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An Optimization Approach on Seven Layers Water Filtration Plant Using Genetic Algorithm

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Abstract

This study gives a description about the development and optimization of water filtration process in a filter plant of a dam using genetic algorithm (GA) to the well known problem of least-cost design of the system. GA methodology is an evolutionary process, basically imitating evolution process of nature. GA optimization is also well suited for optimization of water distribution systems, especially large and complex systems. GA is essentially an efficient search method basically for nonlinear optimization cases. This paper envisages the optimization of seven layers of filter plant, supplying water to the city for daily consumption. The primary objective of this study is optimization of a water filtration distribution network by GA.

The operators involved in the program algorithm are generation, selection, elitism, crossover and mutation. Multipoint crossover and higher rates are advisable. Also pressure penalty parameters are found to be much important than velocity parameters. Below pressure penalty parameter is the most important one and should be so many times higher than the other.

Keywords: Genetic algorithm, Optimization, Water filtration, Elitism, Mutation.

Introduction

A water distribution system is an essential infrastructure that conveys water from the source to the consumers. A typical water distribution system consists of filter units, pumps, tanks, reservoirs and valves. System is mainly designed considering a demand pattern, pressure limitations, velocity limitations, quality assurances and maintenance issues at minimum cost, which can be named as optimal design. Simulation of hydraulic behavior within a pressurized, looped filtration network is quite a complex task, which effectively means solving a number of nonlinear equations. The solution process involves simultaneous consideration of the energy and continuity equations and the head loss function. Even in a small network of seven layer filter, comprising pumps, valves and tanks, there are millions of combinations for the design depending of commercially available products. Traditionally, the design of water filtration networks has been based on the designer’s experience. Several trials are run by changing seven layers until an economically feasible solution is reached that meets the design criteria in regard to the hydraulic conformity. For this kind of applications; designer’s experience, budget and duration of the design period are very important. Success of the modeling is mostly governed by these criteria. Because of time limitations, most of the time, proposed design standards are not fulfilled by a least-cost design. The construction of a large water filtration system costs too much money; that’s why designers are looking for various techniques to reach the optimal design for years. That is where optimization comes into the picture. Main optimization techniques are used to get optimal design of a water filtration system are linear programming, nonlinear programming, and various enumeration techniques. In this optimization study, problem is defined as minimizing the total cost, subjected to both pressure and velocity constraints in the presence of given nodal demands. Since optimization of a water filtration network is rather complicated due to nonlinear relationship between parameters, former optimization techniques have some disadvantages and difficulties.

Literature Review

A Genetic Algorithm is a member of a class of search algorithms based on artificial evolution (Holland,

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1975) [1]. Genetic algorithm is the implementation of Darwin's evolution theory in optimization applications. In this method, the variables are presented as numbers on a string called genes and chromosomes respectively. With the help of some mathematical operations, chromosomes are evolved during generations according to their fitness's. The "fitness" evaluation is based on how well the trial solution meets the "objective function" in terms of defined goals (i.e. lowest cost or highest reliability) of the optimization [2]. In each generation, chromosomes with better fitness values survive; on the other hand, weakest chromosomes are eliminated due to their low fitness's. Natural selection ensures that chromosomes with better fitness will propagate in the next populations.

Mechanism of Genetic Algorithm

Specific parts of the genetic algorithm which have special function are called operators. In its simplest form, a genetic algorithm consists of three basic operators:

• Selection
• Crossover
• Mutation

In addition to these basic operators, **Generation** operator creates the initial population of chromosomes. Also, **Elitism** operator is used in this study which prevents the loss of successful individual chromosomes. These operators are applied to the current generation to form the next generation. Genetic algorithm continues until the design criteria have been reached which is defined by the user at the beginning of the project. At first, the population is evaluated and their fitness's are determined. Then, successful individuals are selected and they replaced the unsuccessful ones [3].

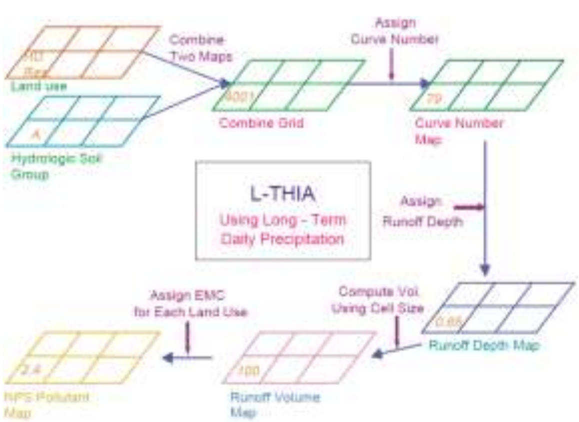

Figure 1: Overview of seven layers system.

Augmentation of the Capacity of an Existing Filtering Plant.

Some of the existing slow sand filtration plants need augmentation. There is a tendency to abandon the old plants and substitute the same with Rapid sand Filtration plants. It is suggested that wherever possible the old slow sand Filtration plants may be retained on account of the following reasons:

- Slow sand filter is less likely to go wrong under inexperienced operation.
- It does not require skilled attendance.
- Head consumed is less.
- It provides greater reliability of the removal of bacteria.
- Operating costs may be less.

It is, however, adapted to waters low in color, turbidity and bacterial count. Under such circumstances, provision of a roughing filter as a pretreatment unit gives good results [4].

Rapid Sand Filtration Plant

The pretreatment units which form essential parts of a Rapid sand filtration unit include

- Coagulation and flocculation with rapid mixing facilities and
- Sedimentation units.

Coagulation and Flocculation

The purpose of coagulation and flocculation is to remove particulate impurities, especially non settable solids (particularly colloids) and color from the water being treated. Non-settable particles in water are removed by the use of coagulating chemical [5].

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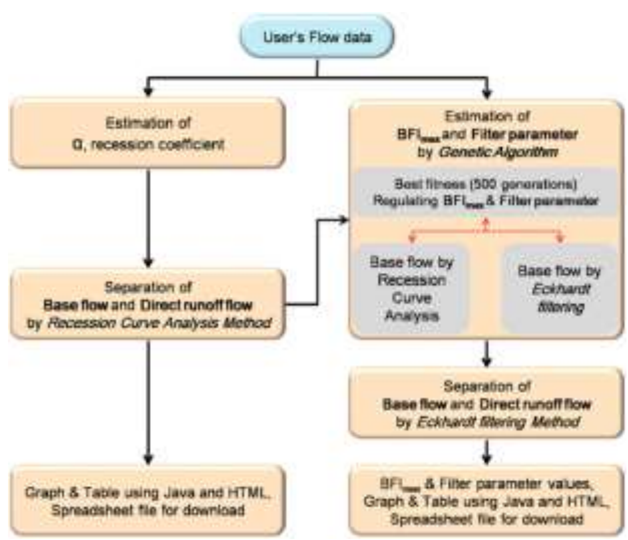

Figure 2: BFI_{max} GA-Analyzer module developed to determine optimum BFI_{max} value and filter parameter

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Trihalomethane formation in direct chlorination of turbid water Pre-treatment of water using cloth filtration and settling/decanting before chlorination have been investigated as potential trihalomethane (THM) mitigation strategies. The study documented that addition of sodium hypochlorite to six source waters of turbidity 4.23–305 NTU did not lead to formation of THM levels that exceeded WHO guideline values for any of the four individual THMs or the additive total THM (TTHM) ratio guideline value [6]. Neither pre-treatment procedure was effective at reducing TTHM concentrations in chlorinated water compared with chlorination-only controls. These are not unexpected results; as THM precursor compounds have been identified as primarily organic carbon particles smaller than 0.45 mm in size [7], it is unlikely that gross filtration mechanisms would remove such small particles. Filtration through sand was not investigated as a potential THM mitigation strategy. Further investigation of the efficacy of using locally available water clarification methods for pre-treatment was recommended.

Locally Available Physical Water Filtration options

Several practical and inexpensive methods for water clarification are available to populations in developing countries who are targeted by point-of-use water treatment intervention program such as the SWS. This study investigated three locally available and commonly utilized physical water clarification methods—cloth filtration, settling/decanting and sand filtration—in laboratory controlled circumstances to determine whether use of these mechanisms reduced turbidity and chlorine demand before chlorination. Investigations of chemical water clarification methods, such as the use of alum and moringa seeds, are ongoing and data is not considered herein. Even though two of these physical water clarification methods have been shown not to reduce THM formation potential, the reduction of turbidity and chlorine demand before chlorination can provide important sensory benefits that may enhance consumer acceptance of treated water and SWS program implementation. Reduction of turbidity would cause a visual improvement in the treated water that could help encourage correct and consistent use among SWS users. Reduction of chlorine demand would allow the use of a lower dosage of sodium hypochlorite, which could increase taste acceptability and reduce the cost of treatment.

Once the initial population is generated, the Genetic Algorithm will translate each gene into the corresponding variable [8] and compute the objective function (i.e. total cost). Once the objective function is achieved, an analysis will then be performed for each chromosome of the population and performance deficiencies will be determined. These deficiencies are defined at the set up stage of the problem. For example, obtaining an acceptable pressure at the nodes within defined pressure interval or obtaining an acceptable velocity at the pipes within defined velocity range will not imply any total cost. On the other hand, genetic algorithm assigns a total cost to each solution (i.e. Million of Rupees for each headloss) which does not satisfy predefined user criteria. Each individual's fitness is determined by dividing its penalty value over total penalty values [9].

Table 1: Chemical coagulants used in the treatment process

Name	Formula	Coagulant Primary/Aid
Ferric alum	$(AlFe)^2(SO4)^3$ H_2O Value of X can be 18-24	Primary
Poly Aluminum Chloride	$Al_2(OH)nCl_6$ — n·xH2O]m (m≤10, n=3~5)	Primary
Ferric Chloride	$Fecl_3$	Primary
Calcium Hydroxide	Ca(OH)2	Primary/Aid
Calcium Oxide	CaO	Primary/Aid

Operators Used in the Process of Filtration

Selection

This operator is used to eliminate the worst chromosomes due to their low fitness's. Once their objective functions are determined at the earlier stage, a certain number of chromosomes with worst fitness's are replaced by the same number of best chromosomes.

Elitism

Elitism is used to protect the fittest chromosomes from crossover and mutation operations. The objective is to have some of the best fittest chromosomes as they are in the next generation and not to loose them. Elitism can rapidly increase the performance of Genetic Algorithm.

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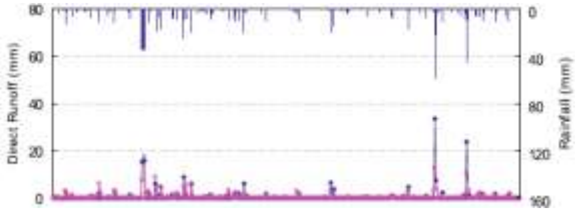

Figure 3: Comparison of L-THIA estimated direct runoff with BFLOW filtered direct runoff.

Crossover

The crossover operator is applied in order to initiate a partial exchange of bits (information) between parent strings to form two offspring strings. Genetic Algorithm will randomly pick two solutions for breeding. Total number of crossover rate is defined by the user at the beginning of the study. Most popular crossover types are single point, two points and multi points crossovers as shown in the figures below. Note that all crossover points are randomly selected.

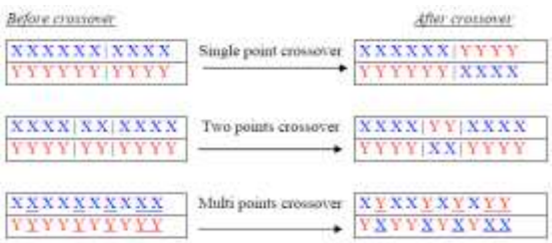

Figure 4: Cross over Operator

Mutation

In order to truly imitate the genetic process, a mutation operator needs to be incorporated to the random mistakes committed by nature. By occasionally flipping some of the gene values, the mutation operator allows the introduction of new features into the pool. In the genetic algorithm process, some alternatives in the genetic pool may disappear which may lead to the final solution (i.e. all numbers in a column could be the same). Therefore, introducing the mutation operator creates the chance to catch these alternatives again. We select the mating pool of the next generation by spinning the weighted roulette wheel four times. Actual simulation of this process using coin tosses has resulted in string 1 and string 4 receiving one copy in the mating pool, string 2 receiving two copies, and string 3 receiving no copies as shown in Table below. Comparing actual number of copies with the expected number of copies, it is obtained that it should be expected that the fittest chromosomes gets more copies, the average stays even, and the worst dies off.

Table 2 – Genetic Algorithm Illustration, Round 1

String Id	Initial Population	x Value	f(x)	pselect$_i$	Expected count	Actual count
	(Randomly generated)	(Integer)	x^2	$f_i / \Sigma f$	$f_i / \bar{f}$	
1	0 1 1 0 1	13	169	0.14	0.58	1
2	1 1 0 0 0	24	576	0.49	1.97	2
3	0 1 0 0 0	8	64	0.06	0.22	0
4	1 0 0 1 1	19	361	0.31	1.23	1
Sum			1170	1.00	4.00	4
Average			293	0.25	1.00	1
Maximum			576	0.49	1.97	2

Having a pool of strings, it is observed that simple crossover proceeds in two steps: (1) strings are mated randomly, using coin tosses to pair off the couples, and (2) mated string couples crossover, using coin tosses to select the crossing sites. Single point crossover is applied in this example

Table 3 – Genetic Algorithm Illustration, Round 2

Mating Pool After Reproduction	Mate	Crossover Site	New Population	x Value	f(x)
(Cross site shown)	(Random)	(Random)			x^2
0 1 1 0 | 1	2	4	0 1 1 0 0	12	144
1 1 0 0 | 0	1	4	1 1 0 0 1	25	625
1 1 | 0 0 0	4	2	1 1 0 1 1	27	729
1 0 | 0 1 1	3	2	1 0 0 0 0	16	256
Sum					1754
Average					439
Maximum					729

Results and discussion

Turbidity reduction

All turbidity samples were tested in triplicate to ensure accuracy; results were averaged for reporting purposes. The average percentage error of these samples was 2.4%, with a minimum of 0.0%, a maximum of 7.9% and a standard deviation of 1.7%. The actual laboratory initial turbidity values were, on average, within 4.7% of the intended turbidity values of 10, 30, 70, 100 and 300 NTU. The minimum error from intended turbidity was 0.1%, the maximum error was 18.3% and the standard deviation was 4.5%. One outlier in the control buckets was discarded from this analysis. After cloth filtration, turbidity was reduced by a minimum of 20.8% at initial turbidity of 10NTU to a maximum of 59.8% at initial turbidity of 300NTU (Table 2). Turbidity was reduced by a consistent 78.4–87.5% in all samples settled and decanted. After sand filtration, turbidity was reduced by a minimum of 57.0% at 10NTU to a maximum of 98.5% at initial turbidity of 300 NTU.

Chlorine demand reduction

After clarification, chlorine dosages of 1.875 and 3.75mg/l were added to the two buckets that had been clarified from each initial turbidity value. A chlorine dosage of 1.875mg/l was directly added to non-clarified water to serve as the control. A single control was deemed sufficient for each test, and as such a 3.75mg/l control was not conducted. Free chlorine residual was monitored for 24 hours after chlorine addition in each bucket. A representative example result from one of the individual tests, showing free chlorine decay over time in the 1.875mg/l dose control, the 1.875mg/l dose after sand filtration, and the 3.75mg/l dose after sand filtration at 100NTU initial turbidity. As can be seen, free chlorine residuals in both the control and the sand filtered water decayed over time. Thus, for further analysis in this paper, only the results from the 1.875mg/l dosages will be used to compare control versus clarification method results. In addition, only the free chlorine residual results at 24 hours after chlorine addition will be depicted, because the goal of the CDC Safe Water System program is to maintain a maximum of 2.0mg/l free chlorine residual 1 hour after chlorine addition and a minimum of 0.2mg/l free chlorine residual 24 hours after chlorine addition. Because only the 1.875mg/l dosage will be used for further analysis, it is not possible for greater than 2.0mg/l of free chlorine residual to be present at any point.

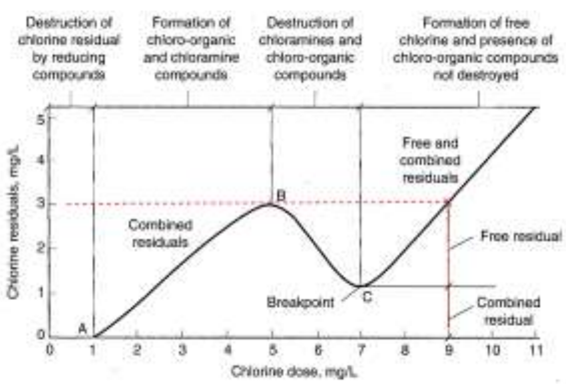

Figure 5: Chlorine dose residual break point

Cloth filtration

Across all initial turbidity values, free chlorine residual was not maintained (P = 0.30) at a higher level in water clarified with cloth filtration before chlorination than in water that was not clarified.

Settling/decanting

Across all initial turbidity values, free chlorine residual was maintained at a significantly (P = 0.005) higher level in waters clarified with settling/decanting before chlorination than in unclarified water. Compared with controls, the increase in free chlorine residual level unsettled/decanted water 24 hours after chlorination ranged from 0.23mg/l at 10NTU to 0.85mg/l at 300NTU

Sand filtration

Free chlorine residual was maintained at a significantly (P = 0.002) higher level in waters clarified with sand filtration before chlorination than in unclarified water across all initial turbidity values (Figure 4). Compared with controls, the increase in free chlorine residual level in sand filtered water at 24 hours after chlorination ranged from 0.41mg/l at 10NTU to 1.11mgl21 at 300NTU

Conclusion

Diarrhoeal diseases kill an estimated 1.9 million people each year, and point-of-use chlorination with sodium hypochlorite is a proven intervention that can reduce diarrhoeal disease incidence and protect health in developing countries. Implementation of SWS program in areas with turbid water has been complicated by unanswered questions regarding correct sodium hypochlorite dosage, potential THM risk and user acceptability. Two locally available water clarification mechanisms, sand filtration and settling/decanting, were found to be effective at reducing turbidity and chlorine demand when used before chlorination of turbid waters. Cloth filtration was shown to reduce turbidity, but not chlorine demand. The recommended sodium hypochlorite dose after sand filtration or settling/decanting is 1.875mgl21, and after cloth filtration is 3.75mgl21. These pre-chlorination clarification mechanisms can be recommended by implementing organizations to improve the effectiveness, increase the acceptability and reduce the cost of chlorinating turbid water at the household level.

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