CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Optimisation is the science of getting choices that satisfy given constraints, and meet a definite goal at its optimal value. Constraints may originate from physical restrictions and technical specifications in engineering field, while constraints are frequently concerned to resources, including manpower, equipment, costs and time in the field of business.

The objective of global optimisation is to find the "best possible" result in nonlinear problem that normally have several sub-optimal (local) solutions. Without global optimisation tools, engineers, academicians and researchers frequently go for feasible solutions, often ignoring the optimum values that cause inferior designs and operations.

Pipeline transport is comparatively new engineering concept which picked up in the latter half of twentieth century. It was initially presented to decrease cost in conveying coal to power generating units. Since then this technology has progressed worldwide to transport other minerals. The mixture of solids and liquid produces a totally different compound with its own rheological and mechanical characteristics. The inability to fully understand the flow performance of slurry could cause severe pipeline failure that could lead to violation of environmental laws, equipment failure or loss of life.

Durand and Condolios (1952) stated that short pipelines had been used for several years in dredging operations and mineral processing. American Gilsonite pipeline, 116 km long, 150 mm diameter in Colorado/Utah started operation in 1957 at the same time 174 km long, 250 mm diameter consolidation coal pipeline in Ohio started functioning. In 1967 the 85 km long, 225 mm diameter Savage River iron concentrate pipeline proved the sustainability of using pipelines for conveyance of abrasive materials. Wasp et al. (1977) stated that Black Mesa coal pipeline systems include the 439 km long, 450 mm diameter pipe in Arizona in 1972, and 395 km long, 500 mm diameter Samarco iron concentrate pipeline in Brazil in 1977, were the pioneered in slurry pipeline transportation field.

In South America, the design of the long distance slurry pipeline continuously present a commercially viable option for the carriage of copper (Chile and Argentina), iron (Chile and Brazil), zinc (Peru), phosphate (Canada, South Africa), and bauxite (Brazil). Presently, there are over 50 commercially operating long distance slurry pipeline all over the world. The requirement for conveyance of slurry through pipeline is continually growing in demand. Currently there are several organizations throughout the world functioning in research and development field of slurry transport.

The hydraulics of slurry (Non-Newtonian fluid) pipelines is similar to the hydraulics of water (Newtonian Fluid) pipelines. However, as it is a flow of mixture, critical mixture velocity of the flow shall be computed. Also, the head loss equation shall be formulated to compute the required energy for the system. The head loss for mixture flows mainly depends on the pipe diameter, concentration of transported material and velocity of mixture. Because of the intricacy of the water distribution system (WDS) optimisation problem, vast research has been carried out to cultivate techniques for WDS optimisation design and analysis in the past few decades.

2.2 Review Based on Pipe Network Optimisation for Newtonian Fluid

These optimisation methods can be distributed into three broad spectrum, which are deterministic optimisation approaches, evolutionary optimisation approaches and the hybrid optimisation approaches. Each type is reviewed below.

2.2.1 Deterministic Optimisation Approaches

Linear Programming (LP), Non-Linear Programming (NLP) and Dynamic Programming (DP) are considered of the optimisation method in water distribution systems which were defined by many authors since nineteenth century. Broadly speaking, Linear and nonlinear programming techniques are the part of applied mathematics dealing with the subsequent problem. It is dissimilar to classical problems of applied mathematics. Linear and nonlinear programming problems normally lack solutions provided by closed formulae and must be solved through numerical processes, called algorithms, performed on computers.

Alperovits and Shamir (1977) presented a linear programming (LP) gradient for optimizing a water distribution network. This is an iterative method and every pipe is divided into sections, each with a changed diameter. At each iteration, a fixed set of flows is tried. The decision variables are the lengths of each section, and the problem is condensed to a linear one. Information available from the solution of linear programming problem can be used to calculate a gradient which is then used to change pipe flows.

Quindry et al. (1981) have decomposed the looped network problem to branched systems but problems arise when examining multiple loads.

Stephenson (1984) also established an LP to deal with the optimisation of the tree network pipes in which, the simplex method was employed to solve the looped LP.

Morgan and Goulter (1985) marked a heuristic LP methodology related with a network solver to find the least-cost design for WDS.

Fujiwara et al. (1987) condemned the model of Alperovits and Shamir for its ineffectiveness when dealing with relatively large WDS; He projected a quasi-Newton method and backtracking line-search method for resolving looped water distribution networks.

Kessler and Shamir (1989) used the linear programming gradient method as an addition of the technique proposed by Alperovits and Shamir (1977).

Eiger et al. (1994) used the similar formulation as Kessler and Shamir (1989), which helps to calculate and find out the lengths of one or more sections in each link with discrete diameters.

Sârbu and Borza (1997) suggested a model based on the process of linear programming to treat looped networks which have intense discharges or uniform discharge along the length of each pipe

LP approach has advantages over other methods in terms of simplicity. Its application to large systems may impose unrealistic constraints on the formulation. For this reason, many researchers have chosen nonlinear formulations. The minimum cost design of WDS with a set of constraints is mathematically nonlinear.

Lansey and Mays (1989) proposed on the development of two-stage process for the design of water distribution under multiple loading conditions.

Fujiwara and Khang (1990) used a two-stage decomposition process extending that of Alperovits and Shamir (1977) to non-linear modelling. The main advantage of this optimisation method is that it is able to produce a series of improving local optimal results.

Paul Boulos and Tom Altman (1991) developed an algorithm to optimize the nonlinear pipe network for all type of distribution system for a well-defined value of boundary nodes and pipe sections within definite range of operating conditions.

Samani and Naeeni (1996) developed a non-linear optimisation method joined with the Newton- Raphson method to minimize the design total cost.

Samani and Mottaghi (2006) developed a binary linear programming (BLP) method for Water distribution network design optimisation, in which the objective function and constraints are linearized using zero-one variables. The benefits of the BLP over LP and NLP are that it is capable to provide discrete pipe diameter results over complete section of pipe lengths.

Schaake and Lai (1969) stated that Dynamic programming is a method for solving a complex problem by breaking it down into a collection of simpler sub problems.

2.2.1.1 Analysis of Deterministic Optimisation Approaches

- **a.** The Linear Programming (LP) and Non-Linear Programming (NLP) method is likely to be trapped by local optimal solutions due to its point by point movement (gradient based) in the feasible reason.
- **b.** The Linear Programming (LP) and Non-Linear Programming (NLP) method permits the continuous pipe diameters in the final solution, which is a weakness as only commercially available discrete pipe diameters can be used. Therefore, a technique is required to round off the continuous pipe diameter to the nearest commercially available discrete pipe. That may lead to an inferior optimal result for the WDS design.
- **c.** The disadvantages of the BLP approach are compromised by ineffectiveness when conducting with large WDS. Also, the global optimum for a looped WDS cannot be assured by the BLP approach since, it is reliant on the initially presumed pipe diameters.

2.2.2 Evolutionary Algorithms (EA)

Numerous traditional optimisation methods, such as linear programming gradient, nonlinear programming and dynamic programming have been developed primarily for solving minimum cost problems. These models are either linearized or simplified to make application promising. Furthermore, Yates et al. (1984) stated that choice of commercially available discrete pipe diameters to generate a minimum cost water supply network is difficult task to solve using traditional optimisation techniques. Currently, probabilistic heuristic algorithms have been developed for optimizing engineering problems.

Evolutionary Algorithms (EA) are a class of search algorithms based on the philosophies of natural evolution and include evolutionary programming, evolution strategies, genetic programming and genetic algorithms. Goldberg (1989) had well defined the Genetic Algorithm, “search algorithms based on natural selection and natural genetics”. It is competent to handle discrete search spaces directly and is less possible to be stuck at local optima. EA explore the search space in a way largely based on stochastic evolution rather than on gradient information as in deterministic optimisation techniques such as LP or NLP. Various EA capable of solving nonlinear mixed-integer programming models and their first significant publication are described such as Genetic algorithms by Simpson et al. (1994), Simulated annealing by Loganathan et al. (1995), Tabu search by Lippai et al. (1999), Harmony search by Geem et al. (2002), Shuffled frog leaping algorithm by Eusuff and Lansey (2003), Ant colony optimisation by Maier et al. (2003), ANN metamodels by Broad et al. (2005), Particle swarm optimisation by Suribabu and Neelakantan (2006), Scatter search by Lin et al. (2007), Cross-entropy algorithm by Perelman and Ostfeld (2007), Differential evolution by Suribabu (2010) and Honey Bee Mating Optimisation by Mohan and Babu (2010). The genetic algorithm (GA), which is the most frequently, used EA, and the differential evolution algorithm (DE), which is a comparatively new EA that has recently received attention in terms of WDS optimisation.

2.2.2.1 Genetic Algorithms

GA has gained popularity among all EA due to their ease of implementation and satisfactory search capability. It is simple, considerably faster, robust at numerical optimisation, and enhance the chance of finding true global optimum during the past decade. The foremost benefit of the GA is that this algorithm always finds a result that may be local optimum occasionally, whether the problem is extremely non-linear or not. Also, this solution can be improved by applying various operators of the algorithm. The GA is a stochastic search method based on artificial evolution by Holland (1975). It also helps for finding optimisation for continuous and discrete variables. Some of the advantages it have over conventional numerical optimisation algorithms are as mention below.

- **a.** GA optimize parameters with exceptionally complex objective function.
- **b.** It is capable to deal with a large number of parameters.
- **c.** It does not require derivative information.
- **d.** Optimize with continuous or discrete parameters.
- **e.** Provide a list of solution satisfying all the constraint.
- **f.** Works with numerically generated data, experimental data, or analytical functions.
- **g.** It always give a solution.

Goldberg and Kuo (1987) design the water resources pipeline using GA. This was the first application of GA to a water resources problem. The applicability of GA on pipeline problems is examined and it is judged that the algorithm converges to very near-optimal solution. Hereafter, many researchers used the similar procedure and applied GA in water resources optimisation problems.

Dandy et al. (1996) applied an improved genetic algorithm formulation for pipe network optimisation by using variable power scaling of the objective function. These include Roulette wheel selection method, applying an adjacency mutation in spite of bitwise mutation to permit the GA to locally search.

Savic and Walters (1997) applied a computer model which elaborates the application of standard genetic algorithm for the result of nonlinear optimisation problems.

Reis et al. (1997) applied the genetic algorithm on a 37-pipe network to find the suitable location of three control valves and their settings to achieve maximum leakage reduction, as the objective function. Murphy et al. (1998) applied the genetic algorithm to the Jamestown system expansion plan, Australia.

Tayal et al. (1999) establishes application of genetic algorithms. The study also compares the performance and results of simulated annealing with genetic algorithms for the same problem.

Sharif and Wardlaw (2000) applied GA to optimize multi-reservoir systems by using both dynamic programming and GA methods, in order to compare the results obtained. In their study, a case is solved by using both dynamic programming and GA methods, in order to compare the results obtained. It is found that the results obtained from both techniques are similar but GA method is more practicable.

Deb (2000) proposed a constraint tournament selection algorithm to enable the GA to successfully handle the constraints.

Vairavamoorthy and Ali (2000) proposed an integer coding method in the preparation of GA strings, thereby evading the redundant states frequently found when using binary or Gray coding.

Wu et al. (2002) proposed a fast messy genetic algorithm (mGA) for optimisation of water networks problem. It presented a substantial enhancement in terms of efficiency and robustness compared to the standard GA.

Vairavamoorthy and Ali (2005) applied a pipe index vector based GA for WDS optimisation problem, a pipe index vector was established to measure the comparative significance of the pipes in terms of their effect on the hydraulic performance of the pipe network. This pipe index minimized the search space for the GA.

Farmani et al. (2007) applied GA technique on the optimum design of pressurized branched irrigation networks. It is compared with the linear programming method, which is a substitute procedure for the problem. It is found that GA is better in satisfying different constraints of the optimisation problem.

Nicklow et al. (2010) proposed an inclusive evaluation of last two decades on the GA applications to numerous water resources planning and management problems. It was established that the GA has been constantly verified to be flexible and powerful in solving difficult water resources problems.

Chandramouli and Malleswararao (2011), proposed to increase the reliability based on the additional pressure existing at demand nodes of a pipe network, using fuzzy logic theory and to integrate it in the optimal design. To achieve this two objective optimisation, Genetic algorithm and EPANET tool kit in the Mat lab has been used.

One of the decisions drawn was that GA has benefit over other methods in finding several solutions of the identical quality. Hence GA is giving more flexibility to the designer.

2.2.2.2 Differential Evolution (DE)

The differential evolution (DE) algorithm, proposed by Storn and Price (1995), has been found to be a comparatively simple evolution algorithm but powerful tool for global optimisation. Currently, the DE algorithm has got much attention for optimisation of WDS problems as stated by Suribabu (2010). Similar to GA, differential evolution (DE) algorithm have three operators including mutation, crossover and selection operators. The operator's names are similar to GA operators name but, there are substantial changes in the order of application and form of these operators.

Vasan and Simonovic (2010) established a DENET optimisation model to tackle the WDS optimisation problem. The efficiency and robustness of the DENET was verified based on two standard WDS problems. Vasan and Simonovic (2010) conveyed that DE was able to provide good quality optimal solutions with great efficiency based on results obtained for the two standard WDS problems. Vasan and Simonovic (2010), and Suribabu (2010) established that the efficiency of a DE algorithm was at least as good as, if not better, than other EA such as GA and ant colony optimisation. On the other hand, Dandy et al. (2010) compared effectiveness of GA and DE in terms of optimizing WDSs and specified that GA gave overall better results than DE.

2.2.2.3 Analysis of Evolutionary Algorithms (EA)

- **a.** EA can be reformed to deal with multi-objective WDS design problems, while deterministic methods are only limited for single objective optimisation problems.
- **b.** EA are competent to cover more search space than deterministic methods such as LP and NLP. Accordingly, it is more likely that EA will reach global optimal solutions for WDS optimisation problems.

c. EA are able of holding the discrete search space of the WDS design problem. Hence, they are capable to provide practical final solutions, with each pipe being allocated a commercially discrete diameter. While, final solutions produced by deterministic methods (LP and NLP), both are impractical in practice.

d. Contrary to deterministic methods approach, EA can deliver a set of solutions at the end of each run. These solutions are slightly altered in cost but absolutely different in design. Thus the design practitioner can choose the more real-world design from the options based on objectives.

Concern in the practice of EA is that a number of parameter values need to be adjusted when EA are applied to numerous optimisation problems. A number of parameters that need to be selected for different EA are stated by Tolson et al. (2009). For different EA, the number of parameters fluctuates from three to eight. The efficiency of the EA heavily dependent on the parameter values. Therefore, it need substantial effort, normally by trial and error, for design practitioners to decide the most suitable parameter values for different optimisation problems. Nicklow et al. (2010) specified the ineffectiveness of EA for large size WDS. Zheng et al. (2011d) explored the search capability of GA, applied to various case studies. The outcomes prove that the GA was able to find the near global optimal solutions (current best known solutions). The GA revealed the best result it differs only 0.53% from the estimated global optimal solution.

2.2.3 Hybrid Optimisation Techniques

Hybrid optimisation methods have been advanced in current years to overcome weaknesses of EA for large WDS optimisation problems. It is the process of enhancing the search performance of EA, with combing EA by deterministic optimisation methods (local search procedures) or controlling an EA's search by providing it with first near- optimal seeding estimates.

Keedwell and Khu (2006) projected an optimisation method that united local representative cellular automata (CA) and a GA (CANDA-GA) for optimizing the design of WDS. In CANDA-GA, the CA is used to locate the fairly accurate optimal solutions and the GA is planted with these near optimal solutions in order to reach better solutions. The competence of an EA is enhanced if its search is initialized with good initial points. This accelerates the convergence speed. The resulting solution is then used to seed one more EA to locate better solutions. This has been established in a number of studies such as Grefenstette (1987), Harik and Goldberg (2000).

Tolson et al. (2009) proposed a hybrid discrete dynamically dimensioned search (HD- DDS) algorithm to optimize the design of WDS. The HD-DDS associates an evolutionary search method with two local search methodologies. The met heuristic search method is first used to explore approximately in the entire search space identified by a WDS design problem. Then second local search approaches are effective to further refine the final solutions obtained by the evolutionary search method.

Krapivka and Ostfeld (2009) suggested a united GA-LP scheme for the least-cost pipe sizing of water networks. The optimisation problem is disintegrated into an "inner" and an "outer" problem. The "inner" LP is framed and solved for a fixed set of flows, while the flows are improved in the "outer" by GA. The method is limited in practical use for a large water network, and can slip the global optimal result for the original water network.

Cisty (2010) projected another collective GA and LP (GA-LP) model for solving WDS design problems. In this proposed GA-LP method, GA is used to make branched networks for a complicated looped network, and LP is used to optimize each branched network. This GA-LP was verified on three WDS case studies and verified to be robust and efficient. However, split pipe solutions in the final optimal solution are a severe limitation for practical application.

Haghighi et al. (2011) united a simple GA with BLP for a WDS optimisation design problem. The computational action required for iterative BLP optimisation in this GA-BLP method is huge when dealing with large water networks and BLP has formerly been found to be very inefficient when attempting large optimisation problems by Savic and Cunha (2008) and Martínez (2008).

2.2.3.1 Analysis of Hybrid Optimisation Techniques

The GA-LP method suggested by Krapivka and Ostfeld (2009), is particularly inefficient to find the least-cost design for the looped water network. The GA-LP technique suggested by Cisty (2010), split pipe results are produced, which is not practical.

The GA-BLP technique suggested by Haghighi et al. (2011) is particularly inefficient to find out with the large tree network with BLP algorithm.

In a conclusion, the presently existing hybrid optimisation method have limited capacity to deal with real-world sized WDS problems. On the contrary, the genetic algorithm resolves optimisation problems by imitating the philosophies of biological evolution, continually altering a population of individual points using rules modelled on gene combinations in biological reproduction. Due to its arbitrary character, the genetic algorithm improves the probabilities of finding a global solution. Thus GA is very competent and stable in searching for global optimum solutions for unconstrained, constrained and general optimisation problems and it does not requisite the functions to be differentiable or continuous. GA is not only always finding a global optimum solution for a problem, but it is normally good on solving complicated problems quickly, reliably, and accurately.

2.3 Review Based on Pipe Network Optimisation for Non-Newtonian Fluid

Slurries (Non-Newtonian Fluid) may be defined as liquid-solid suspensions. The handling of slurry is a significant concern within the chemical, mining, petrochemical and other industries and hence the study of fluid flow is important if fluids are to be efficiently and economically transported in a pipeline system. The pumping of these suspensions in the processing industry normally takes place inside the plant as well as over long distances that includes various chemical and industrial wastes, quarry products, mine, sewage, petroleum and detergent industries. The slurry pipeline transportation was studied at the earliest twenty century by Blatchs (1906). A large number of these industrial suspensions encountered do not follow the simple laws of flow and are therefore referred to as non-Newtonian suspensions i.e., they do not obey Newton's law of viscosity by Govier and Aziz (1972).

While designing system for the transportation of non-Newtonian suspensions, problems encountered are the determination of the pressure gradient, the size of the pipeline and selection of pump capacity. The most accepted way used by industry today is by conducting large scale pipe tests for the efficient design of pipeline systems. For acquiring required parameters and data for design, tests are conducted, simulating normal operating conditions. Even though designer's effort to simulate normal operating conditions, usually a range of variables is covered as desired flow rates cannot be exactly matched by Cheng (1975).

There are three approaches in the literature for modelling non-Newtonian turbulent flow data:

a. Empirical approach by Bowen (1961),

b. Approach based on the slurry rheology by Torrance (1963) or Wilson and Thomas (1985, 1987),

c. Approach based on the particle effect or particle roughness effect by Slatter (1994).

The long history of empirical studies dealing with slurry transport appears to have the maximum attention due to the complexity of slurry properties.

The rheological approach has arisen in a big way in later half of the twentieth century. It is relevant to slurries of ultrafine non colloidal particles, capable of significant rheological characteristics.

The multiphase flow modelling approach provides the most balanced structure for describing such heterogeneous solid-liquid mix flows. Elementary information concerning the effects of the particle on the structure of the turbulent flow is required.

All of the above methods have their own boundaries. Even today, our understanding of the fundamentals of solid-liquid flow does not fulfil engineering requirements. The design of pipelines, pumps has dependent on experimental data. These data have developed the frame of empirical relations and practical guidelines. But it is difficult to correlate these guidelines with slurry pipeline design. Although substantial research efforts, design of slurry pipelines depend on empirical correlations found from the experimental data. Moreover, for higher values of solid concentration, very few experimental data on local solid concentration is available because of the difficulties in the measurement techniques.

The solids shape, particle size distributions systems and solid concentration are not well defined in slurry. Correlation developed among various parameters such as critical velocity, pressure drop has limited range of applicability and validity. Before starting major projects, extensive pilot pipeline test are conducted. Due to the complexity of the process the knowledge of detailed in situ circumstance is often outside reach.

Slurry pipeline design factors comprise flow quantities such as the flow velocity, flow concentration, and pressure drop. Numerous empirical correlations for pressure drop have progressed since the early part of the twentieth century by Howard (1939), Wilson (1942). Durand and Condolios (1952) worked on pressure drop measurements for slurry flows were further advanced by Wasp and co-workers by Wasp et al. (1977). Gillies et al. (1991) predicted two-layer model for pressure drops in slurry pipelines system while Doron and Barnea (1993) envisage pressure drops in slurry pipelines system for three-layer model.

The slurry pipeline designers has been compelled to force concurrent criteria for transport, the consideration of turbulent flow and velocity above the deposit threshold, to avoid the slurry plug incidents during transport at low points by Wasp et al. (1977); Jacobs (1991); Abulnaga (2002). Mere turbulent flow of the liquid phase does not assurance the full suspension of particles. Deposition of slurry particles might be avoided, if velocity variations create a force or have an energy that exceeds the weight of particles. Jesse Capecelatro et al. (2013) presented variance of solid liquid concentration across the cross section in horizontal pipes. The highest deviations in concentration were located in the region just above the surface of the bed.

Numerous models and correlations exist to predict slurry flow behaviour in pipelines by Shook et al. (1986), Gillies et al. (1991), Shook and Roco (1991), Gillies (1993), Gillies and Shook (1994), Matousek (1997), Gillies et al. (2000), Gillies and Shook (2000), Matousek (2004), Gillies et al. (2004a), Sanders et al. (2004). Studies have explored the minimum velocity requirement to hang all particles in a pipe flow (critical deposition velocity). Many attempts have been made to propose a generalized correlation for the prediction of deposition velocity.

At the last count, there are close to 60 correlations for the prediction of the deposition velocity by Dighade (1999). Most of them are based on considering uniform size particles. The long distance transport of iron concentrate is primarily noted in Australia in 1967 by Cowper et al. (2009).The water is mixed with the material to be transported and then pumped over long distances.

In recent years, improvement in our knowledge of turbulent flows has provided the elementary framework for progress of mathematical models of slurry flow. Additionally, advent of powerful numerical method like artificial neural network, Genetic algorithm, computational fluid dynamics etc. along with the accessibility of dominant computes has made it possible to probe such models and to perform investigations.

Simpson et al. (1994) compare the different optimisation techniques by using methods of enumeration, non-linear optimisation and GA to get a least cost alternative for small-scaled pipe network optimisation problem. The researcher found that non-linear optimisation is an effective technique when applied to a small network, but the method generates only one solution and discrete pipe sizes must be transformed to a continuous function in order to use the method. GA technique is preferably appropriate to discrete problems such as selection of commercially available pipe sizes and the GA method generates a range of alternative result near to the optimum solutions.

GA has been also applied successfully in many diverse fields. The numerous applications of GA are: process design and optimisation by Androulakis and Venkatasubramanian (1991), computer-aided molecular design by Venkatasubramanian et al. (1994), optimal design of ammonia synthesis reactor by Upreti and Deb (1996), valuation of heat transfer parameters in trickle bed reactors by Babu and Vivek (1999).

The most vital part is that GA works with a population (Group of results of the problem concerned) of points instead of a single point. The initial population is selected randomly. Consequently the search can progress in any direction.

The intent of this thesis is to redesign procedure with Genetic Algorithm techniques and approach used today to ensure a better, safer and an efficient water and slurry pipeline.

2.4 Research Gaps

Based on the literature review, areas are identified for the Optimisation of pipe network design carrying Newtonian and Non-Newtonian fluid that would benefit from further investigation are as follows.

a. Literature review reveals that the most of the optimisation techniques are based on single variable function. On the contrary, in a slurry pipe line design optimisation function consist of multiple variables. These variables may be discrete or continuous.

b. Durand and Stepanoff (1969) provided the head loss equation for flow of fluid in a pipe with heterogeneous suspension of sediment particles depend upon the multiple variables such as temperature of fluid in pipe (as a continuous function), average flow velocity (as a continuous function), volumetric concentration of flow (as a continuous function), diameter of commercially available pipe (as a discrete function) and material of pipe (as a discrete function). But they have design and converted multiple variables in dependent single variable.

c. Traditional optimisation methods (LP, NLP and BLP) frequently converge at local optimal solutions of the WDS optimisation problem. EA involve a large number of network evaluations to discover optimal solutions, causing in a costly computational overhead, especially for relatively large case studies. Furthermore, EA is not much proficient when dealing with very large real world water distribution problem.

d. The currently available hybrid optimisation techniques (combine EA with deterministic methods) continue in the research domain due to their limitations. This makes difficult for these hybrid optimisation methods to tackle the optimisation of real world water distribution problem.

e. There is no clear definition yet on the typical number of pipes for a real-world sized water network.

f. All the existing methods of pipe network system design are based upon empirical formula without taking any account of optimal solution. Moreover, there are no any guidelines available for selecting the parameters of pipe network system for practicing engineer.