Monte Carlo Analysis for Aeration Design

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ABSTRACT

To minimize the risk of the uncertainties of the influent conditions at a wastewater treatment facility, engineers perform steady state simulations using conservative design loadings to design the aeration system for the activated sludge process. A conservative aeration design can be detrimental to process operation and energy efficiency, especially to biological nutrient removal processes, due to blower oversizing. The use of a probabilistic modeling approach will include the influent uncertainties with the process simulations, and the results can be used to quantify the risk of the design. This paper will go into the details of using a common probability approach called, Monte Carlo analysis, for designing aeration systems.

KEYWORDS: Aeration Design, Monte Carlo Analysis, Risk Analysis, Process Modeling

INTRODUCTION

With the recent increases of energy costs and the requirements of Biological Nutrient Removal (BNR), the design of an aeration system has become one of the most important parts of the design of the activated sludge process.

The problem that engineers have is they often lack plant influent and operational data with actual influent variability suitable to perform the dynamic simulations for aeration design. To overcome the uncertainties and minimize risk of the unknown influent data variability, engineers perform steady state simulations using conservative maximum month, week, or day loadings with a diurnal peaking factor multiplier (Belia *et al*., 2009). The use of conservative steady state models can lead to oversized equipment and operational problems.

The use of a probabilistic modeling approach will include the influent uncertainties with the simulation, and the results can be used to quantify the uncertainty of the design (McCormick *et al.* 2007). Monte Carlo analysis is a probabilistic approach that allows a small sample size of data to be expanded by using probability distribution and correlation data to generate inputs for the simulation.

METHODOLOGY

The method of Monte Carlo analysis is to take a random sampling from multiple input probability distributions to generate a random discrete input set. The input set is then simulated with a deterministic model to generate a discrete result set. The sampling and simulating is repeated several times until the group of the individual results generates a probability distribution. **Figure 1** depicts the method of Monte Carlo analysis.

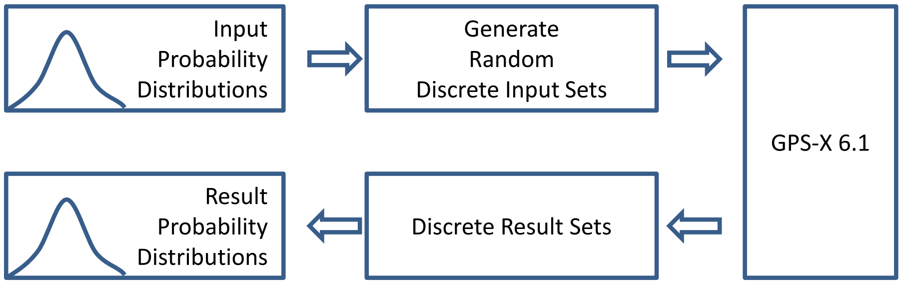

Figure 1: Monte Carlo analysis

A wastewater treatment plant (WWTP) was upgrading the activated sludge aeration system to increase the capacity of the facility from 15,142 to 18,927 m^3/d (4 to 5 million gallons a day). The amount of influent data was limited creating uncertainty on which values to use to design the new aeration system. The following is the methodology used to size the blowers using a Monte Carlo analysis.

Data Collection

The WWTP was only required to report a composite sample of influent BOD and TSS once a week. A basic statistical analysis (mean and standard deviation) of the plant's historical data was able to construct the normal distribution needed for the Monte Carlo analysis. Additional grab sample testing was performed to get influent parameter ratios to help with the influent characterization. Nutrient analyzers were used to obtain diurnal loading peaking factors of influent parameters. **Table 1** is a summary of the influent data of the facility.

Table 1: Influent Data

	Flow	CBOD		TSS		Peaking Factor	TSS/BOD	TKN/BOD
	m^3/d	mg/l	kg/day	mg/l	kg/day	-	-	-
Average	12,150	229	2742	226	2694	1	1.00	0.193
Minimum	7797	134	1307	86	1008	1.35	0.49	0.179
Maximum	16,465	374	4486	440	4389	0.6	1.50	0.226
Standard Deviation	1741	36	611	43	574	-	0.19	0.015

Monte Carlo Analysis and Process Simulation

The commercial available software GPS-X by Hydromantis ESS, Inc. was used in the evaluation to perform the process simulation and Monte Carlo analysis.

A Monte Carlo sensitivity analysis tool is implemented in GPS-X Version 6.1 to allow users to investigate the behavior of a model with uncertain input. Users identify one or more input parameters for analysis, and choose a probability distribution for the parameter (uniform, normal, or log-normal). Each parameter probability distribution is then defined via appropriate statistical measure (e.g. mean, standard deviation), along with a maximum and minimum bound value.

The user chooses the number of simulations to carry out, and whether the simulation is steady-state only, or a dynamic run. At the beginning of each simulation, GPS-X selects a value for each input parameter from its associated distribution, and sets that value for the current run. The model is solved, and the resulting model outputs collected for analysis. At the conclusion of all of the simulations, GPS-X plots a histogram of each output variable, displaying the distribution of output variable values. In addition, a cumulative probably can be calculated for any point on the output graph, showing the percentage of output values lying below any specified threshold. **Figure 2** shows sampling results of the input probability distributions.

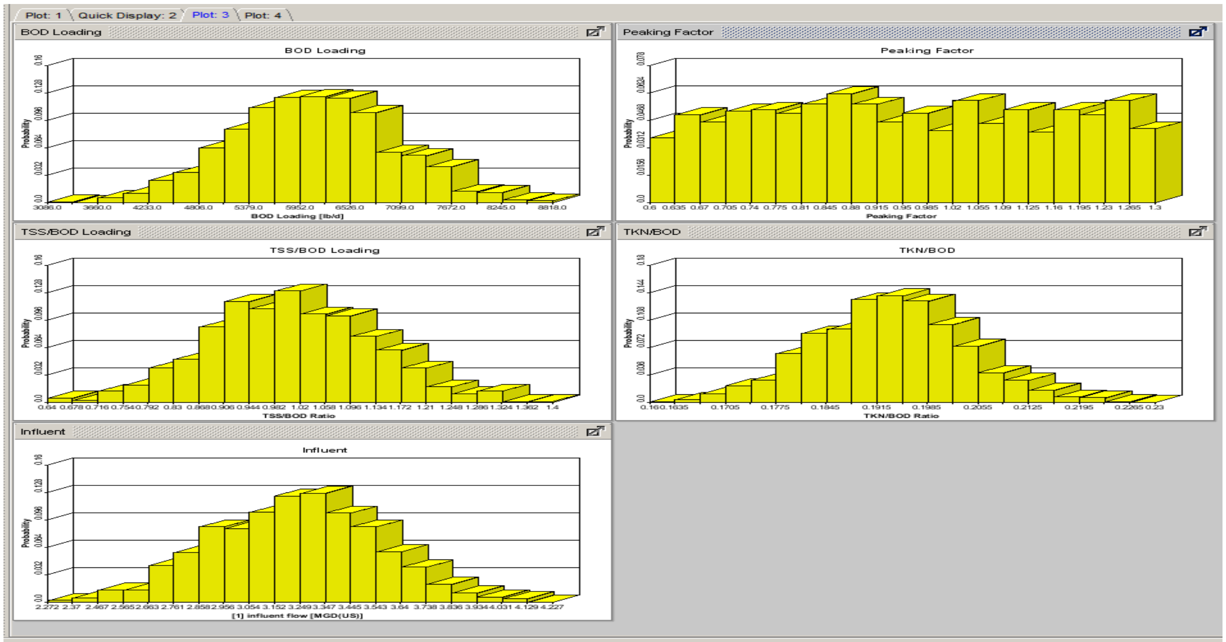

Figure 2: Screenshot of the Monte Carlo analysis input distributions

The initial calibration of the model was conducted using the yearly average raw influent data (NH4, COD, etc.), and running the model as steady state. The steady state results were then compared to yearly average MLSS, %VSS and effluent parameters (NH4, TSS, NO3, etc.) data to confirm if the steady state model was calibrated.

The input probability distributions for the Monte Carlo analysis were: influent flow, diurnal peaking factor, cBOD load, TSS/BOD ration, and TKN/BOD Ratio. The TSS and ammonia loadings were calculated by multiplying BOD loading by the corresponding ratio to insure realistic correlation. Each simulation was setup to run to steady-state using the randomly selected input sampled from the probability distributions mentioned above. The influent fractions were considered to be constant, and the diffuser parameters were preliminarily chosen based upon the steady state simulation results. Two sets of three analyses were completed, one set at current flow and another at design flow and at temperatures of 20, 24 and 28C^{o}. Each analysis was run for 1,000 simulations for a total of 6,000 simulations.

RESULTS

The results from the simulations will provide the complete range of oxygen requirements and airflows needed for sizing the aeration system. The results can be analyzed by creating histograms and cumulative percentile graphs of the data. **Figure 3** is a histogram chart of total airflow required for current and design flow conditions.

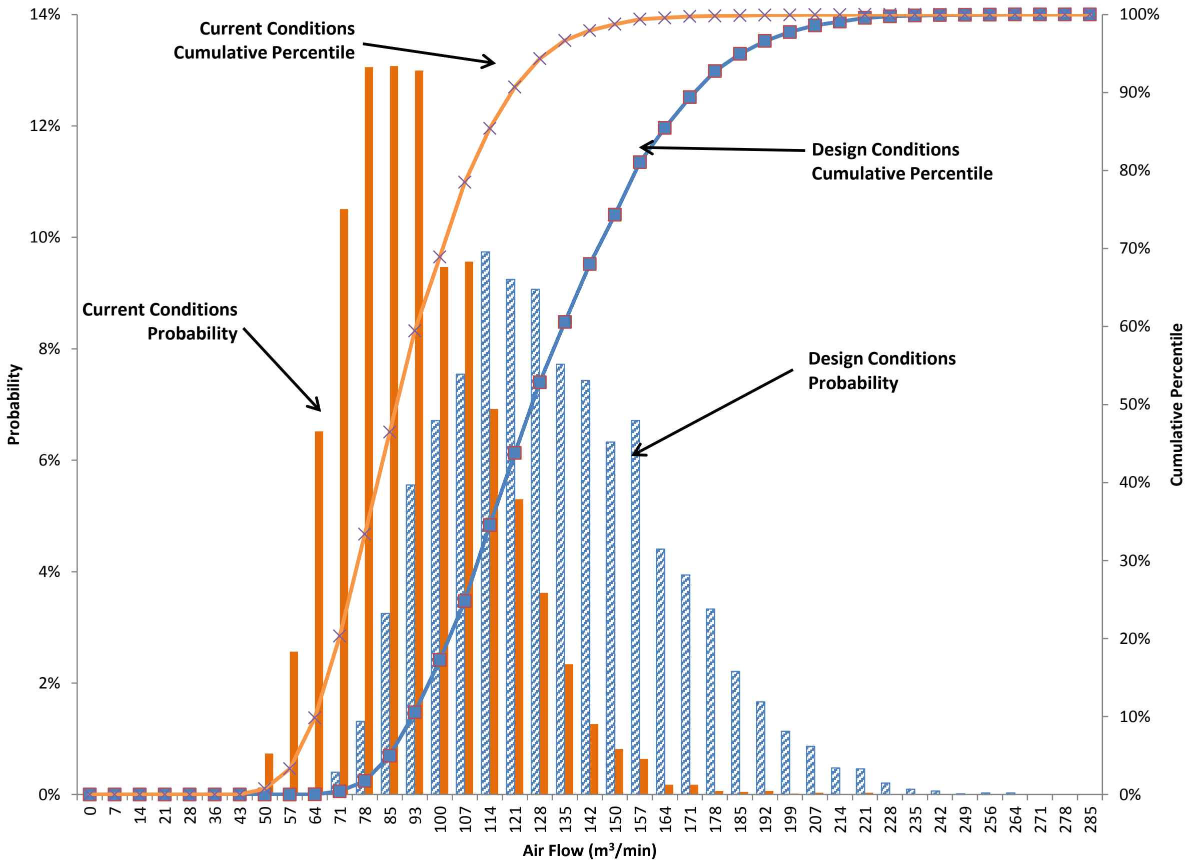

Figure 3: Histogram and cumulative percentile function of the total airflow required at current and design conditions

The histogram depicts the distribution of the data set and makes it easy to see where the majority of the result values fall, and how much variation there is. The cumulative percentile function depicts the probability that a result will be found at a value less than or equal of the result value.

Blower Sizing

To meet the broad range of airflow requirements, adequate blower turndown is needed. The use of the airflow histogram can help determine the number of blowers and the required turndown. A blower range overlaid on the airflow histogram is shown in **Figure 4**. It may not be viable to cover the complete range of the airflows, so the cumulative percentile graph can be used to show the airflow required to meet a percent of the airflow range.

It was determined that blowers with a total airflow range of 57 to 185 m^3/min (2,000 to 6,500 scfm) are required for the facility to achieve 90% of the current and future airflow requirements.

The calculated airflow using maximum design conditions is 235 m^3/min (8,250 scfm), 27% higher then calculated using a Monte Carlo analysis.

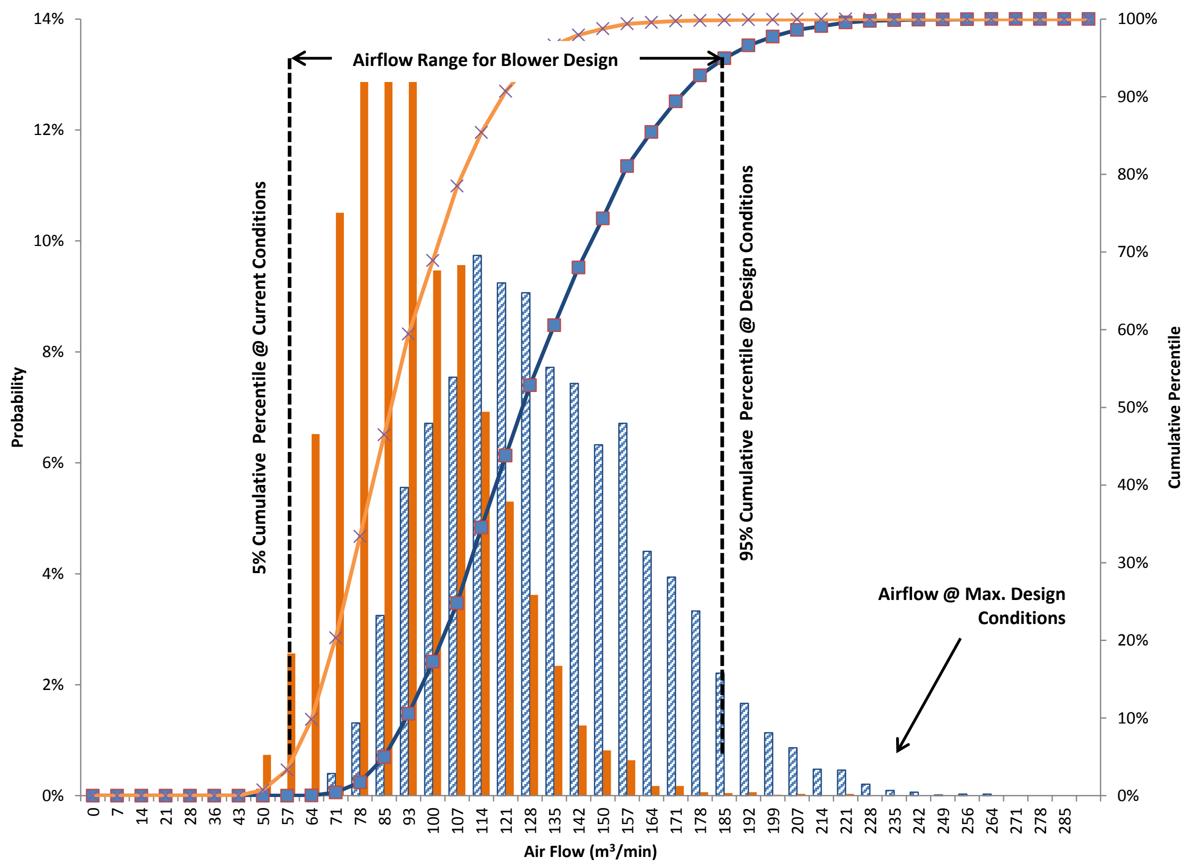

Figure 4: Selected blower range overlaid on the calculated airflow Histogram

DISCUSSION

Risk Analysis

By sizing the blowers to only achieve 90% of the required airflow range a certain amount of risk is introduced to the design. The Monte Carlo analysis can be used to quantify that amount of risk by running the analysis again with the limited airflow range incorporated into the model and compare it to the original analysis. **Figure 5** is the results from the risk analysis. With the limited airflow range the facility will still be under the ammonia design limit of 1 mg/l for 98.5% of the time, compared to 99.6% of the time with the complete airflow range.

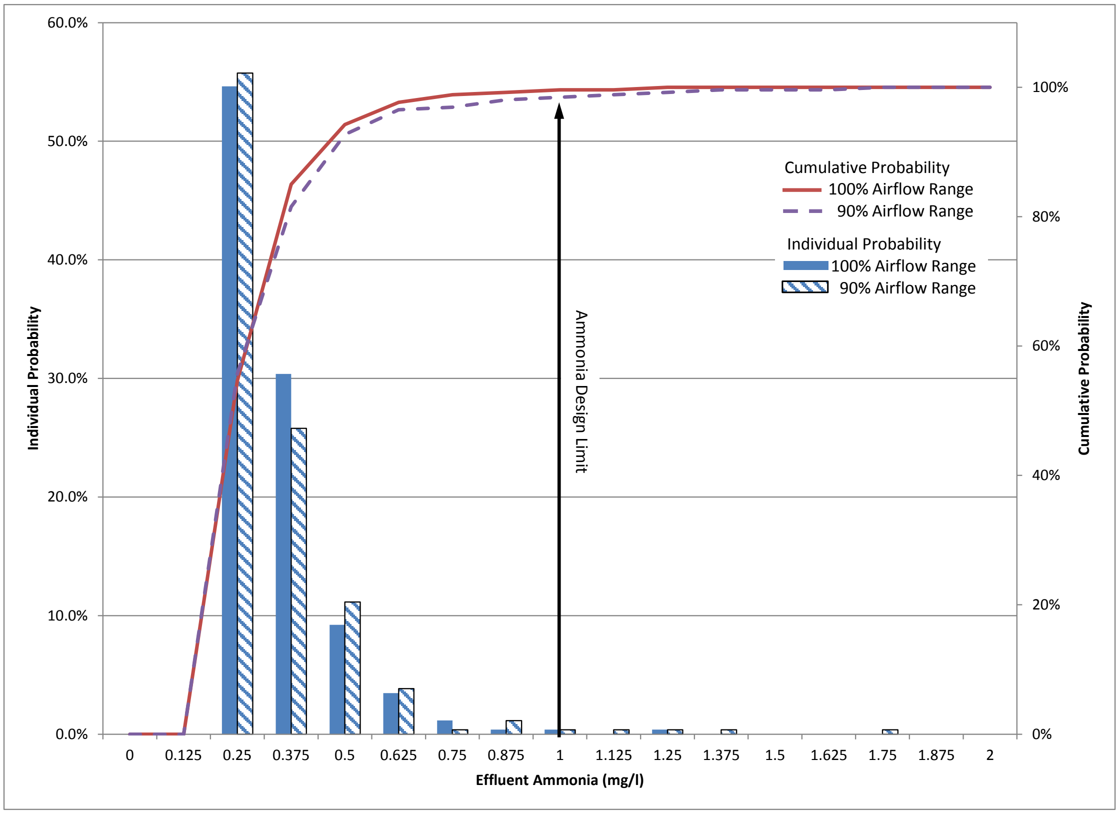

Figure 5: Histogram of the ammonia effluent risk analysis

CONCLUSION

The combined use of the process simulation software and Monte Carlo analysis allows the process engineer to see the full range of airflow requirements need for the aeration design with limited initial data. The conventional method of using maximum loadings would result in oversizing the blowers by 27%, compared to using a Monte Carlo Analysis. The analysis also quantified the risk of the effluent ammonia being above the design limit, a 0.9% increased risk associated with using only 90% simulated airflow range.

Results from the analysis were also used to calculate the amount fine bubble diffusers and size the air distribution piping and air control valves.

The Monte Carlo analysis allows the engineer to quantify the probability of a result or risk based on the uncertainty of the influent loadings.

REFERENCES

McCormick, J.F., Johnson, B. & Turner, A. (2007) Analyzing risk in wastewater process design: using Monte Carlo simulation to move beyond conventional design methods. Proceedings of WEFTEC 2007, San Diego, CA, CD-ROM.

Belia, E., Amerlinck, Y., Benedetti, L., Johnson, B., Sin, G., Vanrolleghem, P.A., Gernaey, K.V., Gillot, S., Neumann, M.B., Rieger, L., Shaw, A. and Villez, K. (2009) Wastewater treatment modeling: dealing with uncertainties. *Water Science & Technology*, 60(8), 1929-1941.