Parameterization and Validation of the Physical Coefficients of a WDNs by BBO

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***Abstract* -The pipeline system is the most important part of the transportation of potable water. In other words, pipes are the most important component of the water distribution system. Because of several factors, they suffer from holes in which water is lost, and therefore an economic loss to states and humanity. Responsible for the water distribution networks always try to minimize the damage. By working to find the most effective way to detect leaks in these networks. This article centers on a mathematical model of a hydraulic system that aims to locate leakage in water transmission pipes. Several optimization techniques can be used. We opted for the BBO (biogeography-based optimization) method because of its performance, in particular the execution time of its algorithm. Using this method, two parameters of the model (friction and effective flow area factor) are determined to obtain the exact position of the leak.**

***Keywords*-leakage, pipeline, localization, BBO, friction, viscosity.**

I-INTRODUCTION

Non-destructive testing methods include the discipline of leak detection. Due to the fluid's limited availability and ability to cause harm around the leaking point, numerous techniques for detection and localization have been developed. A leak is a passage of liquid via a hole in a pipe wall. [1,2,3]. More than 32 billion cubic meters of treated water are wasted annually due to urban water supply systems around the world, according to World Bank research, with half of these losses taking place in developing nations. [4]. To solve these problems or at least reduce them, researchers have suggested several ways of leak detection. One is mentioned in [5]. The most often used field tests are flow direction indicators, tracer gases, earth sensitivity changes, subsurface radar, infrared spectroscopy, microphones, odorant and radioactive tracers, and tracer gases. In those early phases, the majority of pipeline leak detection techniques were straightforward and easy to use [6]. Leakage detection techniques can be broadly categorized into three groups: HIL-based approaches, SIL-based methods, and hybrid methods [7]. To find pipe leaks:

- HIL-based algorithms mainly analyze data collected by specialized sensor devices.

- In contrast, SIL-based methods emphasize the use of various software and simulation tools to model leaks and create integrated leakage detection models.

- A third category combines SIL-based and HIL-based leak detection techniques by gathering and evaluating data from sensors and leaking models.

The various techniques under each category are compiled in figure.1.

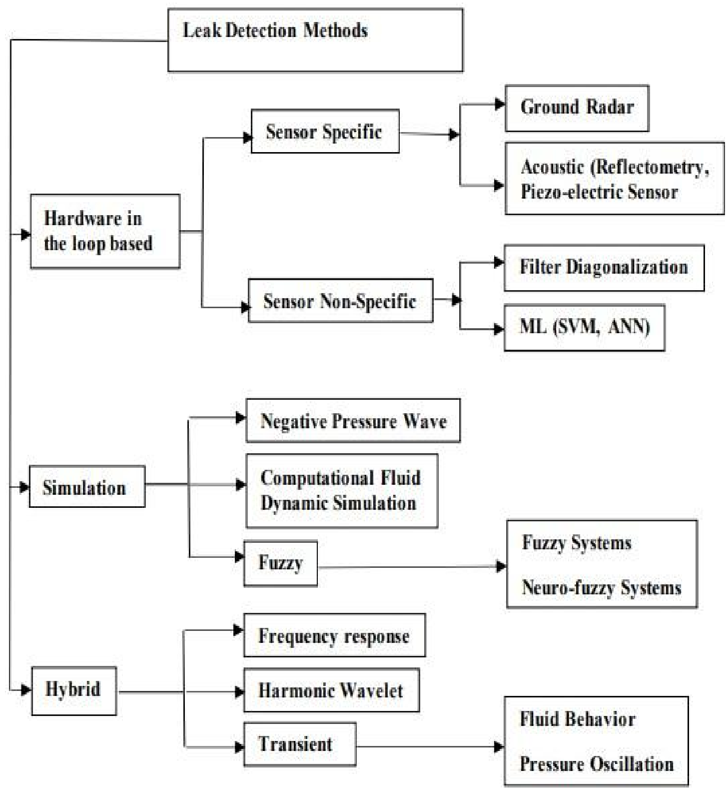

Fig.1. List of Leak Detection Techniques [7]

In this work, Unidimensional flow analysis is the foundation of the developed approach [5]. A model has been created to anticipate where leaks in pipes may occur using transient calculations. To improve the outcome of this model and to obtain a good localization, we optimize his parameters by using a recent method called, biogeography-based optimization (BBO).

II-Biogeography-Based Optimization Algorithm (Bbo)

Charles Darwin and Alfred Wallace, two nineteenth-century naturalists, are credited with developing the field of biogeography. Biogeography was primarily descriptive and historical up until the 1960s. The Theory of Island Biogeography, a classic work by Robert MacArthur and Edward Wilson published in 1967, was the result of their early 1960s collaboration on mathematical models of biogeography, 25,452 papers on the topic of biogeography were published in the year 2005. Dan Simon presented the novel evolutionary algorithm (EA) known as "biogeography-based optimization" in 2008. [8].

Species migration facilitates information transfer through BBO, an evolutionary process. To achieve information sharing is based on the migration and emigration of species between islands. [9]. Each island serves as a representation of a potential solution, with a good issue solution being one that includes a large number of favorable biotic (living) and abiotic (non-living) variables that draw more species to the island than those on other islands [8]. The suitability index variable (SIV), the independent variable of such a problem in BBO, is the name given to each characteristic. The island suitability index (ISI), which varies in tandem with these traits, is the dependent variable in BBO. The following is a problem with n-independent variables and k-islands or individuals: [10]:

$$\mathrm{ISI_i} = \mathrm{f}(\mathrm{SIV_1}, \mathrm{SIV_2}, \ldots \mathrm{SIV_n}) \quad \mathrm{i} = 1,2, \ldots.\mathrm{k} \tag{1}$$

BBO has two main sections: migration, mutation, and an optional section is elitism. Figure.2 represents the species migration model of an island, based on a number of species [11].

S_0: is the equilibrium species count.
S: is the number of species.
E and I are the maximum possible immigration and emigration rates, respectively.
λ and μ are the immigration rate end the emigration rate, respectively.

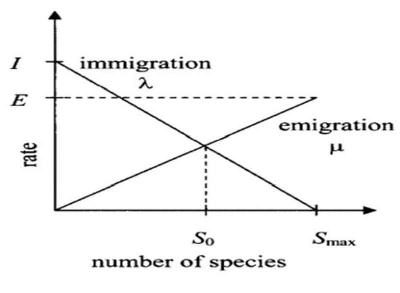

Fig.2. Species migration model of an island, based on a number of species [12].

The variation from $p_s(t)$ to $p_s(t+\Delta t)$ can be described as:

$$p_s(t+\Delta t) = p_s(t)(1-\lambda_s\Delta t - \mu_s\Delta t) + p_{s-1}(t)\lambda_{s-1}\Delta t + p_{s+1}(t)\mu_{s+1}\Delta t \tag{2}$$

Where

$$\mu_s = \frac{E}{S_{max}} S \qquad , 0 < \mu_s < 1 \tag{3}$$

$$\lambda_s = 1 - \mu_s = \mathrm{I}\,(1 - \frac{s}{s_{max}}) \tag{4}$$

II.1. Migration

The migration process employs high ISI islands as a source of modification to share their properties with low ISI islands, allowing the suboptimal solutions to be probabilistically enhanced and perhaps even overcome those that are superior [10].

II.2. Mutation

According to the island theory, certain outside factors can cause the species' equilibrium point to diverge substantially. The total number of species will sharply decline as a result of occurrences like predators from neighboring islands, tsunamis, volcanoes, illnesses, or earthquakes [12]. Mutation rate m can be calculated as:

$$\mathrm{m} = \mathrm{m_{max}}\left(1 - \frac{\mathrm{p_s}}{\mathrm{p_{max}}}\right) \tag{5}$$

m_{max} is a maximum mutation rate that m can reach, which is set by the user, and $p_{max} = \max(p_s)$

II.3. Elitism

After the processes of mutation and migration, there is a strong likelihood that the finest habitats will have vanished after the formation of new populations. We employ the elitist method to rule this possibility out. It understands that the next generation will mimic one or more of the better habitats. This elitism prevents the most successful person from dissipating during replacement. [13].

II.4. BBO algorithm

The BBO algorithm is given by [13]:

start

Generate a random set of initial solutions (islands).

while the stop criterion is not **do**

Rank the solutions based on their fitness (HSI).

Calculate the number of species S, the rate of λ_s immigration and emigration μ_s for each solution.

This phase is optional; however, it involves starting the elitist process to save the best ideas needed for the following generation.

Modify islands on a migration basis.

Mutation.

End **while**

end

Algorithm.1: standard BBO algorithm.

The General Flow Chart of the BBO algorithm is given in Figure.3.

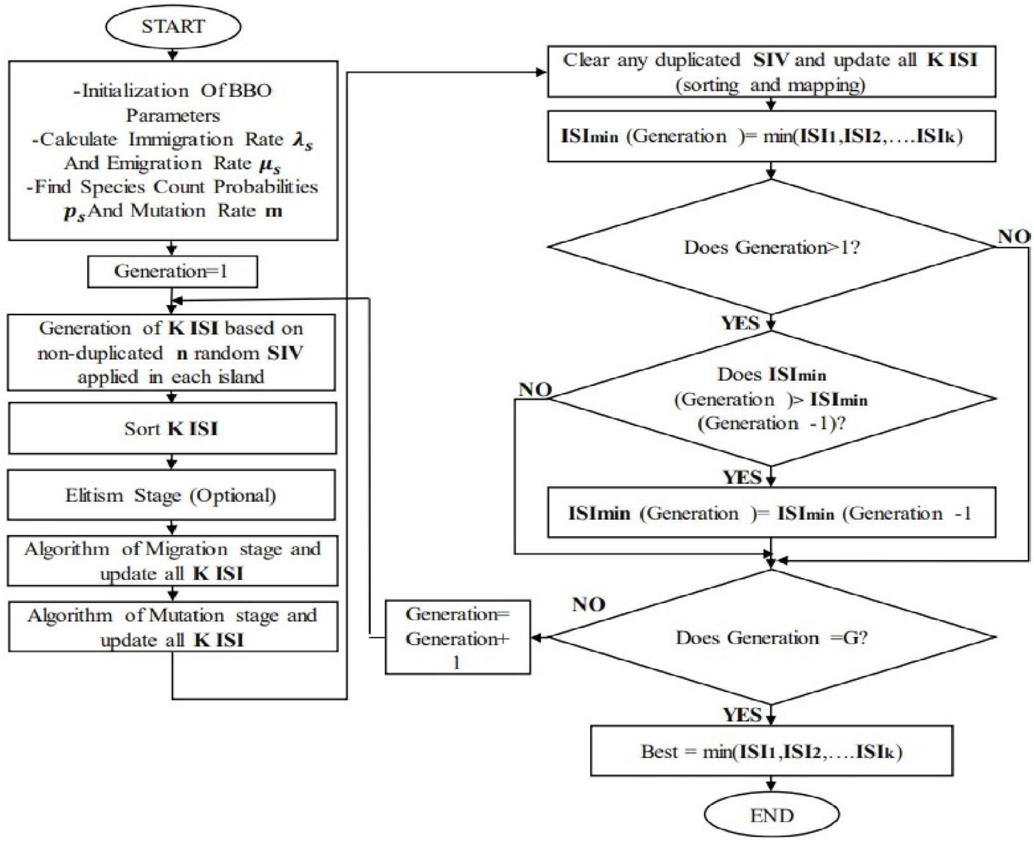

Fig.3. General Flow Chart of BBO Algorithm.[10]

III. MATHEMATICAL MODEL

In this section, we demonstrate the constituent equations of the thoughtful mathematical model. The system is illustrated in Figure.4 [5].

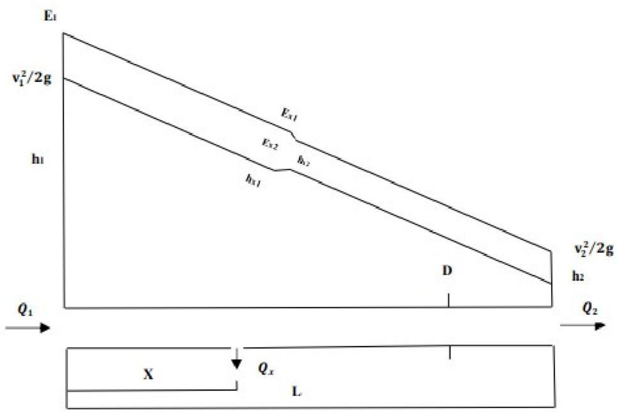

Figure .4. The flow situation under consideration [5].

F_1 : Flow at the inlet.
z_1 : inlet piezo-metric level.
F_2 : Flow rate at the pipe outlet.
z_2 : Piezo-metric level at the outlet.
F_x : Current flowing out of the hole.
z_{x1} : Piezo-metric level just in front of the hole.
z_{x2} : Piezo-metric level just behind the hole.

$(c_d A_x)$: actual flow area

x: Leak point measured from inlet section.

$$E_i = z_i + v_i^2/2g \tag{6}$$

We have nine variables that we need to know to get the exact location of the leak site based on the mathematical model. Five equations are required to address the issue if the discharge and pressure are measured at the pipe's intake and output.

For the resolution of the problem, five equations are necessary if the flow and the pressure are measured at the inlet and the outlet of the pipe.

1. Continuity equation

$$F_1 - F_2 = F_x \tag{7}$$

2. The frictional losses at the length x, upstream from the hole may be expressed as follows:

$$z_1 - z_{x1} = f_1 \frac{X}{D}\frac{F_1^2}{A^2 2g} = K_1 x F_1^2 \tag{8}$$

3. The frictional losses in the section of the pipe with length L- x downstream from the hole may be represented as follows:

$$z_{x2} - z_2 = f_2 \frac{X}{D}\frac{F_2^2}{A^2 2g} = K_2 (L - x) F_2^2 \tag{9}$$

4. The equation describing the flow through an orifice is used to determine the discharge through the hole.

$$\mathrm{F_x = c_d A_x \sqrt{2gE_{x1}}} \quad (10)$$

5. Using the system under consideration and the overall energy balance, the total energy lost in the hole E_{TL} is

$$E_{TL} = \mathrm{F_1E_1 - F_2E_2 - F_1(E_1 - E_{x1}) - F_2(E_{x2} - E_2)} \quad (11)$$

According to the preceding equation, which holds for an incompressible flow, the total energy lost in the hole is equal to the total energy minus the sum of the total energy out plus the total energy lost in the portions of the pipe before and after the hole, respectively. After using algebra, we obtain

$$E_{TL} = \mathrm{F_1E_{x1} - F_2E_{x2}} \quad (12)$$

If the flow is gushing to the atmosphere:

$$E_{TL} = \mathrm{(F_1 - F_2)\, v_x^2/2g} \quad (13)$$

Where

$$\mathrm{v_x = F_x/c_dA_x} \quad (14)$$

v_x: The fluid's exit velocity from the hole.

We readily demonstrate that by substituting for v_x in terms of the discharge per unit effective flow area via the hole, we may readily demonstrate that

$$E_{TL} = \mathrm{C(F_1 - F_2)^3} \quad (15)$$

Where

$$\mathrm{C = 1/2g(c_dA_x)^2} \quad (16)$$

Combining the two E_{TL} equations, representing the constant, and defining E_{x1} and E_{x2} in terms of the corresponding sums of the static and dynamic head.

We put $B = 1/2gA^2$

The two expressions of E_{x1} and E_{x2}

$$\mathrm{E_{x1} = z_{x1} + v_1^2/2g} \quad (17)$$

$$\mathrm{E_{x2} = z_{x2} + v_2^2/2g} \quad (18)$$

The flow rate can be calculated using the follows

$$\mathrm{F = V.A} \quad (19)$$

One replaces equation (19) in (17) and (18)

$$\mathrm{E_{x1} = z_{x1} + BF_1^2} \quad (20)$$

$$\mathrm{E_{x2} = z_{x2} + BF_2^2} \quad (21)$$

Multiply equations (20) and (21)in F_1 and F_2 respectively

$$\mathrm{F_1E_{x1} = F_1z_{x1} + BF_1F_1^2} \quad (22)$$

$$\mathrm{F_2E_{x2} = F_2z_{x2} + BF_2F_2^2} \quad (23)$$

(22) Minus (23)

$$\mathrm{F_1E_{x1} - F_2E_{x2}} = F_1z_{x1} - F_2z_{x2} + (F_1 - F_2)(BF_1^2 + BF_2^2 + BF_1F_2) \quad (24)$$

Equality between the two equations (15)and (24) we get

$$\mathrm{F_1z_{x1} - F_2z_{x2} + (F_1 - F_2)(BF_1^2 + BF_2^2 + BF_1F_2) = C(F_1 - F_2)^3}$$

$$\mathrm{= (F_1 - F_2)[CF_1^2 + CF_2^2 - 2CF_1F_2 - BF_1^2 - BF_2^2 - BF_1F_2]}$$

$$\mathrm{= (F_1 - F_2)[(C - B)F_1^2 - (2C + B)F_1F_2 + (C - B)F_2^2]}$$

$$\mathrm{= \lambda(F_1 - F_2)}$$

One gets

$$F_1z_{x1} - F_2z_{x2} = (F_1 - F_2)[(C - B)F_1^2 - (2C + B)F_1F_2 + (C - B)F_2^2] = \lambda(F_1 - F_2) \quad (25)$$

$$\lambda = (C - B)F_1^2 - (2C + B)F_1F_2 + (C - B)F_2^2$$

Through equations (8) and (9) we conclude

$$\mathrm{z_{x1} = z_1 - K_1}x\mathrm{F_1^2} \quad (26)$$

$$\mathrm{z_{x2} = z_2 + K_2(L - }x\mathrm{)F_2^2} \quad (27)$$

Multiply equations (26) and (27)in $F_1$and F_2respectively

$$\mathrm{z_{x1}F_1 = z_1F_1 - K_1}x\mathrm{F_1F_1^2} \quad (28)$$

$$\mathrm{z_{x2}F_2 = z_2F_2 + K_2F_2(L - }x\mathrm{)F_2^2} \quad (29)$$

(28) Minus (29)

$$z_{x1}F_1 - z_{x2}F_2 = z_1F_1 - K_1xF_1F_1^2 - z_2F_2 - K_2F_2(L - x)F_2^2$$

$$= (F_1 - F_2)\lambda = \lambda F_1 - \lambda F_2$$

$$\mathrm{\lambda F_1 - \lambda F_2 - z_1F_1 + z_2F_2 + K_2F_2LF_2^2 = x(K_2F_2F_2^2 - K_1F_1F_1^2)}$$

$$x = \frac{\mathrm{\lambda F_1 - \lambda F_2 - z_1F_1 + z_2F_2 + K_2F_2LF_2^2}}{\mathrm{(K_2F_2F_2^2 - K_1F_1F)}}$$

$$x_{calc} = \frac{\mathrm{(z_1-z_2)-k_2F_2^2L+(F_1/F_2-1)(z_1-\lambda)}}{\mathrm{(K_1F_1^3/F_2-K_2F_2^2)}} \quad (30)$$

x_{calc}: The calculated value of x.

VI. DISCUSSIONS AND RESULTS

In this section, we review the optimization's outcomes while considering the following information:

The pipeline made of a PEHD pipe of 26 m in length and 40 mm in inner diameter makes up the test rig and we take into account: $F_1 = 10$, $F_2 = 7.5$, $z_1 = 1$, $z_2 = 1$. Here is the result:

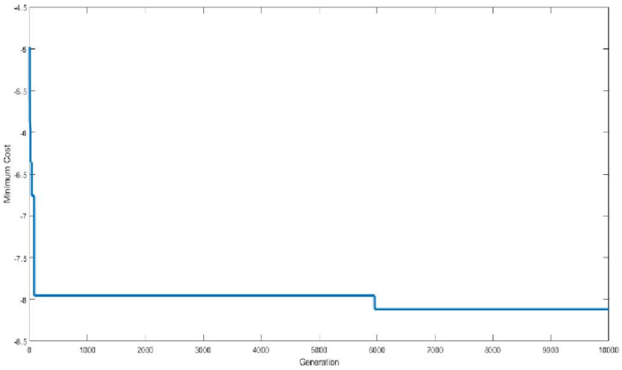

Figure.5: Curve of fitness functions of the mathematical model with BBO

The curve in Figure.5 shows how the cost function evolves as the number of iterations rises (generations). To achieve the best model minimization, we consider a number of iterations equal to 10000. We choice also a mutation probability of 0.03, population size=250, and a number of variables in each solution (problem dimension) =100. The elitism stage is applied to conserve the best solution in each iteration.

After the optimization, we found that the optimum parameters are the following:

$f = 105.34$[N] and $c_d A_x = 0.54[m^2]$

After running the optimization software, we discovered that the Elapsed Time was t = 170.53 seconds. Depending on the improved outcomes, we note how quickly the design's variables need to be calculated using the biogeography-based optimization method.

V. CONCLUSION

Damage to water transportation pipes due to many natural and human factors results in significant losses. This requires the rapid and accurate discovery of the location of the leak to repair the imbalance and thereby reduce the losses and preserve the world's water wealth. This field has attracted numerous researchers, as seen by the vast volume of articles and research previously mentioned. This article touched on one of the methods of leakage detection, which depends on the mathematical model. Two basic parameters of this model were improved using the theory of biogeography-based optimization (BBO), which is intended to achieve the best positioning of the leak.

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