

**PROCESS FOR THE PRODUCTION OF ACETIC ACID BY  
CARBONYLATION**

The present invention relates to a process for the production of acetic acid and in particular, to a process for the production of acetic acid by carbonylation in the presence of an iridium catalyst and methyl iodide co-catalyst.

Preparation of carboxylic acids by iridium-catalysed carbonylation  
5 processes is known and is described, for example in GB-A-1234121, US-A-3772380, DE-A-1767150, EP-A-0616997, EP-A-0618184, EP-A-0618183 and EP-A-0657386.

GB-A-1234121, US-A-3772380 and DE-A-1767150 describe iridium-catalysed carbonylation processes which do not use promoters as in the present  
10 invention.

EP-A-0618184 describes a carbonylation process for the production of carboxylic acids and/or their esters in the presence of an iridium catalyst. The reaction composition is characterised as comprising between 0 exclusive and 10 % water; between 0 exclusive and 10 % halogenated co-catalyst; between 2 and 40 %  
15 ester and carboxylic acid solvent. EP-A-0618184 does not describe the use of a promoter.

EP-A-0618183 describes a carbonylation process for the preparation of carboxylic acids, for example acetic acid, in the presence of iridium and rhodium compounds.

20 EP-A-0657386 describes a process for the preparation of an iridium catalyst solution and its use in a carbonylation reaction for the preparation of acetic acid.

25 EP-A-0642034 describes a process for the carbonylation of methanol and/or a reactive derivative thereof in the presence of acetic acid, an iridium catalyst, methyl iodide, at least a finite concentration of water, methyl acetate and



a promoter selected from ruthenium and osmium. Batch and continuous experiments are described therein. In the continuous experiments the water concentration is as low as 6.8 % by weight.

5 There remains a need for an improved iridium-catalysed carbonylation process.

Thus, according to the present invention there is provided a process for the production of acetic acid comprising (1) continuously feeding methanol and/or a reactive derivative thereof and carbon monoxide to a carbonylation reactor which contains a liquid reaction composition comprising an iridium carbonylation catalyst,  
10 methyl iodide co-catalyst, a finite concentration of water, acetic acid, methyl acetate and at least one promoter; (2) contacting the methanol and/or reactive derivative thereof with the carbon monoxide in the liquid reaction composition to produce acetic acid; and (3) recovering acetic acid from the liquid reaction composition characterised in that there is continuously maintained in the liquid  
15 reaction composition throughout the course of the reaction (a) water at a concentration of no greater than 6.5 % by weight, (b) methyl acetate at a concentration in the range 1 to 35 % by weight and (c) methyl iodide at a concentration in the range 4 to 20 % by weight.

20 The present invention solves the technical problem defined above by continuously maintaining a liquid reaction composition having defined water, methyl iodide and methyl acetate concentrations. This provides several technical advantages.

Thus in the present invention the rate of the carbonylation reaction increases as the water concentration in the liquid reaction composition is reduced  
25 from a concentration of greater than 6.5% by weight, passes through a maximum at a water concentration of no greater than 6.5 % by weight and then declines as very low water concentrations are approached. Therefore, the rate of carbonylation reaction in the process of the present invention will be generally greater than that at a water concentration of greater than 6.5 % by weight (all  
30 other parameters being equal, except the variation in the water concentration being off-set by a variation in the acetic acid concentration). The water concentration at which the carbonylation rate is a maximum increases as the concentration of methyl acetate in the liquid reaction composition is increased. It is believed that the water concentration at which the carbonylation rate is a maximum decreases as the  
35 concentration of methyl iodide in the liquid reaction composition is increased.



Also, it has been found that the promotional effect of a promoter according to the present invention, such as ruthenium, increases as the water concentration is reduced according to the present invention. As noted below, the beneficial effect of a promoter according to the present invention, such as ruthenium has been  
5 found to be greatest at the maximum carbonylation rate in the relationship between carbonylation rate and water concentration. That is, the beneficial effect of a promoter according to the present invention, such as ruthenium, has been found to be greatest at the water concentration which gives the maximum carbonylation rate at any defined methyl acetate and methyl iodide concentrations. In the process of  
10 the present invention, this water concentration is no greater than 6.5 % by weight.

Also, in the process of the present invention, by operating at a water concentration of no greater than 6.5 % by weight, recovery of acetic acid from the reaction composition withdrawn from the carbonylation reactor is facilitated because the amount of water which has to be separated from the acetic acid is  
15 reduced; separation of water from the acetic acid is an energy-intensive part of the recovery process and reduced water concentration results in reduced processing difficulty and/or costs.

The increased carbonylation rate at the low water concentration of the present invention may allow operation at a reduced iridium catalyst concentration  
20 whilst maintaining the rate of carbonylation. This has benefits of reduced production rate of by-products such as propionic acid.

Water may be formed in situ in the liquid reaction composition, for example, by the esterification reaction between methanol reactant and acetic acid product. Small amounts of water may also be produced by hydrogenation of  
25 methanol to produce methane and water. Water may be introduced to the carbonylation reactor together with or separately from other components of the liquid reaction composition. Water may be separated from other components of reaction composition withdrawn from the reactor and may be recycled in controlled amounts to maintain the required concentration of water in the liquid reaction  
30 composition. The water concentration in the liquid reaction composition is no greater than 6.5 % by weight that is, less than or equal to 6.5% by weight and preferably no greater than 6 % by weight. The water concentration is preferably at least 0.1 % by weight, more preferably at least 1 % by weight.

In the process of the present invention, suitable reactive derivatives of  
35 methanol include methyl acetate, dimethyl ether and methyl iodide. A mixture of

methanol and reactive derivatives thereof may be used as reactants in the process of the present invention. Preferably, methanol and/or methyl acetate are used as reactants. At least some of the methanol and/or reactive derivative thereof will be converted to, and hence present as, methyl acetate in the liquid reaction composition by reaction with acetic acid product or solvent. In the process of the present invention the concentration of methyl acetate in the liquid reaction composition is preferably in the range 1 to 30 % by weight, more preferably 5 to 25 % by weight. It has been found that as the methyl acetate concentration is increased, the rate of carbonylation reaction increases and the selectivity to by-products such as propionic acid and carbon dioxide decreases. However, as the concentration of methyl acetate is increased the amount that has to be recycled to the carbonylation reactor from the acetic acid recovery stage increases. Also, too high a methyl acetate concentration may adversely affect phase separation of aqueous and methyl iodide phases during the acetic acid recovery stage. Also, too high a methyl acetate concentration may adversely affect the carbonylation reaction rate by reducing the partial pressure of carbon monoxide at a defined total pressure in the carbonylation reactor.

In the process of the present invention, the concentration of methyl iodide co-catalyst in the liquid reaction composition is preferably in the range 5 to 16 % by weight. As the methyl iodide co-catalyst concentration is increased, the rate of production of by-products such as propionic acid, carbon dioxide and methane is reduced. The increase in rate of carbonylation brought about by increasing methyl iodide concentration is greater at lower water concentrations than at higher water concentrations. Also, as the concentration of methyl iodide is increased, phase separation of aqueous and methyl iodide phases in the acetic acid recovery stage may be facilitated. However, as the concentration of methyl iodide is increased, the partial pressure of carbon monoxide may be adversely reduced at a defined total pressure in the carbonylation reactor.

In the process of the present invention, the iridium carbonylation catalyst is preferably present in the liquid reaction composition at a concentration in the range 400 to 5000 ppm measured as iridium, more preferably in the range 500 to 3000 ppm measured as iridium, yet more preferably in the range 700 to 3000 ppm measured as iridium. In the process of the present invention, the rate of the carbonylation reaction increases as the concentration of iridium is increased.

The iridium catalyst in the liquid reaction composition may comprise any

iridium containing compound which is soluble in the liquid reaction composition. The iridium catalyst may be added to the liquid reaction composition for the carbonylation reaction in any suitable form which dissolves in the liquid reaction composition or is convertible to a soluble form. Examples of suitable iridium-containing compounds which may be added to the liquid reaction composition include  $\text{IrCl}_3$ ,  $\text{IrI}_3$ ,  $\text{IrBr}_3$ ,  $[\text{Ir}(\text{CO})_2\text{I}]_2$ ,  $[\text{Ir}(\text{CO})_2\text{Cl}]_2$ ,  $[\text{Ir}(\text{CO})_2\text{Br}]_2$ ,  $[\text{Ir}(\text{CO})_2\text{I}_2]^- \text{H}^+$ ,  $[\text{Ir}(\text{CO})_2\text{Br}_2]^- \text{H}^+$ ,  $[\text{Ir}(\text{CO})_2\text{I}_4]^- \text{H}^+$ ,  $[\text{Ir}(\text{CH}_3)_3(\text{CO})_2]^- \text{H}^+$ ,  $\text{Ir}_4(\text{CO})_{12}$ ,  $\text{IrCl}_3 \cdot 3\text{H}_2\text{O}$ ,  $\text{IrBr}_3 \cdot 3\text{H}_2\text{O}$ ,  $\text{Ir}_4(\text{CO})_{12}$ , iridium metal,  $\text{Ir}_2\text{O}_3$ ,  $\text{IrO}_2$ ,  $\text{Ir}(\text{acac})(\text{CO})_2$ ,  $\text{Ir}(\text{acac})_3$ , iridium acetate,  $[\text{Ir}_3\text{O}(\text{OAc})_6(\text{H}_2\text{O})_3][\text{OAc}]$ , and hexachloroiridic acid  $[\text{H}_2\text{IrCl}_6]$ , preferably, chloride-free complexes of iridium such as acetates, oxalates and acetoacetates which are soluble in one or more of the carbonylation reaction components such as water, alcohol and/or carboxylic acid. Particularly preferred is green iridium acetate which may be used in an acetic acid or aqueous acetic acid solution.

In the process of the present invention at least one promoter is present in the reaction composition. Suitable promoters are preferably selected from the group consisting of ruthenium, osmium, rhenium, cadmium, mercury, zinc, gallium, indium and tungsten, and are more preferably selected from ruthenium and osmium and most preferably is ruthenium. Preferably, the promoter is present in an effective amount up to the limit of its solubility in the liquid reaction composition and/or any liquid process streams recycled to the carbonylation reactor from the acetic acid recovery stage. The promoter is suitably present in the liquid reaction composition at a molar ratio of promoter : iridium of  $[0.5 \text{ to } 15] : 1$ . As noted above, the beneficial effect of a promoter such as ruthenium has been found to be greatest at the water concentration which gives the maximum carbonylation rate at any defined methyl acetate and methyl iodide concentration. A suitable promoter concentration is 400 to 5000 ppm.

The promoter may comprise any suitable promoter metal-containing compound which is soluble in the liquid reaction composition. The promoter may be added to the liquid reaction composition for the carbonylation reaction in any suitable form which dissolves in the liquid reaction composition or is convertible to soluble form. Examples of suitable ruthenium-containing compounds which may be used as sources of promoter include ruthenium (III) chloride, ruthenium (III) chloride trihydrate, ruthenium (IV) chloride, ruthenium (III) bromide, ruthenium metal, ruthenium oxides, ruthenium (III) formate,  $[\text{Ru}(\text{CO})_3\text{I}_3]^- \text{H}^+$ ,

[Ru(CO)<sub>2</sub>I<sub>2</sub>]<sub>n</sub>, [Ru(CO)<sub>4</sub>I<sub>2</sub>], [Ru(CO)<sub>3</sub>I<sub>2</sub>]<sub>2</sub>, tetra(aceto)chlororuthenium(II,III), ruthenium (III) acetate, ruthenium (III) propionate, ruthenium (III) butyrate, ruthenium pentacarbonyl, trirutheniumdodecacarbonyl and mixed ruthenium halocarbonyls such as dichlorotricarbonylruthenium (II) dimer,  
 5 dibromotricarbonylruthenium (II) dimer, and other organoruthenium complexes such as tetrachlorobis(4-cymene)diruthenium(II), tetrachlorobis(benzene)diruthenium(II), dichloro(cycloocta-1,5-diene)ruthenium (II) polymer and tris(acetylacetonate)ruthenium (III).

10 Examples of suitable osmium-containing compounds which may be used as sources of promoter include osmium (III) chloride hydrate and anhydrous, osmium metal, osmium tetroxide, triosmiumdodecacarbonyl, [Os(CO)<sub>4</sub>I<sub>2</sub>], [Os(CO)<sub>3</sub>I<sub>2</sub>]<sub>2</sub>, [Os(CO)<sub>3</sub>I<sub>3</sub>]<sup>-H<sup>+</sup></sup>, pentachloro- $\mu$ -nitrodiosmium and mixed osmium halocarbonyls such as tricarbonyldichloroosmium (II) dimer and other organoosmium complexes.

15 Examples of suitable rhenium-containing compounds which may be used as sources of promoter include Re<sub>2</sub>(CO)<sub>10</sub>, Re(CO)<sub>5</sub>Cl, Re(CO)<sub>5</sub>Br, Re(CO)<sub>5</sub>I, ReCl<sub>3</sub>.xH<sub>2</sub>O, [Re(CO)<sub>4</sub>I]<sub>2</sub>, [Re(CO)<sub>4</sub>I<sub>2</sub>]<sup>-H<sup>+</sup></sup> and ReCl<sub>5</sub>.yH<sub>2</sub>O.

Examples of suitable cadmium-containing compounds which may be used include Cd(OAc)<sub>2</sub>, CdI<sub>2</sub>, CdBr<sub>2</sub>, CdCl<sub>2</sub>, Cd(OH)<sub>2</sub>, and cadmium acetylacetonate.

20 Examples of suitable mercury-containing compounds which may be used as sources of promoter include Hg(OAc)<sub>2</sub>, HgI<sub>2</sub>, HgBr<sub>2</sub>, HgCl<sub>2</sub>, Hg<sub>2</sub>I<sub>2</sub>, and Hg<sub>2</sub>Cl<sub>2</sub>.

Examples of suitable zinc-containing compounds which may be used as sources of promoter include Zn(OAc)<sub>2</sub>, Zn(OH)<sub>2</sub>, ZnI<sub>2</sub>, ZnBr<sub>2</sub>, ZnCl<sub>2</sub>, and zinc acetylacetonate.

25 Examples of suitable gallium-containing compounds which may be used as sources of promoter include gallium acetylacetonate, gallium acetate, GaCl<sub>3</sub>, GaBr<sub>3</sub>, GaI<sub>3</sub>, Ga<sub>2</sub>Cl<sub>4</sub> and Ga(OH)<sub>3</sub>.

30 Examples of suitable indium-containing compounds which may be used as sources of promoter include indium acetylacetonate, indium acetate, InCl<sub>3</sub>, InBr<sub>3</sub>, InI<sub>3</sub>, InI and In(OH)<sub>3</sub>.

Examples of suitable tungsten-containing compounds which may be used as sources of promoter include W(CO)<sub>6</sub>, WCl<sub>4</sub>, WCl<sub>6</sub>, WBr<sub>5</sub>, WI<sub>2</sub>, or C<sub>9</sub>H<sub>12</sub>W(CO)<sub>3</sub> and any tungsten chloro-, bromo- or iodo-carbonyl compound.

35 Preferably, the iridium- and promoter-containing compounds are free of

impurities which provide or generate in situ ionic iodides which may inhibit the reaction, for example, alkali or alkaline earth metal or other metal salts.

- 5 Ionic contaminants such as, for example, (a) corrosion metals, particularly nickel, iron and chromium and (b) phosphines or nitrogen containing compounds or ligands which may quaternise in situ; should be kept to a minimum in the liquid reaction composition as these will have an adverse effect on the reaction by generating  $I^-$  in the liquid reaction composition which has an adverse effect on the reaction rate. Some corrosion metal contaminants such as for example molybdenum have been found to be less susceptible to the generation of  $I^-$ .
- 10 Corrosion metals which have an adverse affect on the reaction rate may be minimised by using suitable corrosion resistant materials of construction. Similarly, contaminants such as alkali metal iodides, for example lithium iodide, should be kept to a minimum. Corrosion metal and other ionic impurities may be reduced by the use of a suitable ion exchange resin bed to treat the reaction composition, or
- 15 preferably a catalyst recycle stream. Such a process is described in US 4007130. Preferably, ionic contaminants are kept below a concentration at which they would generate 500 ppm  $I^-$ , preferably less than 250 ppm  $I^-$  in the liquid reaction composition.

- 20 The carbon monoxide reactant may be essentially pure or may contain inert impurities such as carbon dioxide, methane, nitrogen, noble gases, water and  $C_1$  to  $C_4$  paraffinic hydrocarbons. The presence of hydrogen in the carbon monoxide feed and generated in situ by the water gas shift reaction is preferably kept low as its presence may result in the formation of hydrogenation products. Thus, the amount of hydrogen in the carbon monoxide reactant is preferably less than 1 mol
- 25 %, more preferably less than 0.5 mol % and yet more preferably less than 0.3 mol % and/or the partial pressure of hydrogen in the carbonylation reactor is preferably less than 1 bar partial pressure, more preferably less than 0.5 bar and yet more preferably less than 0.3 bar. The partial pressure of carbon monoxide in the reactor is suitably in the range 1 to 70 bar, preferably 1 to 35 bar, more preferably
- 30 1 to 15 bar.

The total pressure of the carbonylation reaction is suitably in the range 10 to 200 barg, preferably 15 to 100 barg, more preferably 15 to 50 barg. The temperature of the carbonylation reaction is suitably in the range 100 to 300 °C, preferably in the range 150 to 220 °C.

- 35 The process of the present invention is preferably performed as a

continuous process.

The acetic acid product may be recovered from the liquid reaction composition by withdrawing vapour and/or liquid from the carbonylation reactor and recovering acetic acid from the withdrawn material. Preferably, acetic acid is recovered from the liquid reaction composition by continuously withdrawing liquid reaction composition from the carbonylation reactor and recovering acetic acid from the withdrawn liquid reaction composition by one or more flash and/or fractional distillation stages in which the acetic acid is separated from the other components of the liquid reaction composition such as iridium catalyst, methyl iodide co-catalyst, promoter, methyl acetate, unreacted methanol, water and acetic acid solvent which may be recycled to the reactor to maintain their concentrations in the liquid reaction composition. To maintain stability of the iridium catalyst during the acetic acid product recovery stage, water in process streams containing iridium carbonylation catalyst for recycle to the carbonylation reactor should be maintained at a concentration of at least 0.5 % by weight.

A particularly preferred liquid reaction composition comprises about 5 % by weight water, about 7 % by weight methyl iodide co-catalyst, about 15 % by weight methyl acetate, iridium catalyst at a concentration in the range 400 to 3000 ppm measured as iridium to give a rate of carbonylation reaction in the range of 10 to 40 mol/l/hr at a carbonylation reaction temperature of about 189 °C and a carbonylation reaction pressure of 22 to 30 barg and carbon monoxide partial pressure of 4 to 12 bar, ruthenium promoter at a concentration in the range 400 to 4000 ppm measured as ruthenium to give a molar ratio of ruthenium : iridium of approximately 2.5 : 1 and the balance of the reaction composition comprising substantially acetic acid. Higher or lower concentrations of catalyst and/or higher or lower temperatures and/or higher or lower partial pressures of carbon monoxide may be used to obtain higher or lower rates of reaction.

The invention will now be illustrated by way of example only and with reference to the following examples and drawings in which Figures 1 to 6 represent the effect of water concentration on carbonylation rate in batch autoclave experiments. Figure 7 shows in schematic form apparatus used to illustrate the process of the present invention in continuous operation. Figure 8 represents the effect of water concentration on carbonylation rate in a continuous reactor.

#### **Batch Carbonylation Experiments**

The following batch experiments were performed to illustrate the present

invention. Reaction components were charged to an autoclave with an amount of carbonylatable reactant (methyl acetate) which was consumed during the course of the reaction. In the batch carbonylation experiments the concentration of water decreased as the carbonylation progressed; the carbonylation of methyl acetate and consumption of water being equivalent to the carbonylation of methanol.

By monitoring the rate of carbonylation reaction and calculating the concentration of the reaction components during the experiment, it is possible to determine the rate of carbonylation reaction which would be expected if a carbonylation process were to be operated continuously whilst maintaining under steady state, a liquid reaction composition which is the same as the total reaction composition calculated at any particular point in the batch experiment. In the batch experiments the term 'reaction composition' refers to the total composition of the components in the autoclave in the cold degassed state. In the continuous experiments below, the liquid reaction composition was analysed. The principal difference between the batch experiments and continuous operation is that in the batch experiments, no allowance was made in calculating the component concentrations, for partitioning of the reaction components between the liquid and gaseous phases. Owing to this partitioning, the concentration of the reaction components present in the liquid phase in a batch reaction under reaction conditions was similar, but not identical, to the total reaction composition. In particular, the more volatile components in the reaction composition, such as methyl iodide and methyl acetate, were slightly less concentrated in the liquid reaction composition than in the total reaction composition, whereas the water concentration was comparable between the two. Therefore, the rate calculated in a batch experiment at a certain total reaction composition will be similar to that in a continuous process operating with a liquid composition which is the same as the batch total reaction composition. In addition, trends observed in batch experiments by varying the process variables, such as water concentration, were comparable with the trends observed in continuous experiments. All batch carbonylation experiments were performed using a 300 ml zirconium autoclave reactor equipped with a Dispersimax (Trade Mark) stirrer, liquid catalyst injection facility and cooling coils. A gas supply to the autoclave was provided from a ballast vessel, feed gas being provided to maintain the autoclave at a constant pressure. The rate of gas uptake at a certain point in a reaction run was used to calculate the carbonylation rate, as number of moles of reactant consumed per litre of cold

degassed reactor composition per hour (mol/l/hr), at a particular reactor composition (total reactor composition based on a cold degassed volume).

The methyl acetate concentration was calculated during the course of the reaction from the starting composition, assuming that one mole of methyl acetate was consumed for every mole of carbon monoxide that was consumed. No allowance was made for organic components in the autoclave headspace.

For each batch carbonylation experiment the catalyst,  $\text{H}_2\text{IrCl}_6$ , dissolved in a portion of the acetic acid / water liquid autoclave charge, was charged to the liquid injection facility. If a promoter was used, it was placed in the autoclave with a portion (10g) of the acetic acid charge. The autoclave was then pressure tested with nitrogen, vented via a gas sampling system, and flushed with carbon monoxide several times (3 times at 3-10 barg). The remaining liquid components of the reaction composition were charged to the autoclave via a liquid addition port. The autoclave was then pressurised with carbon monoxide (typically 6 barg) and heated with stirring (1500 rpm) to reaction temperature, 190°C. The total pressure was then raised to approximately 3 barg below the desired operating pressure by feeding carbon monoxide from the ballast vessel. Once stable at temperature (about 15 minutes) the catalyst was injected using an over pressure of carbon monoxide. The iridium concentrations quoted in these batch experiments were based upon a catalyst inject efficiency of 92%. The reactor pressure was maintained at a constant value ( $\pm 0.5$  barg) by feeding gas from the ballast vessel throughout the experiment. Gas uptake from the ballast vessel was measured using datalogging facilities throughout the course of the experiment. The reaction temperature was maintained within  $\pm 1^\circ\text{C}$  of the desired reaction temperature by means of a heating mantle connected to a Eurotherm (Trade Mark) control system. In addition, excess heat of reaction was removed by means of cooling coils. Each experiment was conducted until the gas uptake had ceased. The ballast vessel was then isolated and the reactor crash cooled by use of the cooling coils.

$\text{H}_2\text{IrCl}_6$  (22.2 % w/w Ir aqueous solution) was supplied by Johnson Matthey. The acetic acid was obtained from carbonylation of a mixed methanol/methyl acetate feedstock and contained very low amounts of propionic acid and its precursors. Methyl acetate (29, 699-6), water (32, 007-2) and methyl iodide (I-850-7) were supplied by Aldrich.  $[\text{Ru}(\text{CO})_4\text{I}_2]$  was synthesised from  $\text{Ru}_3(\text{CO})_{12}$  (STREM) and iodine (Aldrich, 37,655-8) and was stored under a carbon monoxide atmosphere in a freezer in a Schlenk tube prior to use.

Examples 1 to 12 demonstrate the effect of water concentration, expressed in % by weight, on carbonylation reaction rate using a ruthenium promoted iridium catalyst (molar ratio of ruthenium : iridium approximately 2 :1) at 190°C and 28 barg total pressure. Charge compositions are given in Table 1. Rate data, at  
5 calculated methyl acetate concentrations in the total reaction composition (as expressed above, cold degassed liquid) of 30%, 25%, 20% ,15% ,10%, 7.5% and 5% by weight, are given in Table 2. The carbonylation rate has been calculated at various methyl acetate and water concentrations and the data according to the  
10 present invention (water concentration no greater than 6.5 % by weight of total reaction composition, cold degassed liquid) are separated from comparative data by a thick solid black line in the Table. From the data it is expected that a continuous carbonylation process could be operated at steady state conditions with a liquid reaction composition the same as the total reaction composition calculated for the batch autoclave experiments with a similar rate of carbonylation achieved.

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**Table 1**

**Charge compositions for ruthenium promoted reactions in a 300 ml zirconium batch autoclave.**

| Example | Ref. | Methyl acetate (g) | Acetic acid (g) | Methyl iodide (g) | Water (g) | H <sub>2</sub> IrCl <sub>6</sub> (g) <sup>a</sup> | Ru(CO) <sub>4</sub> I <sub>2</sub> (g) |
|---------|------|--------------------|-----------------|-------------------|-----------|---------------------------------------------------|----------------------------------------|
| 1       | 637  | 60.02              | 45.65           | 13.96             | 28.30     | 0.641                                             | 1.465                                  |
| 2       | 636  | 60.00              | 53.84           | 13.97             | 20.16     | 0.643                                             | 1.473                                  |
| 3       | 652  | 60.16              | 58.08           | 13.96             | 15.97     | 0.641                                             | 1.460                                  |
| 4       | 656  | 60.03              | 60.43           | 13.96             | 13.51     | 0.643                                             | 1.463                                  |
| 5       | 633  | 60.03              | 62.00           | 13.96             | 11.95     | 0.640                                             | 1.465                                  |
| 6       | 654  | 60.02              | 62.11           | 13.96             | 11.95     | 0.643                                             | 1.460                                  |
| 7       | 655  | 60.04              | 62.16           | 13.97             | 11.96     | 0.643                                             | 1.466                                  |
| 8       | 635  | 60.01              | 62.04           | 13.96             | 11.74     | 0.641                                             | 1.464                                  |
| 9       | 650  | 60.14              | 64.38           | 13.97             | 9.50      | 0.645                                             | 1.466                                  |
| 10      | 658  | 60.07              | 66.01           | 13.95             | 7.96      | 0.641                                             | 1.462                                  |
| 11      | 651  | 60.07              | 67.61           | 13.94             | 6.41      | 0.642                                             | 1.460                                  |
| 12      | 659  | 60.03              | 69.16           | 13.96             | 4.85      | 0.643                                             | 1.459                                  |
| 13      | 648  | 60.17              | 55.51           | 20.50             | 11.91     | 0.642                                             | 1.467                                  |
| 14      | 660  | 60.04              | 43.54           | 13.95             | 28.31     | 0.641                                             | 3.650                                  |
| 15      | 661  | 60.06              | 55.75           | 13.96             | 16.03     | 0.645                                             | 3.650                                  |
| 16      | 632  | 59.98              | 59.85           | 13.96             | 11.97     | 0.639                                             | 3.651                                  |

(a) Weight expressed as pure H<sub>2</sub>IrCl<sub>6</sub>.

**Table 2**  
**Rate data for iridium/ruthenium catalysed reactions in 300 ml autoclave:**  
**Effect of water on rate at various methyl acetate concentrations.**

| Example<br>(ref.) | Water<br>% w/w | Rate /<br>mol/l/hr<br>@ 30%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 25%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 20%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 15%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 10 %<br>methyl<br>acetate |
|-------------------|----------------|--------------------------------------------------|----------------|------------------------------------------------|----------------|------------------------------------------------|----------------|------------------------------------------------|----------------|-------------------------------------------------|
| 1 (637)           | 16.1           | 10.3                                             | 14.8           | 10.8                                           | 13.4           | 11.1                                           | 12.0           | 10.8                                           | 10.7           | 9.2                                             |
| 2 (636)           | 10.9           | 22.2                                             | 9.6            | 22.5                                           | 8.3            | 22.1                                           | 7.1            | 20.3                                           | 5.8            | 16.0                                            |
| 3 (652)           | 8.2            | 32.4                                             | 6.9            | 31.7                                           | 5.7            | 29.5                                           | 4.5            | 25.5                                           | 3.2            | 19.2                                            |
| 4 (656)           | 6.6            | 36.2                                             | 5.4            | 32.1                                           | 4.2            | 27.2                                           | 3.0            | 21.3                                           | 1.8            | 13.1                                            |
| 5 (633)           | 5.6            | 36.5                                             | 4.4            | 31.5                                           | 3.2            | 24.3                                           | 2.0            | 14.7                                           | 0.8            | 6.5                                             |
| 6 (654)           | 5.6            | 37.9                                             | 4.4            | 31.5                                           | 3.2            | 24.7                                           | 2.0            | 15.0                                           | 0.8            | 6.4                                             |
| 7 (655)           | 5.6            | 38.5                                             | 4.4            | 32.8                                           | 3.2            | 24.9                                           | 2.0            | 15.3                                           | 0.9            | 6.7                                             |
| 8 (635)           | 5.5            | 41.0                                             | 4.3            | 33.8                                           | 3.1            | 26.6                                           | 1.9            | 16.4                                           | 0.7            | 4.7                                             |
| 9 (650)           | 4.0            | 37.6                                             | 2.8            | 26.7                                           | 1.7            | 13.8                                           | 0.5            | 6.5                                            | -              | -                                               |
| 10 (658)          | 3.0            | 26.0                                             | 1.9            | 14.9                                           | 0.7            | 7.7                                            | -              | -                                              | -              | -                                               |
| 11 (651)          | 2.0            | 15.1                                             | 0.9            | 7.5                                            | -              | -                                              | -              | -                                              | -              | -                                               |
| 12 (659)          | 1.0            | 7.0                                              | -              | -                                              | -              | -                                              | -              | -                                              | -              | -                                               |
| 13 (648)          | 5.5            | 43.9                                             | 4.4            | 39.2                                           | 3.2            | 33.3                                           | 2.0            | 24.1                                           | 0.8            | 11.9                                            |

**Table 2 cont.**

| Example<br>(ref.) | Water<br>% w/w | Rate<br>mol/l/hr @<br>7.5% methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr @<br>5% Methyl<br>acetate |
|-------------------|----------------|----------------------------------------------|----------------|--------------------------------------------|
| 1 (637)           | 10             | 8.0                                          | 9.3            | 6.2                                        |
| 2 (636)           | 5.1            | 13.5                                         | 4.5            | 10.5                                       |
| 3 (652)           | 2.6            | 15.7                                         | 2.0            | 11.7                                       |
| 4 (656)           | 1.2            | 9.3                                          | 0.6            | 4.3                                        |

- All reactions at 28 barg total pressure and 190°C with a stirrer speed of 1500 rpm.
- At a calculated methyl acetate concentration of 30 % composition calculated to be about 8.4% methyl iodide, 1800 ppm Ir and 2050 ppm Ru.  
At a calculated methyl acetate concentration of 15 % composition calculated to be about 8.0% Methyl iodide, 1700 ppm Ir and 1940 ppm Ru.  
Except example 13 - at a calculated methyl acetate concentration of 15 % composition calculated to be about 12.0 % methyl iodide.
- The methyl iodide concentration was calculated based upon the approximation that each mole of iridium can consume a maximum of 4 moles of methyl iodide to give  $[\text{Ir}(\text{CO})_2\text{I}_4]^-$ .
- Iridium concentration based upon a catalyst inject efficiency of 92%.

Figures 1 and 2 show some of the data from Table 2 in graph form and illustrate the effect of water concentration on rate, at 30% and 15% w/w methyl acetate respectively, for iridium/ruthenium catalysed methanol carbonylation.

Figure 3 shows the data from Table 2 at various methyl acetate concentrations of 5, 7.5, 10 and 15 % by weight.

Further experiments were performed without ruthenium promoter. Experiments A to J demonstrate the effect of water concentration, (expressed as % by weight of total reaction composition, cold degassed liquid), on carbonylation reaction rate using an iridium only catalyst without ruthenium promoter at 190°C and 28 barg total pressure. Charge compositions are given in Table 3. Rate data, at 30%, 25%, 20% ,15% , 10%, 7.5% and 5% by weight calculated methyl acetate concentration, (expressed as % by weight of total reaction composition, cold degassed liquid) are given in Table 4.

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**Table 3****Charge compositions for reactions in a 300 ml zirconium batch autoclave.**

| Experiment | Ref. | Methyl<br>acetate<br>(g) | Acetic<br>acid<br>(g) | Methyl<br>iodide<br>(g) | Water<br>(g) | H <sub>2</sub> IrCl <sub>6</sub><br>(g) <sup>a</sup> |
|------------|------|--------------------------|-----------------------|-------------------------|--------------|------------------------------------------------------|
| A          | 630  | 60.07                    | 47.13                 | 13.96                   | 28.30        | 0.639                                                |
| B          | 609  | 59.99                    | 55.32                 | 13.97                   | 20.11        | 0.640                                                |
| C          | 641  | 60.01                    | 59.40                 | 13.96                   | 16.06        | 0.641                                                |
| D          | 653  | 60.02                    | 59.52                 | 13.97                   | 16.00        | 0.643                                                |
| E          | 598  | 59.99                    | 63.54                 | 13.97                   | 11.94        | 0.641                                                |
| F          | 615  | 60.02                    | 63.51                 | 13.96                   | 11.96        | 0.640                                                |
| G          | 621  | 59.99                    | 63.49                 | 13.96                   | 11.96        | 0.640                                                |
| H          | 634  | 60.05                    | 63.49                 | 13.96                   | 11.98        | 0.649                                                |
| I          | 640  | 60.03                    | 65.95                 | 13.97                   | 9.51         | 0.644                                                |
| J          | 643  | 60.01                    | 66.15                 | 13.96                   | 9.52         | 0.646                                                |
| K          | 642  | 60.02                    | 68.99                 | 13.96                   | 6.46         | 0.642                                                |
| L          | 604  | 60.00                    | 57.04                 | 20.56                   | 11.96        | 0.641                                                |

(a) Weight expressed as pure H<sub>2</sub>IrCl<sub>6</sub>.

**Table 4**  
**Rate data for Ir-catalysed reactions in 300 ml batch autoclave;**  
**effect of water on rate at various methyl acetate concentrations**

| Expt.<br>(ref.) | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 30%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 25%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 20%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 15%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 10 %<br>methyl<br>acetate |
|-----------------|----------------|------------------------------------------------|----------------|------------------------------------------------|----------------|------------------------------------------------|----------------|------------------------------------------------|----------------|-------------------------------------------------|
| A (630)         | 16.1           | 7.1                                            | 14.8           | 7.5                                            | 13.4           | 8.0                                            | 12.0           | 7.7                                            | 10.7           | 6.9                                             |
| B (609)         | 10.9           | 14.9                                           | 9.6            | 14.6                                           | 8.3            | 13.5                                           | 7.0            | 11.2                                           | 5.8            | 7.1                                             |
| C (641)         | 8.2            | 17.7                                           | 7.0            | 15.7                                           | 5.8            | 13.4                                           | 4.5            | 10.5                                           | 3.3            | 7.5                                             |
| D (653)         | 8.2            | 18.2                                           | 7.0            | 17.0                                           | 5.7            | 15.1                                           | 4.5            | 11.7                                           | 3.3            | 8.4                                             |
| E (598)         | 5.6            | 20.4                                           | 4.4            | 17.0                                           | 3.2            | 13.8                                           | 2.0            | 9.5                                            | 0.8            | 4.9                                             |
| F (615)         | 5.6            | 19.7                                           | 4.4            | 17.6                                           | 3.2            | 14.3                                           | 2.0            | 9.9                                            | 0.9            | 5.0                                             |
| G (621)         | 5.6            | 20.5                                           | 4.4            | 17.4                                           | 3.2            | 14.0                                           | 2.0            | 10.5                                           | 0.9            | 5.5                                             |
| H (634)         | 5.6            | 21.1                                           | 4.4            | 17.9                                           | 3.2            | 14.8                                           | 2.0            | 11.1                                           | 0.9            | 6.0                                             |
| I (640)         | 4.0            | 19.7                                           | 2.9            | 15.5                                           | 1.7            | 10.8                                           | 0.5            | N/A                                            | -              | -                                               |
| J (643)         | 4.0            | 22.0                                           | 2.9            | 16.1                                           | 1.7            | 9.9                                            | 0.6            | 4.4                                            | -              | -                                               |
| K (642)         | 2.1            | 12.1                                           | 0.9            | 5.9                                            | -              | -                                              | -              | -                                              | -              | -                                               |
| L (604)         | 5.6            | 22.5                                           | 4.4            | 19.6                                           | 3.2            | 17.0                                           | 2.0            | 14.1                                           | 0.9            | 9.9                                             |

N/A = reaction terminated too early to allow calculation of the rate at this point.

**Table 4 cont.**

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| Experiment<br>(ref.) | Water<br>% w/w | Rate<br>mol/l/hr @<br>7.5% methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr @<br>5% methyl<br>acetate |
|----------------------|----------------|----------------------------------------------|----------------|--------------------------------------------|
| A (630)              | 10.0           | 6.0                                          | 9.3            | 4.8                                        |
| B (609)              | 5.1            | 5.4                                          | 4.5            | 3.9                                        |
| C (641)              | 2.7            | 6.0                                          | 2.1            | 4.5                                        |
| D (653)              | 2.7            | 6.9                                          | 2.0            | 5.4                                        |

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- All reactions at 28 barg total pressure and 190°C with a stirrer speed of 1500 rpm.

- At a calculated methyl acetate concentration of 30 % composition calculated to be about 8.4% Methyl iodide and 1800 ppm Ir.

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At a calculated methyl acetate concentration of 15 % composition calculated to be about 8.0% Methyl iodide and 1700 ppm Ir.

Except experiment L - at a calculated methyl acetate concentration of 15 %, composition calculated to contain 12 % methyl iodide.

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- The methyl iodide concentration was calculated based upon the approximation that each mole of iridium can consume a maximum of 4 moles of methyl iodide to give  $[\text{Ir}(\text{CO})_2\text{I}_4]^-$ .
- Iridium concentration based upon a catalyst inject efficiency of 92%.

Comparison of the data for Table 4 for iridium only with that for Table 2 for iridium/ruthenium is shown in graph form in Figures 4 and 5.

A comparison of the promotional effect of ruthenium, at 30% w/w methyl acetate, at various water concentrations is given in Table 5 below (Experiments A, B, D, H, J & K are compared with Examples 1, 2, 3, 7, 9 & 11).

**Table 5**

| Water concentration<br>% w/w | Carbonylation rate<br>mol/l/hr |                                | Ruthenium<br>rate<br>promotion<br>% |
|------------------------------|--------------------------------|--------------------------------|-------------------------------------|
|                              | Ir catalyst only               | Ir catalyst and<br>Ru promoter |                                     |
| 16.1                         | 7.1                            | 10.3                           | 45%                                 |
| 10.9                         | 14.9                           | 22.2                           | 49%                                 |
| 8.2                          | 18.2                           | 32.4                           | 78%                                 |
| 5.6                          | 21.1                           | 38.5                           | 83%                                 |
| 4.0                          | 22.0                           | 37.6                           | 71%                                 |
| 2.1&2.0                      | 12.1                           | 15.1                           | 25%                                 |

It can be seen from Tables 2, 4 and 5 and Figures 1 to 5 that as the water concentration was reduced from greater than 6.5 % by weight, the carbonylation rate increased, passing through a maximum, and then declined as very low water levels were approached, for both the iridium and iridium/ruthenium catalyst systems. It is also apparent that ruthenium became more effective as a promoter as the water concentration was reduced, ruthenium being most effective in promotional terms when maximum rates were also observed which was at a water concentration no greater than 6.5 % by weight. At lower water levels, at 30% methyl acetate, the rate declined as did the promotional effect of ruthenium.

Figure 5 and Table 6 below (comparison of Experiments A, B, D, & H with Examples 1, 2, 3, & 7) illustrate the same point but at a lower methyl acetate concentration of 15% by weight.

**Table 6**

| Water<br>concentration<br>% w/w | Carbonylation rate<br>mol/l/hr |                                | Ruthenium<br>rate<br>promotion<br>% |
|---------------------------------|--------------------------------|--------------------------------|-------------------------------------|
|                                 | Ir catalyst only               | Ir catalyst and<br>Ru promoter |                                     |
| 12.0                            | 7.7                            | 10.8                           | 40%                                 |
| 7.0 & 7.1                       | 11.2                           | 20.3                           | 81%                                 |
| 4.5                             | 11.7                           | 25.5                           | 118%                                |
| 2.0                             | 11.1                           | 15.3                           | 38%                                 |

5            Figure 3 illustrates that as the methyl acetate concentration is reduced in the process of the present invention from 15% through to 5% by weight calculated methyl acetate concentration in the total reaction composition, the optimum water concentration, in terms of rate, moves to a lower concentration.

10           It is also apparent from Tables 2 & 4 that at 5% by weight calculated methyl acetate concentration in the total reaction composition, and a relatively low water concentration of 2% by weight ( see Example 3) a relatively high carbonylation rate of 11.7 mol/l/hr was observed as compared with the unpromoted Experiment D, which gave a rate of 5.4 mol/l/hr i.e. ruthenium promotion under these conditions was large (117% rate promotion) even at 2% by weight water.

15           Similarly, at 3.2% by weight water and 10% weight methyl acetate a relatively high rate of 19.2 mol/l/hr was observed (Example 3).

             Further batch experiments 13 to 16 and L were performed. Charge compositions are shown in Tables 1 and 3. Results for experiment L are shown in Table 4, for Example 13 in Table 2 and for Examples 14 to 16 in Table 7.

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**Table 7 - Rate data for iridium/ruthenium catalysed reactions in 300 ml autoclave;  
Effect of water on rate at various methyl acetate concentrations.**

| Example (ref.) | Water % w/w | Rate / mol/l/hr @ 30% methyl acetate | Water % w/w | Rate mol/l/hr @ 25% methyl acetate | Water % w/w | Rate mol/l/hr @ 20% methyl acetate | Water % w/w | Rate mol/l/hr @ 15% methyl acetate | Water % w/w | Rate mol/l/hr @ 10 % methyl acetate |
|----------------|-------------|--------------------------------------|-------------|------------------------------------|-------------|------------------------------------|-------------|------------------------------------|-------------|-------------------------------------|
| 14 (660)       | 16.1        | 11.6                                 | 14.8        | 12.2                               | 13.4        | 12.9                               | 12.0        | 13.3                               | 10.7        | 11.6                                |
| 15 (661)       | 8.2         | 39.0                                 | 7.0         | 37.2                               | 5.8         | 34.3                               | 4.5         | 30.7                               | 3.3         | 24.9                                |
| 16 (632)       | 5.6         | 44.0                                 | 4.4         | 36.8                               | 3.2         | 29.8                               | 2.0         | 18.4                               | 0.9         | 7.4                                 |

| Example (ref.) | Water (% w/w) | Rate (mol/l/hr) @ 7.5% methyl acetate | Water (% w/w) | Rate (mol/l/hr) @ 5% methyl acetate |
|----------------|---------------|---------------------------------------|---------------|-------------------------------------|
| 14 (660)       | 10.0          | 10.5                                  | 9.3           | 8.5                                 |
| 15 (661)       | 2.7           | 19.6                                  | 2.1           | 12.0                                |

- All reactions at 28 barg total pressure and 190°C with a stirrer speed of 1500 rpm.
- At a calculated methyl acetate concentration of 30 % the composition was calculated to be about 8.4% Methyl iodide, 1800 ppm Ir and 5090 ppm Ru and at a calculated methyl acetate concentration of 15 % the composition was calculated to be about 8.0% Methyl iodide, 1700 ppm Ir and 4830 ppm Ru.
- The methyl iodide concentration was calculated based upon the approximation that each mole of iridium can consume a maximum of 4 moles of methyl iodide to give  $[\text{Ir}(\text{CO})_2\text{I}_4]^-$ .
- Iridium concentration based upon a catalyst inject efficiency of 92%.

Experiment L shows the effect of increasing methyl iodide co-catalyst concentration for an iridium-only catalysed reaction without promoter. By comparison with experiment H in Table 4, it can be seen that increasing methyl iodide has a beneficial effect on rate of reaction, especially at low water concentration.

Example 13 (Table 2) shows the effect of increasing methyl iodide co-catalyst concentration from about 8 % by weight to 12 % by weight for a ruthenium-promoted, iridium-catalysed process by comparison with Example 7. It is also apparent by comparison with Experiment L that, at low water, the promotional effect of ruthenium was increased when the methyl iodide concentration was raised from 8 % to 12 % (compare experiment H with Example 7), as show in Table 8 below. The effect of increasing methyl iodide concentration from 8 to 12 % by weight at 15 % methyl acetate is also shown in graph form in Figure 6.

**Table 8**

| Experiment | Methyl iodide concentration (% by weight) | Catalyst            | Reaction rate (mol/l/hr) | Ruthenium promotion (%) |
|------------|-------------------------------------------|---------------------|--------------------------|-------------------------|
| H          | 8                                         | iridium             | 11.1                     | 38                      |
| 7          | 8                                         | iridium & ruthenium | 15.3                     |                         |
| L          | 12                                        | iridium             | 14.1                     | 71                      |
| 13         | 12                                        | iridium & ruthenium | 24.1                     |                         |

Comparison of experiment H with experiment L ( 27 % increase in reaction rate in going from 8 to 12 % methyl iodide) and of Example 7 with Example 13 (58% increase in reaction rate in going from 8 to 12 % methyl iodide), shows that under these conditions, the ruthenium promoted iridium catalyst was more sensitive towards methyl iodide concentration than the unpromoted catalyst.

Examples 14 to 16 illustrate the effect of water concentration at various methyl acetate concentrations using ruthenium : iridium molar ratio of about 5 : 1, at 8 % methyl iodide. These examples also demonstrate the additional benefit on reaction rate of increasing the ruthenium : iridium molar ratio from about 2 : 1 (Examples 1 to 12) to 5 : 1

### Continuous Carbonylation Reactor Examples

Experiments were performed to illustrate the present invention using a carbonylation reactor operating continuously at a steady state liquid reaction composition. A schematic diagram of the apparatus is given in Figure 7. The apparatus comprised a stirred carbonylation reactor (1), a flash tank (2) and two distillation columns (3,4) all constructed from zirconium 702. It also had two packed off-gas scrubbers: an optional acetic acid scrubber (not shown) and a methanol scrubber (5) constructed from stainless steel.

In use, commercial grade methanol, which has been used to scrub the off gas was carbonylated in the 6 litre reactor (1) in the presence of the iridium carbonylation catalyst and promoter at a pressure of 24.0 - 30.0 barg and a temperature of 181-195°C. The reactor(1) was fitted with a stirrer/propeller (6) and a baffle cage (not shown) to ensure intimate mixing of the liquid and gaseous reactants. Carbon monoxide was supplied from a commercial plant or from pressure bottles to the reactor via a sparge (7) fitted beneath the stirrer (6). To minimise iron ingress into the reactor the carbon monoxide passed through a carbon filter (not shown). A jacket (not shown), through which hot oil was circulated, enabled the reaction liquid in the reactor to be maintained at a constant reaction temperature. The liquid reaction composition was analysed by near infra red analysis or by gas chromatography.

To purge inerts, high pressure off gas was removed from the reactor at a constant flow rate through line (9). It passed through a condenser (not shown) before the pressure was dropped to 1.48 barg across valve (10) for it to be fed into the scrubbing system.

Liquid reaction composition was withdrawn from the carbonylation reactor down a still well (11) and fed into the flash tank (2) under reactor level control. In the flash tank the liquid reaction composition was flashed down to a pressure of 1.48 barg. The resulting mixture of vapour and liquid was separated: the catalyst

rich liquid returning to the reactor by line (12) and pump (13) and the vapour was passed through a demister (14) and then directly into the light ends distillation column (3), as a vapour. The demister consisted of two parts. The first was a gauze demister section, the second is a packed section. This second section was optionally washed with aqueous material from the head of the light ends column. An ion exchange corrosion metal removal bed (25) was operated to remove corrosion metals from a slip stream of the recycled liquid fraction from the flash tank (catalyst recycle stream) and thereby maintain the concentration of corrosion metals below 100 ppm in the liquid reaction composition.

The acetic acid product recovery section of the apparatus comprised a 36-plate light ends distillation column (3), and a 28-plate drying distillation column (4). Both were fabricated from zirconium with PTFE sieve trays.

Distillation column (3) was operated at the same pressure as the flashtank (about 1.48 barg) with a vapour feed. It had 3 trays below the feed point.

Distillation column (4) operated at 1.8 barg head pressure with a liquid feed at tray 20 counted from the base. The pressure was maintained by using a bleed (26) of carbon monoxide into the head of the column. To minimise heat losses from the columns they are lagged, trace heated and lagged. The trace heating was controlled to a temperature similar to the process temperature at that point within the column.

The overheads from distillation column (3) were passed through a condenser (15); the low pressure off gas passing along line (16) to the scrubbing system, and the condensed liquid falling into a decanter (17). This liquid was two-phase; the heavier organic layer was pumped directly back to the reactor and the lighter aqueous layer was split; some was returned to the top of the column as reflux and some optionally used as the wash to the flashtank and thence to the reactor. The remainder of the aqueous phase was returned to the reactor via the catalyst recycle pump (13). The distillation column (3) had an electrically-heated, thermo-siphon reboiler (not shown), with boil-up controlled on temperature in the reboiler liquid. Crude acetic acid was removed from the reboiler along line 18 and flashed into a vaporiser (19).

The vaporiser was constructed from zirconium 702 and operated at atmospheric pressure with the boil up controlled on the level in the vaporiser. The majority of the material introduced into the vaporiser was removed from the vaporiser overhead as a vapour and was condensed before being pumped by pump

(20) into the drying column (4). The feed to the drying column may also be as a vapour. A base bleed from the vaporiser was recycled along line (21) to the reaction system.

5 It was also possible to operate the distillation column (3) with a vapour take-off from the base with a kettle bleed in place of the vapouriser.

Drying column (4) was heated and controlled in a similar way to column (3), but with boil-up controlled by the temperature on tray 8. Its overhead material was single phase. Some material from the overhead was used as reflux for the distillation column and the remainder was returned to the reactor. Dry acetic acid  
10 product was removed from the base of the column along line (22). The concentration of propionic acid in the dry acetic acid product from the base of the drying column was indicative of the rate of production of propionic acid by-product. Methanol was fed into the column at tray 6, to react with hydroiodic acid.

The low pressure off gas from columns (3, 4) was first passed through the  
15 low pressure off gas fridge condensers (23), condensed liquid being returned to the decanter (17). The resultant vapour was joined with the pressure-reduced high pressure off gas before entering the base of the methanol scrubber (5).

The methanol off gas scrubber (5), contained "knitmesh" packing. It used chilled methanol to remove the methyl iodide from the off gas stream. The  
20 methanol scrubbate from the scrubber was combined with fresh methanol to provide the reactor feed. The scrubbed off gas passed through a control valve (24), which controlled the pressure in the flashtank, and was analysed before passing via a vent to atmosphere.

The off gas: high pressure, low pressure or combined could be passed  
25 through an acetic acid scrubber (not shown), prior to the methanol scrubber. This scrubber was similar to the methanol scrubber but it contained Hastelloy B2 "knitmesh" packing and used ca. 10% of the acetic acid product to scrub the off gas. The scrubbate is then returned to the flashtank. If the acetic acid scrubber was used for the low pressure off gas, the fridge condensers were by-passed.

30 The results for operation with various liquid reaction compositions are shown in Table 9.

**Table 9**

| Experiment | Reaction Composition <sup>a</sup> |                            |                             |                  |                    | Reaction<br>Temp.<br>(°C) | Partial Pressures<br>(bar) |                | Acetic<br>acid<br>production<br>rate<br>(mol/l/hr) | Gaseous by-<br>product rates<br>(% of<br>carbonylation rate) |                 | Liquid<br>By-product<br>Propionic<br>acid<br><br>ppm<br>in acetic<br>acid product |
|------------|-----------------------------------|----------------------------|-----------------------------|------------------|--------------------|---------------------------|----------------------------|----------------|----------------------------------------------------|--------------------------------------------------------------|-----------------|-----------------------------------------------------------------------------------|
|            | Water<br>(wt %)                   | Methyl<br>iodide<br>(wt %) | Methyl<br>acetate<br>(wt %) | Iridium<br>(ppm) | Ruthenium<br>(ppm) |                           | CO                         | H <sub>2</sub> |                                                    | CO <sub>2</sub>                                              | CH <sub>4</sub> |                                                                                   |
| Expt. M    | 7.1                               | 6.9                        | 14.8                        | 1160             | 1510               | 192.6                     | 8.2                        | 0.25           | 17.3                                               | 1.15                                                         | 1.29            | 430                                                                               |
| Example 17 | 4.9                               | 6.8                        | 15.9                        | 1180             | 1690               | 192.5                     | 8.2                        | 0.27           | 22.5                                               | 0.99                                                         | 1.07            | 580                                                                               |
| Example 18 | 4.1                               | 6.7                        | 16.4                        | 1170             | 1720               | 192.6                     | 8.0                        | 0.24           | 22.5                                               | 1.08                                                         | 1.13            | 670                                                                               |
| Example 19 | 2.8                               | 7.0                        | 16.2                        | 1130             | 1640               | 192.5                     | 8.4                        | 0.32           | 19.2                                               | 1.42                                                         | 1.41            | 950                                                                               |

Table 9 cont.

| Experiment | Reaction Composition <sup>a</sup> |                      |                       |               |                 | Reaction Temp. | Partial Pressures (bar) |                | Acetic acid production rate (mol/l/hr) | Gaseous by-product rates (% of carbonylation rate) |                 | Liquid By-product Propionic acid |
|------------|-----------------------------------|----------------------|-----------------------|---------------|-----------------|----------------|-------------------------|----------------|----------------------------------------|----------------------------------------------------|-----------------|----------------------------------|
|            | Water (wt %)                      | Methyl iodide (wt %) | Methyl acetate (wt %) | Iridium (ppm) | Ruthenium (ppm) | (°C)           | CO                      | H <sub>2</sub> |                                        | CO <sub>2</sub>                                    | CH <sub>4</sub> | ppm in acetic acid product       |
| Example 20 | 2.2                               | 6.9                  | 16.7                  | 1130          | 1630            | 192.5          | 8.4                     | 0.29           | 15.4                                   | 1.48                                               | 1.38            | 1150                             |
| Example 21 | 3.4                               | 4.4                  | 18.4                  | 1110          | 1500            | 188.6          | 8.3                     | 0.28           | 15.5                                   | 1.12                                               | 1.10            | 866                              |
| Example 22 | 3.0                               | 6.8                  | 18.6                  | 1120          | 1530            | 188.6          | 8.1                     | 0.27           | 18.4                                   | 1.11                                               | 1.12            | 720                              |
| Example 23 | 3.3                               | 10.1                 | 18.1                  | 950           | 1300            | 186.9          | 7.9                     | 0.26           | 18.0                                   | 0.73                                               | 0.77            | 558                              |
| Example 24 | 6.0                               | 4.0                  | 15.7                  | 1310          | 1710            | 189.7          | 8.3                     | 0.26           | 17.9                                   | 0.92                                               | 0.98            | 609                              |
| Example 25 | 5.2                               | 7.4                  | 14.8                  | 1280          | 1740            | 186.4          | 8.0                     | 0.23           | 17.5                                   | 0.90                                               | 1.00            | 533                              |
| Example 26 | 5.0                               | 7.4                  | 15.5                  | 1440          | 1927            | 189.6          | 8.3                     | 0.29           | 24.2                                   | 0.95                                               | 1.03            | 608                              |
| Example 27 | 4.9                               | 10.1                 | 14.5                  | 1020          | 1350            | 190.2          | 8.0                     | 0.22           | 17.8                                   | 0.82                                               | 0.93            | 480                              |
| Example 28 | 6.2                               | 7.2                  | 11.7                  | 1330          | 1830            | 191.0          | 8.1                     | 0.24           | 17.5                                   | 1.14                                               | 1.25            | 583                              |
| Example 29 | 5.0                               | 6.9                  | 18.7                  | 1350          | 1820            | 181.9          | 8.1                     | 0.25           | 17.9                                   | 0.87                                               | 0.95            | 473                              |

(a) - corrosion metals less than 50 ppm

The results in Table 9 show the effect on carbonylation reaction rate and by-products of varying the water concentration from 7.1 % by weight to 2.2 % weight. From the data in Table 9 it can be seen that as the water concentration was reduced from above 6.5 % by weight to 6.5 % or less, the rate of acetic acid production reaction increased to a maximum (as in the batch examples), which under the particular conditions of Examples 17 to 20, was at about 4 to 5 % by weight. This is shown in graph form in Figure 8.

Examples 21 to 23 were reactions with a liquid reaction composition of about 18 % by weight methyl acetate, 4 to 10 % by weight methyl iodide co-catalyst and about 3 % by weight water. Examples 24 to 27 were reactions with a liquid reaction composition of about 15 % by weight methyl acetate and about 5 % by weight water. These two sets of examples show that as the methyl iodide co-catalyst concentration in the liquid reaction composition was increased, the temperature and/or catalyst concentration required to maintain a given reaction rate was reduced, together with a reduction of the by-product formation.

Examples 28 and 29 show the effect of varying water and methyl acetate concentrations at about 7 % by weight methyl iodide co-catalyst concentration in the liquid reaction composition. Thus, as the water concentration was reduced and the methyl acetate concentration was increased the temperature required to maintain the reaction rate was reduced and the by-product formation was reduced.

#### **Batch experiments using zinc promoter**

Batch examples were performed as for Examples 1 to 12, but using zinc as a promoter in place of ruthenium. The charge compositions are set out in Table 10 and the reaction rate data in Table 11 below.

**Table 10**

**Charge compositions for zinc promoted reactions in a 300 ml zirconium batch autoclave.**

| Example | Ref. | Methyl<br>acetate<br>(g) | Acetic<br>acid<br>(g) | Methyl<br>iodide<br>(g) | Water<br>(g) | H <sub>2</sub> IrCl <sub>6</sub><br>(g) <sup>a</sup> | ZnI <sub>2</sub><br>(g) |
|---------|------|--------------------------|-----------------------|-------------------------|--------------|------------------------------------------------------|-------------------------|
| 30      | 628  | 60.01                    | 55.35                 | 13.98                   | 20.11        | 0.643                                                | 4.988                   |
| 31      | 663  | 60.00                    | 59.41                 | 13.97                   | 16.13        | 0.645                                                | 4.983                   |
| 32      | 627  | 60.10                    | 63.49                 | 13.96                   | 11.97        | 0.641                                                | 5.000                   |

(a) Weight expressed as pure H<sub>2</sub>IrCl<sub>6</sub>.

**Table 11 - Rate data for iridium/zinc catalysed reactions in 300 ml autoclave;  
Effect of water on rate at various methyl acetate concentrations.**

| Example<br>(ref.) | Water<br>% w/w | Rate /<br>mol/l/hr<br>@ 30%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 25%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 20%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 15%<br>methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr<br>@ 10 %<br>methyl<br>acetate |
|-------------------|----------------|--------------------------------------------------|----------------|------------------------------------------------|----------------|------------------------------------------------|----------------|------------------------------------------------|----------------|-------------------------------------------------|
| 30 (628)          | 10.8           | 16.1                                             | 9.5            | 17.2                                           | 8.2            | 17.9                                           | 6.9            | 16.9                                           | 5.7            | 14.1                                            |
| 31 (663)          | 8.3            | 23.1                                             | 7.0            | 23.1                                           | 5.8            | 22.0                                           | 4.6            | 19.8                                           | 3.3            | 15.2                                            |
| 32 (627)          | 5.6            | 29.2                                             | 4.5            | 26.7                                           | 3.3            | 22.4                                           | 2.1            | 16.6                                           | 0.9            | 9.0                                             |

| Example<br>(ref.) | Water<br>% w/w | Rate<br>mol/l/hr @<br>7.5% methyl<br>acetate | Water<br>% w/w | Rate<br>mol/l/hr @<br>5% Methyl<br>acetate |
|-------------------|----------------|----------------------------------------------|----------------|--------------------------------------------|
| 30 (628)          | 5.0            | 11.8                                         | 4.4            | 7.7                                        |
| 31 (663)          | 2.7            | 12.0                                         | 2.1            | 8.6                                        |

- All reactions at 28 barg total pressure and 190°C with a stirrer speed of 1500 rpm.
- At a calculated methyl acetate concentration of 15 % composition calculated to be about 7.8% Methyl iodide, 1660 ppm Ir and 6080 ppm zinc.
- The methyl iodide concentration was calculated based upon the approximation that each mole of iridium can consume a maximum of 4 moles of methyl iodide to give  $[\text{Ir}(\text{CO})_2\text{I}_4]^-$ .
- Iridium concentration based upon a catalyst inject efficiency of 92%.

The data in Table 11 show that as the water concentration was reduced, the rate of carbonylation reaction increased and passed through a maximum at a water concentration no greater than 6.5 % by weight water.

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REPLACED

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**CLAIMS:**

1. A process for the production of acetic acid comprising (1) continuously feeding methanol and/or a reactive derivative thereof and carbon monoxide to a carbonylation reactor which contains a liquid reaction composition comprising an iridium carbonylation catalyst, methyl iodide co-catalyst, a finite concentration of  
5 water, acetic acid, methyl acetate and at least one promoter; (2) contacting the methanol and/or reactive derivative thereof with the carbon monoxide in the liquid reaction composition to produce acetic acid; and (3) recovering acetic acid from the liquid reaction composition characterised in that there is continuously maintained in the liquid reaction composition throughout the course of the reaction  
10 (a) water at a concentration of no greater than 6.5 % by weight, (b) methyl acetate at a concentration in the range 1 to 35 % by weight and (c) methyl iodide at a concentration in the range 4 to 20 % by weight.
2. A process as claimed in claim 1 in which there is continuously maintained in the liquid reaction composition throughout the course of the reaction, water at a  
15 concentration of no greater than 6 % by weight.
3. A process as claimed in claim 1 or claim 2 in which there is continuously maintained in the liquid reaction composition throughout the course of the reaction, water at a concentration of at least 0.1 % by weight.
4. A process as claimed in claim 3 in which there is continuously maintained in  
20 the liquid reaction composition throughout the course of the reaction, water at a concentration of at least 1 % by weight.
5. A process as claimed in any one of the preceding claims in which there is continuously maintained in the liquid reaction composition throughout the course of the reaction, methyl acetate at a concentration in the range 1 to 30 % by weight.
- 25 6. A process as claimed in claim 5 in which there is continuously maintained in



\* C L M S \*

the liquid reaction composition throughout the course of the reaction, methyl acetate at a concentration in the range 5 to 25 % by weight.

7. A process as claimed in any one of the preceding claims in which there is continuously maintained in the liquid reaction composition throughout the course  
5 of the reaction, methyl iodide at a concentration in the range 5 to 16 % by weight.

8. A process as claimed in any one of the preceding claims in which the at least one promoter is selected from the group consisting of ruthenium, osmium, rhenium, cadmium, mercury, zinc, gallium, indium and tungsten, preferably from the group consisting of ruthenium and osmium.

10 9. A process as claimed in claim 8 in which the molar ratio of promoter : iridium is [0.5 to 15] : 1.

10. A process as claimed in claim 1 in which there is continuously maintained in the liquid reaction composition throughout the course of the reaction about 5 % by weight water, about 7 % by weight methyl iodide, about 15 % methyl acetate,  
15 iridium catalyst at a concentration in the range 400 to 3000 ppm and ruthenium promoter at a concentration in the range 400 to 4000 ppm.

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