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Genetic Algorithm Application for Hydrometer Tests

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In this study, the results of the hydrometer tests were analyzed with statistical method and optimized by using genetic algorithms. For hydrometer tests; 0, 10, 20, 30, 40, 50 and 60 g sodium hexametaphosphate was respectively added into the prepared suspension. The specific gravity, pH and the conductivity were measured for each solution. As pointed out in the Turkish Standard (TS 1900), the soil' grain diameter in the suspension prepared with 40 g sodium hexametaphosphate was taken into consideration as reference. As a result, it was determined that the soil' average grain diameter in suspension added 0 g sodium hexametaphosphate was bigger 4.515 times than the reference grain diameter. When respectively added 10 g sodium hexametaphosphate in the suspension, the soil' average grain diameter bigger was 3.907 times than the reference grain diameter, when 20 g was added. It was 3.463 times bigger and in adding it was 30 g 2.119 times bigger. Besides, the hydrometer reading could only be done at 260 min when 50 g sodium hexametaphosphate was added in to the suspension. Moreover, the hydrometer couldn't be read in the suspension prepared with 60 g sodium hexametaphosphate. The obtained data were analyzed statistically by using SPSS programme and the experimental results were optimized by using genetic algorithms.

Key Words: Hydrometer test, Sodium hexametaphosphate, Optimization, Genetic algorithms.

INTRODUCTION

To measure the soil grain diameter smaller than 0.075 mm, is highly important for soil research especially classification of the soil and for drawing the granulometric curve correctly. To determine the soil grain diameter smaller than 0.075 mm. the most popular techniques are the hydrometer method and the pipette method[1]. For hydrometer testing 151 H and 152 H hydrometers which were defined in ASTM E 100[2] are used. In these methods, the diameters of the soil grains are calculated by using the Stock's law. Sodium hexametaphosphate is the most popular solvent ($NaPO_3$) used to prevent the soil grains flock with together in the suspension. The

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hydrometer method provides multiple measurements in the same suspension Day[3,4]. For soil particles, the mass-size formed of the equation used in this study is expressed as described by Tyler and Wheatcraft[5] and Frank[6] for determination of the density of liquids for testing of hydrometers. Several papers have been devoted to the interactions between sodium hexametaphosphate and clay. Kura and Oashi found that hexametaphosphate anion forms with calcium a strong 1:1 complex. The hexametaphosphate anions interact with the exposed atoms of aluminium, giving a complexed anion. Corbridge[3,7] reported the analysis of the behaviour of sodium hexametaphosphate in water. Sodium hexametaphosphate $(NaPO_3)_6$ is a deflocculating widely used in clay industry[8]. It exerts a deflocculating action increasing the negative charge on the clay micelles being adsorbed as an anion[9,10] and Lagaly[11] investigated the effect of soda addition on the rheological properties of bentonite. Buchan *et al.*[12] obtained a detailed particle size distribution by using sieves and sedimentation of dispersed particles in a liquid. Turcotte[13], Tyler and Wheat craft[5], Wu *et al.*[14], Young *et al.*[15] and Bittelli *et al.*[16] used wet sieving, pipette and light-diffraction techniques in order to obtain particle size distribution of 19 soils. Huertas *et al.*[17] studied the dissolution phenomena in an aqueous suspension of kaolinite at different pH of the suspension. Yildiz *et al.*[18] investigated the influence of NaCl, Na-hexametaphosphate and pH on the rheological behaviour of the original and the activated Kütahya bentonite suspensions. Hwang *et al.*[19] adjusted several models to experimental data. Filgueira *et al.*[20] 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.*[21] assessed the effects caused by the addition of sodium hexametaphosphate to a standard kaolin suspension and compared the results with those obtained employing a kaolin. Özgan[22,23] has investigated the effect of quantity of sodium hexametaphosphate $(NaPO_3)$ to the soil grain' diameters as experimental and statistically. In other study, Özgan[23] was simulated and modelled the particle diameter of the soil by using artificial neural network method.

In present study, the effect of quantity of sodium hexametaphosphate $(NaPO_3)$ to the soil grain' diameters were investigated a experimentally and statistically and optimized by using genetic algorithm method (GA). For the GA method, the objective function was formed with multi-linear regression analysis as a model equation as seen in equation 2.

Optimizing of the hydrometer test results for minimum particle diameters of the soil can be complex and a time consuming process since there are large numbers of design variables and constraints. The genetic algorithm can be efficiently applied to complex problems with large numbers of design variables and constraints. The genetic algorithm is a search procedure based on the idea of natural selection and genetics[24]. The genetic algorithm maintains a population of encoded solutions and guides the population towards the optimum solution[25]. Thus, it searches the space of possible individuals and seeks to find the best fitness string. Rather than starting from a single point solution within the search space as in traditional optimization methods, the genetic algorithm is initialized with a population of solutions. Mitchell[26], Gen and Cheng[27], Coley[28] and Mitchalewicz[29] published detailed coverage of the topic.

The genetic algorithm starts with an initial set of random solutions called a chromosome representing a solution to the problem at hand. A chromosome is a string with random combinations of 0s and 1s, but not necessarily a binary bit string. The string evolve through successive iterations, called generations. During each generation, the strings are evaluated using some measure of fitness. In order to select the fittest strings that lead the solution are used fitness function measures and rates the coded variables vector. The algorithm then proceeds by generating new designs until the termination criteria have been satisfied. After the evaluation of each-individual fitness in the population, the genetic operators, selection, cross-over and mutation, are applied to produce a new generation. The newly created individuals replace the existing generation and re-evaluation is started for fitness of new individuals. In each succeeding generation, the genetic algorithm creates a new set of chromosomes using the best information of previous generation. The loop is repeated until an acceptable solution is found.

EXPERIMENTAL

The sample used in this study was taken from the stocks of brick factory randomly in Düzce, Turkey. To determine soil grain diameters that are smaller than 0.075 mm hydrometer test was conducted. The sodium hexametaphosphate was used as a solvent in the hydrometer tests. 151 H type hydrometer was used in these tests. In addition, pH and conductivity of the solutions were measured. However, the sample's microstructure was determined by using Olympus BX51 microscope. The sample was placed on to the micro slide with a drop of entellan and covered with the lamely. The obtained images from the microscope were enlarged 100 times for the sample. The images were shown in Fig. 1. For the chemical composition of the sample XRD, analysis was also done and the results were given below (Table-2). According to the XRD investigation there were montmorillonite, quartz, clinochlore, illite and calcite in clay mineral structure.

One of the most popular techniques is the hydrometer method based on the "Stock's 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 grains were equal. In this test method, the bigger particles settle more quickly than the small particles. Stock's law was stated as below;

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

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 (s).

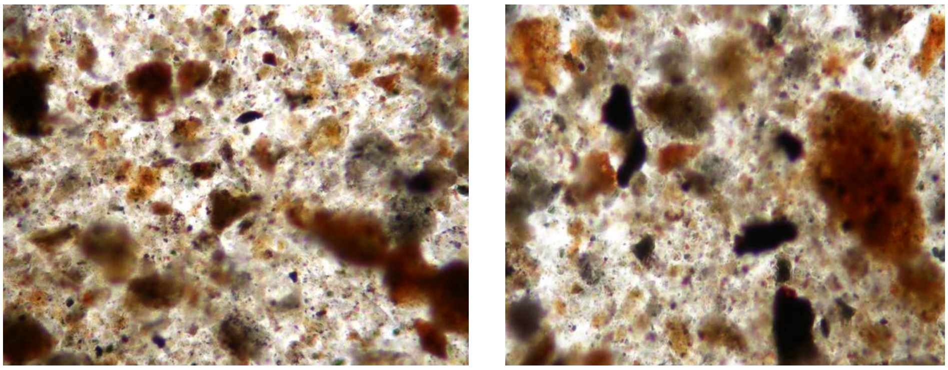

Fig. 1. Obtained images from the microscope enlarged 100 times for the sample

Preparation of the experiments samples: The weight of the samples after passing through 0.075 mm (No: 200) sieve were 30 g in the hydrometer tests. Each samples placed into the glass beher and sodium hexametaphosphate ($NaPO_3$) was added and then mixed with a glass robe to wet for 5 min. The solution was left to dissolve all of the adhered soil particles in desiccators for 16 h. The samples were taken from the desiccators and after mixing them, they were poured into the mixer. The pure water was added to the samples about 2/3 ratio of the mixer. Then the mixer was fixed to its place and the solution was mixed for 1 min. The mixed solution was poured out to the glass measure and the pure water was filled up to 1000 mL. After shaking this mixture for a minute, testing was started immediately. Together with the hydrometer reading, pH and conductivity values of the suspension were measured for each reading time for all of the hydrometer tests.

Hydrometer test results: Hydrometer test results were grouped and tabulated according to the quantity of the sodium hexametaphosphate and the times passed. The diameter of the particles was shown as $\times 10^{-3}$ in table. Nevertheless, when 50 g sodium hexametaphosphate was added in the suspension, the hydrometer reading could be done only after 260th min. On the other hand, the hydrometer reading could not be done for 60 g sodium hexametaphosphate. According to the times passed, calculated particles diameter, pH and conductivity values were shown (Table-1) for 0, 10, 20, 30 and 40 g sodium hexametaphosphate[22,23].

The effects of the solvent on the particle diameters were shown on the graph together with the reference solvent value and the other calculated values from 1 to 60 min as well (Fig. 2).

It was seen from this figure that, the biggest particle diameter was calculated as 48×10^{-3} mm for 0 g solvent and this value was obtained within first minute. All the particle diameters were calculated at the first minute for the other quantities of the solvent except for 30 g solvent, which was calculated at the second minute. For 40 g solvent, the particle diameters were calculated at the 10th minute and for 50 g, the particle diameters were calculated for at only 260th minute. The general appearances of the tendency lines on the graphs are congruous and their shapes are close to parabola.

TABLE-1
PARTICLE DIAMETERS, pH AND CONDUCTIVITY VALUES ACCORDANCE TO THE PASSING TIMES AND SODIUM HEXAMETAPHOSPHATE

$NaPO_3$ (g)	Results	Passing times (min)									
		0	1	2	5	10	15	30	60	120	260
0	pH	6.02	5.98	6.05	6.06	6.05	6.06	6.02	5.98	5.98	5.96
	Conductivity (µS/cm)	4.10	4.20	4.30	4.40	4.60	4.60	4.60	4.70	4.80	5.00
	Particles dia. ($\times 10^{-3}$) mm	0.00	47.66	34.74	22.39	16.56	13.75	9.80	6.98	4.97	3.25
10	pH	6.06	6.06	6.05	6.05	6.04	6.04	6.04	6.04	6.03	6.03
	Conductivity (µS/cm)	7.10	7.20	7.22	7.29	7.50	7.64	7.50	7.58	7.78	7.92
	Particles dia. ($\times 10^{-3}$) mm	0.00	42.37	30.39	19.46	13.90	11.40	8.10	5.81	4.14	2.99
20	pH	5.89	5.90	5.91	5.89	5.89	5.89	5.89	5.89	5.89	5.89
	Conductivity (µS/cm)	11.55	11.48	11.16	11.70	11.68	11.69	11.66	11.64	11.60	11.64
	Particles dia. ($\times 10^{-3}$) mm	0.00	37.23	26.80	17.19	12.35	10.17	7.41	5.25	3.81	2.60
30	pH	5.77	5.77	5.77	5.77	5.77	5.76	5.77	5.77	5.76	5.76
	Conductivity (µS/cm)	15.02	15.09	15.04	15.08	15.07	15.17	15.10	14.95	15.17	15.14
	Particles dia. ($x10^{-3}$) mm	0.00	0.00	23.09	14.62	11.10	9.14	6.47	4.88	3.44	2.38
40	pH	5.80	5.58	5.52	5.50	5.69	5.60	5.69	5.16	6.03	6.40
	Conductivity (µS/cm)	17.17	17.20	17.13	17.05	17.04	15.83	17.18	17.38	17.56	17.70
	Particles dia. ($\times 10^{-3}$) mm	0.00	0.00	0.00	0.00	10.38	8.54	6.29	4.53	3.32	2.38

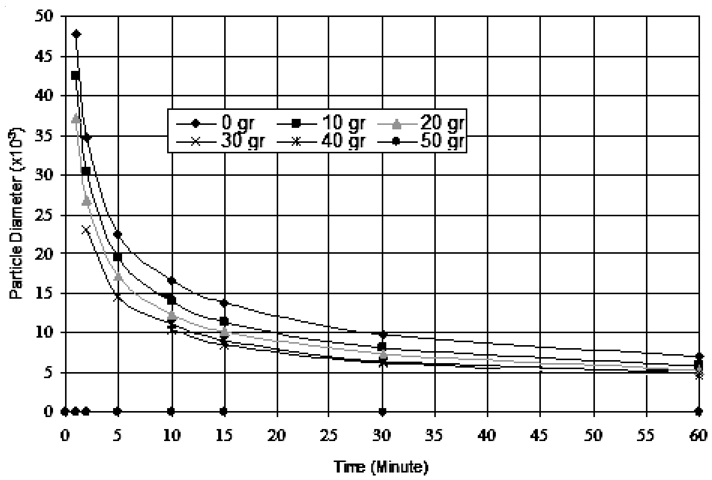

Fig. 2. Relationship between particle diameters and passing times according to the quantity of $NaPO_3$

Optimization of the particle diameter with genetic algorithms

Genetic algorithms is an optimization method based on the genetic concept. It is a strategy for solving the multi-variable optimization problems which are considered to be difficult by conventional optimization methods[30]. Genetic algorithms starts to run with a lot of possible solution according to the initial population which are randomly prepared. Then it tries to find optimum solutions by using genetic operators such as selection, crossover and mutation[25]. Genetic algorithms doesn't start the solution with one initial point. It starts to search with a lot of initial point called initial population. So, the best solutions are selected and worst are eliminated. Genetic algorithms starts the search with the generations of the initial population depending on the represented fitness function (FF) variables. Initial population is generated randomly after coding the variables. Each row of the population is called an individual. Fitness function (FF) values are calculated for each individual. The fitness function (FF), is the difference between the goal function (GF) and the penalty function (PF) consisting constraints functions (CF). After operated elitism, selection, crossover and mutation, a new population is generated according to the fitness function values. With the evaluation of the previous population, the new population is generated till the number of generation fitness function values are calculated in each new population. The best resulted ones are paid attention among these values. Until the stopping criteria are obtained, this process is repeated iteratively. The stopping criteria may be the running time of the algorithm, the number of generation and for fitness functions to give the same best possible values in a specified time. In this study generation size has been used as the stopping criteria.

Application of the genetic algorithms: The fitness function, variable coding and genetic algorithms operators (elitism, selection, crossover and mutation) has been used in the application of genetic algorithms.

Fitness function: In this part, the function obtained with statistical analysis result was optimized to find the minimum particle diameter of the soil. Since genetic algorithms has been searching the minimum particle diameter, F(xi) given below has been accepted as a goal function.

$$F(x_i) = 0{,}00244 - 0{,}0000246\,x_1 - 0{,}000159\,x_2 + 0{,}007822\,x_3 + 0.000368\,x_4 \quad (2)$$

where; x_1: times passed (min), x_2: quantity of sodium hexametaphosphate (g), x_3: hydrometer reading, x_4: temperature of the suspension.

Genetic algorithms runs as an unconstraint optimization method. If there are any constraints, they are subtracted from the fitness function as a penalty function so the problem has been converted to unconstrained optimization problem. With this way fitness function values are constrained. This situation has been taken as constraints. Under the light of these explanations, the constraints would be given as in equations from 3 to 12.

$$g_1 = x_1 + x_2 + x_3 + x_4 - 342.59 \leq 0 \quad (3)$$

$$g_2 = 339.59 - x_1 + x_2 + x_3 + x_4 \leq 0 \quad (4)$$

$$g_3 = x_1 + x_4 - 281.2 \leq 0 \quad (5)$$

$$g_4 = 278.2 - x_1 + x_4 \leq 0 \quad (6)$$

$$g_5 = x_2 + x_4 - 81.2 \leq 0 \quad (7)$$

$$g_6 = 78.2 - x_2 + x_4 \leq 0 \quad (8)$$

$$g_7 = x_1 + x_2 + x_3 + x_4 - 303.19 \leq 0 \quad (9)$$

$$g_8 = 300.19 - x_1 + x_2 + x_3 - x_4 \leq 0 \quad (10)$$

$$g_9 = x_3 + x_4 - 22.59 \leq 0 \quad (11)$$

$$g_{10} = 19.59 - x_3 + x_4 \leq 0 \quad (12)$$

The sum of all constrained functions have formed the construction function. The construction function (CF) and penalty function (PF) could be expressed below:

$$CF = \sum_{i=1}^{n} g(i) \quad (13)$$

$$PF = r * (CF) \quad (14)$$

In this study since the aim is minimization, the fitness function is the subtraction CF from GF. A proper K value is also added to the fitness function so that the fitness function does not take the negative value. When GA stops, this K constant is subtracted from the result. And the real values are calculated by this way. According to these definitions FF is as the eqn. 15:

$$FF = K + GF + PF \quad (15)$$

The vector of design variables, the times passed (x_1), the quantity of the sodium hexametaphosphate (x_2), hydrometer reading (x_3) and tmeperature of the suspension (x_4). Ranges of each design variable is respectively given:

$$0 \leq x_1 \leq 260 \quad (16)$$

$$0 \leq x_2 \leq 40 \quad (17)$$

$$0 \leq x_3 \leq 1.39 \quad (18)$$

$$18.2 \leq x_4 \leq 21.2 \quad (19)$$

Coding of variables: It is necessary to code the GA variables. In this study coding are made by binary system (0, 1). The number of the bits belong to the variable are stated in equation 20. In that equation, "x_{upper} and x_{lower}", respectively shows the upper and lower bounds of variable and ε shows the increase range[31]. The number of bits for coding the variables was given in Table-2.

$$2^{\ell_i} \geq \frac{x_{upper} - x_{lower}}{\varepsilon} + 1 \quad (20)$$

TABLE-2
BIT NUMBERS OF VARIABLES TO BE CODED

Variable Range	Inc	Bit number
$0 < X_1 < 260$ min	1.00	10
$0 < X_2 < 40$ g	0.10	9
$0 < X_3 < 1.39$ hydrometer reading for 151H	0.01	7
$18.2 < X_4 < 21.2$ °C	0.10	5

Individuals are formed by gathering variables which are randomly coded. The formation of an individual has been given in Table-3. The cumulative bit number of an individual (ℓ) is obtained as 31 and this shows that 2^{31} different individuals can be created. Genetic algorithms starts the solution with the initial population created randomly. The individual number in the initial population is called the population size (PS). Population size specifies how many searching number will be in a generation. Population size is specified as 152 according[32] to the equation 21. The randomly created initial population is given in Table-4. Each time while GA is started to run, created different initial population has been created.

$$PS \geq 1.65 * 2^{0.21*\ell} \quad (21)$$

TABLE-3
AN INDIVIDUAL CODE

Variables	Codes
x_1	1 1 1 0 1 0 1 0 0 1
x_2	1 0 1 0 1 1 0 0 1
x_3	1 1 1 0 0 0 1
x_4	0 0 1 1 0
Individual	
1110101001101011001111000100110	

TABLE-4
INITIAL POPULATION

Individual number	Individual codes (randomly)
1	1110101001111010100111010101001100
2	0010101001111010100101010101101100
.	.
.	.
.	.
152	1000101001111010101111010001110 1

Genetic algorithms operators: In genetic algorithms, in order to create the next generation population some operators such as elitism, selection and crossover have been used. With the elitism operator, two individuals which have the best fitness functions values are guaranteed to be included in the next generation. The first two individuals of each new population are the best two individuals of the previous generation[33]. Selection is process for finding the much more proper parents generating the new generations. In this study, since the PS is 152, 75 pairs as parents will be selected with the selection operator and 150 new individuals will be generated by these parents. Two individual will be selected by elitism. In this study tournament selection has been used. According to this method, a group of individuals were randomly selected from the population and one of them, which has the best fitness function value, is selected to be one of the parent and the others are returned to the population. The second member of parent and all parents are selected by the same strategy[31]. Crossover operator is the operation to generate the candidate individuals for the possible next generation with gene crossover. In this study uniform crossover method has been used. In this method, a mask individual which has the same bit number of an individual is created for each parent pair. First candidate individual is created in such a way that if the mask individual is 1, the bit of first pair is copied and if the mask individual bit is 0, the bit of second pair is copied. Second candidate individual is created in such a way that if the mask individual bit is 1, the bit of second pair is copied and if the mask individual bit is 0, the bit of first pair is copied[25]. Some bits of candidate individuals are randomly changed so that they do not become copy of their parent. This process is called mutation. After mutation candidate individuals are now individuals of new population. The mutation rate is given as follows:

$$\frac{1}{PS} < MR < \frac{1}{\ell} \tag{22}$$

In this study, mutation rate (MR) has been taken 0.014 according[34] to the eqn. 22. The processes of generating new individuals by: selection, crossing and mutation have been shown in Tables 5 and 6.

TABLE-5
UNIFORM CROSS OVER

Mask individual	11101010011010110011110001001100
Parent 1	11101110011000100011111001001000
Parent 2	00110011111010110011001000100 1100
Candidate parent 1 (Child I)	11111011111000100011110001001000
Candidate parent 2 (Child II)	00100111011010110011001100 1001100

TABLE-6
MUTATION OPERATOR

Candidate Individual 1 before mutation
11111011111000100011110001001000
Candidate Indivudual 1 after mutation
01111010111000101011111100 01001000

RESULTS AND DISCUSSION

Experimental test results of the hydrometer test were analyzed with statistically and genetic algorithms methods were used to determine the minimum particle diameter of soil.

Statistically analysis of the hydrometer test results: Correlation analysis was conducted to determine the relationship between hydrometer test parameters with together and the results are given in Table-7. (Hydrometer test parameters are; passing times, hydrometer reading, observed temperature for suspension, pH, conductivity, correction coefficient values for solving matter and temperature, corrected hydrometer reading, effective deep, value of K, particle diameter, the specific gravity of the suspension and quantity of the sodium hexametaphosphate).

TABLE-7
CORRELATION COEFFICIENTS FOR HYDROMETER TEST PARAMETERS

	Passing time	Original Hydrometer reading	Observed temperature	pH	Conductivity	The correction coefficients for solving matter and temperature	Corrected hydrometer reading	Effective deep	Value of the K	Particle diameter	Specific gravity for solution	Quantity of $NaPO_3$
Passing time	1.0	.17	.46	-.02	.02	.006	.11	.15	.165	-.28	.00	.000
Original hydrometer reading	.17	1.0	-.15	.76*	-.69*	.016	.79*	.74*	.28	.46	-.64	-.74*
Observed temperature	.46	-.15	1.0	-.19	.43	-.44	.03	-.07	-.28	-.39	.46	.25
pH	-.026	.76*	-.19	1.0	-.80*	-.14	.82*	.89*	-.11	.51	-.77*	-.98*
Conductivity	.019	-.69	.43	-.80	1.0	-.47	-.46	-.56	-.34	-.55	.96*	.75*
Correction coefficient value for solving matter and temperature	.006	.016	-.44	-.14	-.47	1.0	-.45	-.38	.74*	.15	-.44	.20
Corrected hydrometer reading	.11	.79	.03	.82	-.46	-.45	1.0	.90*	-.33	.38	-.42	-.82*
Effective deep	.15	.74	-.07	.89	-.56	-.38	.90	1.0	-.26	.36	-.58	-.93*
Value of the K	.16	.28	-.28	-.11	-.34	.74	-.33	-.26	1.0	.11	-.33	.15
Particle diameter	-.28	.46	-.39	.51	-.55	.15	.38	.36	.11	1.0	-.52	-.48
Specific gravity of the solution	.00	-.64	.46	-.77	.96	-.44	-.42	-.58	-.33	-.52	1.0	.75*
Quantity of $NaPO_3$	.00	-.74	.25	-.98	.75	.20	-.82	-.93	.15	-.48	.75	1.0

Optimization results with genetic algorithms: After completing all individuals of each new generation, the fitness function values are calculated. This process is repeated for the generation number. Generation size (number) has been selected as 500 f. When running GA at least 20 times, it has been observed that the optimum solution has been obtained from the ¾ ratio of the generation size and no new optimum solution has been found. The optimum solution process with GA was showed in Fig. 3.

The results of the experimental values and optimization with GA for hydrometer test parameters were given in Table-8.

It was seen from the table that, the times passed quantity of the sodium hexametaphosphate were found at the same value both in experimental and GA optimization results. Hydrometer reading and temperature of the suspension were

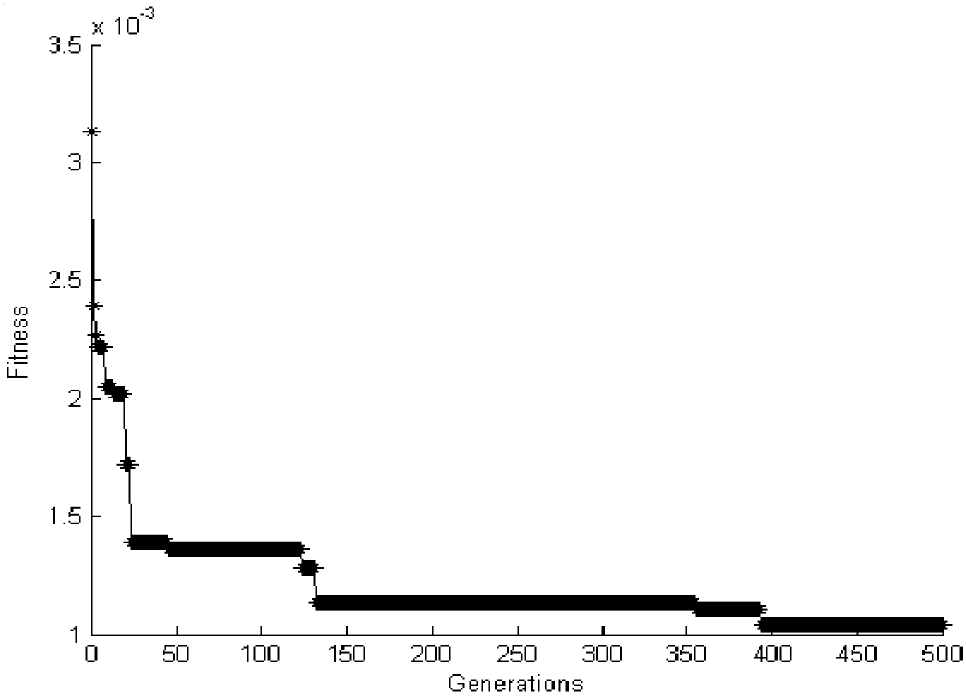

Fig. 3. Genetic algorithms fitness functions values

TABLE-8

Results	Hydrometer test parameters and particle diameter				
	x_1 (Passing times (minute)	x_2 (The quantity of sodium hexameta-phosphate) (g)	x_3 (Hydrometer reading)	x_4 (Temperature of the suspension)	y (Particle diameter) (mm)
Experimental results	260	40	1.29	19.1	0.00239
Genetic algorithms optimization results	260	40	1.35	20.9	0.0024

found at different values. However, particle diameters are nearly the same with experimental and GA results. According to these results it could be said that the GA approach could be used for determining the minimum particle diameter of soil for the hydrometer test results.

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