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ABSTRACT

Novel techniques for the constant rate administration of ABATE (temephos) to mosquito larvae-infested water sources and the controlled release of the pesticide Furadan 3G (carbofuran) for improved rice cultivation comprise an active research and development program at the National Chemical Laboratory (NCL) in Pune, India. Both projects are extremely well-conceived and are consistent with the state-of-the-art of controlled release of biochemically active substances.

The ABATE is released through a novel membrane-reservoir device wherein the pure ABATE liquid is confined to an internal reservoir and aqueous polyacrylamide gels, protrude as two or more arms from the central reservoir. The arms serve as the rate controlling membranes, metering the ABATE to the larvae-containing water sources over a period of years.

The carbofuran is released to and serves as a pesticide in rice cultivation by a novel device formulation comprising encapsulated microgranules. Two coatings have been developed at NCL based upon xanthate-cross-linked starch and urea-formaldehyde based resins, respectively. Both coatings are apparently glassy and, therefore, the mechanism of release appears to be based upon occluded dissolution or osmotic pumping rather than simple solute diffusion across intact barrier membranes.

Both projects have demonstrated sufficient promise to be strongly supported. Continuing studies should include detailed mechanistic analysis of device design and performance. These more fundamental studies might be considered for UNIDO/UNDP support at a university centre-of-excellence of controlled release research in the United States with NCL students working for their degree under the joint supervision of senior scientists from the NCL.

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INTRODUCTION

The National Chemical Laboratory (NCL) in Pune, India has embarked upon the development of a novel device for the controlled release of the larvacide ABATE (temephos) to mosquito-larvae infested water sources and the independent development of a device for the controlled release of the pesticide Furadan 3G (Carbofuran) to rice paddies to control primarily stem rot of the growing rice plants. A series of lectures were prepared and consulting sessions organized to provide a useful forum for the exchange of state-of-the-art methodologies related to the design and analysis of these two quite independent and well- conceived research and development projects.

The lectures which were presented were intended to provide a useful and common basis for the consulting sessions on the specific UNDP-supported research and development programs. The lectures were titled-

"A Generalized Theory Describing Transport in Polymeric Membranes Above and Below the Glass Transition Temperature" (Tuesday, 17 December 1985)

"The Relationship Between Transport in and Physical Aging of Glassy Polymers" (Wednesday, 18 December 1985)

"State-of-the-art of Controlled Release Technology" (Monday, 23 December 1985).

Ultimately, in-depth discussions were held related to analysis of device functionality and continued development of improved device designs. The discussions, lectures, and consultations were conducted during the period 15 December to 28 December 1985 and covered a variety of technologies for the design, analysis, and preparation of controlled release formulations based upon conventional membrane-reservoir methodologies as well as rather unconventional, swelling-controlled monoliths and osmotic pumping-based formulations. Emphasis was placed upon establishing rigorous procedures for the mechanistic analysis and field evaluation of the controlled release formulations. Ultimately, in addition to exchanging information on latest developments and current trends in controlled release technologies, detailed discussions were held to provide a basis for developing a rational understanding and, ultimately, rapid development of the device formulations currently under UNDP-supported study.

I. BACKGROUND AND PERSPECTIVE OF CONTROLLED RELEASE EFFORTS AT THE NATIONAL CHEMICAL LABORATORY

The National Chemical Laboratory has multi-disciplinary expertise in the fields of organic chemistry, physical chemistry, polymer chemistry, chemical engineering, polymer engineering, analytical chemistry, and entomology, all of which contribute to the technology of controlled release chemical formulations. This technology is comparatively new, being developed only during the seventies. The major fields of application at present are drugs and pest control agents. For the latter, such formulation whould be ideal from the viewpoint of environmental pollution as well as costs since such smaller dosages are required to keep sustained concentrations in the environment. Another great advantage is the much lower mammalian toxicity of such formulations of highly toxic pesticides. This makes handling and use much safer and easier.

The UNDP-sponsored efort at NCL has cleverly focused on the administration of biologically active materials to environments which offer predictably constant boundary conditions. The release of ABATE to mosquito-larvae infested waters and the release of carbofuran to rice paddies proceed at virtually constant temperature ($\pm$ 5^{o}C) and at a water activity of unity. In that regard, both projects have the unusual advantage of constancy of environmental conditions not typically common to contolled release formulations used in more conventional agricultural applications.

II. NATIONAL CHEMICAL LABORATORY RESEARCH AND DEVELOPMENT OF CONTROLLED RELEASE FORMULATIONS

A. Release of the mosquito larvicide ABATE (temephos) to mosquito-larvae infested waters

Approach

The device conception for the controlled administration of the larvacide ABATE to mosquito infested water sources is based upon a membrane-reservoir configuration, wherein the pure ABATE liquid is confined to a central reservoir bounded by relatively thick "membranes", protruding as two or more arms from the central reservoir. The rate controlling membrane material comprises aqueous polyacrylamide gels varying between 7-10% by weight in polyacrylamide concentration. The device functions by diffusion of the ABATE through the thick (ca. 2 cm) membrane-arms. The liquid ABATE equilibrates with the internal surface of the gel, presumably at a concentration near the equilibrium concentration (0.025 ppm) reported for ABATE in pure water. It is desired that the device maintain a concentration of 0.01 ppm in the infested water and, therefore, a concentration driving force between the reservoir and the infested water source equal to 0.015 ppm (0.025-0.01) will exist in the steady state. Controlled variation in release rate is obtained by varying the arm length (membrane thickness) and the area of contact of the active membranes with the polluted water source. In addition, polyacrylamide concentration in the gel is varied. Currently, the area is varied by increasing the number of otherwise identical arms protruding from the central reservoir. The arms are fabricated from polypropylene tubes surrounding the polyacrylamide gels.

Analysis and recommendations

The device functionality is based upon diffusion from a central reservoir of pure liquid ABATE through relatively thick 'membranes' of polyacrylamide gel. The relatively large ABATE molecule, with a molecular weight of 466, diffuses through the membrane arm which can be considered physico-chemically as a stagnant water layer immobilized within the arm by the gelling action of the polyacrylamide.

Since the arms are relatively long, the transients involved in the transport process from the reservoir to the polluted water source must be considered and, ultimately, may be cleverly exploited in modified device design and use. Specifically, if the device were used immediately after fabrication a lag based upon the relationship:

$$\theta = \frac{\ell^2}{6D}$$

would be expected wherein θ is the time lag to achieve the onset of steady state operation, ℓ is the membrane thickness (arm length) and D is the diffusion coefficient of ABATE n the polyacrylamide gel.

Alternatively, if the devices are stored (or controllably aged) before use, the ABATE concentration profile within the gel should approach uniformity and, therefore, the initial rate of release would be characterized by a burst rather than a lag since the initial concentration gradients at the downstream membrane surface would be initially steep, decaying to the steady-state gradient given by the steady concentration difference divided by the arm length.

The continuing research program should include explicit determination of the diffusion coefficient of ABATE in the poly-acrylamide gels. These independently determined diffusion coefficients will be critically important as design parameters in the continuing development of this particular device embodiment. Moreover, estimation of the diffusion coefficient will permit direct prediction of the magnitude of the time lag or the magnitude of the burst (depending upon storage conditions) and might provide useful guidance regarding appropriate protocols for storage of the devices before use.

The partition coefficient of ABATE into all device components, including especially the polypropylene arms, should be determined to estimate the fraction of the ABATE loaded into the device which might migrate into the structural polymeric components of the device.

Ultimately, the laboratory analyses and field testing should be complemented by model testing in, say, 20 gallon aquaria. These aquaria studies shuld be designed to test explicitly, and under controlled conditions, the effects of contaminating slimes, derived from algae and fungi. These model studies may ultimately suggest that appropriate biocides should be incorporated into the structural components of the controlled release device.

As an adjunct to this study, the development of swelling-controlled devices based upon monolithic, initially dry, glassy hydrogels containing dispersed ABATE, might be considered. This alternative approach might initially involve preparation of dried, ABATE-containing polyacrylamide gels, since the technical staff at NCL has a high degree of skill and experience working with this system.

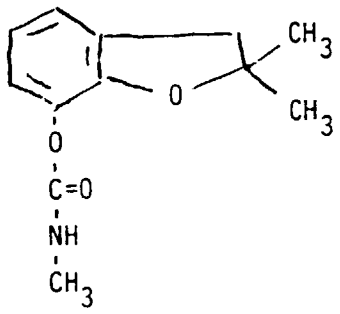
B. Release of Furadan 3G (Carbofuran) for the control of pests in rice paddies

Approach

The controlled release of carbofuran is accomplished by encapsulating the carbofuran microgranules in novel glassy polymeric coating formulations developed at the NCL. These coatings include xanthate crosslinked starch or urea-formaldehyde resins. In both cases, the coatings are glassy and are designed to encapsulate completely the carbofuran particles. The carbofuran is typically sold as a 3% active ingredient granule combined with inert material. The pure carbofuran has an equilibrium solubility in water of 700 ppm at pH 7 and cleaves hydrolytically at the amide linkage above pH 9. The carbofuran is conventionally used as a pesticide in rice cultivation at a level of 0.5 kg of active ingredient/hectare. In principle, controlled release formulations should reduce the amount of carbofuran used providing economic advantage since the carbofuran currently sells for 400 Rs./kg.

Analysis and recommendations

It would appear that the large carbofuran molecule represented structurally as:



would not diffuse at any significant rate through an intact glassy, polymeric encapsulant since the diffusion coefficients of even much smaller molecules in polymeric glasses are typically less than 10^{-16} cm^2/sec.

The observed release of carbofuran from these novel, micro-encapsulated systems, suggests one of the alternative mechanisms which are listed and discussed below.

(1) The particles may simply be incompletely encapsulated, significantly reducing the contact area between carbofuran and the water. In this case the reduced rate of release may be a simple consequence of the limited area available for direct dissolution of the pesticide.

(2) The carbofuran may be essentially coated, however, the coating may be microfissured. In this case water would diffuse across the intact portions of the glassy coating tending to dissolve the carbofuran. The osmotic driving force for dissolution could, in turn, lead to

distension of the encapsulating film or, alternatively, if the film has sufficient mechanical strength, controlled osmotic pumping through the microfissures in the surface coating would occur. The resulting release could be modelled predictably, in that case, as 'osmotic pumping' which is well known to the technology of controlled release formulations.

(3) The carbofuran may initially form an intact coating, however, after osmotic inhibition of water, the brittle, glssy encapsulating layer may microfissure _in situ_ under the influence of the osmotically induced pressure buildup in the confines of the originally intact surface coating.

In an attempt to confirm these various hypothesis, a laboratory effort should be initiated to confirm expicitly that carbofuran does not diffuse at any appreciable rate through the intact coatings under consideration. Moreover, the requirement for formulating carbofuran with 97% inert material should be exploited by varying the osmotic character of the otherwise inert material to moderate the osmotic pumping which may, in fact, control the observed sustained release of carbofuran from these formulations.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The UNDP supported project on controlled release technology is well conceived and completely consistent with the state-of-the-art of related technology worldwide. The two projects which comprise this overall programme involve release of biologically active components to virtually pure aqueous media under essentially isothermal conditions. In that regard, these projects enjoy special advantages related to constancy of boundary conditions, which are atypical for agricultural application of controlled release technology.

The scope of the project should include fundamental determination of the physico-chemical parameters which control or contribute to device performance. In that regard, these more fundamental studies might be considered for UNIDO/UNDP support at a university center of excellence of controlled release research in the United States with NCL students working toward their degree under the joint supervision of senior scientists at the NCL.

Field testing of the devices developed by NCL is an essential and lengthy process, since the basic devices will require modification and retesting after the feedback information is received from the field. It is strongly recommended, therefore, that the present project be extended by UNIDO/UNDP by at least three years to enable NCL to include mechanistic studies, pilot studies in controlled aquaria, and field studies in the comprehensive experimental plan.

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Dr. L. K. Doraiswamy offered more than courtesy and more than technical interest. He was a model host. The students at the NCL are, in turn, shining examples of ability and courtesy.

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