical pressure, and the aqueous phase was stirred by a magnetic stirrer with a mild speed (180 rpm). The critical pressure was defined as a pressure where the oil phase began to permeate through the pores of the membrane into the aqueous phase. The obtained emulsion was transferred to a suspension polymerization reactor after the emulsification. Except the stirring rate was 160 rpm instead of 300 rpm, the suspension polymerization process was the same as the conventional process.

Characterization of droplets and microspheres

Emulsion droplets and polymer microspheres were observed with an XSZ-H_3 optical microscope (Coic, China). A JSM-6700F (JEOL) of scanning electron microscopy (SEM) was used to observe the surface feature of polymer microsphere. The specific surface area and pore properties were analyzed by BET nitrogen adsorption method with Quantasorb apparatus (Quantachrome Corp., USA). Diameters of 500 droplets or microspheres were counted to calculate average diameters and size distribution. The size distribution was characterized by a CV value, which was defined as follows:

$$\mathrm{CV} = \frac{\left[\sum_{i=1}^{n} \frac{(d_i - d)^2}{N}\right]^{1/2}}{d}$$

where d_i is the diameter of the ith particle, d is the average diameter, and N is the total number of particles counted. The yield of microspheres was determined gravimetrically. The polymer was precipitated by methyl alcohol from the serum, separated by centrifugation, dried in a vacuum, and weighed.

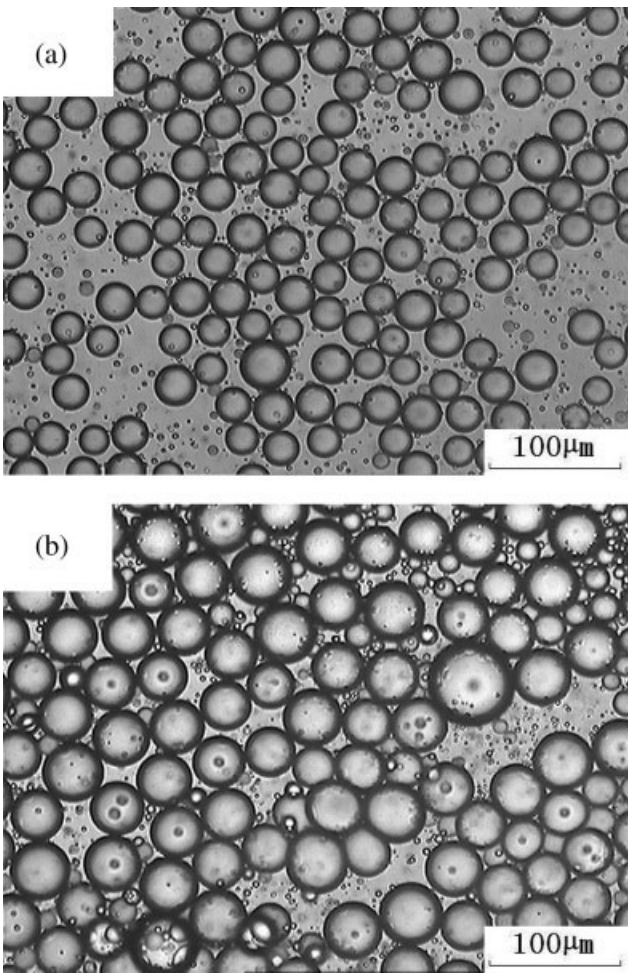

Figure 5 Optical micrograph (OM) of droplets prepared by using membrane with larger pore. Membrane pore size was (a) 7.0 μm; (b) 9.5 μm.

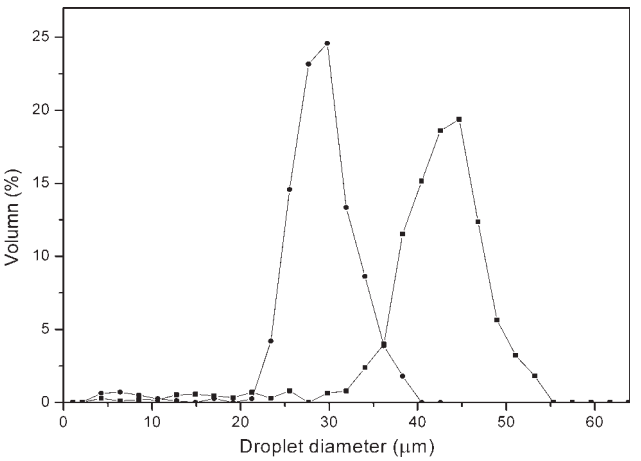

Figure 6 Size distribution of droplets prepared by membrane emulsification. Membrane pore size was (●) 7.0 μm; (■) 9.0 μm.

RESULTS AND DISCUSSION

Optimization of recipe to prepare porous P(GMA-DVB) microsphere

Effect of stabilizer on morphology of P(GMA-DVB) microspheres

The break-up and coalescence of the droplets occur continuously under agitation until a stage of the polymerization where the partially polymerized microspheres are sticky; at this point, satellite droplets (formed from droplet break-up) will attach to the surface of the polymer microspheres, which will eventually lead to the coagulation of obtained microspheres.[1] So, the stabilizer such as gelatin or PVA was usually used to prevent the coagulation of microsphere.[21,22] However, it was found that the stabilizer also affected the surface morphology. As shown in Figure 2(a), when gelatin was used as a stabilizer in the aqueous phase (R101), the dispersion of microspheres was stable without microsphere coagulation. For the defected microspheres [Fig. 2(c)], it was found that a smooth skin layer covered the inside porous structure. When PVA GH20 was used as the stabilizer (R103), the surface of microspheres as well as the interior was porous [Fig. 2(d)]. However, the dispersion of microspheres was unstable and partial coagulation also observed [Fig. 2(b)]. It could be hypothesized that gelatin preferred to adsorb on the surface of the polymer than diluent agent, resulting in lower interfacial tension between the polymer and the aqueous phase, and leading to a smooth surface and porous interior of microsphere with polymer localizing on the surface and engulfing the diluent agent inside. On the other hand, when PVA GH20 was used as the stabilizer, the interfacial tension between the polymer and the aqueous phase was close to that between diluent agent and the aqueous phase, so that both diluent agent and polymer contacted the aqueous phase, which led to porous surface as well as porous interior. At the same time, this nonhomogeneous property of the surface resulted in poor dispersion of microspheres.[23] Therefore, PVA GH20 was more suitable stabilizer than gelatin for the preparation of porous microsphere; however, the problem of coagulation could not be solved. It was found in the following session that coagulation of microspheres could be decreased when droplets were prepared by membrane emulsification–polymerization.

Effect of diluent on the morphology of P(GMA-DVB) microspheres

Isooctane was added into oil phase functioning as both a nonpolar additive and a component of diluent. Isooctane was a precipitation agent of P(GMA-DVB) copolymer, which led to rapid phase separation during the process of polymerization and left porous structure in the microsphere. To obtain lager pore in the microsphere, more isooctane was required in oil phase. However, when too much isooctane was added into the oil phase, the phase-separation between polymer and isooctane occurred too quickly, resulting in the formation of irregularly shaped particles as shown in Figure 3. Therefore, a mixture of isooctane and 4-methyl-2-pentanol was used as diluent to prepare porous PGMA microspheres. The content of isooctane in diluent was optimized to find a suitable recipe. It was found that the regular porous microspheres could be obtained as isooctane content in the mixture diluent was 40 wt %.

TABLE IV
Effects of Pore Sizes on Droplet Size and Size Distribution

Membrane pore size (μm)	Critical pressure (kPa)	Droplet average size (μm)	CV (%)
1.4	14.8	4.89	11.6
5.2	2.1	18.52	12.0
7.0[a]	1.2	28.41	11.3
9.5[b]	0.6	41.49	10.9

[a] Droplet of size under 20 μm was not counted.
[b] Droplet of size under 27 μm was not counted.

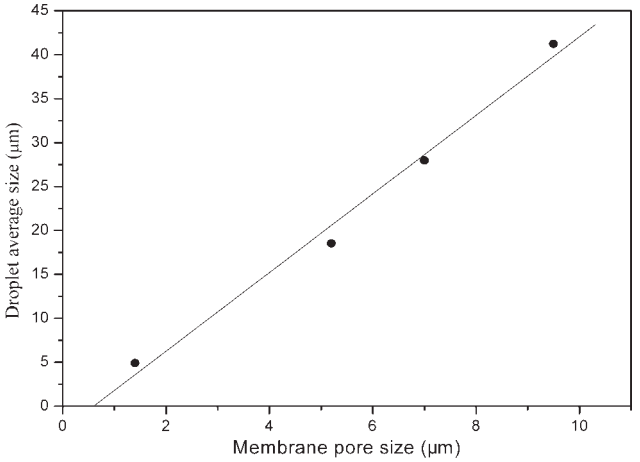

Figure 7 Relation of droplets average size with membrane pore size.

Effects of DVB content on the average pore size and specific surface area of microspheres

The trade-off between phase separation and crosslinking of polymer governed the final phase-separation structure. The rigidity and the porosity of microspheres were affected by crosslinking degree of polymer. In the absence of a crosslinker, complete phase separation occurred with a hollow structure left. As the amount of crosslinker increased, polymer precipitated in diluent agent more quickly, resulting in more pore number and higher specific surface area.[23] To obtain P(GMA-DVB) microspheres of various pore sizes and special surface areas, DVB contents were changed from 20 to 60 wt % in monomer, i.e., R103–106. As expected, with the increase of the crosslinking degree, the special surface area of P(GMA-DVB) microsphere increased and the average pore size decreased, which was shown in Table II.

Preparation of uniform porous P(GMA-DVB) microspheres

Effect of components in oil phase on size distribution of droplets

As described earlier, the suitable stabilizer and diluent were determined to prepare porous microspheres. Then, the size distribution of the microspheres was improved by the membrane emulsification–polymerization technology. In $R_{ME}102$, 4-methyl-2-pentanol was alone used as the diluent. At the beginning stage of membrane emulsification (within 5 min), the average diameter of droplets was around 16 μm. However, as the membrane emulsification processed, smaller and larger droplets were continuously produced and finally droplets size distribution became broader, which was shown in Figure 4(a). Because of the relatively higher hydrophilicity of 4-methyl-5-pentanol and GMA, the hydrophilic pore wall of SPG membrane was wetted by oil phase, so that a jet like stream was generated, which led to a broad size distribution of droplets. However, in $R_{ME}103$ (i.e., 4-methyl-5-pentanol/isooctane = 3/2 wt), uniform droplets were obtained and droplets size distribution coefficient (CV value) was 12.0%, which was shown in Figure 4(b). In the case of $R_{ME}102$, the critical pressure of oil phase permeating through the membrane pores into aqueous phase was 1.4 kPa while the critical pressure in the case of $R_{ME}103$ was 2.1 kPa, which showed that the addition of isooctane into oil phase resulted in the increase of interfacial tension between oil phase and aqueous phase, which controlled the uniformity of emulsion droplets.

The crosslinker DVB was a strongly hydrophobic substance, so that DVB also worked as a additive in membrane emulsification process to affect uniformity of droplets. As shown in Table III, with increase of DVB content in monomer, CV value decreased slightly, indicating a narrow size distribution. Because the DVB

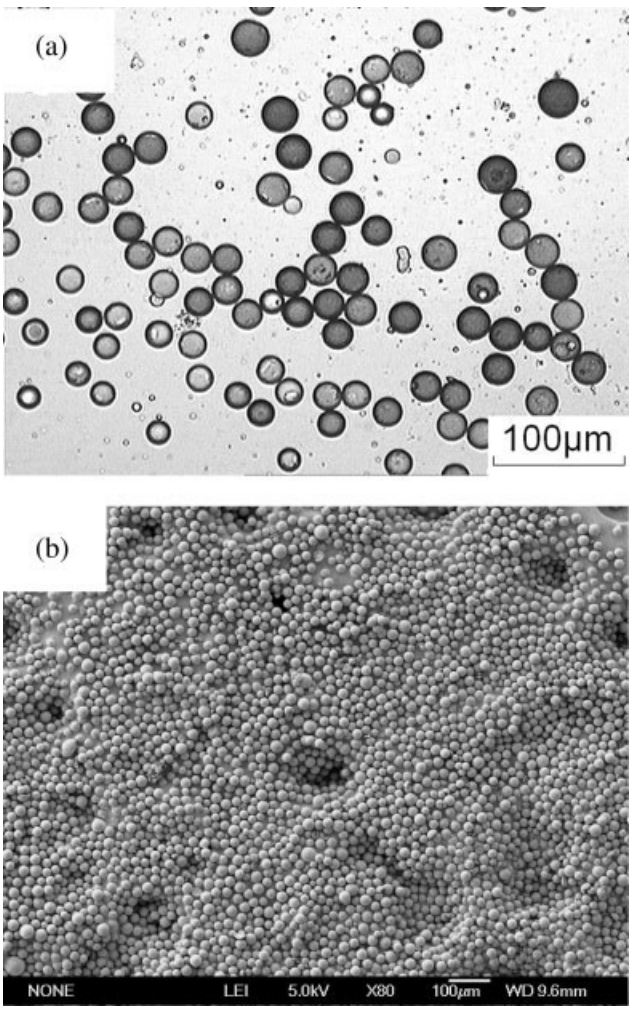

Figure 8 Photos of $R_{ME}103$. (a) Optical micrograph (OM) image of microspheres in serum after polymerization; (b) SEM image of microspheres after washed and dried.

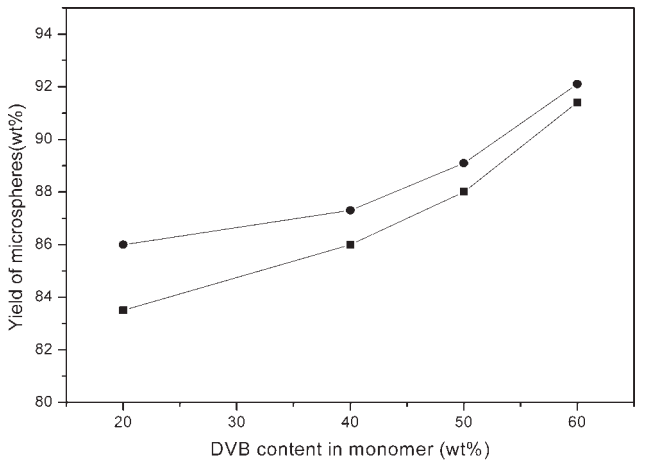

Figure 9 Yield of microspheres prepared by (●) SPG membrane emulsification and (■)conventional suspension polymerization.

content in oil phase was low, its effect was not apparent. After isooctane was added, the change of DVB content in monomer only had slight effect on the uniformity of emulsion droplets.

Effect of membrane pore size on size distribution of droplets

The recipe of $R_{ME}103$ was used to investigate the effect of membrane pore size on the size distribution of droplets. Glass membranes with 1.42, 5.2, 7.0, and 9.5 μm in pore size were employed and around 5–40 μm droplets were obtained depending on the pore size. It was found that smaller droplets were formed besides desired ones when the membrane pore size surpass 7.0 μm, as shown in Figures 5 and 6. If the smaller droplets were neglected, and only larger droplets were counted based on Figure 6, the average size of droplets almost linearly increased with the pore size of the membrane and the slope was 4.5 (Table IV and Fig. 7). Omi et al. found that with hydrophobic styrene monomer there was a linear relationship between droplets size and pore size and the slope was around 6.6.[24,25] The difference was possibly a result of the difference in interfacial tension between aqueous phase and oil phase. The reason for the formation of small droplet in the case of large pore size (7.0, 9.5 μm) was unknown, probably because that the critical pressure was very low when the pore size was large, a slight variation of pressure would increased the permeation rate of oil phase apparently, resulting in formation of undesired smaller droplets. Omi et al. reported that there existed a maximum pressure, above which the size distribution of droplets became broader in the case of styrene,[24] and also reported that the maximum pressure decreased with increase of pore size of the membrane. In this study, the hydrophilicity of GMA was much higher than that of styrene; the maximum pressure would be very low and close to the critical pressure when the pore size was large. Therefore, a slight variation of pressure would exceed the maximum pressure.

Dispersion stability of microspheres prepared by membrane emulsification–polymerization

Comparing Figures 8(a) and 2(b), it was evident that the coagulation of microspheres decreased obviously when monomer droplet was prepared by membrane emulsification. By conventional suspension polymerization, microspheres were unstable because of the broad size distribution and intense agitation. The droplets were in a dynamic equilibrium between coalescence and redispersion.[26] In membrane emulsification technology, mild agitation (usually less than 200 rpm) decreased the frequency of collide of droplets and redispersion hardly takes place, so that droplets in emulsion was quite stable. Therefore, the coagulation of microspheres decreased

Yield of microspheres in membrane emulsification–polymerization technology

As shown in Figure 9, the yield of microspheres by membrane emulsification–polymerization was slightly higher than that of conventional suspension polymer-

TABLE V
Recipe and Results to Prepare P(GMA-EGDMA) Microsphere (Membrane Pore Size = 5.2 μm)

	Recipe no.			
	$R_{ME}201$	$R_{ME}202$	$R_{ME}203$	$R_{ME}204$
GMA (g)	6	5	4	2
EGDMA (g)	4	5	6	8
Isooctane (g)	3	3	3	3
4-Methyl-2-pentanol (g)	6	6	6	6
Droplet average size (μm)	26.1	26.7	27.2	28.4
CV% (droplets)	11.9	12.5	13.4	13.7
Polymer microspheres average size (μm)	25.6	25.9	26.1	27.1
CV% (microspheres)	13.3	13.6	14.2	14.9
Yield of microspheres (wt %)	85.2	86.1	86.5	86.5

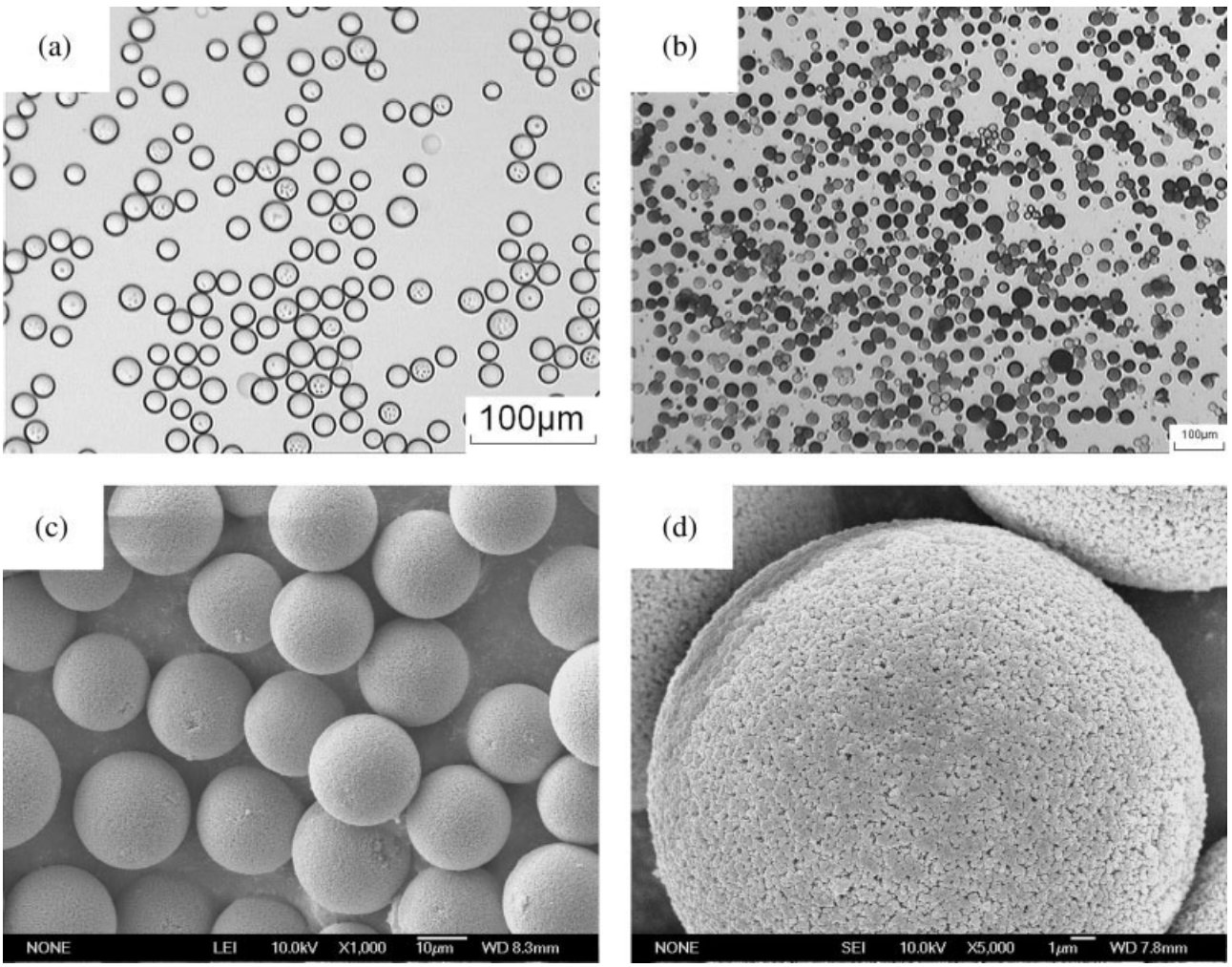

Figure 10 Typical optical micrograph (OM) and SEM photo of P(GMA-EGDMA) microsphere ($R_{ME}201$). Average pore size = 18.7 nm. Specific surface area = 195.7 m^2/g. (a) OM image of droplets in emulsion; (b) OM image of microspheres in serum; (c) SEM of total image; (d) SEM of surface image.

ization. As DVB content in oil phase increased, the yields of microspheres of the two cases were close to each other. In conventional process, the tiny droplets formed by intense agitation was unstable, and hydrophilic monomer diffused readily into the aqueous phase to promote the formation of the secondary nuclei, which could not be precipitated by methyl alcohol from the serum, and as a result, the measured yield of microspheres became lower. Contrarily, the droplets prepared by membrane emulsification were stable so that the secondary nucleation decreased. With increase of hydrophobic monomer content, the secondary nuclei decreased, so that the yield of microspheres in the two cases became close.

Preparation of uniform P(GMA-EGDMA) porous microspheres

In presence of the mixture of isooctane and 4-methyl-2-pentanol, SPG membrane with 5.2 μm pore size was used to prepare more hydrophilic P(GMA-EGDMA) particles. The recipe and the results are shown in Table V. The photos of typical droplets and P(GMA-EGDMA) microspheres ($R_{ME}201$) are shown in Figure 10. The critical pressures to prepare uniform droplets were 2.2–2.5 kPa. Although EGDMA was a more hydrophilic crosslinking agent than DVB, uniform P(GMA-EGDMA) microsphere was also able to be prepared by membrane emulsification–polymerization when isooctane was added, which illustrating isooctane was an efficient additive in preparing uniform PGMA microsphere by membrane emulsification.

CONCLUSIONS

It was found that PVA GH20 was a more suitable stabilizer than gelatin to prepare porous P(GMA-DVB) microsphere. When isooctane was added into oil phase, the oil phase with hydrophilic substances can be prepared to be uniform droplets directly by

membrane emulsification. Isooctane works both as the diluent and as the hydrophobic additive. With membrane emulsification–polymerization, porous P(GMA-DVB) microsphere and P(GMA-EGDMA) microsphere with the size over 20 μm were prepared. Furthermore, it was found that microspheres coagulation decreased and the yield of microspheres increased using membrane emulsification technology. In conclusion, with suitable diluent composition, membrane emulsification–polymerization technology was proved to be a promising method to prepare uniform PGMA porous microsphere.

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