

- [54] **LIQUID MEMBRANE PROCESS FOR THE SEPARATION OF AQUEOUS MIXTURES**
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- [*] Notice: **The portion of the term of this patent subsequent to Nov. 2, 1988, has been disclaimed.**
- [21] Appl. No.: **951,352**
- [22] Filed: **Oct. 13, 1978**

Related U.S. Patent Documents

Reissue of:

- [64] Patent No.: **3,779,907**
Issued: **Dec. 18, 1973**
Appl. No.: **174,900**
Filed: **Aug. 25, 1971**

U.S. Applications:

- [63] Continuation-in-part of Ser. No. 28,094, Apr. 13, 1970, Pat. No. 3,617,546, and Ser. No. 36,686, May 12, 1970, Pat. No. 3,637,488.
- [51] Int. Cl.² **B01D 13/00; C02B 1/46; C02B 1/60**
- [52] U.S. Cl. **210/22 R; 210/23 R; 210/37 R; 210/38 R; 210/38 B; 210/59; 252/188.3 R**
- [58] Field of Search **210/21, 22 R, 23 R, 210/24, 28, 37 R, 38 R, 38 B, 42 R, 55, 59; 252/303, 314, 188.3 R, 309**

[56] **References Cited**
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[57] **ABSTRACT**

This invention relates to a process for the removal of dissolved species from aqueous solutions, which comprises contacting said aqueous solution with an emulsion, said emulsion comprising an exterior phase which is characterized as being immiscible with said aqueous solution and yet permeable to said dissolved species, and an interior phase which contains a reactant capable of converting said dissolved species to a non-permeable form. The dissolved species permeate the exterior phase, into the interior phase where they are converted into nonpermeable forms and thus retained in the interior phase of said emulsion. The aqueous solution, depleted in said dissolved species, is separated from said emulsion and the emulsion cycled for reuse. In one preferred embodiment said dissolved species are ions, and an ion exchange compound is incorporated in the exterior phase of the emulsion, to promote the permeation of said ions through the exterior phase.

22 Claims, No Drawings

LIQUID MEMBRANE PROCESS FOR THE SEPARATION OF AQUEOUS MIXTURES

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. application Ser. Nos. 28,094 and [99,267] 36,686 filed on Apr. 13, 1970 and [Dec. 17, 1970] May 12, 1970 respectively, in the names of Li, Cahn and Shrier. Application Ser. No. 28,094 has issued as U.S. Pat. No. 3,617,546, and application Ser. No. [99,267] 36,686 has issued as U.S. Pat. No. [3,710,519] 3,637,488.

BACKGROUND OF THE INVENTION

This invention relates to a process for the removal of dissolved species (solute) from aqueous solutions, which comprises contacting said aqueous solution with an emulsion, said emulsion comprising an exterior phase which is characterized as being immiscible with said aqueous solution and yet permeable to said dissolved species, and an interior phase which contains a reactant capable of converting said dissolved species to a non-permeable form. The dissolved species permeate the exterior phase, into the interior phase where they are converted into non-permeable forms and thus retained in the interior phase of said emulsion. The aqueous solution, depleted in said dissolved species, is separated from said emulsion and the emulsion cycled for reuse. In one preferred embodiment said dissolved species are ions, and an ion exchange compound is incorporated in the exterior phase of the emulsion, to promote the permeation of said ions through the exterior phase.

Liquid surfactant membranes, as disclosed in U.S. Pat. No. 3,454,489, may be utilized to separate dissolved compounds from their aqueous solutions. The process described therein is based on diffusion through the liquid surfactant membrane, and thus the limit of separation was reached when the concentration of the dissolved compounds on both sides of the membrane became equal.

It has now been unexpectedly discovered that a dissolved species may be efficiently removed from an aqueous solution by contacting said aqueous solution with an emulsion, said emulsion comprising an exterior phase which is immiscible with said aqueous solution and permeable to said dissolved species, and an interior phase comprising a reactant which is capable of converting said dissolved species to a form in which it is no longer permeable. The dissolved species in its non-permeable form is thus trapped in the interior phase and the concentration gradient of the permeable form of said compound between the aqueous solution and the interior phase is maintained. The concentration gradient acts to drive the dissolved compound efficiently through the exterior phase of the emulsion into the interior phase. By use of this technique small volumes of emulsion may be used to treat large volumes of aqueous solution efficiently. Thus the instant process, although not limited thereto, is useful in water pollution control, wherein large bodies of water must be treated to re-

move small amounts of dissolved impurities, e.g., the dissolved species.

The exterior phase of the emulsion will comprise one or more surfactants, a solvent, if needed, and/or various other additives, as further elucidated below. The exterior phase is designed to be immiscible with said aqueous solution, and to form an effective emulsion, must also be immiscible with the interior phase and with the reactant in the interior phase. The exterior phase acts as a liquid membrane through which selected, dissolved species may permeate into the interior phase where they are converted to nonpermeable forms.

The dissolved species which may be removed by the instant process include inorganic and organic, neutral and ionic, acidic and basic compounds. In each specific case the exterior phase of the emulsion must be chosen so that the dissolved species is at least slightly soluble therein. It will be obvious to the skilled artisan which exterior phase may be used for any specific dissolved species. The exterior phase may be specially adapted to solubilize any dissolved species by use of a solubilizing additive. For example, hydrocarbon soluble ion exchange compound can be dissolved in a hydrocarbon exterior phase to promote the solubility of ionic species therein.

The choice of reactant will be made in view of two factors. It must be capable of converting the dissolved species, e.g., compound, which has permeated into the interior phase, into a nonpermeable form, thus trapping said dissolved compound and keeping the concentration of said compound low in the interior phase. Also, said reactant must itself remain trapped in the interior phase. Usually the reactant will be soluble in the interior phase, but the use of insoluble reactants, i.e., solid adsorbents, or slightly soluble reagents like lime in an aqueous interior phase is feasible.

In a typical example of how the instant process may be utilized, a water immiscible solvent containing a surfactant soluble therein, is mixed with an aqueous solution containing a reactant under high shear conditions to form a stable water in oil emulsion. Said emulsion is then contacted with an aqueous stream containing a dissolved species by any of various methods, i.e., agitating a mixture of the emulsion and the aqueous stream together in a batch process, cocurrent containing in a continuous flow reactor; countercurrent contacting by bubbling said aqueous stream through a column containing said emulsion, or vice versa. In all of these procedures a difference in density between said aqueous stream and said emulsion is maintained in order to permit separation of the emulsion and the aqueous stream after contact.

During contact, the dissolved species present in the aqueous stream permeates through the exterior phase of the water in oil emulsion, into the interior phase, which comprises the reactant-containing solution, wherein said dissolved species reacts with said reactant and is converted into a nonpermeable form (thus keeping the concentration of the permeable form low in the interior phase). If the reactant was not present, the dissolved species would continue to permeate into the interior phase until the concentration of said dissolved species in the interior phase was equal to its concentration in the aqueous stream. At this point further permeation into the interior phase would cease.

By providing a reactant capable of converting said permeable species into a nonpermeable form, in the interior phase, the concentration of the permeable form

wherein n varies from 10 to 60, x varies from 3 to 10, R_5 , R_6 , R_7 , R_8 and R_9 are hydrogen, and y is selected from the group consisting of hydrogen and oxygen-containing hydrocarbyl radicals having up to 10 carbons e.g., acetyl, etc.

Once the ions permeate into the interior phase, they may be converted into a nonpermeable form by precipitation, complexing, etc. with a reactant maintained in the interior phase. Examples of such conversions include precipitation of Ag, Cu, Cd, and Hg ions with sulfide ions; precipitation of Ca ions with phosphate ions and vice versa; reduction of nitrate ions with ferrous ions and complexing of nitrogen oxide with ferric sulfate. Any of the well known ion complexing agents such as ethylene diamine tetra acetic acid may be utilized as reactants.

An interesting variation of the above process for separating ions from aqueous solution involves maintenance of a pH differential between the interior phase and the aqueous solution, whereby the pH at the aqueous solution-exterior phase interface promotes the solubility of the ions in the ion exchange compound containing exterior phase, and the pH at the exterior phase-interior phase interface promotes the desorption of the ions from the exterior phase and subsequent solubilizing in the interior phase.

The process of this invention contemplates the separation of dissolved compounds from aqueous solution, and thus [in order to maintain the emulsion as a phase separate from said aqueous solution] it is necessary that the emulsion be of the water in oil type. The surfactants utilized will be of the oil soluble type. In general the surfactants must have low solubility in both the aqueous solution and the interior phase. Also, the surfactant preferably promotes the permeability of the dissolved species of interest through the membrane. Specific surfactants which may be used include anionic, cationic, or nonionic surfactants.

The following anionic surfactants are useful for the process of the instant invention:

Carboxylic acids, including fatty acids, rosin acids, tall oil acids, branched alkanolic acids, etc.

Sulfuric acid esters, including alcohol sulfates, olefin sulfates, etc.

Alkane and alkylaryl sulphonates, including alkyl benzene sulphonates, alkyl naphthalene sulphonates, etc.

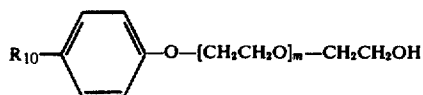
Phosphoric acid esters, including mono and dialkyl phosphates.

The following cationic surfactants are useful for the process of the instant invention:

Quaternary amine salts.

Nonionic surfactants are the preferred surfactant type for the practice of the process of the instant invention. A useful group of nonionic surfactants include the polyethenoxyether derivatives of alkyl phenols, alkyl-mercaptans, and alcohols, e.g. sorbitol, pentaerythritol, etc.

Particular nonionic surfactants for use in the instant process include compounds having the general formula



wherein R_{10} may be C_8H_{17} , C_9H_{19} , or $\text{C}_{10}\text{H}_{21}$ and m is an integer varying from 1.5 to 8.

The most preferred nonionic surfactant is Span 80, a fatty acid ester of anhydro sorbitol condensed with ethylene oxide.

Short-chain fluorocarbons with polar groups are frequently sufficiently soluble in hydrocarbon oils to function as surfactants. Long-chain fluorocarbons attached to a hydrocarbon chain of sufficient length are soluble in hydrocarbon oils.

Silicone oils differ broadly in their chemical structure and surface-active properties. Those of sufficiently low molecular weight to be soluble in the hydrocarbon solvent and which contain only CH_3 groups attached to silicon in the $(\text{Si}-\text{O})_n$ skeleton can be expected to be surface-active.

Since the number of surfactants is extremely large, it is not intended to burden this application with numerous examples. The following publications may be referred to for further examples: Surface Chemistry by Lloyd I. Osipow, Reinhold Publishing Company, New York (1962) chapter 8 and Surface Activity, Moilliet et al, Van Nostrand Company, Inc. (1961) Part III.

Generally the exterior phase of the emulsion comprises a water immiscible solvent, as well as one or more surfactants. The solvent may be chosen from the class consisting of hydrocarbons, halogenated hydrocarbons, ethers, higher oxygenated compounds such as alcohols, ketones, acids and esters.

The various additives which have been previously mentioned as useful for transporting ions across the membrane may function as the water immiscible solvent. In particular the various amines previously mentioned are useful solvents for the formation of water in oil emulsions.

The solvent, of course, must be liquid at the conditions at which the instant process is operated, and also must be capable, in conjunction with the surfactant, of forming a stable water in oil emulsion with the interior phase. Conveniently the interior phase is aqueous but any solvent which forms and maintains the interior phase of a stable emulsion with the selected surfactant-solvent exterior phase mixture may be used.

The interior phase exists as droplets surrounded by the solvent-surfactant exterior phase. When the water in oil emulsion is contacted with the aqueous solution, the exterior phase acts as a liquid membrane which allows certain dissolved species to permeate into the interior phase where a reactant contained therein converts them to a form which cannot permeate back through the "liquid membrane."

The water in oil emulsion must be stable so that the exterior phase coating the droplets of the interior phase does not rupture and thus allow mixing of the components of the interior phase with the aqueous solution.

It should be noted that a variation of the above process is possible wherein the aqueous solution comprises the interior phase of the water in oil emulsion, which is then contacted with a solution containing a reactant for the dissolved species. This variation although possible is not economically favored for treating pollution, where large volumes of aqueous solution would have to be emulsified, but may be of interest where small streams must be treated with large volumes of reactant.

The emulsion used in the instant process may be prepared by various methods. Weight ratios of from 0.1 to 1.8, preferably of from 0.5 to 1.0, of a reactant solution is mixed with a water immiscible solvent in which is

dissolved at least about 0.0001 percent by weight, preferably from about 0.01 percent by weight to 10 percent by weight, most preferably from 0.1 percent by weight to 5 percent by weight of an oil soluble surfactant. The reactant solution is preferably aqueous with a concentration that is dependent primarily on the solubility of the reagent in the aqueous solution. Preferably the aqueous solution is saturated with the reactant or may be a slurry containing undissolved reactant. The above mixture is emulsified by use of high speed stirrers, colloid mills, valve homogenizers, ultrasonic generators or mixing jets.

When an ion exchange compound is incorporated in the exterior phase of the water in oil emulsion, it may comprise from about 1 to 99.9 percent by weight of said exterior phase. Preferably said ion exchange compound will comprise from about 4 to about 40 percent by weight of said exterior phase.

A typical water in oil emulsion, for use in separating ions from aqueous solutions, will thus comprise from 0.01 to 10 percent by weight nonionic surfactant, from 5 to 75 percent by weight ion exchange compound, and from 25 to 75 percent by weight of an aqueous solution containing a reactant for the aforesaid ion.

The emulsion is then contacted with an aqueous solution containing dissolved compounds, in a manner as previously described, whereby the dissolved compounds permeate through the "liquid membrane" exterior phase into the reagent-containing interior phase, wherein said dissolved compounds are converted to nonpermeable forms. The emulsion is then separated from the aqueous solution, which is now depleted in the dissolved compounds, and optionally the emulsion is cycled to a recovery area, where it may be regenerated. For example, the emulsion may be broken, the surfactants and solvent reused for making fresh emulsion, and the reactant regenerated for reuse.

The above process may be operated at any temperature at which the emulsion and the aqueous solution are fluid and stable; conveniently, ambient temperature is used. The pressure must likewise be sufficient to maintain the fluidity of various phases; conveniently, ambient pressures are used.

The following are specific embodiments of the instant process. The above process is general in scope, and thus there is no intention of being limited to said specific embodiments.

EXAMPLE 1

In the following runs, phenol was removed from an aqueous solution. The solution was introduced into a separation zone which was provided with a mixer. The zone was maintained at a temperature of 25° C. and a pressure of 1 atmosphere. The surfactant used was Span 80, a commercial name for sorbitan monooleate with a viscosity of 1,000 cps at 25° C., in an amount of 2 percent by weight. The mixture of surfactant, sodium hy-

dioxide solution and surfactant solvent (a high molecular weight isoparaffin having a carbon number range of from about 25 to about 35) was emulsified and then contacted with the phenol-containing aqueous feed.

After the emulsion and the aqueous solution were mixed at a rate of 100 rpm for about 50 minutes, the emulsion and the aqueous solution were separated and analyzed. The results and additional details of the experiments are included in Table I. The aqueous solution was analyzed by UV spectrography method for phenol concentration and by titration with acid for caustic concentration.

The Table indicates that in Run 1 where no sodium hydroxide was added, a high phenol concentration remained after 43 minutes of agitation. On the other hand, in Run 2 where 0.4 wt. percent of caustic was used, at the end of 19 minutes only 3 parts per million of phenol remained. In Run 3 where the caustic concentration was increased slightly to 0.5 wt. percent, phenol was reduced from 1,000 to 33 parts per million in just 53 minutes.

It should be noted that the Na content of the waste water rose very slowly, indicating very little permeation of Na-ion from the "inside" of the emulsion to the outside waste water stream.

EXAMPLE 2

In this example phosphoric acid and mono sodium phosphate were removed from aqueous solutions. The aqueous solution of phosphate was introduced into a separation zone which was provided with a mixer. The zone was maintained at ambient temperature and pressure. The surfactant used was Span 80. The mixture of emulsion containing surfactant, calcium compounds, surfactant solvents, high molecular weight amines with molecular weight below 1,000, and the phosphate-containing aqueous feed was stirred at a rate of 100 rpm for about 50 minutes. The results and additional details of the experiments are included in Table II. The feed recovered was analyzed by colorimetric method for phosphate concentration and by titration method for chloride concentration when calcium chloride was used.

Table I

EXPERIMENTAL PHENOL REMOVAL FROM WASTE STREAMS			
	Run number		
	1	2	3
Aqueous phenol solution:			
Ce	250	250	250.
Phenol, p.p.m	1,000	200	1,000.
Emulsion:			
Exterior phase	Iso- paraffin	Iso- paraffin	Iso- paraffin.
Volume of exterior phase, cc	200	200	200.
Surfactant	2% Span 80	2% Span 80	2% Span 80.
Interior aqueous phase, cc	100	96.8	97.
Caustic conc., wt. percent	0	0.4	0.5.

RUN DATA

Time, min.	Phenol in aqueous solution, p.p.m.	Percent removed	Time, min.	Phenol in aqueous solution, p.p.m. ¹	Percent removed	Time, min.	Phenol in aqueous solution, p.p.m. ²	Percent removed
0	990	0	0	200	0	0	1,000	0
2	730	26	1	83	59	2	652	35
5	667	33	2	60	70	5	288	71
8	615	38	3	36	82	18	41	96
28	606	39	5	17	92	38	44	96

RUN DATA

²Na in final aqueous phase = 43 p.p.m.

Cl-ion from the "inside" of the emulsion to the outside waste water stream.

EXPERIMENTAL PHOSPHATE REMOVAL FROM WASTE WATER

(9) RUN DATA

$$\begin{array}{c} \text{CH}_3 \quad (\text{CH}_3) \\ | \quad | \\ \text{H}-\text{C}-\left[\text{C} \right]_m \\ | \quad | \\ \text{CH}_3 \quad (\text{CH}_3) \end{array} - \begin{array}{c} \text{H} \quad \text{O} \\ | \quad // \\ \text{C} \quad \text{N} \\ | \quad | \\ \text{H}-\text{C} \quad \text{C} \\ | \quad // \\ \text{H} \quad \text{O} \end{array} - \left(\text{CH}_2 - \text{CH}_2 - \text{N} \begin{array}{c} \text{H} \\ | \\ \text{N} \end{array} \right)_4 - \begin{array}{c} \text{H} \\ | \\ \text{C}-\text{CH}_3 \\ || \\ \text{O} \end{array}$$

m is an integer of about 40, giving said polyamine derivative a molecular weight of about 2,000.

^bAmberlite LA-2 is a trade name for high molecular weight (mol. wt. 353-393) primary and secondary amines which are oil-soluble but not water-soluble, have anion exchange resin properties, possess a neutralization equivalent of 360-380, an ion exchange capacity of 2.7 meq./gm., a viscosity of 18 cps. at 25° C. and a density of 0.83 gm./ml.

EXAMPLE 3—Separation of nitrate.

279 gm of liquid membrane emulsion are mixed with 465 gm of an aqueous nitrate solution at 200 RPM. The emulsion was made by emulsifying 100 gm reagent solution composed of 50 percent H_2SO_4 , 20 percent FeSO_4 , and 30 percent H_2O in 200 gm surfactant solution (2 percent Span 80 and 98 percent isoparaffin [See Example 1]). The aqueous solution contained 219.3 ppm of NaNO_3 in water. After the feed and the emulsion were contacted for 2 minutes, the concentration of NaNO_3 in the feed dropped to 35.64 ppm. The concentration only increased slightly to 41.12 ppm after continuous mixing for 53 minutes more, thus indicating that there was very little membrane rupture during the mixing period.

A blank run was made in which 282 gm of liquid membrane emulsion was mixed with 492 gm. feed. The

emulsion, containing no reagent, was made by emulsifying 100 gm pure water in 200 gm of the same surfactant solution. The same aqueous solution was used in the run. After the aqueous nitrate solution was continuously mixed with the emulsion for 68 minutes the concentration of NaNO_3 was only reduced from 219.3 ppm to 205.6 ppm, indicating the removal of the nitrate in the absence of reagent was insignificant.

EXAMPLE 4—Separation of Ammonia

Aqueous solution: Water containing NH_4OH (690 ppm)
Surfactant solution=2 percent Span 80 + 98 percent isoparaffin (see Example 1) 200 gm.

Reagent solution=2 percent HCl in water—100 gm.
Mixed 237 gm. of the water in oil emulsion with 500 gm feed at 250 RPM. Samples were taken from time to time from the aqueous solution.

Mixing time (Min)	NH_4OH Concentration in Aqueous solution (ppm)
0	690
2	250
5	130
18	<30
38	<30
53	<30
Total Time of mixing = 53 minutes.	

What is claimed is:

1. A process for removal of a dissolved species from an aqueous solution which comprises, contacting said aqueous solution with an emulsion, said emulsion comprising an interior phase, surrounded by a surfactant containing exterior phase, said exterior phase being immiscible with said aqueous solution and said exterior phase being permeable to said dissolved species, and said interior phase comprising a reactant capable of converting said species to a nonpermeable species, whereby said species permeates the exterior phase and is converted to a nonpermeable species in the interior phase.

2. The process of claim 1, wherein said exterior phase comprises from about 0.01 to 10 weight percent of an oil soluble surfactant.

3. The process of claim 2 wherein said interior phase is aqueous.

4. The process of claim 3 wherein said dissolved species is converted to a nonpermeable form by complexing with a reactant in the interior phase.

5. The process of claim 3 wherein said dissolved species is an ion.

6. The process of claim 5 wherein said exterior phase comprises an ion exchange compound.

7. The process of claim 6 wherein said ion is a cation.

8. The process of claim 7 wherein said exterior phase comprises a compound selected from the group consisting of sulfonic acids, organophosphoric acids and carboxylic acids.

9. The process of claim 6 wherein said ion is an anion.

10. The process of claim 9 wherein said exterior phase comprises an amine.

11. The process of claim 3 wherein said dissolved species is converted to a nonpermeable form in the interior phase by neutralization.

12. The process of claim 11 wherein said dissolved species is a weak acid and is neutralized in the interior phase by a strong base.

13. The process of claim 12 wherein said weak acid is selected from the group consisting of CO_2 , SO_2 , acetic acid, H_2S , phenol, HCN and citric acid.

14. The process of claim 11 wherein said dissolved species is a weak base and is neutralized in the interior phase by a strong acid.

15. The process of claim 14 wherein said dissolved species is selected from the group consisting of NH_3 and nitrogen containing organic compounds.

16. The process of claim 3 wherein said dissolved species is converted to a nonpermeable form by precipitating in the interior phase.

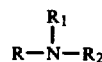
17. The process of claim 16 wherein said dissolved species is selected from the group consisting of metal ions.

18. The process of claim 17 wherein said metal ion is selected from the group consisting of Ag , Cu , Cd and Hg .

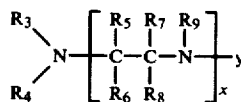
19. The process of claim 3 wherein said surfactant is Span 80.

20. The process of claim 7 wherein said ion exchange compound is selected from the group consisting of sulfonated styrene copolymers, petroleum sulfonic acids, naphthenic acids, sulfonated phenol formaldehyde copolymers, styrene-maleic acid copolymers, and styrene acrylic acid copolymers.

21. The process of claim 9 wherein said ion exchange compound is selected from compounds having the general formula:

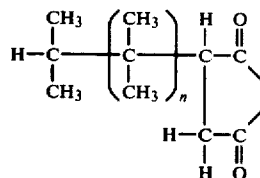


wherein R and R_1 are independently selected from the group consisting of hydrogen, C_1 to C_{20} alkyl, C_6 to C_{20} aryl and C_7 to C_{20} alkaryl radicals and R_2 is selected from the group consisting of C_6 to C_{30} alkyl, C_6 to C_{20} aryl and C_7 to C_{20} alkaryl radicals; and



wherein R_3 , R_4 , R_5 , R_6 , R_7 , R_8 , R_9 and y are independently selected from the group consisting of hydrogen, C_1 to C_{20} alkyl, C_6 to C_{20} aryl, C_7 and C_{20} alkaryl radicals and substituted derivatives thereof, and x is an integer of from 1 to 100.

22. The process of claim 21 wherein R_3 and R_4 together form an alkyl succinic radical having the general formula



wherein m is an integer varying from 10 to 60, x varies from 3 to 10, and y is selected from the group consisting of hydrogen and oxygen containing hydrocarbyl radicals having up to 10 carbons.

* * * *