UNIVERSITI PUTRA MALAYSIA

SOLVENT FREE OXIDATION OF BENZYL ALCOHOL TO PRODUCE BENZALDEHYDE USING BIMETALLIC Au-Pd SUPPORTED CATALYSTS

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By

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The study of using a gold and palladium as heterogeneous catalyst is commonly investigated for many oxidation process now days especially in benzyl alcohol oxidation. In this respect, the main goal of this research is to study the influence of oxidant with Au-Pd bimetallic catalyst to achieve highest potential to obtain more benzaldehyde. The monometallic and bimetallic catalysts are synthesized via impregnation and sol-immobilization methods. The structural, texturalphysico-chemical, morphological, and thermal characteristics of the synthesized catalysts hav investigated by using X-Ray Diffraction (XRD), Thermogravimetric Analysis (TGA), Transmission Electron Microscope (TEM) , High Resolution Transmission Electron Microscopy (HRTEM) , Brunauer-Emmett-Teller (BET), Field Emission Scanning Electron Microscopy (FESEM) and Temperature Programmed Desorption (TPD-NH_3).On the other hand, an examination of the reusability and leaching of gold and palladium into benzyl alcohol also was carried out. As a result, sol-immobilization methods was shown produced stable catalysts, highly active density of both metal loading, highest strength, large surface area and more selective for the oxidation benzyl alcohol. The result also revealed that 1wt%Au-Pd/C catalyst prepared by sol-immobilizations methods showed the best catalytic activity in the oxidation of benzyl alcohol at temperature of 80℃ for 4hours. Comparing with mono Au or Pd catalyst, bimetallic Au-Pd gave alloy formation that contribute a synergy effects and showed an improvement for conversion and selectivity on the benzyl alcohol oxidation. In addition, the effect of variable parameters, such as reaction temperature, effect of different support , heat treatment conditions, oxidant ratio, reaction time and metal loading ratio have been evaluated for optimization to produce more benzaldehyde. It was found that the activity and selectivity of the oxidation benzyl alcohol was highly dependent on these variables. A good reusability of the catalysts with less of leaching gold into the product has obtained also.

As a conclusion, the oxidation of benzyl alcohol was successfully studied and the best catalyst was Au-Pd/C that synthesized by using sol-immobilization. This catalyst was found had a good distribution of narrowed small particles (2.79nm). Furthermore, the importance of the H_2O_2 as an oxidant have been proven in this research.

Abstrak tesis yang dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGOKSIDAAN BENZIL ALKOHOL TANPA PELARUT UNTUK MENGHASILKAN BENZALDEHID MENGGUNAKAN MANGKIN BERPENYOKONG DWILOGAM Au-Pd

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Hasil kajian menggunakan emas dan paladium sebagai mangkin heterogen biasanya disiasat dalam banyak proses pengoksidaan sekarang ini terutama peengoksidaan bagi benzil alkohol. Dalam hal ini, matlamat utama penyelidikan adalah untuk kajian kesan bahan pengoksidaan dengan mangkin Au-Pd untuk mencapai potensi tertinggi bagi menghasilkan lebih benzaldehid. Mangkin monologam dan dwilogam disintesis melalui kaedah pemendakan dan sol-immobilisasi. Ciri-ciri struktur, tekstur fiziko-kimia, morfologi, dan ciri-ciri terma mangkin yang disintesis telah dicirikan dengan menggunakan kaedah Pembelauan Sinar-X (XRD), Analisis Terma Gravimetri (TGA), Mikroskop Transmisi Elektron (TEM), Mikroskop Transmisi Elektron Beresolusi Tinggi (HRTEM), Brunauer-Emmett-Teller (BET), Mikroskop Imbasan Elekron (FESEM) dan Program-Suhu-Nyahjerapan Ammonia (TPD-NH_3). Tambahan lagi, penelitian terhadap keupayaan kebolehgunaan dan keterlarutan emas dan palladium dalam benzil alkohol juga telah dijalankan. Keputusannya, teknik sol immobilisasi menunjukkan penghasilan mangkin yang stabil, ketumpatan yang aktif bagi kemuatan kedua-dua logam, kekuatan yang tinggi, luas permukaan yang besar dan kepilihan yang tinggi bagi pengoksidaan benzil alkohol. Hasil kajian ini juga menunjukkan bahawa mangkin 1wt% Au-Pd/C yang disediakan menggunakan kaedah sol-immobilisasi mempamerkan aktiviti pemangkinan terbaik dalam proses pengoksidaan benzil alkohol pada suhu 80℃ selama 4 jam. Perbandingan dengan mono mangkin Au atau Pd, dwilogam Au-Pd memberikan pembentukan aloi yang menyumbang kepada kesan sinergi dan menunjukkan peningkatan terhadap penukaran dan kepilihan terhadap pengoksidaan benzil alkohol. Tambahan lagi, kesan pelbagai pembolehubah seperti suhu tindak balas, kesan sokongan yang berbeza, keadaan rawatan haba, nisbah bahan pengoksidaan, masa tindak balas dan nisbah pemuatan logam telah pun dikaji untuk mengoptimumkan penghasilan lebih benzaldehid. Ia telah mendapati penukaran dan kepilihan oleh pengoksidaan benzil

alkohol adalah bergantung kepada pembolehubah tersebut. Sebagai kesimpulannya, pengoksidaan benzil alkohol telah berjaya dikaji dan mangkin terbaik adalah Au-Pd / C yang disintesis melalui kaedah sol-immobilisasi. Mangkin ini didapati mempunyai sebaran zarah-zarah kecil sempit yang bagus (2.79 nm). Tambahan pula, kepentingan H_2O_2 sebagai bahan pengoksidaan telah terbukti dalam kajian ini.

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I certify that a Thesis Examination Committee has met on 14 May 2018 to conduct the final examination of Sanaa Tareq Sarhan on her thesis entitled "Solvent Free Oxidation of Benzyl Alcohol to Produce Benzaldehyde Using Bimetallic Au-Pd Supported Catalysts" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

H_2O_2	Hydrogen peroxide
$HAuCl_4$	Chloroauric acid
PVA	Poly vinyl alcohol
$NaBH_4$	Sodium tetrahydridoborate
STEM	Scanning transmission electron microscopy
XPS	X-ray photoelectron spectroscopy
$PdCl_2$	Palladium chlorid
GC	Gas chromatography
GC-FID	Gas chromatography with flame ionisation detector
GC-MS	Gas chromatography mass spectrometry
XRD	X-ray diffraction analysis
HRTEM	High resolution transmission electron microscopy
BET	Brunauer–Emmett–Teller surface area measurement technique
AAS	Atomic absorption spectrophotometer
UV	UV- Visible spectroscopy
FESEM-EDS	Field emission scanning electron microscope-energy dispersive X-ray spectroscopy
TPD	Temperature-programmed desorption
TGA	Thermogravimetric analysis
TPDRO	Temperature programed desportion reduction-oxidation .

TEM	Transmission electron microscopy
TBHP	Tert-butyl hydroperoxide
IM	Impregnation preparation technique
SI	Sol-immobilization preparation technique

CHAPTER 1

INTRODUCTION

Benzyl Alcohol is an aromatic alcohol, of molecular formula $C_6H_5CH_2OH$ is a colourless liquid with a sharp burning taste and slight odor flavouring. The benzyl group is often abbreviated "Bn" (not to be confused with "Bz" which is used for benzoyl), thus benzyl alcohol is denoted as BnOH. Benzyl alcohol is a colorless liquid with a mild pleasant aromatic odor. It is a useful solvent due to its polarity, low toxicity, and low vapor pressure. Benzyl alcohol has moderate solubility in water (4 g/100 mL) and is miscible in alcohols and diethyl ether. The anion produced by deprotonation of the alcohol group is known as benzylate or benzyloxide.

1.1 Uses of benzyl alcohol

Several of its natural and synthetic esters have long been used in perfumery; the alcohol itself has become important in the second half of the 20th century as a developer booster in the processing of colour motion-picture film and as a dyeing assistant for filament nylons. Benzyl alcohol is manufactured by the hydrolysis of benzyl chloride in the presence of soda ash.

It is a precursor to a variety of esters used in the manufacture of soap, perfume, flavors & fragrances, and food additives. Benzyl alcohol is also useful as a degreasing agent, dyeing polyamide, and as a bonding aid. Pharmaceutical grade benzyl alcohol is used as a bacteriostatic and as a local anesthetic.

Benzyl alcohol used in a wide variety of cosmetic formulations as a fragrance component, preservative, solvent, and viscosity-decreasing agent. It is used as a local anesthetic and to reduce pain associated with Lidocaine injection. Also, it is used in the manufacture of other benzyl compounds, as a pharmaceutical aid, and in perfumery and flavoring.

1.2 Methods of Manufacturing benzyl alcohol

Firdt method by hydrolysis of benzyl chloride; second method from benzaldehyde by catalytic reduction or Cannizzaro reaction (Lewis, 2007).

Other processes for the production of benzyl alcohol include the hydrogenation of benzoic acid, the electrochemical reduction of benzoic acid, the hydrolysis of benzyl sulfonic acid, and the decarboxylation of benzyl formate. These processes have no importance in the industrial production of benzyl alcohol, but they may be used to produce derivatives substituted on the aromatic nucleus (In, 2003).

1.3 Possible mechanisms for benzyl alcohol oxidation reaction

Oxidation of benzyl alchohol leads to form various products (Li G. a., 2006). Benzaldehyde is formed at the beginning of the oxidation reaction, which is the main product in most oxidation reactions of benzyl alcohol. Continuing the oxidation reaction leads to the forming of benzoic acid (**Figure 1.1**) (Li, 2006).

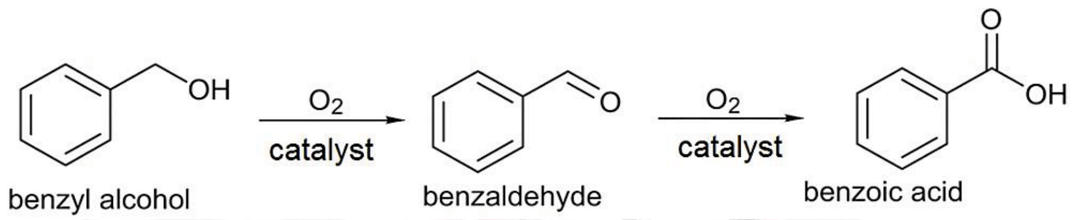


Figure 1.1 : Oxidation reactions of benzyl alcohol (Li, 2006)

According to Li et al. other by-products formed from the side reactions, where any of those by-products can be produce on the reaction settings and they used metal catalyst. Among the possible routes of the side reactions, the decarbonylation reaction leads to produce benzane. An additional possible route of the side reaction is the condensation reaction between benzyl alcohol and benzaldehyde, this reaction forms a hemiacetal, which is unsteady under the reaction conditions and is thereafter either oxidised to the corresponding ester (Figure 1.2) or, tracking the next condensation with a second molecule of alcohol, where that reaction also catalysed by the acid–basic sites of the catalysts, the latest condensation reaction leads to the formation of the corresponding dibenzyl acetal (Figure 1.2), (**Figure 1.3**) and (**Figure 1.4**) (Li G. a., 2006).

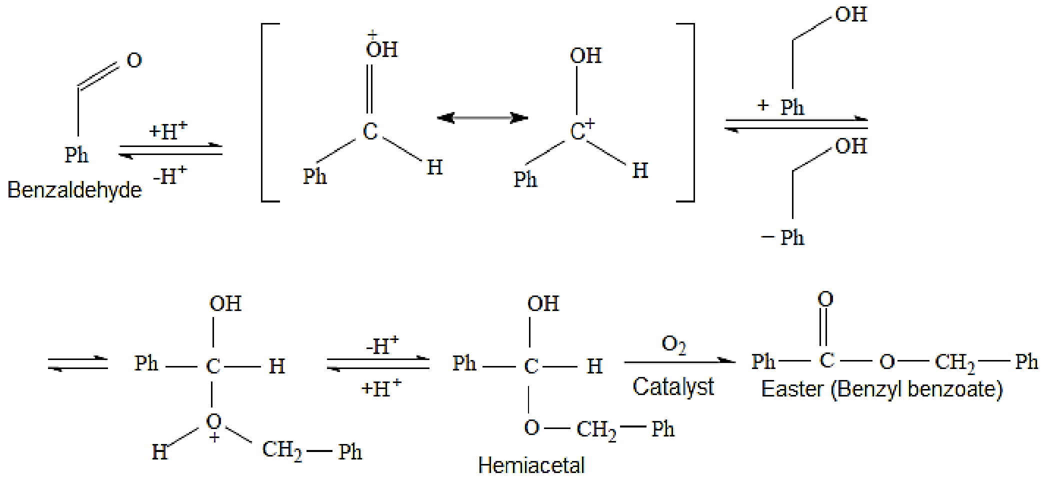


Figure 1.2 : Condensation reaction between benzaldehyde and benzyl alcohol

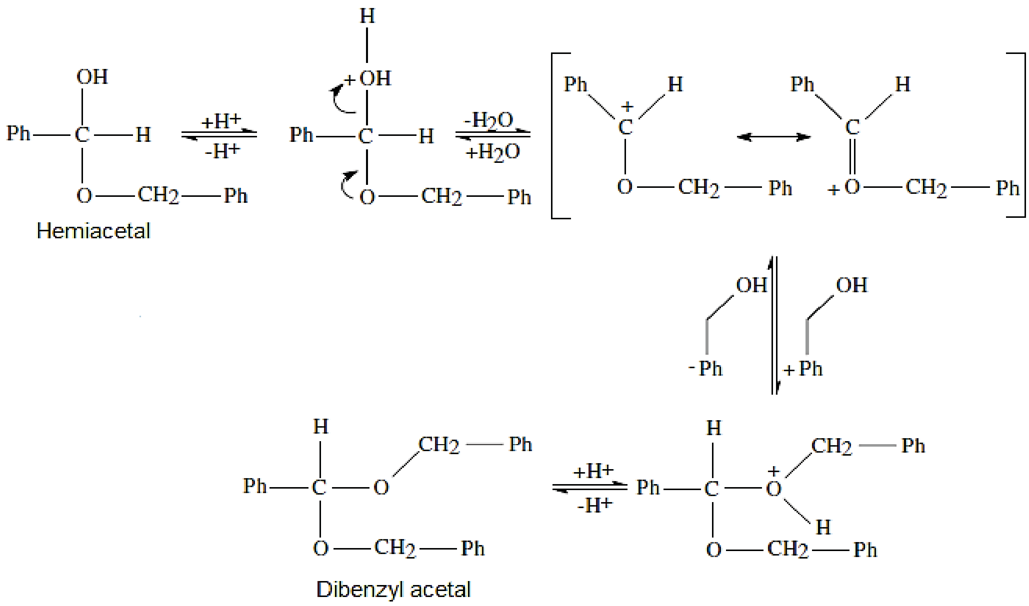


Figure 1.3 : Hemiacetal oxidation to the corresponding ester (Li G. a., 2006)

Another catalysed reaction by the acid–basic sites of the catalyst leads to generate dibenzylether (**Figure 1.4**).

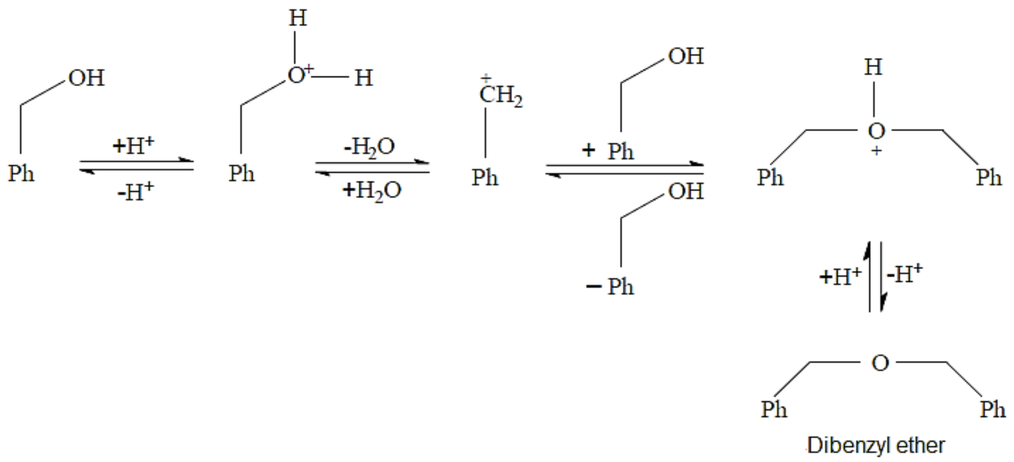


Figure 1.4 : Formation of dibenzyl ether mechanism (Li G. a., 2006)

1.4 Benzaldehyde

Raw materials are essential in the production or synthesis of other chemical compounds at commercial quantity. Chemical compounds such as benzene, alcohols, aldehydes and benzaldehyde are utilized in food, flavour and perfume industries. Some of these compounds are naturally occurring in nature. Nevertheless, the demand of these compounds as raw materials for the production various products at commercial scale supersedes the amount that occur naturally, and therefore, it is necessary to device sustainable techniques for their production. A number of techniques using catalytic process have so far been adopted for the production of various organic compounds such as toluene, alcohol and benzaldehyde.

Selective oxidation is one of the essential techniques employed for the production of various fine chemicals needed at commercial scale in food and beverage industry. Aldehydes are produced by the oxidation of primary alcohol in both laboratory and industrial scale (Enache D. I., 2006). Aldehydes are known as mutually valued as intermediary or high-valued component of the pharmaceutical and medical industries and in perfume production. The preparation of this type of oxidation usually employed oxygen providers such as chromate or permanganate. However, these reagents are not only costly but also dangerous toxic materials, which are harmful to the environment. Typically, aldehydes are obtained from activated alcohols in which the carbon bears a phenyl group, such as benzyl alcohol (Sheldon, 1981; Pillai U. R.-D., 2003; Griffith, 1991). In many previous interactions aldehydes were obtained only from the activation of alcohol in which the carbon carries a vinyl group. The common example of such alcohol is benzyl alcohol (Markó, 1996; Schultz, 2005).

Catalytic dual-phase system was used to convert pentan-1-ol to aldehyde in the first place and later results to the formation of acid when hexan-1-ol was utilized.

The production of such chemicals has faced many restrictions as a result of longer reaction period and low product yield. The development of heterogeneous catalysts using either O_2 or H_2O_2 as oxidants has reduced much of such drawbacks (Neumann, 1995).

Recent studies have proved that nanoparticles of metal support showed high effectiveness as catalysts for the oxidation of alcohol to aldehydes when oxygen is utilized under relatively mild reaction conditions. According to Kaneda and his work team (Mori, 2004) the hydroxyapatite-supported by palladium Nano-clusters (Pd / HAP) showed higher turnover frequencies (TOFs) for phenyl-ethanol and alcohols oxidation such as octan-1-ol oxidation. Coma and his work team (Abad A. C., 2005), revealed that it is possible to convert the CeO_2 oxide from a stoichiometry oxidant to a catalytic system when Au Nano crystals is added, thereby promoting the earlier findings of Kaneda and co-workers (Mori, 2004), with similar TOFs.

1.4.1 Chemical and physical properties of benzaldehyde

Selective oxidation reaction process of aromatic hydrocarbon compounds to produce important chemicals at commercial scale maintains to be a major task for the chemical industries to date (Thomas J. M., 1999; Stahl, 2004; Limberg, 2003; Sadow, 2003). Recently, researchers all over the world have focussed their researcher work in developing new catalysts that are capable of catalysing the oxidation process of such hydrocarbon compounds to obtain their corresponding by-products. Benzaldehyde is one of the most important substrates currently attracting research interest in industry and academia. Benzaldehyde is one of the organic compounds made up of a benzene ring and a substituent. Benzaldehyde is considered as the simplest aromatic compound (aldehyde) and one of the most useful industrially. Benzaldehyde also known as benzene carbaldehyde, phenyl methanol or Benzoic aldehyde is a mono substituted benzene derivative in which the single hydrogen atom from benzene is replaced by –COH (RA Sheldon and H. van Bekkum, 2001).

Benzaldehyde is also a representative of aromatic hydrocarbons categorized as hazardous material (U.S E Protection, 1999). Therefore, the development of better methods for the oxidation of aromatics such as benzaldehyde is necessary for environmental reasons.

Table 1.1 : Chemical properties of benzaldehyde Chemical Properties http://en.wikipedia.org/wiki/Toluene)

Molecular formula	C_7H_6O or C_6H_5CHO
Molar Mass	106.124 g/mol
Appearances	Colourless liquid and strongly refractive
Density	1.044 g/mL, Liquid
Melting points	-57.12 ºC
Boiling Points	178.1 ºC
Solubility in water	3 g/L (20 ºC)

1.4.2 Uses of benzaldehyde

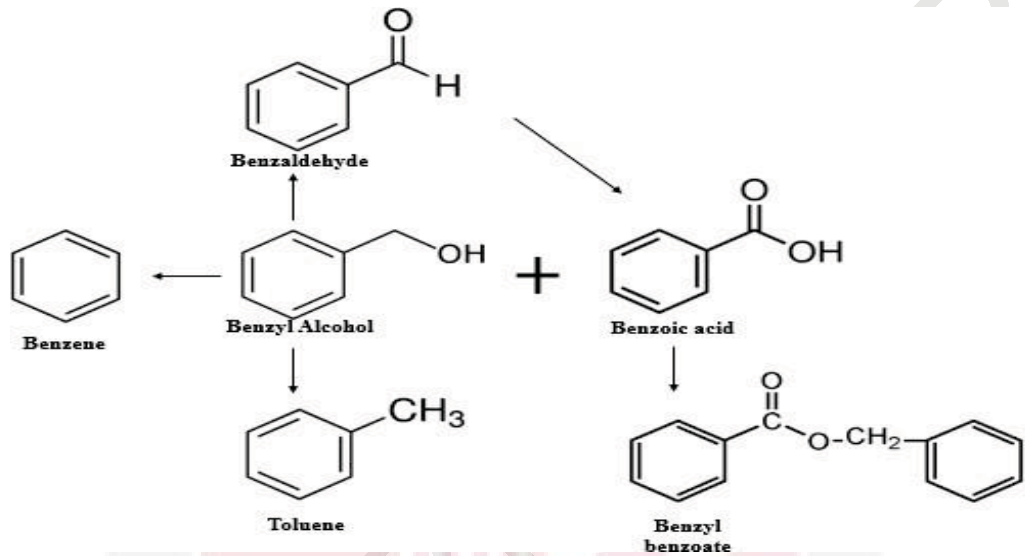
Benzaldehyde is usually used to confer almond flavours to food and other related scented products. Benzaldehyde like many aromatic compounds is employed in the production of cosmetics (Andersen, 2006). Industrially, benzaldehyde is utilized chiefly as a precursor to various organic compounds such as chemical intermediate in the manufacture of dyes, pharmaceuticals, perfumes and flavouring chemicals. Others include plastic additives, precursor in the preparation of aniline dye malachite green, cinnamaldehyde and styrene.

1.4.3 Manufacture benzaldehyde

Benzaldehyde is the major product of interest in this study, as a result of its high demand in the present chemical industries practices. Benzaldehyde is found to be one of the most needed chemical compounds used as raw materials for the preparation of many useful compounds at industrial scale. Benzaldehyde is currently produced by various chemical processes both at laboratory and industrial scale. The main routes used for its preparation are oxidation of toluene and liquid phase chlorination. Other routes that were developed include partial oxidation of benzyl alcohol, alkali hydrolysis of benzyl chloride and the carbonylation of benzene (Brühne, F., & Wright, E., 2002).

About 7000 tonnes of synthetic benzaldehyde and 100 tonnes of natural benzaldehyde were reported to be produced annually as of 1999. The significant amount of natural benzaldehyde is synthesized from cinnamaldehyde obtained from cassia oil using retro-aldol reaction (Passos, Maria Laura.,et. al, 2009). During the reaction process, the cinnamaldehyde is subjected to heating in aqueous/alcoholic solution at a temperature of 90 and 150 ºC with base for a period of 5 to 80 h (Wiener & Charles & Alan , 1986) and the produced benzaldehyde will undergo distillation process.

In gas phase oxidation process of toluene, the contact time might be decreased and therefore the oxidation of benzaldehyde might be reduced so that high selectivity to benzaldehyde may be achieved (Centi & et. al, 2000; Larrondo & et. al, 2001). Nevertheless, there is no commercial plants for the production of benzaldehyde from the oxidation of toluene by air in gas phase that are currently available due to the low activity/ and or selectivity. Studies are currently on-going to develop proper catalysts for the improved catalytic behaviour towards benzaldehyde production (Xue & et. al, 2009). The main mechanism for the production of benzaldehyde is depicted in scheme 1.1



Scheme 1.1 : Mechanism for the production of benzaldehyde and other compounds

1.5 Catalysis

Catalysis can be defined as an important technology for accelerating rate of chemical reactions/conversions. It recognises the environmentally benign and commercially feasible chemical reactions that are used to transform energy carriers to more useful energy form. Moreover, Nano-catalysts, besides decreasing the activation energy of the reaction, which eventually reduce the total input energy required for reaction processes but also advances two major considerable catalysts properties i.e thermal stability and selectivity and therefore, resulting to ecologically friendly catalytic system.

Recently, Nano-materials are reported to be used as Nano-catalysts, which are used in the range of liquid and solid catalysis applications. Meanwhile, solid catalysts are classified as one of the previously used catalysts at industrial scale for main chemical processes (Serrano *et al*., 2009; Zäch*et al.,* 2006). Thus *catalysis play a fundamental role in the improvement of sustainable reactions, which are principal to allow the* *present and future, universal production of energy and chemicals while avoiding harmful consequences to the surrounding environment* and *has demonstrated the meaning of the key technology.* Synthesis of ammonia and methyl alcohol are some of the few industrial operations that currently employ catalysis technology.

Both ammonia and methyl alcohol synthesis at commercial scale attain the development of the water-gas shift process and solid catalysis. About $900 billion dollars were reported to be generated through the chemical products manufacturing world-wide, which account for about 85-90% of the out-put (Robertson, 1970).

1.6 Gold history

The earliest discovering was done by Dulong and Thenard in 1823, who they discovered gold as one of the metals that have the ability to catalysed the ammonia decomposition; this could possibly be the earliest mention to the fact which is gold not all the time showing weak activities. Michael Faraday In 1834, made the reaction of hydrogen with oxygen by using gold catalysed at room temperature. In 1861, for the first time Thomas Graham noticed through investigations the gold effects on the solubility of hydrogen in palladium.

In 1906 Faraday reaction was carried out again to study of the oxidation of hydrogen using gold gauze (Nikolaeva, 2014). In 1925, gold powder approved as an effective catalyst (Chapman, 1925). Later, the first report was published explaining the CO oxidation using gold gauze. Also, at that time it had been noted that gold have minor action for ethane hydrogenation (Benton, 1927). In 1973, Bond and the research team were able successfully in catalyse the process of hydrogenation of alkenes and alkynes using gold in small particles scattered on SiO_2 or Al_2O_3. So they approved for the first time that gold has the ability to be a remarkable active catalyst when dispersed in the form of nanoparticles (Bond G. C., 1973).

The practical proof of the fact that nano-particulate gold could be the optimal catalyst for some reactions came from Hutchings and his team, who they estimated that gold could be the highest active catalyst for etheylene hydrochlorination proscess (Hutchings G. J., Vapor Phase l-lydrochlorination of Acetylene: Correlation of Catalytic Activity of Supported Metal Chloride Catalysts, 1985), and Haruta found also, the full activity of catalysts when supported by gold, especially for CO oxidation process at low temperature. Thereafter, the nanoparticles of gold catalysts had attracted considerable interest because of the amazing characteristics (Haruta M. a., 1989).

A unique work has been developed in many studies on improving the catalysis with gold. Only in the late 1990's Prati discovered that gold could be a catalyst for alcohol oxidation (Prati L. a., 1998). It was proved that, unlike Pt/C and Pd/C that can oxidise alcohol independently of the solution pH, a base was required for activity with Au/C.

1.7 Problem statement

Organic compounds such as toluene, benzoic acid and benzaldehyde are among the most important fine chemicals needed as either a raw materials or intermediates in the production process of many flavours, food, beverages and cosmetics. Although such organic compounds/materials can occur naturally, yet their production in commercial scale is necessary for varieties of industrial applications. Oxidation of alcohols, particularly primary alcohols is considered as one of the important methods for the conversion of such organic compounds to their corresponding carbonyl carbon compounds. A lot of techniques have been proven positive for such transformations. However, most of the reported earlier research employed conservative technique, which adopted the oxidation process performed with stoichiometric amounts of inorganic oxidants and notably chromium (VI) reagents (Cardillo, 2012; Pillai U. R.-D., 2003).

One of the major drawbacks of such oxidants is that apart from being relatively expensive, the oxidants also generate plentiful amounts of heavy-metal waste product. Moreover, the oxidation reaction process has demonstrated to be carried out using some environmentally unwanted solvents, typically chlorinated hydrocarbons, which led to production of more toxic waste. A wide variety of metal and non-metal-based stoichiometric reagents have been reported to be employed for the oxidation of primary alcohols to their corresponding aldehydes.

Considering the environmental effects of the utilization of conventional techniques, oxidants, solvents and catalysts for the oxidation/selective oxidation of alcohols to corresponding aldehydes, it has become necessary to device more environmental benign methods for such processes. Thus, the development of greener oxidation systems using less poisonous catalysts, less toxic oxidants and solvents become a vital aim for this study. Hydrogen peroxide is considered as one of the most perfect candidates as an environmentally friendly oxidant for selective oxidation reaction of alcohol. There are some few selective oxidation reactions that were reported to utilize molecular oxygen as an oxidant. Nevertheless, the selectivity of the reaction was found to be poor and therefore, the process can only be achieved if the stoichiometric oxygen donor such as manganates or any activated form of oxygen such as tert-butyl hydro peroxide is employed. As a result of the aforementioned problems associated to conservative oxidation reaction processes, there is need for the new catalytic routes that utilize less harmful oxidants especially H_2O_2, which produces only water as the reaction by-products and therefore harmless to the environment.

Homogeneous catalysts were reported to have excellent activity in the oxidation reaction of alcohols and many other reaction processes. However, such catalysts have displayed many disadvantages, which include difficulty in separation after use and polluting the environment during water washing. Heterogeneous catalysts system was recently reported to be excellent in the oxidation reaction of alcohols to their corresponding carbonyl compounds. This study will employ metal oxides in mono and bimetallic form supported on transition metal oxides and carbon based supports for the selective oxidation of primary alcohol to benzaldehyde using hydrogen peroxide as an oxidant under mild reaction conditions. Typically, gold-palladium nanoparticle supported on titanium oxide and carbon catalysts are employed for this study.

1.7.1 Scope of the study

The scope of research is limited to the synthesise of mono Au,Pd and bimetallic Au-Pd catalyst using sol immobilization and impregnation methods by utilizing different supports of TiO_2 and activated carbon and characterization of the catalyst. Moreover, attention has been paid to the preparation of gold based catalysts in order to assess the relation between support/active metal, preparation method the catalysts characterisation (XRD, TEM, HRTEM, TGA, BET, and TPD).

The catalysts characterizations will help to study the composition, acidity/basicity and surface morphology of the synthesised gold Nano-particles catalyst. The studies will help to greatly modify the activity and/or the selectivity of the whole catalyst. The aim of this study is to produce benzaldehyde from benzyl alcohol using suitable gold base catalysts synthesized from a suitable preparation technique. The synthesized catalysts were examined in the oxidation reaction of benzyl alcohol in the presence of hydrogen peroxides as the oxidant.

The contribution of this study is that the hydrogen peroxide was employed as an oxidant for the benzyl alcohol oxidation. This is because of its environmental benign, water being the only chemical by-product; on the other hand, the water is actually used as a process solvent, so the reactions are of general interest due to their potential in combinational chemistry, simple processes, easy work-up, low cost and reduction in harmful waste materials. This study mainly focuses on the selective oxidation of benzyl alcohol to benzaldehyde by using hydrogen peroxide as a green oxidant.

1.8 Objectives of the research

The main objectives of the study are:

- To synthesize mono gold, palladium and bimetallic gold-palladium supported titanium oxide and carbon via different impregnation and sol immobilization.
- To characterize the catalysts using Thermogravimetry Analysis (TGA), X-Ray Diffraction (XRD), Scanning Electron Microscope (SEM), High-Resolution Transmission Electron Microscope (HRTEM) and Temperature Programmed Desorption (TPD)
- To study the oxidation of benzyl alcohol using prepared catalyst and H_2O_2 as an oxidant for the conversion and selectivity to benzaldehyde.
- To optimize the conditions based on effect of the oxidants, amount of the catalyst, different loading H_2O_2 as an oxidant and different temperature) towards enhance conversation and selectivity of benzyl alcohol oxidation.

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