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A review of Performance Evaluation and Performance Optimisation of Water Treatment Plant

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Abstract: One of the most important functions of government organizations is providing its citizens with safe, clean and aesthetic drinking water. Over the years, the standards for drinking water have been made stringent, however the processes for purification remains the same. The individual units of treatment plants have been designed keeping in consideration the drinking water standards at the time of construction. It is mandatory to check whether the treatment plant along with its units are capable of delivering water as per the current drinking water standards. Developed countries such as USA have developed Comprehensive Performance Evaluation for water treatment plants as part of its strategy to provide clean drinking water to its citizens. However, no such manual exists for developing countries such as India. This paper aims to study the viability, necessity and options for carrying out evaluation of drinking water treatment plants in India alongwith performance optimisation of the same.

Keywords: Performance optimisation, Performance evaluation, Composite Correction Program

I. INTRODUCTION

As per Manual on Water Supply and Treatment prepared by CPHEEO (Central Public Health and Environmental Engineering Organization), GOI (Government of India) the water treatment unit is designed for meeting the requirement of 15 years[1]. Additionally, the Indian Standards for Drinking Water that were introduced in 1990 have since been revised and new Standards for Drinking Water have been updated in 2012[2]. In the new revision additional parameters have been introduced and simultaneously the existing standards have been made more stringent. The water treatment plants that have outlived their design period and that are operating after introduction of new standards need to be checked whether they can provide output water quality as per the new standards. In India, no evaluation manual or standard operating procedure exists for checking the quality of output water from the various units. The Drinking Water Standards as per IS 10500:2012 gives the standards that drinking water should conform to after being treated. However, the units of treatment plants do not conform to any standards and perform as per their design. Hence it is required to check the working of water treatment plants and output quality with respect to a standard procedure.

II. COMPOSITE CORRECTION PROGRAMME

Maintaining public health protection at water supply systems has become more challenging in recent years with the resistance of some pathogens to disinfection using chlorination and an increase in the immuno-compromised population (e.g., people with HIV, organ transplant patients, the elderly).

Microbial pathogens, including protozoan parasites, bacteria, and viruses, can be physically removed as particles in flocculation, sedimentation, and filtration treatment processes or inactivated in disinfection processes. Consequently, the level of protection achieved in a water system can be increased by optimizing the particle removal processes in a system and by proper operation of the disinfection processes. Turbidity monitoring is the most common method of assessing particle removalin surface water system, performance goals based on this parameter have been developed for the Composite Correction Programme[3].

In a conventional plant, the coagulation step is used to develop particles that can be physically removed by sedimentation and filtration processes. Effective use of these processes as part of a multiple barrier strategy for microbial protection represents an operational approach for water systems that choose to optimize performance.

Individual Sedimentation Basin Performance Goals

- Settled water turbidity less than 1 NTU 95 percent of the time when annual average raw water turbidity is less than or equal to 10 NTU.
- Settled water turbidity less than 2 NTU 95 percent of the time when annual average raw water turbidity is greater than 10 NTU.

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Individual Filter Performance Goals

- Filtered water turbidity less than 0.1 NTU 95 percent of the time (excluding 15minute period following backwashes) based on the maximum values recorded during 4-hour time increments.
- Maximum filtered water measurement of 0.3 NTU.
- Initiate filter backwash immediately after turbidity breakthrough has been observed and before effluent turbidity exceeds 0.1 NTU.
- Maximum filtered water turbidity following backwash of less than 0.3 NTU.
- Maximum backwash recovery period of 15 minutes (e.g. return to less than 0.1 NTU).

Disinfection Performance Goal

- CT values to achieve required log inactivation of Giardia and virus.

Minimum Data Monitoring Requirements

- Daily raw water turbidity
- Settled water turbidity at 4-hour time increments from each sedimentation basin
- On-line (continuous) turbidity from filters
- One filter backwash profile each month from each filter

A. Comprehensive Performance Evaluation

The evaluation phase as part of Composite Correction Programme, called a Comprehensive Performance Evaluation (CPE), is a thorough review and analysis of a facility's design capabilities and associated administrative, operational, and maintenance practices as they relate to achieving optimum performance from the facility. A primary objective is to determine if significant improvements in treatment performance can be achieved without major capital expenditures.

Major components of the CPE process include:

1. Assessment of plant performance:

The performance assessment uses historical data from plant records supplemented by data collected during the CPE to determine the status of a facility relative to achieving the optimized performance goals, and it starts to identify possible causes of less than optimized performance.

To achieve optimized performance, a water treatment plant must demonstrate that it can take a raw water source of variable quality and produce a consistent high quality finished water.

Further, the performance of each unit process must demonstrate its capability to act as a barrier to the passage of particles at all times. The performance assessment determines if major unit treatment processes consistently perform at optimum levels to provide maximum multiple barrier protection.

If performance is not optimized, it also provides valuable insights into possible causes of the performance problems and serves as the basis for other CPE findings.

2. Evaluation of major unit processes:

The major unit process evaluation is an assessment of treatment potential, from the perspective of capability of existing treatment processes to achieve optimized performance levels. If the evaluation indicates that the major unit processes are of adequate size, then the opportunity to optimize the performance of existing facilities by addressing operational, maintenance or administrative limitations is available. If, on the other hand, the evaluation shows that major unit processes are too small, utility owners should consider construction of new or additional processes as the initial focus for pursuing optimized performance.

It is important to understand that the major unit process evaluation only considers if the existing treatment processes are of adequate size to treat current peak instantaneous operating flows and to meet the optimized performance levels. The intent is to assess if existing facilities in terms of concrete and steel are adequate and does not include the adequacy or condition of existing mechanical equipment. The assumption here is that if the concrete and steel are not of adequate size then major construction may be warranted, and the pursuit of purely operational approaches to achieve optimized performance may not be prudent.

The evaluation approach uses a rating system that allows the evaluator to project the adequacy of each major treatment process and the overall plant as either Type 1, 2 or 3.

Type 1 plants are those where the evaluation shows that existing unit process size should not cause performance difficulties. In these cases, existing performance problems are likely related to plant operation, maintenance, or administration. Plants categorized as Type 1 are projected to most likely achieve optimized performance through implementation of non-construction oriented follow-up assistance.

The Type 2 category is used to represent a situation where marginal capability of unit processes could potentially limit a plant from achieving an optimum performance level. Type 2 facilities have marginal capability, but often these deficiencies can be "operated around" and major construction is not required.

Type 3 plant may incur significant expenditures to modify existing facilities so they can meet optimized performance goals. Depending on future water demands, they may choose to conduct a more detailed engineering study of treatment alternatives, rate structures, and financing mechanisms. CPEs that identify.

Type 3 facilities are still of benefit to plant administrators in that the need for construction isclearly defined. It is important to note that the major unit process evaluation should not be viewed as a comparison to the original design capability of a plant. The major unit Process evaluation is based on an assessment of existing unit processes to meet optimized performance goals. These goals are most likely not the goals that the existing facility was designed to achieve.

Determination of Rated capacity

Flocculation

$$\text{Rated Capacity}=\frac{\text{Basin volume (gal)}}{\text{Hydraulic Detention Time (min)}}\times\frac{\text{MGD}}{694.4\text{ gpm}}$$

Sedimentation Tank

$$\text{Rated Capacity}=\text{Surface area}\left(\text{ft}^2\right)\times\text{Surface Overflow rate}\left(\frac{\text{gpm}}{\text{ft}^2}\right)\times\frac{\text{MGD}}{694.4\text{ gpm}}$$

Filtration

$$\text{Rated Capacity}=\text{Surface area}\left(\text{ft}^2\right)\times\text{Filtration rate}\left(\frac{\text{gpm}}{\text{ft}^2}\right)\times\frac{\text{MGD}}{694.4\text{ gpm}}$$

Disinfection

$$\text{Rated Capacity}=\frac{\text{Functional Volume (gal)}}{\text{Contact Time (min)}}\times\frac{\text{MGD}}{694.4\text{ gpm}}$$

3. Identification and prioritization of performance limiting factors:

A significant aspect of any CPE is the identification of factors that limit the existing facility's performance. This step is critical in defining the future activities that the utility needs to focus on to achieve optimized performance goals. After performance limiting factors are identified,they are prioritized in order of their adverse impact on plant performance. This prioritization establishes the sequence and/or emphasis of follow-up activities necessary to optimize facility performance.

Prioritization of factors is accomplished by individually accessing factors with regard to their adverse impact on plant performance and assigned an "A", "B" or "C" rating.

A - Major effect on a long term repetitive basis.

"A" factors are the major causes of performance deficiencies and are the central focus
of any subsequent improvement program.

B - Moderate effect on routine basis or major effect on a periodic basis

Factors are assigned a "B" rating if they fall in one of two categories:

1. Those that routinely contribute to poor plant performance but are not the major problem.
2. Those that cause a major degradation of plant performance, but only on a periodic basis

C - Minor effect

Factors receive a "C" rating if they have a minor effect on performance.

4. Assessment of applicability of the follow-up phase:

Proper interpretation of the CPE findings is necessary to provide the basis for a recommendation to pursue the performance improvement. The initial step in assessment of Comprehensive Technical Assistance applicability is to determine if improved performance is achievable by evaluating the capability of major unit processes. A CTA is typically recommended if unit processes receive a Type 1 or Type 2 rating. However, if major unit processes are deficient in capability (e.g., Type 3), acceptable performance from each "barrier" may not be achievable; and the focus of follow-up efforts may have to include construction alternatives. Another important consideration with Type 3 facilities is the immediate need for public health protection regardless of the condition of the plant.

5. Reporting results of the evaluation:

Results of a CPE are summarized in a brief written report to provide guidance for utility staff and, in some cases, state regulatory personnel. It is important that the report be kept brief so that maximum resources are used for the evaluation rather than for preparation of an all-inclusive report. The report should present sufficient information to allow the utility decision makers to initiate efforts toward achieving desired performance from their facility. it should not provide a list of specific recommendations for correcting individual performance limiting factors. Making specific recommendations often leads to a piecemeal approach to corrective actions, and the goal of improved performance is not achieved.

B. Application of CPE in India

The National Environmental Engineering Research Institute (NEERI), a constituent laboratory of CSIR, in collaboration with USEPA is engaged in improving drinking water quality in India by facilitating the demonstration of the Composite Correction Program (CCP). With a view to demonstrating the efficacy of CCP, a study was initiated with following objectives:

- Initiate work on water quality and safety, improve water treatment performance, and reduce microbial contamination by demonstration of the Composite Correction Program.
- Improve water quality and thereby reduce the health burden of water-related diseases through enhanced safety of public drinking water supplies.

Under this study programme, it was decided to carry out the composite correction programme in a water treatment plant in three different cities with varying systems of treatment plants operations. The water treatment plants that were identified were Asifnagar Water Treatment Plant, Hyderabad, Parvati Water works, Pune and Haidarpur Water Treatment Plant, Delhi. At the end of the study several limiting factors in the working of water treatment plant were identified and solutions to the limiting factors were given. Additional suggestions to improve the treatment plant were also provided[4].

III. APPLICATION OF CPE DATA IN PERFORMANCE EVALUATION AND PERFORMANCE OPTIMISATION

The performance limiting factors can be identified from CPE. These identified parameters can be used in conjunction with tools to determine weightages of these identified parameters. Methods such as Analytical Hierarchy Process, Dynamic Programming and Genetic Algorithm can be used to determine efficiency from the identified parameters.

A. Analytical Hierarchy Process

Developed by Professor Saaty, AHP can be used to determine the relative weight value of each performance indicator. Decisions involve many intangibles that need to be traded off. To do that, they have to be measured alongside tangibles whose measurements must also be evaluated as to, how well, they serve the objectives of the decision maker. The Analytic Hierarchy Process (AHP) is a theory of measurement through pairwise comparisons and relies on the judgements of experts to derive priority scales.

To make a decision in an organised way to generate priorities the decision is decomposed into the following steps.

1. Define the problem and determine the kind of knowledge sought.
2. Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives).
3. Construct a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.
4. Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Then for each element in the level below add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level is obtained[5].

It is these scales that measure intangibles in relative terms. The comparisons are made using a scale of absolute judgements that represents, how much more, one element dominates another with respect to a given attribute.

After statistical analysis of the retrieved data, it may be found that it is difficult to obtain uniform agreement among results in the survey. Therefore, a process to evaluate the uniformity of the results should be conducted. According to Saaty's recommendations, non-uniformity is acceptable if the C.I. (consistency index) value is 0.1. Since persons filling out the survey form of study are not familiar with the level analysis method, the acceptable C.I. value can be relaxed. Answer sheets with C.I. values greater than relaxed values must be discarded. Saaty suggests that if that ratio exceeds 0.1 the set of judgments may be too inconsistent to be reliable. In practice, CRs of more than 0.1 sometimes have to be accepted. A CR of 0 means that the judgements are perfectly consistent.

Chang et al.[6] applied AHP in conjunction with CCP to Taipei Water Treatment Plant. After the establishment of performance indicators (seven in this research), the corresponding evaluation items and their relative weights were revealed throughout forum discussion and questionnaire survey based on the CPE technique and AHP method, respectively. Meanwhile, according to the results of performance evaluation and simulation studies by the developed model, an implementation plan for upgrading the performance of the Taipei water treatment plant was proposed, with two important items:

1. Proper adjustment of the water production rate, PAC dosage, and sludge management for different turbidities in source water based on the required finished water quality can minimize the total treatment cost and enhance the performance of the water treatment plant; and
2. Establishing a regular performance evaluation system to identify potential and existing problems so that correction action could be immediately taken.

The study concluded that according to the CPE practice, the performance evaluation system initially developed for the water production department was categorized into management, maintenance, and operation areas and then used for the Taipei water treatment plant with the determination of detailed evaluation items for each performance indicator. The model was found suitable to be applied to other water treatment plants in Taiwan.

B. Dynamic Programming

Dynamic programming was developed by an American Mathematician, Rechard Bellman, who described the way of solving problems where it is needed to find the best decision one after another. Dynamic programming is an approach developed to solve sequential, or multi-stage, decision problems; hence, the name "Dynamic programming". A Dynamic Programming solution has three components:

1. Formulate the answer as recurrence relation or recursive algorithm.
2. Show that the number of different instances of your recurrence is bounded by a Polynomial.
3. Specify an order of evaluation for the recurrence so you always have what you need.

Dynamic programming usually takes one of two approaches[7]:

Top-down Approach: The problem is broken into sub problems, and these sub problems are solved and the solutions remembered, in case they need to be solved again. This is recursion and memoization (memoization we can retrieve and reuse our already-computed solution) combined together.

Bottom-up Approach: All sub problems that might be needed are solved in advance and then used to build up solutions to larger problems. This approach is slightly better in stack space and number of function calls, but it is sometimes not intuitive to figure out all the sub problems needed for solving the given problem.

DP problems have the following features:

1. The problem can be divided into stages, with policy decision required at each stage.
2. Each stage has a number of states associated with it.
3. The effect of the policy decision at each stage is to transform the current state into a state associated with the next stage.
4. Given the current state, an optimal policy for the remaining stages is independent of the policy adopted in previous stages.
5. The solution procedure begins by finding the optimal policy for each state of the last stage.
6. A recursive relationship that identifies the optimal policy for each state at stage n, given the optimal policy for each state at stage (n+1), is available.
7. Using this recursive relationship, the solution procedure moves backward stage by stage – each time finding the optimal policy for each state at the stage –until it finds the optimal policy when starting at initial stage.

Khezri Seyed Mostafa et al.[8] have applied DP to optimization of water treatment plant. By applying DP algorithm, fundamental system design with minimal cost is prepared. The case study indicates the model capability for reducing the annual cost of WTP between 4.5 and 9.5% variables using decision-making process. In addition, these parameters describe the important role of keeping the adequate output of specified standards from each unit.

It has been concluded that increasing the inflow by 20%, the total annual cost would increase to about 12.6%, while 20% reduction in inflow leads to 15.2% decrease in the total annual cost. Similarly, 20% increase in alum dosage causes 7.1% increase in the total annual cost, while 20% decrease results in 7.9% decrease in the total annual cost. Furthermore, the pressure decrease causes 2.95 and 3.39% increase and decrease in total annual cost of treatment plants.

The author has described the importance of efficient working of different units of water treatment plant. It has also been suggested that in order to increase the model integration, it is better to monitor the output of units such as rapid mixing and coagulation and flocculation to the amount of input suspended materials. Moreover, it is better to add chemical parameters such as pH, acidity, and so on, to other variables as decision variables. It has been implied that considering various particle sizes and using different filters make the models more comprehensive.

C. Genetic Algorithm

In an evolutionary algorithm, a representation scheme is chosen by the researcher to define the set of solutions that form the search space for the algorithm. A number of individual solutions are created to form an initial population. The following steps are then repeated iteratively until a solution has been found which satisfies a pre-defined termination criterion. Each individual is evaluated using a fitness function that is specific to the problem being solved. Based upon their fitness values, a number of individuals are chosen to be parents. New individuals, or offspring, areproduced from those parents using reproduction operators. The fitness values of those offspring are determined. Finally, survivors are selected from the old population and the offspring to form the new population of the next generation[9].

Ajay Kumar Gupta and Rakesh Kumar Shrivastava[10] have applied Genetic Algorithm to optimise water treatment plants. The reviewer has combined genetic algorithm (GA) as an optimization tool with Monte Carlo simulation (MCS) based reliability program for reliability-constrained optimal design of water treatment plant. The reliability of a water treatment plant is defined as the probability that it can achieve the desired effluent water quality standard (WQS). The objective function minimizes the treatment cost, subjected to design and performance constraints, and to achieve desired reliability level for meeting the given effluent WQS. The random variables used to generate the reliability estimates are suspended solids concentration, flow rate, specific gravity of floc particle, temperature of raw water, sedimentation basin performance index, and model coefficients. Analysis suggests that higher reliability at lower annual cost of treatment can be achieved by limiting the fluctuation of uncertain parameters. Results show that distribution of effluent SS is also affected by the uncertainty. The suggested GA-MCS approach is efficient to evaluate treatment cost-reliability trade-off for WTP. Results demonstrate that the combination of GA with MCS is an effective approach to obtain the reliability-constrained optimal/near-optimal solution of WTP design problem consistently.

IV. CONCLUSION

This review shows that Comprehensive Performance of Treatment Plants can be undertaken in conjunction with various decision making tools to improve output of various units of water treatment plants as well as provide safer drinking water.

It is seen that each and every water treatment plant is unique with respect to the quality of incoming water. The parameters such as Solids, pH, Turbidity etc. vary for different water treatment plants. Hence different water treatment plants with the same units work very differently. It is necessary to keep the uniqueness of working in water treatment plants due to the fact that performance evaluation of one plant cannot be applied to the other. Furthermore, the experience of the water treatment plant operator and the individual carrying out performance evaluation have a huge impact with respect to the identification of limiting factors in water treatment plant and giving comprehensive technical assistance for water treatment plant.

The benefits accruing from implementation of the CCP with decision making software at the water treatment plants include[4]:

- Minimization of microbial health risks to public
- Improved control and operation of treatment works
- Improved water quality achieved with minimal capital outlay and minor changes to existing facility
- Cost effective performance improvements are possible.

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