Indian Journal of Chemical Technology
Vol. 11, May 2004, pp 401-409

Vapour phase transesterification over solid acids for the synthesis of isoamyl salicylate

Joyce D'Souza & N Nagaraju*

Department of Chemistry, St. Joseph's College Post-Graduate Centre, 46, Langford Road, Bangalore 560 027, India

Received 20 February 2003; revised received 14 October 2003; accepted 4 February 2004

The transesterification of methyl salicylate with isoamyl alcohol has been studied in vapour phase over solid acid catalysts for the synthesis of isoamyl salicylate. The catalysts used include simple oxides — Al_2O_3, SiO_2, ZrO_2 and mixed oxides ZrO_2-Al_2O_3 and ZrO_2-SiO_2. The effect of sulphation on the catalytic activity of the oxides and mixed oxides has also been investigated for this reaction. Catalytic activity studies have been conducted at 200°C for two different flow rates, 5 and 10 mL/h to check the effect of the contact time of the reactants with the catalyst. All the catalysts used in the reaction have been found to be active for the formation of isoamyl salicylate via transesterification of methyl salicylate with isoamyl alcohol. SO_4^{2}/ZrO_2-SiO_2 (2:8) has been found to be the most active catalyst with 63% conversion of methyl salicylate to isoamyl salicylate. SO_4^{2-}/ZrO_2, which exhibited good selectivity was chosen as the catalyst for optimisation of the reaction conditions to obtain better yield and higher selectivity of isoamyl salicylate. Optimum yield of isoamyl salicylate was obtained with the following reaction conditions: amount of catalyst = 0.5 g, calcination temperature = 550°C, reaction temperature = 200 °C, preheater temperature = 250 °C, molar ratio of methyl salicylate to isoamyl alcohol = 1:1.

IPC Code: C07B 41/2

Keywords: Transesterification, solid acid catalysts, methyl salicylate, isoamyl alcohol

Solid acids are safe alternatives for conventional liquid acid catalysts used in synthetic organic chemistry in petroleum refineries, fine chemicals syntheses, pharmaceuticals, etc[1]. Due to the environmental hazards and technical difficulties associated with the use of liquid acids, extensive research is in progress to phase out these catalysts from chemical industry. Solid acids like zeolites, cation exchange resins, oxides and ALPOs have been used successfully as catalysts for several acid-catalysed reactions such as isomerisation, catalytic cracking, oligomerisation, dehydration, acylation, etc[2]. The solid acids have been successfully used in the laboratory as catalysts in esterification and alkylation reactions[3-8].

Transesterification is an industrially important acid-catalysed reaction with wide range of applications[9-13]. It is worthwhile to explore the possibility of finding a suitable environmentally benign solid catalyst for this reaction considering the fact that the existing procedures require expensive or corrosive acids and solvents which cannot be reused due to tedious methods of isolation[14].

Salicylate esters are an important group of esters used in perfumery, flavouring, sun tan preparations and sweeteners[15]. Isoamyl salicylate is one of the important salicylate esters used primarily in perfumery and flavour technology[16]. It is obtained by esterification of salicylic acid with isoamyl alcohol. As the solubility of salicylic acid in isoamyl alcohol is very low, this method requires the use of the latter in higher molar ratios. Hence, the method of transesterification of methyl salicylate with isoamyl alcohol is employed wherein the reactants, being mutually soluble in one another, can be mixed in different molar ratios. Also, the solid acid catalysts that have been chosen for this work are known to possess moisture-sensitive active centers, which get poisoned by water molecules produced during the direct esterification reaction between alcohol and the acid[17]. Thus, the anhydrous condition prevalent in transesterification of methyl salicylate with isoamyl alcohol is an added advantage. Transesterification is an equilibrium-driven reaction. Hence, vapour-phase

* For correspondence
(E-mail: nagarajun@sjc.in ; Fax: 080-2245831)

conditions of the experiment are better suited than liquid phase reaction conditions. In a vapour-phase reaction, the products of the reaction are not in contact with the catalysts during the entire reaction period, thereby preventing backward reaction.

Among the solid acids, Al_2O_3, SiO_2, and ZrO_2 are known to catalyse several reactions in synthetic organic chemistry[18,19]. When these oxides[20-23] are taken in the mixed forms as ZrO_2-Al_2O_3 and ZrO_2-SiO_2, the catalytic activity has been found, in several instances, to increase significantly. Another modification that provides strongly acidic and super-acidic solids with high catalytic activity is the process of sulphation[24]. ZrO_2, when sulphated, results[25-29] in a super-acid SO_4^{2-}/ZrO_2. This solid super-acid is taking the place of conc. H_2SO_4 in several acid catalysed organic reactions. Therefore, a systematic study on the effect of sulphate ions on the catalytic activity of various oxides and mixed oxides in acid-catalysed organic reactions, for instance, transesterification is of considerable interest.

Present paper contains the results of studies on vapour phase transesterification of methyl salicylate with isoamyl alcohol in the presence of a few solid acids as catalysts. The catalytic activity of oxides such as Al_2O_3, SiO_2 and ZrO_2, mixed oxides such as ZrO_2-Al_2O_3 and ZrO_2-SiO_2 (with 0-30% ZrO_2 content) has been studied in the synthesis of isoamyl salicylate by transesterification method. The effect of modification of surface acidity of these oxides and mixed oxides by sulphate-treatment has been reported. The reaction conditions have been optimised over SO_4^{2-}/ZrO_2 by varying the reaction parameters such as flow rate of reactant mixture, molar ratio of reactants, calcination temperature of catalyst, amount of the catalyst, preheater temperature and catalyst bed temperature.

Experimental Procedure

Catalyst Preparation

a. Preparation of hydrated alumina

100 g of aluminium isopropoxide was added in small quantities into 1000 mL of hot deionised water with vigorous stirring. The aluminium hydroxide gel obtained was washed with deionised water (by decantation process), filtered, dried in an oven at 120 °C for 24 h and ground well to obtain hydrated alumina powder, $Al(OH)_3.xH_2O$.

b. Preparation of hydrated silica

A 0.5 M solution of sodium silicate prepared in deionised water was heated to about 80 °C and treated with 1:1 hydrochloric acid till H_2SiO_3 precipitation was complete. The precipitate was filtered, washed thoroughly with deionised water until there were no chloride ions detectable in the washings. The gel was dried at 120 °C for 24 h and ground well to obtain hydrated silica powder, $SiO_2.xH_2O$.

c. Preparation of hydrated zirconia

To a 0.5 M solution of $ZrOCl_2.8H_2O$ in water, 28 wt% aqueous NH_4OH was added dropwise under vigorous stirring at room temperature upto a pH of 8.4, when the precipitation of zirconium hydroxide was complete. The gel was filtered and washed with deionised water until there were no chloride ions detectable in the washings. The gel was dried at 120 °C for 24 h to obtain hydrated zirconia powder, $Zr(OH)_4.xH_2O$.

The hydrated alumina, silica and zirconia obtained by the above methods are abbreviated for convenience as Al_2O_3, SiO_2 and ZrO_2.

Preparation of mixed oxides

Samples of mixed oxides ZrO_2-Al_2O_3 and ZrO_2-SiO_2 with 10, 20 and 30% of ZrO_2 content have been prepared following the procedure given below.

Preparation of ZrO_2-Al_2O_3

The freshly prepared aluminium hydroxide gel [obtained by method (a)] was suspended in 1000 mL deionised water. A 0.5 M solution of $ZrOCl_2.8H_2O$ containing precalculated amount of ZrO_2 was added into it with vigorous stirring followed by dropwise addition of 28 wt% aqueous NH_4OH until the pH of the solution was 8.4. The precipitate obtained was filtered, washed with deionised water until washings were free from chloride ions and dried at 120 °C for 24 h. The different samples with varying amounts of ZrO_2 were labeled as ZA(10), ZA(20), ZA(30). The numbers in the brackets indicate the percentage of ZrO_2 in the mixed oxide, ZrO_2-Al_2O_3.

Preparation of ZrO_2-SiO_2

The freshly prepared wet silica gel [obtained by method (b)] was suspended in 1000 mL water. A 0.5 M solution of $ZrOCl_2.8H_2O$ containing precalculated amount of ZrO_2 was added. To this mixture, 28 wt% aqueous NH_4OH was added dropwise with vigorous stirring, until the pH of the solution was 8.4. The precipitate was filtered and washed with deionised water until there were no chloride ions detectable in the washings. The gel was dried at 120°C for 24 h and labeled as ZS(10), ZS(20), ZS(30).

Preparation of sulphated oxides and mixed oxides

A part of the hydrated oxides and mixed oxides prepared by the methods given above was taken and subjected to sulphation separately. A known amount of each sample was treated with 1M H_2SO_4 solution (2 mL/g) and mixed well for 1h at room temperature, filtered without washing and dried at 120 °C for 24 h. The sulphated oxides were labeled as S-Al_2O_3, S-SiO_2 and S-ZrO_2. The sulphated mixed oxides were labeled as S-ZA (10), S-ZA (20), S-ZA (30) and S-ZS (10), S-ZS (20), S-ZS (30). The oxides, mixed oxides and their sulphated forms thus prepared were calcined to 550 °C for 4 h before their use as catalysts.

All the catalysts were analysed for their total surface acidity by *n*-butylamine back-titration method using bromothymol blue indicator. The surface acidity was calculated from the decrease in the concentration of n-butylamine when a known weight of the catalyst was treated with a known volume of n-butylamine of definite concentration[30].

Catalytic activity studies

The catalytic activity of all the catalysts was determined in vapour phase transesterification of methyl salicylate with isoamyl alcohol in a fixed bed continuous downflow borosilicate glass tube reactor (i.d. 30 mm) heated by a tube furnace with a temperature control.

In a typical reaction, 0.5 g of the catalyst pre-calcined at 550°C was placed over glass wool in the reactor and maintained at 200 °C for 2 h. The reactants were taken in 1:1 molar ratio and introduced into the pre-heater maintained at 250 °C by means of an infusion pump before passing over the catalyst. The reactant mixture was fed into the reactor with two different flow rates, 5 and 10 mL/h. The product samples were collected and analyzed by a Gas Chromatograph fitted with 10% SE 30 on Chromosorb W-HP 2m ss column and flame ionization detector. The percentage yield of the products was calculated from the GC results based on the relative response of the different compounds in the reaction mixture with respect to methyl salicylate. The reaction conditions were optimised using SO_4^{2-}/ZrO_2 as the catalyst.

Results and Discussion

The catalytic activity of a solid acid and its selectivity in the formation of a particular product in an organic reaction depends on its acid strength and number of active sites. These factors are mainly dependent on the method of preparation, pre-treatment conditions and composition of the solids[18].

Surface acidity

The total surface acidity of simple oxides, mixed oxides and their sulphated forms is presented in Table 1. The acidity of the samples, in general, increases in the order:

oxides < mixed oxides < sulphated oxides < sulphated mixed oxides

Among the simple oxides, SiO_2 exhibited the highest total surface acidity while ZrO_2 was the least acidic. Though ZrO_2 is the least acidic among these oxides, addition of even small amounts of ZrO_2 into Al_2O_3 or SiO_2 resulted in mixed oxides with enhanced acid sites concentration compared to individual oxides. The acidity of Al_2O_3 and SiO_2 was found to vary in a definite pattern by the addition of ZrO_2. When mixed with small amounts of ZrO_2 (0-20%), the acidity of Al_2O_3 and SiO_2 was found to decrease. In ZrO_2-Al_2O_3 mixed oxides, the acidity exceeded that of pure Al_2O_3 when the amount of ZrO_2 was 30%. On the other hand, in ZrO_2-SiO_2 mixed oxides, the acidity exceeded that of pure SiO_2 even with a lower percentage of ZrO_2 (20%). This may be due to the fact that SiO_2 is more acidic than Al_2O_3 (Table 1). In a general comparison of the mixed oxides, for similar composition of ZrO_2, the surface acidity of ZrO_2-SiO_2 > ZrO_2-Al_2O_3.

Effect of sulphation on total surface acidity

The acidity of all the simple and mixed oxides were found to increase with sulphation. In the case of simple oxides, the least acidic oxide, ZrO_2, undergoes a five-fold increase in its acidity on treatment with sulphate ions. On the other hand, in Al_2O_3 and SiO_2, which are more acidic than ZrO_2 there is less than two-fold increase in the acidity on sulphation. Thus, it is observed that the total surface acidity of S-ZrO_2 is much greater than that of S-Al_2O_3 and S-SiO_2. The difference in the extent of increase in acidity of the oxides on sulphation could be attributed to the fact that the surface acidity of the untreated ZrO_2 is less than that of Al_2O_3 and SiO_2 (Table 1). The interaction between the sulphate ions and the acidic sites of the

Table 1 — Total surface acidity of the oxides, mixed oxides and their sulphated forms calcined at 550°C.

(n-butyl amine back-titration; Indicator : bromothymol blue)

Catalyst code	Surface acidity (m mol g^{-1})	Catalyst code	Surface acidity (m mol g^{-1})
Al_2O_3	0.37	S-Al_2O_3	0.51
SiO_2	0.41	S-SiO_2	0.56
ZrO_2	0.23	S-ZrO_2	1.02
ZA(10)	0.20	S-ZA(10)	0.91
ZA(20)	0.20	S-ZA(20)	0.90
ZA(30)	0.49	S-ZA(30)	1.09
ZS(10)	0.30	S-ZS(10)	0.52
ZS(20)	0.70	S-ZS(20)	0.75
ZS(30)	1.09	S-ZS(30)	1.29

simple oxides play a major role in changing the strength of the existing acid sites and also the development of new acid sites. The acid-acid interaction between the sulphate ions and the surface acidic/basic sites of the oxides determines how strongly the sulphate ions are held on to the surface. Thus, it may be concluded that the sulphate ions are retained more on the almost neutral ZrO_2 which has less number of acid sites than on the acidic oxide SiO_2 and amphoteric oxide Al_2O_3, resulting in the higher acidity of S-ZrO_2. The effect of sulphate treatment and addition of another oxide on pure Al_2O_3 and SiO_2 can be compared and summarised as follows: The order of acidity of pure oxides is ZrO_2 < Al_2O_3 < SiO_2. The trend is reversed on sulphating, i.e, acidity of S-SiO_2 < S-Al_2O_3 < S-ZrO_2. However, the addition of another oxide ZrO_2 does not affect the order of acidity, i.e., the acidity of Al_2O_3 is less than SiO_2, and their acidity when mixed with ZrO_2 is in the order that Al_2O_3 < SiO_2.

In the mixed oxides, upto four-fold increase in the acidity is observed on sulphation. The sulphated mixed oxides of zirconia-alumina (S-ZA) is more acidic than that of zirconia-silica (S-ZS). This is again attributed to the fact that the surface acidity of zirconia-alumina is less than that of zirconia-silica of corresponding composition (Table 1). The sulphate ions are retained more on the less acidic zirconia-alumina mixed oxides than that of zirconia-silica. This results in higher surface acidity of sulphated zirconia-alumina than that of sulphated zirconia-silica. In general, the order of increasing acidity of sulphated oxides and mixed oxides samples is:

Sulphated oxides < Sulphated ZrO_2-SiO_2 < Sulphated ZrO_2-Al_2O_3

Table 2 — Percentage yield of isoamyl salicylate on transesterification of methyl salicylate with isoamyl alcohol (taken in 1 : 1 molar ratio) over oxides and mixed oxides

Amount of the catalyst: 0.5 g, Calcination temperature of catalyst: 550 °C, Catalyst temperature: 200 °C, Preheater temperature: 250 °C

Catalyst code	Flow rate			
	5 mL/h		10 mL/h	
	Isoamyl salicylate	Phenol	Isoamyl salicylate	Phenol
Al_2O_3	35	1	14	1
SiO_2	31	23	35	14
ZrO_2	17	4	15	14
ZA (10)	45	16	35	4
ZA (20)	53	11	33	3
ZA (30)	39	11	27	10
ZS (10)	30	17	20	2
ZS (20)	24	25	18	4
ZS (30)	35	7	45	5

Catalytic activity

The catalytic activity of the various oxides, mixed oxides and their sulphated forms have been investigated in vapour phase transesterification of methyl salicylate with isoamyl alcohol for the synthesis of isoamyl salicylate. The results are presented in Tables 2 and 3. In general, it was found that all the catalysts used for the study exhibited catalytic activity for transesterification. It was also observed that the only side-product formed was phenol, apart from the primary by-product methanol. Phenol formation may be due to decarboxylation of salicylic acid formed by the acid hydrolysis of methyl salicylate. There was no activity towards transesterification when the reaction was conducted in the absence of catalyst.

Table 3 — Percentage yield of isoamyl salicylate on transesterification of methyl salicylate with isoamyl alcohol (taken in 1:1 molar ratio) over sulphated oxides and mixed oxides

Amount of the catalyst: 0.5 g, Calcination temperature of catalyst: 550 °C, Catalyst temperature: 200 °C, Preheater temperature: 250 °C

Catalyst code	Flow rate			
	5 mL/h		10 mL/h	
	Isoamyl salicylate	Phenol	Isoamyl salicylate	Phenol
S-Al_2O_3	37	15	25	3.5
S-SiO_2	23	14	14	4
S-ZrO_2	51	10	42	6
S-ZA (10)	30	7	31	3
S-ZA (20)	34	24	32	10
S-ZA (30)	51	16	30	9
S-ZS (10)	20	4	19	9
S-ZS (20)	35	16	63	10
S-ZS (30)	43	14	49	5

Among the simple oxides, Al_2O_3 was found to be a good catalyst with 35% conversion and minimal side product formation (1%). Though the use of SiO_2 resulted in a comparatively good amount of isoamyl salicylate (31-35%), for both 5 and 10 mL/h flow rates, the side product (phenol) formation is also more (14-23%), which is undesirable. ZrO_2 did not prove to be a good catalyst for this reaction, because it gave low yield of isoamyl salicylate (15-17%). Transesterification is an acid catalysed reaction. As expected, SiO_2 being more acidic, is more active than ZrO_2, which has relatively low acidity. However, for the same reason, the selectivity of ZrO_2 towards isoamyl salicylate is much higher than that of SiO_2. The type of strong acid sites predominant in SiO_2 is responsible for excessive phenol formation.

The catalytic activity of Al_2O_3 and SiO_2 is known to increase[20,22] several-fold in the presence of small amounts of ZrO_2. This was found to be true also for the transesterification reaction considered here, when the mixed oxides ZA (10), ZA (20), ZA (30) were used as catalysts. There was a significant increase in the catalytic activity of Al_2O_3 in the presence of ZrO_2. However, no noticeable change was observed in the activity of SiO_2 by the addition of ZrO_2 in the same ratios –ZS (10), ZS (20) and ZS (30). Also, the activity of ZrO_2-Al_2O_3 for the reaction is greater than that of ZrO_2-SiO_2, in spite of the acidity of ZrO_2-SiO_2 being greater than that of ZrO_2-Al_2O_3 for similar amounts of ZrO_2. This clearly indicates that the catalytic activity is not only related to the total surface acidity of the catalyst, but is also governed by the concentration of acid sites of a particular strength. This is further confirmed by the following observation: In the mixed oxide ZrO_2-Al_2O_3, as the ZrO_2 content increased, the catalytic activity decreased, but in ZrO_2-SiO_2, as the ZrO_2 content increased, the catalytic activity increased, though not significantly.

Thus, it may be concluded that the mixing of oxides give rise to different interactions between the component oxides. Interactions between individual oxides in different mixed oxides are different. This mainly depends on the surface properties of the individual oxides and their compositions. This results in the variation of the concentration of acid sites of different strengths in the mixed oxides, thereby altering the catalytic activity and selectivity of the system for a particular reaction.

Effect of sulphation on catalytic activity

Sulphation of Al_2O_3 led to an increase in the side product formation without any increase in the yield of isoamyl salicylate. In the case of SiO_2, there was considerable reduction in the side product formation on sulphation, with a simultaneous reduction in the yield. ZrO_2 has provided encouraging results with large increase (3-fold increase) in the yield of isoamyl salicylate on sulphation. With 42-51% yield of isoamyl salicylate and relatively lesser amount of side product (6-10%), SO_4^{2-}/ZrO_2 appears to be a better catalyst than S-Al_2O_3 and S-SiO_2. S-ZrO_2 exhibited the highest selectivity towards isoamyl salicylate formation and hence proves to be a good catalyst for the transesterification reaction.

It may be observed from Table 3 that the activity of sulphated Al_2O_3 and SiO_2 is enhanced by the addition of a certain minimum amount of ZrO_2. A high yield (63%) of isoamyl salicylate was obtained with S-ZS (20), with 10-16% of side product formation. The activity of sulphated zirconia-alumina mixed oxide (S-ZA) does not vary significantly with the ZrO_2 content in the studied range (10-30%). The activity of sulphated zirconia-silica (S-ZS) is lesser than that of S-ZA at lower ZrO_2 content (upto 20%) but increases with higher ZrO_2 (30%) content and exceeds that of S-ZA. In general, it is observed that sulphate ions have a promoting effect on the catalytic activity of oxides and mixed oxides. The sulphated oxides and mixed oxides were found to turn brown in colour after the reactions, which may be due to coke formation. The increased total acidity may have induced side reactions leading to coke formation. However, the catalysts could still be reused after a simple step of recalcination.

Correlation between total acidity and catalytic activity

By and large, it is observed that there is no direct correlation between the catalytic activity and the total surface acidity in transesterification reaction for all the oxides studied. This is mainly because of the fact that apart from total surface acidity, the number and the distribution of the acid sites also play a major role in the performance of the various catalysts. The chemical composition of a catalyst varies with the addition of another oxide and/or sulphate ions, and causes a variation in the surface acidity and catalytic activity. Also, the number of sulphate species may not be uniform in all the catalysts owing to the unavoidable loss of sulphate ions that is inherent during preparation and post-treatment, even when the procedure followed is same.

From the above discussions, it can be concluded that mixing Al_2O_3 or SiO_2 with a certain minimum amount of ZrO_2 (20-30%) increases the acidity and the activity of the simple oxides. Similar effect is seen when the simple oxides and mixed oxides are sulphated. On account of better selectivity, SO_4^{2-}/ZrO_2 is more effective as catalyst for transesterification than any other catalyst. Hence, SO_4^{2-}/ZrO_2 has been chosen to study further the effect of various factors on the reaction and optimise the reaction conditions.

Optimisation of reaction conditions

The reaction conditions for the synthesis of isoamyl salicylate were optimised over SO_4^{2-}/ZrO_2. Suitable temperature conditions for the reaction system were determined by varying the pre-heater and catalyst-bed temperatures between 150 and 300 °C. The results are presented in Table 4. When the pre-heater temperature was maintained at 200 °C, the reactant molecules condensed within the tube before reaching the catalyst, and the conversion was low. At 250 °C, the conversion was higher. On further increase of pre-heater temperature to 300 °C, though the conversion increased, there was excessive coke formation and the selectivity was low. As far as the catalyst-bed temperature was concerned, at temperatures less than 200 °C, the side product formation was less. However, at this temperature, the yield of isoamyl salicylate was also low. When the catalyst-bed temperature was 300 °C, the temperature was found to be too high because the yield of isoamyl salicylate formed was low and the side product formation was high along with excessive coke formation. Thus, it was observed that a pre-heater temperature of 250 °C and catalyst temperature of 200 °C had to be maintained for good yield of isoamyl salicylate with better selectivity.

Table 4 — Effect of variation of catalyst and preheater temperatures in the synthesis of isoamyl salicylate by the transesterification of methyl salicylate with isoamyl alcohol (1:1) over 0.5g SO_4^{2-}/ZrO_2

Catalyst bed (°C)	Preheater (°C)	Flow rate mL/h	Percentage yield (%)	
			Isoamyl salicylate	Phenol
150	250	5	14	0
	300	5	34	9
200	250	5	51	10
	250	10	42	6
	300	5	38	16
250	250	5	60	15
	250	10	42	7
	300	5	41	20

Sulphated zirconia calcined to 550 °C was used with the above standardized conditions in amounts ranging from 0.25 to 1.25 g. The results are given in Table 5. When the amount of catalyst was less than 0.5 g, the side product was formed in lesser quantities and also, the percentage yield of isoamyl salicylate was low. 0.5 g of SO_4^{2}/ZrO_2 gave a better yield of isoamyl salicylate with minimum side product formation. As the amount of catalyst was increased, the side product formation also increased. This is because as the thickness of the catalyst-bed increases, the product molecules probably get trapped within the catalyst layer leading to side product formation.

Table 5 — Effect of the amount of catalyst in the transesterification of methyl salicylate with isoamyl alcohol over SO_4^{2-}/ZrO_2

Catalyst temperature = 200 °C, Calcination temperature of the catalyst = 550 °C, Preheater temperature = 250 °C, Molar ratio of the reactants = 1:1

Amount of catalyst (g)	Flow rate					
	5 mL/h			10 mL/h		
	(ester : catalyst) weight ratio	Isoamyl salicylate (%)	Phenol (%)	(ester : catalyst) weight ratio	Isoamyl salicylate (%)	Phenol (%)
0.25	14.256	33	7	7.128	22	14
0.5	7.128	51	10	3.564	42	6
0.75	4.752	53	22	2.376	61	9
1.0	3.564	54	16	1.782	55	10
1.5	2.376	43	20	1.188	55.3	18

SO_4^{2-}/ZrO_2 was calcined at different temperatures from 450 to 850 °C and used as catalyst in transesterification to study the effect of calcination temperature on the yield and selectivity of the product. With the sample calcined at 450 °C, though the conversion was high, the selectivity was less. The results in Table 6 clearly indicate that the use of SO_4^{2-}/ZrO_2 sample calcined at 550 °C gave the maximum yield of isoamyl salicylate. At higher calcination temperatures, the yield of the product decreased which agrees with the fact that on calcination at 650 °C, SO_4^{2-}/ZrO_2 undergoes loss of sulphate ions[31,32]. As the calcination temperature of catalyst was increased to 700 °C, there was further loss of sulphate ions, and at 750 °C, there was complete loss of catalytic activity for the formation of isoamyl salicylate. A gradual decrease in the yield of isoamyl salicylate beyond a calcination temperature of 650 °C is an indication that the sulphate ions are responsible to a great extent for the catalytic activity of SO_4^{2-}/ZrO_2.

The molar ratio of isoamyl alcohol to methyl salicylate, was varied from 2:1 to 1:2 and the catalytic studies were performed over SO_4^{2-}/ZrO_2. The results are given in Table 7. A molar ratio of 2:1 *i.e.*, with higher concentration of alcohol content gave maximum yield of isoamyl salicylate. This may be due to the fact that transesterification is a reversible reaction, and excess of alcohol favours forward reaction, leading to the formation of more isoamyl salicylate. Hence, a molar ratio of 1:1 was found to be suitable in terms of atom efficiency.

Table 6 — Effect of calcination temperature of SO_4^{2-}/ZrO_2 in the synthesis of isoamyl salicylate by the transesterification of methyl salicylate with isoamyl alcohol

Catalyst temperature = 200 °C, Preheater temperature = 250 °C, Flow rate = 5 mL/h

Calcination temperature (°C)	Percentage yield	
	Isoamyl salicylate	Phenol
450	39	15
550	51	10
650	26	6
700	18.5	0
750	0	0
850	0	0

Table 7 — Effect of molar ratio of reactants in the synthesis of isoamyl salicylate by the transesterification of methyl salicylate with isoamyl alcohol

Catalyst: 0.5 g SO_4^{2-}/ZrO_2, Catalyst temperature: 200°C, Calcination temperature of the catalyst: 550°C, Preheater temperature: 250°C

Molar ratio (Isoamyl alcohol: Methyl salicylate)	Percentage yield			
	Flow rate			
	5 mL/h		10 mL/h	
	Isoamyl salicylate (%)	Phenol (%)	Isoamyl salicylate (%)	Phenol (%)
2:1	65	10	63	1
1:1	51	10	42	6
1:1.5	8	0	4	0

Effect of feed flow rate

The title reaction was further studied at two flow rates of the reactant mixture, 5 and 10 mL/h. In general, the percentage of side product (phenol) formed for a flow rate of 10 mL/h was found to be lesser than that for 5 mL/h. This may be attributed to the higher contact time of reactant and product molecules on the catalyst when the flow rate is less (5 mL/h). A higher contact time could probably result in further reaction of products leading to the formation of various side-products including coke-formation. Backward reaction may also be possible, thus decreasing the yield of isoamyl salicylate. When the flow rate is increased, the contact time of the molecules with the catalyst is too low to promote any reversible reaction (to give back the reactants) or consecutive reaction (to give undesirable products). Even in the case of other sulphated catalysts, the selectivity for isoamyl salicylate was found to be higher for a flow rate of 10 mL/h than 5 mL/h. This data coupled with the fact that a flow rate of 10 mL/h provides double the amount of the product, makes it more reasonable to be adopted than 5 mL/h for the synthesis of isoamyl salicylate.

Catalyst productivity/Reusability of the catalyst

The vapour phase reaction was conducted continuously for 5 h to study the stability of the catalyst with time. The percentage yield of isoamyl salicylate was found to reduce gradually with time. After 5 h, the percentage yield reduced by about 6% of isoamyl salicylate. The catalyst is regenerated by calcining to 550 ^{o}C for 2 h. There is no significant decrease in the percentage yield of the product on recycling twice.

Thus, the optimised reaction conditions for the synthesis of isoamyl salicylate by transesterification over SO_4^{2-}/ZrO_2 as follows: pre-heater, catalyst bed and catalyst calcination temperatures are 250, 200 and 550 ^{o}C respectively, the amount of catalyst is 0.5 g, and the molar ratio of isoamyl alcohol to methyl salicylate is 1:1.

Conclusion

Isoamyl salicylate can be conveniently prepared by vapour phase transesterification of methyl salicylate with isoamyl alcohol using various oxides mixed oxides and their sulphated forms as the catalysts. The reaction process is simple and the reactants can be easily taken in equimolar ratio. SO_4^{2-}/ZrO_2 proves to be a good catalyst for this reaction. Also, by incorporating Al_2O_3 and SiO_2 and optimizing the ZrO_2 content to 20-30%, the catalytic activity remains almost the same. As the ZrO_2 content is less, and the catalysts are reusable, these sulphated mixed oxides are environment-friendly and cost-effective. Thus, sulphated zirconia and sulphated mixed oxides of zirconia-silica and zirconia-alumina have been found to be efficient catalysts for the synthesis of isoamyl salicylate in high yields with good selectivity via transesterification.

Acknowledgements

The authors gratefully acknowledge the help extended by the authorities of Indian Institute of Science, Bangalore for permitting the use of library facilities and George Kuriakose for the help with gas chromatographic analysis and discussions.

References

1 Corma A, *Chem Rev*, 95 (1995) 559.
2 Tanabe K & Holderich W F, *Appl Catal A: General*, 181 (1999) 399.
3 D'Souza J & Nagaraju N, *Indian J Chem* , 40B (2001) 266.
4 Nagaraju N, Peeran M & Devaprasad, *React Kinet Catal Lett*, 61 (1997) 155.
5 Nagaraju N & Peeran M, *Indian J Chem Technol*, 3 (1996) 253.
6 Sharath K R, Nagaraju N, Murthy KVVSBSR & Narayanan S, A*ppl Catal A:Gen*, 226 (2002) 175.
7 Sharath K R, Vijayashree S & Nagaraju N, *Indian J Chem Technol*, 8 (2001) 362.
8 George K & Nagaraju N, *Green Chem*, 4 (2002) 269.
9 Otera J, *Chem Rev*, 93 (1993) 1449.
10 Corma A, Iborra S, Miquel S & Primo J, *J Catal*, 173 (1998) 315.
11 Ilankumaran P & Verkade J G, *J Org Chem*, 64 (1999) 3086.
12 Otera J, Dan-oh N & Nozaki H, *J Org Chem*, 56 (1991) 5307.
13 Stanton M G, Allen C B, Kissling R M, Lincoln A L & Gagne M R, *J Am Chem Soc*, 120 (1998) 5981.
14 Chavan S P, Zubaidha P K, Dantale S W, Keshavaraja A, Ramaswamy A V & Ravindranathan T, *Tetrahedron Lett*, 37 (233) 1996.
15 Vane J R & Botting R M (Eds), *Aspirin and Other Salicylates*, Ist edn (Chapman & Hall, London), 1992.
16 *Aromatic Chemicals, Perfumes and Flavour Technology* by SBP Board of Consultants and Engineers, SBP Chemical Engineering Series No. 54 (Small Business Publications, Delhi).
17 Sen S E, Smith S M & Sulivan K A, *Tetrahedron*, 55 (1998) 12657.

18 Tanabe K, *Solid acids and Bases – their catalytic properties* (Academic Press, New York, London), 1970.

19 Nakano Y, Iizuka T, Hattori H & Tanabe K, *J Catal*, 57 (1979) 1.

20 Klimova T, Rojas M L, Castillo P, Cuevas R & Ramirez J, *Microporous & Mesoporous Materials*, 20 (1998) 293.

21 Moreno J M & Poncelet G, *J Catal*, 203 (2001) 453.

22 Navio J A, Colon G, Macias M, Campelo J M, Romero A A & Marinas J M, *J Catal*, 161 (1996) 605.

23 Bosman H J M, Krussink E C, Van der Spoel & Van den Brink F, *J Catal*, 148 (1994) 660.

24 Jin T, Yamaguchi T & Tanabe K, *J Phys Chem*, 90 (1986) 4794.

25 Arata K, *Adv Catal* , 37 (1990) 65.

26 Garin F, Andriamasinoro D, Abdulsamad A & Sommer J, *J Catal*, 131 (1991) 199.

27 Davis B H, Keogh R A & Srinivasan R, *Catal Today*, 20 (1994) 219.

28 Gao Z, Chen J M & Tang Y, *Acta Chim Sin*, 52 (1994) 36.

29 Morterra C, Cerrato G, Pinna F, Signoretto M & Strukul G, *J Catal*, 149 (1994) 181.

30 Benesi H A, *J Phys Chem*, 61 (1957) 970.

31 Srinivasan R, Keogh R A, Milburn D R & Davis B H, *J Catal*, 153 (1995) 123

32 Chen F R, Couderier G, Joly J F & Vedrine J C, *J Catal*, 143 (1993) 616.