CHAPTER-7.0

ASSESSMENT ON THE RELEASE OF MAGNETITE NANOPARTICLES EMBEDDED WITH PVA NANOFIBER IN HYDRODYNAMICS
7.1 BRIEF INTRODUCTION

The delivery of nanoparticles to a desired location and its release from a nanofiber support has remained a difficult task. In this work, we have adopted a technique to analyze the release mechanism of nanoparticles embedded with biocompatible nanofibers. This technique involves embedding magnetite nanoparticles in PVA nanofiber and assembling the nanofiber into flexible polymeric mesh; the experimental conditions of this work are discussed in Chapter.3 under section 3.4. Hydrodynamic studies were performed to analyze the release of magnetite nanoparticles from PVA nanofiber, an in-line spectroscopic unit is also utilized to monitor the magnetite nanoparticles released from nanofiber assembly; the results of this work is presented in this Chapter.

7.2 RESULTS AND DISCUSSION

7.2.1 Morphological analysis

The electrospun PVA nanofibers embedded with magnetite nanoparticles were characterized by high resolution scanning electron microscope (HRSEM) and it is observed that the average diameter of nanofiber is around 115 nm as shown in Figure.7.1 (a). The nanoparticles are analyzed using high resolution transmission electron microscope (HRTEM) as shown in Figure.7.1 (b) and the size distribution is found to be in the range of 7-10 nm with average particle size 8.9 nm as shown in Figure.7.1(c). Since nanoparticles were very small compared to the diameter of nanofiber, the particles were properly embedded inside the fibers during electro spinning process [170]. We have reported a systematic process in our previous work [107] to tune the magnetic properties of iron oxide nanoparticles using co-precipitation method and observed superparamangetic behavior for the magnetite nanoparticles which is utilized for this work.
7.2.2 UV-Visible Spectroscopy studies

Prior to electrospinning process the PVA-magnetite nanoparticles solution was analyzed using UV-Visible spectrophotometer, the same analysis is performed on the nanofiber which is dissolved in water medium after electrospinning process as shown in Figure. 7.2, it is observed from the spectra that the absorbance of the PVA magnetite nanoparticles solution have higher value than dissolved nanofiber, this is due to the phase transition of PVA solution to fiber form, which eventually exhibits lower absorbance at the mentioned region 300-800 nm, which was due to decrease in the polymer concentration. The measurements are made in terms of transmittance (T) observed by the sample and the relation between absorbance and transmittance is defined by

\[ A = -\log_{10}(T) \]  \hspace{1cm} (7.1)

Figure. 7.2 [inset] confirm that the quantity of magnetite nanoparticles remains similar even after dissolving the nanofiber in the water medium. This indicates that the required quantity of nanoparticles can be precisely controlled by embedding with nanofibers.
Figure 7.2: Absorbance spectra of MNP-PVA Solution and fiber, [inset] comparative Spectra of MNP-PVA before and after dissolving in water medium

After the electrospinning process the nanofiber is allowed to dissolve in water and the solution is analyzed. Since PVA will be easily dissolvable in water medium [171], the whole electrospun nanofiber is immersed in 5 ml of ultrapure water, the nanofiber immediately started reacting with ultrapure water as shown in Figure 7.3, it is clearly observed that the color of the solution becomes darker with respect to increase in the duration [i.e 15,30,45,60 mins]. It indicates the release of magnetite nanoparticles in the water medium from the PVA nanofibers. A neodymium magnet is placed under the solution to drag the entire magnetite nanoparticles suspended in the solution, since the particles are in the nano size; it remains in the suspended state even after diffusing from nanofibers. This mechanism clearly indicates that the magnetite nanoparticles can be easily released from water soluble polymer nanofibers.
7.2.3 Hydrodynamics studies of MNP embedded in PVA nanofiber

Figure 7.3: Reaction of MNP-PVA nanofiber in static water medium (a) t-15 (b) t-30 (c) t-45 (d) t-60

Figure 7.4 (a) shows the mass profile of nanofiber samples at different duration. Sample code L1, L2, L3, L4 represents number of layers at which the nanofiber is folded. During hydrodynamics, all the samples exhibits increase in weight at t-15 due to intake of water and allows the polymer to swell [172]. Since fiber is in nano scale, it readily reacts with ultrapure water and transforms into film like substance, the intake of water content makes the polymer to swell, which eventually increase the weight of the film. All the samples with polymeric mesh were weighed prior to hydrodynamics to analyze the variation in nanofiber weight. The mesh was carefully removed and weighed instantly, the change in the nanofiber weight can be clearly observed in Figure.7.4 (a). All the samples exhibits similar trend for variation in weight at each intervals during hydrodynamics.
Figure. 7.4: (a) Nanofiber weight profile during Hydrodynamics for samples L1, L2, L3, L4, [inset] weight profile in static mode (b) Swelling percentage L1, L4 samples in hydrodynamics and L1 sample in static medium

The color of the nanofiber turns brownish immediately after reacting with water; this clearly indicates the presence of magnetite nanoparticles in the nanofiber, which reacts with water due to hydration process [173]. For comparative analysis, the nanofiber is immersed in ultrapure static water medium to analyze the mass profile of nanofiber, mass of nanofiber is measured at same intervals as shown in Figure.7.4 (a) [inset], it is observed from the plot that initially the fiber transforms into film like substance by swelling property at t-15, the mass was consistent till t-30 and rapidly decreases from t-30 to t-60, at final stage, it undergoes critical phase transition by completely dissolving in the water medium. At t-60 only the polymeric mesh remained without any trace of PVA film, it is believed that the nanoparticles were released from the fibers at this stage. Both the mesh acts as protective layer for the nanofiber and prevents from wash away during the hydrodynamics. By increasing the number of layers, the release rate of nanoparticles can be tuned for required duration. During such
occasions, a strong magnet can be placed at required location to attract the nanoparticles from nanofiber [174].

The swelling percentage data is shown in Figure 7.4 (b), it is clear from the data that during static mode the rate of swelling of nanofiber increases after reacting with water at t-15 and it stops further swelling by resisting water intake and undergoes dissolution process, the rate of swelling is reduced after t-15. Whereas in case of hydrodynamics, the swelling percentage increases immediately after reacting with water and maintains the similar value. It indicates that the hydrodynamic forces prevent the polymer from further swelling process and the continuous flow dissolves the layers of polymer. While comparing both data, the rate of swelling is high in statics compared to hydrodynamics. The sandwiched mesh layers prevent nanofiber samples from rapid swelling and washaway during flow conditions. Thus, the release of nanoparticles can be achieved by regulating the swelling process of nanofiber with polymer mesh assembly.

### 7.2.4 Morphological Analysis of nanofibers after hydrodynamics

The nanofiber samples were carefully separated from mesh setup for SEM analysis, Figure 7.5 shows the effect of hydrodynamics on nanofibers at different intervals [15, 30, 45 and 60 mins]. Figure. 7.5 (a) shows the effect at t-15, it is clearly observed that overall density of fibers were decreased and the size of individual nanofibers increased while compared to non-reacted nanofiber [average: 115 nm] as shown in Figure 7.1 (a). Due to absorption of water, at t-30, the density of fibers was further reduced and sizes of few fibers were gradually increased up to 0.25-0.40 µm as shown in Figure 7.5 (b). At t-45, the fiber form is deformed by intake and motion of water during hydrodynamics, the fiber form is transforming into film like structure Figure 7.5 (c). At t-60, it is clearly observed that a thin layer like structure is deposited over the nanofiber, which indicates the transformation of polymeric layer from fiber to film form. Figure 7.5 (d), it is also
observed that the fibers swell and diameter is increased. The size of fibers were gradually increased and transformed into flake form as shown in Figure 7.5 (a) to Figure 7.5 (d).

Figure 7.5: HR-SEM images of MNP-PVA nanofiber at various intervals during hydrodynamics (a) t-15 (b) t-30 (c) t-45 (d) t-60

7.2.5 Studies on the Concentration of dispersed nanoparticles

The collected substance from the outlet is analyzed using UV-Visible spectrophotometer, absorbance spectra of pure MNP [20 µl] which is dispersed in polymer solution for electro spinning is compared with the spectra of collected substance during hydrodynamics, initially there were no traces of MNP in UV-Visible spectra, this trend continued for nearly 30 minutes of duration, at 45 mins the collected sample [L1] shows the trace by absorbance spectra as shown in Figure 7.6, inset image shows clear evidence of the presence of nanoparticles by Plasmon peak in visible region, a comparative plot is given in the same figure for 20 µl quantities of nanoparticles, which was the total content of nanoparticles dispersed in PVA solution. The flow rate and nanofiber thickness are important parameters during the release of nanoparticles. It is also observed from
Figure 7.4 (a) that, at t-45 the weight of the films were reduced as an effect of wash away mechanism during hydrodynamics and the water collected at outlet contain both polymer and nanoparticles.

![Absorbance spectra of MNP before electrospinning and during hydrodynamics](image)

**Figure. 7.6: Absorbance spectra of MNP before electrospinning and during hydrodynamics**

It is evident that the quantity of nanoparticles is higher than the PVA in collected substance, since the UV-Visible spectra of collected substance doesn't exhibited signals of PVA in Figure. 7.6, [inset] enlarged image of spectra for collected sample during hydrodynamics but PVA nanofiber dissolved in static medium exhibited the trace of PVA in absorbance spectra as observed in Figure.7.2.
Figure. 7.7: Transmittance spectra of Nanofiber and film at different intervals [t-0, t-15, t-30]

This mechanism is also analyzed using UV-Visible spectrophotometer in film mode, the films were carefully analyzed for transmittance (%T) at particular intervals [0, 15, 30 mins] as shown in Figure. 7.7. Initially the transmittance (% T) is observed for nanofiber before reacting with water and the same was measured for samples at particular intervals during hydrodynamics. The percentage of transmittance is increased with increase in time and at t-30 the transmittance spectra exhibited plasmonic peak of nanoparticles in the region from 350-450 nm similarly as observed in Figure. 7.2 [inset].

While comparing with Figure.7.4 (a), for this particular dimension [10 mm²] the release of nanoparticle is predominant from t-15 to t-45. Further, when water is passed through nanofiber embedded in mesh the phase transition starts gradually from fiber to film form as shown in Figure. 7.8, the inset images shows the fiber which has been placed inside the mesh for hydrodynamics analysis.
Figure. 7.8: Transmittance spectra for indicating the Phase transition of fiber to film form, [inset] Nanofiber and film

After a particular duration the fiber is transformed into film form as shown in the same image Figure. 7.8 [inset], both the fiber and film were analyzed using UV-Visible spectrometer in film mode. The plot shows that the nanofiber is mostly opaque and there is no transmission, when the fiber is transformed into film the transparency increases up to 2- 5% in the visible region, the transmittance increased up to 10% in the same region at t-15 and further increase up to 40% at t-30. After t-45, the thickness of the film sample is reduced and it is hard to analyze for obtaining transmittance spectra.

7.2.6 Qualitative analysis by light scattering technique

The releases of magnetite nanoparticles were analyzed using simple light scattering technique and optical spectroscopy, at different intervals [0, 15, 30, 45 and 60 mins]. For initial confirmations on presence of substance, a simple laser diode [630 nm and 530 nm] is passed through the collected substance from outlet during hydrodynamics for qualitative analysis as shown in Figure.7.9. The
Image shows the light scattering of different samples. Figure.7.9 (a) shows the image of ultrapure water which did not exhibit any light scattering due to absence of any substance even at extreme smaller size, Figure.7.9 (b) show the 2μl volume of magnetite nanoparticles dispersed in 3ml of ultrapure water without light scattering ,the presence of suspended particles were not visible and Figure.7.9 (c) shows the presence of suspended particles , which is visible due to light scattering (Figure.7.9 (d) and (e)) shows the light scattering of the collected substance during hydrodynamics after t-30 , since till t-30 there is no trace of any substance which is collected from the outlet . The collected substance will have both polymer and nanoparticles, this simple technique is used only to identify the release duration of nanoparticles embedded with nanofiber from polymer mesh assembly. Two types of laser diodes were used only to differentiate the samples between statics and hydrodynamics.

Figure. 7.9: Light Scattering Experiments on various samples to identify the presence of nanoparticles in static and hydrodynamic conditions

### 7.2.7 Online Spectroscopic investigation during hydrodynamics

An online spectroscopic technique was used to investigate the release of substance from the mesh set-up during hydrodynamics. Figure.7.10 shows the absorbance spectra of the online spectroscopy technique. Light source with filters [spectral response range = 350-450 nm] is used and the light is allowed to pass through squared glass section which was fused between two cylindrical
section for hydrodynamics purpose. The mesh assembly is placed in the cylindrical section for further analysis during hydrodynamics. The optical transmittance was recorded through the squared section [industry grade optical glass with 80% transmittance [300-1000 nm], this squared transparent section is especially developed to avoid optical aberration due to convex region in cylindrical section. Photo diodes [Perkin Elmer, VTB8440BH with spectral range of sensitivity 330-720 nm] are positioned in a line of sight from light source, the squared section of glass tube is positioned between the light source and photodiode assembly.

The photodiode and light source were calibrated prior to experiments and a constant current output is supplied for the light source, the photodiodes were placed to encounter the entire light passing through the squared glass section. Ultra-pure water is initially passed through the tube and the output is recorded as reference value for the carrier medium without nanoparticles. The photodiode output is reported in milli volts, which is the direct transmittance values ($I_t$) values used to calculate the Absorbance as shown in below equation

$$A = -\log_{10} \left( \frac{I_t}{I_o} \right)$$  \hspace{1cm} (7.2)

The absorbance values were recorded at different duration [0, 15, 30, 45 and 60 mins]. ($I_t$) is the intensity of transmitted light and ($I_o$) is intensity of incident light in milli volts (mV), the output value is used to calculate the absorbance. Figure. 7.10 show the calculated absorbance plot of L1, L2, L3 and L4 at different intervals. It is observed that the absorbance spectrum fluctuates due to collective random motion of nanoparticles during hydrodynamics experiment.
Initially the approximate absorbance values are in the range of $[A_{\text{max}} \sim 0.015]$ for L1; $[A_{\text{max}} \sim 0.04]$ for L2; $[A_{\text{max}} \sim 0.1]$ for L3 and $[A_{\text{max}} \sim 0.3]$ for L4. It is observed from the spectrum that the quantity of nanoparticles released by L2 is twice the order compared L1; for L3 it is 6 times the order compared to L1; for L4 it is 20 times the order compared to L1 sample. Previously, the quantity of settled nanoparticles were visible only after 30 mins duration in static mode, the rate of settling of nanoparticles is high in static state compared to hydrodynamics under the presence of magnetic field. This behavior is due to the flow force that that prevents nanoparticles to settle in tube, literatures reported that in order to overcome such force, an external magnetic field is focused on the nanoparticles to trap the particles at required location [67].
Nanoparticles embedded with nanofiber with a sandwich polymer mesh allow controlling the quantity of nanoparticles to be released at specific site. This sandwich mesh model can be fabricated as per the required dimension and introduced into vein or even capillary like channel through catheterization process to place the nanofiber precisely at required location for the release of nanoparticles [175]. Further the magnetite nanoparticles released from nanofiber can also be attracted from mesh like setup with an external magnetic field. This technique will be highly useful for controlled release of magnetite nanoparticles from nanofiber at desired locations and magnetic drug targeting applications.

7.3 CONCLUSION

A systematic analysis is performed on the release of magnetite nanoparticles embedded in PVA nanofiber assembled with flexible polymeric mesh. The magnetite nanoparticles [7-10 nm] were dispersed in PVA solution which is electrospun to obtain fine nanofiber with average diameter 115 nm. The nanofiber is carefully assembled over a flexible polymeric mesh and inserted into glass tube for hydrodynamics studies. The mesh setup is analyzed in static ultrapure water medium to compare with hydrodynamics to investigate the release mechanism of nanoparticles. The results reveal that, nanofiber is getting transformed into film like substance after reacting with ultrapure water. The dissolution rate of polymer along with release of nanoparticles is controlled with constant flow rate during hydrodynamics. The hydrodynamics experiments were carried out for 60 mins for different samples and found that the mesh like setup is promising mechanism to control the release of magnetite nanoparticles embedded in PVA nanofiber. Further this method can be adapted for quantitative analysis on the release of various magnetic nanoparticles embedded in nanofiber medium and for the studies on sustained release of nanoparticles using flexible polymeric mesh assembly.