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Choose the suitable fuzzy membership function in prediction of diameter of nanofibers produced from electrospinning using fuzzy logic system as artificial intelligence technique

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Fuzzy logic System is used to predict some parameters. In this system the crisp data were converted into fuzzy data using membership function. There are many members ship function used in fuzzy system to fuzzify data. In this search, nanofibers were obtained by electrospinning process and scanned by SEM.
Nanofiber's diameters were predicted as output of the system using all membership functions in fuzzy system by Matlab. The parameters of electrospinning process were constant except electrospinning room temperature. A comparison has been made among the predicted data using different membership functions. One membership function had been selected based on minimum error in prediction of data. It had been cleared that the best membership function was Gauss function.

Keywords: Electrospinning, Nanofibers, Fuzzy logic Membership function, Artificial intelligence.

1. INTRODUCTION

Electro-spinning is a simple and essential process for producing fibers with very fine diameters called nanofibers that randomly form non-woven fabrics with unique characteristics such as high surface density and high porosity [3]. Nanofibers have been utilized in various fields such as tissue engineering, electronics, pressure sensors, clothing, and medicine. The attractive properties of nanofibers, including the high surface area–to-volume ratio and ability to be doped with other materials that enhance its physical and electrical properties, warrant suitability for the aforementioned applications [6]. Nanofibers and nanowires can be obtained by electrospinning technique [3]. The one-dimensional (1D) mesoscopic systems such as nanowires, nanotubes with small L/D are a novel structure [5], and nanorods have attracted a great deal of attention due to their numerous potential applications in nanoscale electronics, optoelectronic de- vices, and sensor development [4].

In the electro-spinning process, a pole is charged with a positive or negative charge connected with a metal needle and the other pole charged with the opposite charge connected to the collector where the polymeric droplet from the capillary tube is pulled into a nanofiber and deposits on the collector. During the process, the droplet from the capillary tube converts from the spherical shape to the conical, forming the so-called Taylor cone, which is pulled by the applied voltage, moving in a straight line for a few seconds. The process of pulling and evaporation of the solvent before falling on the collector forms nanofibers [1]. Figure 1 shows the principle of electric spinning.

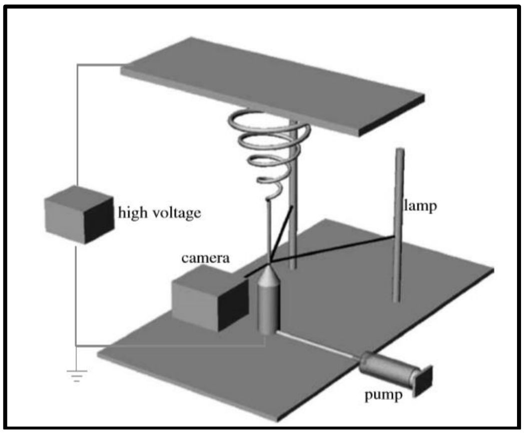

Figure 1 General electrospinning set-up [3]

2. ELECTROSPINNING PROCESS PARAMETERS:

The parameters of the electrospinning process are generally divided into 3 sections:
1) Parameters related to polymer solution (viscosity of polymer solution and molecular weight of polymer, surface tension of polymer solution, electrical insulation of solvent, electrical conductivity of polymer solution)
2) Process-related parameters (high voltage, polymeric feed rate, distance between collector and extrusion nozzle, extrusion nozzle diameter, electrode placement, temperature)
3) Parameters related to ambient atmosphere (humidity, pressure, ambient air) [5].
In this research we have changed one of these parameters, the temperature of the electrospinning chamber and the other the parameters were constant.

2.1. Fuzzy Logic

It is a type of digital logic. This logic was originated in 1965 by Azerbaijani scientist Lutfi Zadeh from the University of California, where he developed it to use as the best method of data processing. Fuzzy logic has been used in many products as cameras.
Fuzzy logic in the broad sense is a logical system based on a broader generalization of the traditional classical digital two-valued logic based on only 0 or 1, to infer in uncertain conditions by using inputs between (0 and 1). He noted that true and false are not enough to represent all the logical forms, especially the problems facing us now. Classical logic relies on only 0 or 1, while there are other relationships where the position in which it can be considered partially true or partially false at the same time.
There were many motivations led scientists to develop the science of fuzzy logic. This approach has resulted in what is known as expert systems or artificial intelligence. Fuzzy logic is one of the theories through which such systems can be built. This logic is an easy way to characterize and represent human experience, and it offers practical solutions to real problems, solutions that are cost-effective and reasonable, compared to other solutions offered by other technologies [2].

2. EXPERIMENTAL
2.1. Materials

a- Poly vinyl alcohol (PVA), Available in a finely divided form, its degree of polymerization (1800-1700), degree of hydrolysis (98-99%), is made in MUMBAI-INDIA.

b- Distilled water, made by our laboratory distillation unit.

2.2. Equipment

- Heater with magnetic stirring and some glassware: to prepare the polymer solution.
- Electro-spinning device which consists mainly of three sections (extrusion equipment and collector in addition to high voltage power supply): to obtain nanofibers Figure 2.
- Electronic microscope: to scan the samples resulting from the electric spinning device for analysis.
- programs (image j- Matlab): image j program to analyze the images of samples we obtained from the electronic microscope and to get the average fiber diameters in each sample, while Matlab program to apply the system of fuzzy logic to the fuzzy bases and then predict the diameter of the fibers.

2.3. Procedure

1- Prepare the polymeric solution in the concentration of 14%wt, and raise the temperature up to 85 ° C with constant magnetic stirring until the complete disintegration of PVA and get a transparent viscous solution.
2 - Apply electrospinning process on the solution resulting from (1) constants the parameters of the solution and the process and change the temperature of the spinning chamber.
3- Scan the resulting samples using an electronic microscope.
4- Analyze the sample images using image software to obtain the true values of the diameters of nanofibers. Image j gives us the measurement for each nanofiber in the sample and the average nanofiber diameter.

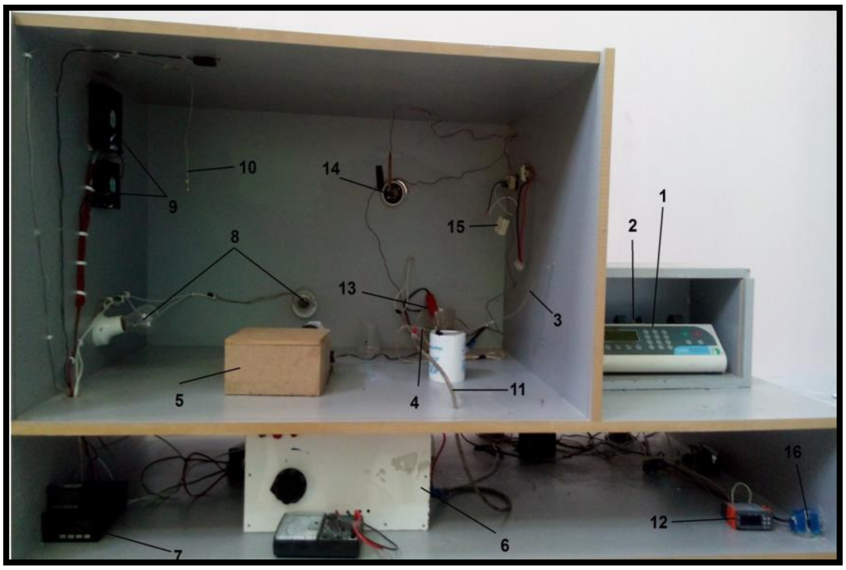

Figure 2 Locally Electrospinning apparatus used at this research.

5 - Using MATLAB program to apply the fuzzy logic system in the prediction where temperatures as input taking in consideration the other parameters.
6 - Determine the output, which is the average diameter of nanofibers in each sample.
7-Selection of the fuzzy field.
8- Selecting the fuzzy factor (membership function).
9- Fuzzy rules.
10- Fuzzing.
11-Predict the average diameter of nanofibers per sample.

12-Calculate the average relative error based on the values of the average real and predicted average countries based on the coefficient of affiliation.
13-Repeat steps (8, 9, 10, 11, 12) for each function separately.
14-Select the most appropriate membership function based on the smallest average error of relative error of the predicted values.
15-Using Matlab:
- Output range represented by the average diameter of the nanofibers per sample:
[253.5- 562.3] nm. These values were taken from step4.
- Input range represented by the temperature of the electric spinning chamber:
[15-35] ºC.
16- Using Excel software for calculating the relative error for each predicted output and the average relative error for each membership.

3. RESULTS AND DISCUSSION

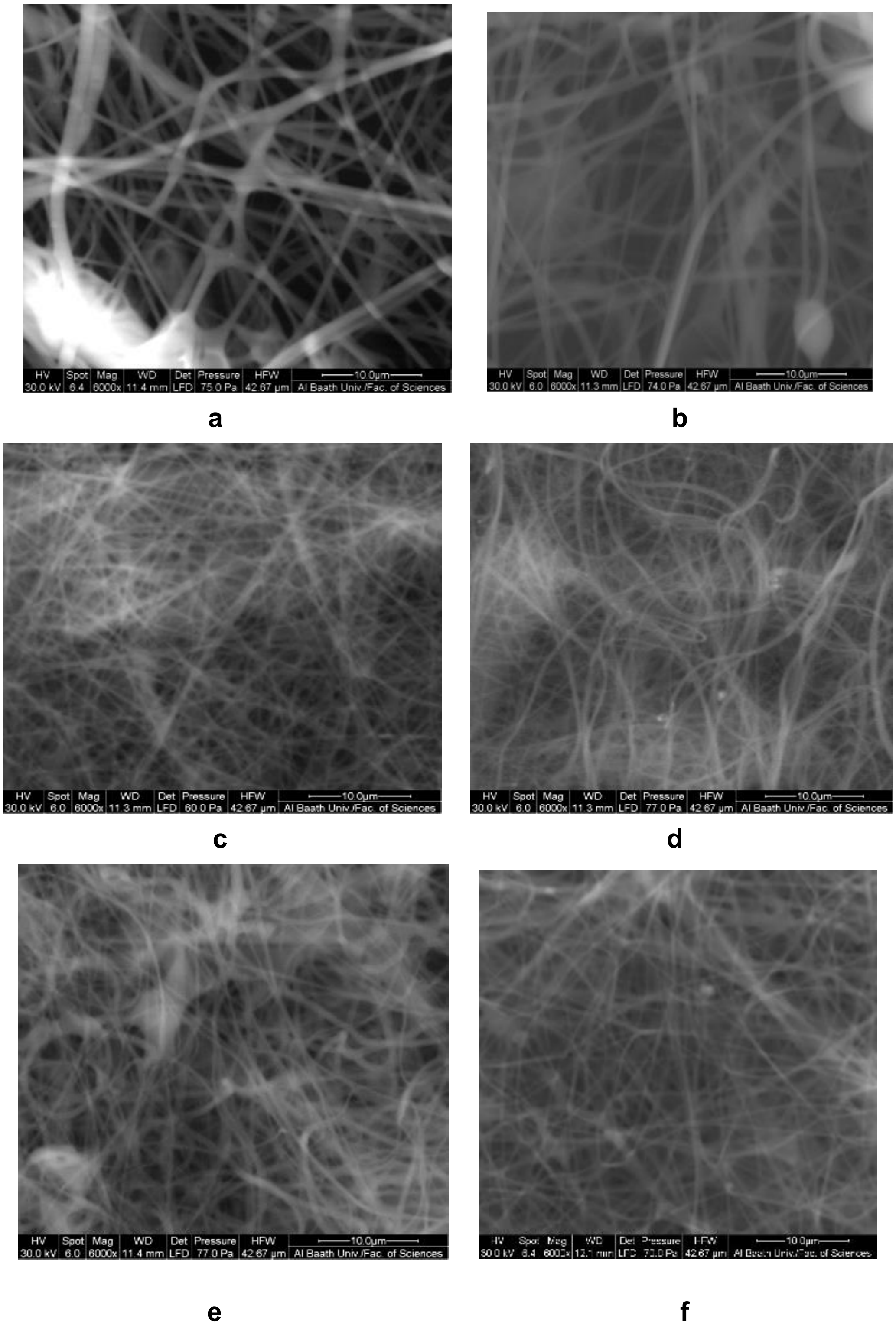

Figure 3 Some SEM images magnified 6000x of nonwoven nano-fibers mats samples prepared at different electrospinning room temperatures

Table 1 Relative error of predicted values using Trap MF.

Input (C◦)	Real output (Nm)	Predicted output (Nm)	E(%)
15.0	562.3	553	1.7
16.3	543.1	536	1.3
17.5	527.9	522	1.1
18.8	516.8	491	5.0
20.0	509.8	446	12.5
21.3	472.6	457	3.3
22.5	441.8	434	1.8
23.3	425.4	398	6.4
25.0	382.9	374	2.3
26.3	364.3	353	3.1
27.5	341.8	330	3.5
28.8	319.7	292	8.7
30.0	264.6	263	0.6
31.3	261.4	260	0.5
32.5	258.6	257	0.6
33.8	254.9	252	1.1
35.0	253.5	249	1.8

Average relative error: 3.3%.

Table 2 Relative error of predicted values using Tri MF.

Input (C◦)	Real output (Nm)	Predicted output (Nm)	E(%)
15.0	562.3	553	1.7
16.3	543.1	535	1.5
17.5	527.9	522	1.1
18.8	516.8	514	0.5
20.0	509.8	491	3.7
21.3	472.6	457	3.3
22.5	441.8	433	2.0
23.3	425.4	404	5.0
25.0	382.9	373	2.6
26.3	364.3	352	3.4
27.5	341.8	330	3.5
28.8	319.7	292	8.7
30.0	264.6	260	1.7
31.3	261.4	263	0.6
32.5	258.6	257	0.6
33.8	254.9	252	1.1
35.0	253.5	250	1.4

Average relative error: 2.5%.

Table 3 Relative error of predicted values using gbell MF.

Input (C◦)	Real output (Nm)	Predicted output (Nm)	E(%)
15.0	562.3	553	1.7
16.3	543.1	535	1.5
17.5	527.9	527	0.2
18.8	516.8	518	0.2
20.0	509.8	494	3.1
21.3	472.6	473	0.1
22.5	441.8	442	0.0
23.3	425.4	399	6.2
25.0	382.9	375	2.1
26.3	364.3	354	2.8
27.5	341.8	336	1.7
28.8	319.7	302	5.5
30.0	264.6	263	0.6
31.3	261.4	260	0.5
32.5	258.6	257	0.6
33.8	254.9	255	0.0
35.0	253.5	254	0.2

Average relative error: 1.6%.

Table 4 Relative error of predicted values using gauss MF.

Input (C◦)	Real output (Nm)	Predicted output (Nm)	E (%)
15.0	562.3	553	1.7
16.3	543.1	543	0.0
17.5	527.9	526	0.4
18.8	516.8	518	0.2
20.0	509.8	494	3.1
21.3	472.6	473	0.1
22.5	441.8	443	0.3
23.3	425.4	399	6.2
25.0	382.9	392	2.4
26.3	364.3	362	0.6
27.5	341.8	336	1.7
28.8	319.7	301	5.8
30.0	264.6	269	1.7
31.3	261.4	261	0.2
32.5	258.6	257	0.6
33.8	254.9	254	0.4
35.0	253.5	254	0.2

Average relative error: 1.5%.

Table 5 Relative error of predicted values using gauss2 MF.

Input (C◦)	Real output (Nm)	Predicted output (Nm)	E (%)
15.0	562.3	553	1.7
16.3	543.1	541	0.4
17.5	527.9	523	0.9
18.8	516.8	517	0.0
20.0	509.8	495	2.9
21.3	472.6	470	0.6
22.5	441.8	437	1.1
23.3	425.4	398	6.4
25.0	382.9	390	1.9
26.3	364.3	361	0.9
27.5	341.8	333	2.6
28.8	319.7	300	6.2
30.0	264.6	283	7.0
31.3	261.4	261	0.2
32.5	258.6	257	0.6
33.8	254.9	255	0.0
35.0	253.5	254	0.2

Average relative error: 2%.

Table 6 Relative error of predicted values using Sig MF.

Input (C◦)	Real output (Nm)	Predicted output (Nm)	E (%)
15.0	562.3	553	1.7
16.3	543.1	555	2.2
17.5	527.9	547	3.6
18.8	516.8	541	4.7
20.0	509.8	536	5.1
21.3	472.6	522	10.5
22.5	441.8	506	14.5
23.3	425.4	496	16.6
25.0	382.9	475	24.1
26.3	364.3	466	27.9
27.5	341.8	455	33.1
28.8	319.7	443	38.6
30.0	264.6	421	59.1
31.3	261.4	413	58.0
32.5	258.6	411	58.9
33.8	254.9	409	60.5
35.0	253.5	409	61.3

Average relative error: 28.3%.

Table 7 Relative error of predicted values using Dsig MF.

Input (C◦)	Real output (Nm)	Predicted output (Nm)	E (%)
15.0	562.3	553	1.7
16.3	543.1	553	1.8
17.5	527.9	536	1.5
18.8	516.8	522	1.0
20.0	509.8	507	0.5
21.3	472.6	493	4.3
22.5	441.8	460	4.1
23.3	425.4	423	0.6
25.0	382.9	403	5.2
26.3	364.3	375	2.9
27.5	341.8	352	3.0
28.8	319.7	324	1.3
30.0	264.6	301	13.8
31.3	261.4	264	1.0
32.5	258.6	259	0.2
33.8	254.9	257	0.8
35.0	253.5	254	0.2

Average relative error: 2.6%.

Table 8 Relative error of predicted values using Psig MF.

Input (C◦)	Real output (Nm)	Predicted output (Nm)	E (%)
15.0	562.3	553	1.7
16.3	543.1	552	1.8
17.5	527.9	536	1.5
18.8	516.8	522	1.0
20.0	509.8	507	0.5
21.3	472.6	493	4.3
22.5	441.8	459	4.1
23.3	425.4	422	0.6
25.0	382.9	403	5.2
26.3	364.3	374	2.9
27.5	341.8	351	3.0
28.8	319.7	323	1.3
30.0	264.6	300	13.8
31.3	261.4	263	1.0
32.5	258.6	259	0.2
33.8	254.9	256	0.8
35.0	253.5	254	0.2

Average relative error: 2.6%.

Table 9 Relative error of predicted values using Pi MF.

Input (C◦)	Real output (Nm)	Predicted output (Nm)	E (%)
15.0	562.3	555	1.7
16.3	543.1	538	1.8
17.5	527.9	522	1.5
18.8	516.8	514	1.0
20.0	509.8	495	0.5
21.3	472.6	458	4.3
22.5	441.8	460	4.1
23.3	425.4	436	0.6
25.0	382.9	403	5.2
26.3	364.3	375	2.9
27.5	341.8	355	3.0
28.8	319.7	334	1.3
30.0	264.6	298	13.8
31.3	261.4	263	1.0
32.5	258.6	260	0.2
33.8	254.9	257	0.8
35.0	253.5	257	0.2

Average relative error: 2.6%.

Table 10 Relative error of predicted values using S MF.

Input (C◦)	Real output (Nm)	Predicted output (Nm)	E (%)
15.0	562.3	556	1.1
16.3	543.1	550	1.3
17.5	527.9	548	3.8
18.8	516.8	541	4.7
20.0	509.8	538	5.5
21.3	472.6	523	10.7
22.5	441.8	506	14.5
23.3	425.4	496	16.6
25.0	382.9	475	24.1
26.3	364.3	466	27.9
27.5	341.8	455	33.1
28.8	319.7	440	37.6
30.0	264.6	421	59.1
31.3	261.4	413	58.0
32.5	258.6	411	58.9
33.8	254.9	409	60.5
35.0	253.5	409	61.3

Average relative error: 28.2%.

Table 11 Relative error of predicted values using Z MF.

Input (C◦)	Real output (Nm)	Predicted output (Nm)	E (%)
15.0	562.3	404	28.2
16.3	543.1	395	27.3
17.5	527.9	387	26.7
18.8	516.8	383	25.9
20.0	509.8	374	26.6
21.3	472.6	356	24.7
22.5	441.8	345	21.9
23.3	425.4	327	23.1
25.0	382.9	314	18.0
26.3	364.3	303	16.8
27.5	341.8	293	14.3
28.8	319.7	276	13.7
30.0	264.6	258	2.5
31.3	261.4	257	1.7
32.5	258.6	255	1.4
33.8	254.9	254	0.4
35.0	253.5	254	0.2

Average relative error: 16.1%.

Table 12 Average Relative error of predicted values for all functions.

AE(%)	Mf
1.49	Gauss
1.59	Gbellmf
1.96	Gauss2
2.5	Trimf
2.6	Pimf
2.6	Psigmf
2.6	Dsigmf
3.77	Trapfm
16.1	Zmf
28.16	Smf

4. CONCLUSIONS

The nanofibers were produced using an electrospinning process, and fuzzy logic was applied to predict the values of fiber diameters using Matlab program. The relative error of the predicted diameters was calculated for each of the membership functions in the fuzzy logic system.
The mean error values for each member ship are summarized in Table (12). It is noted that the lowest mean error was at the Gauss function and is therefore considered the best function to predict the values of the average diameters for each sample according to the field of variables studied.

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