Faculty of Science

Chemistry Department

Simultaneous Production of Hydrogen and Carbon Nanotubes via Methane Decomposition over Some Transition Metals Containing Catalysts

Thesis Submitted for
Ph.D. Degree of Science in Chemistry
By

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(M. Sc. 2010)
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To
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TABLE OF CONTENTS

ACKNOWLEDGMENT

TABLE OF CONTENTS…….. i

LIST OF TABLES……. v

LIST OF FIGURES……... vi

LIST OF ABBREVIATIONS……... x

ABSTRACT……... xii

AIM OF THE WORK……... xiv

1. LITERATURE SURVEY……. 1

1.1. Natural Gas……. 1

1.1.1. Zohr Field…….. 1

1.2. Hydrogen Energy…… 2

1.2.1. Sources of Hydrogen……. 3

1.2.2. Hydrogen Applications…….. 4

1.3. Hydrogen Production Technologies……. 6

1.3.1. Hydrogen from Renewable Sources…….. 7

1.3.1.1. Reformation of biomass…….. 8

1.3.1.2. Electrolysis of water……... 8

1.3.2. Hydrogen production from fossil fuel……... 9

1.3.2.1. Steam methane reforming (SMR)……... 10

1.3.2.2. Partial oxidation…….. 11

1.3.2.3. Dry reforming of methane (DRM)……. 12

1.3.2.4. Autothermal reforming (ATR)……... 12

1.3.2.5 Coal Gasification……. 13

1.4. Methane Catalytic Decomposition (CDM)……... 13

1.4.1. Catalysts for methane catalytic decomposition……. 15

1.4.1.1. The active component……. 15

1.4.1.2. The support……. 20
1.4.1.3. The promoter…….. 23
1.5. Description of Carbon Produced from Catalytic Decomposition of Methane……. 27
1.6. Carbon Nanotubes…… 28
1.6.1. Structure of carbon nanotubes……... 29
1.6.2. Properties of carbon nanotubes…….. 30
1.6.3. Synthesis methods……. 31
1.6.3.1. Arc discharge…….. 32
1.6.3.2. Laser ablation……. 33
1.6.3.3. Catalytic chemical vapor deposition……... 34
1.6.4. Growth mechanism of carbon nanotubes…….. 36
1.6.5. Potential application of carbon nanotubes……. 38
2. EXPERIMENTAL……. 40
2.1. Materials……... 40
2.1.1. Chemicals…….. 40
2.1.2. Gases…….. 40
2.2. Catalyst Preparation…….. 41
2.2.1. Preparation of Co/ZrO_2-MgO catalysts……. 41
2.2.2. Preparation of Co/ZrO_2-M (M = Al_2O_3, SiO_2, La_2O_3 and CeO_2) catalysts…… 41
2.2.3. Preparation of ZrO_2-MgO supported Fe and Ni catalysts……. 42
2.3. Catalytic Activity Tests…… 42
2.4. Material Characterization……. 44
2.4.1. X-ray powder diffraction……... 44
2.4.2. Temperature programmed reduction……. 46
2.4.3. Surface area……... 46

2.4.4. Transmission electron microscopy…… 46

2.4.5. Raman spectroscopy…….. 47

3. RESULTS AND DISCUSSION…… 48

3.1. Methane Decomposition over ZrO_2-MgO Supported Cobalt Catalysts with Various Zr/Mg Atomic Ratios…… 48

3.1.1. Characterization of Freshly Calcined Co/ZrO_2-MgO Catalysts… 49

3.1.1.1. XRD results of fresh Co/ZrO_2-MgO catalysts…… 49

3.1.1.2. TPR results of fresh Co/ZrO_2-MgO catalysts……. 52

3.1.1.3. BET surface areas of fresh Co/ZrO_2-MgO catalysts…….. 55

3.1.3. Evaluation of Catalytic Activity and Stability Co/ZrO_2-MgO Catalysts……... 55

3.1.3. Characterization of Spent Co/ZrO_2-MgO Catalysts…….. 59

3.1.3.1. TEM images of spent Co/ZrO_2-MgO catalysts…….. 59

3.1.3.2. XRD results of spent Co/ZrO_2-MgO catalysts……... 66

3.1.3.3. Raman spectroscopy of spent Co/ZrO_2-MgO catalysts…….. 68

3.2. Methane Decomposition over ZrO_2-M (M = MgO, Al_2O_3, SiO_2 La_2O_3 or CeO_2) Binary Oxides Supported Cobalt Catalysts……... 71

3.2.1. Characterization of Freshly Calcined Co/ZrO_2-M (M= MgO, Al_2O_3, SiO_2 La_2O_3 or CeO_2) Catalysts…….. 71

3.2.1.1. XRD results of fresh Co/ZrO_2-M catalysts…… 71

3.2.1.2. TPR results of fresh Co/ZrO_2-M catalysts…….. 75

3.1.3. BET surface areas of fresh Co/ZrO_2-M catalysts…….. 77

3.2.3. Evaluation of Catalytic Activity and Stability of Co/ZrO_2-M Catalysts……... 78

3.2.3. Characterization of Spent Co/ZrO_2-M Catalysts……... 82

3.2.3.1. TEM images of spent Co/ZrO_2-M Catalysts…….. 82

3.2.3.2. XRD results of spent Co/ZrO_2-M catalysts…… 87

3.2.3.3. Raman spectroscopy of spent Co/ZrO_2-M catalysts……... 89

3.3. Methane Decomposition over ZrO_2-MgO Mixed Oxides supported Co, Fe and Ni catalysts……... 91

3.3.1. Characterization of Fresh Co, Fe and Ni/ZrO_2-MgO Catalysts…. 91

3.3.1.1. XRD results of fresh Co, Fe and Ni/ZrO_2-MgO catalysts…….. 91

3.3.1.2. TPR results of fresh Co, Fe and Ni/ZrO_2-MgO catalysts……... 95

3.3.1.3. BET surface areas of fresh Co, Fe and Ni/Zr-Mg catalysts…..... 97

3.3.2. Evaluation of Catalytic Activity and Stability Co, Fe and Ni/ZrO_2-MgO Catalysts……... 98

3.3.3. Characterization of Spent Co, Fe and Ni/ZrO_2-MgO Catalysts… 101

3.3.3.1. XRD of spent Co, Fe and Ni/ZrO_2-MgO catalysts……. 101

4. SUMMARY AND CONCLUSION…….. 103

REFERENCES…….. 108

ARABIC SUMMARY

LIST OF TABLES

Table 1.1 List of some biomass material used for hydrogen production..... 7

Table 2.1 List of origin of the used chemicals..... 40

Table 3.1 Texture properties and crystallite size of the fresh calcined Zr-Mg supported cobalt catalysts..... 52

Table 3.2 Texture properties and crystallite size of the fresh calcined Zr-M (M =Mg, Al, Si, La and Ce) supported cobalt catalysts..... 74

Table 3.3 Texture properties and average crystallite size of the fresh calcined Zr-Mg supported Co, Fe and Ni catalysts..... 95

LIST OF FIGURES

Figure 1.1 Some feedstocks used for hydrogen production……... 4

Figure 1.2 Flow sheet of the main hydrogen production technologies…….. 6

Figure 1.3 A diagram of a typical SMR process…… 10

Figure 1.4 Schematics of direct thermocatalytic decomposition of methane……. 14

Figure 1.5 Various types of nanocarbon formed in MCD reaction. (A) SWCNTs; (B) MWCNTs; (C, D, E) regular CNFs with different structures. (F) octopus CNFs; (G) bamboo-shaped CNFs; (H) carbon nanoonions……... 28

Figure 1.6 Structural model (left) and transmission electron microscopy image (right) of a multi-walled carbon nanotube……... 29

Figure 1.7 Scheme of an arc discharge setup for the synthesis of CNTs……. 32

Figure 1.8 Scheme of a laser ablation setup for the synthesis of CNTs……. 33

Figure 1.9 Typical schematic diagram of the catalytic chemical vapor deposition of CNTs in a horizontal reactor…… 35

Figure 1.10 Carbon nanotubes growth mechanism (a) tip-growth model and (b) base-growth model…… 37

Figure 1.11 Present, near term and long term applications of CNTs... 39

Figure 2.1 Flow sheets for preparing the catalysts under study……. 43

Figure 2.2 A typical schematic diagram of methane decomposition reaction system……. 45

Figure 3.1 XRD of fresh calcined Zr-Mg supported cobalt catalysts

(a) $Co/Zr_{1.0}$, (b) $Co/Zr_{0.8}Mg_{0.2}$, (c) $Co/Zr_{0.6}Mg_{0.4}$, (d) $Co/Zr_{0.4}Mg_{0.6}$, (e) $Co/Zr_{0.2}Mg_{0.8}$ and (f) $Co/Mg_{1.0}$..... 50

Figure 3.2 TPR profiles of fresh calcined Zr-Mg supported cobalt catalysts (a) $Co/Zr_{1.0}$, (b) $Co/Zr_{0.8}Mg_{0.2}$, (c) $Co/Zr_{0.6}Mg_{0.4}$, (d) $Co/Zr_{0.4}Mg_{0.6}$, (e) $Co/Zr_{0.2}Mg_{0.8}$ and (f) $Co/Mg_{1.0}$..... 53

Figure 3.3 Hydrogen yield as a function of reaction time over Zr-Mg supported cobalt catalysts..... 56

Figure 3.4 TEM images of as-deposited carbon over $Co/Zr_{1.0}$ catalyst..... 60

Figure 3.5 TEM images of as-deposited carbon over $Co/Zr_{0.8}Mg_{0.2}$ catalyst..... 61

Figure 3.6 TEM images of as-deposited carbon over $Co/Zr_{0.6}Mg_{0.4}$ catalyst..... 62

Figure 3.7 TEM images of as-deposited carbon over $Co/Zr_{0.4}Mg_{0.6}$ catalyst..... 63

Figure 3.8 TEM images of as-deposited carbon over $Co/Zr_{0.2}Mg_{0.8}$ catalyst..... 64

Figure 3.9 TEM images of as-deposited carbon over $Co/Mg_{1.0}$ catalyst..... 65

Figure 3.10 XRD of spent Zr-Mg supported cobalt catalysts (a) $Co/Zr_{1.0}$, (b) $Co/Zr_{0.8}Mg_{0.2}$, (c) $Co/Zr_{0.6}Mg_{0.4}$, (d) $Co/Zr_{0.4}Mg_{0.6}$, (e) $Co/Zr_{0.2}Mg_{0.8}$ and (f) $Co/Mg_{1.0}$..... 67

Figure 3.11 Raman spectra of as-deposited carbon over (a) $Co/Zr_{1.0}$, (b) $Co/Zr_{0.8}Mg_{0.2}$, (c) $Co/Zr_{0.6}Mg_{0.4}$, (d) $Co/Zr_{0.4}Mg_{0.6}$, (e) $Co/Zr_{0.2}Mg_{0.8}$ and (f) $Co/Mg_{1.0}$ catalysts..... 70

Figure 3.12 XRD of fresh calcined Zr-M supported cobalt catalysts (a) Co/Zr-Mg, (b) Co/Zr-Al, (c) Co/Zr-Si, (d) Co/Zr-La and (e) Co/Zr-Ce……. 72

Figure 3.13 TPR profiles of fresh calcined Zr-M supported cobalt catalysts (a) Co/Zr-Mg, (b) Co/Zr-Al, (c) Co/Zr-Si, (d) Co/Zr-La and (e) Co/Zr-Ce……. 76

Figure 3.14 Hydrogen yield as a function of reaction time over Zr-M supported cobalt catalysts……. 79

Figure 3.15 TEM images of as-deposited carbon over Co/Zr-Al catalyst…….. 83

Figure 3.16 TEM images of as-deposited carbon over Co/Zr-Si catalyst…….. 84

Figure 3.17 TEM images of as-deposited carbon over Co/Zr-La catalyst…….. 85

Figure 3.18 TEM images of as-deposited carbon over Co/Zr-Ce catalyst…….. 86

Figure 3.19 XRD of spent Zr-M supported cobalt catalysts ((a) Co/Zr-Mg, (b) Co/Zr-Al, (c) Co/Zr-Si, (d) Co/Zr-La and (e) Co/Zr-Ce……. 88

Figure 3.20 Raman spectroscopy of spent Zr-M supported cobalt catalysts (a) Co/Zr-Mg, (b) Co/Zr-Al, (c) Co/Zr-Si, (d) Co/Zr-La and (e) Co/Zr-Ce…….. 90

Figure 3.21 XRD of fresh calcined Zr-M supported catalysts (a) Ni/Zr-Mg, (b) Fe/Zr-Mg and (c) Co/Zr-Mg……. 92

Figure 3.22 TPR profiles of fresh calcined Zr-M supported catalysts (a) Ni/Zr-Mg, (b) Fe/Zr-Mg and (c) Co/Zr-Mg…… 96

Figure 3.23 Hydrogen yield as a function of reaction time over Zr-M

supported iron, cobalt and nickel catalysts……... 99

Figure 3.24 XRD of spent Zr-M supported catalysts (a) Ni/Zr-Mg, (b) Fe/Zr-Mg and (c) Co/Zr-Mg……... 102

LIST OF ABBREVIATIONS

NG	natural gas
LPG	liquefied petroleum gas
SMR	steam methane reforming
WGS	water–gas shift
PSA	pressure swing adsorption
PO	partial oxidation
DRM	dry reforming of methane
ATR	autothermal reforming
PEMFC	proton exchange membrane fuel cell
DCFC	direct carbon fuel cell
CNTs	carbon nanotubes
CNFs	carbon nanofibers
CNMs	carbon nanomaterials
TOS	time on stream
SBA	Santa Barbara Amorphous
ZSM-5	Zeolite Socony Mobil–5
SWCNTs	single-walled carbon nanotubes
CVD	chemical vapor deposition
MWCNTs	multi-walled carbon nanotubes
CCVD	catalytic chemical vapor deposition
HiPCO	high-pressure CO process
CAEM	controlled atmosphere electron microscopy
Sccm	slandered cubic centimeter per minute
TCD	thermal conductivity detector
XRD	X-ray diffraction
TPR	temperature programmed reduction

TEM	transmission electron microscopy
BJH	Barrett–Joyner–Halenda
HRTEM	high-resolution transmission electron microscopy
GS	graphene sheets
GHG	greenhouse gases
MSI	metal-support interaction

1

LITERATURE SURVEY

1.3. Natural Gas

Natural gas (NG) production in Egypt has been increasing, while the production of oil has been decreasing since the mid-1990s. Egypt is rapidly developing large gas reserves, which represented 15% and 13% of the total proven gas reserves in Africa in 2010 and 2014, respectively **(Siddig et al. 2016)**. The estimated Egyptian crude oil reserves in Egypt would last for about 24 years whereas that NG will last for 150 years **(Ibrahim 1998)**. Egypt is the largest non-OPEC oil producer in Africa and the second largest gas producer in the continent, starting from 2014 investment and economic growth started picking up on the back of political stability **(Hegazy 2015)**. Around eighty percent of Egypt's natural gas reserves are in the Mediterranean and the Nile Delta, whereas the smaller amounts in the Western Desert and the Gulf of Suez **(Bahgat 2013)**.

1.1.1. Zohr Field

Zohr Field is considered as the biggest natural gas discovery in the eastern Mediterranean and also one of the largest gas discoveries over the entire world; it was discovered in August 2015 by ENI (Italian company). Zohr Field reserve was evaluated to be up to 30 tcf with estimated value over $100 billion, is the largest discovery to date in the Eastern Mediterranean. Egypt has started efforts to put Zohr Field in services

quickly and it is believed that developing Zohr field will help Egypt to reduce gas imports **(Ratner 2016)**.

1.2. Hydrogen Energy

Currently, the world has been confronted with an energy crisis due to depletion of resources and increased environmental problems **(Barnwal and Sharma 2005)**. The widespread use of fossil fuels within the current energy infrastructure is considered as the largest source of anthropogenic emissions of carbon dioxide, which is largely blamed for global warming and climate change **(Zanganeh and Shafeen 2007)**. In addition to declining crude oil supplies and political instability in the regions with large oil reserves, strict emission regulations are creating a need for alternative fuels **(Campen et al. 2008)**. An alternative fuel must be technically feasible, economically competitive, environmentally acceptable, and readily available **(Meher et al. 2006)**. Numerous potential alternative fuels have been proposed, including biodiesel, methanol, ethanol, hydrogen, boron, natural gas, liquefied petroleum gas (LPG), Fischer–Tropsch fuel, electricity, and solar fuels.

One of these alternative fuels, hydrogen, has the highest specific energy content of all conventional fuels and is the most abundant element in the universe **(Campen et al. 2008)**. Hydrogen will be a key contribution to sustainable development, because in the future it may be produced in virtually unlimited quantities using renewable energy sources. The major future markets for hydrogen depend primarily upon four factors: (1) the future cost of hydrogen, (2) the rate of advances of various technologies that use hydrogen, (3) potential long-term restrictions on greenhouse gases, and (4) the cost of competing energy systems **(Forsberg 2007)**.