CHEMISTRY LETTERS, pp. 1237-1240, 1982. © The Chemical Society of Japan 1982

SILICA GEL-ASSISTED TWO-PHASE AZO-COUPLING REACTIONS

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Commercially available wet silica gel facilitated the solid-liquid two-phase reactions of p-nitrobenzenediazonium tetrafluoroborate with aromatic amines to afford the corresponding azo-products in excellent yields. The silica gel could be recovered for reuse. The dependence of the yields on amounts of water impregnated on silica gel was discussed.

In recent years, considerable attention has been given to phase transfer catalysts improving two-phase acid-catalyses or electrophilic reactions.1) Ellwood and Griffiths have reported for the first time that an azo-coupling reaction is promoted by sodium dodecylbenzenesulfonate (SDBS) acting as a phase transfer catalyst for the diazonium cation.2) However, such surfactant as SDBS has been acknowledged to have a common disadvantage: the isolation of products and reuse of these catalysts are particularly difficult due to their strong tendency to emulsify the reaction mixture. More recently, Kobayashi and the coworkers have reported that tetrakis[3,5-di(F-methyl)phenyl]borate is an efficient phase transfer catalyst for the azo-coupling reaction.3) Although this system seems to be quite promising without emulsification, the catalyst is not commonly available. In order to overcome the drawback of these processes, we have made a search for catalysts of insoluble type. This report describes the successful use of silica gel as a diazonium salt activator for a solid-liquid interfacial azo-coupling reaction. Silica gel itself has an apparent advantage for the simplicity of its handling and recycling, and thus is of current widespread interest as catalysts or supports.4) Activation by solid supports has been offered as an attractive alternative to phase transfer catalyst in organic synthesis.

A typical reaction procedure is as follows: To a solution of aromatic amine (2 mmol) in 50 ml of CH_2Cl_2 solid p-nitrobenzenediazonium tetrafluoroborate (1 mmol) and silica gel[5)] were added. Reactions were allowed to proceed at 3°C under constant stirring. After the reaction was completed, the mixture was filtered to remove the silica gel. The preparative TLC separation of the filtrate afforded the azo product. The results thus obtained are summarized in Table 1. For comparison, the reaction with SDBS in a CH_2Cl_2-H_2O system was duplicated according to the procedure of Ellwood and Griffiths, and these results are given in Table 2.

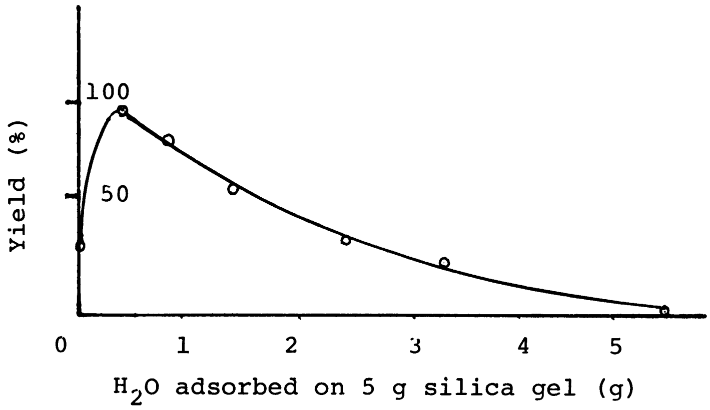
Table 1. Yields of azo products for the reaction of p-nitrobenzenediazonium tetrafluoroborate[a)] in the presence of silica gel at 3°C

Substrate[b)]	Silica gel,[5)] g	H_2O added,[c)] g	Solvent[d)]	Reaction time, d	Isolated yield, %
N-Et-carbazole	0		H	2	0
	5		H	2	20.6
	0		B	2	0
	5		B	2	33.4
	0		C	2	7.0
	1		C	1	39.2
	2.5		C	1	54.5
	5		C	1	91.3
	5 (reused)		C	1	93.6
	10		C	1	95.4
	5[e)]	-0.28	C	1	34.6
	5	+0.40	C	1	85.0
	5	+0.90	C	1	65.3
	5	+2.3	C	1	35.1
	5	+3.0	C	1	25.0
	5	+5.0	C	1	2.3
N,N-di-Me-aniline	10		C	1	79.7
Phenol	10		C	1	84.7

a) 1 mmol. b) 2 mmol. c) Unless otherwise noted, silica gel was a commercially available one and contained 4% of H_2O. d) H: hexane; B: benzene; C: CH_2Cl_2.
e) Prepared by stripping H_2O under a vacuum of 1 mmHg at 100°C for 1 h.

Several points are worth noting from Table 1. The first and interesting observation is that the reaction using silica gel is less sensitive to changing reaction medium than that of the corresponding liquid-liquid surfactant-catalyzed reaction (Table 2), undoubtedly suggesting that the reaction has occurred at solvent-silica gel interfaces. Thus, the azo-coupling can be carried out in non-polar solvents such as benzene and even in hexane. On the other hand, the use of polar solvents, for example, acetone and acetonitrile results in formation of a complicated reaction mixture and hence remarkable low yields of the azo product. Second, the yields increase as the used amounts of silica gel (containing 4% H_2O) are increased, the best yield ($>$ 95% of isolated yield) being obtained on use of 10 g of silica gel after 24 h.$^{6)}$ Third, the dependence of the yields on amounts of impregnated H_2O is quite important; when dried silica gel which was considered to have no physically adsorbed H_2O was employed,$^{7)}$ the yield was reduced to only 35%. As limited amounts of H_2O was added, the yield was increased up to a maximum at which the H_2O quantity was 4% by weight, beyond which addition of further H_2O decreased the activity, and too high H_2O concentration ($>$100%) completely deactivated the catalyst. The feature is illustrated in Fig. 1.

Fig. 1. Effect of amounts of H_2O on the yield



The important role of small but finite amounts of H_2O in solid-liquid phase transfer processes has been well documented by several workers:$^{8)}$ small amounts of H_2O solubilizes an inorganic salt at silica surfaces, and thereby facilitates the PTC reactions. In contrast, addition of a large amount of H_2O floods the surfaces to form a thick H_2O layer, leading to the decreased reactivity. Accordingly, the azo-coupling is visualized as taking place at organic solvent-adsorbed H_2O interfaces, as illustrated in Fig. 2. The H_2O makes the salt compatible or come in contact with the organic phase, and activates the diazonium cation.

In conclusion, this study demonstrates an advantageous utilization of silica gel as an alternative to organic phase transfer catalysts for activating a diazonium cation. A small but finite amount of water adsorbed on silica surfaces affects profoundly its activity. Extension of these studies to other electrophilic reactions is under current investigation in these laboratories.

Fig. 2.

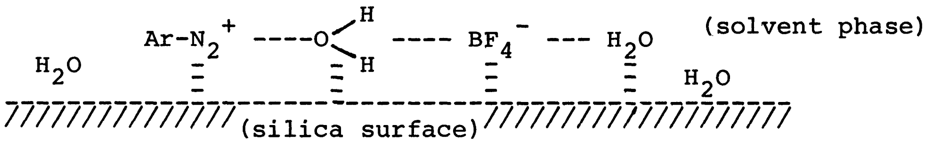


Table 2. Azo-coupling of N-ethylcarbazole[a] in organic solvent-H_2O at 3°C

Catalyst	Solvent[c]	Reaction time, d	Isolated yield, %
none	C-W	1	0
SDBS[b]	C-W	1	8.8
	C-W	2	22.9
	C-W	7	54.3
	H-W	2	0
	B-W	2	1.6

a) N-Ethylcarbazole, 2 mmol; p-nitrobenzenediazonium tetrafluoroborate, 1 mmol.
b) 0.2 mmol. c) 1:1; 50 ml; C: CH_2Cl_2; H: hexane; W: H_2O.

Ackowledgement. This research was supported in part by a Grant-in-Aid for Special Project Research from the Ministry of Education, Science, and Culture, Japan.

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5) Wakogel C-300 purchased from Wako Pure Chemical Industry, LTD, Tokyo.
6) Under the identical conditions, aluminas and celite gave only low yields of <5% and 11%, respectively, and addition of a trace of H_2O did not improve the yields.
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(Received May 27, 1982)