CHAPTER 5: OPTIMISATION OF PIPE NETWORK FOR NON-NEWTONIAN FLUID USING GENETIC ALGORITHM

5.1 Introduction

There is a substantial research work that has been done in the past to predict the pressure drop, friction loss, velocity profile and concentration profile for solid liquid slurry (Non-Newtonian fluid) flow through pipeline. Friction loss is directly proportional to pressure drop, which is the foremost parameter for slurry transport in many industries. Power consumption and consequently the whole economics of the hydro-transport governed by it. The accurate knowledge about slurry provides a great help in selection of slurry pump and hence improve power consumption. There are enormous empirical and semi empirical correlations accessible in literatures to predict friction loss. Most of these equations have been developed based on limited data.

The friction loss in pipe flow parameters provides a great help to improve power consumption. The friction loss in the slurry pipe network is mainly depend upon pipe diameter, pipe material, temperature of carrier fluid, velocity of fluid in the pipe and slurry concentration. Hence, by adjusting the value of above said parameters the friction loss can be minimized that leads to lower power consumption. In this study, emphasis is given on minimisation of friction loss in network. The literature suggest the slurry pipe line can carry settling or non-settling particles. Slurry flow problems may be divided into two main cases. One is for slurry carrying fine particles where the particle size is less than 40 micron and another for coarse slurry particle where average particle size is above 100 micron.

CASE-1

PIPE NETWORK CARRYING NON-NEWTONIAN FLUID (SLURRY WITH FINE PARTICLES)

5.2 The Test Problem

For our case study a pipe network (figure-5.1) is considered which comprises, one kilometre pumping main straight pipeline carries a slurry of average sediment particle size of 40 µm with mass densities of particles and fluid ratio as 2.5. Designing the pipe network for minimum friction loss is main objective. The details of commercially available pipe size (tables-5.1) and the average roughness height of pipe materials (tables-5.2) are given. The other details regarding temperature of flow, volumetric concentration, and average flow velocity can be assumed as per industrial requirement.

5.3 Implementation of Genetic Algorithm

In this study, GA has been used as optimisation tool. The purpose of the study in this chapter is to minimize the friction loss in the system.

5.3.1 Objective Function

The objective of the pipe network is to minimize the friction loss. Neglecting the other factors, it is assumed that pumping cost of the network is solely depending upon friction loss of the pipe.

Durand and Stepanoff (1969) gave the following equation for head loss (h_f) for flow of fluid in a pipe (length=L) with heterogeneous suspension of sediment particles (solid particle of slurry).

$$\text{Minimum cost (z)}, \; h_f = \frac{fLV^2}{2gD} + \frac{81(s-1)C_v fL\sqrt{(s-1)gD}}{2C_D^{0.75}V} \tag{5.1}$$

Where s = ratio of mass densities of slurry particle and mass density of fluid (fluid in which solid particle of slurry is flowing), C_v = Volumetric concentration, C_D = Drag coefficient of particle, f = friction factor of sediment fluid and D= diameter of pipe, V is the Average velocity of flow m/s and g = gravitational force.

5.3.1.1 Friction Factor (f)

Swamee (1993) gave the following equation for friction factor (f) valid in the laminar flow, turbulent flow and transition in between them.

$$f = \left\{ \left(\frac{64}{R} \right)^{8} + 9.5 \left[\ln\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{R^{0.9}} \right) - \left(\frac{2500}{R} \right)^{6} \right]^{-16} \right\}^{0.125} \tag{5.2}$$

Where ε the roughness height of the pipe material in meter.

5.3.1.2 Reynolds Number (R)

Reynolds Number, $R = \frac{VD}{\nu}$ (5.3)

Where V is the Average velocity of flow m/s , v is the kinematic viscosity of fluid in the pipe.

5.3.1.3 Kinematics Viscosity (ν)

The kinematics viscosity (ν) of fluid that can be obtained using the equation given by Swamee (2004)

$$\nu = 1.792x10^{-6} \left[1 + \left(\frac{T}{25} \right)^{1.165} \right]^{-1} \tag{5.4}$$

Where T is the water temperature (${}^{0}C$)

5.3.1.4 Drag Coefficient of Particle

For spherical particle of diameter d, Swamee and Ojha (1991) gave the following equation for C_D.

$$C_D = 0.5 \left\{ 16 \left[\left(\frac{24}{R_S} \right)^{1.6} + \left(\frac{130}{R_S} \right)^{0.72} \right]^{2.5} + \left[\left(\frac{40000}{R_S} \right)^{2} + 1 \right]^{-0.25} \right\}^{0.25} \tag{5.5}$$

Where R_s =Sediment particle Reynolds number

5.3.1.5 Sediment Particle Reynolds Number

The Reynolds number of sediment particle is given by,

$$R_s = \frac{wd}{\nu} \qquad \text{(When } R_s \leq 1.5\text{x}10^5\text{)} \tag{5.6}$$

5.3.1.6 Fall Velocity (w)

According to Swamee and Ojha, (1991), the fall velocity (w) is given by

$$w = \sqrt{(s-1)gd}\left\{\left[\left(18\nu^*\right)^2 + \left(72\nu^*\right)^{0.54}\right]^5 + \left[\left(10^8\nu^*\right)^{1.7} + 1.43x10^6\right]^{-0.346}\right\}^{-0.1} \tag{5.7}$$

$$\nu^* = \nu / [\sqrt{(s-1)gd}] \tag{5.8}$$

Where, (ν) = kinematics viscosity

5.3.2 Commercially Available Pipes

The details of commercially available pipes are given in table-5.1.

Table-5.1 Details of Commercially Available Pipes

Sl No.	Pipes (mm)
1	150
2	200
3	250
4	300
5	350
6	400
7	450
8	500

5.3.3 Average Roughness Heights

The details of average roughness height of commercially available pipe materials are given in table-5.2.

Table-5.2 Average Roughness Heights, ε (Millimetre)

Sl No	Pipe Materials	Roughness Height (mm)
1	Wrought Iron	0.04
2	Asbestos Cement	0.05
3	Polyvinyl Chloride	0.05
4	Steel	0.05
5	Asphalted cast iron	0.13
6	Galvanized Iron	0.15
7	Cast/Ductile Iron	0.25
8	Concrete	0.3 to 3.0

5.3.4 Design Variables

In the GA formulation for test problem, five variables namely Temperature (T), Average Velocity (V), Volumetric Concentration (c_v), Diameter of Pipes (D), Roughness height (€) were selected and each variables were represented by a three-bit binary substring, as shown in table-5.3.

Table-5.3 Design Option for Case Study

Sl No.	Variables (Parameters)	Description of Variables Option	Total Number of Option
1	Fluid Temperature as x_1	Ranges from 10 ^{0}C to 50 ^{0}C	Continuous
2	Average Flow Velocity (V), as x_2	Ranges from 1 meter/second to 5 meter/second	Continuous
3	Volumetric Concentration of Flow (c_v), as x_3	Ranges from 10 % to 60%	Continuous
4	Diameter of Pipes (D), as x_4	150, 200, 250, 300, 350, 400, 450, 500	Discrete (8)
5	Roughness height (€) as x_5	Wrought Iron, Asbestos Cement, Polyvinyl Chloride, Steel, Asphalted cast, iron, Galvanized Iron, Cast/Ductile Iron and	Discrete (8)

In a binary-coded GA solution vector x [f(x_1, x_2, x_3, x_4, x_5)] in which every variable is coded in a fixed length binary substring (here, binary substring length=3). For example, the following is a string, representing five variables. To code each of the five variables, the overall GA string has a length 15 (5X3=15). A typical string and corresponding decision variables are shown in Figure- 5.2. In the problem the i_{th} variable is coded in a binary substring of length l_i ($l = 3$) so that the total number of alternatives allowed in that variable is 2^{l_i} (2^3=8). The lower bound solution $x_i^{\min}$ is represented by the solution (00......0) and the upper bound solution $x_i^{\max}$

is represented by the solution (11......1). Any other substring S_i decodes to a solution x_i by Deb (2000).

$$x_i = x_i^{\min} + \frac{x_i^{\max} - x_i^{\min}}{2^{l_i} - 1} DV(\mathrm{S}_i) \tag{5.8}$$

Where DV (S_i) is the decoded value of the substring S_i. A binary string look like a linear chromosome containing of a number of genes taking one of two values - one or zero. Considering these strings as individuals, one can now mimic natural crossover and mutation operators similar to their natural counterparts.

5.3.4.1 Lower and Upper Limit of Variables

For variables x_1, x_2 and x_3:

$x_1^{\min}$ =10 ^{0}C (lower limit, corresponding substring is 000);

$x_1^{\max}$ =50 ^{0}C (upper limit, corresponding substring is 111);

Similarly, $x_2^{\min}$ =1.0 m/s (lower limit, corresponding substring is 000);

$x_2^{\max}$ =3.0 m/s (upper limit, corresponding substring is 111);

and, $x_3^{\min}$ =10 % (lower limit, corresponding substring is 000);

$x_3^{\max}$ =60% (upper limit, corresponding substring is 111);

Any other value of substring (x) can be calculated from the equation (5.8). e.g.- suppose the substring (for example-x_1) binary substring is 011 (S_i=0 1 1), then corresponding value of x_1 in terms of temperature in ^{o}C can be calculated as shown below,

x_1 = 0 0 0 (lower limit, corresponding substring value is 10 ºC) = x_1^{min}

x_1 = 1 1 1 (upper limit, corresponding substring value is 50 ºC)= x_1^{max}

Here, decoded value of the substring $S_i(0 \ 1 \ 1) = 3$ ($0x2^2 + 1x2^1 + 1x2^0 = 3$),

l_i =3 (length of substring),

Hence, $x_i = x_i^{min} + \frac{x_i^{max} - x_i^{min}}{2^{l_i} - 1} DV(S_i)$

i.e., $x_i = 10 + \frac{50-10}{2^3 - 1}(3)$,

$x_i = 28$ ºC

The value of x can be tuned to more accurate by increasing the length of substring, i.e., one can increase the length from 1 to any integer (l_i=5 or 9 or any positive integer) depending upon the problem. Here, l_i=3 has been taken.

5.3.4.2 Binary Coding for Commercially Available Pipes

In the GA formulation for test problem, variable (x_4) was represented by a three-bit binary substring. Three bit substring length were selected representing eight possible alternatives as shown in table-5.4. The substring length of variable, x_4 is independent of substring length of other variables (x_1, x_2, x_3 etc.). If commercially available pipe were more than eight numbers then, the length of substring can be increased. The binary coding for different pipes are taken arbitrary. E.g. - the binary coding for pipe 150 mm diameter is taken (000) randomly and so on.

Table-5.4 Details of Commercially Available Pipes with Binary Coding in GA

Sl no.	If New Pipes (mm)	Binary Coding
1	150	000
2	200	001
3	250	010
4	300	011
5	350	100
6	400	101
7	450	110
8	500	111

5.3.4.3 Binary Coding for Roughness Height (€)

GA formulation for test problem, variable (x_5) was represented by a three-bit binary substring were selected representing eight possible alternatives as shown in table-5.5. The binary coding for different roughness height are taken arbitrary. E.g. - the binary coding for wrought iron is taken (000) randomly and so on.

Table-5.5 Details of Roughness Height (€) with Binary Coding in GA

Sl No.	If New pipes (mm)	Binary Coding
1	Wrought Iron	000
2	Asbestos Cement	001
3	Polyvinyl Chloride	010
4	Steel	011
5	Asphalted cast iron	100
6	Galvanized Iron	101
7	Cast/Ductile Iron	110
8	Concrete	111

5.3.4.4 Chromosomes or String

Five different variables have been optimized in this problem. A binary substring of three bits can be used to represent the options for all of the decision variables (table-

5.3). A 15-bit (5variables, each represented by three bits) binary string represents (chromosomes) the network to be optimized (figure-5.2).

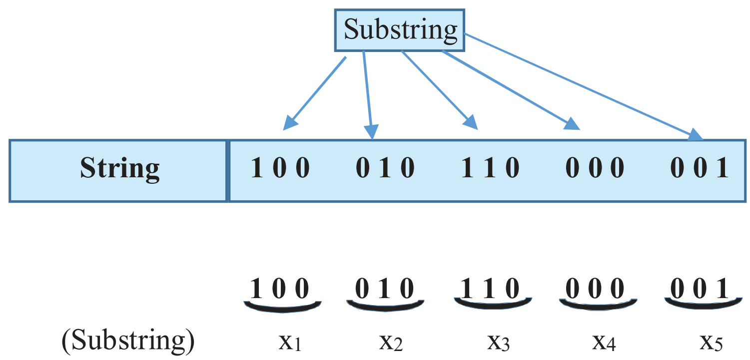

Figure-5.1 Different Variables

5.3.5 Generation of Population

The Genetic Algorithm (GA) generates the initial solutions (say, size n =100, table-5.6) using a random number generator. The solutions (n=100) are together known as population.

Table-5.6 Initial Solutions (Population) Randomly Generated by GA

Chromosomes -1	001 110 101 011 000 110 101 111
Chromosomes -2	111 100 101 001 101 100 001 100
Chromosomes -3	101 110 001 111 010 110 101 011
…	…
…	…
Chromosomes -100	110 010 101 011 011 000 111 000

5.3.6 Minimisation of Objective Function

Once the population is initialized or an offspring population is created, the fitness values of the candidate solutions are evaluated by putting the value of decision variables into the equation (5.1), to equation (5.7). The GA computes the fitness for the network in the population. Similar process has already been discussed in section-4.4.8 to section-4.4.11.

5.3.7 Computation of Network Cost Using Matlab Software

Pipe network optimisation is achieved by using Genetic Algorithm comprising reproduction, crossover and mutation.

a. In GA, the value of five parameters (population size, crossover point, and mutation rate, number of iteration and percentage of crossover) necessity to be tuned when it is applied to several optimisation problems by Tolson et al. (2009). The performance of the GA has been established to be heavily dependent on the parameter values used and appropriate parameter values are dependent on the optimisation problem under consideration. Thus, it requires substantial effort, normally by trial and error, for practitioners to decide the most appropriate parameter values for GA in order to apply them to various optimisation problems. To establish GA's parameter values trial and error methods is considered.

b. The following parameters has taken. Population size=100 to 300, probability of crossover= 0.2 to 1.0, probability of mutation=0.01 to 0.05, dimension (number of variables) =5, string length=3. A software programming has been developed in MATLAB for getting optimal or near optimal solution for this case study.

c. In table-5.7, the population size (50), crossover point (single), and mutation rate (0.05) are kept constant and number of iterations and crossover point changes. It is observed from convergence study (figure-5.3) that fitness value at higher crossover and at higher iteration rate are very close. Crossover as 80% and number of iteration as 300 for further convergence of fitness value has been selected.

Table-5.7 Total Head Loss in Pipe in Meter (Fitness Value)

Number of Iterations	Percentage of Crossover			
	20	50	80	100
50	2.0307	1.9959	1.9865	1.9959
100	1.9715	1.9715	1.9715	1.8242
200	1.8019	1.8019	1.8019	1.8019
300	1.8019	1.8019	1.8019	1.8019
500	1.8019	1.8019	1.8019	1.8019
Note:- population size=50, Crossover point=1, Mutation rate=0.05				

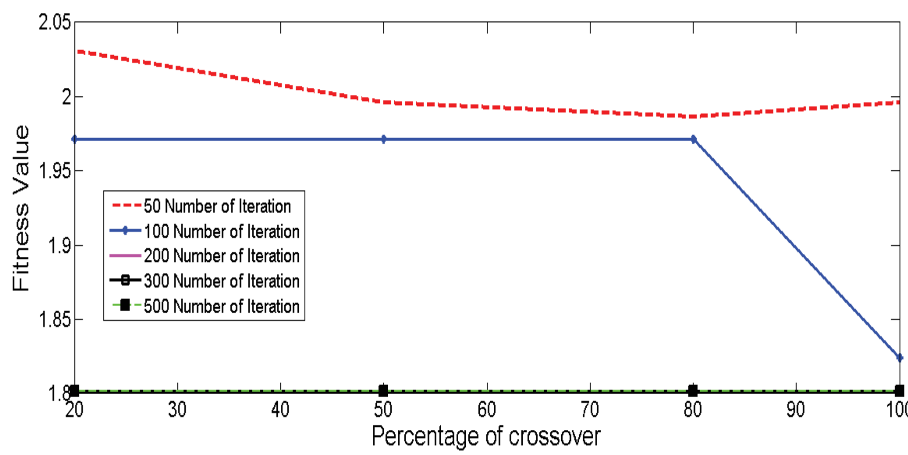

Figure-5.2 Variation of Fitness Value vs. Percentage of Crossover

d. When the number of iteration (300), crossover point (single), and percentage of crossover (80%) are kept constant. For different mutation rates of 0.01, 0.02, 0.03 and 0.05 and population sizes of 100, 150, 200, 300 and 500, the head loss (fitness value) has a constant value of 1.8019 meter. Population size as 300 and mutation rate as 0.05 for further convergence of fitness value has been selected.

e. When the number of iteration (300), percentage of crossover (80%) and mutation rate (0.05) are kept constant. For different crossover points (1-point, 2-point and 3-point) and population sizes 150 and 300, the head loss (fitness value) has a constant value of 1.8019 meter. Hence single crossover point has been selected.

However, Population size (300), percentage of crossover (80%), number of iteration (300), mutation rate (0.05) and single point crossover has been adopted to find the optimum value (minimum value of head loss) of network. The best five solutions are given in table-5.8.

Table-5.8 Best 5 Fitness Value or Solutions (Total Head Loss in Meter)

Sl. No	Total Head loss in meter)	Temperature (T) in Degree Centigrade	Average Velocity (V) m/s	Volumetric Concentration (Cv) in %	Diameter of Pipes (D) In m	Roughness Height (€)	Remarks
1	1.28	10	0.51	10	500	4e-05	X^a [10, 50; 0.1, 3.0; 0.10, 0.40]
2	1.89	10	1	10	500	4e-05	X^a [10, 40; 1.0, 3.0; 0.10, 0.40]
3	2.12	10	0.51	20	500	4e-05	X^a [10, 50; 0.1, 3.0; 0.20, 0.40]
4	1.71	10	0.51	10	250	4e-05	X^a [10, 40; 0.1, 3.0; 0.10, 0.40], Diameter of pipe=250 mm
5	1.40	10	0.51	10	500	15e-05	X^a [10, 40; 0.1, 3; 0.10, 0.40], Pipe=Galvanized iron

Here, $X^a[x^1, x^2, x^3]$ represent X^a [range of temperature (T), range of average velocity (V), range of volumetric concentration (Cv)]

Best Cost Results (Total Head Loss, 1.28 meter) Shown in Graph

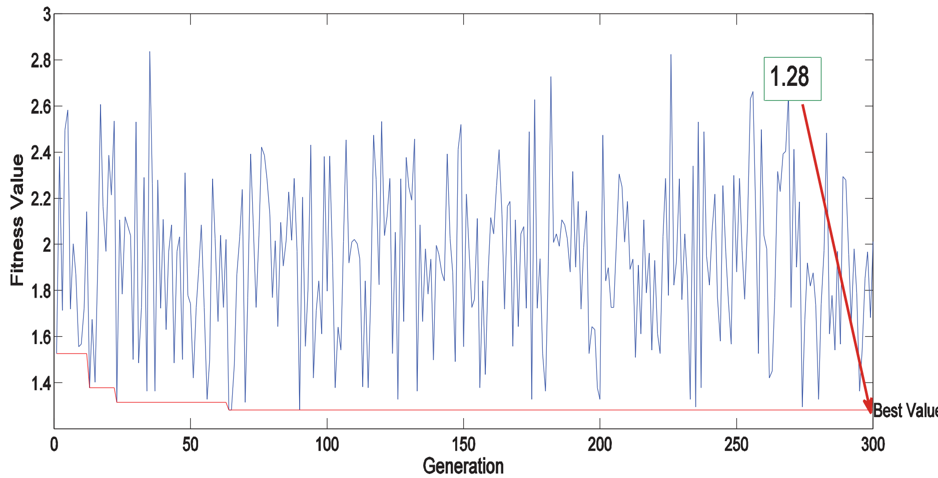

Figure-5.3 Generation vs. Fitness Value (Best Cost Results)

5.4 Discussion and Conclusion

The GA is proposed for optimal design of slurry pipe network. Simple, three-operators of genetic algorithm namely reproduction, crossover, and mutation have been used. Results show that the genetic algorithm techniques are very effective in finding near-optimal or optimal solutions for case study network. Table-5.10 shows only few results. Many other results can be achieved by the proposed technique for different ranges of variables (temperature, average velocity of liquid, volumetric concentration of slurry, pipe sizes and pipe material) as per the particular industry requirement. The significant advantages of GA technique are that a set of solutions are produced. So that the decision maker can select the best alternative. The genetic algorithms technique is still in research stage and further development can improve the search method for practical problem.

CASE-2

PIPE NETWORK CARRYING NON-NEWTONIAN FLUID (SLURRY WITH COARSE PARTICLES)

5.5 The Test Problem

For our case study a pipe network (figure-5.1) is considered which contains, one kilometre pumping main pipeline carries a slurry of average sediment particle size of 0.1 mm with mass densities of particles and fluid ratio as 2.5. The details of commercially available pipe size (tables-5.5.1) and the average roughness height of pipe materials (tables-5.5.2) are given. Design of the pipe network is for minimum friction loss. The other details regarding temperature of flow, volumetric concentration, and average flow velocity can be assumed.

5.6 Application of Genetic Algorithm

In this study, the designated optimisation method for the optimum design of slurry pipelines is GA. The purpose of the problem is to minimize the friction loss of the system.

5.6.1 Objective Function

The objective function of the pipe network is to minimize the friction loss. Neglecting the other factors, it is assumed that pumping cost of the network is solely depending upon friction loss of the pipe.

5.6.1.1 Head Loss Equation

Equation (5.1) of Durand and Stepanoff (1969) for head loss for flow of fluid in a pipe with heterogeneous suspension of sediment particles can be used here.

$$\text{Minimum cost (z)}\ h_f = \frac{fLV^2}{2gD} + \frac{81(s-1)C_v fL\sqrt{(s-1)gD}}{2C_D^{0.75}V}$$

(From Equation 5.1)

Where s=ratio of mass (densities of particle and fluid, C_V=Volumetric concentration, C_D= Drag coefficient of particle, and f = friction factor of sediment fluid, D=diameter of pipe.

Other details like friction factor, Reynolds number, kinematic viscosity, drag coefficient of particle, sediment particle Reynolds number and fall velocity are taken from equation number (5.2), (5.3), (5.4), (5.5), (5.6) and (5.7) respectively.

5.6.1.2 Function of Concentration by Weight $f(CW)$

Critical mixture velocity or the critical settling velocity is the limit velocity, below which the particles start to settle. According to Burhan et al. (2014) and Wilson et al. (2006) the relation between critical mixture velocity (V_{CR}), concentration by volume (C_V), particle diameter (d), concentration by weight (CW), $f(CW)$

represent the function of concentration by weight (CW), specific gravity (S_s) and diameter (D) of the pipe can be indicated as follows:

$$V_{CR} = 2966.45 * f(CW) d^{0.75} S_S^{0.75} D^{0.5} \quad (5.9)$$

and $$CW = S_S * (C_V) / (1 + (S_S - 1) * C_V) \quad (5.10)$$

For $0.30 \leq CW < 0.45$,

$$f(CW) = 0.2067\,CW + 1.035$$

(5.11)

For $0.45 \leq CW < 0.55$,

$$f(CW) = 1.5200\,CW + 0.444 \quad (5.12)$$

For $0.55 \leq CW \leq 0.70$,

$$f(CW) = 6.1000\,CW + 2.075$$

(5.13)

The function of concentration by weight $f(CW)$ below 30% is not available in the literature. Taking the asymptotic behaviour into account, for $CW < 0.30$, $f(CW)$ is set equal to 1.097 by Burhan et al. (2014). Here, Specific gravity (S_S) of slurry taken as 1.2 from RENUSAGAR POWER PLANT, U.P.

5.6.1.3 Design Variables

In the GA formulation for test problem, five design variables namely temperature (T), average velocity (V), volumetric concentration (c_V), diameter of pipes (D), roughness height (€) were each represented by a three-bit binary substring have been selected which representing eight possible alternatives as shown in table-5.3. Details of commercially available pipes and roughness height (€) are taken from table-5.4 and table-5.5 respectively.

5.6.1.4 Generation of Initial Population and Objective Function

Generation of initial population and minimisation of objective function have been done in similar way as stated in chapter-5, section-5.3.3 and section-5.3.4 respectively.

5.6.2 Computation of Network Cost Using Matlab Software

A computer programming has been developed in MATLAB platform for getting optimal or near optimal solution for the case study.

a. In GA, the value of five parameters (population size, crossover point, mutation rate, number of iteration and percentage of crossover) necessity to be tuned when it is applied to several optimisation problems (Tolson et al. (2009)). The performance of the GA has been established which is heavily dependent on the parameter values used and appropriate parameter values are dependent on the optimisation problem under consideration. Thus, it requires substantial effort, normally by trial and error, to decide the most appropriate parameter values for GA in order to apply them to various optimisation problems. To establish GA's parameter values trial and error methods is considered.

b. The following parameters has taken. Population size=100 to 300, probability of crossover= 0.2 to 1.0, probability of mutation=0.01 to 0.05, Number of variables (dimension) =5, string length=3.

c. In table-5.9, the population size (150), crossover point (single), and mutation rate (0.05) are kept constant and number of iterations and percentage of crossover changes. It is observed from convergence study (figure-5.4) that fitness value at higher crossover and at higher iteration rate are very close. Crossover as 80% and number of iteration as 300 for further convergence of fitness value have been selected.

Table-5.9 Total Head Loss in Pipe in Meter (Fitness Value)

Number of Iterations	Percentage of Crossover				Remarks
	20	50	80	100	
50	5.2657	5.1342	5.1117	5.1025	population size=150
100	5.1030	5.0521	5.0653	5.0765	Crossover point=1
200	5.0813	5.0512	5.0095	5.0095	
300	5.0095	5.0095	5.0095	5.0095	Mutation rate=0.05
500	5.0095	5.0095	5.0095	5.0095	

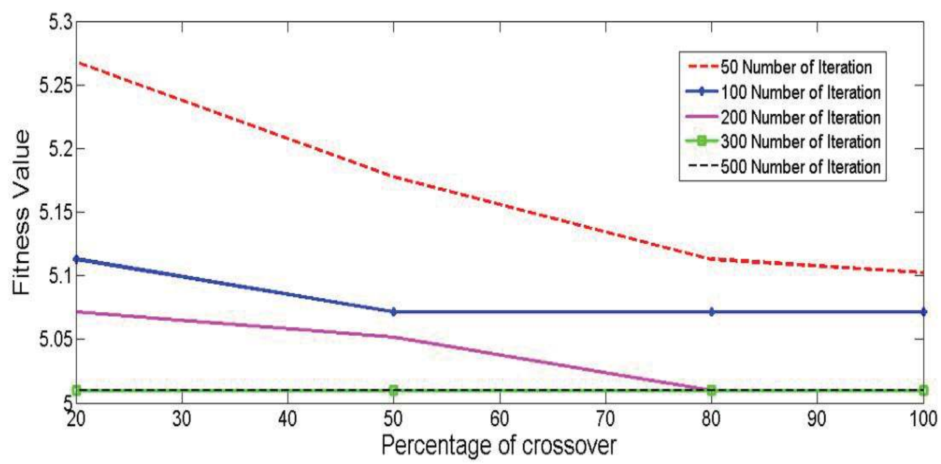

Figure-5.4 Variation of Fitness Value vs. Percentage of Crossover

d. When the number of iteration (300), crossover point (single), and percentage of crossover (80%) are kept constant. For different mutation rates of 0.01, 0.02, 0.03 and 0.05 and population sizes of 100, 150, 200, 300 and 500, the head loss (fitness value) has a constant value of 5.009 meter. Population size as 300 and mutation rate as 0.05 for further convergence of fitness value have been selected.

e. When the number of iteration (300), percentage of crossover (80%) and mutation rate (0.05) are kept constant. For different crossover points

(1-point, 2-point and 3-point) and population sizes 150 and 300, the head loss (fitness value) has a constant value of 5.009 meter. Hence single crossover point has been selected.

However, population size (300), percentage of crossover (80%), number of iteration (300), mutation rate (0.05) and single point crossover have been selected to find the optimum value (minimum value of head loss) of network. The best five solutions are given in table-5.10.

Table-5.10 Best 5 Solutions (Total Head Loss in Meter)

Sl. No	Total Head loss in (meter)	Temperature (T) in Degree Centigrade	Average Velocity (V) m/s	Volumetric Concentration (Cv) in %	Diameter of Pipes (D) In m	Roughness Height (€)	Remarks
1	11.26	10	2.14	10	0.350	4e-05	X^a [10, 50; 1, 3; 0. 10, 0.60]
2	11.11	10.86	2.42	10	0.450	4e-05	X^a [10, 50; 1, 3; 0.10, 0.60]
3	11.43	10	2.43	17.1	0.450	4e-05	X^a [10, 50; 1, 3; 0.10, 0.60]
4	12.06	20.71	2.43	10	0.450	4e-05	X^a [20, 40; 1, 3; 0.10, 0.60]
5	12.58	10.86	2.43	17.1	0.450	4e-05	X^a [10, 40; 1, 3; 0.10, 0.60]

Here, $X^a[x^1, x^2, x^3]$ represent X^a [range of temperature variable (T), range of average velocity variables (V), range of volumetric concentration (Cv)]

The best optimized value in table-5.14 is 11.11 meter (figure-5.5)

Best Cost Results (Total Head Loss, 11.11 meter) Shown in Graph

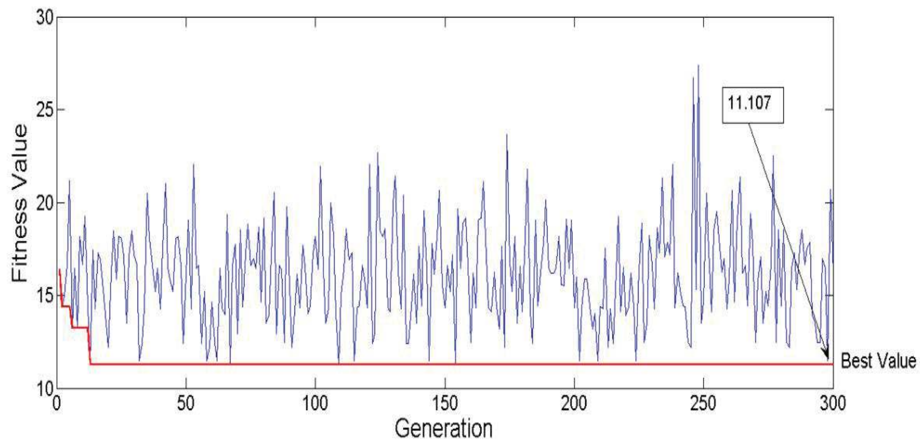

Figure-5.5 Generation vs. Fitness Value (Best Cost Results)

The capacity of pump required for slurry transportation (best optimized value in table-5.14 i.e., 11.11 meter)

$$P = \frac{\rho g Q H}{\eta} \; watt$$

$\rho =$ Density in kg/m^3 (slurry) = 1200 kg/m^3

g= Gravitational force (9.81 m/s^2)

H=Total development head in meter=30 m (assume)

η = Efficiency between 0 and 1

Q= Discharge in pipe (AV)

A= Cross sectional area of pipe (m^2)

V= Velocity of fluid in m/s^2

$A = \Pi d^2 / 4$

Q= [3.14$(0.45)^2$X2.42)]/4 (here, V= 2.42 m/s, d=0.450 meter)

Q=0.385 m^3/s

Power (P) = $P = \frac{\rho g Q H}{\eta}\ watt$ (H=Pressure head in pipe)

P= [1200*9.81*(.385)*30]/0.8 (Assume, Pressure head (H) in pipe is 30 meter)

P= 170KW

P= 170/0.746=228 hp

Pump capacity of 228 horse power is required to transmit the slurry in pipe for optimum friction loss. This can be further modified as per the site conditions. The slurry Pump capacity are available in international market ranging from one to 2000 horse power. The manufacture supply the pump as per customer requirement.

5.7 Results and Conclusion

Five design variables namely Temperature (T), Average Velocity of flow (V), Volumetric Concentration (C_V), Diameter of Pipes (D), Roughness height of the transported material (€), Pipe diameters are the decision variables which are taken here for optimisation problem. To conclude, the optimum design of slurry pipelines is done by using GA. The significant advantages of GA technique is that a set of solutions are produced. So that the decision maker can select the best alternative.

For future research, cost function of the problem can be improved by involving all possible cost parts into the objective function. The genetic algorithms technique is still in research stage and further development can improve the search method for practical problem.

5.8 Some Other Observations

Five design variables namely Temperature (T), Average Velocity of flow (V), Volumetric Concentration (C_V), Diameter of Pipes (D), Roughness height of the transported material (€), Pipe diameters are the decision variables of the optimisation problem. If one fix any four decision variables and make adjustment in fifth variables for minimizing friction loss in pipe. Tables-5.15 to table-5.19 shows the specific observations for selecting the best combination of parameters for designing of the slurry pipe network.

5.8.1 Friction Loss versus Temperature of Fluid

In table 5.11, average velocity of fluid is fixed to 3.0 m/s. Similarly, Pipe material of wrought iron with diameter of 350 mm and fluid solid concentration is fixed to 10%. Only Temperature of fluid can vary between 10 to 50 ^{0}C.

Table-5.11 Best 4 solutions (Total Head Loss in Meter)

Sl. No	Total Head loss in (meter)	Temperature (T) in Degree Centigrade	Average Velocity (V) m/s	Volumetric Concentration (Cv) In %	Diameter of Pipes (D) in m	Roughness Height (€)	Remarks
1	19.704	10	3	10	0.350	4e-05	X^a [10, 40], V=3, Cv =0.1, D=350, wrought iron is fixed
3	20.223	20	3	10	0.350	4e-05	X^a [20, 40], V=3, Cv =0.1, D=350, wrought iron is fixed
4	23.112	40	3	10	0.350	4e-05	X^a [40, 50], V=3, Cv =0.1, D=350, wrought iron is fixed

Observation

- The head loss in pipe network is proportional to temperature of fluid. It is also verified by the equation (5.4), as temperature of fluid increases, the value of kinematics viscosity decreases that leads to enhancement of Reynolds's number (equation-5.3), that further increases the friction factor of pipe (equation-5.2) that finally increases the head loss in the pipe (equation-5.1).

5.8.2 Friction Loss vs. Volumetric Concentration (Cv)

In table 5.12, average velocity of fluid is fixed to 3.0 m/s. Similarly, Pipe material of wrought iron with diameter of 350 mm and fluid temperature is fixed to 10 ^{0}C. Only solid concentration can vary between 10% - 60%.

Table-5.12 Best 4 Solutions (Total Head Loss in Meter)

Sl. No	Total Head Loss in (meter)	Temperature (T) in Degree Centigrade	Average Velocity (V) m/s	Volumetric Concentration (Cv) In %	Diameter of Pipes (D) in m	Roughness Height (€)	Remarks
1	19.773	10	3	10	0.350	4e-05	Cv [0.10, 0.6],V=3, T=10, D=.350,wrought iron is fixed
2	21.220	10	3	20	0.350	4e-05	Cv [0.20, 0.6],V=3, T=10, D=.350,wrought iron is fixed
3	22.667	10	3	30	0.350	4e-05	Cv [0.30, 0.6],V=3, T=10, D=.350,wrought iron is fixed
4	NA*	10	3	NA	0.350	4e-05	Cv [0.40, 0.6],V=3, T=10, D=.350,wrought iron is fixed

NA*- Results is outside the feasible region when concentration has increased from 30 to 40 %.

Observation

- It is observed from the table that as the concentration increases the head loss is also increasing. i.e., the head loss in pipe network is proportional to concentration of fluid. Sl. No.4 in above table suggests that solution is not possible at higher concentration (40% and above) that satisfy all the constraints while fixing the temperature of fluid at 10 ºC, velocity of flow at 3.0 m/s, Wrought iron pipe with diameter of 350 mm.
- One can note that by changing other variables values like temperature of fluid, velocity of flow, pipe diameter, pipe materials the flow is possible at higher concentration of slurry while satisfying all the constraints.

5.8.3 Friction Loss vs. Average Flow Velocity (V)

In table 5.13, average velocity of fluid is can vary between 1.0 m/s to 3.0 m/s. Pipe material of wrought iron with diameter of 350 mm and fluid temperature is fixed to 10 ^{0}C. The solid concentration is also fixed to 10%.

Table-5.13 Best 3 Solutions (Total Head Loss in Meter)

Sl. No	Total Head Loss in (meter)	Temperature (T) in Degree Centigrade	Average Velocity (V) m/s	Volumetric Concentration (Cv) In %	Diameter of Pipes (D) in meter	Roughness Height (€)	Remarks
1	11.750	10	2.143	10	0.350	4e-05	V [01, 03], T=10, Cv =0.1, D=0.350, wrought iron is fixed
2	19.773	10	3	10	0.350	4e-05	V= 03, T=10, Cv =0.1, D=.350, wrought iron is fixed
3	49.772	10	5	10	0.350	4e-05	V [05, 03], T=10, Cv =0.1, D=.350, wrought iron is fixed

Observation

- It is observed from the table that as the velocity of fluid increases the head loss is also increasing. i.e., the head loss in pipe network is proportional to square of velocity of fluid.

5.8.4 Friction Loss vs. Diameter of Pipe (D)

In table 5.14, average velocity of fluid is fixed to 3.0 m/s. Pipe material of wrought iron with diameter vary from 350 mm to 500 mm and fluid temperature is fixed to 10 ^{0}C. The solid concentration is also fixed to 10%.

Table-5.14 Best 3 Solutions (Total Head Loss in Meter)

Sl. No	Total Head loss in (meter)	Temperature (T) in Degree Centigrade	Average Velocity (V) m/s	Volumetric Concentration (Cv) In %	Diameter of Pipes (D) in meter	Roughness Height (€)	Remarks
1	19.77	10	3	10	0.350	4e-05	V=3, T=10, Cv =0.1, wrought iron is fixed, D[150,200,250,300, 350,400,450,500]
2	15.14	10	3	10	0.450	4e-05	V=3, T=10, Cv =0.1, wrought iron is fixed, D[150,200,250,300, 350,400,450,500]
3	13.59	10	3	10	0.500	4e-05	V=3, T=10, Cv =0.1, wrought iron is fixed, D[150,200,250,300, 350,400,450,500]

Observation

- It is observed from the table that as the diameter of pipe increases the head loss is decreasing. i.e., the head loss in pipe network is inversely proportional to diameter of pipe.

5.9 Discussion and Conclusion

The GA is proposed for optimal design of slurry pipe network. Simple, three-operators of genetic algorithm namely reproduction, crossover, and mutation have been used. Results show that the genetic algorithm techniques are very effective in finding near-optimal or optimal solutions for case study network.

a. The head loss in the pipe network is proportional to the temperature, concentration and average velocity of fluid but it is inversely proportional to the diameter of pipe.

b. On the basis of optimal solution, a new design table (table 5.10) for selection of different parameters of pipe network system has been proposed here, for practicing engineer. The above said table shows only few results. Many other results can be achieved similarly by the proposed technique for different ranges of variables (temperature, average velocity of liquid, volumetric concentration of slurry, pipe sizes and pipe material) as per the particular industry requirement. The significant advantages of GA technique are that a set of solutions are produced. So that the decision maker can select the best alternative.