# MORPHOLOGICAL ANALYSIS OF CARBON NANOTUBES SYNTHESIZED FROM CYCLOPENTADIENYL IRON DICARBONYL DIMER BY TRANSMISSION ELECTRON MICROSCOPY (TEM)

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***Abstract:*** *Carbon nanotubes (CNTs) are among the most promising nanomaterials due to their unique structural, physicochemical, and adsorption properties. In this study, single-walled carbon nanotubes (SWCNTs) were synthesized using cyclopentadienyl iron dicarbonyl dimer as a combined carbon source and catalyst precursor via the chemical vapor deposition (CVD) method. The morphological and structural characteristics of the synthesized nanotubes were systematically investigated by transmission electron microscopy (TEM).*

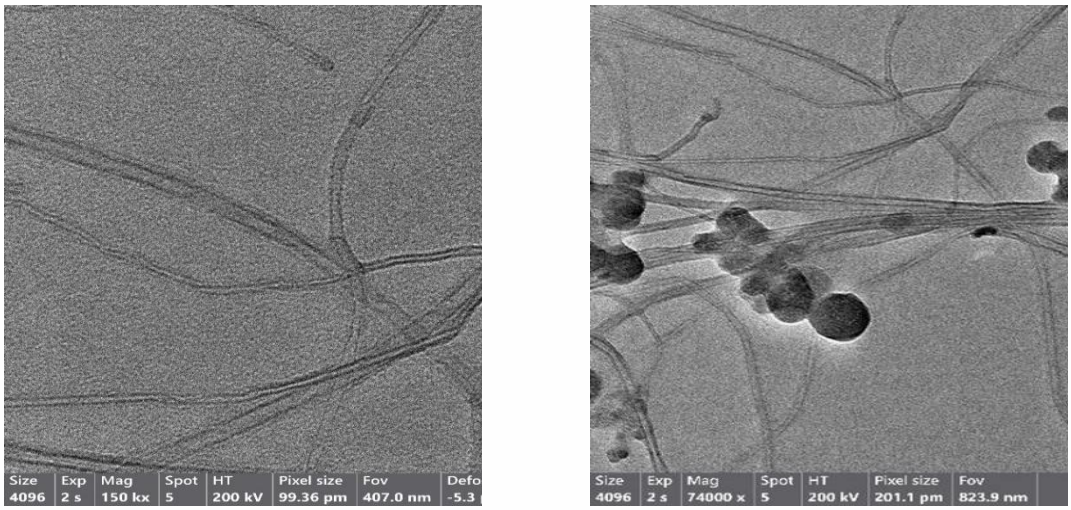
***Keywords:*** *Carbon nanotubes; Single-walled carbon nanotubes; Transmission electron microscopy; Cyclopentadienyl iron dicarbonyl dimer.*

## Introduction

Carbon nanotubes (CNTs) have attracted significant attention since their discovery due to their exceptional mechanical strength, electrical conductivity, thermal stability, and large specific surface area. Among various types of

CNTs, single-walled carbon nanotubes (SWCNTs) are particularly attractive for applications in adsorption, catalysis, energy storage, and sensing because of their well-defined structure and high surface activity [1]. Chemical vapor deposition (CVD) is one of the most widely used methods for CNT synthesis owing to its simplicity, scalability, and ability to control structural parameters such as diameter, length, and number of walls [2]. Transmission electron microscopy (TEM) is a powerful technique for directly visualizing the morphology, size distribution, and growth features of carbon nanotubes at the nanoscale. TEM analysis provides critical insight into the growth mechanism and structural quality of CNTs synthesized under different conditions. The present study focuses on the synthesis of SWCNTs using cyclopentadienyl iron dicarbonyl dimer and their detailed morphological characterization by TEM. The obtained results contribute to a deeper understanding of the role of organometallic iron precursors in CNT growth and highlight the potential of the synthesized nanotubes for adsorption and catalytic applications [3].

Transmission electron microscopy (TEM) was employed to investigate the morphological and structural characteristics of carbon nanotubes (CNTs) synthesized using cyclopentadienyl iron dicarbonyl dimer via the chemical vapor deposition (CVD) method. TEM is considered one of the most reliable and informative techniques for determining the shape, diameter, length, number of walls, and growth mechanism of carbon nanotubes, particularly those formed in the presence of metal catalysts. The TEM results revealed that the samples synthesized from cyclopentadienyl iron dicarbonyl dimer predominantly consist of **single-walled carbon nanotubes (SWCNTs)**. The nanotubes exhibit a cylindrical hollow tubular morphology with smooth and well-defined walls.




a) b)

**Figure 1.** TEM image of CNTs synthesized from cyclopentadienyl iron dicarbonyl dimer at 50 nm, 100 nm scale.

At the 50 nm scale, individual carbon nanotubes can be clearly distinguished. The nanotubes show a relatively narrow diameter distribution, with an average diameter ranging from **1.8 to 5 nm**. The TEM images also demonstrate that the nanotubes are entangled with one another; however, severe agglomeration is not observed. This suggests that the synthesis conditions were appropriately optimized, resulting in well-dispersed nanotubes. Such a dispersed structure contributes to an increased specific surface area, which is particularly advantageous for adsorption-related applications. At the 100 nm scale, the overall morphology and length of the nanotubes become more evident. The length of the nanotubes ranges from several hundred nanometers to several micrometers. In some instances, the nanotubes exhibit curved or bent shapes, which reflects their high mechanical flexibility. Furthermore, the uniformity of the nanotube walls and consistency of the structure are clearly observed at this scale. These results confirm that cyclopentadienyl iron dicarbonyl dimer acts not only as an efficient carbon source but also as an effective catalyst precursor.

In summary, the TEM results confirm that carbon nanotubes synthesized from cyclopentadienyl iron dicarbonyl dimer possess a high-quality, predominantly single-walled, and structurally stable morphology. These findings are in good agreement with the **adsorption and physicochemical characterization results** presented in subsequent sections of the dissertation.

## REFERENCES

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