

Full Length Research Paper

Adaptive neuro fuzzy inference system for estimating particle diameter of soils in micro structure for varying quantities of sodium hexametaphosphate

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In the present study, 0, 10, 20, 30, 40, 50 and 60 g. Sodium hexametaphosphate (NaPO₃) suspensions were prepared for hydrometer tests. After the completion of the tests, the particle diameters of the soil were calculated for each hydrometer reading at time intervals of (0, 1, 2, 5, 10, 15, 30, 60, 120 and 260 min). A model was developed using an adaptive neuro-fuzzy inference system (ANFIS) to predict the particle diameter of soil for different cases without the need for a test. The quantities of the NaPO₃ and the hydrometer reading times were used as inputs in the model. Test results and predicted outcomes were compared and high correlations were obtained.

Key words: Soil mechanics, particle diameters, hydrometer test, ANFIS.

INTRODUCTION

The measurement of soil grain diameter smaller than 0.075 mm is highly important for soil research; especially for the classification of the soil and for drawing the granulometric curve. In order to determine soil grain diameter, the hydrometer test and the pipette are the most popular techniques (Gee and Bauder, 1986). For hydrometer testing 151 - 152 h hydrometers defined in the ASTM E 100 are used (ASTM, 2001). In these methods, the diameters of the soil particles are calculated using stoke's law. NaPO₃ is the most popular solvent used to prevent the soil particles flocking together in the suspension. The hydrometer method provides multiple measurements from the same suspension (Day, 1965; ASTM, 1998).

For soil particles, the mass-size form of the equation used in this study is described by Tyler and Wheatcraft (1992); Frank (1995). For the determination of the density of liquids for the testing of hydrometers several papers (Frank, 1995; Van, 1963; Kronberg et al., 1986) have been

devoted to the interactions between NaPO₃ and clay. Kura and Oashi (1974) found that, NaPO₃ anion forms a strong 1:1 complex with calcium. The NaPO₃ anions interact with the exposed atoms of aluminum, giving a complex anion. Several investigations (Thilo, 1965; Corbridge, 1980) have been devoted to the analysis of the behaviour of NaPO₃ in water. NaPO₃ is a deflocculate widely used in the clay industry (Manfredini et al., 1990) it increases the negative charge on the clay micelles being adsorbed as an anion.

Various researchers (Brandenburg and Lagaly, 1988; Keren, 1989; lagaly, 1989) have investigated the effect of soda addition on the rheological properties of bentonit. Volzone and Garrido (1991) studied the effect of Na₂CO₃ on several argentine bentonit. Buchan et al. (1993) obtained a detailed particle size distribution (PSD) using sieves and the sedimentation of dispersed particles in a liquid. Turcotte 1986; Tyler and Wheatcraft, 1992; Young et al., 1997; Bittelli et al., 1999 used wet sieving, pipette and light-diffraction techniques in order to obtain the PSD of 19 samples.

Huertas et al. (1999) studied the dissolution phenomena in an aqueous suspension of kaolinite at pH levels of the solution. Yildiz et al. (1999) investigated the influence

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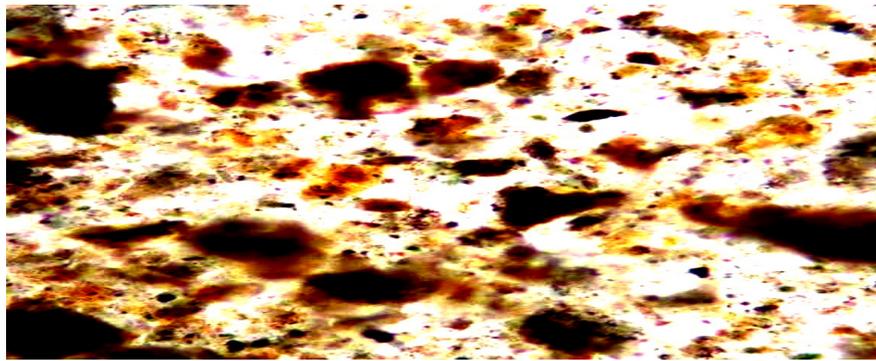


Figure 1. The images of the sample obtained from the microscope.

Table 1. XRD analysis result for samples.

Al ₂ O ₃	SiO ₂	Na ₂ O	K ₂ O	CaO	Fe ₂ O ₃	MgO	SO ₃	L.O.I	Total
20.73	51.82	0.74	3.71	3.74	6.50	1.74	1.19	9.4	99.57

of NaCl, NaPO₃ and pH on the rheological behaviour of original and activated kütahya bentonit suspensions. Hwang et al. (2002) used several models to examine experimental data. Filgueira (2003) presented an explicit relationship between time, soil suspension density and the fragmentation fractal dimension applied to particles with the fractal mass–size distribution. Andreola et al. (2004) assessed the effects resulting from the addition of NaPO₃ to a standard kaolin suspension and compared the results with those obtained employing.

Ozgan (2009a) investigated the effect of a quantity of sodium hexametaphosphate (NaPO₃) to the diameter of the soil grain experimentally and statistically. Hydrometer testing was conducted on 0, 10, 20, 30, 40, 50 and 60 g. Solutions of NaPO₃. The specific gravity, pH and conductivity were measured for each suspension. As indicated in the Turkish standard (TS 1900, 2006) the soil grain diameter in the solution prepared with 40 g. NaPO₃ was used as the reference. Thus, the soil grain diameter in the suspension with “0” g. NaPO₃ was 4.51 times greater than the reference grain diameter. The obtained data were analyzed statistically using an SPSS program and the coefficient of determination for the hydrometer test parameters (passing time, original hydrometer reading, temperature, pH, conductivity) were determined. Ozgan (2009b) simulated and modeled the particle diameter of soil samples using an artificial neural network method. The relationship between the experimental results and the artificial neural network (ANN) model output exhibited good correlation. The coefficient of determination were found to be R² = 0.99 for training set and R² = 0.94 for testing set with ANN.

In this study, the effect of adding varying quantities of NaPO₃ to soil samples were investigated experimentally

and using the ANFIS method. The experimental and test results were then compared.

MATERIALS

The samples used in this study were randomly taken from the stocks of a brick factory in Duzce, turkey. To determine the diameter of the soil particles smaller than 0.075 mm the hydrometer test was conducted. The NaPO₃ was used as a solvent and a 151 h type hydrometer was used in the hydrometer tests. To determine the particle's microstructure, an Olympus bx51 microscope was used. The sample was placed on to the micro slide with a drop of Entellan and covered with the lamellae. The images obtained from the microscope were enlarged 100 times as shown below (Figure 1).

In addition, an XRD analysis was carried out for the chemical composition of the sample and the results are given in Table 1 below, Montmorillonite, quartz, clinocllore, illite and calcite were found in the clay mineral structure. One of the most popular techniques is the hydrometer method based on the “stokes law” which employs the relationship between time, travel distance, and a coefficient named k (for solution temperature and sample's specific gravity). In the hydrometer test, it was found that the specific gravities of the soil particles were equal with the larger particles settling more quickly than the smaller particles. Stock's law is given below in Equation (1);

$$D = K \sqrt{\frac{L}{T}} \dots\dots\dots (1)$$

Where;

D: radius of a spherical particle, (diameter of the equivalence sphere, mm).

K: coefficient (for solution temperature and specific gravity of soil sample).

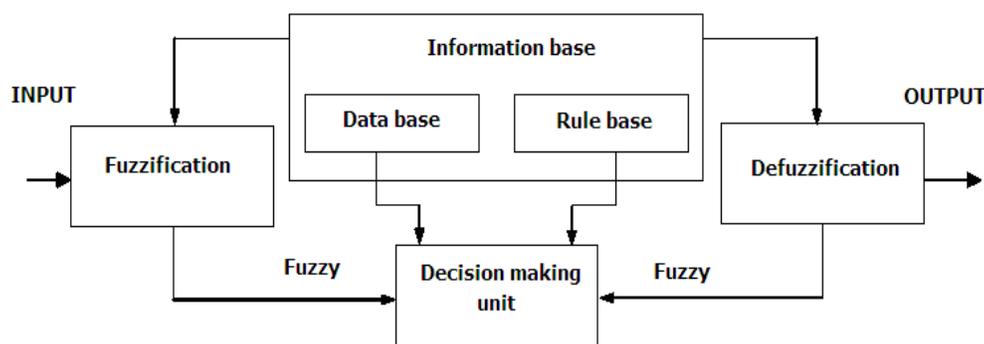
L: the travel distance of the spherical particle settling, (cm).

T: time (second).

Table 2. Soil particle diameters based on time and the quantity of the NaPO₃.

NaPO ₃ (g)	Result	Time (Min)								
		1	2	5	10	15	30	60	120	260
0	Diameter ^a	47.66	34.74	22.39	16.56	13.75	9.80	6.98	4.97	3.25
10	Diameter ^a	42.37	30.39	19.46	13.90	11.40	8.10	5.81	4.14	2.99
20	Diameter ^a	37.23	26.80	17.19	12.35	10.17	7.41	5.25	3.81	2.60
30	Diameter ^a	0	23.09	14.62	11.10	9.14	6.47	4.88	3.44	2.38
40	Diameter ^a	0	0	0	10.38	8.54	6.29	4.53	3.32	2.38

a. Unit of the particle diameter was taken as $\times 10^{-3}$ mm (For example 47.66×10^{-3} mm).

**Figure 2.** General structure of the ANFIS.

Preparation of the samples

30 g samples which could pass through a 0.075 mm (No: 200) sieve were prepared. To each sample NaPO₃ was added and mixed with a glass robe to wet for 5 min. The solution was left for 16 h in the desiccators in order to dissolve all the adhered soil particles. The samples were taken from the desiccators and after mixing, they were poured into the mixer. Pure water was added to the samples in approximately 2/3 ratio of the mixer, and the solution was mixed for 1 min. The mixed solution was poured into measuring beaker and pure water was added until the mixture reached 1000 ml. Then, the beaker was shaken for one minute and the test began immediately. For all of the hydrometer tests for varying quantities of NaPO₃, the hydrometer reading and temperature of the suspension were recorded for each time phase.

Hydrometer test results

The hydrometer test results were grouped and tabulated according to the quantity of NaPO₃ and times. The calculated particle diameters according to the time elapsed, hydrometer reading and temperature of the suspension values are shown for 0, 10, 20, 30 and 40 g NaPO₃ (Table 2). The diameter of the particles is shown in Table 2. However, after 50 g of NaPO₃ was added to the solution, the hydrometer reading could only be made for the 260th min and the hydrometer reading for 60 g of NaPO₃, reading could not be carried out.

Adaptive neuro fuzzy inference system (ANFIS)

The ANFIS consists of three basic concepts the "rule base"

gathered from fuzzy rules, the "input base" used for the identification of the degree of membership and the "inference mechanism" used for the collection of the rules and production of the suitable results on inputs and outputs of the system (Young et al., 1997; Bittelli et al., 1999; Ozçalik et al., 2003). The process of modeling with fuzzy logic (FL) consists of determining the membership degree of the input variables constituting the rules, determining the output characteristics from these rules, passing to the output membership functions and obtaining the output of this system. In the modeling with FL, the most important stage is determining the membership degree of the input/output variable. Using the NN learning ability, ANFIS connects the input and output variable with together and constitutes the fuzzy rules.

In this study, a hybrid learning algorithm consisting of a combination of the gradient descent and least squares methods was used to determine the model parameters. The gradient descent method puts the nonlinear input parameters in order and the least squares method orders the linear output parameters (Nayak et al., 2004; Firat and Güngör, 2007).

Furthermore, the gradient descent method is used in the modeling to change and update the coefficients of the weight for accessing the network error. With the hybrid learning algorithm, the membership function parameters of the inputs and output are updated and the most suitable values are obtained.

In the literature, the most frequently used FL inference systems are the Mamdani and Sugeno types. The principle important difference between the Mamdani and Sugeno systems is identification of the output variables. Interested readers are referred to Firat and Gungor (2007) for more information about the difference of Sugeno and Mamdani types. In this study, the Sugeno fuzzy inference system was used. The general structure of the fuzzy inference system is given in Figure 2.

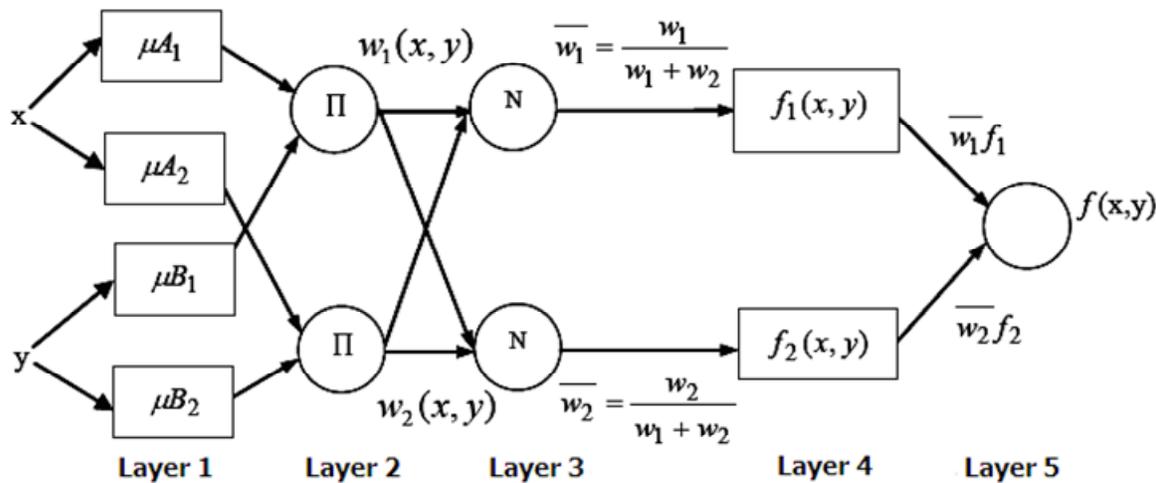


Figure 3. Architecture of the ANFIS.

Table 3. Experimental and predicted results of the particle diameter based on time and the quantity of the NaPO₃.

Time (min)	NaPO ₃ (gr)	Experimental values (×10 ⁻³)	ANFIS values (×10 ⁻³)
5	0	22,39	30,0
260	0	3,25	3,25
2	10	30,39	30,9
120	10	4,14	4,14
10	20	12,35	15,1
30	20	7,41	4,07
2	30	23,09	18,3
120	30	3,44	3,44
5	40	0	1,71
60	40	4,53	3,93

In the fuzzy inference system, the output variable is defined in two ways namely; the 0th degree Sugeno and the 1st degree Sugeno .the “0th degree Sugeno” model has a constant coefficient or a function, on the other hand, the “1st degree Sugeno” model is dependent on the input variables. Calculations in the study were performed by using Matlab package program.

Architecture of ANFIS

The ANFIS architecture consists of a network structure of the Sugeno type fuzzy system which has neural learning ability. This network is formed by joining the nodes that have settled in layers to realize a known function (Hwang et al., 2002; Sen, 2004; Chang and Chang, 2006). The architecture of the ANFIS with two inputs and an output is shown schematically in Figure 3. The rules of the 1st degree ANFIS for a structure with two inputs can be written as;

Rule 1: if x is A1 and y is B1. So,

$$f1 = p1 * x + q1 * y + r1 \tag{2}$$

Rule 2: if x is A2 and y is B2.

$$So, f2 = p2 * x + q2 * y + r2 \tag{3}$$

Where;

X and y are input values that are not fuzzy, p1, q1, r1, p2, q2 and r2 are the parameters of the output function in the inference system. In generally, ANFIS consists of the following steps.

Input node (layer 1): Each node in this layer is point out the membership function of the input variables and the output of each node is calculated as below;

$$o1i = \mu a (x) \quad i=1, 2 \tag{4}$$

$$o1i = \mu bi-2 (y) \quad i=3, 4 \tag{5}$$

Mai and μ_{bi} show the membership function for Ai and Bi fuzzy set. In this study, a “trimf” type membership function was used.

Rule node (layer 2): Each node in this layer using and/or operators is multiplied with the input signals (π) and the ignition of force $o2i$ is obtained;

$$O_i^2 = w_i = \mu a_i (x) \mu b_i (y), \quad i = 1, 2 \tag{6}$$

Mean node (layer 3): In this layer, the ignition of force obtained from each node is collected and normalized using the following equation;

$$O_i^3 = \bar{w}_i = \frac{w_i}{w_1 + w_2}, \quad i = 1,2 \tag{7}$$

Layer 4: In this layer, the contribution of each node is calculated for output of the model

$$O_i^4 = \bar{w}_i \cdot f_i = \bar{w}_i \cdot (p_i x + q_i y + r_i) \tag{8}$$

Output node (layer 5): In this layer, general output of the system is calculated and the defuzzification process of the fuzzy value is transformed to final value.

$$f(x, y) = \frac{w_1(x, y)f_1(x, y) + w_2(x, y)f_2(x, y)}{w_1(x, y) + w_2(x, y)} = \frac{w_1 f_1 + w_2 f_2}{w_1 + w_2} \tag{9}$$

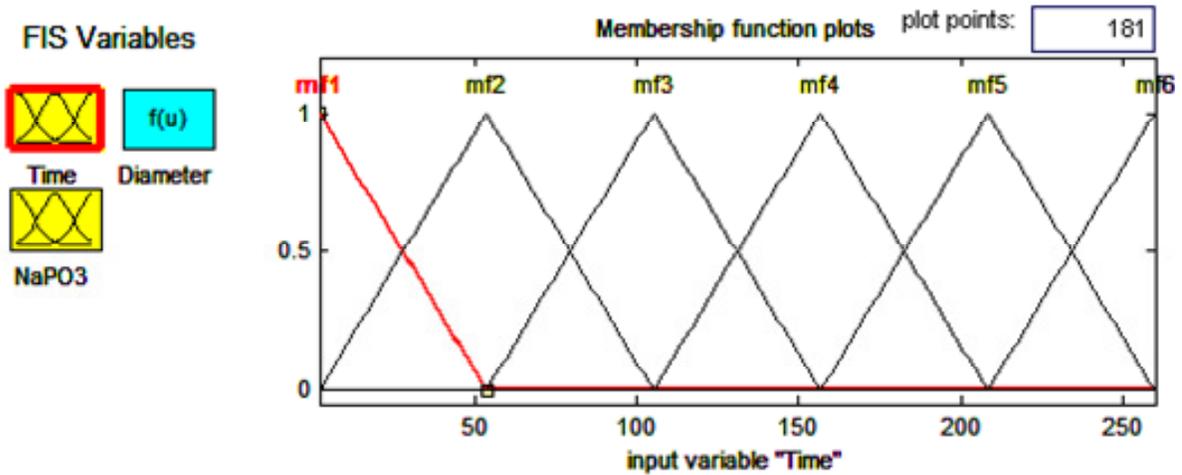


Figure 4. Membership function for the “Time” input variable.

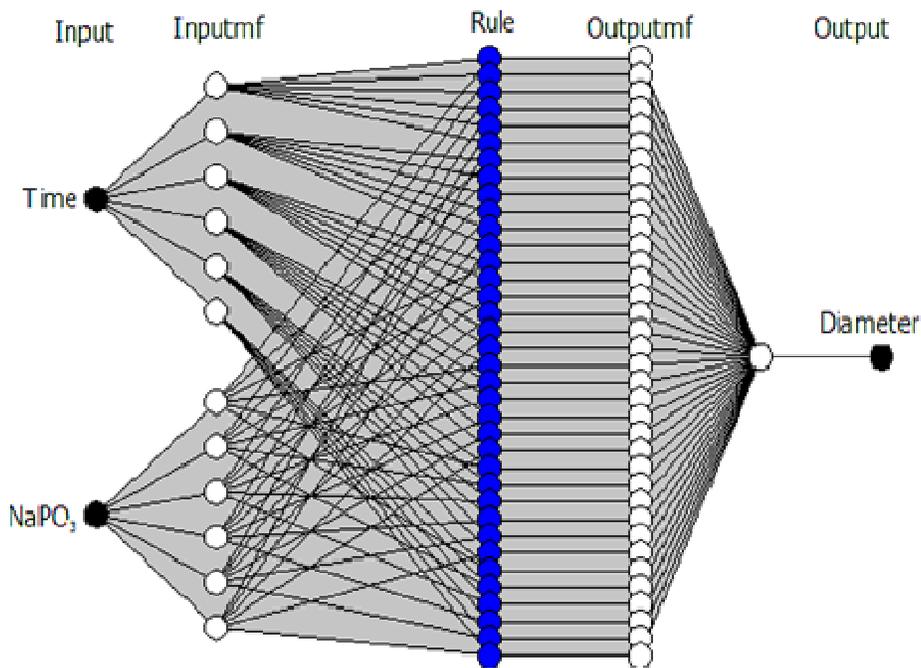


Figure 5. Architecture of the ANFIS model developed for this research.

$$Q_i^5 = f(x, y) = \sum_i \bar{w}_i \cdot f_i = \bar{w}_1 f_1 + \bar{w}_2 f_2 = \frac{\sum_i w_i f_i}{\sum_i w_i} \tag{10}$$

Application of the developed ANFIS network

In this stage, a model was developed based on the ANFIS to predict the diameter of the soil particles that are smaller than 75 μm. In the model the time and the quantity of the NaPO₃ were used

as input and soil particle diameter was used as output. The number of the data set was 40 for training and 10 for testing, respectively. In the training of the model a “hybrid learning algorithm” was used and the number of epochs was chosen as 100. The number of the membership function is 6 for each input and the total rules were 36 (6 × 6), respectively. The numbers of nodes were 101, linear parameters were 108, nonlinear parameters were 36 and totally parameters were 144, respectively, in the model. The error of the model was 2.64817 and type of the membership function was “trimf”, output membership function is linear. The membership function, architecture, and the training process of the model are shown below (Figures 4, 5 and 6).

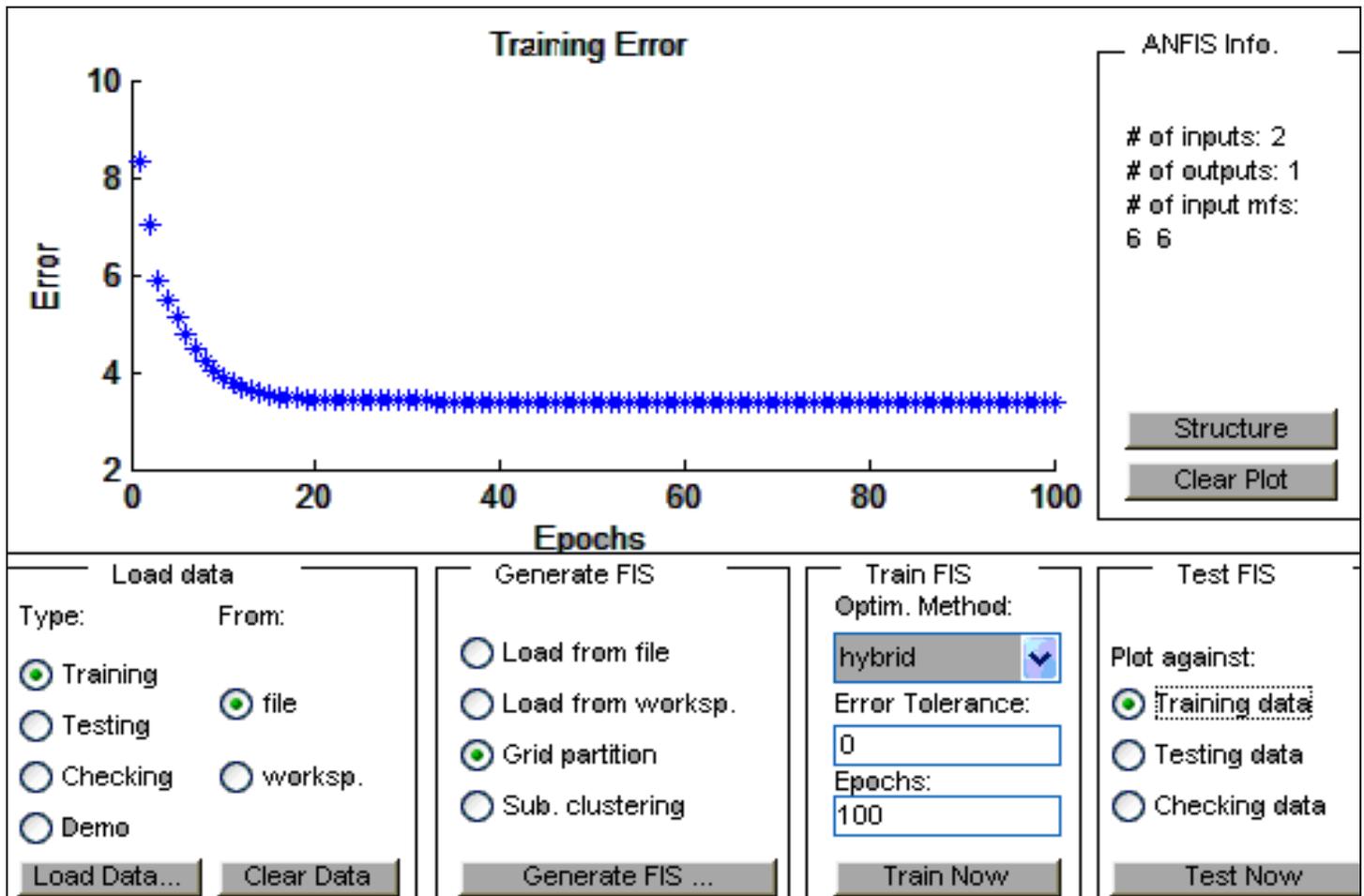


Figure 6. Training process of the ANFIS model.

RESULTS AND DISCUSSION

Being able to measure the soil grain diameter that smaller than 0.075 mm is highly important for soil research; in particular for the classification of the soil and for drawing the granulometric curve.

As a result of this study, the effects of varying quantities of NaPO_3 on the diameter of soil particles were investigated through experimental and ANFIS methods. To determine the soil particle diameter a model based on the elapsed time and the quantity of the NaPO_3 was developed using the ANFIS. The experimental results and the results of the ANFIS method were compared. It was seen from the hydrometer test results that the particle diameters of the soil have various values depending on the quantity of NaPO_3 and time elapsed. According to the ts 1900 (TS, 2006), the soil particle diameters in the solution prepared with 40 g NaPO_3 was taken as reference.

It was found that the average soil grain diameter for 0 g

NaPO_3 was about 4.5 times greater than the reference diameter, for 10 g was 3.9 times, for 20 g was 3.46 times, for 30 g was 2.12 times greater. The hydrometer reading could only be taken up to the 260th min for 50 g of NaPO_3 and for 60 g of NaPO_3 ; the hydrometer could not be read. The relationships between experimental results and ANFIS model exhibited a good correlation.

The coefficient of determination was found to be $R^2 = 0.91$ for the testing set with ANFIS. Based on the results of the study, it could be said that the ANFIS method can be used for modeling of the particle diameter of the soil according to the time elapsed and the quantity of the NaPO_3 . The experimental and ANFIS results of the particle diameter are given in Table 3 and correlations in Figure 7.

Based on the values of Table, the coefficient of determination between the experimental and ANFIS values is shown in a graph (Figure 7) and the relationship between the ANFIS model and experimental results is given as an equation. The coefficient of determination was found to

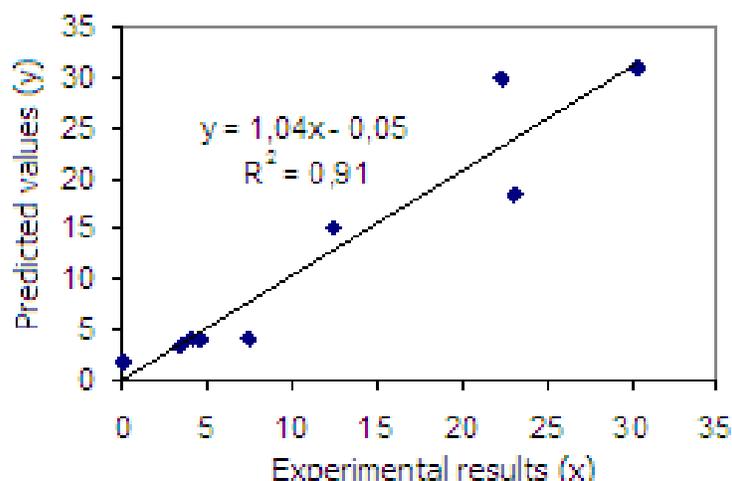


Figure 7. The correlation coefficient between the experimental and ANFIS model values.

be good at $R^2 = 0.91$ (Figure 7).

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