Appendix 1

To characterize the structural and physicochemical properties of Fe-MSNs, Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), scanning electron microscopy (SEM), and nitrogen adsorption–desorption analysis (BET) were performed.

The FT-IR spectrum of Fe-MSN indicates the presence of 3 types of peaks in this compound. The Si-O-Si peak exists both in bending and stretching forms, with their main characteristic being their short and limited range in the cm-13435 region. This decrease indicates that the silanol group has reacted with M (Fe metal) and the formation of a new Si-O-M bond has caused a decrease in the height of the OH peak. In the cm-1 460 region, these observations indicate that Fe has been well loaded onto MSN. The two strong peaks in the cm-11069 and cm-1800 regions represent Si-O-Si stretching, while the peak at 470 corresponds to the Si-O-Si bending or banding bond (Fig1).

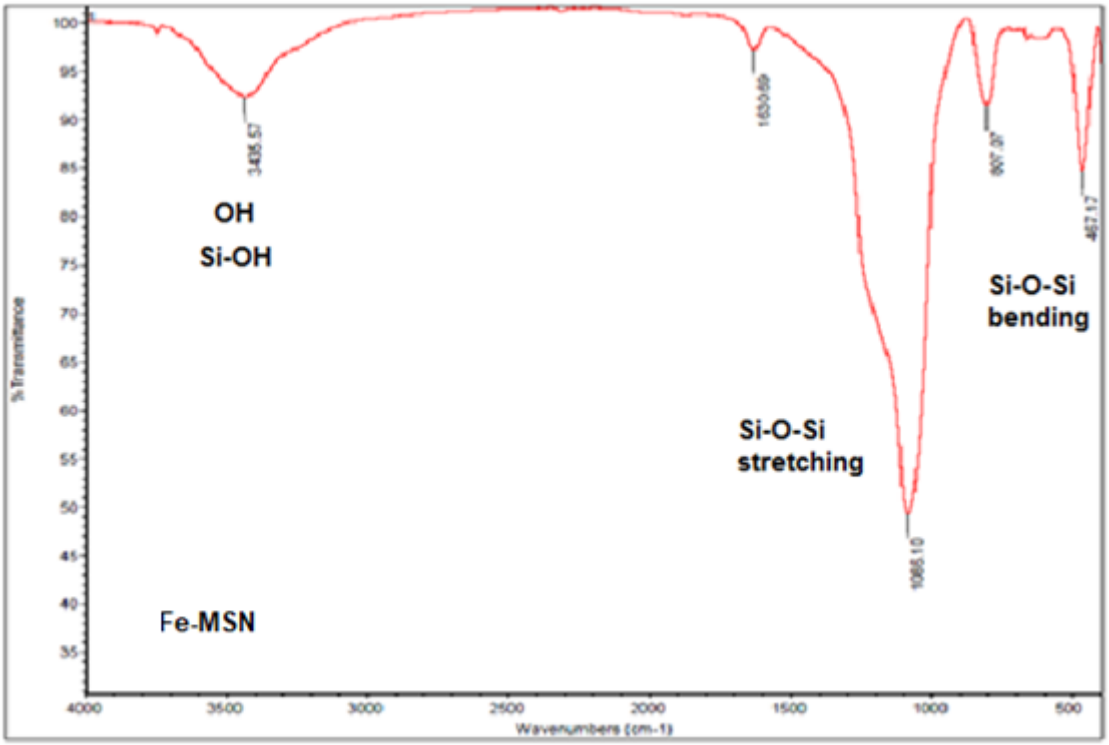

Fig1. Fe-MSN FTIR

The XRD spectrum of MSN-Fe nanoparticles shows peaks in both short and long angle regions. In the XRD pattern, the short angle between 0.8 to 10 degrees, the intensity of the sharp peak in the 100 regions has decreased, and the peaks at 110 and 200 have been eliminated. This indicates the loading of Fe into the MSN structure, causing a change in the structure and altering the pristine MSN main planes, resulting in a more irregular shape. Therefore, with the addition of metals to MSN, the crystalline order of MSN has decreased. The peak at 100 appears in the region around 0.8. However, in the High Angle mode from 10 to 80 degrees, the presence of an amorphous structure indicates the loading of iron and manganese metals in the nanoparticle at angles of approximately 32-35o and 73o, respectively. (Fig2)

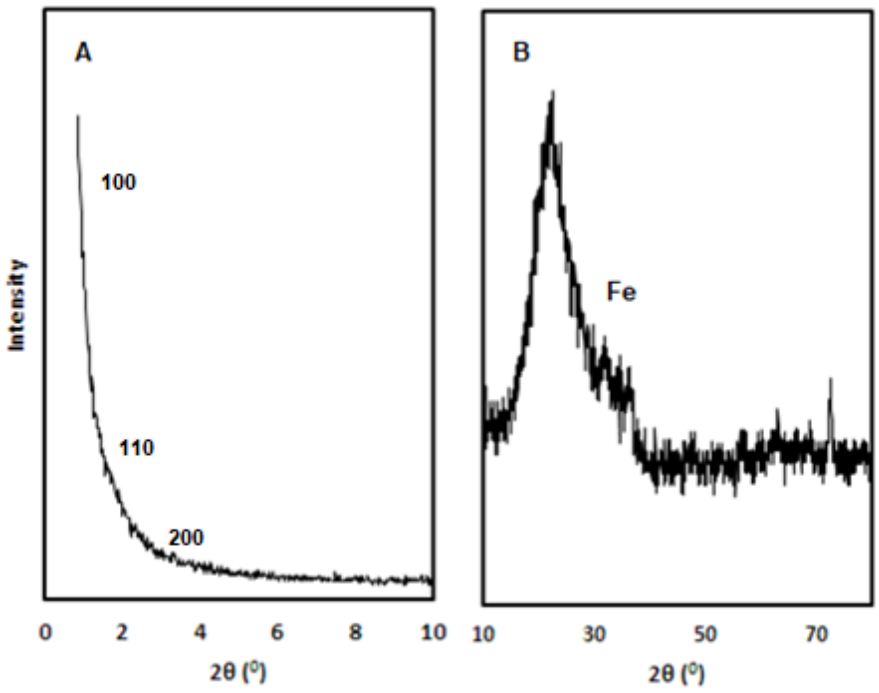

Fig2. Fe-MSN XRD

SEM images depict the morphology of the obtained products. As seen in figure 3, the Fe/MSN nanosphere exhibits a regular spherical structure, with the spherical particles being approximately uniform. The addition of Fe onto the MSN structure does not induce a change in the spherical structure, and the particle sizes range from around 20 nm to 150 nm.

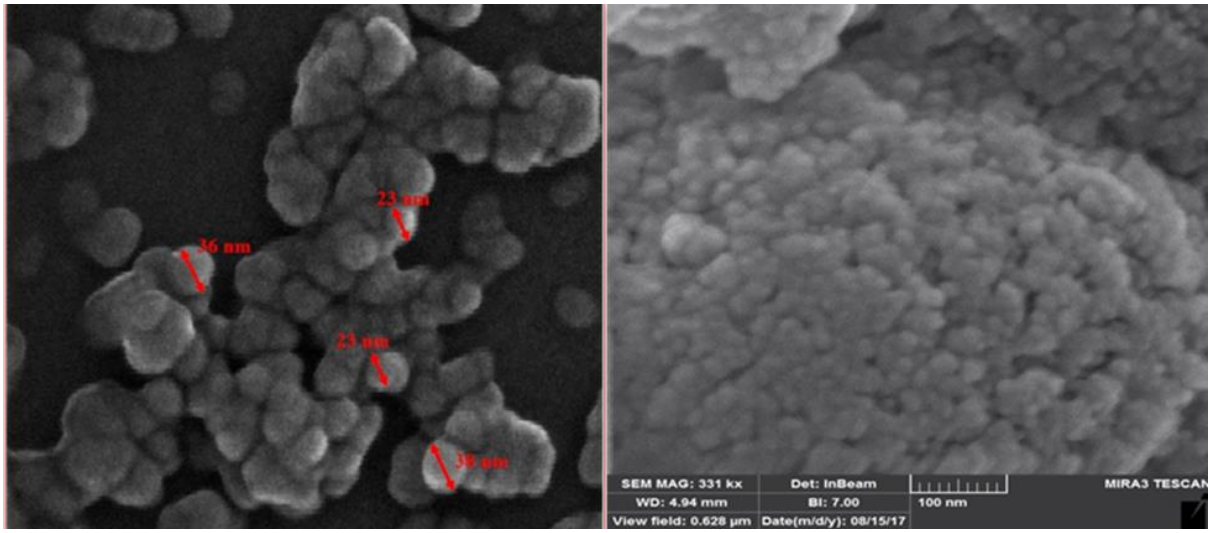

Fig3. Fe-MSN SEM image

Table 1 shows the physical characteristics of MSN and Fe-MSN. It is evident that the surface area of these compounds decreases with the addition of metals. The reason for this is the blocking of pore openings and the occupation of a large surface area of MSN nanoparticles by these metals. Therefore, with an increase in Fe content, the volume of the pores decreases, reducing from cm3/g 0.35 to cm3/g 0.22. Both the surface area and pore volume decrease with loading.

Table 1. BET analysis of nitrogen adsorption and desorption/ reabsorption

Sample	***S*** **(m^2/g)**	***Vp*** **(cm^3/g)**	***W*** **(nm)**
MSN	896	0.35	3.42
Fe-MSN	497	0.22	3.15

S, BET surface area (m^2/g) obtained from N_2 adsorption; V_p, total pore volume (mL/g); *W*, pore size (nm) obtained from BJH method