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Synthesis of *m*-Phenoxybenzaldehyde Starting from Chlorobenzene and *m*-Cresol: Some Aspects of Process Development

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Abstract:

m-Phenoxybenzaldehyde (MPB) is an important intermediate for synthetic pyrethroids. In the present paper, an economic process scheme was developed to synthesize MPB starting from cheaper reactants. The process scheme was started with the synthesis of *m*-phenoxytoluene (MPT). Oxidation of MPT by air gave MPB, but the selectivity was found to be high at low conversions of about 10%, and if the conversion level was increased, then large amounts of the undesired *m*-phenoxybenzoic acid (MPBA) was formed. To obtain the desired aldehyde, Rosenmund reduction of MPBA was carried out to give high yields of the MPB. The effects of different parameters such as catalyst, substrate concentration, temperature, etc., were studied for all three of the reactions, *viz.*, Ullmann ether synthesis, oxidation, and Rosenmund reduction. MPT was prepared from chlorobenzene, a relatively cheaper starting material, in the presence of poly(ethylene glycol) as cosolvent and cuprous chloride as the catalyst. A selectivity of 97% was obtained with 86% conversion to the product. Oxidation of MPT was carried out by air in the presence of cobalt acetate as catalyst and sodium bromide as catalyst promoter. The selectivity with respect to the aldehyde and the ester was 37.4 and 30.6%, respectively, at a restricted overall conversion of 24%. The process parameters were controlled to achieve high selectivity towards the aldehyde. The acid, formed as the side product, was reduced to the aldehyde by Rosenmund reduction via the acyl chloride. At a conversion level of 85%, a selectivity of 87% to MPB was obtained using Pd/C.

Introduction

m-Phenoxybenzaldehyde (MPB) is an important intermediate for the manufacture of synthetic pyrethroids which have high negative insecticidal activity specially for army worms and are also herbicidal antidotes for cotton and legumes. MPB can be prepared by (1) starting from benzaldehyde—the formyl group is protected with aluminum trichloride followed by bromination. The complex is deprotected with dilute acid. *m*-Bromo benzaldehyde is then protected with ethylene glycol for Ullmann condensation, with a salt of phenol; by (2) side-chain bromination of *m*-phenoxytoluene (MPT), followed by hydrolysis of mixture of benzal/benzyl halide; or by (3) liquid-phase air oxidation of MPT by air. In the first method, the protection and then deprotection increases the number of steps and also the cost of the process. In the second method, due to the high cost of bromine involved it was not an attractive process. The latter method, air oxidation of MPT, was chosen as it would be a relatively cheaper method.

MPT, the starting material for our process scheme, is costly; therefore, it was also prepared in an economic way so as to make over-all, a cheaper process scheme. In the present work it was found that the yields of oxidation of MPT to MPB were poor as acid is formed as the byproduct, aldehyde being more susceptible to oxidation than its toluene derivative. The acid formed was converted to aldehyde by Rosenmund reduction. Thus, an attractive process scheme for the synthesis of MPB can be suggested starting from halo benzene and *m*-cresol (Figure 1).

MPT can be synthesized by Ullmann condensation of a phenolic salt of *m*-cresol with halobenzene in the presence of copper salts as catalysts. The chemistry of the Ullmann reaction is well known as it involves the attack of nucleophile and results in the cleavage of the carbon—halogen[1] bond. The ease of substitution of the halogen atom decreases[1] in the order I > Br > Cl > F. The condensation is carried out with copper[2,3] or its salts, which serves as the catalyst, by complexing with the aromatic halide. Generally, reaction rates are very low due to the overall heterogeneous system; therefore, organic aprotic solvents[3,4] containing heteroatoms such as N, O, and S, for example, pyridine, quinoline, diglyme, dimethyl sulfoxide, etc., are employed in the condensation reaction for dissolving the cuprous chloride and thus make the system homogeneous. The solvent and the system must be completely free from water as the coordination of the hydroxide ion with copper causes depletion of the true catalytic species.[2] The emphasis was on using chlorobenzene which is relatively cheap and readily available compared to bromobenzene. Also the possibility of using any other cosolvent such as PEG instead of other costly solvents was explored. An attempt was also made to vary the process conditions so that high selectivities are obtained at higher conversion levels.

For the autoxidation[5] of MPT to MPB by air the catalyst used is reduced during the reaction which is then oxidized by air in the redox chain system. Lower saturated fatty acids[6] such as acetic acid,[5,7–9] its anhydrides, or the corresponding acid[10] which is formed as the byproduct itself can be used as the solvent. The catalysts generally used are cobalt

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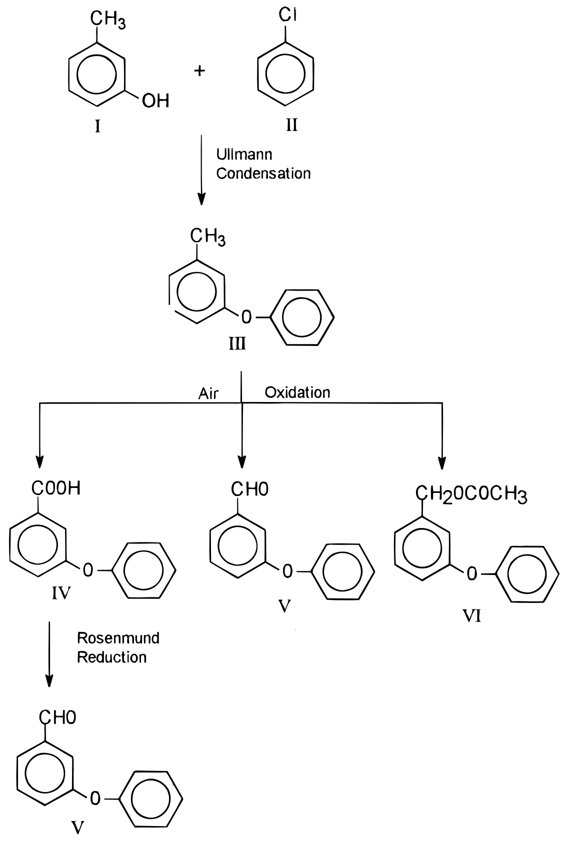

I - *m*-Cresol
II - Chlorobenzene
III - *m*-Phenoxytoluene
IV - *m*-Phenoxybenzoic acid
V - *m*-Phenoxybenzaldehyde
VI - *m*-Phenoxybenzyl acetate

Figure 1. **Process scheme for synthses of *m*-phenoxybenzaldehyde. (I) *m*-Cresol, II chlorobenzene, (III) *m*-phenoxytoluene, (IV) *m*-phenoxybenzoic acid, (V) *m*-phenoxybenzaldehyde, (VI) *m*-phenoxybenzyl acetate.**

acetate,[7,9] manganese acetate,[8] copper acetate,[7] etc. Catalyst activators/promoters such as methyl ethyl ketone or ozone,[8] hydrogen bromide,[11] sodium bromide,[7,12] paraldehyde,[12] hydrogen chloride, etc. are used. The temperature and time of the reaction which are important in deciding the aldehyde selectivity as given by the patentees are in the range 50−120 °C[6−9,12] and 2.8 min to 5[6,7] h, respectively.

Patent literature also reports the preparation of MPB from either *m*-phenoxybenzoic acid (MPBA) or its esters using zirconium or its oxide[13] containing an element[13,14] selected from Cr, Co, In, Re, Pb, Mn, or Mg. Another patentee has carried out the hydrogenation over vanadium[15] catalysts such as V_2O_5 supported on Al_2O_3, TiO_2, or SnO_2. These reductions require high temperatures of about 375 °C.[14,15] The specific reduction of *m*-phenoxybenzoyl chloride to MPB by Rosenmund reduction[16] with supported Pd was not reported in the literature. Rosenmund reduction was chosen, as it can be done even at room temperature instead of at vapor phase as mentioned by other patentees.

The present paper was an attempt to synthesize MPB, starting from cheaper reactants so as to make the over-all process economic and industrially workable. An attempt was also made to vary the process conditions so that high selectivities at higher conversions could be obtained from the viewpoint of process research and development.

Experimental Section

Materials. *m*-Cresol, chlorobenzene, bromobenzene, potassium hydroxide, toluene, cobalt(II) acetate, copper acetate, acetic acid, thionyl chloride, *N*,*N*-dimethyl formamide (DMF), PEG-4000 (laboratory grade, from S. D. Fine Chemicals, India); sodium bromide − analytical grade; cuprous chloride (prepared in laboratory − cupric chloride, hydrochloric acid and sodium bisulfite)*;* toluene (used for Rosenmund reduction): AR grade toluene − dried by refluxing with sodium metal; Palladium on charcoal − procured from Hindustan Platinum Ltd. Bombay (Type C-1025/C−III).

1. Synthesis of *m*-Phenoxytoluene (MPT). Experimental Setup and Procedure. Predetermined quantities of *m*-cresol (8.3 g) and potassium hydroxide (5 g) in 3 mL of distilled water were taken in a 100 mL capacity, borosilicate round-bottom flask. The contents were stirred for 0.5 h. A Dean−Stark apparatus with the condenser was fitted on the flask, toluene was added to the reaction mixture. The reaction mixture was azeotropically refluxed for 20 h, to ensure almost complete removal of water. The solid, potassium *m*-cresolate, obtained after distillation of toluene was immediately transferred to the hastelloy autoclave (Parr Instrument Company, U.S.A.) of 100 cm^3 capacity. The autoclave was equipped with a magnetically driven, six-bladed turbine impeller, electric heater, two baffles, and a cooling coil. The pressure gauge, pressure release valve, safety head port, and sampling valve were all situated on the top head. Temperature was measured by a chromium−aluminum thermocouple inserted in a thermo-well and regulated by a temperature indicator controller.

Predetermined quantities of halobenzene and the catalyst were charged in the autoclave. The reaction temperature was maintained at ±1 °C of the desired value by controlling the flow rate of cooling water in the internal coil and the heating rate. Agitation was started. The time of reaction was reckoned after the desired temperature was attained.

Workup and Isolation of the Product. After the completion of the reaction, about 800 mL of distilled water was added to the contents to dissolve the potassium chloride, which was formed during the reaction. A large amount of water was added, to avoid any solubility of organic material in the aqueous medium due to PEG-4000. Dilute sodium

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hydroxide was added to make the reaction mixture alkaline. The reaction mixture was then filtered to remove the catalyst. The two layers were then separated. The aqueous layer was used for analyzing the chloride content. This layer also contained unreacted *m*-cresol which was obtained by acidification of the aqueous layer and then by extraction with ether, while the organic layer containing the product was analyzed by gas chromatography.

Analysis. The aqueous layer was analyzed by Volhards method.[17] The amount of the chloride obtained by this method was corrected for the amount of the catalyst added as cuprous chloride. The analysis of the organic layer was done by gas chromatography (GC)(Chemito 8510), using diphenyl oxide as an internal standard. The GC column and conditions used were as follows: column used, stainless steel, 3.2 mm i.d. ×2 m; packing, 10% SE-30 on Chromosorb-W; carrier gas, nitrogen; flow rate, 30 mL/min; detector, FID; oven temperature, 150 °C; 2 min.; 10 °C/min to 300 °C; 5 min; injector temperature, 300 °C; detector temperature, 300 °C. The amount of *m*-phenoxytoluene determined by Volhards method matched with that obtained by G. C.

2. Synthesis of *m*-Phenoxybenzaldehyde (MPB) by Air Oxidation. Experimental Setup. The reactions were carried out in a 750 mL capacity, bubble column reactor. The reactor consisted of a stainless steel tube of 5 cm inside diameter and 44 cm length. It was provided with an air sparger, a thermometer pocket, a pressure gauge and a vertical water condenser. The reactor was heated, when necessary, by use of a Nichrome heating element wound on the reactor, and the heat input was controlled by a "Varaic". With proper manipulation of heat input, it was possible to maintain the desired temperature in the reactor within ±5 °C. A compressor was used for supplying air. The pressure inside the reactor and the air flow rate was controlled by means of needle valves provided at the inlet and the outlet of the reactor. A calibrated rotameter was provided at the exit to measure the air flow rate.

Experimental Procedure. Predetermined amounts of the catalyst and the substrate were mixed with the solvent, and the solution was shaken thoroughly to make it homogeneous. The reactor was then kept at the desired temperature, and the flow of air was started. After the reaction was allowed to proceed for predetermined period, the reactor was cooled to room temperature and the pressure was released.

The major products of the reaction were the aldehyde, the carboxylic acid, and the acetate. The reaction mixture was filtered and distilled under vacuum to remove solvent. It was then diluted with water and the organic compound extracted in toluene. The organic layer was washed with water for further analysis.

Analytical Section

Analysis of Aldehyde Formed in the Reaction by Oximation. In a typical procedure, an accurately measured organic layer was diluted with methanol, and the pH of the solution was adjusted to 3.0. For measuring the pH, an electronic pH meter (Chemito) was used. A solution of hydroxylamine hydrochloride in 90% methanol was made, and the pH was adjusted to 3.0 separately. Both solutions were mixed and kept at 45 °C for 1 h.

The liberated HCl was titrated potentiometrically to pH 3.0 using 0.1 N sodium hydroxide solution.

Analysis of Acid Formed in the Reaction. The carboxylic acid present in the reaction mixture was analyzed by diluting a sample with water and extracting with ether. The combined ether extracts were washed with aqueous sodium bicarbonate solution to extract the carboxylic acid as sodium salt. The aqueous layer was neutralized with mineral acid to precipitate the carboxylic acid. The latter was dried and weighed. If the acid formed was low, then the ether extract after washing with water was titrated with standard methanolic sodium hydroxide to estimate the carboxylic acid.

Analysis of Ester and unreacetd *m*-Phenoxytoluene. *m*-Phenoxybenzyl acetate, and unreacted MPT were analyzed by gas chromatography (GC), as before. The analysis was done using diphenyl oxide as an internal standard.

3. Synthesis of *m*-Phenoxybenzaldehyde (MPB) by Rosenmund Reduction. *(a) Preparation of Acid Chloride of* m-*Phenoxybenzoic Acid. Experimental Procedure and Setup.* The carboxylic acid (107 g), thionyl chloride (90 g), toluene (600 mL) and *N*,*N*-dimethylformamide (2 mL) were charged in the reactor. The reaction mixture was refluxed at 80 °C in a water bath for 4 h. Gaseous sulfur dioxide, hydrochloric acid, and unreacted thionyl chloride escaping from the condenser were trapped in the water and alkali traps. After the completion of the reaction, the unreacted thionyl chloride was removed under vacuum. Then 25 mL of toluene was added, and the mixture of toluene and thionyl chloride was removed under vacuum. This process was repeated 4−5 times to remove traces of thionyl chloride, whose presence might affect the activity of the catalyst used in the Rosenmund reduction. Finally, *m*-phenoxybenzoyl chloride was distilled under vacuum.

(b) Synthesis of m-*Phenoxybenzaldehyde (MPB) from Acyl Chloride. Experimental Procedure and Setup.* The acid chloride in a suitable solvent and the catalyst were taken in the reactor. Then hydrogen gas was bubbled through the reaction mixture at a slow constant rate at atmospheric pressure. It was ensured that there was always a positive flow of hydrogen at the outlet of the reactor by connecting to a scrubber containing the solvent. At regular intervals, samples were withdrawn.

Analysis

Estimation of Aldehyde. The analysis by GC was done as before by using diphenyl oxide as an internal standard. Aldehyde was also analyzed by oximation method.

Estimation of Unreacted Acid Chloride. The analysis of acyl chloride was carried out by Volhard's method as given before.

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Table 1. **Effect of Type of Catalyst**[a]

catalyst	conversion, %
nil	5.5
copper	22
cuprous chloride	29

[a] Reaction conditions: initial concentration of potassium cresolate, 32% w/v; bromobenzene, 35 mL; catalyst, 4% w/v; temperature, 180 °C; atmospheric conditions; time, 6 h.

Table 2. **Effect of Halobenzenes and *N*,*N*-dimethyl Formamide As Cosolvent**[a]

N,*N*-dimethyl formamide	conversion (%)
nil (chlorobenzene)	10[b]
6% (w/v of chlorobenzene)	32.5[b]
nil (bromobenzene)	31.5
9% (w/v of bromobenzene)	52
16% (w/v of bromobenzene)	78

[a] Reaction conditions: initial concentration of potassium *m*-cresolate, 32% w/v; bromobenzene, 45 mL; cuprous chloride, 1.7 g; temperature 180 °C; atmospheric conditions; time, 6 h. [b] Time − 16 h.

Table 3. **Effect of Polyethlene Glycol As a Cosolvent**[a]

PEG −4000	conversion, %
nil	68
5% w/v of chlorobenzene	79
10% w/v of chlorobenzene	86
15% w/v of chlorobenzene	87

[a] Reaction conditions: initial concentration of potassium cresolate, 32% w/v; chlorobenzene, 44 mL; cuprous chloride, 2 g; PEG-4000, 1.05 g.; temperature, 250 °C; time, 12 h; pressure, 4 atm.

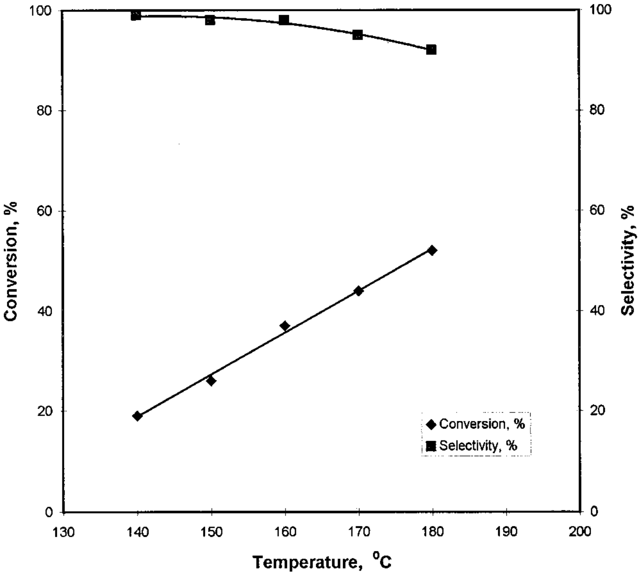

Figure 2. **Effect of temperature reaction conditions: potassium *m*-cresolate, 32% w/v; bromobenzene, 45 mL; cuprous chloride, 1.7 g; DMF, 9% w/v; atmospheric conditions; time, 6 h.; temperature 180 °C.**

Table 4. **Material Balance for *m*-Phenoxy Toluene**[a]

input	mol	%
m-cresol taken (as K-salt)	0.0963	100
output	mol	%
potassium cresolate	0.0076	8.1
m-phenoxytoluene (isolated)	0.0828	83
residue	0.0027	2.8
		93.9

[a] Reaction conditions: initial concentration of potassium *m*-cresolate, 32% w/v; chlorobenzene, 45 mL; cuprous chloride, 2 g; PEG- 4000, 1.05 g.; temperature, 250 °C; time, 12 h; pressure, 4 atm.

Results and Discussion

Definitions. *Conversion.* The conversion is defined as the ratio of total moles of reactant reacted to the moles of the reactant initially taken.

Selectivity. The selectivity to a particular product is defined as the ratio of the moles of the reactant reacted for the formation of that particular product to the moles of reactant reacted.

1. Synthesis of *m*-Phenoxytoluene (MPT)

Effect of Process Parameters on Reaction Rate and Selectvity with respect to MPT. The use of cuprous chloride as a catalyst and the use of cosolvent such as DMF and PEG-4000 was found to enhance the reaction rate (Tables 1−3). As expected bromobenzene gave higher conversions compared to chlorobenzene at 180 °C (Table 2). The effect of temperature was studied in the range of 140 to 180 °C with DMF as cosolvent using bromobenzene; it was found that as the temperature was raised from 140 to 180 °C the conversion increases (Figure 2) but the selectivity decreases from 99 to 92% due to the formation of residue.

However, if higher temperature of 250 °C is used, conversion to, and selectivity of 86 mol % and 97%, respectively, could be obtained even in the case of chlorobenzene (Table 3). The substitution of bromobenzene by chlorobenzene, which is relatively much cheaper, is therefore feasible, and the same is recommended. It may be noted that DMF cannot be used above 180 °C because of its tendency to decompose, and hence at 250 °C PEG-4000 was used.

Material Balance. It was possible to account for 94% material balance on the basis of the limiting reactant, *viz.*, potassium cresolate. The product MPT was distilled under vacuum at 5 Torr. (Table 4).

Kinetic Interpretation. Typical kinetic runs with different initial concentration of potassium salt of *m*-cresol are given in Figure 3. As the substrate concentration was increased from 32 to 48% the rate of the reaction also increased. It is expected to be a second order reaction, the reaction rate being directly proportional to the concentration of potassium phenoxide and chlorobenzene. Since the potassium salt of *m*-cresol has very limited solubility in the reaction medium, even in the presence of cosolvent, such as, DMF or PEG-4000, the reaction system is heterogeneous, and the dissolved concentration of potassium salt of the phenol in the reaction medium would remain constant for a given solvent system and temperature. Also, as chlorobenzene is used in excess compared to cresol salt, the overall reaction is supposed to follow the first-order kinetics with

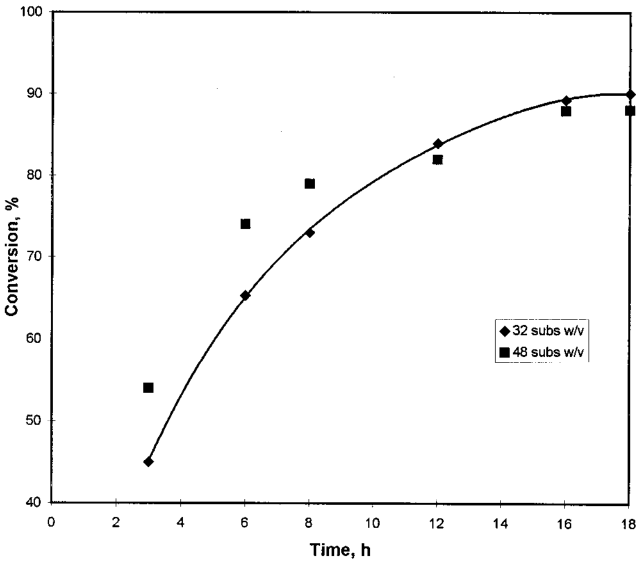

Figure 3. **Effect of substrate concentration on rate of the reaction. Reaction conditions: potassium *m*-cresolate, 32% w/v; chlorobenzene, 44 mL; PEG-4000, 1.05 g; cuprous chloride, 2 g; temperature, 250 °C; time, 12 h; pressure, 4 atm.**

Table 5. **Effect of Salt on Rate Constant**[a]

time, h	conversion, %	specific reaction rate (k)
3	46.3	5.76×10^{-5}
6	65.3	4.9×10^{-5}
8	73	4.55×10^{-5}
12	84	4.24×10^{-5}
16	89.3	3.88×10^{-5}

[a] Reaction conditions: initial concentration of potassium *m*-cresolate, 32% w/v; chlorobenzene, 44 mL; cuprous chloride, 2 g; PEG 4000, 1.05 g.; temperature, 250 °C; pressure, 4 atm.

respect to *m*-cresolate for which the specific reaction rate was determined. As mentioned in a reference,[18] the conversion level decreases markedly towards the completion due to potassium chloride formed during the reaction. This "salt effect" is particularly pronounced because the amount of potassium salt of *m*-cresol used is at a higher concentration in the range 32−48% w/v on the basis of solvent, as the resulting amount of potassium chloride will also be quite high which influences the kinetics (Table 5).

2. Synthesis of *m*-Phenoxybenzaldehyde (MPB) by Air Oxidation of *m*-Phenoxytoluene (MPT)

The reactions, as mentioned in the literature, are carried out using acetic acid as a solvent, and the catalyst used was cobalt(II) acetate as claimed by most of the patentees.

The formation of the aldehyde is accompanied with the formation of *m*-phenoxybenzyl acetate by the condensation of alcohol; an intermediate in the process, presumably with acetic acid. The acetate formed can be converted back to aldehyde by hydrolysis to the alcohol followed by oxidation with sodium hypochlorite.[19] Since the acetate is also used as an intermediate for pyrethroid, total selectivity of acetate and aldehyde was also considered.

Effect of process parameters on reaction rate and selectivity. *Effect of Different Promoter.* Among sodium bromide and paraldehyde used as promoter, the former was preferred because although the conversion was less the selectivity was comparatively high (Table 6). Therefore, subsequent work was carried out with sodium bromide as catalyst promoter. Using cobalt acetate and sodium bromide, when copper acetate was incorporated in the catalyst system, the combined selectivity towards aldehyde and ester increased markedly although the reaction rate was drastically low as revealed (Table 6) by the period of reaction which increased from 0.5 to 5 h for similar conversion.

Effect of Period of Reaction and Substrate Concentration. The reaction was carried out by varying the amount of substrate in the range of 25−35% w/v of the total reaction mixture at 110 °C under a pressure of 12 atm. It was observed that high selectivity was obtained at higher substrate concentrations (Figure 4). Therefore for further work 35% w/v of reactant was used.

With an increase in period of reaction from 10 to 30 min the conversion increased from 5.9 to 24%, but the selectivity of the aldehyde decreased from 46.5 to 37% (Figure 5). Although a selectivity of 46.5% is comparatively better, the conversion is too low to be carried out on an industrial scale; therefore, the conversion level was restricted to 24%.

Effect of Air Pressure and Flow Rate. With the increase in air pressure from 4 to 14 atm, conversion increased markedly but the selectivity to the aldehyde decreased marginally. At 12 atm the conversion and selectivity leveled off and the same was chosen for further work (Figure 6).

As expected when the flow rate was increased from 20 to 40 mL/s, conversion level increased, and the selectivity at the same level of conversion was comparable; therefore, for further work flow rate of 30 mL was used (Figure 7).

Effect of Temperature. The temperature was varied in the range of 90−120 °C, and the conversion increased marginally with substantial increase in selectivty (Figure 8). To obtain a reasonable selectivity at acceptable conversion levels, a temperature of 110 °C was selected for further work.

Synthesis of *m*-Phenoxybenzaldehyde by Rosenmund Reduction

Effect of Process Parameter on Reaction Rate and Selectivity. *Effect of Acylating Reagent.* Acylation of MPBA was carried out with thionyl chloride and phosphoryl chloride to give *m*-phenoxybenzoyl chloride. $SOCl_2$ was found to give comparatively higher yields (Table 7). Therefore, further work was carried out using thionyl chloride as the acylating agent.

Effect of Speed of Agitation. Speed of agitation was varied from 500 to 1200 rpm (Figure 9). There was no significant change in the conversion obtained beyond 1000 rpm, thereby indicating that the effects of mass transfer from the gas phase to gas−liquid interface is completely eliminated. Further observation, that the initial reaction rate was proportional to catalyst loading (Figure 10), corroborated the finding that the process was kinetically controlled.

Effect of Type of Solvent. The reduction was carried out using different solvents such as toluene, acetone, and ethyl

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Table 6. **Effect of Different Promoter**[a]

catalyst system	conversion (%)	acid selectivity (%)	ester selectivity (%)	aldehyde selectivity (%)	total selectivity (%)
cobalt acetate + paraldehyde	33	57	17	24	41
cobalt acetate + sodium bromide	24	31	30.6	37	67.6
cobalt acetate + copper acetate + sodium bromide	18	25	35	40	75

[a] Reaction conditions: initial concentration of *m*-phenoxytoluene, 35% w/v, cobalt acetate, 5 g; sodium bromide, 3.2 g; copper acetate, 3.2 g; temperature, 110 °C, solvent, acetic acid; total volume 300 mL; time, 0.5 h; flow rate, 30 mL/sec; air pressure, 12 atm.

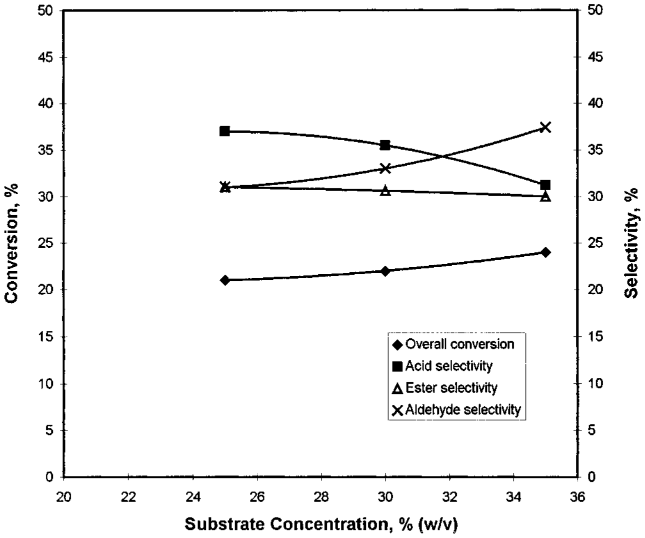

Figure 4. **Effect of substrate concentration. reaction conditions: cobalt acetate, 5 g; sodium bromide, 3.2 g, temperature, 110 °C, time, 0.5 h; solvent, acetic acid, total volume, 300 mL; flow rate, 30 mL/s; air pressure, 12 atm.**

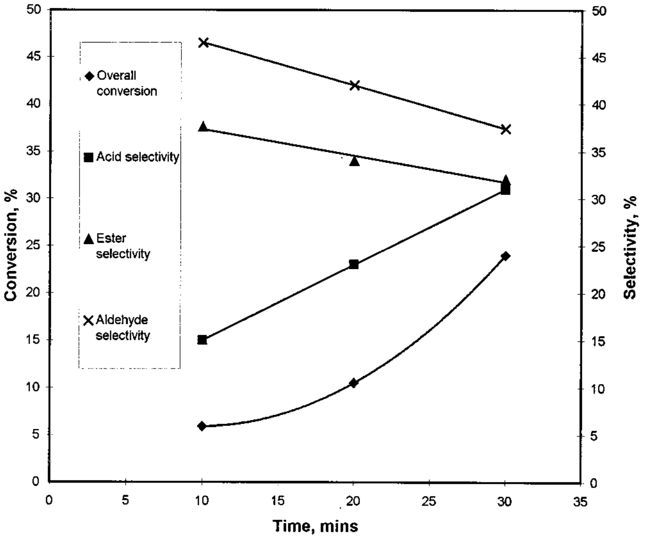

Figure 5. **Effect of period of reaction. reaction conditions: *m*-phenoxytoluene, 35% w/v, cobalt acetate, 5 g; sodium bromide, 3.2 g, temperature, 110 °C, solvent, acetic acid, total volume, 300 mL; flow rate, 30 mL/s; air pressure, 12 atm.**

acetate (Table 8). It was observed that the conversion levels and selectivity remained almost similar with a marginal change. Further work was done by using toluene as the solvent.

Effect of Initial Concentration of m-Phenoxybenzoyl Chloride and Period of Reaction on the Rate of Reduction.

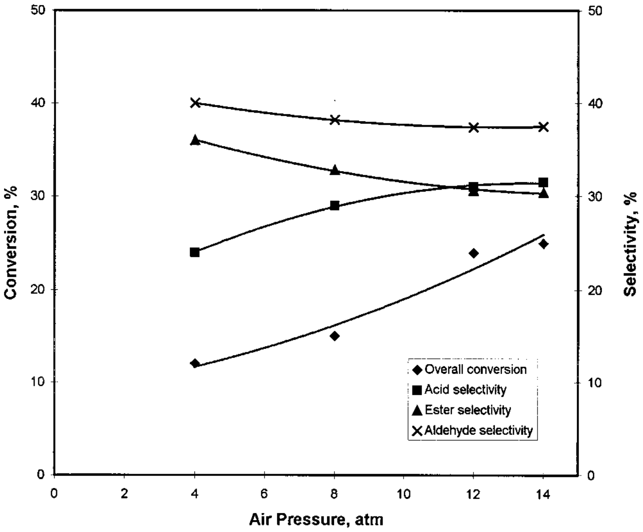

Figure 6. **Effect of air pressure on rate of the reaction. Reaction conditions: *m*-Phenoxytoluene, 35% w/v; cobalt acetate, 5 g; sodium bromide, 3.2 g, temperature, 110 °C, time, 0.5 h; solvent, acetic acid, total volume, 300 mL; flow rate, 30 mL/s.**

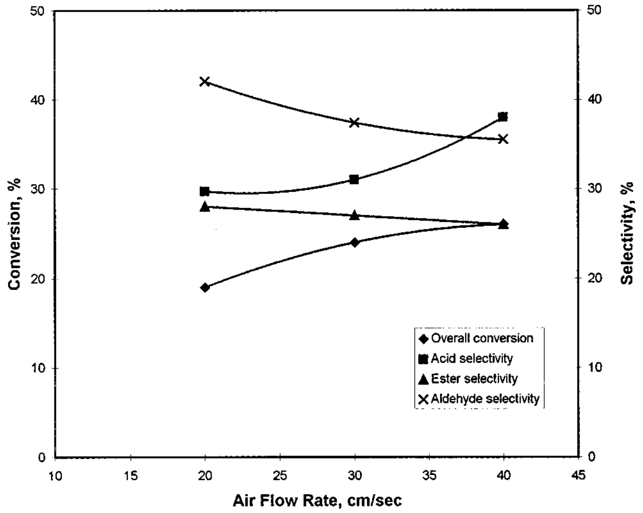

Figure 7. **Effect of air flow rate on rate of the reaction. Reaction conditions: *m*-phenoxytoluene, 35% w/v; cobalt acetate, 5 g; sodium bromide, 3.2 g; temperature, 110 °C; time, 0.5 h; solvent, acetic acid, total volume, 300 mL; air pressure, 12 atm.**

As the amount of acyl chloride was varied in the range of 10−20% w/v (Figure 11), the selectivity to the aldehyde increased marginally, but the overall conversion was found to decrease (Table 9).

At a substrate concentration of 10% w/v, with the increase in the reaction period from 0.25 to 3 h, the conversion of

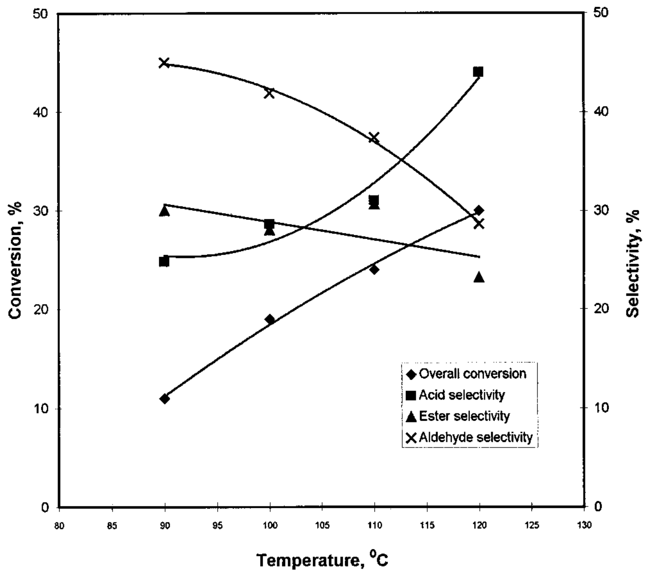

Figure 8. **Effect of temperature on the rate of reaction reaction conditions: *m*-phenoxytoluene, 35% w/v; cobalt acetate, 5 g; sodium bromide, 3.2 g, time, 0.5 h; solvent, acetic acid, total volume, 300 mL; air pressure, 12 atm; flow rate, 30 mL/s.**

Table 7. **Effect of Acylating Reagent**[a]

acylating reagent	conversion, %	selectivity, %
$SOCl_2$	67	92
$POCl_3$	65	89

[a] Reaction conditions: initial concentration of *m*-phenoxybenzoyl chloride, 10% w/v; speed of agitation, 1000 rpm; catalyst loading, 1.5% w/v; time, 1 h; time, 2 h; solvent, toluene, 100 mL.

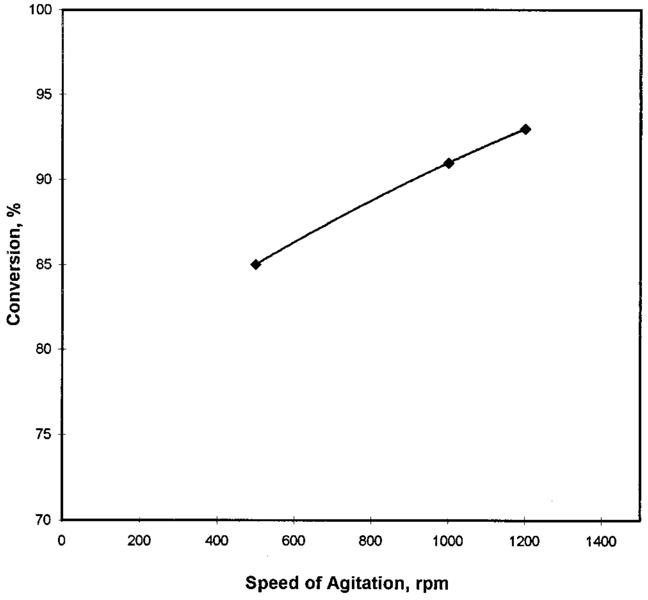

Figure 9. **Effect of speed of agitation. Reaction conditions: initial concentration, 10% w/v; catalyst loading, 1.5% w/v; temperature, 30 °C; solvent, toluene; reaction volume, 100 mL.**

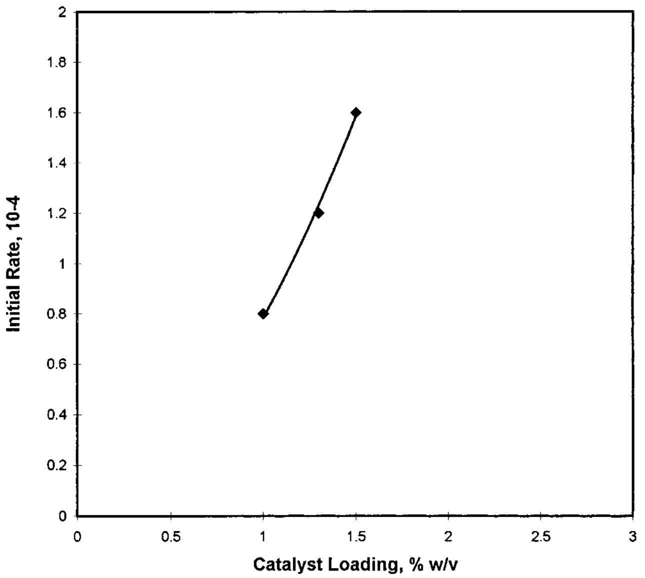

Figure 10. **Effect of catalyst loading. Reaction conditions: initial concentration, 10% w/v; speed of agitation, 1000 rpm; temperature, 30 °C; solvent, toluene; reaction volume, 100 mL.**

Table 8. **Effect of Type of Solvent**[a]

type of solvent	conversion, %	selectivity, %
toluene	67.5	92
acetone	66	91
ethyl acetate	65.5	90.5

[a] Reaction conditions: initial concentration of *m*-phenoxybenzoyl chloride, 10% w/v; speed of agitation, 1000 rpm; catalyst loading, 1.5% w/v; temperature, 30 °C; time, 2 h; solvent, toluene, 100 mL.

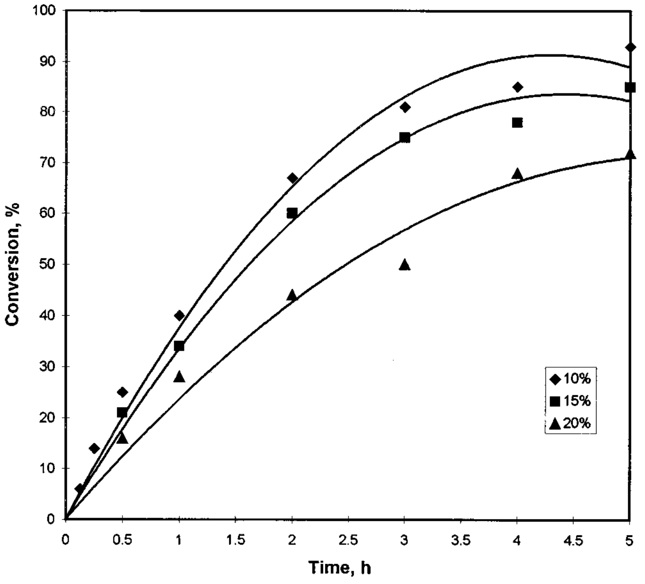

Figure 11. **Effect of substrate concentration on conversion. Reaction conditions: catalyst loading, 1.5% w/v; speed of agitation, 1000 rpm; temperature, 30 °C; solvent, toluene, 100 mL.**

m-phenoxybenzoyl chloride increased from 14 to 81%, while the selectivity decreased from 96 to 88% (Figure 12).

Effect of Temperature. The reaction temperature was varied from 20 to 40 °C which increases the conversion from 35 to 84% in 2 h (Figure 13). It was observed that the selectivity towards aldehyde decreases from 98 to 84% due to the formation of alcohol (Table 10).

Effect of Catalyst Loading. The catalyst loading expressed as the wt % of catalyst based on the total reaction volume was varied at 1, 1.3, and 1.5% w/v of reaction mixture, using

Table 9. **Effect of Substrate Concentration on Selectivity**[a]

substrate concentration %, w/v	conversion, %	selectivity, %
10	40	94
15	34	95
20	28	98

[a] Reaction conditions: speed of agitation, 1000 rpm; catalyst loading, 1.5% w/v; temperature, 30 °C; time, 1 h; solvent, toluene, 100 mL.

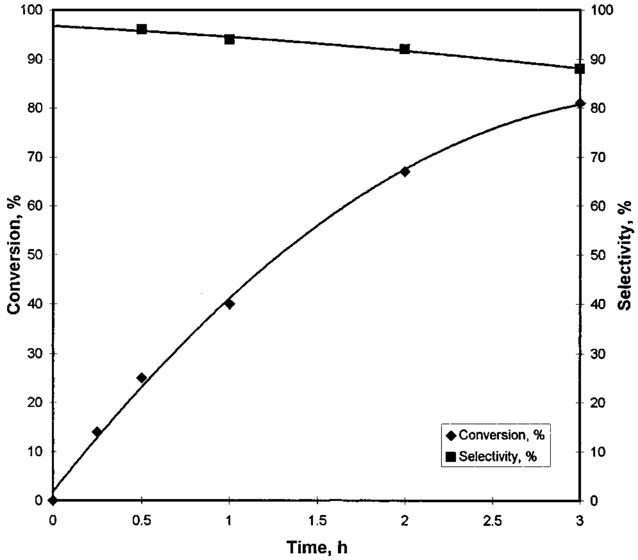

Figure 12. **Effect of period of reaction on conversion. Reaction conditions: initial concentration, 10% w/v; speed of agitation, 1000 rpm; catalyst loading, 1.5% w/v; temperature, 30 °C; solvent, toluene; reaction volume, 100 mL.**

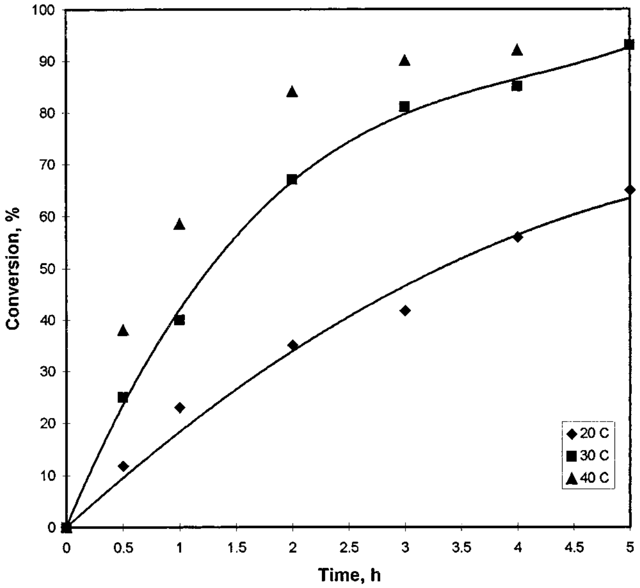

Figure 13. **Effect of temperature. Reaction conditions: initial concentration, 10% w/v; speed of agitation, 1000 rpm; catalyst loading, 1.5% w/v; solvent, toluene, 100 mL.**

Pd/C as catalyst (Figure 14). As expected higher conversions were obtained with higher catalyst loading.

Effect of Catalyst Reusability. The catalyst could be reused for 3 times with marginal decrease in the conversion levels (Table 11).

Table 10. **Effect of Temperature**[a]

temperature, °C	conversion, %	selectivity, %
20	35	98
30	67	92
40	84	84

[a] Reaction conditions: initial concentration of *m*-phenoxybenzoyl chloride, 10% w/v; speed of agitation, 1000 rpm; catalyst loading, 1.5% w/v; time, 2 h; solvent, toluene, 100 mL.

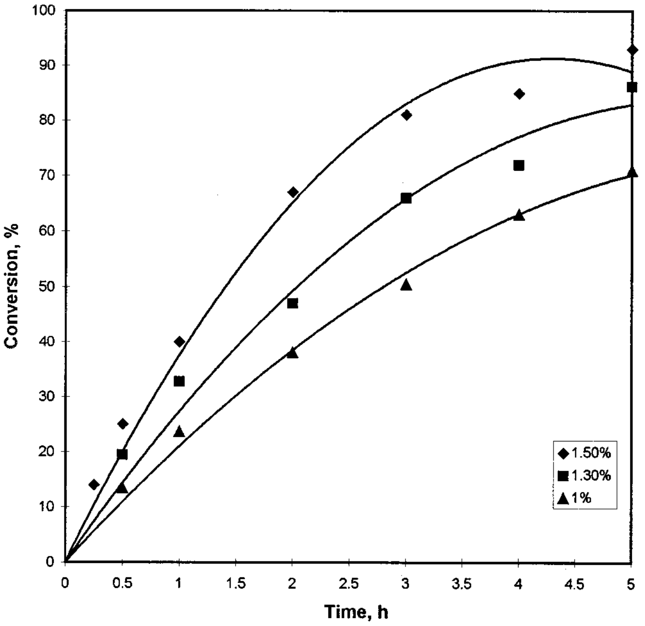

Figure 14. **Effect of catalyst loading. Reaction conditions: initial concentration, 10% w/v; speed of agitation, 1000 rpm; temperature, 30 °C; solvent, toluene, 100 mL.**

Table 11. **Effect of Reusability of Catalyst**[a]

catalyst	conversion, %
fresh	85
1st use	83.5
2nd use	82
3rd use	80

[a] Reaction conditions: initial concentration of *m*-phenoxybenzoyl chloride, 10% w/v; speed of agitation, 1000 rpm; catalyst loading, 1.5% w/v; temperature, 30 °C; time, 4 h; solvent, toluene, 100 mL.

Conclusions

Synthesis of *m*-Phenoxytoluene. 1. Under suitable reaction conditions using PEG-4000 as the cosolvent the Ullmann condensation of potassium salt of *m*-cresol with chlorobenzene gave 86% conversion to *m*-phenoxytoluene with 97% selectivity in 12 h.

2. The rate of reaction decreases towards the end of the reaction due to the salt effect of potassium chloride.

3. The formation of residue was less than 3% when the reaction was carried out for 12 h at 250 °C.

Synthesis of *m*-Phenoxybenzaldehyde by Air Oxidation. 1. Air oxidation of *m*-phenoxytoluene to *m*-phenoxybenzaldehyde in the presence of cobalt acetate and sodium bromide gave a selectivity of 37 and 30.6% towards aldehyde and the ester, respectively, at a conversion of 24%.

2. The use of 1.5% w/v of copper acetate in addition to sodium bromide and cobalt acetate as catalyst gave a comparatively higher selectivity of 40 and 35% compared to 37 and 30.6% with respect to the aldehyde and the ester, respectively, but the reaction rate drastically decreased, comparable conversion being obtained in 5 h instead of 0.5 h.

Synthesis of *m*-Phenoxybenzaldehyde by Rosenmund Reduction. 1. The hydrogenation of *m*-phenoxybenzoyl chloride to *m*-phenoxybenzaldehyde gave 93% conversion to the product with a selectivity of 86% at 10% substrate concentration, 30 °C and a catalyst loading of 1.5% w/v.

2. With the increase in substrate concentration, the conversion to the aldehyde decreased.

3. The catalyst Pd/C could be reused three times with marginal decrease in the conversion level.

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