

Fluorous Biphasic Catalysis

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In recent years the pursuit of more economical chemical processes has inspired researchers to design catalytic systems that combine the high selectivities and mild reaction conditions of homogeneous catalysis with the easy separation of catalyst and product afforded by heterogeneous catalysis. The concept of biphasic catalysis has been developed to address this issue. Biphasic catalytic systems, like the Ruhrchemie/Rhône-Poulenc commercial process,¹ employ a homogeneous catalyst that has been modified in order to make it preferentially soluble in a phase separate from the substrate and product.

The unique properties of perfluorocarbon fluids have attracted attention as possible solvents to be used in biphasic systems.² For instance, some mixtures of perfluorocarbon and hydrocarbon liquids have been shown to form a homogeneous mixture upon heating (Figure 1). Under these conditions a reaction occurs in a homogeneous environment. Upon completion, the reaction mixture is cooled and the system again becomes biphasic. The products are collected from the hydrocarbon phase and the catalyst in the fluorocarbon phase is recycled.³

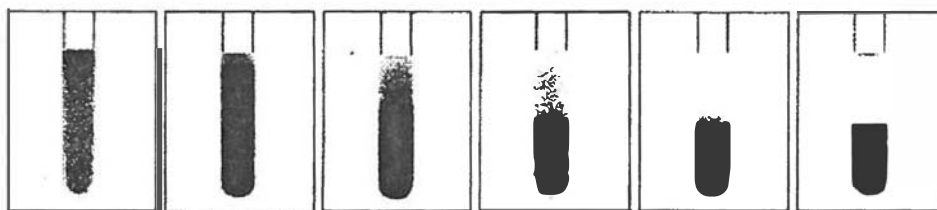


Figure 1. Phase separation of a hand-warmed n-hexane/toluene/perfluoromethylcyclohexane mixture upon cooling from 36.5°C to ~25°C.⁶

Typically, the transition metal catalyst has two or three highly fluorinated alkyl or aryl phosphine ligands coordinated to the metal center. The structure of the ligands (Figure 2) should allow the catalyst to be preferentially soluble in the fluoruous phase,⁴ and should not alter the structure and thus the activity and selectivity of the catalyst.⁵ Spacer groups, usually methylene or aryl groups, are located between the phosphorus atom and the fluorocarbon tail of the ligand in order to insulate the phosphorus-metal bond and the metal center from the electronegative fluorines.

Horváth and Rábaj, published a seminal study involving the use of $\text{HRh}(\text{CO})\{\text{P}[(\text{CH}_2)_2(\text{CF}_2)_5\text{CF}_3]_3\}_3$ as a hydroformylation catalyst in a fluorous biphasic system.⁶ They demonstrated the hydroformylation of primary alkenes to aldehydes as well as the facile separation and recycling of the catalyst. In a later study they extended the hydroformylation to smaller alkenes such as ethylene as well as higher alkenes like 1-octene and 1-decene.⁷

Foster et. al. have studied the effects of different fluorinated triarylphosphite and triarylphosphine ligands on the catalytic activity of related rhodium(I) catalysts.⁸ They found significant catalyst and ligand leaching into the organic phase when using, e.g. $P(OC_6H_4-p-(CF_2)_5CF_3)_3$. They also observed the production of $HOC_6H_4-p-(CF_2)_5CF_3$, which they attributed to a side reaction occurring between the product aldehyde and the phosphite ligand.

Richter et. al. have synthesized fluorous versions of Wilkinson's catalyst, e.g. $RhCl[P(C_6H_4-p-SiMe_2(CH_2)_2(CF_2)_7CF_3)_3]$. The catalyst is active in the hydrogenation of 1-alkenes and is comparable in activity to $RhCl(PPh_3)_3$.⁹ de Wolf et. al. have synthesized a different type of fluorous catalyst that is active in the hydrogenation of 1-alkenes and 4-alkynes.¹⁰ Their catalyst, $[Rh(cod)(L\sim L)][BX_4]$ ($X = F, Ph$), where $L\sim L$ is a fluorous derivative of 1,2-bis(diphenylphosphino)ethane, is one of only a few fluorous phase-soluble ionic complexes. Chechik and Crooks have demonstrated the feasibility of using dendrimer-encapsulated Pd nanoparticles for catalysis in a fluorous biphasic system.¹¹ The encapsulated nanoparticles are made soluble in a fluorous solvent by reacting the amine end group of the dendrimer with the carboxylic end group of a perfluoropolyether.

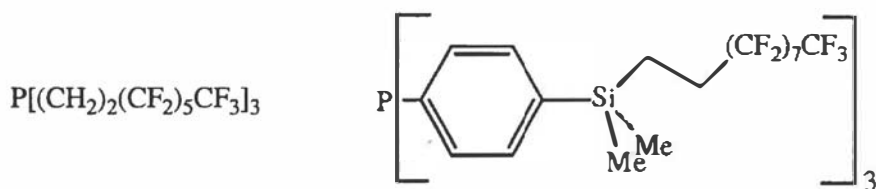


Figure 2. Examples of fluorinated phosphine ligands.

Fluorous biphasic catalysis has been demonstrated for many other catalytic reactions. Some examples are hydroboration,¹² hydrosilylation,¹³ and Stille coupling.¹⁴ However, this list is likely to continue to grow as interest increases in this area. Further research must be done in order to optimize current systems and reduce costs in order to bring promising systems to commercial practice.

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