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CO to CO_2 Using Magnesium Based Catalysts: An Overview

GAURAV RATTAN*, MANINDER KUMAR, MEENAKSHI SHEORAN

Dr. S.S. Bhatnagar University Institute of Chemical Engineering and Technology
Panjab University Chandigarh-160014, India

*Assistant Professor, Dr. S.S.B.U.I.C.E.T., Panjab University, Chandigarh, 160014

***Email id: grattan@pu.ac.in**

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Abstract Stringent environmental regulations have been adopted by the government in order to decrease the emission of vehicular exhaust such as SOx, NOx, CO and unburned hydrocarbons. Therefore, the development and exploration of catalysts started in the last century for the oxidation of carbon monoxide by different methods have attracted many researchers. Therefore, large number of catalysts have been modified and tested for CO oxidation. The developed catalysts have the ability of 100% conversion. Keeping in view of the literature accumulated in the last few decades for CO oxidation, Magnesium based catalysts have been reported by many scientists for CO oxidation due to its unique characteristics such as high catalytic performance at low temperatures and good durability and stability toward CO oxidation. This article represents a short review in tabular form which facilitates a quick view on compounds that have been reported with magnesium previously.

Keywords: CO, oxidation, Magnesium, Catalyst, Support, Review, Automobile exhaust.

1. INTRODUCTION

Automobiles are a necessary evil, while they have made life easy and convenient; but they also complicated it with toxic emissions. Automobile exhaust significantly contributes to environment pollution. Pollution comes as a by product of the combustion process and evaporation of fuel itself. Million tons of gasoline burned in millions of car each year, moreover the number of vehicles is increasing exponentially. About 19 million vehicles are added every year across the world which will lead the environmental pollution at alarming

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level and with the expected increase in vehicles causes ever increasing global emissions. The primary pollutants from vehicles comprised of carbon monoxide (CO), hydrocarbons (HCs) and nitrogen oxides (NO_x) [1]. These three harmful pollutants are major source of air pollution and it affects humans, vegetation, and atmosphere in number of ways. Among all types of exhaust gases carbon monoxide is most harmful [2]. It also contributes indirectly to global warming and ozone depletion [3]. Thus, CO levels in the ambient air play a role in determining the air quality of a region.

Catalytic oxidation of CO is a simple and straightforward approach in order to curb the menace of stringent regulation adopted for vehicles as shown by equation 1.

$$2CO + O_2 \rightarrow CO_2 \quad \textbf{(1)}$$

Due to incomplete combustion or partial combustion of fuel in the engine, it releases pollutants to atmosphere. Therefore catalytic oxidation of CO to CO_2 is a reaction studied especially by automotive industry [4-6]. Moreover CO_2 found in the atmosphere is less harmful and is useful for vegetation. Hence, CO oxidation has been studied extensively over various types of catalyst such as noble metals (Pt, Pd, Rh, Au, etc.) [7-8], base metals (Cu, Mn, Cr, Co, Ni, Fe, etc.) [9-10] perovskite structures [11].

Noble metals are known for their high oxidation power and terms as paramount in automobile industry since the seventeenth century. Moreover they are thermally and mechantically stable. But the high cost of noble metals and their low availability provokes the researchers around to substitute them with other easily available and economical material which can be considered as an alternative to noble metals. In this regard transition base metals are widely studied for oxidation reactions [12-13]. Intense literature reveals that Mg is easily available and good support for oxidation studies. Magnesium based catalysts have been studied in detail for CO oxidation attributed to the catalytic activity and stability tests [14-15]. The significant activity in the development of magnesium based catalyst for CO emissions control technology is also depicted in the many patents [16-17] and proceedings of seminars and symposia but still there is a gap in the literature for a review article solely devoted to magnesium based catalyst for CO oxidation. Therefore, in order to fill the gap, the present review updates some of the data accumulated on magnesium based catalyst.

2. SOURCES OF CO EMISSIONS

There are several ways of CO emission which include natural and anthropogenic ways; The generation of CO from industries, human's activities and nature adds CO to atmosphere in many ways. However, vehicular exhaust contributes the largest share of CO emission in the environment.

2.1 CO from Automobiles

The primary purpose of internal combustion engine is to produce energy by combustion reaction of HCs and ambient oxygen. However, the combustion reaction is incomplete most of the times which leads to the formation of CO in the internal combustion engine. CO is formed as an intermediate reaction product during combustion of HC. This occurs when the ratio of air to fuel in the combustion chamber is too low for complete combustion, when there is inadequate mixing of fuel and air, low combustion temperature or too short a reaction time. When the air-fuel ratio is too low, there is insufficient oxygen to convert all the carbon in the fuel to carbon dioxide [18]. During the cold start period of vehicles, a lot of carbon monoxide (CO) is released in atmosphere [19]. Exhaust composition [1] of gasoline fuelled engine:

I. Carbon monoxide (CO, 0.5 vol. %);
II. Hydrocarbons (HC, 350 vppm);
III. Nitrogen oxides (NO_x, 900 vppm);
IV. Hydrogen (H_2, 0.17 vol. %);
V. Water (H_2O, 10 vol. %);
VI. Carbon dioxide (CO_2, 10 vol. %);
VII. Oxygen (O_2, 0.5 vol. %).

2.2 Adverse Effects of CO

Carbon monoxide is an odourless, colourless and toxic gas. It is about 3% lighter than air. It is also called as silent killer. It is a non-irritant gas and is very slightly soluble in water. It's a common industrial hazard created by the incomplete burning of any carbon based fuel. Carbon monoxide is a poison for any air-breathing animal. Nitrogen oxides lead to smog and acid rain, and hydrocarbons produce smog. Carbon monoxide is responsible for a large percentage of the accidental poisonings and deaths reported throughout the world each year. There are some conditions in which a small percentage of the population to become exposed to dangerous levels of carbon monoxide. High levels of CO can be fatal causing death within minute's i.e. when carbon monoxide reacts or binds with the haemoglobin (which is responsible for oxygen carrying) to form carboxyhaemoglobin which greatly reduces the oxygen carrying capacity of blood. If there is a lot of CO in the air, the body may replace oxygen in blood with CO. This blocks oxygen from getting into the body, which can damage tissues and result in death [2].

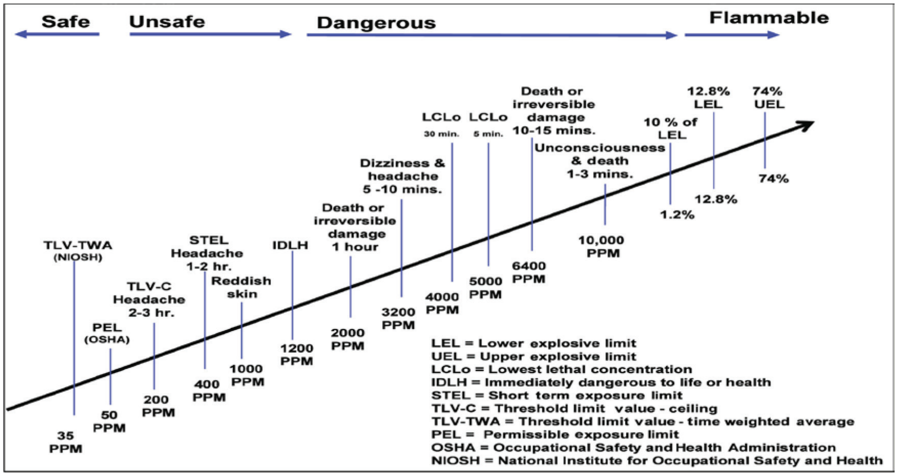

Figure 1 Effect of exposure to various concentrations of CO [20]

3. EMISSION REGULATIONS

Urban air quality is mainly degraded by automobiles i.e. from internal combustion engine exhaust gas emissions, and by more harmful species derived from them via photochemical reactions. Emissions legislation has significantly tightened in most regions, and led to major air control in various parts of the world. There are three main regulatory bodies; Europe, America and Japan, and each have different test drive cycles. In the USA there are two regulators, the Environmental Protection Agency (EPA) and the California Air Resources Board (CARB). Permissible limits have been continuously decreased with time. Table 2 summarises scenario of Europe legislations. Other countries adopted either American or European regulations when they introduced emissions controls, for instance China and India followed European regulations while Korea and Brazil adopted earlier US standards.

Table 1 European Legislation limits

European emission standard					
year	**stage**	**Emissions (g/km)**			
		HC	CO	NOx	HC + NOx
1993	Stage 1^a	-	2.72	-	0.97
1997	Stage 2^a	-	2.2	-	0.5
2000	Stage 3^b	0.2	2.3	0.15	-
2005	Stage 4^b	0.1	1.0	0.08	-

2008/10	Stage 5[c]	0.75	1.0	0.06	-
[a]Measured over MVEG-A test cycle with unmeasured start up and 40 s idle.					
[b]Measured over MVEG-B cold-start test cycle.					
[c]Proposal, European stage V regulations not defined at time of writing					

4. CONTROL OF CO EMISSION

There are many ways of reducing harmful gases from vehicles such as general inspection and maintenance of the vehicle at certain levels of time; technological improvements and fuel modifications and the last but not the least is using catalytic convertor.

4.1 Catalytic Converter

It was in the year 1972 that volvo motor company came up with the first catalytic converter fitted in a car that was the first step towards pollution control and for a clean environment; further many attempts were made for the development of catalytic converter.

A **catalytic converter** is used to convert three harmful compounds in car exhaust into harmless compounds. **Hydrocarbons** (unburned gasoline), Carbon monoxide (formed by the combustion of gasoline), Nitrogen oxides (created when the heat in the engine forces nitrogen in the air to combine with oxygen). It consist of two ceramic blocks consist of layered with catalyst (in the form of platinum and palladium) onto a ceramic honeycomb or ceramic beads that are attached to the exhaust pipe. The catalyst helps to convert carbon monoxide into carbon dioxide. It converts the hydrocarbons into carbon dioxide and water. It also converts the nitrogen oxides back into nitrogen and oxygen. In the year 1920, [21] discovered a catalyst to convert CO to CO_2 and hence with the advances in technology we now have catalysts which convert most of the CO to CO_2. But during the cold start period of the vehicle the catalytic converter does not work properly which adds CO to the environment [4-6, 22]. There are two types of converter, two-way converter: removes CO and HCs, and the modification of two way which is three-way catalytic converter [1].

Traditionally many catalysts have been developed and most of them are still in use, whether in pharmaceutical industry, oil, petroleum, fertilizers, food, biotechnology, gas etc [23-24]. As far as air pollution is concerned variety of catalysts are available for their abatement. But the development of catalyst is need of the time in view of the globally increasing interest towards enhancing the rate of reaction in order to decrease the production cost and time. Good catalyst should have high activity, selectivity, thermal stability and should have low cost.

5. CATALYST FOR CO OXIDATION

5.1 Noble metals catalysts supported on base metal

Cohn in the year 1963 used noble metals for the first time [25]. Rhodium, Platinum, Palladium are used in the catalytic converter [1]. At present, automobile industry completely rely on noble based catalysts to meet the stringent regulations. The unique activity, stability, selectively of these catalysts makes them favourable for oxidation of CO. various supports like alumina, iron, silica, zirconia have been depicted in literature for CO oxidation. Noble metal catalysts (Pt, Pd, Rh) are predominantly used in automotive pollution control. In search of an alternative to these highly scarce and costly noble metals, many catalysts have been reported for CO oxidation. They are deposited on the support which is generally a cheap compound having very high surface area per unit gram of the catalyst. Transition metals are usually used as a precursor. They are impregnated on the support which makes the reaction feasible. Catalysts consisting of base and noble metals are highly active for CO oxidation. The base metals used are cobalt, ceria, zirconium, copper which enhances the activity of the catalyst due to their oxidation property. Also, with the addition of small amount of base metals (copper) the activity of gold based catalyst is increased [26]. Addition of cobalt in minor quantity enhances the activity of $Au/Co_3O_4–TiO_2$ catalysts reported for the preferential oxidation of CO in H_2 rich streams [27]. Number of combinations of base and noble metal were also tested for CO oxidation such as Silver and cobalt, ceria (base metal) mixed oxide catalysts were prepared [8] at different metal/metal oxide molar ratios and tested for the selective CO oxidation reaction. Platinum supported on MgO [28] for the partial oxidation of CO at a wide range of temperatures and kinetic study was also carried out by the researcher.

Further, platinum catalyst modified by magnesium oxide prepared by incipient wetness impregnation method reported by [29] and it was found that the activity of catalyst increased by the moisture content present in the reactants. The catalyst $Pt\text{-}Mg/Al_2O_3$ is superior to the catalyst Pt/Al_2O_3. Basically there are two reasons of increasing the activity of the catalyst: 1. Magnesium increases the basicity of the catalyst which further enriches the concentration of the hydroxyl group on the surface of platinum. 2. $Pt\text{-}Mg/Al_2O_3$ has weaker interaction with carbon monoxide so that absorption of oxygen increases on the catalyst surface, also the magnesium increases the electron density of the platinum. Complete conversion of CO takes place at 180°C.

Further, Arnby et al. [30] studied the effect of magnesium (MgO) on Pt/Al_2O_3 catalyst for carbon monoxide oxidation. The catalyst was prepared by impregnation method and showed better activity in comparison to Kim, et al., 2005 [29]. Impregnation of alumina with magnesium nitrate solution resulted in formation of $MgAl_2O_4$ spinel which further gives MgO after calcination. MgO enhances the low temperature activity of the platinum making the catalyst more resistant toward ammonia inhabitation.

Catalyst having 1wt% Au supported on MgO reported by Carabineiro, et al., 2011 [31] concluded that the double impregnation method have smallest particle size and gives best result followed by LPRD and ultrasonication. They prepared the catalyst by double impregnation method, liquid phase reductive deposition and ultrasonication method. The 5% CO was used for the oxidation purpose and the full conversion of CO was achieved at very high temperature. The double impregnation method have smallest particle size and gives best result followed by LPRD and ultrasonication.

Catalyst with 2wt% Au supported on Mg_2AlO studied by Chen, et al., 2009 [32] showed that the molar ratio of Mg/Al in Mg_xAlO affect the pH in final solution and determine the actual gold loading of the catalyst. Further 2wt% Au/Mg_2AlO was prepared by modified deposition precipitation method and the support was prepared by co-precipitation method. Pre-treatment of the catalyst and gold loading critically determines the activity of the gold. As the calcination temperature increases from 100 to 500°C the catalytic activity decreases. Moreover the conversion temperature decreases by 50°C because 2wt% Au was used and only 1%CO used for the conversion instead of 5% that in comparison to the results shown by Carabineiro, et al., 2011[31].

The catalyst $AuMg_4Al_2$ prepared by double ion exchange and deposition precipitation method with Mg:Al (molar ratio 4:2) was reported by Pitchon, et al., 2005 [33]. The chloride ions affect the activity of the catalyst so they were removed by different washing treatments. The pre-treatment was done at low temperature and the sample washed in warm water to make it more favourable. The higher calcination temperature increases the surface area of the catalyst and gold dispersion and in effect the activity of the catalyst. The catalyst prepared by double ion exchange method has low $T_{50\%}$ and low chloride ions as compared to that prepared by deposition method.

Chu, et al., 2011 [34] showed that the gold supported on silica alone did not perform well but when MgO was used as a promoter, the activity of the catalyst increases appreciably. Moreover, the size of the gold particle was reduced, better dispersion of gold particles and number of active sites also increased. The catalyst was prepared by deposition precipitation method. Further, low temperature activity and oxygen mobility were pronouncedly enhanced by using 6wt% of MgO and reduces the conversion temperature up to 150K than supported on silica alone.

Foralewska, et al., 2010 [35] prepared Au/MgF_2-MgO catalyst by sol gel method with 1wt% Au. The support MgF_2-MgO prepared by impregnation method has mesoporous structure and greater surface area than those of pure

MgF_2 and MgO. Depending on the content of MgO the catalyst prepared show higher catalytic activity than the gold supported on MgO or MgF_2 under same conditions. The pure supports have poor crystalline characters. Activity of the catalyst depends on the size of Au crystallite, presence of unreduced Au cationic species and the type of metal support interaction. When 1wt% Iridium supported on MgF_2-MgO prepared by sol gel method has shown good activity as depicted by Foralewska, et al., 2011 [36]. Use of magnesium support with 60-85 mol% MgO with $Ir(acac)_3$ leads to high surface area and increase in the iridium dispersion. The surface area and pore size distribution of the catalyst were determined by BET and BJH respectively. 100% conversion of CO was achieved in the range 150-220°C by using the above catalyst.

5.2 Base metal catalyst

Base metal catalysts have been considered as an alternative for CO oxidation because they also exhibit the same characteristics as those of the noble metal catalysts at elevated temperatures. Hopcalite is another name in the field of oxidation catalyst; which is a mixture of copper, manganese, cobalt and a small amount of other base metals for the oxidation of CO, methanol, ethylene, toluene, nitric oxide and combustion reactions [37-40]. It was developed in the last century and the modification of this small genius is on full swing. Hopcalite is used in the respiratory systems in military, mining and space exploration [9-10]. Magnesia-supported ZnO nanoparticles were prepared [41] in order to see the effect of nano sized magnesia particles for the oxidation. The activity of the prepared catalyst was explained in terms of the size of the particles.

The catalytic activity of the copper cobalt and copper manganese oxide supported on MgF_2 or Al_2O_3 has been studied [42]. The catalyst was prepared by co-impregnation method. The wt proportions of Cu/Mn or Cu/Co are 1/1, ½, ¼. The active phases of the catalyst are spinels formed during the calcination which further affect the activity of the catalyst. The result showed that the catalyst supported on MgF_2 give better performance than those supported on alumina and copper manganese catalyst is more active than the copper cobalt catalyst. CuO/MgO catalyst prepared by three different methods: 1. Deposition from colloidal solution. 2. Mechanical mixing of the component. 3. Impregnation method [43]. The nonoparticles have several advantages over bulk phase. In mechanical mixing nanoparticles of copper and magnesium oxide are used which showed best catalytic activity over deposition and impregnation method. The size of the nanoparticles was 10-12 nm. Total conversion of CO occur at 240°C. Result showed that method of preparation have significant effect on the activity of the catalyst.

It is also reported that the catalyst Cu/MgO-SiO_2 prepared by sol-gel method at PH 3 and 9 [14]. The PH 3 gives high specific surface area i.e. 500 m^2/g. the PH of the gelling solution determines the structural properties of the catalyst. If the basicity of the support is higher then the conversion of the CO is also higher. Good activity of the catalyst is obtained in the presence of the acidic and basic sites in the same catalyst for CO oxidation. The PH 9 gelled catalysts have the higher acid/base density site ratio and also have the higher catalytic activity. Ceria has high oxygen storage/release efficiency and introduction of other oxides like alumina or magnesia improved its textural properties, greatly. The catalyst CeO_2-MO_X(M=Mg^{2+},Al^{3+},Si^{4+}) prepared by co-precipitation method have been studied by[15]. CeO_2-Al_2O_3 has highest specific surface area when calcined at 450°C and also show higher catalytic activity than other mixed oxide. The activity of the ceria based mixed oxides decreased with increasing calcination temperature. The catalyst CeO_2-MgO calcined at 450°C exhibited less activity and even did not reach up to 50% conversion than pure ceria calcined at the same temperature. Chromium catalyst doped with MgO and supported on MgF_2 prepared by impregnation and co-impregnation method showed better activity than supported on other base metal reported by (Goslar, et al., 2005). The result shows that catalyst prepared by both methods form spinel like phase and magnesium clearly influence the activity and selectivity of the chromium. The catalyst prepared by this method show high catalytic activity at room temperature. [44] it was reported that the chromium catalyst $MgCr_2O_4$ prepared by solid state reaction, sol-gel and co-precipitation in reverse microemulsion (ME) method. The process showed the formation of single active spinel phase in all cases which increases the catalytic activity but in the catalyst formed by solid state reaction some segregation of chromium in the form of Cr_2O_3 also appear. The result showed that the catalyst prepared by ME have high specific surface area and higher catalytic activity.

Magnesium oxide itself does not show any catalytic activity in oxidation of carbon monoxide so it is used as a support. It was studied the catalytic activity of the Co_3O_4 supported on MgO prepared by impregnation method varying from 125-300°C [45]. the catalytic activity of the catalyst increases by increasing the loading of Co_3O_4 up to 37.5wt%. Cobalt magnesium and vanadium magnesium oxide catalyst were reported by [46] the catalyst prepared by aerogel method and have high activity and stability and the size of nanoparticles prepared by this method does not exceed 10 nm. The catalyst has unique morphology, have high surface area and uniform distribution. After treating the catalyst at high temperature its T_{50}=143°C. Co-Mn-Mg-Al mixed oxide catalyst was prepared by co-precipitation method examined for CO oxidation in O_2 [47]. The catalyst composed spinel like phase produced by calcination of hydrotalcite precursor and high surface area than Co-Mn catalyst. The catalyst prepared by hydrotalcite rout showed 100% conversion at 120°C and high durability for CO oxidation and did not show any deactivation after 60h of working.

5.3 Nano catalysts

Haruta [48-52] is the name in the field of catalysis that developed nano sized gold particles for the first time in 1989. Since then researchers have tested and explored so many nano sized gold particles for the oxidation of CO. various methods have also been developed by which there is considerable increase in the activity of nano size catalyst. Various supports have been used in order to to increase the surface area of the catalysts which in turn enhances the activity of the catalyst. The supports used are alumina, silica, magnesium. In order to increase the catalyst activity various comparisons have been made i.e. Comparison of Au/SiO_2 with Au/Al_2O_3 and Au/TiO_2 which were made for CO oxidation at 273 K [48]. Catalytic activity, Textural, structural, and morphological characterizations of nanosized $CeO_2–MO_x$ ($M = Mg^{2+}, Al^{3+}, Si^{4+}$) mixed oxides for CO oxidation was studied and evaluated by [15], and concluded that the combination of $CeO_2–Al_2O_3$ exhibited highest activity. Gold with 1 wt% on a commercial MgO support catalyst was prepared for CO oxidation by [31] in order to test the activity of catalyst prepared by different routes.

Recently Fattah, Z., et al [77] reported, Co-MgO(30 wt. % Co) catalyst prepared by co-precipitation method for low temperature CO oxidation reaction. The effects of pH of solution, aging temperature, aging time and molarity of precursor solution at three levels were investigated. The results revealed that the optimized sample showed a mesoporous structure with a narrow pore size distribution centered in the range of 7–17 nm and particle size about 5.5 nm. It was found that the molarity of solution and aging time had the most influence on the CO conversion, respectively. The catalytic results showed that the highest CO conversion was about 90% at 200°C, while the CO conversion for optimized sample was 95%.

5.4 Effect of Magnesium on catalyst activity

The aim of any researcher is to enhance the activity of catalyst which depends on many parameters. Out of them surface area is also an important parameter because activity of the catalyst is directly proportional to surface area. Since precious metals are highly active but in order to utilize the precious metal more effectively supports are employed. Because of high surface area of supports the obtained catalyst is in a highly dispersed form and hence in a highly active form when expressed as a function of the weight of the active component. However, base metals are impregnated on supports in order to improve the catalyst stability so that it can withstand at high temperature. Most active materials are not thermally and mechanically stable. By using suitable support, the optimal dispersion of active component and stabilizing against sintering can be achieved. Various supports Alumina, Zeolite, Zirconia, and Silica are employed for catalyst development. But MgO attract particular attention because it can withstand without detriment at sufficiently high temperature i.e. 1000 K [53]. MgO has been the more widely investigated in this regard [54-55], partly because it can be so readily prepared with high specific surface area greater than 150 m^2/g. The effect of support can be studied by the use of different support with the same metal. Magnesium was used as a support for CO oxidation. Testing the oxidation power of metals with different supports is way adopted by many researchers in order to check the activity of the catalyst. Copper catalyst when tested with Magnesium (MgO) the conversion temperature is reduced to 473.15 K [56]. MgO is also used as a promoter for increasing the activity of the catalyst. The preparation method and pre-treatment procedure plays a crucial role in deciding the CO oxidation activity. Generally supports are made in order to increase in surface area, stability, activity etc. of the catalyst. Techniques such as impreganation [26,35-36, 38, 42-43, 45, 57-59], deposition-precipitation (DP) [37, 60-62, 33-34, 12,56], co-precipitation (CP) [15, 44, 47, 63-64] and vapour deposition (VD) [51] can be successfully employed to obtain highly dispersed nano catalysts. The methods used for the preparation of magnesium catalyst reported by [65] have remarkably properties as compared to the previous reported methods [66-67]. A wide range of techniques [68] has been discussed for the incorporation of the catalytically active species on the support material. Every technique has their own influence on the catalytic activity, selectivity, dispersion and chemical properties of the catalyst.

Table 2 Recent literature review at a glance on Magnesium based catalyst for the oxidation of CO

Sr. no.	**Catalyst Pepn. method**	**Operating parameter**	**Remarks**	**Ref.**
1.	Au/MgO, DIM, LPRD, US methods, ascorbic acid as a promoter. Calc. temp 473.15 K.	Continuous flow reactor, 0.2 g cat, 5% CO, 10% O in He, flow rate-50 ml/min.	DIM is the best Au loading method followed by LPRD and US. $T_{100\%}$=653.15 K. Au/MgO CAT supported on alumina are extremely active.	[31]

2.	Cr_2O_3-MgO/MgF_2, Impregnation, co-impregnation method. Calc. temp 673.15 K.	Continuous reactor, 0.1g cat, 2% CO in air, flow rate- 50 ml/min.	Amount of Cr increase the activity. 8wt% of Cr gives best result. Doping of MgO enhances the activity.	[13]
3.	Pt-Mg/Al_2O_3, wet impregnation method. Calc temp-773.15 K,	Quartz flow reactor, CO-500ppm in N_2, flow rate-600ml/min.	CO conversion is higher if we used 5wt%Mg than 0.5wt%. $T_{100\%}$=404.15 K. Addition of Mg enhances low temp activity and resist against ammonia inhabitation.	[30]
4.	$LaFe_{1-x}Mg_xO_3$, citrate method, calc. temp-1073.15 K.	Fixed bed reactor, 0.5g cat, 1% CO,20%O_2 in He, SV=12000Ncm^3/g/h	$T_{100\%}$=773.15 K. Activity of catalyst deceases as amount of Mg increases.	[11]
5.	CuO-NiO/Cordierite, wet impregnation method, calc temp-623.15-973.15 K.	200mg catalyst, CO+O_2 at 2 torr.	Cat. Activity of binary oxide is greater than single oxide and cat calcined at different temp led to a progressive increase in catalytic activity.	[69]
6.	Cu-Mn oxide/MgF_2, Cu-Co oxide/MgF_2 co-impregnation method, calc temp-673.15 K.	Continuous flow reactor, 0.1g cat, 2%CO in air, flow rate=50ml/min.	Catalyst activity is higher when supported on MgF_2 than supported on Al_2O_3. Best proportion of Cu-Mn is 1:2. The activity of Cu-Mn is greater than Cu-Co catalyst.	[7]
7.	Au/Mg_xAlO, DP method, calc temp= 373.15-773.15 K. 2wt% Au.	Tubular stainless steel reactor, 100mg cat,CO 1%, $H_2$50%, O_2 1%,He 48%, flow rate=100ml/min	$T_{100\%}$=323.15 K for x=2, 338.15 K for x=1, 2% Au/Mg_2AlO calcined at 373.15 K was most active.	[32]
8.	Ir/MgF_2-MgO, impregnation method, 30-85 mol% MgO.	Continuous reactor, 50mg cat, 3 vol% CO in air, flow rate=50 cm^3/min.	$T_{100\%}$=423.15 K, for 60 mol% MgO, activity depends upon the type of Ir precursor used,$Ir(acac)_3$> $Ir_4(CO)_{12}$> H_2IrCl_6.	[36]
	Au/Mg_4Al_2, DP method, direct anionic exchange method, calc temp=573.15 K.	Fixed bed reactor, 50 mg cat, 2%CO, 5%O_2 in He,flow rate=50cm^3/min.	Direct anion exchange is the best method, $T_{100\%}$=563.15 K, low Cl content.	[33]
9.	ZnO/MgO, ZnO 1wt%, DP method, calc temp=623.15 K.	Quartz flow tube reactor,2 vol% CO, 20 vol% O_2, He as balance, flow rate=100 cm^3/min.	$T_{100\%}$=818.15 K, activity changes if particle size changes, catalyst particle size of 2.3nm gives 100% conversion.	[12]

10.	CoMnMgAl spinel oxide catalyst, co-precipitation method, calc temp= 773.15-1073.15 K.	Fixed bed tubular reactor, 0.1 g cat, 3%CO, 6%O_2 in He, SV=30000h^{-1}.	$T_{100\%}$= 473.15, for all ratio of Co/Mn, the catalst having Co/Mn ratio 4 and calcined at 773.15 K have higher activity.	[47]
11.	CuO/APT clay, DP method, MgO= 5.8-6.51% in clay, calc temp= 473.15 K.	Continuous fixed bed reactor, 200 mg cat, 10 vol% CO and air, SV = 11000 ml/h/g, no pre-treatment of catalyst.	$T_{100\%}$=393.15 K for CuO= 16, 20, 24%, at low CuO (8%) and calc temp= 773.15 K, $T_{100\%}$= 503 K.	[62]
12.	CeO_2-MgO_X, co-precipitation method, Ce:Mg= 1:1 mole ratio, calc temp=723.15-1023.15 K.	Fixed bed quartz reactor, 50mg cat, 1.4% CO in air, SV=30000ml/g/h.	Catalyst calcined at 1023.15 K gives poor performance, catalyst supported on Al give better result.	[15]
13.	Au/MgO/SiO_2, DP method, 6wt% MgO, 1.5wt% Au, calc temp=533K, Mg as a promoter,precipitation agent= NH_3OH, Na_2CO_3, NaOH.	Fixed bed flow reactor, 100mg cat, 1%CO, 21%O_2, 78% Ar, flow rate=30ml/min.	Addition of MgO decrease Au crystalline sizes and improve activity, catalyst with NaOH (precipitation agent) show better activity, $T_{100\%}$= 523.15 K.	[34]
14.	$MgCr_2O_4$, three method of ppn, 1- solid state reaction, 2- co-precipitation in microemulsion, 3- sol-gel , calc t_1=11473.15 K, t_2= 873.15 K, t_3= 1123.15 K.	Cylindrical pyrex reactor, 500mg cat, 1% CO, 2% O_2 in N_2, SV=30000ml/h/g.	Micro emulsion method is better, catalyst prepared by solid state reaction show less activity, $T_{100\%}$= 623.15 K of M.E.	[44]
15.	Au/MgO_X, Au=1 wt%, DP method, calc temp= 673.15 K.	Fixed bed flow reactor, 0.75ml cat, flow rate= 30ml/min, volume ratio CO:O_2:He=2:20:78 volume %	$T_{60\%}$= 523.15 K, the catalyst with TMO support were more active and gives 100% conversion at 303.15-373.15 K, whereas cat supported on MgO were less active.	[61]
16.	Co_3O_4/MgO, impregnation method, calc temp=573.15-973.15 K.	200 mg cat, mixture of CO and O_2 at a pressure of 2 torr.	Specific surface area found to decrease if amount of Co_3O_4 increase and calc temp increase, catalytic activity of 37.5% is higher than other.	[45]
17.	Pt-Mg/AlO_3, incipient wetness method, calc temp= 673.15 K, Mg used as a promoter.	Micro fixed bed reactor, CO 20%, 0.1g cat, flow rate=100 ml/min.	$T_{100\%}$= 443.15 K, cat show higher activity at low temp, if the reactant containing moisture CO conversion rate was significantly improved.	[29]

18.	Cu/MgO-SiO_2, sol-gel method, calc temp= 773.15 K, 4 and 6.7 wt% MgO.	Static quartz flow reactor, 100 mg cat, CO= 0.76 mol/min, O_2=0.38 mol/min, He= 240 mol/min.	The PH 9 with MgO 6.7 wt% catalyst show higher activity for CO oxidation.	[14]
19.	CoO_X.MgO, aerogel method, Mg/Co molar ratio is 5:1 or 2:1, calc temp= 773.15 K.	Flow reactor, 0.15% CO, 14% O_2, N_2, 5 heating cooling cycle.	$T_{50\%}$= 429.15 K for second and third cycle, $T_{50\%}$= 416.15 K for fourth and fifth cycle when catalyst heated in reaction gas flow up to temp 873.15 K.	[46]
20.	Au/$Mg(OH)_2$, 5wt% Au, modified DP method, calc temp= 523.15 K.	Stainless steel tubular reactor, 1% CO in air, 0.01g cat, diluted in 0.3g inert quartz powder, SV=400000ml h^{-1} g-cat^{-1}.	Near 443.15 K moist catalyst is highly active and water act as a promoter, at 323.15 K water becomes a poison.	[60]
21.	Au/MgF_2-MgO, 1wt% Au, base is prepared by sol-gel method and cat is prepared by impregnation method, calc temp= 673.15 K.	Continuos flow reactor, 3 vol% in air, 50mg cat, flow rate=50ml/min.	The catalyst containing 30% and 70% MgO are most active, activity of dried catalyst with increasing temp grows faster than that of calcined one.	[35]
22.	MgO-Cr_2O_3/MgF_2/ Al_2O_3, Impregnation method, calc temp= 673.15 K.	Continuous flow reactor, 0.1g cat, 2%CO in air, flow rate=50ml/min.	The catalyst on Al_2O_3 showed good activity at 4wt% Cr content, but most active were those supported on MgF_2.	[42]
23.	NiO-MgO, CoO-MgO, Impregnation method, calc temp= 1473 K.	Silica reactor, CO:O_2= 2:1, 0.6g cat, pressure 25 torr, catalyst activated under vaccum.	The activity of CoO-MgO is higher than NiO-MgO.	[58]
24.	Cu-Mn-O/MgF_2, 2wt% Cu, co-impregnation method, calc temp= 673.15 K, 823.15 and 1223.15 K.	Flow reactor, 0.1g catalyst, CO=1 vol% with flow rate= 15ml/min in He, air flow rate= 55ml/min.	$T_{40\%}$=room temp, the activity of catalyst varying with Cu/Mn ratio, Mn wt% 4 and 8 showed same result.	[26]
25.	$_{X}MgO._{Y}Fe_2O_3$, Y=5, 40, 70%, coprecipitation method, calc temp = 873 K.	Vaccum unit, 1% CO and 99% air.	High yield of CO_2 could be obtained using samples with a high content of the spinel phase at reaction temp above 593.15 K.	[64]
26.	Au/MgO/SiO_2, Mg= 2, 6 and 10wt%, DP method, calc temp=533.15 K.	Fixed bed flow reactor, 100 mg cat, 1% CO, 21% O_2, 78% Ar, flow rate = 30ml/min, no pre-treatment of catalyst.	Catalyst of 6wt% Mg gives best result, $T_{100\%}$=623.15 K, if MgO increases conversion temp reduces largely.	[37]

27.	Pd/Al_2O_3, precursor used are $PdCl_2$ and MgBrMes, impregnation method, calc temp= 973.15 K.	1% CO, 0.5% O_2 in He, 18.4g cat, reaction temp= 423.15 – 473.15 K.	Catalyst become active on 463.15 K, and gives 25% conversion at this temp,calcined sample gives 100% conversion on 463.15 K.	[59]
28.	NiO/cordierite, 5wt% cordierite, wash coatimg method, wet impregnation method, calc temp= 623.15 K.	Static method, 200mg cat, CO+1/2O_2 at 2 torr.	$T_{100\%}$= 473.15 K, increase in calcination temp from 623.15 K to 873.15 K drops the activity.	[70]
29.	Pd/MgO, Pd clusters are epitaxially grown under UHV on MgO, cluster sizes (4-15nm).	UHV chamber, CO=3.5*10^{-5}Pa, O_2=1.3*10^{-5}Pa.	When CO beam is opened, CO_2 production rate first increases instantaneously, and then slowly to its maximum.	[71]
30.	CuO/MgO, 1. Deposition from colloidal solution (773.15 K), 2. Mechanical mixing of components 15,573. 15, 673.15, 773.15 K), 3. Impregnation method (553.15-623.15 K).	Quartz flow reactor, atmospheric pressure, 2% CO, 20% O_2 in He, volumetric velocity= 6000h^{-1}.	The catalyst prepared by mechanical mixing (523.15 K) showed highest activity and gives 100% conversion at lowest temp, $T_{100\%}$= 513.15 K.	[43]
31.	Mg Todorokite, 3 step procedure, layered birnessite synthesis, ion-exchange to buserite , final hydrothermal treatment of buserite, calc temp= 573.15 K.	Fixed bed reactor, 3% CO, 20% O_2 in N_2, 0.05G of todorokite, flow rate= 50ml/min.	Highest activity was obtained on proton type todorokite which was prepared by birnessite aged for 3 h; [Mg^{2+}] todorokite of shorter aging time gave higher activity than those of longer aging time.	[72]
32.	Au/$Mg(OH)_2$, 0.7wt% Au loading, colloidal deposition method, calc temp= 648.15 K.	Plug flow reactor, 1%CO, 20%O_2 in N_2.	$T_{73\%}$= 363.15 K, catalyst is highly active at 503.15 K, increase in space velocity also increases the conversion.	[73]
33.	$MgCr_2O_4/Al_2O_3$, impregnation method, calc temp= 623.15, 773.15 and 973.15 K.	Flow reactor, CO= 5-6% in air, SV=900h^{-1}.	$T_{100\%}$=463.15 K, increase in calcination temperature increase the temperature for 100% conversion.	[57]
34.	Ni-Mg-CeO_2, impregnation method, calc temp= 673.15 K.	Flow reactor, 4% CO, 2.05% O_2 in He, flow rate=10000h^{-1}.	$T_{50\%}$= 448.15 K, use of CeO_2 nanoparticles provided a considerable decrease in temperature of CO conversion.	[74]

35.	(Au/MgFe$_2$O$_4$), colloidal deposition method, calc. temp. 823.15 K.	plug flow reactor, 50mg, gas mixture of 1% CO in air, SV= 80,000 ml/ h g$_{cat}$.	catalytic performance of gold particles supported on spinel type MgFe$_2$O$_4$ nanocrystals (Au/MgFe$_2$O$_4$) which exhibit high activity for low temperature CO oxidation.	[75]
36.	Au/MgO/Mn-Fe, DP method, cal. temp. of 837.15 K.	quartz reactor, 0.025–0.075 g, space velocity was 30l h^{-1} /(g$_{cat}$)	Different Au/MgO catalysts modified with Mn, and Fe were prepared by precipitation–deposition and were tested in CO oxidation in the temp. range of 243.15-543.15 K. The tests revealed the high activity of catalysts prepared.	[76]
37.	Co–MgO mixed oxides, Co-precipitation method, cal. temp. of 673.15 K.	fixed bed quartzmicro-reactor, 60 mg, 2% CO, 20% O$_2$ and10% N$_2$ balanced with He, Gas hourly space velocity (GHSV)of 60,000 ml/(g h).	Co–MgO mixed oxides (30 wt. % Co) showed 90% at 200°C, while the CO conversion for optimized sample was 95%. In addition, the effect of operational conditions was studied over optimized sample.	[77]

6. CONCLUSION

This review summarizes the advances in the magnesium based catalyst for CO oxidation. The composition, crystalline structure, chemical nature of the surface, porosity and other feature of the support are known to influence the dispersion and stabilisation of active phase. In oxidation of CO the support participate in the activation of the reactant especially oxygen. Magnesium floride can also be used as a support and metallic active phase to obtain active and selective catalyst for CO oxidation. The use of magnesium as a support resulted in significant modification of active phase and the mechanism of the formation of oxides, double oxide or metallic layer on its surface has been well recognised [29]. The higher catalytic performance for CO oxidation could be exhibited over silica supported gold catalyst by modified with proper amounts of magnesium oxide and preparation procedure [34]. The tabular data presented above can be used for carrying out further research for complete conversion of CO. The minimum temperature for CO conversion was found to be 250 K [34] by using Au/MgO/SiO$_2$ catalyst prepared by deposition precipitation method.

Abbreviations used:

DIM (Double impregnation)
LPRD (Liquid phase reductive deposition)

US Ultra sonication)
DP (Deposition precipitation)
$T_{X\%}$ = Means X% conversion takes place at temperature T.

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