

METHODS AND SYSTEMS FOR PROCESSING COMPLEX SHAPED HYDROGEL DEVICES

FIELD OF THE INVENTION

This invention relates to processing complex shaped hydrogel devices, specifically including methods of processing ophthalmic lenses made from silicone hydrogels in order to leach components from the lenses and release the lenses from molds.

BACKGROUND OF THE INVENTION

It is well known that contact lenses can be used to improve vision. Various contact lenses have been commercially produced for many years. Early designs of contact lenses were fashioned from hard materials. Although these lenses are still currently used in some applications, they are not suitable for all patients due to their poor comfort and relatively low permeability to oxygen. Later developments in the field gave rise to soft contact lenses, based upon hydrogels.

Hydrogel contact lenses are very popular today. These lenses are often more comfortable to wear than contact lenses made of hard materials. Malleable soft contact lenses can be manufactured by forming a lens in a multi-part mold where the combined parts form a topography consistent with the desired final lens.

Multi-part molds used to fashion hydrogels into a useful article of a complex shape, such as an ophthalmic lens, can include for example, a first mold portion with a convex surface that corresponds with a back curve of an ophthalmic lens and a second mold portion with a concave surface that corresponds with a front curve of the ophthalmic lens. To prepare a lens using such mold portions, an uncured hydrogel lens formulation is placed between the concave and convex surfaces of the mold portions and subsequently cured. The hydrogel lens formulation may be cured, for example by exposure to either, or both, heat and light. The cured hydrogel forms a lens according to the dimensions of the mold portions.

Following cure, traditional practice dictates that the mold portions are separated and the lens remains adhered to one of the mold portions. A release process detaches the lens from the remaining mold part. The extraction step

removes unreacted components and diluents (hereinafter referred to as "UCDs") from the lens and affect clinical viability of the lens. If the UCDs are not extracted from the lens, they may make the lens uncomfortable to wear.

According to prior art, release of the lens from the mold can be facilitated by exposure of the lens to aqueous or saline solutions which act to swell the lens and loosen adhesion of the lens to the mold. Exposure to the aqueous or saline solution can additionally serve to extract UCDs and thereby make the lens more comfortable to wear and clinically acceptable.

New developments in the field have led to contact lenses that are made from silicone hydrogels. Known hydration processes using aqueous solutions to effect release and extraction have not been efficient with silicone hydrogel lenses. Consequently, attempts have been made to release silicone lenses and remove UCDs using organic solvents. Processes have been described in which a lens is immersed in an alcohol (ROH), ketone (RCOR'), aldehyde (RCHO), ester (RCOOR'), amide (RCONR'R'') or N-alkyl pyrrolidone for 20 hours-40 hours and in the absence of water, or in an admixture with water as a minor component (see e.g., U.S. Pat. No. 5,258,490).

However, although some success has been realized with the known processes, the use of highly concentrated organic solutions can present drawbacks, including, for example: safety hazards; increased risk of down time to a manufacturing line; high cost of release solution; and the possibility of collateral damage, due to explosion.

Therefore, it would be advantageous to find a method of producing a silicone hydrogel contact lens which requires the use of little or no organic solvent, avoids the use of flammable agents, that effectively releases lenses from the molds in which they were formed, and which removes UCDs from the lens.

SUMMARY OF THE INVENTION

Accordingly, the present invention provides methods of releasing a silicone hydrogel contact lens from a mold and leaching the lens of UCDs without soaking the lens in organic solvents. According to the present invention, release of a silicone hydrogel lens from a mold in which the lens is formed is facilitated by exposing the lens to an aqueous solution of an effective amount of a release aid. In addition,

leaching of UCDs from the lens is also facilitated by exposing the lens to an aqueous solution of an effective amount of a leach aid

The present invention further relates to a contact lens produced using a method which comprises treating the cured lens in an aqueous solution of an effective amount of a release aid and to ophthalmic lenses produced using a method comprising treating the cured lens in an aqueous solution of an effective amount of a leaching aid.

DETAILED DESCRIPTION OF THE INVENTION

It has been found that a silicone hydrogel ophthalmic lens can be released from a mold in which it was cured by exposing the cured lens to an aqueous solution of an effective amount of a release aid. It has also been found that adequate removal of Leachable Materials from the silicone hydrogel ophthalmic lens can be realized by exposing the cured lens to an aqueous solution of an effective amount of a leach aid.

Definitions

As used herein, “adequate removal of Leachable Materials” means that at least 50%, of the Leachable Materials have been removed from a lens after treating the lens.

As used herein, “Leachable Material” includes UCD’s and other material which is not bound to the polymer and may be extracted from the polymer matrix, for example, by leaching with water or an organic solvent.

As used herein, a “Leaching Aid” is any compound that if used in an effective amount in an aqueous solution to treat a ophthalmic lens can yield a lens with an adequate amount of removal of Leachable Materials.

As used herein the term “monomer” is a compound containing at least one polymerizable group and an average molecular weight of about less than 2000 Daltons, as measured via gel permeation chromatography refractive index detection. Thus, monomers can include dimers and in some cases oligomers, including oligomers made from more than one monomeric unit.

As used herein, the term “Ophthalmic Lens” refers to devices that reside in or on the eye. These devices can provide optical correction, wound care, drug delivery, diagnostic functionality, cosmetic enhancement or effect or a combination of these properties. The term lens includes but is not limited to soft contact lenses, hard contact lenses, intraocular lenses, overlay lenses, ocular inserts, and optical inserts.

As used herein, a “release aid” is a compound or mixture of compounds, excluding organic solvents, which, when combined with water, decreases the time required to release an ophthalmic lens from a mold, as compared to the time required to release such a lens using an aqueous solution that does not comprise the release aid.

As used herein, “released from a mold” means that a lens is either completely separated from the mold, or is only loosely attached so that it can be removed with mild agitation or pushed off with a swab.

As used herein, the term “treat” means to expose a cured lens to an aqueous solution including at least one of: a leaching aid and a release aid.

As used herein and also defined above, the term “UCD” means unreacted components and diluents.

Treatment

According to the present invention, treatment can include exposing a cured lens to an aqueous solution which includes at least one of: a leaching aid and a release aid. In various embodiments, treatment can be accomplished, for example, via immersion of the lens in a solution or exposing the lens to a flow of solution. In various embodiments, treatment can also include, for example, one or more of: heating the solution; stirring the solution; increasing the level of release aid in the solution to a level sufficient to cause release of the lens; mechanical agitation of the lens; and increasing the level of leach aid in the solution to a level sufficient to facilitate adequate removal of UCDs from the lens.

By way of non-limiting examples, various implementations can include release and UCD removal that is accomplished by way of a batch process wherein lenses are submerged in a solution contained in a fixed tank for a specified period of time or in a vertical process where lenses are exposed to a continuous flow of a solution that includes at least one of a leach aid and a release aid.

In some embodiments, the solution can be heated with a heat exchanger or other heating apparatus to further facilitate leaching of the lens and release of the lens from a mold part. For example, heating can include raising the temperature of an aqueous solution to the boiling point while a hydrogel lens and mold part to which the lens is adhered are submerged in the heated aqueous solution. Other embodiments can include controlled cycling of the temperature of the aqueous solution.

Some embodiments can also include the application of physical agitation to facilitate leach and release. For example, the lens mold part to which a lens is adhered can be vibrated or caused to move back and forth within an aqueous solution. Other embodiments may include ultrasonic waves through the aqueous solution.

These and other similar processes can provide an acceptable means of releasing the lens and removing UCDs from the lens prior to packaging.

Release

According to the present invention, release of a silicone hydrogel lens is facilitated by treating the lens with a solution including one or more release aids combined with water at concentrations effective for causing release of the lens. In some embodiments, release can be facilitated by the release solution causing a silicone hydrogel lens to swell by 10% or more in which percentage of swelling is equal to 100 times the diameter of lens in release aid solution/diameter of lens in borate-buffered saline.

In some embodiments, the release aid can include alcohols, such as, for example, C₅ to C₇ alcohols. Some embodiments can also include alcohols that are useful as release aids and include primary, secondary and tertiary alcohols with one to 9 carbons. Examples of such alcohols include methanol, ethanol, n-propanol, 2-propanol, 1-butanol, 2-butanol, *tert*-butanol, 1-pentanol, 2-pentanol, 3-pentanol, 2-methyl-1-butanol, *tert*-amyl alcohol, neopentyl alcohol, 1-hexanol, 2-hexanol, 3-hexanol, 2-methyl-1-pentanol, 3-methyl-1-pentanol, 4-methyl-1-pentanol, 2-methyl-2-pentanol, 3-methyl-2-pentanol, 3-methyl-3-pentanol, 1-heptanol, 2-heptanol, 3-heptanol, 4-heptanol, 1-octanol, 2-octanol, 1-nonanol, and 2-nonanol. In some embodiments, phenols may also be used.

In addition, in some embodiments of the present invention Leach Aids, which are further discussed below, can also be combined with alcohols to improve the rate of release. In some cases leach aids may be used as release aids without the addition of alcohols. For example, leach aids at concentrations greater than about 12%, or when used to release lenses with water soluble diluents such as *t*-amyl alcohol.

Lens materials

Ophthalmic lenses suitable for use with the current invention include those made from silicone hydrogels. Silicone hydrogels offer benefits to ophthalmic lens wearers as compared to conventional hydrogels. For example, they typically offer much higher oxygen permeability, Dk , or oxygen oxygen/transmissibility, Dk/l , where l is the thickness of the lens. Such lenses cause reduced corneal swelling due to reduced hypoxia, and may cause less limbal redness, improved comfort and have a reduced risk of adverse responses such as bacterial infections. Silicone hydrogels are typically made by combining silicone-containing monomers or macromers with hydrophilic monomers or macromers.

Examples of silicone containing monomers include SiGMA (2-propenoic acid, 2-methyl-,2-hydroxy-3-[3-[1,3,3,3-tetramethyl-1-[(trimethylsilyl)oxy]disiloxanyl]propoxy]propyl ester), α,ω -bismethacryloxypropylpolydimethylsiloxane, mPDMS (monomethacryloxypropyl terminated mono-n-butyl terminated polydimethylsiloxane) and TRIS (3-methacryloxypropyltris(trimethylsiloxy)silane).

Examples of hydrophilic monomers include HEMA (2-hydroxyethylmethacrylate), DMA (N,N-dimethylacrylamide) and NVP (N-vinylpyrrolidone).

In some embodiments, high molecular weight polymers may be added to monomer mixes and serve the function of internal wetting agents. Some embodiments can also include additional components or additives, which are generally known in the art. Additives can include, for example: ultra-violet absorbing compounds and monomer, reactive tints, antimicrobial compounds, pigments, photochromic, release agents, combinations thereof and the like.

The silicone monomers and macromers are blended with the hydrophilic monomers or macromers, placed into ophthalmic lens molds, and cured by exposing the monomer to one or more conditions capable of causing polymerization of the monomer. Such conditions can include, for example: heat and light, wherein the light may include one or more of: visible, ionizing, actinic, X-ray, electron beam or ultra violet (hereinafter "UV") light. In some embodiments, the light utilized to cause polymerization can have a wavelength of about 250 to about 700 nm. Suitable radiation sources include UV lamps, fluorescent lamps, incandescent lamps, mercury vapor lamps, and sunlight. In embodiments, where a UV absorbing compound is

included in the monomer composition (for example, as a UV block), curing can be conducted by means other than UV irradiation (such as, for example, by visible light or heat).

In some embodiments a radiation source, used to facilitate curing can be selected from UVA (about 315 – about 400 nm), UVB (about 280-about 315) or visible light (about 400 –about 450 nm), at low intensity. Some embodiments can also include a reaction that mixture includes a UV absorbing compound.

In some embodiments, wherein the lenses are cured using heat then a thermal initiator may be added to the monomer mix. Such initiators can include one or more of: peroxides such as benzoyl peroxide and azo compounds such as AIBN (azobisisobutyronitrile).

In some embodiments, lenses can be cured using UV or visible light and a photoinitiator may be added to the monomer mix. Such photoinitiators may include, for example, aromatic alpha-hydroxy ketones, alkoxyoxybenzoin, acetophenones, acyl phosphine oxides, and a tertiary amine plus a diketone, mixtures thereof and the like. Illustrative examples of photoinitiators are 1-hydroxycyclohexyl phenyl ketone, 2-hydroxy-2-methyl-1-phenyl-propan-1-one, bis (2,6-dimethoxybenzoyl)-2,4,4-trimethylpentyl phosphine oxide (DMBAPO), bis (2,4,6-trimethylbenzoyl)-phenylphosphineoxide (Irgacure 819), 2,4,6-trimethylbenzoyldiphenyl phosphine oxide and 2,4,6-trimethylbenzoyl diphenylphosphine oxide, benzoin methyl ester and a combination of camphorquinone and ethyl 4-(N,N-dimethylamino)benzoate. Commercially available visible light initiator systems include Irgacure 819, Irgacure 1700, Irgacure 1800, Irgacure 819, Irgacure 1850 (all from Ciba Specialty Chemicals) and Lucirin TPO initiator (available from BASF). Commercially available UV photoinitiators include Darocur 1173 and Darocur 2959 (Ciba Specialty Chemicals).

In some embodiments, it may also be useful to include diluents in the monomer mix, for example to improve the solubility of the various components, or to increase the clarity or degree of polymerization of the polymer to be formed. Embodiments can include secondary and tertiary alcohols as diluents

Various processes are known for processing the reaction mixture in the production of ophthalmic lenses, including known spincasting and static casting. In some embodiments, a method for producing an ophthalmic lens from a polymer includes molding silicone hydrogels. Silicone hydrogel molding can be efficient and provides for precise control over the final shape of a hydrated lens.

Molding an ophthalmic lens from a silicone hydrogel can include placing a measured amount of monomer mix in a concave mold part. A convex mold part is then placed on top of the monomer and pressed to close and form a cavity that defines a contact lens shape. The monomer mix within the mold parts is cured to form a contact lens. As used herein, curing the monomer mix includes a process or condition which allows or facilitates the polymerization of the monomer mix. Examples of conditions which facilitate polymerization include one or more of: exposure to light and application of thermal energy.

When the mold halves are separated the lens typically adheres to one or the other mold half. It is typically difficult to physically remove the lens from this mold half, and it is generally preferred to place this mold half into a solvent to release the lens. The swelling of the lens that results when the lens absorbs some of this solvent typically facilitates release of the lens from the mold.

Silicone hydrogel lenses may be made using relatively hydrophobic diluents such as 3,7-dimethyl-3-octanol. If one attempts to release such lenses in water, such diluents prevent absorption of water, and do not allow sufficient swelling to cause release of the lens.

Alternatively, silicone hydrogels may be made using relatively hydrophilic and water soluble diluents such as ethanol, t-butanol or t-amyl alcohol. When such diluents are used and the lens and mold are placed into water, the diluent may more easily dissolve and the lens may more easily release in water than if more hydrophobic diluents are used.

Leachable Material

After a lens is cured the polymer formed typically contains some amount of material that is not bound to or incorporated into the polymer. Leachable Material not bound to the polymer may be extracted from the polymer matrix for example by leaching with water or an organic solvent (hereinafter "Leachable Material"). Such Leachable Material may not be favorable to the use of the contact lens in an eye. For example, Leachable Material may slowly be released from a contact lens when the contact lens is worn in an eye and may cause irritation or a toxic effect in the eye of the wearer. In some cases, Leachable Material may also bloom to the surface of a contact lens where it may form a hydrophobic surface and may attract debris from tears, or may interfere with wetting of the lens.

Some material may be physically trapped in the polymer matrix and may not be able to be removed for example by extracting with water or an organic solvent. As used herein, trapped material is not considered Leachable Material.

Leachable material typically includes most or all of the material included in the monomer mix that does not have polymerizable functionality. For example, a diluent may be a Leachable Material. Leachable material may also include nonpolymerizable impurities which were present in the monomer. As polymerization approaches completion, the rate of polymerization will typically slow and some small amount of the monomer may never polymerize. Monomer that never polymerizes can be included in the material that will be leached from the polymerized lens. Leachable material may also include small polymer fragments, or oligomers. Oligomers can result from the termination reactions early in the formation of any given polymer chain. Accordingly, Leachable Materials can include any or all of a mixture of the above described components, which may vary one to another in their properties such as toxicity, molecular weight or water solubility.

Leach aids

According to the present invention, leaching of a silicone hydrogel lens is facilitated by exposing the lens to a solution including one or more leaching aids combined with water at concentrations effective to remove UCDs from the lens.

For example, in some embodiments, ophthalmic lenses can be subjected to a treatment exposing the lenses to a leach aid and a GC Mass Spectrometer can be used to measure the level of one or more UCDs in the ophthalmic lenses. The GC Mass Spectrometer can determine whether treatment with a particular leaching aid is effective to reduce an amount of particular UCDs present in the lenses to a maximum threshold amount.

Accordingly, in some embodiments, a GC Mass Spectrometer can be used to check for a maximum threshold of UCDs, such as SiMMA, mPDMS, SiMMA glycol, and epoxide, of approximately 300 ppm. A minimum hydration treatment time period necessary to reduce the presence of such UCDs to 300 ppm or less in specific lenses can be determined by the periodic measurements. In additional embodiments, other UCDs, such as, for example, D3O or other diluents, can be measured to detect the

presence of a maximum amount of approximately 60 ppm. Embodiments can also include setting a threshold amount of a particular UCD at the minimum detection level ascertainable by the testing equipment.

Examples of leaching aids, according to the present invention include: ethoxylated alcohols or ethoxylated carboxylic acids, ethoxylated glucosides or sugars, optionally with attached C8 to C14 carbon chains, polyalkylene oxides, sulfates, carboxylates or amine oxides of C8-C10 compounds. Examples include cocoamidopropylamine oxide, C₁₂₋₁₄ fatty alcohol ethoxylated with 10 ethylene oxides, sodium dodecyl sulfate, polyoxyethylene-2-ethyl hexyl ether, polypropylene glycol, polyethylene glycol monomethyl ether, ethoxylated methyl glucoside dioleate, and the sodium salt of n-octylsulfate, sodium salt of ethylhexyl sulfate.

In order to illustrate the invention the following examples are included. These examples do not limit the invention. They are meant only to suggest a method of practicing the invention. Those knowledgeable in contact lenses, as well as other arts, may find other methods of practicing the invention, those methods are deemed to be within the scope of this invention.

Examples:

About 1 g of polymer was formed by UV curing 5000 MW α,ω -bismethacryloxypropyl polydimethylsiloxane, TRIS and DMA with t-butanol as diluent. and soaked in 50 g of 15% (wt) ethoxylated nonylphenol (Ethal NP-9) in water overnight at room temperature, followed by submersion in boiling water for 5 hours. The polymer was rinsed three times with 50 ml deionized water. The resulting polymer was analyzed for residual PDMS, TRIS and DMA as compared to polymer that was not leached. The results are shown in Table 1.

In addition, a Comparative example 1 was prepared with the same polymer used in Example 1. The Comparative Example was soaked 2 hours in 50 g IPA, one hour in 50 g fresh IPA, and one hour again in 50 g fresh IPA. The Comparative example polymer was analyzed for residual monomers and the results are shown in Table 1.

Table 1 also includes data from the same polymer which was not leached.

Table 1

	PDMS	TRIS	DMA
Example 1	BLD*	BLD*	BLD*
Comparative Example 1	BLD*	BLD*	BLD*
Not leached	2.1%	0.034%	BLD*
Limit of detection	0.8%	0.017%	0.012%

CLAIMS

What is claimed:

1. A method for removing unreacted components and diluents from an ophthalmic lens comprising silicone, the method comprising:
 - exposing said ophthalmic lens to a first aqueous solution comprising about 15% or more of a leaching agent comprising ethoxylated nonylphenol;
 - heating said first aqueous solution to which the ophthalmic lens is exposed; and
 - rinsing said ophthalmic lens through contact with a second aqueous solution until said lens comprises a level of unreacted components and diluents that is below a predetermined threshold.
2. The method according to claim 1, wherein the first aqueous solution comprises essentially 100% ethoxylated nonylphenol.
3. The method according to claim 1, wherein said second liquid comprises deionized water.
4. The method according to claim 1, wherein said first liquid, said second liquid, or both comprise a buffered aqueous solution.
5. The method according to claim 4, wherein said first liquid, said second liquid, or both comprise sodium chloride, boric acid, sodium borate, dihydrogen sodium phosphate, sodium citrate, sodium acetate, sodium bicarbonate or any combination thereof.
6. The method according to claim 1, wherein the predetermined threshold comprises a threshold of detection of unreacted components and diluents.
7. The method according to claim 1, wherein said ophthalmic lens comprises a contact lens comprising from 0 to about 90 percent water.

8. The method according to claim 1, wherein said ophthalmic lens further comprises a diluent and said method further comprises removing said diluent from said ophthalmic lens.
9. The method according to claim 8, wherein said ophthalmic lens has a functional size and swells during said diluent removal.
10. The method according to claim 1, wherein said ophthalmic lens is tinted.
11. The method according to claim 1, wherein said ophthalmic lens comprises a pattern of colorant.
12. The method of claim 1 wherein wherein the exposing of the ophthalmic lens to the first aqueous solution comprises immersing the ophthalmic lens in the first aqueous solution and the first aqueous solution is heated to its boiling point with the ophthalmic lens immersed in it.
13. The method of claim 12 wherein the ophthalmic lens is immersed in the boiling first aqueous solution for a period of time comprising more than one hour.
14. The method of claim 12 wherein the ophthalmic lens is immersed in the boiling first aqueous solution for a period of time comprising between one hour and five hours.
15. The method of claim 1 additionally comprising the step of forming the ophthalmic lens by UV curing at 5000 MW a monomer comprising α,ω -bismethacryloxypropyl polydimethylsiloxane, TRIS and DMA with a diluent comprising t-butanol.
16. The method of claim 1 wherein the step of rinsing the ophthalmic lens comprises exposing the ophthalmic lens three times to at least 50 ml of deionized water.

17. The method of claim 1, wherein, the first aqueous additionally comprises one or more of: ethoxylated alcohols; ethoxylated carboxylic acids, ethoxylated glucosides; ethoxylated sugars; ethoxylated carboxylic acids with attached C8 to C14 carbon chains, ethoxylated glucosides with attached C8 to C14 carbon chains; ethoxylated sugars with attached C8 to C14 carbon chains; polyalkylene oxides, sulfates, carboxylates or amine oxides of C8-C10 compounds.
18. The method of claim 1, wherein, the first aqueous additionally comprises, one or more of: cocoamidopropylamine oxide, C₁₂₋₁₄ fatty alcohol ethoxylated with 10 ethylene oxides; sodium dodecyl sulfate; polyoxyethylene-2-ethyl hexyl ether; polypropylene glycol; polyethylene glycol monomethyl ether; ethoxylated methyl glucoside dioleate; the sodium salt of n-octylsulfate; and sodium salt of ethylhexyl sulfate.
19. The method of claim 1 wherein the exposing of the ophthalmic lens to the first aqueous solution comprises flowing the first aqueous solution over the ophthalmic lens.
20. The method of claim 1 wherein the exposing of the ophthalmic lens to the first aqueous solution comprises immersing the ophthalmic lens in the first aqueous solution.