Carbon nanotubes synthesis using Fe-Co-Mo/MgO tri-metallic catalyst: study the effect of reaction temperature, reaction time and catalyst weight

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Abstract: MgO supported tri-metallic catalyst containing combination of transition metals Fe, Co, and Mo was used to synthesise carbon nanotubes (CNT) from liquefied petroleum gas by chemical vapour deposition (CVD) method. The effect of reaction temperature, reaction time and catalyst weight to the yield and the CNT properties was investigated. It found that the CNT yield increased with increasing the reaction temperature. Besides, increasing the reaction temperature lead to the increase of the diameter and wall thickness of the CNT. Moreover, it was found that the crystallinity of the synthesised CNT increase when the reaction temperature is raised. The meso pores dominate the pore structure of the CNT product and contribute around 90% of the total pores volume. Meanwhile, micro pores with pore size range around 0.3–0.4 nm dominate the micro pores and contribute approximately 50–60% of the total micro pores volume. It also found that the CNT yield is decreased along with the increasing catalyst weight.

Keywords: carbon nanotubes; CNT; reaction time; reaction temperature; yield; liquefied petroleum gas; supported catalyst.

Reference to this paper should be made as follows: Setyopratomo, P., Wulan, P.P.D.K. and Sudibandriyo, M. (2020) 'Carbon nanotubes synthesis using Fe-Co-Mo/MgO tri-metallic catalyst: study the effect of reaction temperature, reaction time and catalyst weight', *Int. J. Nanomanufacturing*, Vol. 16, No. 1, pp.1–20.

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1 Introduction

Once discovered by Iijima (1991), carbon nanotubes (CNT) have raised broad interest in the fields of science and technology. Because of its superiority in terms of physical and chemical properties, studies on the synthesis of CNT continue to grow for a wide variety of applications. Some its superior properties are: has a very high tensile strength, i.e., ≈ 150 GPa, it is 100 times stronger than stainless steel, while it is six times lighter, its density is 1/6 times lower (1,100–1,300 kg/m^3); has a very high modulus (1 TPa); has a very high aspect ratio (length/diameter ratio); chemically stable; stable up to 4,000 K; its thermal conductivity is comparable to diamond [3,500 W/(m.K)], while its thermal capacity is twice that of pure diamond; it has very high electron mobility (100,000 cm^2/Vs), its current-carrying capacity is 1,000 times higher than that of copper; it can be metallic or semiconducting, depend on their diameter and chirality (Bazargan and McKay, 2012; Purohit et al., 2014; Saha et al., 2014).

CNT can be implemented in plenty of industrial applications, some of them are: in composites sector (such as electric insulator, thermal insulator, composites used in automobiles and aerospace sector), CNT was used to produce polymer composites by incorporating the nanotubes into the polymer matrix (Mittal et al., 2015); because of its semiconducting properties, in nano electronic devices it has potential to be used as integrated circuits material (Yang et al., 2007); as the electrode in electrochemical double-layer capacitors (Chen et al., 2002); as high-performance heavy metal adsorbent (Ihsanullah et al., 2016; Li et al., 2003); for removal of organic pollutants (Ncibi and Sillanpää, 2015); for electrode of fuel cells (Kibria et al., 2001); field emitter for field-emission display (Chouhan et al., 2015; Gautier et al., 2016); as hydrogen storage (Barghi et al., 2014); and so on.

Chemical vapour deposition (CVD) is considered as the most leading method for CNT synthesis (Pilatos et al., 2016). The advantage of the CVD method is not only due to its effectiveness in generating carbon feedstock but also because of its potential to produce various types of CNT by controlling various parameters that influence the growth of CNT (Kong et al., 1998). The synthesis will take place in the presence of a catalyst and CNT grow from the carbon atoms by the catalyst action. In this case, transition metals, such as Fe, Co, and Ni, have been widely used as the catalyst. The carbon source in the CVD method can be hydrocarbon or carbon monoxide (CO) (Ni et al., 2009).

CNT growth mechanisms have been widely discussed in the literature, but the detail of the growth mechanism is still not fully understood. The most accepted model is the

mechanism proposed by Baker and co-workers, which is based on the model of vapour-liquid-solid (VLS) (Tessonnier and Su, 2011; Wei et al., 2008). The VLS model consists of the following stages (Ago et al., 2006):

1 decomposition of the carbon source on the surface of the nanoparticles catalyst, then carbon atoms were formed

2 the carbons diffuse and dissolve into the nanoparticles forming molten metastable metal carbide

3 after experiencing supersaturation, precipitation of carbon atoms was taken place to form CNT.

Metal carbide is an intermediate compound, which eventually decomposes into metal and carbon (Pérez-Cabero et al., 2003; Snoeck et al., 1997).

In CVD synthesis, there are some key factors that can affect the growth of CNT such as carbon source, catalyst, growth temperature, growth time, gas flow rate, reactor geometry, and so on (Shah and Tali, 2016). In the case of the catalyst, it is still very rare use of catalyst involving the combination of more than two metal components. In this study, tri-metallic catalyst supported on MgO, Fe-Co-Mo/MgO, was used as catalyst. The role of Fe is to produce high yield because Fe is known to have high activity in CNT synthesis. Co took a role to improve the graphitisation of the resulting CNT. While, Mo serves to improve dispersion and prevent the sintering of nanoparticles Fe, thus avoiding the rapid deactivation of the catalyst. The reason for choosing MgO as support is because there is a strong metal-support interaction between Fe and MgO, so that the Fe component will remain well dispersed on the support surface. Compare to other supports, MgO is easier to be separated from CNT product, so that high efficiency will be achieved in the process of purification of CNT product. In addition, a review reported that it was still no clear understanding of the influence of the key factors on the properties of synthesised CNT, such as the diameter, the length, the purity, the porosity, and the morphology (Son et al., 2008).

Accordingly, this work was addressed to observe the performance of tri-metallic catalyst Fe-Co-Mo/MgO in CNT synthesis from liquefied petroleum gas. The study was aimed to investigate the effect of the reaction temperature, the reaction time, and catalyst weight on the yield and properties of the produced CNT.

2 Experimental method

The catalyst, with mass ratio Fe:Co:Mo:MgO = 4:4:2:90, was prepared by wet impregnation method. The mass ratio of the catalyst components is the optimum result obtained from our previous study. In such preparation, 18.0000 g MgO powder was mixed with 360 ml distillate water, sonicated and then stirred for 1 hour. Subsequently, metal precursor solution, which was a mixture of 5.7848 g ($Fe(NO_3)3.9H_2O$), 3.9491 g ($Co(NO_3)_2.6H_2O$), 0.7358 g ($(NH_4)_6Mo_7O_{24}.4H_2O$), and 180 ml distillate water, was added to the MgO slurry, while continue stirring for another 30 minutes. The solution then dried in a vacuum at 110°C and the obtained solid catalyst was milled afterward. The next stage is calcination of the dried catalyst, which was conducted in an electric furnace at 500°C for 4 hours.

The CNT synthesis was conducted in 1.6 cm inner diameter vertical tubular reactor which was made of quartz. Firstly, as much as 0.2 g calcined catalyst was fed into the reactor and underwent reduction process in a stream of 90 cm^3/minutes hydrogen at 450°C for 5 hours. After the reduction step was completed, the reactor temperature was raised according to the desired reaction temperature. Then a gas mixture, which was consisting of LPG, hydrogen, and argon at a mole fraction of 13%, 10% and 77%, was fed to the reactor at total flow rate of 194 cm^3/minutes. The gas flow rate was identical in all experiments.

Some analysis and characterisation were performed to determine the properties of the CNT. The CNT orientation was observed using scanning electron microscope (JSM-6510A/JSM-6510LA – analytical/analytical low vacuum SEM), while transmission electron microscope analysis – TEM JEOL JEM 1400, was used to observe the CNT morphology and diameter. The surface area and pore size distribution of the CNT were measured using surface area analyser (Quantachrome Nova 2000 Series – NovaWin – Instruments version 11.03). To observe the effect of reaction temperature to the graphitic nature of the CNT product, XRD analysis was performed using Shimadzu X-Ray Diffractometer 7000 Maxima-X.

3 Results and discussion

3.1 The effect of the reaction temperature

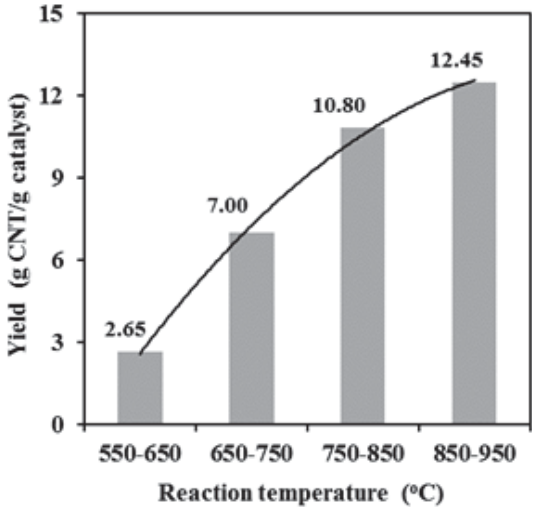
To observe the effect of reaction temperature on yield and CNT properties, the synthesis was performed at four different temperature levels, i.e., 550–650°C, 650–750°C, 750–850°C and 850–950°C, while catalyst weight was fixed at 0.2 g and the reaction time is 2 hours. The reaction temperature level is presented in a range of 100°C. This range shows the width of temperature deviation during the reaction.

The CNT yield as a function of the reaction temperature was presented in Figure 1. In this study, CNT yield is defined as a mass of CNT produced per mass of catalyst used. In which, a mass of CNT is the difference between a mass of as-grown CNT and a mass of fresh catalyst fed. So, in this case, the mass of CNT also includes the mass of amorphous carbon formed during the synthesis. It is shown that the CNT yield increased with increasing the reaction temperature and reach the highest value at 12.45 g CNT/g catalyst which corresponds to reaction temperature of 850–950°C.

To date, the overall control of CNT growth is far from perfect understanding and remains to be a major challenge (Gohier et al., 2008). However, it was suggested that the diffusion of carbon through the metal particles is the controlling step (Hernadi et al., 1996). In the supported catalyst, the support also serves as a substrate, and the active components were dispersed over the substrate surface. There is an adhesion force between the substrate and the active components. The growth of the CNT occurs starting with the decomposition of the hydrocarbon compound at the surface of the active component that produces the carbon atoms, then the carbon atoms diffuse into the active component and ultimately precipitates to form CNT. The hydrocarbon decomposition, carbon diffusion and carbon precipitation were taken place very quickly. Thus, in other words, the CNT growth occurs once the feed gas is contacted with the catalyst at the reaction temperature. While at the end of the reaction, the catalyst particles remain bonded to the CNT product. In this case, the catalyst particles become the impurities of

the CNT product. Effect of the reaction temperature on the CNT growth and the carbon yields in the synthesis of CNT by CVD method has been widely reported by other researchers. Among others, Lee et al. (2001) conduct CVD synthesis of acetylene gas on iron-deposited silicon oxide substrate at temperature range 750–950°C and found that the carbon yield increase progressively with the reaction temperature. They also suggest that the increasing carbon yield is attributed to the enhanced diffusion and reaction rate of carbon at a higher temperature. While, Atthipalli et al. (2011) were underlined that the CNT growth in CVD deposition was significantly controlled by temperature-driven diffusion. Then the increasing yield might be associated with increased the carbon diffusion rate due to the temperature rise.

Figure 1 The CNT yield at all the reaction temperature varied

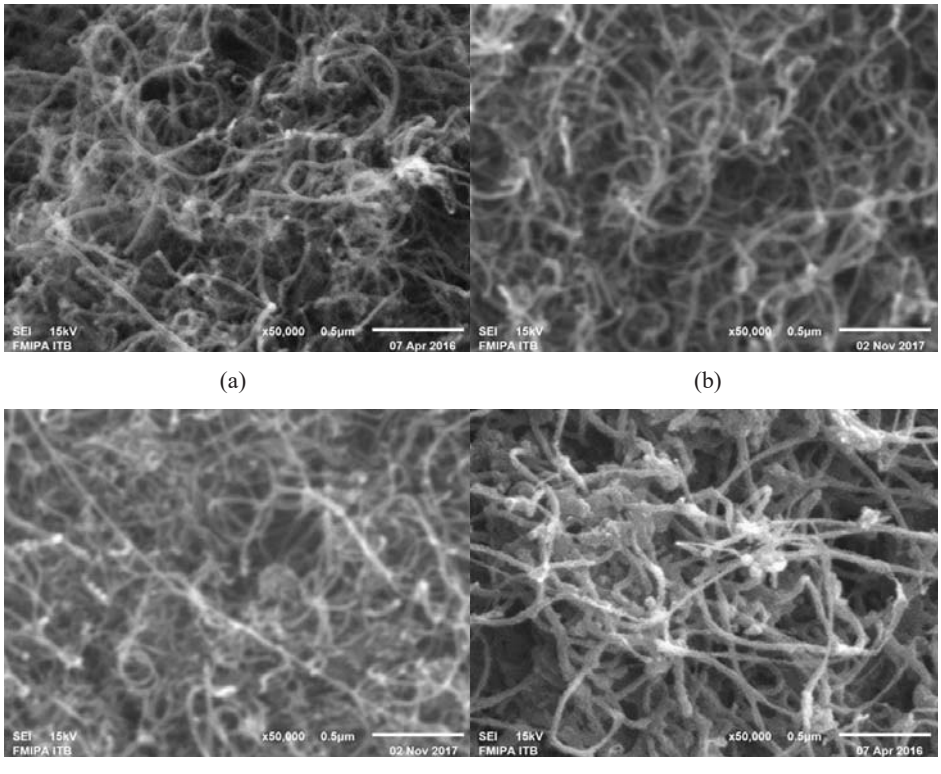


The orientation of the CNT product was observed using SEM images. The SEM images of the CNT which was synthesised at all reaction temperature varied were presented in Figure 2. It can be seen that the increase of the reaction temperature does not cause changes the orientation of the resulting CNT. A randomly oriented which mutually entangled with one another was still produced at both temperature level. However, it was seen quite clear that the diameter of the CNT which were produced at a higher reaction temperature are bigger than those which were produced at a lower temperature.

To observe the effect of the reaction temperature on the diameter and wall thickness of the carbon nanotube, TEM analysis was performed on the CNT products synthesised at 550–650°C and 850–950°C and the results were presented in Figure 3. It was found that at reaction temperature 550–650°C the CNT have an outer diameter range of 7–17 nm with a wall thickness range of 1–2 nm, while at reaction temperature 850–950°C the outer diameter to be 29–43 nm with a wall thickness 7–17 nm. The result is in agreement with the tendency observed by some other researchers. Among others, a similar finding was found in the study conducted by Song et al. (2009) who observe the effect of temperature on tube structure during CVD synthesis using Fe-Mo/Al_2O_3. They found that synthesis at reaction temperature 800°C promotes the formation of multi-walled CNT with a wall thickness of 2–7 nm, however, further increase of the reaction temperature to

1,100°C leads to the generation of multi-walled CNT with a wall thickness of 3–15 nm. They underlined that the wall thickness of CNT is very sensitive to the reaction temperature. Meanwhile, on the study conducted by Sengupta et al. (2010), who produced Fe-filled CNT by CVD of propane on Si and apply a metal organic molecular $Fe(acac)_3$ as precursor using modified photoresist, found that the average diameter of the CNT also increases when the reaction temperature was raised from 550°C to 950°C. On the work done by Lee et al. (2001), it was reported that the average CNT diameter increase from 30 nm to 130 nm when the reaction temperature is raised from 750°C to 950°C. Huang et al. (2008) grow CNT from LPG using ferrocene as the catalyst precursor by floating catalyst method and found that the diameter of CNT forest increase from 6.8 nm to 12 nm when the reaction temperature was raised from 700°C to 800°C. In addition, Awadallah et al. (2013) reported that multi-walled CNT were produced with a diameter of 10–19 nm at reaction temperature 600 and 650°C and with a diameter of 8.0–28.6 nm at 700°C. All these findings have revealed that reaction temperature has a significant effect on the diameter and wall thickness of the CNT formed. However, there is no clear explanation why the reaction temperature greatly affects the diameter and wall thickness of CNT.

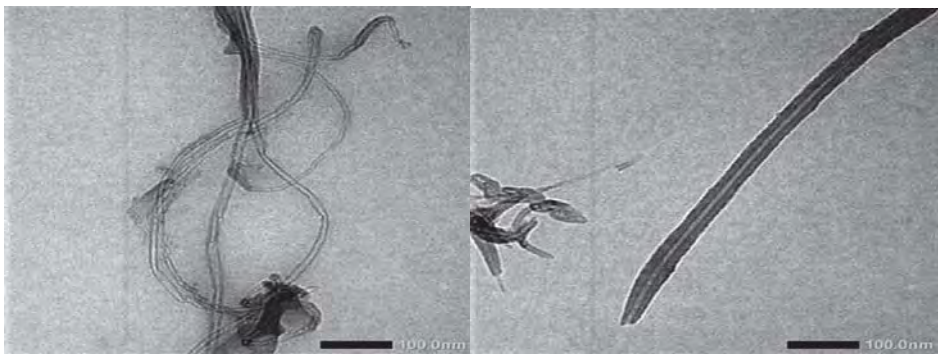
Figure 2 The SEM images of the CNT produced at different reaction temperature, (a) 550–650°C (b) 650–750°C (c) 750–850°C (d) 850–950°C



(a) (b)

(c) (d)

Figure 3 The TEM images of the CNT produced at different reaction temperature, (a) 550–650°C (b) 850–950°C



(a) (b)

Surface area and pore distribution are important properties of CNT related its applications in various fields. Surface area and pore volume distribution were determined by physical adsorption of N_2. This method is able to accurately determine the amount of gas adsorbed on a solid material, which can be used to measure the pores characteristics and structure. Surface area and pores volume can be directly derived from the isotherm of the adsorption/desorption obtained from such measurement (Groen et al., 2003). Measurements on a wide range of relative pressure (P/Po), where Po is the nitrogen saturation pressure, the N_2 adsorption isotherm will provide information on the pore size distribution of micro, meso and macro pores at pore size range of about 0.3–200 nm. A linear multipoint plot of the Brunauer-Emmett-Teller (BET) adsorption isotherms relation for the relative pressure range P/Po 0.004 to 0.300 was used to determine the specific surface areas of the CNT. The total pore volume was determined from the amount of nitrogen vapour adsorbed at a relative pressure P/Po ≈ 1, in which the pores were assumed to be filled with liquid N_2. The Horvath-Kawazoe (HK) slit model was used to evaluate the micro pores (pore size < 2 nm). The micro pores size distribution was obtained from the low relative pressure (P/Po) region of the adsorption isotherm. While, the meso pores (pore size 2–50 nm) distribution was determined using the Barret, Joyner and Halenda (BJH) method. Among several methods which were developed to calculate the size distribution ofmeso pores, the BJH method is the most commonly used. The method is based on the Kelvin equation and corrected for multilayer adsorption and applies only to the meso porous and limited range of macro pores (Musa et al., 2011).

Figure 4 shows the BET surface area of the CNT as a function of the reaction temperature. Table 1 summarises the pores volume distribution at any reaction temperature applied. While, the cumulative micro pores and cumulative BJH pores volume were presented on Figure 5 and Figure 6, respectively.

Increasing reaction temperature from 550–650°C to 650–750°C resulted in the increase of BET surface area of the CNT, reaching 206.7 m^2/g which become the highest value. Further increase in the reaction temperature resulted in a decrease in the surface area which reaches the lowest value of 36.0 m^2/g when the reaction temperature is 850–950°C. The specific surface area, which determined by the BET method with nitrogen adsorption at 77 K, of low purity multi-walled CNT is reported to be about 200 m^2/g, while it reaches 800 m^2/g for single-walled CNT with high purity. Those

surface area is to be in the range 268–877 m^2/g after acid treatment (Ioannatos and Verykios, 2010). Multi-walled CNT have a wide range of surface area, from 50 to 150 m^2/g as reported by Lee and Park (2012).

Figure 4 The BET surface area of the CNT at all reaction temperature varied (see online version for colours)

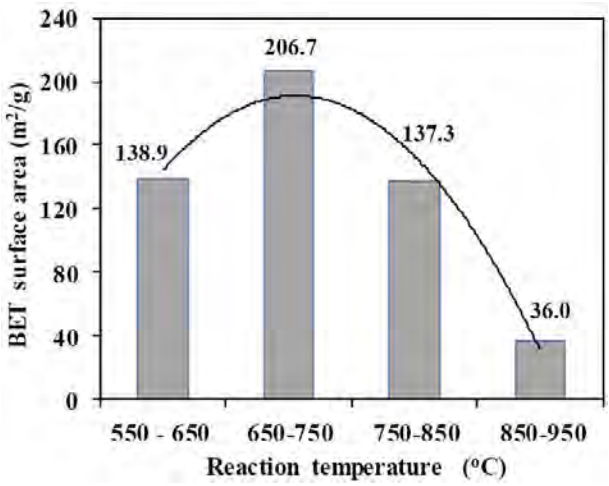


Table 1 The pores volume distribution of the CNT at all reaction temperature varied

Reaction temperature (°C)	*Pores volume (cm^3/g)*		
	Micro pores	*BJH pores volume*	*Total pores*
550–650	0.055	0.465	0.494
650–750	0.083	1.027	1.070
750–850	0.055	0.810	0.820
850–950	0.013	0.187	0.182

The highest value of pores volume of the carbon nanotube product was also obtained when the reaction temperature is 650–750°C which reach 1.070 m^2/g, and tend to decrease when the reaction temperature further increase. Since the value of BJH pores volume close to the total pores volume, it indicates that the meso pores give a major contribution to total pores volume. The pores structure of the CNT synthesised by varying the reaction temperature consist of around 7–11% micro pores and 89–93%meso pores.

Micro pores structure of the CNT product which was displayed in cumulative micro pores volume profiles showed that at all reaction temperature applied, micro pores with pore size range around 0.3–0.4 nm dominate the micro pores. It contributes approximately 50–60% of the total volume of the micro pores. It was also showed that synthesis at a reaction temperature of 650–750°C resulted in the highest micro pores volume, i.e., 0.083 (cm^3/g). All of the cumulative BJH pores volume profiles tend to be flat in the range of pore sizes larger than 50 nm. This fact revealed that the pore structure of CNT contains a very little portion of macro pores (pore size > 50 nm). This fact reconfirmed that the meso pores dominate the pore structure of the CNT product. In fact,

it very hard to find a study of the effect of reaction temperature on the pore structure of CNT.

Figure 5 Cumulative micro pores volume as function of pore size at all reaction temperature varied

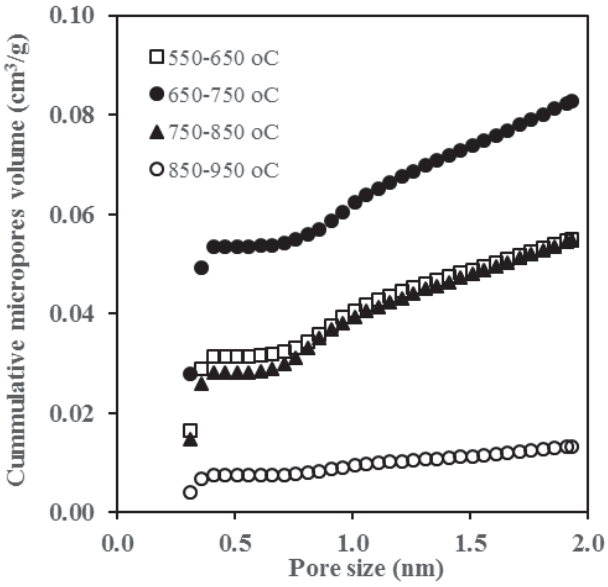
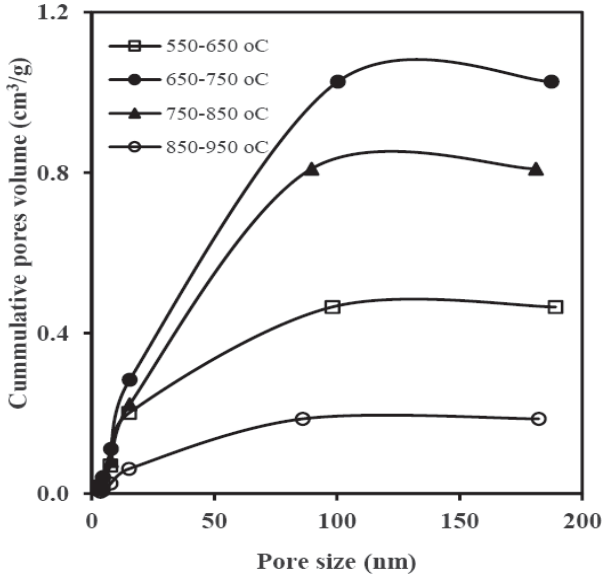


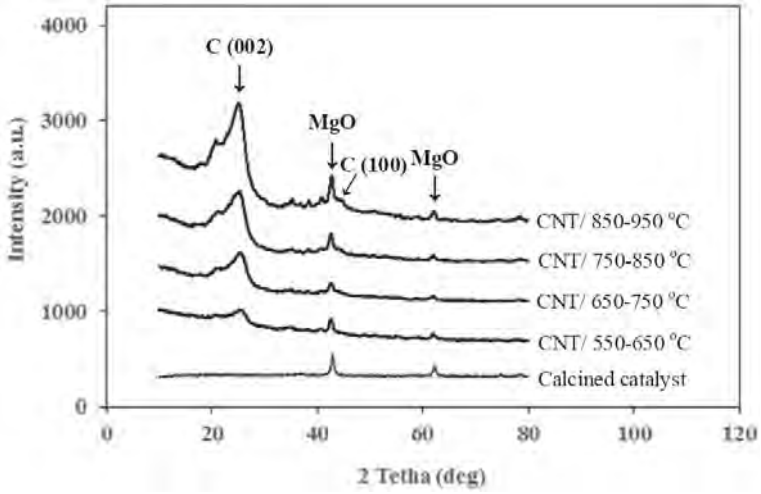
Figure 6 Cumulative BJH pores volume as function of pore size at all reaction temperature varied



The surface area and micro porosity of CNT is very significant for some applications, especially in regard to the hydrogen storage capacity, then much effort has been done to increase the surface area and to develop the micro porosity of CNT through various methods of activation (Chen and Huang, 2007; Im et al., 2011, 2012; Lee and Park, 2010, 2012; Park and Lee 2010; Rather et al., 2008). The hydrogen storage capacity of CNT was also reported to have dependencies to its pore volume. The multi-walled CNT which have the narrowest micro pores will have the highest adsorption capacity (Lee and Park, 2012).

The result of XRD analysis of the calcined catalyst and the as-grown CNT synthesised at all reaction temperature varied were presented in Figure 7.

Figure 7 XRD patterns of the calcined catalyst and the as grown CNT synthesised at all reaction temperature varied



The existence of MgO clearly detected at 2 theta 42.90° and 62.30° in the as-grown CNT and the calcined catalyst. The XRD pattern could be used as an indication of the presence of CNT crystalline since its diffraction peak is close those of graphite. It is shown that the existence of highly oriented pyrolytic graphite (HOPG) – C (002) was detected at 2 theta ≈ 26°. The same finding was also found in the work of Hsieh et al. (2009), Kibria et al. (2004), Maccallini et al. (2010), Ni et al. (2006, 2009) and Tsoufis et al. (2007). In addition, the presence of CNT was indicated by the existence graphitic structure of C (100) with low intensity, which was detected at 2 theta ≈ 44°. This peak was also detected in XRD pattern of CNT product resulted in the work of Hsieh et al. (2009).

A common method used to examine the crystallinity of the CNT product is Raman spectroscopy based on the result of the ID/IG value, which is the intensity ratio of the defect band against the graphitic band (Rashidi et al., 2011). However, it has been widely known that XRD pattern could also be used to observe the graphitic nature of the CNT (Sengupta et al., 2010). It was reported that the degree of graphitisation of the synthesised CNT associated with the intensity of the C (002) diffraction peak. In general, more ideal graphitised materials exhibit an increase C (002) diffraction peak (Awadallah et al., 2013; Maccallini et al., 2010; Tsoufis et al., 2007). As shown in the XRD patterns generated in this study, the intensity of graphitic C (002) steadily increases with the increase in

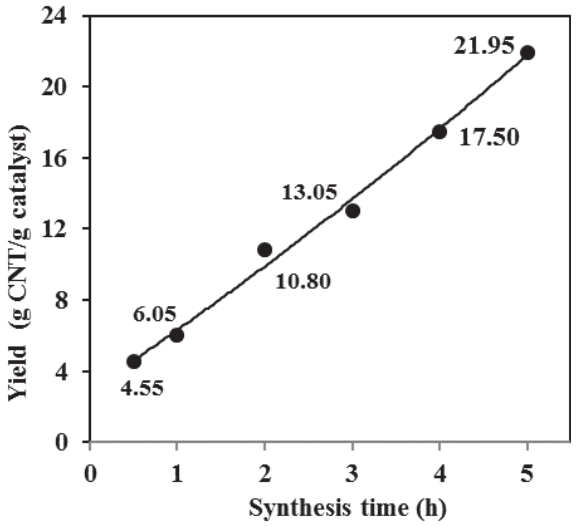
reaction temperature. This means that the crystallinity of the synthesised CNT continues to increase when the reaction temperature is raised from 550–650 to 850–950°C. The same finding also obtained in some other studies, among others, Chiangga et al. (2009) who synthesised CNT from C_2H_2 on thin iron film over the quartz substrate reported that the crystallinity of the CNT increases when the reaction temperature was increased from 700 to 900°C. While Chen et al. (2004) also reported that the crystallinity of the synthesised CNT increased when the reaction temperature was raised from 650 to 900°C that implies that the amount of ordered carbon increased with the increase of reaction temperature. Moreover, in the study conducted by Hsieh et al. (2009), it was found that the intensity of C (002) peak increased with the increase of the growth temperature and noticed that high-temperature growth would enhance the graphitisation degree of the synthesised CNT. In addition, it was also reported that the crystallinity of the CNT improves progressively with increasing growth temperature (Sengupta et al., 2010).

3.2 The effect of the reaction time

The effect of reaction time on the yield and CNT properties was studied by varying the reaction time to be 0.5, 1, 2, 3, 4 and 5 hours, while catalyst weight is made equal as much as 0.2 g and reaction temperature is fixed at 750–850°C.

Figure 8 exposed the effect of reaction time on the CNT yield. While SEM images of the CNT produced at all reaction time varied were presented in Figure 9.

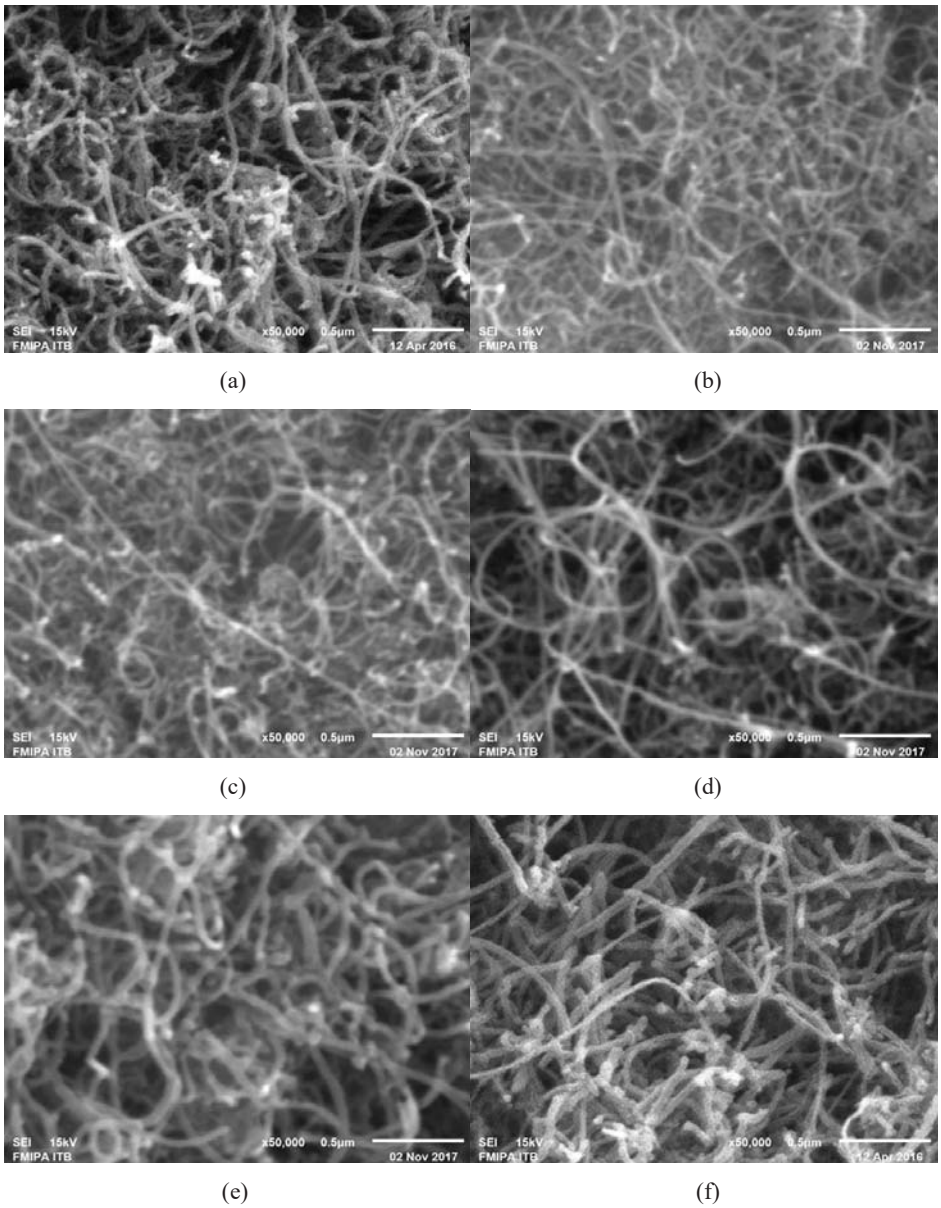
Figure 8 The CNT yield at all reaction time varied



It is shown that the yield is steadily increased with increasing reaction time and reach the highest yield at 21.95 g CNT/g catalyst which corresponds to 5 hours reaction time. There are a very limited number of CNT synthesis studies which use LPG as a carbon source. In a study conducted by Qian et al. (2002), who use LPG containing 13 ppm sulphur over Fe/Mo/Al_2O_3 catalyst, it was reported that they obtained 8 g CNT/g catalyst. While Jeong et al. (2010) synthesise CNT from LPG using Co-Fe-Mo/Al_2O_3 by varying

the metal loading on the range 30–70%w and gain productivity in the range of 5.17–21.13 g CNT/g catalyst. There are many factors that can affect the CNT yield such as carbon source, catalyst, reaction temperature, reaction time, type of carrier gas, type of reactor, the gas flow rate, gas composition, etc. It was reported that the CNT yield resulted from CVD synthesis using MgO supported catalyst varies from 0.1–45 g of CNT/g catalyst (Li et al., 2005; Tsoufis et al., 2007).

Figure 9 The SEM images of the CNT produced at different reaction time, (a) 0.5 hour (b) 1 hour (c) 2 hours (d) 3 hours (e) 4 hours (f) 5 hours



(a) (b)

(c) (d)

(e) (f)

Something interesting which can be observed from the CNT yield profile is the dependence on reaction time which is still quasi-linear over the reaction time range applied. This is noteworthy that even for 5 hours reaction time the catalyst is still active, decomposing the flowing hydrocarbon molecules and transform them into carbon deposits and thus does not show any indication of deactivation. So an extension of the reaction time is still potential to increase the CNT yield. Catalyst deactivation may result from the deposition of amorphous or graphitic carbon that leads to complete encapsulation of metal nanoparticles and block them from contact with the gas phase reactants (Becker et al., 2013). This result has confirmed that the addition of Mo in the catalyst component that acts as a promoter has been shown to be effective in preventing the rapid deactivation of the catalyst. Molybdenum (Mo) is usually added to the Fe or Co catalyst in order to prevent rapid catalyst deactivation (Ago et al., 2006).

Observation the effect of reaction time on the orientation of the CNT was done by taking SEM images at all reaction time varied. It is shown that longer reaction time does not change the orientation of the CNT produced. It still a randomly oriented which mutually entangled with one another.

The effect of reaction time on the surface area and pores size distribution of the CNT is expressed in the following displays, i.e., the BET surface area of the CNT (Figure 10), the pores volume distribution (Table 2), cumulative micro pores volume (Figure 11), cumulative BJH pores volume (Figure 12).

Table 2 The pores volume distribution of the CNT at all reaction time varied

Reaction time (hours)	*Pores volume (cm^3/g)*		
	Micro pores	*BJH pores volume*	*Total pores*
0.5	0.093	0.997	1.024
1	0.082	0.977	0.996
2	0.055	0.810	0.820
3	0.045	0.533	0.551
4	0.024	0.283	0.286
5	0.030	0.444	0.454

The highest BET surface area is 228.85 m^2/g corresponding to 0.5 hours reaction time. It is shown that the BET surface area generally decreases with increasing reaction time and reach a very low surface area which is around 60–77 m^2/g when reaction time is extended to 4 hours or more. The measured pores volume of the CNT, which includes micro pores, BJH pores and total pores volume, all show a decrease when the reaction time is increased. The highest pores volume is 0.093 cm^3/g, 0.997 cm^3/g and 1.024 cm^3/g for the micro pores volume, the BJH pores volume and the total pores volume, respectively, all are associated with a reaction time of 0.5 hours. Meanwhile, the lowest pores volume is 0.030 cm^3/g, 0.444 cm^3/g and 0.454 cm^3/g for the micro pores volume, the BJH pores volume and the total pores volume, respectively all are associated with a reaction time of 5 hours. Since the BJH pores volume values very close to the total pores volume, it means that the pore structure of the CNT is dominated bymeso pores. This pore structure profile is similar to that demonstrated when the reaction temperature was varied. The pores structure of the CNT synthesised by varying the reaction time consist of around 7–9% micro pores and 91–93% meso pores. Also identic with the CNT synthesised by

varying the reaction temperature, the micro pores structure of the CNT obtained by varying the reaction time was dominated by pores having a pore size in the range of 0.3–0.4 nm. They contribute 50–60% of the total volume of micro pores. The cumulative BJH pores volume as function of pore size demonstrating that the cumulative pores volume, at all reaction time varied, only slightly increased in the macro pores size range (pore size > 50 nm), which reconfirmed that reaction time does not shift the dominance of the meso pores in the pore structure of the CNT product.

Figure 10 The BET surface area of the CNT at all reaction time varied

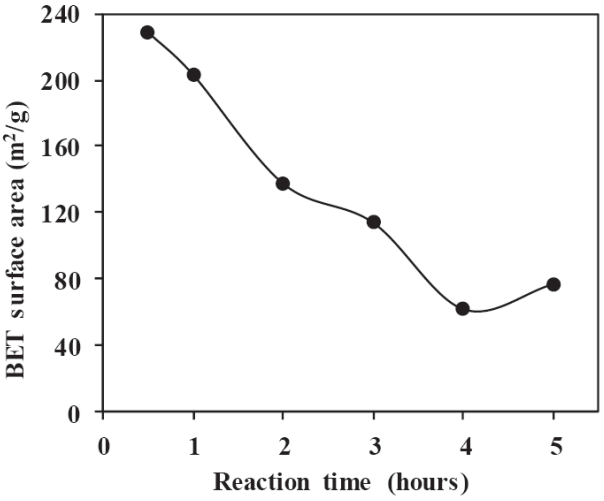
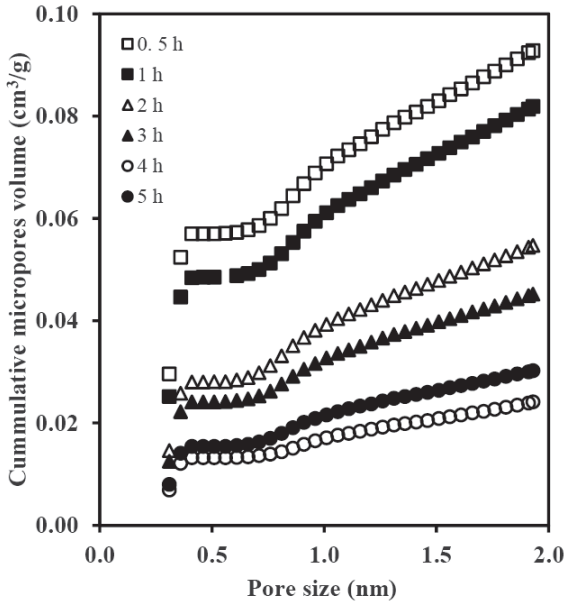


Figure 11 Cumulative micro pores volume as function of pore size at all reaction time varied



Another thing observed from the results of this study is both the BET surface area and the pore volume decreased with increasing reaction time. This indicates that the decrease of BET surface area if the reaction time is increased correlated with the decreasing of pore volume.

Figure 12 Cumulative BJH pores volume as function of pore size at all reaction time varied

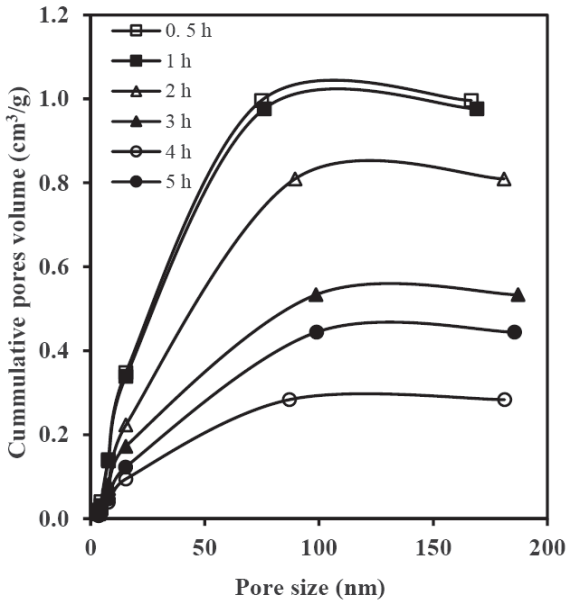
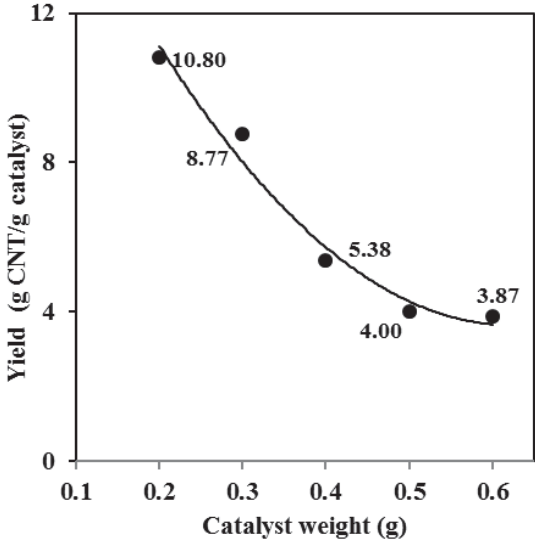


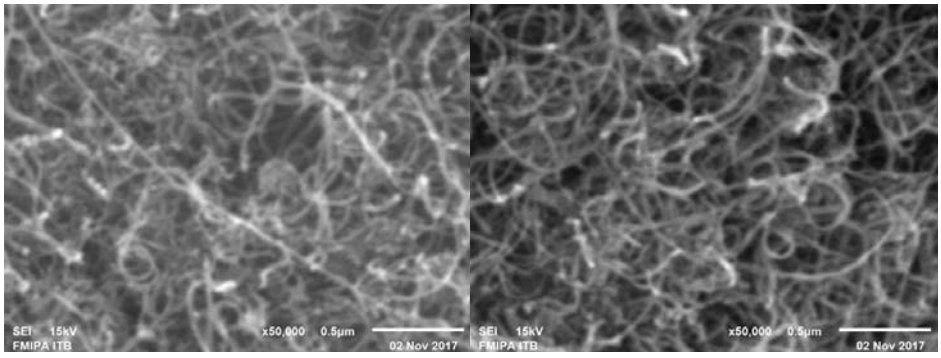
Figure 13 The CNT yield at all catalyst weight varied



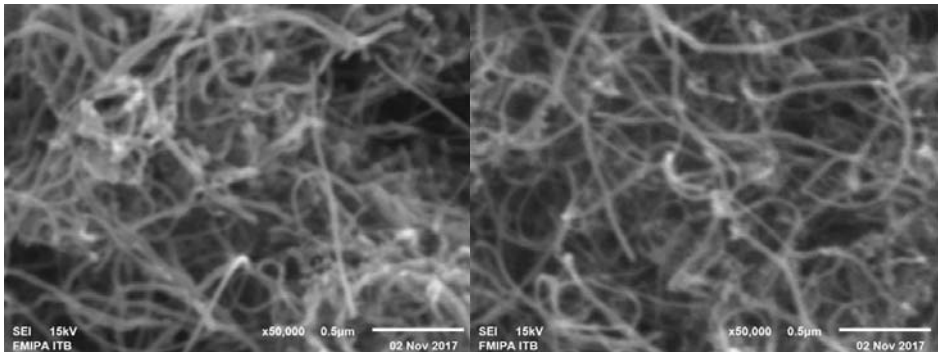
3.3 The effect of catalyst weight

In this study, the catalyst weight is varied to observe its effect on the CNT yield. Experiments were performed at five different levels of catalyst weight, i.e., 0.2, 0.3, 0.4, 0.5 and 0.6 g, while the reaction temperature is maintained at 750–850°C and the reaction time is kept fixed for 2 hours. The effect of catalyst weight variation on the CNT yield was presented in Figure 13.

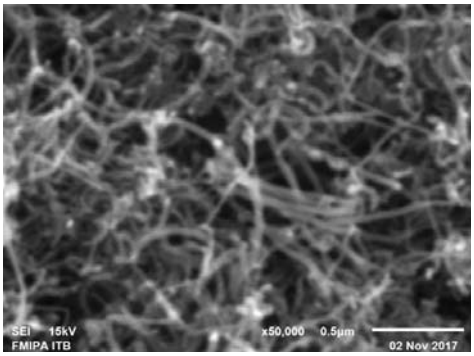
Figure 14 The SEM images of the CNT produced at different of catalyst weight, (a) 0.2 g (b) 0.3 g (c) 0.4 g (d) 0.5 g (e) 0.6 g



(a) (b)



(c) (d)



(e)

It is shown that the CNT yield is decreased along with the increasing catalyst weight. The CNT yield is 10.80 g CNT/g catalyst when catalyst weight is 0.2 g. The decrease in yield is approximately linear when the weight of the catalyst is increased up to 0.4 g. The CNT yield was roughly halved when the catalyst weight is doubled from 0.2 g to 0.4 g. The decreasing CNT yield at a further increase of catalyst weight is slighter. The CNT yield decrease one-third from 5.38 g CNT/g catalyst to 3.87 g CNT/g catalyst when catalyst weight is increased from 0.4 g to 0.6 g. The increase in weight of the catalyst fed to the reactor resulted in the more dense catalyst bed. The availability of space to support the growth of the CNT is of great importance. At a more dense catalyst bed, the availability of space for the growth of CNT become less. Therefore at a more dense catalyst bed, the growth of CNT will be more restricted and resulted in less CNT yield.

Observation the effect of catalyst weight on the orientation of the CNT was done by taking SEM images at all catalyst weight varied and was presented in Figure 14. It is shown that the increasing catalyst weight does not change the orientation of the CNT produced. It still a randomly oriented which mutually entangled with one another.

4 Conclusions

The CNT yield increased with increasing the reaction temperature. The increasing yield might be associated with increased the carbon diffusion rate due to the temperature rise. It was also found that increasing the reaction temperature lead to the increase of the diameter and wall thickness of the CNT. Analysis of the XRD patterns revealed that the crystallinity of the synthesised CNT increase when the reaction temperature is raised. The experiments have proved that the catalyst was able to avoid a very rapid deactivation. The pores volume of the CNT decreases when the reaction time is increased. The meso pores dominate the pore structure of the CNT product. Increasing the catalyst weight lead to the formation of the more dense catalyst bed and resulted in a reduction of the availability space for the growth of CNT then lowering the CNT yield.

Acknowledgements

The authors wish to thank The Directorate Research and Community Services, Universitas Indonesia, for providing the financial support through The Research Cluster Grant 2015.

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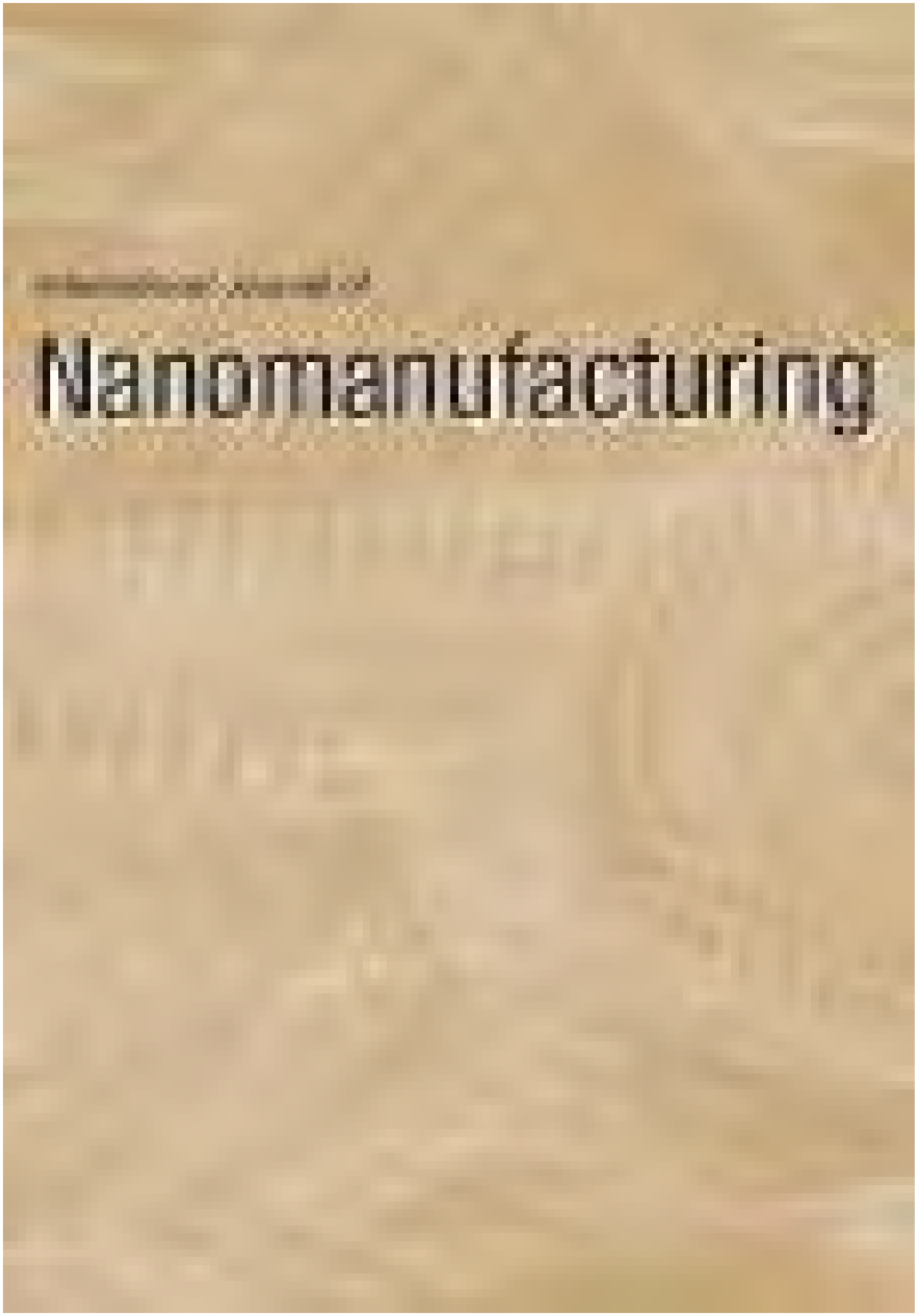
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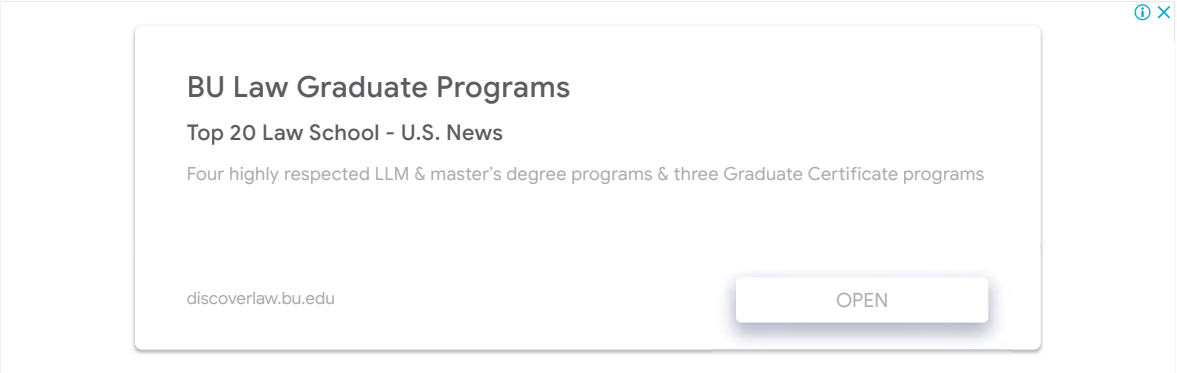

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Engineering
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H-INDEX

14

PUBLICATION TYPE

Journals

ISSN

17469392, 17469406

COVERAGE

2007-2014, 2020

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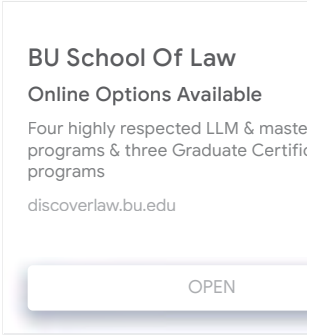

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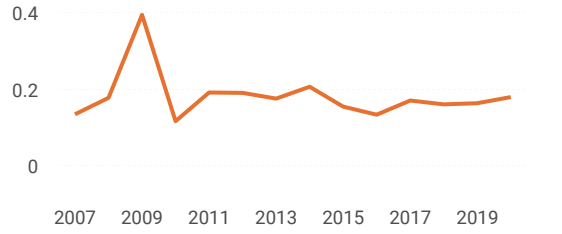

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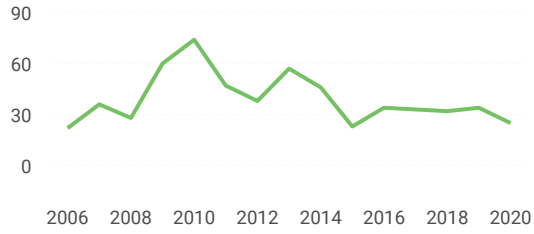

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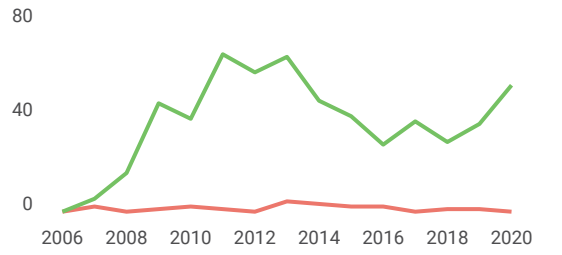

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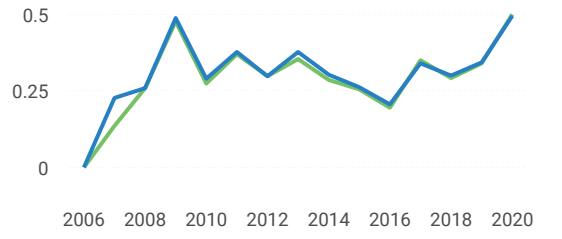

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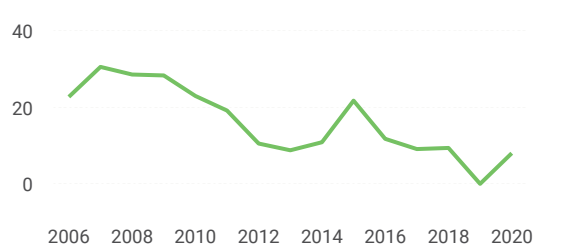

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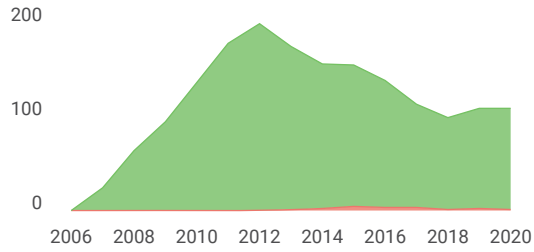

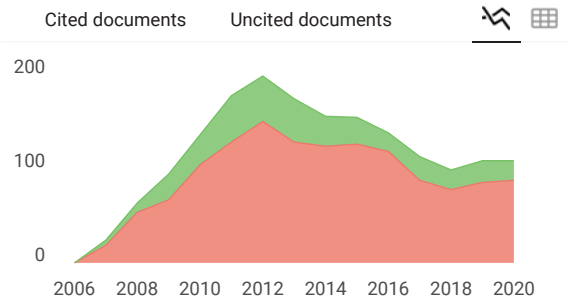

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Metrics based on Scopus® data as of April 2021

A **Agus Sudianto** 1 year ago

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Agus Sudianto

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The users of Scimago Journal & Country Rank have the possibility to dialogue through comments linked to a specific journal. The purpose is to have a forum in which general doubts about the processes of publication in the journal, experiences and other issues derived from the publication of papers are resolved. For topics on particular articles, maintain the dialogue through the usual channels with your editor.

International Journal of Nanomanufacturing- Impact Score, Overall Ranking, h-index, SJR, Rating, Publisher, ISSN, and Other Important Metrics

Last Updated on November 16, 2021

Important Metrics

Title	International Journal of Nanomanufacturing
Abbreviation	Int. J. Nanomanufacturing
Publication Type	Journal
Subject Area, Categories, Scope	Industrial and Manufacturing Engineering (Q3); Nanoscience and Nanotechnology (Q4)
h-index	14
Overall Rank/Ranking	20767
SCImago Journal Rank (SJR)	0.179
Impact Score	0.64
Publisher	Inderscience Enterprises Ltd.
Country	United Kingdom
ISSN	17469406, 17469392

About International Journal of Nanomanufacturing

International Journal of Nanomanufacturing is a **journal** covering the technologies/fields/categories related to **Industrial and Manufacturing Engineering (Q3); Nanoscience and Nanotechnology (Q4)**. It is published by **Inderscience Enterprises Ltd.**. The overall rank of International Journal of Nanomanufacturing is **20767**. According to **SCImago Journal Rank (SJR)**, this journal is ranked **0.179**. SCImago Journal Rank is an indicator, which measures the scientific influence of journals. It considers the number of citations received by a journal and the importance of the journals from where these citations come. SJR acts as an alternative to the Journal Impact Factor (or an average number of citations received in last 2 years). This journal has an **h-index** of **14**. The **best quartile** for this **journal** is **Q3**.

The ISSN of **International Journal of Nanomanufacturing** journal is **17469406, 17469392**. An International Standard Serial Number (ISSN) is a unique code of 8 digits. It is used for the recognition of journals, newspapers, periodicals, and magazines in all kind of forms, be it print-media or electronic. **International Journal of Nanomanufacturing** is cited by a total of **49** articles during the last 3 years (Preceding 2020).

International Journal of Nanomanufacturing Impact Score 2020-2021

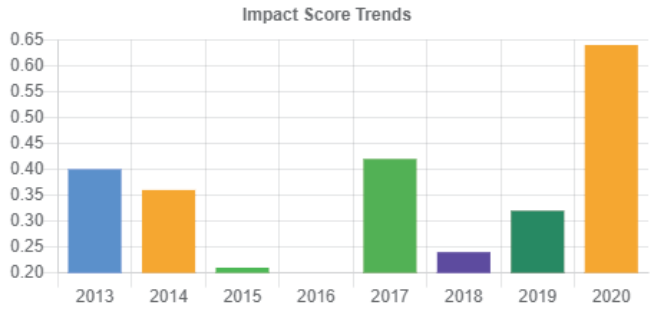
The **impact score** (IS) 2020 of **International Journal of Nanomanufacturing** is **0.64**, which is computed in 2021 as per its definition. **International Journal of Nanomanufacturing** IS is **increased** by a factor of **0.32** and approximate percentage change is **100%** when compared to preceding year 2019, which shows a **rising** trend. The impact score (IS), also denoted as Journal impact score (JIS), of an academic journal is a measure of the yearly average number of citations to recent articles published in that journal. It is based on Scopus data.

International Journal of Nanomanufacturing Impact Score 2021 Prediction

IS 2020 of **International Journal of Nanomanufacturing** is **0.64**. If the same upward trend persists, impact score of joule may **rise** in 2021 as well.

Impact Score Trend

Year wise Impact Score (IS) of International Journal of Nanomanufacturing. Based on Scopus data.



Year	Impact Score (IS)
2021/2022	Coming Soon
2020	0.64
2019	0.32
2018	0.24
2017	0.42

International Journal of Nanomanufacturing h-index

International Journal of Nanomanufacturing has an h-index of **14**. It means **14** articles of this **journal** have more than **14** number of citations. The h-index is a way of measuring the productivity and citation impact of the publications. The h-index is defined as the maximum value of h such that the given journal/author has published h papers that have each been cited at least h number of times.

International Journal of Nanomanufacturing ISSN

International Journal of Nanomanufacturing Rank and SCImago Journal Rank (SJR)

The overall rank of **International Journal of Nanomanufacturing** is **20767**. According to SCImago Journal Rank (SJR), this journal is ranked **0.179**. SCImago Journal Rank is an indicator, which measures the scientific influence of journals. It considers the number of citations received by a journal and the importance of the journals from where these citations come.

International Journal of Nanomanufacturing Publisher

International Journal of Nanomanufacturing is published by **Inderscience Enterprises Ltd.**. It's publishing house is located in **United Kingdom**. Coverage history of this **journal** is as following: **2007-2014, 2020**. The organization or individual who handles the printing and distribution of printed or digital publications is known as Publisher.

Call For Papers

Visit the official website of the journal/conference to check the further details about the call for papers.

Abbreviation

The IS0 4 standard abbreviation of **International Journal of Nanomanufacturing** is **Int. J. Nanomanufacturing**. This abbreviation ('Int. J. Nanomanufacturing') is well recommended and approved for the purpose of indexing, abstraction, referencing and citing goals. It meets all the essential criteria of ISO 4 standard.

ISO 4 (International Organization for Standardization 4) is an international standard that defines a uniform and consistent system for abbreviating serial publication titles and journals.

How to publish in International Journal of Nanomanufacturing

If your research field is/are related to **Industrial and Manufacturing Engineering (Q3); Nanoscience and Nanotechnology (Q4)**, then please visit the official website of this **journal**.

Acceptance Rate

The acceptance rate/percentage of any academic journal/conference depends upon many parameters. Some of the critical parameters are listed below.

- The demand or interest of researchers/scientists in publishing in a specific Journal/Conference.

It is essential to understand that the acceptance rate/rejection rate of papers varies among journals. Some Journals considers all the manuscripts submissions as a basis of acceptance rate computation. On the other hand, few consider the only manuscripts sent for peer review or few even not bother about the accurate maintenance of total submissions. Hence, it can provide a rough estimation only.

The best way to find out the acceptance rate is to reach out to the associated editor or to check the **official website** of the Journal/Conference.

Credits and Sources

- Scimago Journal & Country Rank (SJR), https://www.scimagojr.com/
- Journal Impact Factor, https://clarivate.com/

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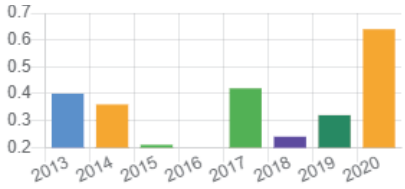
Impact Score, h-Index, and Other Important Details of These Journals, Conferences, and Books

Journal/Conference/Workshop/Book Title	Type	Ranking	Publisher	h-index	Impact Score
Clinical Pharmacology: Advances and Applications	journal	7291	Dove Medical Press Ltd.	27	2.85
Kritike	journal	28518	Department of Philosophy, University of Santo Tomas	1	0.06
2019 29th International Conference Radioelektronika, RADIOELEKTRONIKA 2019 - Microwave and Radio Electronics Week, MAREW 2019	conference and proceedings	23768		4	0.80
TEMS-ISIE 2018 - 1st Annual International Symposium on Innovation and Entrepreneurship of the IEEE Technology and Engineering Management Society	conference and proceedings	24961		3	0.59

Marketing Intelligence and Planning	journal	6584	Emerald Group Publishing Ltd.	70	2.99
IEEE International Conference on Adaptive Science and Technology, ICAST	conference and proceedings	21266		6	0.89
Horticulture Journal	journal	11969	Japanese Society for Horticultural Science	36	1.00
Journal of Orthopaedic Research	journal	4133	Wiley-Blackwell	155	3.26

Check complete list

Year wise Impact Score (IF) of International Journal of Nanomanufacturing



Impact Score Table

Year	Impact Score (IS)
2021/2022	Coming Soon
2020	0.64
2019	0.32
2018	0.24
2017	0.42
2016	0.20
2015	0.21
2014	0.36

Top Journals/Conferences in Industrial and Manufacturing Engineering

 # Journal of Operations Management
John Wiley and Sons Inc. | Netherlands

 # International Journal of Machine Tools and Manufacture
Elsevier Ltd. | United Kingdom

 # Production and Operations Management
Wiley-Blackwell | United States

 # Additive Manufacturing
Elsevier BV | Netherlands

 # Chemical Engineering Journal
Elsevier | Netherlands

 # International Journal of Production Economics
Elsevier | Netherlands

 # CIRP Annals - Manufacturing Technology
Elsevier USA | United States

 # Journal of Manufacturing Systems
Elsevier | Netherlands

 # Composites Part B: Engineering
Elsevier Ltd. | United Kingdom

 # Advanced Materials Technologies
Wiley-Blackwell | United States

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Advanced Functional Materials
Wiley-VCH Verlag | Germany

Nano Today
Elsevier | Netherlands

ACS Nano
American Chemical Society | United States

Nano Letters
American Chemical Society | United States

Small
Wiley-VCH Verlag | Germany

Nano-Micro Letters
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Biomaterials
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