

Versatile Applications of Metal/Mixed Metal Oxides as Fuels

Dr. Ritu

Department of chemistry, Chhotu Ram Arya Collage, Sonapat-131001 (Haryana)

ABSTRACT:

The metal oxides / mixed metal oxides have various applications as catalyst, photocatalyst, sensors, superconductors, adsorbent, ceramics, fuels, antifungal agents and have large number of applications in medicines. These metal / mixed metal oxides play a very important role in day to day human life. Today metal oxides are attracting special attention of scientists due to their easy mode of formation and multifunctional behavior. In this article an attempt has been made to focus on their applications as Fuels in various chemical reactions.

Keywords: Metal oxides, Mixed metal oxides, Fuels, chemical reactions

INTRODUCTION:

Metal oxides play a very important role in many areas of chemistry, physical and materials science [1-6]. Metal oxides are formed as a consequence of co-ordination tendency of metal ions so that oxide ions form co-ordination sphere around metal ions and give rise to close packed structure. The different physical, magnetic, optical and chemical properties of metal oxides are of great interest to chemists because these are extremely sensitive to change in composition and structure. Extensive studies of this relationship lead to a better understanding of the chemical bond in crystal. The metal oxides are attracting special attention of scientists due to their easy mode of formation and multifunctional behavior.

The transition metals and their compounds are used as catalysts in chemical industry and in battery industries. Besides, these compounds can be used in formation of interstitial compounds and alloy formation. The transition metals have the special properties of formation of colored compounds and show magnetic properties. Metals of d-block elements are used for many industrial applications. They behave as catalysts, super conducting materials, sensors, ceramics, phosphors, crystalline lasers etc.

Besides these they are excellent photoactive materials and work as photosensitizer. Mixed metal oxide (MMO) electrodes are devices with useful properties for chemical electrolysis. The term refers to electrodes in which the surface contains two kinds of metal oxides- one kind usually RuO_2 and IrO_2 desired reaction such as production of chlorine gas. The other metal oxides is typically titanium dioxide which does not conduct or catalyze the reaction,

but is cheaper and prevents corrosion of the interior. The interior of the electrode is typically made of titanium. The amount of precious metal (that is other than titanium) can be around 10 to 12 grams per square meter.

Applications include electrolytic cells for producing free chlorine from salt water in swimming pools and cathodic protection of buried a submerged structure.

Fuels:

Metal / Mixed metal oxides have wide application as Fuels some of them are described here. Greg Coffey et al. [7] synthesized copper doped lanthanum strontium ferrite for reduced temperature solid oxide fuel cells. Copper doped lanthanum strontium ferrite showed superior kinetics for the electro-reduction of oxygen. The improvement was confirmed with cyclic Volta metric studies on half cells and on full fuel cell tests. Copper doped materials have unusual electrochemical characteristics and copper apparently undergoes a one electron reduction at overpotentials less than -01.V. This occurred only in air but not in oxygen. Zhan *et al.* [8] used thin film solid oxide fuel cells (SOFCs). Composed of thin coatings of 8 mol% Y₂O₃-stabilized ZrO₂ (YSZ) and thick substrates of (La_{0.8}Sr_{0.2})_{0.98}MnO₃ (LSM)- YSZ cathodes, are fabricated using the conventional tape casting and tape lamination techniques. Maximum power densities for hydrogen and propane at 800⁰C are 0.26W cm⁻² for CuO-YSZ ceria anodes and 0.35 Wcm⁻² and 0.22W cm⁻² for CuO-SDC- ceria anodes, respectively. Electrochemical impedance analysis suggests that CuO-SDC ceria exhibits a much lower anodic polarization resistance than CuO-YSZ-ceria, which could be explained by the intrinsic mixed oxygen ionic and electronic conductivities for SDC in the reducing atmosphere. Na Ai *et al.* [9] followed vacuum assisted placeless Cu incorporated by vacuum assisted electroless plating into porous Ni/Sm_{0.2}Ce_{0.8}O_{1.9} (Ni/SDC) anodes as the active anodes for the oxidation reaction of hydrogen and methane of intermediate temperature solid oxide fuel cells (IT-SOFCs). The increase in the performance of the cell with the Cu electroless plated Ni/SDC anodes is most likely attributed to the enlarged effective three phase boundaries (TPBs) by interconnecting the isolated Ni and/or SDC particles with the electroless plated Cu network and the formation of TPBs at the Cu/SDC interface due to the activation of SDC surface by the Cu deposition. The stability test shows that cell degradation in dry methane due to carbon deposition is significantly reduced by the electroless copper plating. Zhao *et al.* [10] prepared high-performance cathode supported solid oxide fuel cells with copper anodes. Thin film solid oxide fuel cells, composed of thin coatings of 8 mol% Y₂-O₃ stabilized ZrO₂ (YSZ), thick substrates of infiltrated La_{0.8}S_{0.2}FeO₃ (LSF)-YSZ cathodes and CuO- SDC (Ce_{0.85}Sm_{10.15}O_{1.925}) – ceria anodes, are fabricated using the conventional tape casting and infiltration methods. M. Ferki *et al.* [11] showed synthesis, structural analysis and electrochemical performance of solid oxide-fuel cells (SOFCs), La₂Ni_{1-x}CuO₄₊₅ (x=0, 0.01, 0.02, 0.05 and 0.1) doped with copper in percentages, varying between 1% and 10% were prepared following the modified Echini method.. In contrast, doping with higher amounts of copper (2%, 5% and 10%), led, after heating at 1000⁰C for 48 h, to the formation of another phase resulting from the diffusion of copper into the YSZ electrolyte, limiting the interest of these materials as SOFC cathodes. Wang *et al.* [12] physically mixed LiLaNi-Al₂O₃ and copper as conductive anode catalysts in a solid oxide fuel cell for methane internal reforming and partial oxidation. copper is

added to LiLaNi-Al₂O₃ to improve the electronic conductivity property for application as the materials of the anode catalyst layer for solid oxide fuel cells operating on methane. The surface conductivity tests demonstrate it is extremely improved for LiLaNi-Al₂O₃/Cu catalyst due to the addition of 50 wt% copper. A cell with LiLaNi-Al₂O₃/Cu (50:50) catalyst layer is operated on mixtures of methane O₂, methane – H₂O and methane – CO₂, and peak power densities of 1081, 1036 and 988 mW cm⁻² are obtained at 850⁰C, respectively, comparable to the cell with LiLaNi-Al₂O₃ catalyst layer. In summary, the results of the present study indicate that LiLaNi-Al₂O₃/Cu (50:50) catalysts are highly coking resistant and conductive catalyst layers for solid oxide fuel cells. Tavares *et al.* [13] developed a novel copper-based anode for low-temperature solid oxide fuel cells was prepared through the conventional ceramic technology and using CuO and SDC (Ce_{0.8}Sm_{0.2}O_{1.9}) powders with controlled, particle size. Solid oxide fuel cells having the new anode were tested for both humid hydrogen and methane. Power densities of ca. 250 mW cm⁻² were achieved in H₂ at 600⁰C and in CH₄ 700⁰C even if the SDC- electrolyte supporting membrane was 250 – m thick. Short term stability tests (maximum 64h) showed an initial impairment, but not dramatic, of the new anode performance and the formation of carbon deposits. Senguttuvan *et al.* investigate. Kwang Lee *et al.* [14] determine whether a copper oxide modified Pt cathode (PtCuO_m) improves a performance of direct methanol fuel cells (DMFC), we performed structural and morphological analysis of the cathode and measured current – potential prole and impedance spectroscopy. These results may play a role in better long – term stability of DMFC systems. Senguttuvan *et al.* [15] investigate solid oxide fuel cells (SOFC) are emerging as an alternate source of energy. Anodes form one of the components of the fuel cells. Ni/Yttrium stabilized zirconia is a classic anode material for SOFC when hydrogen is used as the fuel source, but it is not that effective when methane is used as fuel source due to carbon deposition on the anode. Scanning and back scattered electron micrographs reveal a clear two – phase structure only in the samples with greater than 20 mol% of CuO loading. Atomic force microscopy carried out on 33 mol% loaded zirconia shows a three-phase structure with flattened seven – fold – coordination of Zr⁴⁺ with oxygen. Sapkota *et al.* [16] found that a zinc air fuel cell (ZAFC) of taper – end structure was designed and manufactured with a polyamide – base plastic. An air cathode with multiply layers of blended inexpensive metal oxide. MnO₂ and CeO₂ showed a remarkably stable electricity – generating performance even at high current density. A cheap thin Nylon filter was found as a potential candidate for the separator in ZAFC because of its high stability and durability in the alkali electrolyte and proper pore size. Visinescu *et al.* [17] reported a suitable fuel in new low temperature combustion-based synthesis of zinc aluminate oxide. Starch has been tested as single- fuel and in a two – fuel mixture, together with N-methyl urea, in a new combustion and equivalence ratios ϕ_e (ϕ_e = fuel/oxidant). Crystal structures were refined by Rietveld method. UV-Vis spectroscopic analysis has confirmed the intrinsic properties of the resulted mixed metal oxide, but also shows the presence of a certain disorder degree for all the other samples. The superior values of the band gap (4.2-4.7 eV) for the obtained oxides relative to the bulk case (3.8 eV) are the result of the nanometric dimensions o the particles. Jungdeok *et al.* [18] examined zinc-doped barium strontium – cobalt ferrite (Ba_{0.5}Sr_{0.5}CO_{0.2}Zn_xFe_{0.8}O₃₋₅ (BSCZF); x=0, 0.05, 0.1, 0.15, 0.2) powders with various proportions of zinc-were prepared using the ethylenediamine tetra acetic acid (EDTA) citrate method with repeated ball-milling and calcining.

The resistance decreased further by about 30% when $\text{Sm}_{0.2}\text{Ce}_{0.8}\text{O}_{2.5}$ (SDC) electrolyte particles were incorporated and the sintering temperature was increased to 1000°C . Compared to BSCF without zinc, BSCZF experienced the lowest decrease in electrochemical properties when the sintering temperature was increased from 950°C to 1000°C . Using a composite cathode of BSCZF05 and 30 wt% of SDC button cells composed of an Ni – SDC support with a $30\ \mu\text{m}$ dense SDC membrane exhibited a maximum power density of $605\ \text{mW cm}^{-2}$ at 700°C . Lee *et al.* [19] in preliminary comparative studies of zinc and zinc oxide electrode on corrosion reaction and reversible reaction for Zn/air energy system is considered to be a promising power energy source. While both the zinc oxide and the modified zinc oxide electrodes are reversible. However, as far as dendrite formation is concerned there is no marked improvement in case of the zinc oxide and the modified zinc oxide electrodes. Kwon *et al.* [20] investigated the sensing properties of Al_2O_3 -doped ZnO for combustion control in lean-burn conditions. Planar – type sensing elements made of heater, electrode and sensing layer were formed on an alumina substrate using a screen printing technique. Our exhaust gas sensor exhibits significant resistance changes even under lean conditions, apparently due to the simultaneous functioning of bulk and surface conduction mechanisms. Utilizing the sensor for the feedback control of a domestic boiler. Shie *et al.* [21] examined the effects of additives of potassium carbonate (K_2CO_3) and zinc oxide (ZnO) on the pyrolysis of waste sunflower – oil cake using a 60 kW pilot – scale plasma torch reactor. In order to match the appeal of resource reutilization, one can use the waste K_2CO_3 resulted from the sorption of CO_2 with KOH in greenhouse gas control and the waste ZnO obtained from the melting process as additives for the co-pyrolysis of sunflower oil – cake, yielding fuels rich in CO and H_2 , respectively. Utilize the effect of additives on the electrochemical behavior of zinc anode due to its low cost and high power density, the Zn/air energy system is considered to be a promising power energy source. Similarly, hydrogen overpotential plays a major role. Their study attempts to reduce dendrite formation and raise hydrogen overpotential through the addition of cellulose and lead oxide, respectively. It is concluded that cellulose reduces dendrite formation to some extent. It also works well to raise the hydrogen overpotential even in the absence of lead oxide. Sapkota *et al.* [22] characterize zinc air fuel cell (ZAFC), which generates electricity by the reaction between oxygen and zinc pellets in a liquid alkaline electrolyte is a potential candidate for an alternative energy generator. It is applicable to portable mobile, stationary, and military purposes. In spite of its high potential as an alternative power source, it is yet in a preliminary stage of commercialization because of a few uncertainties remained. Zhang *et al.* [23] worked on a series of gold zinc oxide catalysts prepared using a coprecipitation procedure, and their performance for catalytic oxidation removal of CO from H_2 rich gas was investigated in a fixed bed – reactor. When the content of platinum in Au (1.5)/ZnO-300 was lowered with increasing content of Pt. The ideal composition for Au (1.5) – Pt/ZnO-300 was 1.0 wt.% Pt. (Au (1.5) – P (1.0)/ ZnO-300. Guo *et al.* [24] checked the effects of zinc modification methods on membrane sintering, electrical conductivity of $\text{BaZr}_{0.4}\text{Ce}_{0.4}\text{Y}_{0.3}\text{O}_{3.5}$ (BZCY4) and the thermo – mechanical match of the BZCY4 electrolyte with anode were systematically investigated. Only the electrolyte from method 3 had similar shrinkage behavior to the anode. An anode-supported thin film BZCY4-3 electrolyte solid oxide fuel cell (SOFC) was successfully fabricated, and the fuel cell delivered an attractive performance with a peak power density of $307\ \text{mW}$

cm^{-2} at 700°C . Rasouli *et al.* [25] prepared cobalt – doped ZnO nanoparticles were synthesized by combustion method. Mixture of citric acid and glycine were used as fuel. Citric acid combustion alone led to amorphous powder. Scherrer's equation demonstrated that the crystallite size increases with citric acid/ glycine (C/G) ratio (38-61nm). SEM and TEM images illustrated that the morphology of the powder depends on the C/G ratio and changes from rod – like to spongy hexagonal particles. Reflectance spectra showed that by higher C/G ratios, deeper green colors are obtained. Guo *et al.* [26] discussed proton – conducting solid oxide fuel cells with a dual – layer electrolyte, constructed of a highly protonic conductive $\text{BaCe}_{0.8}\text{Y}_{0.2}\text{O}_{3-\delta}$ (BZCY4) electrolyte, was easily fabricated by dry pressing the electrolyte powders onto an NiO+BZCY4 anode substrate, followed by co-sintering at a high temperature. The performance of the as fabricated cell with the BCY and BZCY4 dual – layer electrolyte was studied. Peak power densities of 249 and 101 mW cm^{-2} were achieved at 700 and 500°C , respectively. Tsukada *et al.* [27] studied composite sorbents, for the simultaneous removal of sulfur compounds and alkali and heavy metals from coal gasifier products in the integrated qualification fuel cell (IGFC) system, were prepared. Iron oxide and zinc – ferrite was selected as desulphurization sorbents and they were synthesized by precipitation from either ferric chloride, ferric nitride or ferric and zinc nitride solution in these solution fine oxide particles such as kaolinite, saprolite, and activated clay, which have the capability of alkali and heavy metal absorption, were dispersed. Chockalingam *et al.* [28] discussed gadolinium – doped ceria has demonstrated a high –ionic conductivity at moderate temperatures and is a potential candidate as electrolyte in solid oxide fuel cell (SOFC) devices. This design is principally similar to the grain boundary design in zinc- oxide varistors. In order to not overload the entire composition with insulating particles (and thus reducing the ionic conductivity substantially due to volumetric dilution) the insulating grains have to be small (nanometer sized) and uniformly distributed throughout the matrix (cerium oxide). Moreover, the insulating grains should not dissolve or otherwise alter the cerium oxide matrix. Small sizes for the alumina particles will prevent the overall composition from being overloaded with non-conducting particles and the coating process will enhance a very uniform distribution of the alumina particles in be (microwave) sintered. Characterized by SEM, TEM, XRD, density and conductivity measurement are prescribed to evaluate properties of the proposed Nano-composite electrolyte. Wu *et al.* [29] studied the characteristics of a novel method for Hg removal using H_2S and sorbents containing iron oxide were studied. The following results were obtained (1) the presence of H_2S was indispensable for the removal of Hg from coal derived fuel gas; (2) Hg was removed effectively by the sorbents containing iron oxide in the temperature range of $60\text{-}100^{\circ}\text{C}$ (3) the presence of oxygen may play very important role in the Hg removal .and Formation of elemental sulfur was observed upon heating of the used sample. a process for the removal of Hg using H_2S over iron oxides sorbents, which will be located just before the wet desulfurization unit and catalytic COS converter of a coal gasification system. it is necessary to understand the reactions between the iron oxide sorbent and other components of the fuel gas such as H_2S , CO, H_2 , H_2O , etc. Bhaskar *et al.* [30] developed the recycling of waste lubricant oil from automobile industry was found to be best alternative to incineration. Silica (SiO_2), alumina (Al_2O_3), silica – alumina ($\text{SiO}_2\text{-Al}_2\text{O}_3$) supported iron oxide (10 wt.% Fe) catalysts were prepared by wet impregnation method and used for the desulphurization of waste

lubricant oil into fuel oil. The extent of Sulphur removal increases in the sequence of Fe/SiO₂-Al₂O₃<Fe/Al₂O₃<Fe/SiO₂ and this might be due to the presence of smaller crystalline size (7.4nm) of Fe₂O₃ in Fe/SiO₂ catalyst. X-ray diffraction results suggest the presence of iron sulphide in the used catalyst. Gas chromatography with thermal conductivity detector analysis confirms the presence of H₂S in gaseous products. In addition, Fe/SiO₂ catalyst facilitated the formation of lower hydrocarbons by cracking higher hydrocarbons (C₄₀) present in waste lubricant oil. Cheng *et al.* [31] developed acid mine drainage (AMD) is an important contributor to surface water pollution due to the release of acid and metals. Fe (II) in AMD reacts with dissolved oxygen to produce iron oxide precipitates, resulting in further acidification, discoloration of stream beds, and sludge deposits in receiving waters. It has recently been shown that new fuel cell technologies, based on microbial fuel cells, can be used to treat AMD and generate electricity. Here we show that this approach can also be used as a technique to generate spherical nano-particles of iron oxide that, upon drying, are transformed to goethite. fuel cell technologies can not only be used for simultaneously AMD treatment and power generation, but that can generate useful products such as iron oxide particles having sizes appropriate for used as pigments and other applications. Halmann and Steinfeld [32] studied fuel gases from coal, gas, or oil –fired power stations, as well as from several heavy industries, such as the production of iron, lime and cement, are major ethnographic sources of global CO₂ emissions. The thermodynamic constraints are determined for the production of syngas suitable for methanol, hydrogen, or ammonia synthesis. The environmental and economic consequences are assessed for large – scale commercial production of these chemical commodities. The production of ammonia in the above processes seems particularly attractive, as it consumes the nitrogen in the fuel gases. Leion *et al.* [33] studied chemical – looping combustion (CLC) is a novel technology that can be used to meet demands on energy production without CO₂ emissions. The experiments were carried out in a laboratory fluidized – bed reactor that was operating cyclically with alternating oxidation and reduction phases. The exhaust gases were led to an analyzer where the contents of CO₂, CO, CH₄ and O₂ were measured. Gas samples collector in bags were used to analyze the content of hydrogen in a gas chromatograph. The results showed that both the iron one and the oxide scale worked well as oxygen carrier and both oxygen carriers increased their reactivity with time. Otsuka *et al.* [34] investigated pseudo – Storage of hydrogen and its recovery by redox of iron oxide have been proposed as a new method of the storage and supply of hydrogen for PEFC vehicles. Among the additives to iron oxide tested, Al, Cr, Zr, Ga and V were the effective elements enhancing both the reduction with H₂ (storage of H₂) and deoxidation with water (recovery of H₂) of the iron oxide (3Fe+4H₂O=Fe₃O₄+4H₂) at low temperatures (<400⁰C). The additives moderated the sintering of iron oxide markedly with repeated redox cycles. It is suggested that another important role of additivities is to activate H₂ and H₂O at the surface of iron oxide or to enhance the diffusion of O²⁻ as a result of the formation of compound oxides between the additive and iron oxide. Lorente *et al.* [35] discussed the Steam – Ron process, based on the redox reaction of iron oxides (Fe₃O₄+4H₂ → 3F₂+4H₂O), is an interesting alternative to other methods of storing and generating pure hydrogen to a solid oxide fuel cell (SOFC), a mathematical mode for the oxidation process in a fixed bed reactor has been developed and is used to estimate the behavior of the reactor under various operating conditions

(e.g. amount of iron, steam flow rate; temperature). Huang *et al.* [36] found the oxidation kinetics and electrical properties of oxide scales thermally grown on the surface of a commercial ferrite alloy have been investigated on the un oxidized and pre-oxidized alloys as functions of temperature and time under oxidizing atmospheres with four different electrodes. Oxidation kinetic studies with the an-oxidized alloys show a nearly parabolic dependence on time of oxide-scale growth rate, but a significantly increased growth rate with a coating of LSCo compared to those without and with the coatings of LSM and platinum. It mechanism associated with the formation of Cr_2O_3 . SEM observations show that oxidation of the un-oxidized alloy in the presence of an oxide electrode results in considerable inter diffusion of Cr and the electrode cations especially Co across the interfaces. The FeO_x - based catalyst was applied to the decomposition of extra heavy oils such as vacuum distilled residual oil and Orimulsion. These extra heavy oils were effectively decomposed over the $\text{ZrO}_2\text{-Al}_2\text{O}_3\text{-FeO}_x$ catalyst with steam, and the yields of lighter hydrocarbon reached to above 60%. Ozaki *et al.* [37] studied development of an elemental mercury (Hg^0) removal process for coal derived fuel gas is an important issue in the development of a clean and highly efficient coal power generation system. recently, iron – based sorbents such as iron oxide (Fe_2O_3), supported iron oxide on TiO_2 , and iron disulfide have been proposed as active mercury sorbents. Temperature programmed decomposition desorption (TPDD) experiments revealed that the decomposition characteristics of mercury species captured on the sorbent was similar to that of HgS reagents (meta cinnabar). Furthermore, it was observed that the characteristics of the decomposition of mercury species depended on the sorbent type of sorbents and reaction conditions. Yang *et al.* [38] discussed perovskite – oxide $\text{Ba}_{1.0}\text{CO}_{0.7}\text{Fe}_{0.2}\text{Nb}_{0.1}\text{O}_{3-\delta}$ has been reported as oxygen transport membrane and cathode material for solid oxide fuel cells (SOFCs). No obvious variation can be observed in TEC by A – site deficiency. The electrical conductivity and TEC of $\text{Ba}_{1.0}\text{CO}_{0.7}\text{Fe}_{0.2}\text{Nb}_{0.1}\text{O}_{3-\delta}$ decrease while the cathode polarization resistance increases with the increase in iron doping concentration. The highest conductivity of 13.9 S cm^{-1} and the lowest cathode polarization resistance of 0.07. Wang *et al.* [39] produce $\text{Ni-Al}_2\text{O}_3$ composites with varying contents of nickel are synthesized via a glycine nitrate process (GNP) and an impregnation process (IMP). Their potential application as an anode functional layer for internal methane CO_2 reforming in a solid oxide fuel cell is investigated. H_2 -TPR results show that the chemical interaction between NiO and Al_2O_3 decreases as the nickel content increases. Catalytic tests demonstrate that 15 wt. % $\text{Ni-Al}_2\text{O}_3$ catalysts exhibit the best catalytic activity for methane CO_2 reforming. However, the carbon formation rates over $\text{Ni-Al}_2\text{O}_3$ prepared via GNP are lower than those over $\text{Ni-Al}_2\text{O}_3$ prepared via IMP using the same amounts of nickel, with the exception of the 1 wt. % $\text{Ni-Al}_2\text{O}_3$ catalyst. Raman spectroscopy and O_2 -TPO results indicate that the degree of graphitization and the amount of carbon deposited on the 15 wt % $\text{Ni-Al}_2\text{O}_3$ catalyst synthesized via GNP are lower than those of the catalyst prepared via IMP following a 60 h stability test. A cell with a 15 wt.% $\text{Ni-Al}_2\text{O}_3$ catalyst layer prepared via GNP is fabricated that delivers a peak power density of 1006 mW cm^{-2} at $850 \text{ }^\circ\text{C}$ when operating on methane – CO_2 gas mixtures, which is comparable to that observed when operating in hydrogen fuel. Pratihari *et al.* [40] characterize nickel – yttria stabilized zirconia (Ni-YSZ) cermet is widely used as an anode material for solid oxide fuel cells (SOFCs). While the nickel to nickel chain maintains the electrical conductivity path, the YSZ contributes to lowering the thermal expansion and in habits nickel

coarsening during high temperature (1000°C) operation. An electroless technique is employed to prepare a uniform nickel coating on the YSZ powder the process parameters for this technique are optimized. Notably, the cermet thus prepared shows percolation at a much lower nickel content (10-20 vol%) compared with those reported in the literature. Halzer *et al.* [41] studied the effects of compositional and environmental parameters on the kinetics of micro structural degradation are investigated for porous Ni/CGO anodes in solid oxide fuel cells (SOFC). Improved methodologies of SEM-imaging, segmentation and object recognition are described which enable precise qualification of nickel grain growth over time. Due to these methodological improvements the grain growth can be described precisely with a standard deviation of only 5-15 nm for each time step. Coffey *et al.* [42] discussed copper doped lanthanum strontium ferrite for reduced temperature solid oxide fuel cells. Copper doped lanthanum strontium ferrite showed superior kinetics for the electro-reduction of oxygen. The generic formulation was $\text{La}_{1-x}\text{Sr}_x\text{Cu}_{1-y}\text{Fe}_y\text{O}_3$ (LSCuF) where x ranged from 0.2 to 0.3 and y varied from 0 to 0.4. Doping with copper improved the electrocatalytic activity compared with undoped material. In oxygen, the $\text{La}_{0.7}\text{Sr}_{0.3}\text{Cu}_{0.2}\text{Fe}_{0.8}\text{O}_3$ sample showed current densities approximately 2–3 times that of $\text{La}_{0.7}\text{Sr}_{0.3}\text{FeO}_3$ and 10 times that of $\text{La}_{0.8}\text{Sr}_{0.2}\text{FeO}_3$. Faungnawaki *et al.* [43] studied Hydrogen production from dimethyl ether steam reforming over composite catalysts of copper ferrite spinel and alumina. Dimethyl ether steam reforming (DME SR) was performed over composite catalysts of copper ferrite spinel (CuFe_2O_4) and alumina for hydrogen production, applicable to fuel cell. A highly active composite was achieved when the calcination temperature of the Cu spinel was at 900 °C and that of the alumina was at or below 700 °C. Mixing state of the copper spinel and the alumina was also investigated. After mixing with alumina, the present CuFe_2O_4 markedly exhibited excellent activity for DME SR in comparison to the commercial CuFe_2O_4 and $\text{Cu/ZnO/Al}_2\text{O}_3$. Tsoncheva [44] Thermally synthesized nanosized copper ferrites as catalysts for environment protection. Nanosized copper ferrites were prepared by thermal method from the corresponding hydroxide carbonate precursors varying the temperature of synthesis. The phase composition of the obtained materials was characterized by XRD, Mossbauer spectroscopy, DSC and TPR analysis. Their catalytic properties were tested in total oxidation of toluene and methanol decomposition to CO and hydrogen. The relation between the synthesis parameters, phase composition of the samples and their transformation under the oxidation or reduction reaction medium was investigated in turns to understand the catalytic behavior of the obtained materials. Chün Lieu [45] discussed magnetic and catalytic properties of copper ferrite Nano powders prepared by a microwave-induced combustion process. Copper ferrite Nano powders were successfully synthesized by a microwave-induced combustion process using copper nitrate, iron nitrate, and urea. The process only took a few minutes to obtain CuFe_2O_4 nanopowders. The CuFe_2O_4 powders specific surface area was 5.60 m²/g. Moreover, these copper ferrite magnetic Nano powders also acted as a catalyst for the oxidation of 2,3,6-trimethylphenol to synthesize 2,3,5-trimethylhydrogenquinone and 2,3,5-trimethyl-1,4-benzoquinone for the first time. On the basis of experimental evidence, a rational reaction mechanism is proposed to explain the results satisfactorily. Kamble *et al.* [46] discussed synthesis of $\text{Mg}_{0.48}\text{Cu}_{0.12}\text{Zn}_{0.40}\text{Fe}_2\text{O}_4$ ferrite and its aptness for multilayer chip component application. As-synthesized ferrite samples were then subjected to crystallographic, structural and magnetic investigations by

techniques viz. X-ray diffraction, IR spectroscopy and B–H measurements. Purity and phase formation were confirmed by XRD examinations. Cation redistribution was also suggested by XRD analyses which supplement the variation of magnetic properties. IR absorption bands were found to be in the expected high frequency range (574.95 cm^{-1} and 582.39 cm^{-1}) and low frequency range ($\approx 431\text{ cm}^{-1}$) which fortifies the spinel phase formation. Boost in magnetic performance of sucrose methods' yield was observed owing to reduced porosity and increased surface area. Fresno *et al.* [47] discussed Comparative study of the activity of nickel ferrites for solar hydrogen production by two-step thermochemical cycles. The samples leading to higher hydrogen yields, averaged over three cycles, are those calcined at $700\text{ }^{\circ}\text{C}$ in each group (supported and unsupported) of materials. The comparison of the two groups shows that higher chemical yields are obtained with the supported ferrites due to better utilization of the active material. Therefore, the highest activity is obtained with ZrO_2 -supported NiFe_2O_4 calcined at $700\text{ }^{\circ}\text{C}$. Sora *et al.* [48] discussed crystal structures and magnetic properties of strontium and copper doped lanthanum ferrites. The average bond distance (Fe/Cu)–O and the pseudo-cubic unit cell volume decrease with increasing Cu content in accordance with the presence of higher valence states of the transition metals. The magnetic structure was modeled for the monophasic samples ($x=0.05$ and 0.10) assuming an antiferromagnetic interaction between Fe/Cu neighboring cations (G-type): the magnetic moments order antiferromagnetically along the b -axis, with the spin direction along a -axis. The magnetic moments of the Fe/Cu atoms are $\mu_x=2.66(3)\mu\text{B}$ and $2.43(3)\mu\text{B}$ for the compositions $x=0.05$ and 0.10 , respectively. By measuring the first magnetization curve and the hysteresis loops, coexisting antiferromagnetic and weak ferromagnetic interactions were observed for all samples. Lee *et al.* [49] worked on inter-diffusion between NiCuZn-ferrite and LTCC and its influence on magnetic performance. The magnesium (Mg) and aluminum (Al) ions from LTCC also diffuse into ferrite for a shorter distance. Several new phases form through such inter-diffusion. For example, the inter-diffusion between alumina and ferrite induces the formation of hematite whose presence is detrimental to the saturation magnetization and permeability of ferrite. Additionally, inter-diffusion also induces changes in the lattice parameters of ferrite. We note a linear relationship between the lattice constant of ferrite and saturation magnetization, which demonstrates that magnetic properties are strongly tied to the crystalline structure of ferrite. Satyendra Singh *et al.* [50] investigated on effects of surface morphologies on response of LPG sensor based on nanostructured copper ferrite system. Synthesis of a copper ferrite system (CuFe_2O_4) via chemical coprecipitation method is characterized by X-ray diffraction, surface morphology (scanning electron microscope) and optical absorption spectroscopy. Study of gas sensing properties shows the spinel CuFe_2O_4 synthesized in 1:1 molar ratio exhibits best response to LPG adsorption/resistance measurement. Thus, resistance based LPG sensor is found robust, cheap and may be applied for kitchens and industrial applications. Abbaspour *et al.* [51] worked on electrocatalytic hydrogen evolution reaction on carbon paste electrode modified with Ni ferrite nanoparticles. Nanoparticles of mixed oxides of Fe and Ni are prepared by a low temperature coprecipitation method. The effects of Ni content in synthesized nanoparticles on the electrocatalysts performance for hydrogen evolution reaction are investigated by electrochemical techniques. Scanning electron microscopy and X-ray diffraction spectroscopy are used for studying the morphology and structure of Ni-ferrite nanoparticles (NPs). The Tafel slopes for the hydrogen

evolution reaction are found to be between $97.75 \text{ mV dec}^{-1}$ and $122.19 \text{ mV dec}^{-1}$ on carbon paste electrodes modified with ferrite NPs and kinetic parameters show that the Volmer step must control the hydrogen evolution reaction. The electrodes are resistive to passivation and they can be renewed easily. Hagary *et al.* [52] studied the influence of Cd doping on the microstructure and optical properties of nanocrystalline copper ferrite thin films. Nanocrystalline thin films of mixed Cu–Cd ferrites, $\text{Cu}_{1-x}\text{Cd}_x\text{Fe}_2\text{O}_4$ ($x = 0, 0.2, 0.3, 0.5, 0.7, 0.8, 0.9$ and 1), were deposited by electron beam evaporation technique. The films were annealed at $450 \text{ }^\circ\text{C}$ for 1 h. The effect of Cd doping on the structural and optical properties of the deposited films has been investigated by using X-ray diffraction (XRD) and optical spectrophotometry. XRD patterns of the annealed films show spinel cubic structure. The refractive index dispersion of the films was found to increase with Cd content and discussed in terms of the Wemple–Domenico single oscillator model. Kuo [53] assessment of redox behavior of nickel ferrite as oxygen carriers for chemical looping process. After five successive cycles, NiFe_2O_4 powder with a single phase of spinel structure demonstrated higher redox cycling behavior and better stability than standard NiO and Fe_2O_3 . We also addressed the mechanism underlying the redox cycling by NiFe_2O_4 spinel powder. Our results demonstrate the feasibility of using the proposed preparation of NiFe_2O_4 as an oxygen carrier in a reversible chemical looping process (CLP). Pattanaik [54] worked on growth of Nanoscale Nickel Ferrite on Carbonaceous Matrix- A Novel Method of Turning Harmful Particulates into a Functional Nanocomposite. The nickel ferrite content in the composite varies with the Fe/Ni ratio in particulate, fuel type, and combustion condition. Such variation may lead to the composite exhibiting diverse physical behaviors. Detailed structure and cation distribution in dispersed ferrite have been studied using Fe and Ni *K*-edges XAFS spectroscopy. Peaks are identified in the radial structure function with specific atom pair correlations within the spinel ferrite from which the relative occupancy of the cations in the octahedral and tetrahedral sites can be discerned. The results show that Ni(II) has strong preference for the octahedral site, while Fe(III) prefers both sites which is consistent with that of an inverted spinel ferrite. Kuo *et al.* [55] carried out assessment of redox behavior of nickel ferrite as oxygen carriers for chemical looping process. NiFe_2O_4 powder with a single phase of spinel structure demonstrated higher redox cycling behavior and better stability than standard NiO and Fe_2O_3 . We also addressed the mechanism underlying the redox cycling by NiFe_2O_4 spinel powder. Our results demonstrate the feasibility of using the proposed preparation of NiFe_2O_4 as an oxygen carrier in a reversible chemical looping process (CLP). Lin *et al.* [56] worked on synthesis and characterization of nickel ferrite Nano catalysts for CO_2 decomposition. The complete decomposition of CO_2 was possible because of higher degree of oxygen deficiency and surface-to-volume ratio of NFNs. The pre-edge XANES spectra of Fe atom in NFNs exhibits an absorbance feature at 7115 eV for the $1s$ to $3d$ transition which is forbidden by the selection rule in case of perfect octahedral symmetry. The EXAFS data showed that the NFNs had two central Fe atoms coordinated by primarily Fe–O and Fe–Fe with bond distances of 1.87 and 3.05 \AA , respectively. Methane gas was produced during the reactivation of NFNs by flowing H_2 . Decomposition of CO_2 , moreover, recovery of valuable CH_4 using heat energy of off gas produced from power generation plant or steel industry is an appealing alternative for energy recovery.

CONCLUSION:

Above mentioned literature shows wide applications of metal /mixed metal oxides as fuels in various reactions like assessment of redox behavior of nickel ferrite as oxygen carriers for chemical looping process. After five successive cycles, NiFe₂O₄ powder with a single phase of spinel structure demonstrated higher redox cycling behavior and better stability than standard NiO and Fe₂O₃. We also addressed the mechanism underlying the redox cycling by NiFe₂O₄ spinel powder. Our results demonstrate the feasibility of using the proposed preparation of NiFe₂O₄ as an oxygen carrier in a reversible chemical looping process (CLP). Nanoscale Nickel Ferrite on Carbonaceous Matrix- A Novel Method of Turning Harmful Particulates into a Functional Nanocomposite. The nickel ferrite content in the composite varies with the Fe/Ni ratio in particulate, fuel type, and combustion condition. So, metal/mixed metal oxides have broad applications as fuels in various chemical reactions.

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