

Research Article

Studies on Development of Polymeric Materials Using Gamma Irradiation for Contact and Intraocular Lenses

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For the development of materials for contact lenses and intraocular lenses, the selection criteria is based on the (i) capacity to absorb and retain water, (ii) hydrophilicity and hydrophobicity, (iii) refractive index and (iv) hardness besides the other essential properties. Various monomers are being studied to develop suitable materials for such applications. Selection of suitable monomers that can be converted into optical materials of desired characteristics is the most essential step. In the present paper, an attempt has been made to develop suitable optical polymers based on 2-hydroxy ethyl methacrylate (HEMA), N-vinyl pyrrolidone (NVP), methyl methacrylate (MMA), methacrylic acid (MAA), and styrene. Compositions were prepared in such a way that polymers of varying hydrophilicity or hydrophobicity could be obtained keeping HEMA as the base (main) monomer. For polymerization, gamma irradiation (Co-60 as a source) was used. The results of the study showed that: (i) an increase in NVP and MAA content brought in an increase in hydrophilicity of polymerized HEMA (pHEMA), while the addition of styrene and MMA decreased hydrophilicity of polymerized HEMA (pHEMA), (ii) polymers for contact lenses with water retention capacity as high as >50 wt.% and as low as <10 wt% with varying content of suitable comonomers can be designed, (iii) polymeric materials for contact lenses can be made by using radiation processing such as Co-60 and (iv) a dose of 40 kGy was found to be ideal for purpose.

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1. Introduction

Optical plastics have already become popular and the most preferred materials replacing conventional inorganic materials (mostly glass) for different applications. The use of optical plastics for ophthalmic applications, like spectacle lenses, contact lenses, intraocular lenses, and so forth, has been the subject of interest for material scientists over the world [1, 2]. During the past two decades, several types of polymers for optical applications have been tried and as a result, a number of products have been successfully launched in the market [3–5]. However, this does not mean that the search for a suitable polymeric material for a given application is over. In fact, the demand for newer and affordable materials has increased more than ever before. This is true, more so for the developing world where the number of patients with ophthalmic defects have been increasing with a higher rate

than their capacity to afford optical plastics. The technologies for the manufacture of optical plastics exists mostly with a select few manufacturers in the developed countries [6, 7]. Moreover, the base materials for optical plastics is also a cause of concern, since they are either costly or are not available locally. Hence, there is a need for development of technologies using locally available or easily available raw materials for making optical plastics [8, 9].

The development of the desired polymer materials for optical applications is done based on the design parameters and criteria for selection as per the desired application. The properties such as refractive index, transmittance, Abbe number, and physico-mechanical properties are essential [10, 11]. A list of selected monomers is already available based on the research conducted so far [12, 13]. Even though the candidate monomers are many, only a few have been found to be commercially viable. For spectacle lenses, the

TABLE 1: Various compositions of HEMA: Comonomer.

| HEMA(%) | 100 | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 0 |
|----------------|-----|----|----|----|----|----|----|----|----|----|-----|
| Comonomer* (%) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |

*Comonomer: MMA or MAA or Styrene or NVP

market leadership lies mainly with a couple of monomers [14]. Similarly, for contact lenses and intraocular lenses, only five monomers have been used commercially [15]. The need for new materials thus remains a top priority even today.

The designing of optical plastics involves three approaches, that is, (i) developing a new chemistry with molecular bonds of unique optical properties as well as physico-mechanical behavior [16, 17], (ii) trying combinations of several homopolymers or copolymers with synergistic properties [18, 19], and (iii) combining inorganics with organics to achieve properties derived from the complementary effects of two different (organic and inorganic) base materials [20, 21]. Each of these approaches has resulted in unexpected success with the advent of newer materials, besides providing various leads for researchers to pursue further for improved products.

The manufacture of optical plastics is mostly by the process of thermal polymerization [16]. Recently, there have been studies to show that radiation processing leads to polymers of desired properties with greater efficiency [17]. Whether the use of radiation processing to develop a series of candidate polymers with varying properties, especially related to water absorption and water retention would be a practical approach [22], has been studied in the present work. The different monomers have been polymerized using gamma radiation and studied for their capacity to absorb and retain water.

For the IOL lenses of the foldable type, optical plastics are supposed to be hydrophobic in nature with no water absorption. On the other hand, IOLs of the rigid type require materials with controlled capacity to absorb water. Similarly, for contact lenses, materials of varying water absorption capacity are needed.

2. Materials

The monomers, that is, N-vinyl pyrrolidone (NVP) of purity 99.0%, methyl methacrylate (MMA) of purity 99.0%, and 2-hydroxyethyl methacrylate (HEMA) of purity 97.0% were procured from ACROS Organics, NJ, USA; while methacrylic acid (MAA) of purity 99.0%, from CDH, Delhi, India, and styrene of purity of 99.0% from OttoKemi, Mumbai, India, were procured and used as such without any purification. Distilled water was used for the studies.

3. Methods

3.1. Sample Preparation. The mixtures of monomers were prepared by accurately weighing the quantities in varying ratios. It may be noted that HEMA has been taken as the base monomer and the quantities of the comonomers were varied.

3.2. Polymerization. Polymerization was carried out by gamma radiation technique using Co-60 as the radioactive source. The monomers were taken in glass vials of 18 mm diameter and exposed to gamma radiation for a total dose of 40 kGy. After polymerization, the vials were broken and the polymers in the form of discs were obtained. Polymers obtained at a dose of 40 kGy and above were found to be completely hard, transparent, and clear, hence suitable for further studies. Dose of less than 40 kGy leads to incomplete polymerization while a dose of greater than 40 kGy leads to the formation of yellow colored polymers.

Polymerization was carried out for the individual monomers as such, as well as in combination with various comonomers (as listed in Table 1). Studies have been carried out using comonomer involving hydrophilic monomer like NVP and MAA and hydrophobic monomers like Styrene and MMA.

(a) *Water Absorption.* Amount of water absorbed [23] by the polymers was determined by immersing the polymerized samples in water for a period of 50 hours. The weight of the samples was measured after regular intervals of 5 hours. Water absorption (%) was determined as follows:

$$\text{Water absorption (\%)} = \frac{(\text{Final wt.} - \text{Initial wt.}) \times 100}{\text{Final wt.}} \quad (1)$$

(b) *Water Desorption.* Desorption of absorbed water by the polymers was determined by placing the water-absorbed polymer in a petridish, in a hot air oven maintained at $100 \pm 2^\circ\text{C}$ for a period of 50 hours. The water lost by the polymer was measured at regular intervals of 5 hours. The desorption studies were also carried out by keeping the polymers at room temperature for an extended period.

(c) *Shore-D Hardness.* Shore-D Hardness is a measure of the resistance of a material to the penetration of a needle under a defined spring force. It was measured with a Shore-D durometer as per ASTM D 2240–2005 [24].

(d) *Refractive Index.* The refractive index of the polymers was determined as per ASTM D542,1990 [25].

(e) *Transmittance.* Transmittance was measured on a UV-Visible spectrophotometer (Shimadzu 1700) in the UV-Visible range of 200–800 nm.

4. Results and Discussions

4.1. Polymerization of HEMA. The results of water absorption capacity of HEMA polymerized by gamma irradiation at a dose of 40 kGy are presented in Table 2. From the results, it is evident that HEMA gets polymerized in the solution

TABLE 2: Properties of HEMA polymerized in the presence of water.

| Composition HEMA: Water | Shore-D hardness | Transmittance (%) | Refractive index | Appearance |
|-------------------------|------------------|-------------------|------------------|------------------------------|
| 100 : 0 | 80 | 90 | 1.453 | Transparent, clear, and hard |
| 90 : 10 | 80 | 90 | 1.439 | Transparent, clear, and hard |
| 80 : 20 | 80 | 90 | 1.423 | Transparent, clear, and hard |
| 70 : 30 | 80 | 90 | 1.417 | Transparent, clear, and hard |
| 60 : 40 | 70 | 90 | 1.383 | Transparent, clear, and hard |
| 50 : 50 | 60 | 0 | 1.383 | Transparent, clear, and hard |
| 40 : 60 | 60 | 0 | Not measurable | Opaque and hard |
| 30 : 70 | 60 | 0 | Not measurable | Opaque and hard |
| 20 : 80 | 50 | 0 | Not measurable | Opaque and hard |
| 10 : 90 | 50 | 0 | Not measurable | Opaque and hard |

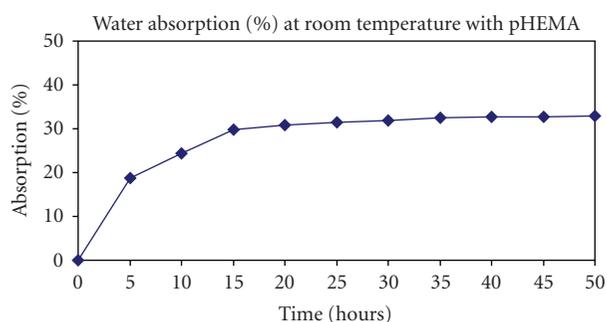


FIGURE 1: pHEMA shows water absorption of ~40 wt.% and remains transparent throughout.

form in water at all concentrations starting from 10 wt.% to 90 wt.% of water. The following notable observations were made: (i) the polymer is hard and transparent upto compositions with less than 50 wt.% of water. Beyond 50 wt.% of water content, the material turns opaque and remains hard; (ii) the polymer retains the water added to the monomer upto an extent of 40 wt.% (for compositions with more than 40 wt.% of water, the excess of water is released from the polymer); (iii) in the case of compositions containing 90 wt.% of water and 10 wt.% of HEMA, more than 40 wt.% of water was found to get released from the polymer (a soft solid).

Based on the above observations, it is understood that the water absorption capacity of polymerized HEMA (pHEMA) is 40% and any excess water present during polymerization would remain unused. This is as expected. However, the material turning opaque in cases where the percentage by wt. of water was more than 40 is something unusual. The results of the studies involving the polymerization of HEMA as such (Figure 1) show the following properties:

- (i) pHEMA, when immersed in water absorbs a maximum (approximately 40% by wt.) of water and remains transparent;
- (ii) material remains transparent throughout the absorption studies contrary to the opaque material obtained in the case when polymerization was conducted in the presence of excess amount (>50 wt.%) of water.

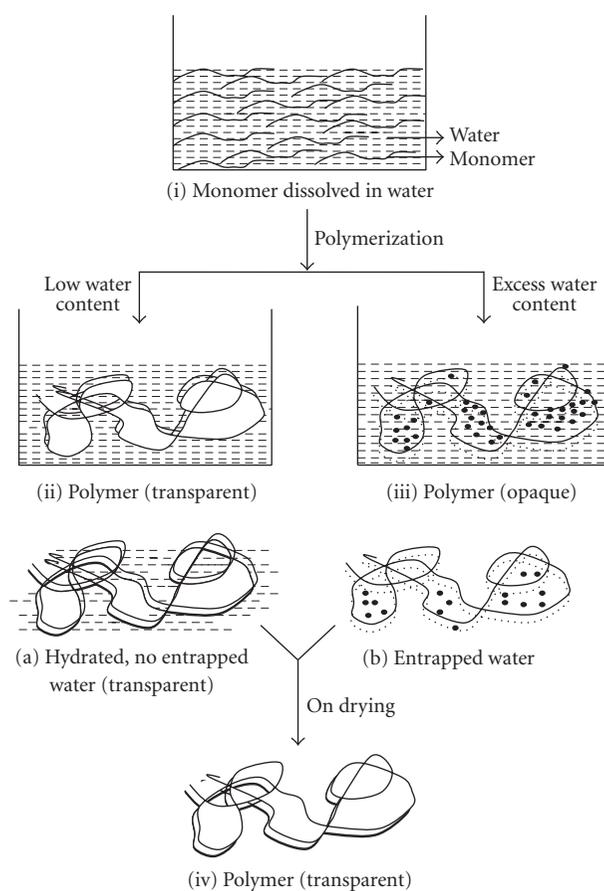


FIGURE 2: Polymerization of HEMA and mixtures of HEMA with other monomers in the presence of water (i) solution of monomer or monomer mixture in water, (ii) hydrated polymer without entrapped water remains transparent, (iii) hydrated polymer with entrapped water appears opaque, and (iv) dehydrated polymer from both the hydrated, transparent and opaque polymers.

This demonstrates that HEMA when polymerized in the presence of water is able to retain more amounts of water than the case where the polymerization is carried out in the absence of water. This behavior can be explained on the basis of the process of polymerization in water. While the monomers start interacting with each other by the

TABLE 3: Properties of polymers obtained with HEMA : MMA by varying ratios.

| Composition HEMA : MMA | Shore-D hardness | Transmittance (%) | Refractive index | Appearance |
|------------------------|------------------|-------------------|------------------|------------------------------|
| 100 : 0 | 80 | 90 | 1.453 | Transparent, clear, and hard |
| 90 : 10 | 80 | 90 | 1.446 | Transparent, clear, and hard |
| 80 : 20 | 80 | 90 | 1.442 | Transparent, clear, and hard |
| 70 : 30 | 80 | 90 | 1.439 | Transparent, clear, and hard |
| 60 : 40 | 80 | 90 | 1.435 | Transparent, clear, and hard |
| 50 : 50 | 80 | 90 | 1.432 | Transparent, clear, and hard |
| 40 : 60 | 80 | 90 | 1.428 | Transparent, clear, and hard |
| 30 : 70 | 80 | 90 | 1.423 | Transparent, clear, and hard |
| 20 : 80 | 80 | 90 | 1.419 | Transparent, clear, and hard |
| 10 : 90 | 80 | 90 | 1.415 | Transparent, clear, and hard |
| 0 : 100 | 80 | 90 | 1.412 | Transparent, clear, and hard |

mechanism of free radical polymerization, the solvation of the monomer is affected. As a result, the water molecules detach from the monomer everytime the polymerization proceeds in the right direction. In this process, however, some amount of water remains entrapped within the polymer molecule. It is due to this reason that the polymer appears opaque. On removal of both types of water, that is, associated as well as entrapped, the polymer turns transparent. When the dehydrated polymer is reimmersed in water, it does not turn opaque which confirms the proposed reason for obtaining an opaque material when polymerization is done in the presence of water, as depicted in Figure 2.

- (1) Monomer dissolved in water remains as a clear solution where each monomer chain is solvated.
- (2) With polymerization, monomer-monomer interactions occur in place of monomer-water interaction.
- (3) As long as the amount of water is within the range of the maximum possible amount for hydration, the polymer remains transparent with the hydrophilic part hydrated completely. The excess water maybe entrapped causing it to be opaque.

4.2. Effect of Different Monomers on Water Absorption of HEMA. The results of the effect of different monomers on water absorption and water desorption at room temperature and at 100°C, on HEMA are presented in Figure 3–6. The properties of the various compositions obtained on polymerization are described in the following sections and in Tables 3–6.

4.3. MMA and HEMA. The results of the effect of methyl methacrylate on water absorption and water desorption at room temperature and at 100°C on HEMA are shown in Figure 3. The properties of the various compositions of HEMA : MMA obtained on polymerization are presented in Table 3. The following observations were noted.

- (1) Water absorption capacity of pHEMA is reduced from 32.82% to 4.42% with an increase in the concentration of MMA. Initial resistance to the uptake of water upto 30 hours indicates hydrophobic nature of MMA.

- (2) As the amount of MMA increases, refractive index of the composition decreases due to low molar refraction of MMA.
- (3) With varying ratios, transparency and hardness of polymers do not change due to good compatibility of MMA with HEMA
- (4) On absorption of water, all the samples retain their transparency.
- (5) The water that is absorbed is completely lost on dehydration.

From the fact that the absorption of water by the copolymer is reversible and leads to complete transparency, it can be said that the absorption takes place due to the hydrophilic nature of the copolymer without any entrapment of water.

4.4. MAA and HEMA. The results of the effect of methacrylic acid on water absorption and water desorption at room temperature and at 100°C, on HEMA are shown in Figure 4. The properties of the various compositions of HEMA : MAA obtained on polymerization are presented in Table 4. The following observations were noted.

- (1) Water absorption capacity of pHEMA decreases from 32.82% to 28.02% with increase in the amount of MAA. This indicates lower hydrophilicity of MAA as compared to HEMA.
- (2) As the ratio of MAA increases, refractive index of the composition decreases due to low molar refraction of MAA.
- (3) Copolymerization of HEMA with MAA leads to transparent and hard polymers for ratios of HEMA : MAA upto 60% by wt. while ratios beyond 60 wt.% of MAA leads to opacity of polymer.
- (4) The copolymer remains transparent and the water is attached with the hydrophilic part of the copolymer.
- (5) The amount of water that is absorbed is completely lost on dehydration.

4.5. Styrene and HEMA. The results of the effect of Styrene on water absorption and water desorption at room temperature and at 100°C, on HEMA are shown in Figure 5. The properties of the various compositions of HEMA : Styrene obtained on polymerization are presented in Table 5. The results of copolymerization of styrene and HEMA apparently show that the following observation holds true.

- (1) Addition of styrene to HEMA brings reduction in the water absorption capacity of HEMA from 32.82% to 0.08%. This indicates the hydrophobic nature of styrene.
- (2) As the ratio of styrene increases, refractive index of the composition increases due to a high molar refraction of the phenyl ring present in styrene.
- (3) Copolymerization of HEMA with styrene leads to hard and transparent polymers for ratios of HEMA : Styrene upto 60 wt.% while ratios beyond 60 wt.% of styrene leads to opacity.
- (4) Absorption of water is reversible with complete loss of water on dehydration and vice versa.
- (5) Transparency of hydrated copolymers show that the absorption of water is by the solvation of the hydrophilic part of the copolymer.

4.6. NVP and HEMA. The results of copolymerization of HEMA with varying amounts of NVP as shown in Figure 6 and Table 6 show that the following reasons hold true.

- (1) NVP brings a positive effect as far as the absorption of water is concerned. It is due to higher hydrophilicity of NVP as compared to HEMA.
- (2) As the ratio of NVP increases, refractive index of the composition increases due to high molar refraction of pyrrolidone ring present in NVP.
- (3) With varying ratios, transparency and hardness of polymers do not change due to good compatibility of NVP with HEMA.
- (4) The water absorption is completely reversible meaning that the amount of water that is absorbed can be removed on dehydration.
- (5) Transparency of the hydrated copolymers obtained shows that the water remains absorbed in the polymer as a result of solvation of the hydrophilic part of the copolymer.

From the studies (Tables 3–6), it is evident that all the polymers are found to be transparent upto a particular compositions, HEMA : MMA is transparent for all compositions; HEMA : MAA and HEMA : styrene is transparent upto 60% of MAA and styrene, respectively. In case of HEMA : NVP, transparent polymers at all compositions were obtained. This is an interesting observation, keeping in view the fact that all the monomers used in the study are otherwise known to form transparent polymers when polymerized as such. The reason as to why HEMA : styrene and HEMA : MAA are

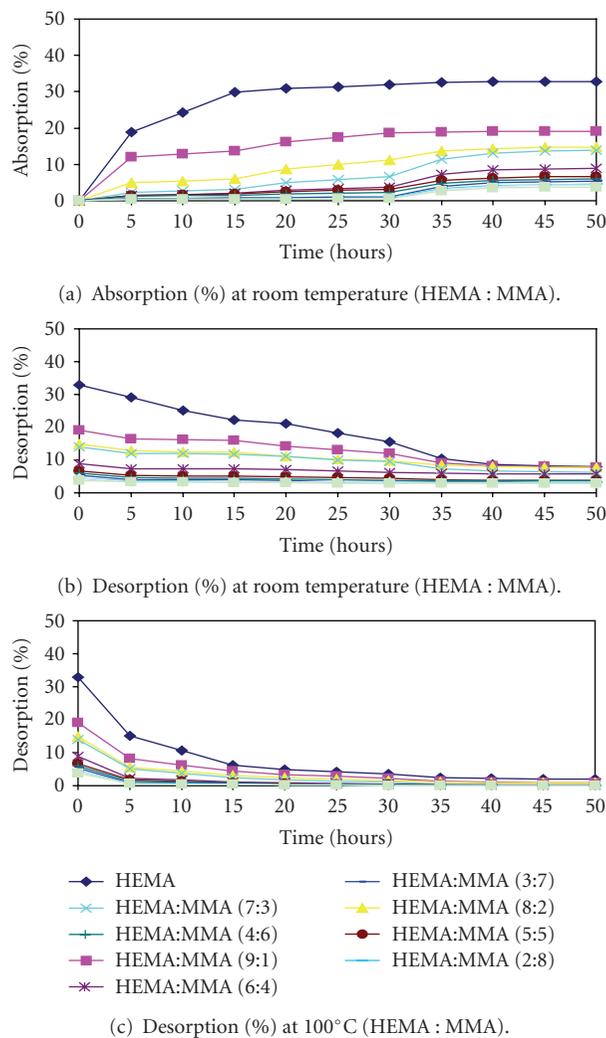


FIGURE 3: Studies on water absorption and desorption of polymers obtained with HEMA : MMA.

opaque when the concentration of HEMA is brought down to less than 40% is that the copolymer does not form at low concentrations of HEMA. The present work of polymerizing styrene and MAA by gamma irradiation has shown that polystyrene as well as polymethacrylic acid do not form easily. In fact, the transparency achieved with polystyrene as well as polymethacrylic acid by gamma irradiation at the dose rate studied in this paper is found to be poor. The findings of the present study, therefore, have significance in the sense that the copolymers using styrene as well as MAA with HEMA could be made transparent upto a given ratio of monomers. The transparency achieved for all compositions of HEMA with NVP as well as MMA are as per the expected lines; poly(N-vinyl pyrrolidone) and poly(methyl methacrylate) as obtained by gamma irradiation are also transparent.

The effect of various monomers on the water absorption capacity of HEMA can be better understood from the results presented in Figure 7. Taking the water absorption capacity of HEMA as directly proportional to the content of HEMA, it

TABLE 4: Properties of polymers obtained with HEMA : MAA by varying ratios.

| Composition HEMA : MAA | Shore-D hardness | Transmittance (%) | Refractive index | Appearance |
|------------------------|------------------|-------------------|------------------|------------------------------|
| 100 : 0 | 80 | 90 | 1.453 | Transparent, clear, and hard |
| 90 : 10 | 80 | 90 | 1.449 | Transparent, clear, and hard |
| 80 : 20 | 80 | 90 | 1.447 | Transparent, clear, and hard |
| 70 : 30 | 80 | 90 | 1.445 | Transparent, clear, and hard |
| 60 : 40 | 80 | 90 | 1.444 | Transparent, clear, and hard |
| 50 : 50 | 80 | 90 | 1.442 | Transparent, clear, and hard |
| 40 : 60 | 80 | 90 | 1.439 | Transparent, clear, and hard |
| 30 : 70 | 80 | 0 | Not measurable | Opaque and hard |
| 20 : 80 | 80 | 0 | Not measurable | Opaque and hard |
| 10 : 90 | 80 | 0 | Not measurable | Opaque and hard |
| 0 : 100 | 80 | 0 | Not measurable | Opaque and hard |

TABLE 5: Properties of polymers obtained with HEMA : Styrene by varying ratios.

| Composition HEMA : Styrene | Shore-D hardness | Transmittance (%) | Refractive index | Appearance |
|----------------------------|------------------|-------------------|------------------|---------------------------|
| 100 : 0 | 80 | 90 | 1.453 | Transparent, clear & hard |
| 90 : 10 | 80 | 90 | 1.460 | Transparent, clear & hard |
| 80 : 20 | 80 | 90 | 1.470 | Transparent, clear & hard |
| 70 : 30 | 80 | 90 | 1.480 | Transparent, clear & hard |
| 60 : 40 | 80 | 90 | 1.490 | Transparent, clear & hard |
| 50 : 50 | 80 | 90 | 1.500 | Transparent, clear & hard |
| 40 : 60 | 80 | 0 | 1.506 | Transparent, clear & hard |
| 30 : 70 | 80 | 0 | Not measurable | Opaque & hard |
| 20 : 80 | 80 | 0 | Not measurable | Opaque & hard |
| 10 : 90 | 80 | 0 | Not measurable | Opaque & hard |
| 0 : 100 | N.A* | N.A* | N.A* | Transparent liquid |

Not polymerized by gamma radiation

is possible to assess the hydrophilic or hydrophobic behavior of the added monomer.

It is evident from the results (Figure 7) that the hydrophobicity of the monomers added falls in the following decreasing order:

$$\text{Styrene} > \text{MMA} > \text{HEMA} > \text{MAA} > \text{NVP} \quad (2)$$

In the case of MAA, however, the trends of change in water absorption are different from all other monomers. The presence of a phenyl ring in the molecular structure of styrene makes it more hydrophobic than MMA, HEMA, and MAA which are characterized by the presence of a linear bond structure. Moreover, the functional groups in MAA and MMA have more hydrophilic character than styrene beside the presence of aromatic ring in the latter. This is the reason as to why the water absorption capacity of HEMA drops down from 32.82% to 0.08% on the addition of even 10 wt.% of styrene. Further, with the comonomers of HEMA with MAA and NVP, it is evident that the water absorption capacity of HEMA increases with increase in concentration of comonomer. It may be noted, however, that in the case of

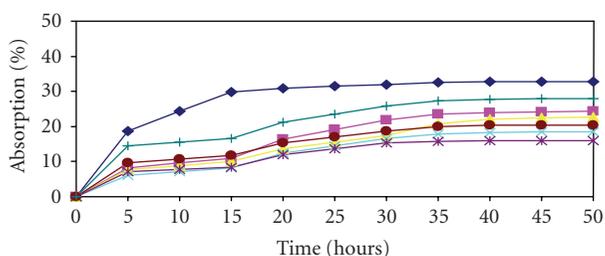
MAA, the trend is different from what is observed for NVP. Here, there is an initial drop in water absorption capacity when MAA is increased from 0% to 40% by wt.. Beyond 40 wt.% of MAA, the absorption capacity rises, reaching well above the value (32.82%) obtained for HEMA alone. The water absorption capacity data for HEMA : MAA, inspite of the fact that the polymer is opaque, suggest that it is possible to develop polymers based on HEMA : MAA with varying water absorption capacity which can be used for other applications.

Based on these results it can be said that the following:

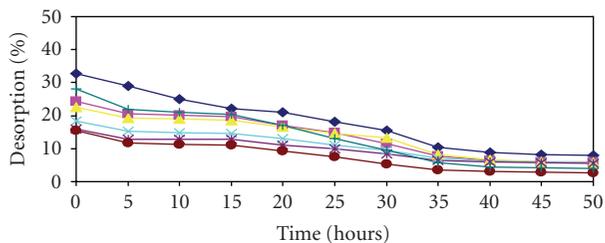
- (i) While the addition of a hydrophobic monomer brings about a reduction in capacity to absorb water, the presence of a more hydrophilic component, increases the capacity to absorb water.
- (ii) The absorption of water takes place in two stages; upto 30 hours with a low rate and beyond 30 hours with a higher rate of absorption. This is true mainly for copolymers having a significant amount of hydrophobic portion, for example, MMA and styrene. Such behavior is not seen with NVP and MAA.

TABLE 6: Properties of polymers obtained with HEMA: NVP by varying ratios.

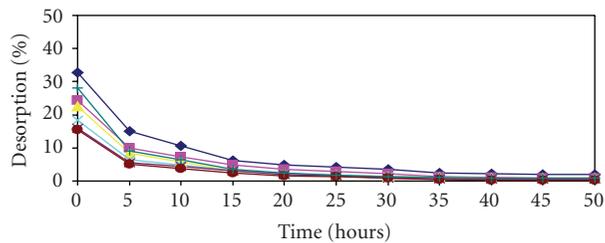
| Composition HEMA : NVP | Shore-D hardness | Transmittance (%) | Refractive index | Appearance |
|------------------------|------------------|-------------------|------------------|------------------------------|
| 100 : 0 | 80 | 90 | 1.453 | Transparent, clear, and hard |
| 90 : 10 | 80 | 90 | 1.458 | Transparent, clear, and hard |
| 80 : 20 | 80 | 90 | 1.465 | Transparent, clear, and hard |
| 70 : 30 | 80 | 90 | 1.470 | Transparent, clear, and hard |
| 60 : 40 | 80 | 90 | 1.475 | Transparent, clear, and hard |
| 50 : 50 | 80 | 90 | 1.486 | Transparent, clear, and hard |
| 40 : 60 | 80 | 90 | 1.487 | Transparent, clear, and hard |
| 30 : 70 | 80 | 90 | 1.490 | Transparent, clear, and hard |
| 20 : 80 | 80 | 90 | 1.491 | Transparent, clear, and hard |
| 10 : 90 | 80 | 90 | 1.497 | Transparent, clear, and hard |
| 0 : 100 | 80 | 90 | 1.508 | Transparent, clear, and hard |



(a) Absorption (%) at room temperature (HEMA : MAA).



(b) Desorption (%) at room temperature (HEMA : MAA).

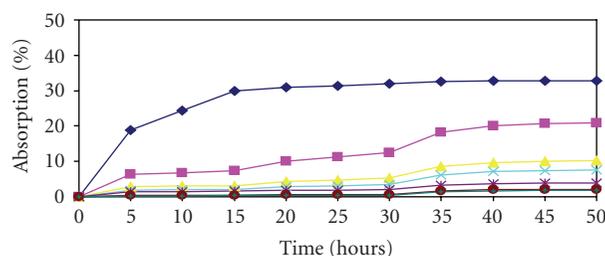


- ◆ HEMA
- ◆ HEMA:MAA (6:4)
- ◆ HEMA:MAA (7:3)
- ◆ HEMA:MAA (8:2)
- ◆ HEMA:MAA (4:6)
- ◆ HEMA:MAA (5:5)
- ◆ HEMA:MAA (9:1)

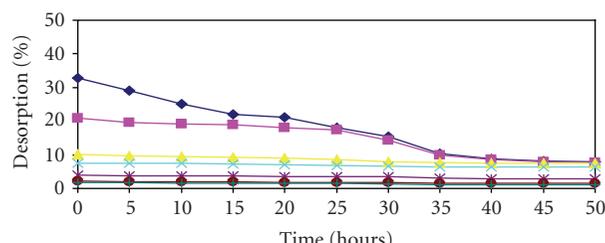
(c) Desorption (%) at 100°C (HEMA : MAA).

FIGURE 4: Studies on water absorption and desorption of polymers obtained with HEMA : MAA.

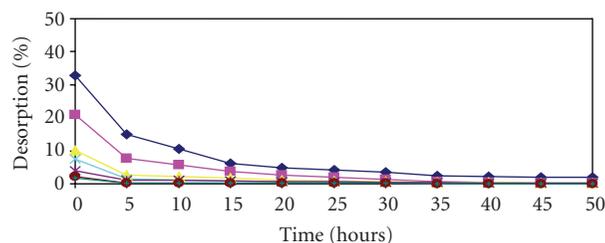
In all the cases, the transparency of the copolymer remains unchanged even with the water absorbed. This shows that materials of varying optical properties like refractive index with different capacities of water absorption can be



(a) Absorption (%) at room temperature (HEMA : Styrene).



(b) Desorption (%) at room temperature (HEMA : Styrene).

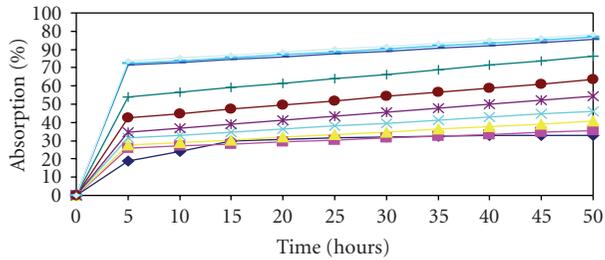


- ◆ HEMA
- ◆ HEMA:styrene (9:1)
- ◆ HEMA:styrene (8:2)
- ◆ HEMA:styrene (7:3)
- ◆ HEMA:styrene (6:4)
- ◆ HEMA:styrene (5:5)

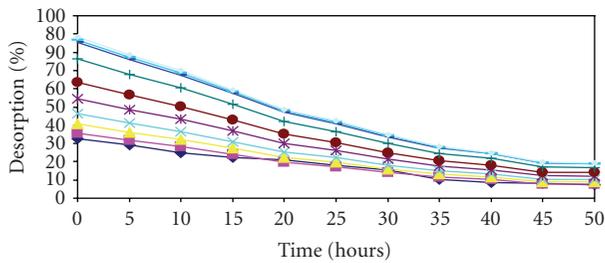
(c) Desorption (%) at 100°C (HEMA : Styrene).

FIGURE 5: Studies on water absorption and desorption of polymers obtained with HEMA : Styrene.

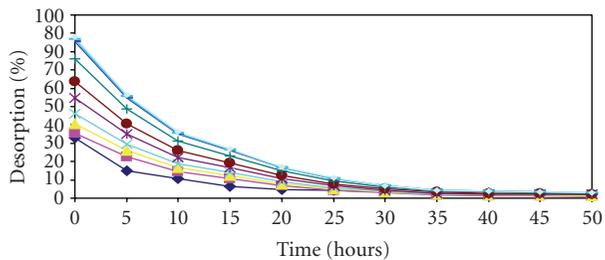
obtained by the use of different comonomers with HEMA. This is a notable achievement of this study. Further, the use of irradiation using gamma rays for polymerization is established with this research work. Since the polymerization



(a) Absorption (%) at Room temperature (HEMA : NVP).



(b) Desorption (%) at Room temperature (HEMA : NVP).



(c) Desorption (%) at 100°C (HEMA : NVP).

◆ HEMA
 ◆ HEMA:NVP (7:3)
 ◆ HEMA:NVP (4:6)
 ◆ HEMA:NVP (1:9)
 ◆ HEMA:NVP (9:1)
 ◆ HEMA:NVP (6:4)
 ◆ HEMA:NVP (3:7)
 ◆ HEMA:NVP (8:2)
 ◆ HEMA:NVP (5:5)
 ◆ HEMA:NVP (2:8)

FIGURE 6: Studies on water absorption and desorption of polymers obtained with HEMA : NVP.

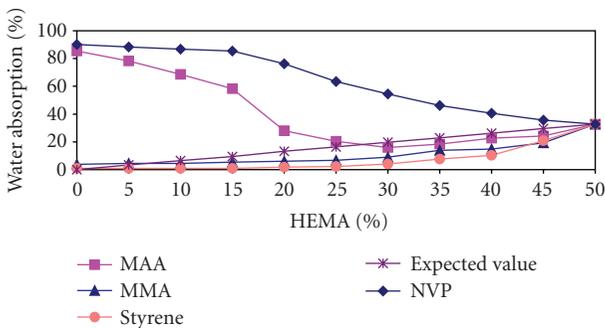


FIGURE 7: Water absorption of pHEMA with different copolymers.

is carried out at ambient conditions, this would be a preferred option for polymerization compared to conventional methods like thermal polymerization.

5. Conclusion

The present study can be concluded with the following knowledge.

- (i) HEMA can be polymerized easily using gamma rays at a dose of 40 kGy. The polymerization is possible even in the presence of water.
- (ii) The use of comonomers of different hydrophilicity and hydrophobicity results in enhanced and reduced capacity of water absorption, respectively.
- (iii) Optical plastics of varying optical properties and water absorption capacities can be developed based on HEMA, a well-known monomer for optical plastics.
- (iv) Materials with the capacity to contain various hydrophilic as well as hydrophobic substances can be obtained based on the data presented here.
- (v) Here, it may be noted that the absorption of water in the case of combination of HEMA with various monomers follows a set pattern of initial resistance to absorb water. As evident from the fact that after an initial uptake of water upto 5 hours, there appears to be a plateau upto 30 hours. Beyond 30 hours, the water uptake increases and this is apparent in almost all the cases except MAA and NVP. This could be ascribed to the hydrophilic barrier created due to the incorporation of the hydrophobic segment in the copolymer. This barrier appears to be only kinetic in nature.
- (vi) The observations would help in designing combination of copolymers for intraocular and contact lenses for which water absorption and retention in the life cycle of the lenses are key factors.

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