# Synthesis and Application of an Organotin Functionalised Highly Porous Emulsion-Derived Foam

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**Abstract:** A new type of organotin chloride catalyst supported on a highly porous polymer has been prepared by polymerisation of a highly concentrated reverse emulsion the organic phase of which contains several monomers. This polymer-supported organotin chloride shows a good activity and good stability towards dehalogenation and radical cyclisation.

**Keywords:** organotin hydride; polyHIPE; polymer supports; radical cyclisations.

The development of polymer-supported chemistry is one of the main features of modern organic synthesis. The supports generally used in these applications are based on lightly cross-linked styrene/divinylbenzene beads called gel resins. These resins have no permanent porosity and therefore are usable only in solvents effecting a good swelling of their polystyrenic structure, such as toluene or THF.[1] An impressive amount of work using these resins as supports of catalysts,[1] reagents,[3] and for solid-phase synthesis,[4] have been reported, generally on an analytical scale. The scale-up for preparative purposes (on a gram basis), may be problematic as the soft beads used are difficult to manipulate in batches as well as in continuous-flow column devices.[5]

The use of macroporous beads with a permanent porosity can be an alternative but is not completely satisfactory.[1] The approach consisting of synthesising macroporous monoliths in a column shape has been successfully proposed.[6] However, the poor permeability of these materials requires the use of high-pressure column operations and reduces their use for organic synthesis.

An alternative approach consists in the use of porous polymer foams having a high permeability to solvents which makes them usable in low-pressure, continuous flow methods.

These materials are well known and have been produced by a wide variety of techniques ranging from leaching soluble fillers through gas-blowing to phase separation, although the structure of these materials is often irregular and difficult to control. A novel method for producing porous materials with a more regular structure has been developed based on high internal phase emulsion (HIPE®). These foams were initially developed by Unilever[7] and called polyHIPE®. The characteristics and synthesis of these polyHIPE® materials have been reviewed recently.[8]

If one takes a liquid oil, introduces water and a suitable emulsifier with agitation, a dilute emulsion is produced with small water droplets dispersed within the oil phase, about the consistency of milk. If the amount of water (i.e., the internal or pore forming) phase is increased a concentrated emulsion will be formed and the consistency of the mixture changes into a more viscous fluid. As further water is introduced, a limit is reached where the droplets are so prevalent that they approximate a close-packed emulsion. This packing limit corresponds to 74% by volume and is the accepted definition of a high internal phase emulsion.[9]

The structure of the emulsion is now analogous to soap bubbles, with thin films surrounding and separating the droplets. If a polymerisable monomer was previously incorporated in the continuous oil phase in a water/oil high internal phase emulsion, then polymerisation of the monomer yields to a continuous polymeric matrix structure containing compartimentalised droplets of water. During the polymerisation step, holes are formed in the thin films separating the droplets, and an open structure is formed. The water is easily removed to produce a foam of the corresponding structure.

Styrene-divinylbenzene polyHIPE® polymers have been studied fairly extensively, and conditions for the control of their cellular structure[10] and cell size[11] are well documented. The preparation of poly(styrene-co-alkylmaleimide)[12] and poly(aryl ether sulfone)[13] foams was also reported. 4-(Chloromethyl)-styrene can be inserted without destabilising the styrene/divinylbenzene emulsion.[14] However, the major part of the functionalised polyHIPEs presented so far, has been prepared by chemical modification of a styrene-divinylbenzene precursor.[15]

Free-radical reactions such as dehalogenation of alkyl, vinyl or aryl halides, often followed by intra- or intermolecular C-C bond formation are in increasing use in organic synthesis[16] since a large variety of functional groups is tolerated, avoiding laborious protection and deprotection sequences. However, the toxicity of tributyltin hydride, the most commonly used radical source implicated in these reactions, is now well established.[17] This drawback strongly limits the development of its use in the synthesis of pharmaceutical derivatives. Several alternatives to tributyltin hydride have been proposed. Amongst them, tris(trimethylsilyl)silane,[18] and its thiol derivative,[19] seems the more promising. A review of these alternatives to tin has been published recently.[20] However, a total substitution of organotin hydride by other, more innocuous radical sources seems, at the present time, improbable but a credible alternative could be the use of polymer-supported organotin hydrides.[21,22]

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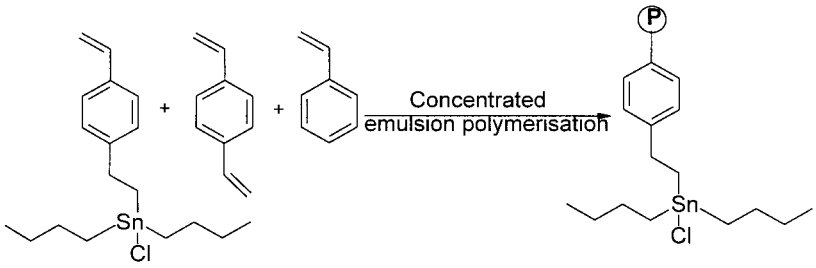



**Scheme 1.** Preparation of a polyHIPE®-supported organotin chloride.

We present here our preliminary results concerning the preparation of an emulsion-derived foam obtained from 4-ethyl-(2-dibutylchlorostannyl)styrene[23] **(1)** as the functional monomer (Scheme 1).

A scanning electron micrograph of the resulting material is shown in Figure 1.

Note the 5 – 20 μm cells formed by the temporary pore former and the large number of 2 – 5 μm "windows" between adjacent cells. The characteristic dimension of the cell diameter (about 10 μm) is to be compared with the characteristic pore diameter (about 10 nm) of the macroporous resins.[24] The general range of measurement/properties of the emulsion-derived foam prepared may be summarised as follows:

- macroscopic density as low as 0.05 g/cm$^3$,
- internal void volume about 95%, i.e., 95% pore volume/5% polymer,
- fully interconnected uniform structure, with every cell being connected to all its neighbours.

The loading in SnCl moieties (0.6 mmol/g) is of the same order as with classical gel-type or macroporous beads.[22] The polyHIPE®-supported organotin chloride has to be reduced in its organotin hydride counterpart in order to be used as a mild and selective dehalogenation reagent.[15] The amount of SnH formed onto the polymer was estimated by using the obtained polyHIPE®-supported tin hydride in the reduction of bromodecane to decane. This reaction is known to be rapid and quantitative with $Bu_3SnH$,[15] so the amount of decane formed (as estimated by GC using an internal standard) in conjunction with the amount of bromine grafted on the polymer (estimated by elemental analysis) was considered to be equivalent to the level of accessible SnH moieties present on the support. The analysis of the recovered polymer after use gave 0.3 mmol/g of Cl and 0.3 mmol/g of Br. These results are in quite agreement with the conversion of decane observed (53%). Therefore, about 50% of the SnCl bonds initially present on the support were transformed to Sn-H by $NaBH_4$, the remaining chlorine atoms being probably too deeply buried inside the non-porous walls of the material to be easily accessible to the reducing agent.

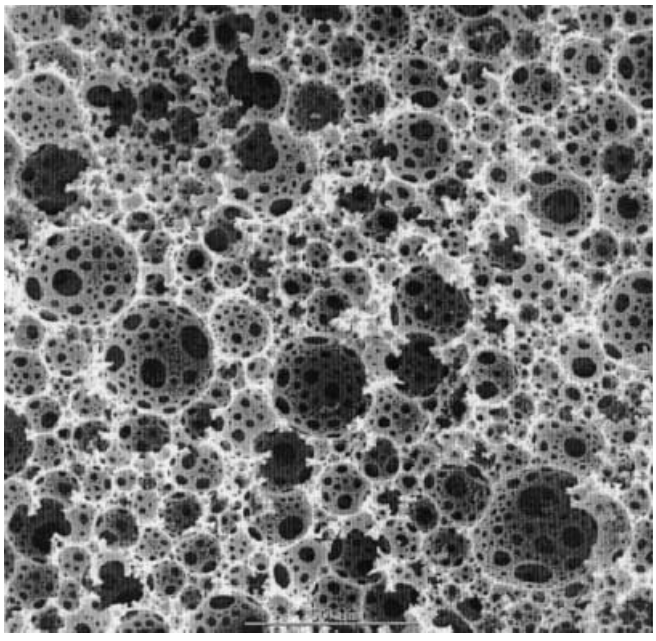
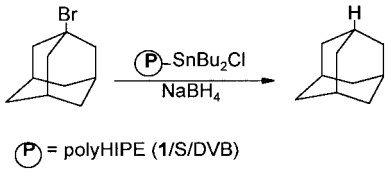


**Figure 1.** Scanning electron micrograph of a polyHIPE-supported organotin chloride.

The activity and stability to recycling of our support was tested in the reduction of bromoadamantane to adamantane by organotin chloride. In order to reduce the volume of low-density material involved, we performed this reaction using our polymer-supported organotin chloride as a catalyst (10 mol % in SnCl moieties). The active species, the organotin hydride, was generated *in situ* by using sodium borohydride (2 equivalents) as the recycling reducing agent. The initiator used is AIBN (0.05 equivalents) (Scheme 2).

The first use of our support gave a quantitative yield of adamantane in 30 min. Successive reuses of the polyHIPE®-supported catalyst were performed by addition, after completion of the reaction (30 min, followed by GC), of another portion of bromoadamantane (1 equivalents, 0.25 mmol), $NaBH_4$ (2 equivalents) and AIBN (0.1 equivalents). The reaction was then performed in the same conditions without isolation of the support. Five successive reuses could then be performed without noticeable loss of activity (Figure 2).

After run no. 6, the conversion in 30 min was limited to 70% probably due to the obstruction of the cells with the by-




**Scheme 2.** Catalytic reduction of 1-bromoadamantane with $NaBH_4$ and polymer-supported organotin chloride.

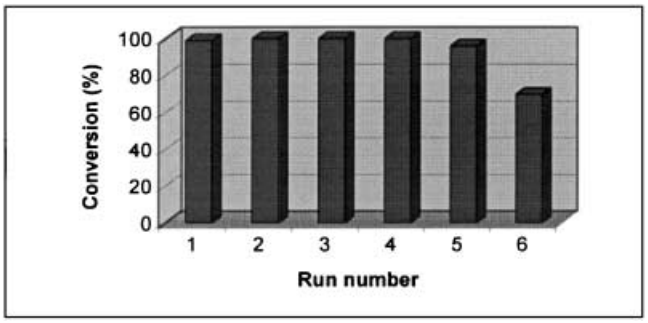
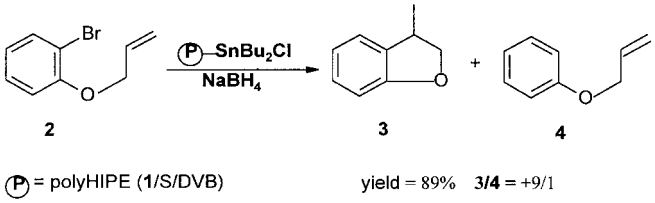



**Figure 2.** Catalytic stability of the polymer-supported organotin chloride performed with the reduction of 1-bromoadamantane.

products of the reduction. The polymer was then filtered, washed with water, ethanol and then ether before being reused as previously. The conversion in 30 min then reached over 90%. The activity and stability of the polyHIPE®-supported organotin hydride presented here are better than those of macroporous beads synthesised using the same organotin monomer.[23]

Having demonstrated the efficiency of our polyHIPE®-organotin hydride, we used it to study the radical cyclisation of 1-bromo-2-(prop-2-enyloxy)benzene (**2**). This reaction is usually performed using the tributyltin hydride and gives a mixture of 5-membered ring cyclised (**3**) and dehalogenation (**4**) products (Scheme 3).[25]




**Scheme 3.** Catalytic radical cyclisation of **4** by using $NaBH_4$ and polymer-supported organotin chloride.

The reaction works well with a selectivity toward the product of cyclisation comparable with the one obtained with $Bu_3SnH$[25] and with an excellent yield (89%).

In summary, we have described in this communication a new type of organotin chloride catalyst supported on a polyHIPE polymer showing a good activity towards dehalogenation and radical cyclisation. This highly porous support could be a credible alternative of classical gel-type or macroporous beads in terms of activity of the grafted catalysts due to a better diffusion inside the polymer matrix. We are currently developing a low-pressure continuous flow application of this functional monolith.

## Experimental Section

### Synthesis of 4-Ethyl-(2-dibutylchlorostannyl)styrene (1)

A two-necked flask was charged with *p*-DVB (18.2 g, 140 mmol) synthesised as described previously,[23a] dichlorodibutyltin (10.5 g, 34 mmol) and AIBN (280 mg, 1.7 mmol). The flask was purged with $N_2$ and dibutyltin dihydride (8.13 g, 34 mmol) was added dropwise keeping the reaction temperature below 30 °C. The mixture was stirred overnight and the unreacted *p*-DVB was evaporated under vacuum ($bp_{0.5} = 45$ °C) to give 27.7 g of a grey oil containing a mixture of the mono- and dihydrostannation products (molar composition 85/15% as estimated by $^1$H NMR). This mixture was used in the polymerisations without further purification. $^1$H NMR (main product; $CDCl_3$, 250 MHz): $\delta = 7.4 - 7.2$ (m, 4H, Ar), 6.7 (dd, 2H, =C−H−Ar, $^3J_{trans} = 18$ Hz, $^3J_{cis} = 10$ Hz), 5.7 (d, 2H, $H_{trans}$C=C−Ar, $^3J_{trans} = 18$ Hz), 5.2 (d, $H_{cis}$ C=C−Ar, $^3J_{cis} = 10$ Hz), 2.9 – 3.0 (m, 2H, Ar-$CH_2$), 0.8 – 1.8 (m, 20H, aliphatic).

### Typical Preparation of a PolyHIPE-Supported Organotin Chloride

4-Ethyl-(2-dibutylchlorostannyl)styrene (**1**; 2 mmol), divinylbenzene (80% commercial solution, 7 mmol), styrene (30 mmol) and sorbitan monooleate (Span® 80; 0.4 g) were placed in a reactor. The mixture was stirred with a rod fitted with a D-shaped paddle, connected to an overhead stirrer motor, at approx. 300 rpm. The aqueous phase was prepared separately by dissolving the initiator potassium persulfate ($K_2S_2O_8$; 1.0 g) and sodium chloride (NaCl; 1.5 g) in distilled water (100 mL). 95 mL of this solution were added, dropwise, under constant mechanical stirring, to the organic solution in order to obtain a thick white homogeneous emulsion without apparent free water. Once all the aqueous phase had been added, stirring was continued for a further 15 min to produce an emulsion as uniform as possible. The high internal phase emulsion was then placed in a 150-mL polyethylene bottle as polymerisation mold. The HIPE was then polymerised by immersing the plastic bottle in a waterbath, thermostatted at 60 °C for 10 hours. The container was then cut away to collect the resulting polymeric monolith. This was extracted with acetone in a Soxhlet apparatus for 48 hours then was dried under vacuum at 60 °C for 48 hours. The resulting monolith was cut in cubes (approx. 5 mm per side). A loading of: 0.6 mmol of Sn and 0.58 mmol of Cl per gram of dry material was determined by elemental analysis.

### Use of PolyHIPE-Supported Organotin Chloride for the Reduction of Bromoadamantane

A 25-mL, three-necked flask was charged with polymer-supported organotin chloride (1.0 g, 0.6 mmol · g$^{-1}$ of Sn-Cl), bromoadamantane (1.3 g, 6 mmol) and ethylene glycol dimethyl ether (10 mL). The solution was purged with argon, then AIBN (50 mg, 0.3 mmol) and sodium borohydride (0.46 g, 12 mmol) were added. The suspension was gently stirred at 80 °C until completion of the reduction (about 30 min as estimated by GC). A fresh portion of bromoadamantane (6 mmol) was then added to the reactor and the reaction monitored again. Five successive reuses were performed in this way.

### Use of PolyHIPE-Supported Organotin Chloride for the Cyclisation of 1-Bromo-2-(prop-2-enyloxy)benzene (2)

A 50-mL, three-necked flask was charged with polymer-supported organotin chloride (1.2 g, 0.7 mmol · g$^{-1}$ of Sn-Cl), **2** (1.5 g, 7 mmol) and ethylene glycol dimethyl ether (20 mL). The solution was purged with argon, then AIBN (50 mg, 0.3 mmol) and sodium borohydride (0.53 g, 14 mmol) were added. The suspension was gently stirred during one hour at 80 °C. The mixture was then filtered and washed with ether (3 × 20 mL). 30 mL of water were added to remove $NaBH_4$ residue. The aqueous phase was extracted with ether (2 × 30 mL). The organic phases were combined and

concentrated to afford 1 g (89%) of a 9:1 mixture of **3** and **4** as determined by GC analysis.

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