New Dimensions on Value Added Aldol Chemicals of Acetone

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Aldol condensation of acetone provides a class of value added chemicals: α,β-unsaturated ketones and phenols. α,β-Unsaturated ketones are formed by various cross condensation and Michael reactions of aldol products with acetone or between themselves and phenols are formed by either condensation of acetone with methanol or β-keto-alcohol or isopropanaldehyde or by diene-phenol rearrangement of α,β-unsaturated ketone such as isophorone or by alkylation of isophorone with methanol. These processes are highly eco-friendly and economically viable and are also very selective. All the products can be separated and recovered by distillation and optionally, a more valuable ketone isophorone can be obtained free of other products by selectively converting them back to the starting material acetone, thus absolutely requiring no effluent treatment. All these processes highlight many new dimensions in the production and emerging trends in the unconventional utility in wide range of industries extending to pharmaceutical, food and vegetable and allied industries.

Introduction

Acetone serves as an important industrial intermediate leading to numerous chemicals, thus making it a frontline raw material in many industries. There are many reviews on acetone-based chemicals; it is not the intention of this paper to add to this line. In recent years, acetone is gaining significance as the starting material for making selectively α,β-unsaturated ketones, wherein the aldol products formed from acetone (Chart 1) undergo various cross condensation and Michael reactions with acetone or between themselves, leading to a variety of products and the production line extends to dimethyl- and trimethyl phenols by ecofriendly processes (water is the only byproduct) (Chart 2). These chemicals find many industrial applications and, in fact, the primary condensation product, 4-hydroxy-4-methyl-2-pentanone (diacetone alcohol, DAA) exhibits some wonderful properties and it may be termed as “viagra” to elephants. Thus, the aim of this paper is to reveal new dimensions of these aldol products of acetone in many areas in terms of the versatility of the process, selectivity, ecofriendliness, absolutely requiring no effluent treatment and also wide range of industrial applications extending their utility in pharmaceutical, food, vegetable and allied industries in recent years.

The basic raw material is acetone and under mild process conditions, the process is very viable for the production of two classes of compounds, α,β-unsaturated ketones and phenols. Acetone is a cheaper raw material and the processes for producing these compounds are highly selective compared to the established industrial processes and it is abundantly available in India. HOCL produces 24,000 MT while Herdillia has a capacity of 18,000 MT mostly by oxidation of cumene, NOCIL makes 14,000 MT from isopropyl alcohol1. Regarding the conventional end use pattern, 60% of the total demand is accounted by DAA, MIBK and methyl methacrylate. In this direction, the future production and end use potential of aldol products of acetone have been highlighted.

α,β-Unsaturated Ketones from Acetone

Auto-condensation of acetone proceeds by aldol condensation which can be catalysed by acids as well as bases. A large number of products (Chart 1) are formed through either competitive paths at the addition-dehydration stage of diacetone alcohol itself or with the unused reactant, acetone. The major products in the reaction are: diacetone alcohol, mesityl oxide, phorone, mesitylene, triacetone dialcohol, isophorone and isoxylitones which have significant market potential2-10 (Table 1). A detailed discussion on the reaction pathways of formation of these products has been reported earlier10-21. Though multiplicity of products arise in the product, reaction can be optimised for the desired product through proper choice of process conditions (temperature, pressure and catalyst).
Chart 1

Reaction pathways of formation of aldol products from acetone

1. Formation of Diacetone alcohol by aldol condensation of Acetone

\[ 2\text{CH}_3\cdot\text{C}\cdot\text{CH}_3 \rightarrow (\text{CH}_3)_2\cdot\text{C}\cdot\text{CH}_2\cdot\text{C}\cdot\text{CH}_3 \]

2. Formation of Mesityl oxide by dehydration of Diacetone alcohol

\[ \text{OH} \quad \text{O} \quad \text{OH} \quad \text{H}_2\text{O} \quad (\text{CH}_3)_2\cdot\text{C}\cdot\text{CH}_2\cdot\text{C}\cdot\text{CH}_3 \rightarrow (\text{CH}_3)_2\cdot\text{C}=\text{CH}\cdot\text{C}=\text{CH}\cdot\text{CH}_3 \]

3. Formation of Triacetone dialcohol by aldol condensation of Diacetone alcohol with Acetone

\[ (\text{CH}_3)_2\cdot\text{C}\cdot\text{CH}_2\cdot\text{C}\cdot\text{CH}_3 + \text{CH}_3\cdot\text{C}\cdot\text{CH}_3 \rightarrow (\text{CH}_3)_2\cdot\text{C}\cdot\text{CH}_2\cdot\text{C}\cdot\text{CH}_2\cdot\text{C}(\text{CH}_3)_2 \]

4. Formation of Phorone by dehydration of Triacetone Dialcohol

\[ (\text{CH}_3)_2\cdot\text{C}=\text{CH}\cdot\text{CH}_3 + \text{H}_2\text{O} \rightarrow (\text{CH}_3)_2\cdot\text{C}\cdot\text{CH}_2\cdot\text{C}\cdot\text{CH}_3 \rightarrow (\text{CH}_3)_2\cdot\text{C}=\text{CH}\cdot\text{C}=\text{CH}=\text{C}(\text{CH}_3)_2 \]

5. Formation of Phorone by aldol condensation of Mesityl oxide with Acetone

\[ (\text{CH}_3)_2\cdot\text{C}=\text{CH}\cdot\text{C}=\text{CH}_3 + \text{CH}_3\cdot\text{C}=\text{CH}_3 \rightarrow (\text{CH}_3)_2\cdot\text{C}=\text{CH}\cdot\text{C}=\text{CH}=(\text{CH}_3)_2 \]

6. Formation of Isophorone by 1,6-Michael cyclization of Phorone

\[ (\text{CH}_3)_2\cdot\text{C}=\text{CH}\cdot\text{C}=\text{CH}=(\text{CH}_3)_2 \rightarrow \text{H}_3\text{C} \quad \text{H}_3\text{C} \quad \text{H}_3\text{C} \quad \text{H}_3\text{C} \]

7. Formation of Mesitylene from Mesityl oxide and Acetone by aldol condensation and 1,6-internal cyclization reaction

\[ (\text{CH}_3)_2\cdot\text{C}=\text{CH}\cdot\text{C}=\text{CH}_3 + \text{CH}_3\cdot\text{C}=\text{CH}_3 \rightarrow \text{H}_3\text{C} \quad \text{H}_3\text{C} \quad \text{H}_3\text{C} \quad \text{H}_3\text{C} \]

Contd....
Chart 1—Contd

8 Formation of Semiphorone by dehydration of triacetone dialcohol

\[
\begin{align*}
(\text{CH}_3)_2\text{C} - \text{CH}_2 - \text{C} - \text{CH}_2 - \text{C}(\text{CH}_3) & \longrightarrow (\text{CH}_3)_2\text{C} - \text{CH}_2 - \text{C} - \text{CH} = \text{C}(\text{CH}_3)_2 \\
\end{align*}
\]

9 Formation of Semiphorone by hydration of Phorone

\[
\begin{align*}
(\text{CH}_3)_2\text{C} = \text{CH} - \text{C} - \text{CH} = \text{C}(\text{CH}_3)_2 + \text{H}_2\text{O} & \longrightarrow (\text{H}_3\text{C})_2\text{C}-\text{CH}_2 - \text{C} - \text{CH} = \text{C}(\text{CH}_3)_2 \\
\end{align*}
\]

10 Formation of Tr-Tetralone by reaction of Isophorone with Mesityl oxide

\[
\begin{align*}
\text{H}_3\text{C} & + (\text{CH}_3)_2\text{C} = \text{CH} - \text{C} - \text{CH}_3 \\
\end{align*}
\]

11 Formation of Isoxylitones by aldol condensation of Isophorone with Acetone

\[
\begin{align*}
\text{H}_3\text{C} & + \text{CH}_3 - \text{C} - \text{CH}_3 \\
\end{align*}
\]

12 Formation of Isoxylitones by self condensation of Mesityl oxide

\[
\begin{align*}
4 (\text{CH}_3)_2\text{C} = \text{CH} - \text{C} - \text{CH}_3 & \longrightarrow \\
\end{align*}
\]

13 Formation of 2,2,6,6,-Tetramethyl pyron-4-one by cyclization of Semiphorone

\[
\begin{align*}
(\text{CH}_3)_2\text{C} - \text{CH}_2 - \text{C} - \text{CH} = \text{C}(\text{CH}_3)_2 & \longrightarrow \text{H}_3\text{C} - \text{CH}_3 \\
\end{align*}
\]

14 Formation of 3,3,6,8-Tetramethyl tetralone by reaction of Isophorone with Mesityl oxide

\[
\begin{align*}
\text{H}_3\text{C} & + (\text{CH}_3)_2\text{C} = \text{CH} - \text{C} - \text{CH}_3 \\
\end{align*}
\]
Chart 2

Reaction paths of formation of phenols from acetone

1. Formation of m-Cresol by condensation of Methanol with Acetone
   \[ \text{CH}_3\text{OH} \rightarrow \text{CH}_2\text{O} + \text{H}_2\text{O} \]
   \[ \text{CH}_3\cdot\text{CO}\cdot\text{CH}_3 + \text{CH}_2\text{O} \rightarrow \text{CH}_3\cdot\text{CO}\cdot\text{CH}_2\cdot\text{CH}_2\text{OH} \]
   \[ \text{CH}_3\cdot\text{CO}\cdot\text{CH}_2\cdot\text{CH}_2\text{OH} \rightarrow \text{CH}_3\cdot\text{CO}\cdot\text{CH}_2\cdot\text{CHO} + \text{H}_2 \]
   \[ \text{CH}_3\cdot\text{CO}\cdot\text{CH}_2\cdot\text{CHO} + \text{CH}_3\cdot\text{CO}\cdot\text{CH}_3 \rightarrow \text{+ 2H}_2\text{O} \]

2. Formation of 3,5-Xylenol by condensation of ethanol with Acetone
   \[ \text{CH}_3\cdot\text{CH}_2\text{OH} \rightarrow \text{CH}_3\cdot\text{CHO} + \text{H}_2 \]
   \[ \text{CH}_3\cdot\text{CHO} + \text{CH}_3\cdot\text{CO}\cdot\text{CH}_3 \rightarrow \text{CH}_3\cdot\text{CO}\cdot\text{CH}_2\cdot\text{CHOH}\cdot\text{CH}_3 \]
   \[ \text{CH}_3\cdot\text{CO}\cdot\text{CH}_2\cdot\text{CHOH}\cdot\text{CH}_3 \rightarrow \text{CH}_3\cdot\text{CO}\cdot\text{CH}_2\cdot\text{CO}\cdot\text{CH}_3 + \text{H}_2 \]
   \[ \text{CH}_3\cdot\text{CO}\cdot\text{CH}_2\cdot\text{CO}\cdot\text{CH}_3 + \text{CH}_3\cdot\text{CO}\cdot\text{CH}_3 \rightarrow \text{+ 2H}_2\text{O} \]

3. Formation of 3,5-Xylenol by diene-phenol rearrangement of Isophorone (formed from Acetone)
   \[ 3 \text{CH}_3\cdot\text{CO}\cdot\text{CH}_3 \rightarrow \text{+ 2 H}_2\text{O} \]

4. Formation of 2,3,5-Trimethyl phenol and m-Cresol by disproportionation of 3,5-Xylenol
   \[ 2 \text{OH} \rightarrow \text{OH} + \text{OH} + \text{H}_2\text{O} \]

5. Formation of 2,3,5-Trimethyl phenol by alkylation of Isophorone with Methanol
   \[ \text{H}_3\text{C} + \text{CH}_3\cdot\text{CO}\cdot\text{CH}_3 \rightarrow \text{H}_3\text{C} + \text{CH}_3\cdot\text{CO}\cdot\text{CH}_3 + \text{CH}_4 + \text{H}_2\text{O} \]

6. Formation of 2,3- and 2,5-xylenols by decomposition of 2,3,5-Trimethyl phenol
   \[ 2 \text{OH} - \text{OH} + \text{H}_2\text{O} + \text{C}_2\text{H}_4 \]
Table 1 - Industrial applications of aldol chemicals from acetone

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Product</th>
<th>Industrial Applications</th>
</tr>
</thead>
</table>
| 1      | Diacetone alcohol | Bactericidal to Staphylococci 
In brake fluids 
In polyvinylacetate, styrene-butadiene latex compositions 
In printing inks without environmental hazards 
In corrosion inhibiting paints, leuco vat dyes compositions |
| 2      | Mesityl oxide    | As solvent and plasticiser in PVC formulations 
In paint remover formulations and in removing resins or chlorinated rubber coatings 
Perfume and fragrance compositions 
As solvent of polymer in phenolic resins, poly styrenes, epoxy resins and polyisocyanates |
| 3      | Isophorone       | In phenol-formaldehyde and phenol furural resins 
In PVC compositions, swelling agents 
Industrial solvent for epoxy and phenolic resins 
Chlorinated isophorone as fungicide |
| 4      | Mesitylene       | In making 3,5-xenol and 2,3,5-trimethyl phenol |
| 5      | Phorone          | As stimulant for stem and leaf growths in beans 
For decreasing the storage breakdown of apples |

The formation of diacetone alcohol is equilibrium controlled so that reverse reaction to acetone or dehydration to mesityl oxide can occur. Triacetone dialcohol is formed by the condensation of acetone with diacetone alcohol, but it gets either reverted to acetone rapidly or dehydrated to phorone over the catalyst. The condensation reaction of acetone with mesityl oxide anion gives phorone which can undergo 1,6-internal Michael cyclization to isophorone. Isophorone can also be obtained through condensation of acetone anion with mesityl oxide and subsequent 1,6-aldol reaction. Mesitylene is formed by either condensation of acetone with mesityl oxide anion or acetone anion with mesityl oxide followed by 1,6-aldol reaction.21

As mentioned above, it is essential to exercise control over process conditions; otherwise the reactions lead to higher condensation products. For example, self-condensation of mesityl oxide on anion-exchange resin yields 4-isopropyllidene-3,5,5-trimethyl-2-cyclohexenone,22 mesityl oxide can also dimerize over lithium to give 6-acetyl-1,3,5,5-tetramethyl-2-cyclohexanone. Formation of 2-acetyl-1,3,3,4,4-pentaethylycyclo-pentene and 5-(2-methyl-1-propenyl)- 2,4,4,5-tetramethyl dihydrofuran has also been reported.23

Dehydration of triacetone dialcohol yields semiphorone. 2,2,6,6-Tetramethyl-pyron-4-one is the cyclization product of hemiphorone.23 Tetralone is formed by the reaction of mesityl oxide with isophorone with the loss of methane. Isoxylitones are formed by either the condensation of acetone with isophorone or by auto-condensation of mesityl oxide.23

The processes involving the formation of aldol products of acetone are governed by acid-base catalysis. The steps aimed at achieving the selectivity of desired product and process conditions have been reported in detail earlier.20,21 Now stage is set for the next step, separation of products. Aldolization of acetone constitutes such a versatile process whereby the process conditions can be very satisfactorily achieved for obtaining the desired product. Though α,β-unsaturated ketones and phenols synthesized from acetone differ significantly in their boiling points and can be separated by distillation, the separation of ketones forms a separate entity by itself. Isophorone can be separated from other ketones by distillation.21 If the sample is coloured, decolourisation may be effected by heating it to 90-150°C with acidfullers earth of pH 4.0. In case mesityl oxide and diacetone alcohol are to be removed, they can be freed
by treatment at 130-200°C with sufficient amount of 0.1N NaOH solution so that they are converted back to acetone without affecting isophorone. If the product is to be cleansed of mesityl oxide and phorone, treatment with 3% aqueous FeCl₃ or NH₄Cl solution at 100°C reverts them to acetone, while isophorone remains unchanged in the solution.

Another interesting fact is that the product can be freed of mesitylene by azeotropic distillation with acetic acid. Thus, a more valuable ketone, isophorone, can be recovered optionally from the product while other ketones are reverted back to the starting compound, acetone. Further, if by chance, higher condensation products - isoxylitones - are formed in the process, they can be hydrolysed with 2.6% alkali solution at 175°C under a pressure of 10 atm to give isophorone. Thus, production of α,β-unsaturated ketones from acetone is economically viable and a very eco-friendly process since all the byproducts can be converted back to acetone and the effluents contain only water and do not necessitate any treatment.

**Phenols from Acetone**

Phenols are valuable industrial intermediates (Table 2) for obtaining various bactericidal, polymers,
resins, dyestuffs, etc. A number of processes such as alkylation of phenol, sulfonation of benzene homologues, hydrodealkylation of polyalkylated phenols, oxidation of aromatic hydrocarbons, pyrolysis of Mannich bases of 2-methyl cyclohexanones, catalytic conversion of aromatic carboxylic acids, etc. are available for making phenols. Phenols can also be sourced from tars of low temperature carbonization of Indian coals. Phenol contents can vary from 30% in Kohagudem coals (Singareni Collieries) to 40% in Jambal-Bowla or upper Kajora coals. About 62 individual phenols such as cresols, dimethyl-, trimethyl-, ethyl-phenols, 4,5-indanols, methyl dihydric phenols have been characterized and separated by Rao et al. (Indian Institute of Chemical Technology, Hyderabad). However, it is not viable to produce any individual phenol from coal tars. In this context, it is mentioned that processes have been developed and patented for the selective preparation of alkyl phenols, in particular, o-cresol, 2,6-xylene and 3,5-xylene.

Phenol, m-cresol, 2,5-xylene and 3,5-xylene can be obtained by the condensation of methanol with acetone (Table 3) by passing their mixture over an alumina catalyst containing 10% Fe at 400-410°C with a flow rate 8-8.5 mL/hour over 100 mL of the catalyst. Formation of phenols is believed to have originated with the initial formation of formaldehyde which condenses with acetone to give CH₃CO.CH₂CO.CHO. This compound yields readily CH₃CO.CH₂CHO, which in turn, condenses with acetone to yield phenol and water in the product (Table 3). Similarly, catalytic condensation of ethanol with acetone gives 3,5-xylene.

m-Cresol can also be prepared by a β-ketoalcohol over Fe₂O₃-Al₂O₃ catalyst at 400°C. The required β-ketoalcohol, 2-butanone-4-ol can be obtained by the reaction of acetone and formaldehyde in 60-62% yield. 7.6% yield of phenol is reported at 24.5% conversion.

Phenols can also be prepared by dehydrogenation-condensation of acetone with isopropanaldehyde over chromia supported on magnesia. Phenol, m-cresol, 3,5-xylene and m-ethyl phenol can be prepared in 12-34% yield.

Phenols, in general 3,5-xylene, can be prepared selectively from acetone in high yields (Table 3). Several improved processes have been developed and patented with various catalysts such as magnesia, nickel-chromium-iron, chromia-alumina, etc. In principle, the reaction takes place in two steps, dehydrocyclization of acetone to isophorone and diene-phenol rearrangement of isophorone to 3,5-xylene. These processes gave 80% yield of 3,5-xylene at 95% selectivity. The aromatization activity of these metal oxides is ascribed to coordinatively unsaturated cation sites (e.g. Cr⁺), accompanied by the formation of carbonium which rearranges to the diene leading finally to 3,5-xylene. It is also found that the aromatization reaction is a function of the extent of Cr⁺ species present on the surface of the catalyst. m-Cresol and 2,3,5-trimethyl phenol are formed in the reaction by disproportionation of 3,5-xylene. Alternatively, 2,3,5-trimethyl phenol can also be prepared by methylation of 3,5-xylene with methanol (Table 3). A single step process by alkylation of isophorone with methanol has also been reported to give 2,3,5-trimethylphenol. The mechanistic pathway for this reaction is not yet established. It is possible that 2,3,5-trimethyl phenol formation can be routed in which isophorone is aromatized to 3,5-xylene which in turn gets methylated to 2,3,5-trimethyl phenol, or isophorone itself can get methylated followed by diene-phenol rearrangement leading to 2,3,5-trimethyl phenol. In fact, available literature on the alkylation of isophorone to 2,3,5-trimethyl phenol is very limited. All these phenols find many industrial applications and are used either directly or dispersed in various fields.

Patterns in the End-use of Aldol Chemicals

The final scenario regarding the aldol chemicals centres round the new dimensions in the end-use pattern of two classes of compounds – phenols and α,β-unsaturated ketones. The end-use pattern of phenol is: about 60% in the manufacture of phenolic resins, 10% in alkyl phenols, 7% in epoxy resins and 4% in tanning agents. The utility is now increasingly being extended to personal and health care market which is gaining @10% annually. Phenols are increasingly finding applications in such areas as eye make-up, hair tonics and dyes, mouth wash, germicides in soap, deodorants, shampoos, bio-pesticides and insect repellants. However, the aldol products besides possessing industrial applications are upholding their utility in nascent areas. Diacetone alcohol is reported to affect chemical communications among Asian Elephants eliciting Flehman response and erection in elephants with amazing effect, indicating its potential use in pharmaceutical industry. White crystalline reaction products of urea, acetone and mesityl oxide in the proportion 1-10% are used either directly or dispersed
Table 3 — Proven processes and selectivities of aldol chemicals of acetone

<table>
<thead>
<tr>
<th>Si No.</th>
<th>Aldol chemical</th>
<th>Catalyst</th>
<th>Reaction temp. °C</th>
<th>Reactor, reaction period (h)</th>
<th>Yield (%)</th>
<th>Selectivity (%)</th>
<th>Ref.</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Diacetone</td>
<td>Na metal</td>
<td>0</td>
<td>Batch</td>
<td>26.7</td>
<td>92.1</td>
<td>71.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3g)¹ of feed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ca(OH)₂:Ba(OH)₂·8H₂O (1:1-15)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BaO</td>
<td>0</td>
<td>batch</td>
<td>22.9</td>
<td>100</td>
<td>73.</td>
</tr>
<tr>
<td>2</td>
<td>Mesityl oxide</td>
<td>SiCl₄/Zn powder</td>
<td>Room temp.</td>
<td>Lab, Batch</td>
<td>25.9</td>
<td>60.0</td>
<td>74.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ZnO – ZrO₂ (82:18%)</td>
<td>450</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oxydes / hydroxides of Ce, K, Zr, Hf, Ta, Cr</td>
<td>150</td>
<td>Adiabatic (LHSV 0.7 h⁻¹)</td>
<td>17.9</td>
<td>77.2</td>
<td>75.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ZnO – Cr₂O₃</td>
<td>1 h</td>
<td>batch</td>
<td>15.9</td>
<td>87.4</td>
<td>76.</td>
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<tr>
<td></td>
<td></td>
<td>Activated with Fe₂O₃</td>
<td>300</td>
<td>(NA)</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>Isophorone</td>
<td>Alkali hydroxide</td>
<td>240</td>
<td>Fixed bed (LHSV 0.3 h⁻¹)</td>
<td>14.2</td>
<td>87.7</td>
<td>77.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fixed bed Flow (931g/h) (0.36 h)</td>
<td>13.8</td>
<td>54.9</td>
<td>78.</td>
</tr>
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<td></td>
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<td></td>
<td>Fixed bed LHSV 2.0 h⁻¹</td>
<td>21.8</td>
<td>64.5</td>
<td>79.</td>
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<td></td>
<td>Fixed bed LHSV</td>
<td>13.7</td>
<td>36.0</td>
<td>80.</td>
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<tr>
<td>4</td>
<td>Phorone</td>
<td>AlCl₃, 10%</td>
<td>Room temp.</td>
<td>Lab, batch</td>
<td>22</td>
<td>24</td>
<td>81.</td>
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<tr>
<td></td>
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<td>Batch</td>
<td>39</td>
<td>31</td>
<td>82.</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>(NA)</td>
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<td>5</td>
<td>Mesitylene</td>
<td>HCl</td>
<td>200</td>
<td>Batch</td>
<td>38</td>
<td>74</td>
<td>83.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(LHSV 0.99 h⁻¹)</td>
<td></td>
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</tr>
<tr>
<td>6</td>
<td>3,5-Xylenol</td>
<td>Lithium phosphate</td>
<td>530</td>
<td>Fixed bed (LHSV 1.0)</td>
<td>74.2</td>
<td>82.8</td>
<td>42.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MgO</td>
<td>580</td>
<td>(LHSV 0.5 h⁻¹)</td>
<td>79.6</td>
<td>83.2</td>
<td>42.</td>
</tr>
<tr>
<td>7</td>
<td>2,3,5-</td>
<td>Magnesium</td>
<td>400-600</td>
<td>Fixed bed (LHSV 0.1-3)</td>
<td>8.6</td>
<td>NA</td>
<td>85.</td>
</tr>
<tr>
<td></td>
<td>Trimethyl</td>
<td></td>
<td></td>
<td>Fixed bed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>carbonate / Mg(OH)₂</td>
<td></td>
<td></td>
<td>(LHSV 0.5 h⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>m-Cresol</td>
<td>Fe₂O₃-Al₂O₃</td>
<td>400</td>
<td>Fixed bed</td>
<td>7.6</td>
<td>31</td>
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</tbody>
</table>

NA = Data not available
in edible feeds for cattle, sheep, foxes, minks, skumps and poultry animals\(^8\).

India is the second largest (next to China) producer of vegetables (33 million tonnes) with a share of 13.38\% in total global output. It is also a large producer of fruits (47 million tonnes), accounting for 10\% of the world production. India occupies top position with regard to mangoes, bananas, grapes and chikku. But, our country is a very poor global player and its global market share is a meagre 1\%. It is worth noting that only 1.3\% of the total fruits are processed against 40\% in the developed countries. Though many reasons are given for these short falls, it needs attention for remedy regarding the use of obsolete technology, traditional methods of processing, lack of awareness with respect to scientific methods, etc.

Aldol products of acetone show promising trends in this area also. To brief a few, phorone is reported to stimulate greatly the stem and leaf growth in beans\(^9\). It also showed marked reduction in the disorders regarding core flush, superficial scald and bitter pit in apples. It also decreased storage breakdown in apples\(^9\) too. Aldol chemicals are also found useful as perfume and fragrance compounds. They are reported to impart roasted chicken like odour to certain food preparations\(^9\).

Diacetone alcohol is bactericidal to staphylococci, and it considerably increases the bactericidal action of phenol\(^9\). The condensation product of diacetone alcohol with urea, diacetone monourea, is reported to improve the egg laying capacity of hens\(^9\). Chlorinated isophorones are fungicides\(^14\). Isophorone is a selective insecticide against Ceratitis capitata, Daenens oleae, Rha goletis cerasi and Anastopha ludens but has limited affect on Musca domestica (housefly)\(^9\).

Hence, it may be concluded that acetone provides a potential source of a class of aldol chemicals \(\alpha,\beta\)-unsaturated ketones and phenols which besides being very important industrial intermediates show new dimensions in their utility in pharmaceutical, food, vegetable and allied industries. The processes are very ecofriendly leaving no side product except water necessitating no effluent treatment. The processes are also so versatile that by proper choice of process conditions the reaction can be optimized for the desired product.

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