San Nicolas Pipeline Cooling Research Report

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Part I

Introduction

The AguaClara water treatment plant in San Nicolas was inaugurated on April 5, 2014, and has successfully started operation. However, a major problem that has become apparent is the heating of raw water during the day from the source to the plant entrance tank. Raw water travels 4.5 km through a steel pipeline exposed to sunlight which has been identified as the likely cause for the temperature increase. Since the plant is hydraulic and gravity-powered, the temperature of the influent water affects its properties and behavior in the various stages of the AguaClara treatment system, particularly in the sedimentation tank. While the stacked rapid sand filter has been able to keep effluent turbidities low enough to be deemed acceptable, the resulting required amount of backwash places excess stress on the system; therefore, it is imperative to seek a method to maintain a relatively low raw water influent temperature to ensure plant success in producing potable water.

Part II

Literature Review

The San Nicolas plant operates 24 hours a day and has been able to produce potable water consistently and successfully from 3 pm to 9 am . Influent water temperature at these times is typically 22-23ºC. Between 9 am and 3 pm, the water temperature rises to approximately 30°C, with maximum temperature occurring between 1 and 2 pm. The worst plant performance occurs between 9 am and 12 pm, where the temperature gradient is the largest. A sample of log book data displaying influent and effluent turbidities with relation to time and influent temperature is shown in Figure 1. The raw water temperature increases during the daytime and has a negative effect on plant performance based upon effluent turbidity values. The poorest performance is associated with the highest temperature gradient because that corresponds to the largest difference in

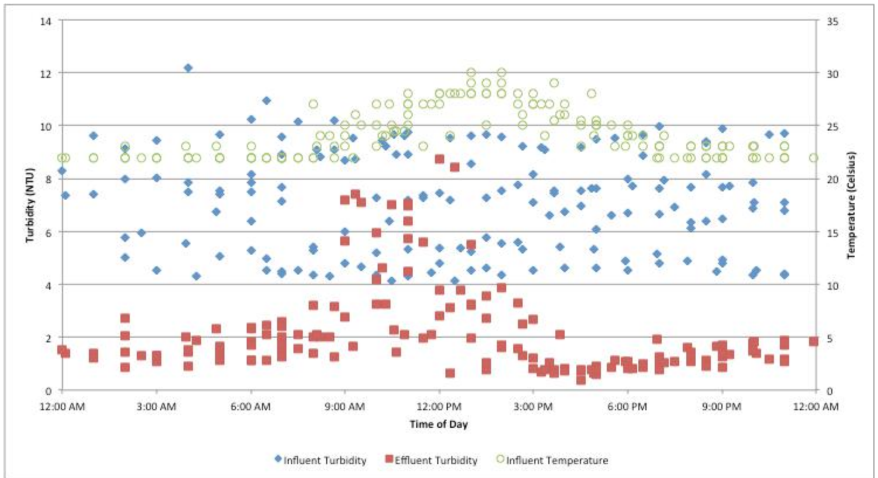

Figure 1: March 7, 2014 - March 14, 2014 Plant Performance Log Book Data

temperature between the water entering the sedimentation tanks and the water in the sedimentation tanks. That temperature difference corresponds to a density difference that causes the warm water to create a plume that rises rapidly to the top of the sedimentation tank. The influent temperature increases are most likely due to the 4.5 km of exposed pipeline, thus prompting research in solutions for reducing pipe heat transfer utilizing various coatings or built structures.

Part III
Methods

1 Pipe Analysis

The first step in determining best possible solutions lies in assessing the causes of the increased temperature. The easiest method to make this determination would be to analyze the heat transferred through the pipe via convection and the corresponding temperature change. One of the heat sources is the warm air that surrounds the pipe carrying the water, assumed to have an ambient temperature of 35°C. The other main heat source is the sun's irradiance, which heats up the water in the pipeline via the exposed steel pipe. Equations 1, 2, and 3 were utilized to determine the temperature change values due to these effects. Constants, terms, and assumptions for these calculations are listed below:

- q is the heat transferred through the pipe $\left[\frac{W}{m^2}\right]$
- w is the width of the area to which heat is being transferred $[m]$

- h is the heat transfer coefficient; for air, $12.5\,\frac{W}{m^2K}$ (Reference)
- c is the specific heat capacity; for water, $4,187\,\frac{J}{kg\cdot K}$
- Q is the flow rate of water; set at $22\,\frac{L}{s}$
- ρ is the density of water; $1000\,\frac{kg}{m^3}$

Temperature change due to heat transfer can be characterized by Equation 1, which is dependent on the length of the pipeline (dL).

$$\frac{dT}{dL} = \frac{q \cdot w}{c \cdot Q \cdot \rho} \tag{1}$$

The heat transfer values (q) for air and sunlight effects are as follows

- $q_{air} = h(T_{Ambient} - T_i)$
  - h is the thermal conductivity coefficient; for air, $12.5\,\frac{W}{m^2K}$
  - T is the temperature of the water in the pipeline. The initial temperature of the water entering the pipeline, T_i, is assumed to be $22^{\circ}C$
  - $T_{Ambient}$ is the ambient temperature of air, assumed to be $35^{\circ}C$
- $q_{sun} = (1 - r)I_{Sun}$
  - r is the reflectance of the pipeline, initially assumed to be 0
  - I_{Sun} is the irradiance of the sun, assumed to be $1000\,\frac{W}{m^2}$

The total temperature change can therefore be calculated using Equation 2. The width for air, w_{air}, can be characterized as πD (surrounds pipe) while the width for the sun, w_{sun}, can be characterized as D (rectangular projection of pipe). D is the outer diameter of the pipeline, set at $16.84\,cm$.

$$\frac{dT}{dL} = \frac{q_{air} \cdot w_{air}}{c \cdot Q \cdot \rho} + \frac{q_{sun} \cdot w_{sun}}{c \cdot Q \cdot \rho} \tag{2}$$

Integrating Equation 2 from the initial to the final temperature of the water, the final temperature of the water can be found using Equation 3. L is the length of the pipeline, set at $4.5\,km$.

$$T_f = T_{Ambient} + \frac{q_{sun}}{\pi h} - \frac{T_{Ambient} + \frac{q_{sun}}{\pi h} - T_i}{exp\left(\frac{\pi D h}{cQ\rho}L\right)} \tag{3}$$

The temperature change resulting in the water traveling through the 4.5 km pipeline can then be calculated taking the difference of T_f (from Equation 3) and T_i ($22^{\circ}C$). Utilizing this method, the total temperature change of the water in the pipeline is $9.84^{\circ}C$.

Since the maximum temperature rise observed in the pipeline is $8^{\circ}C$, the reflectivity of the pipeline was calculated to be 0.25 (utilizing the same process detailed above), not 0 as previously assumed. The maximum temperature rise possible from sunlight is $6.19°C$ and the maximum temperature rise possible from the ambient air is $2.4°C$. Figure 2 shows the temperature change due to sunlight, ambient air, and the total temperature change as a function of pipeline reflectivity. Note that calculations required for Figure 2 utilized the environmental and fluid assumptions listed above.

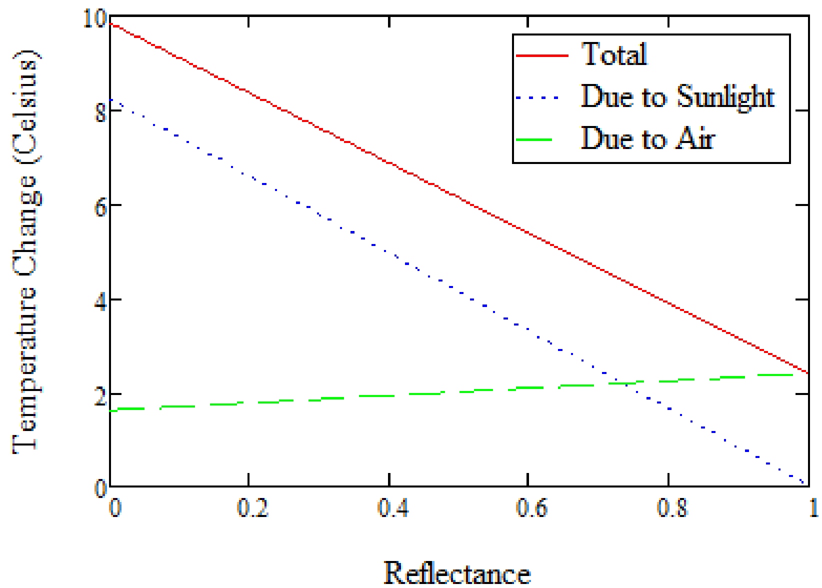

Figure 2: Pipeline Reflectance versus Temperature Change (Celsius)

2 Cool Roof Coatings

A possible method to reduce the temperature rise would be to utilize a cool roof coating on the pipeline. Cool roof coatings reduce roof temperatures by reflecting sunlight and heat away from buildings. Many different types of materials and paints can accomplish reflectance goals, but the best method for the San Nicolas situation would be to utilize end-user paint products because the pipeline is already in place. Based upon data collected by the Cool Roof Rating Council (CRRC), the end-user paint products with the two highest aged solar reflectance values are the AcryShield High Reflectance A590 (produced by National Coatings) and the NXT Cool Zone Gloss White (produced by Nutech Paint). Respective solar reflectance values are 0.87 and 0.86, resulting in adjusted sun irradiance values of $130\,\frac{W}{m^2}$ and $140\,\frac{W}{m^2}$. The resulting maximum temperature increase values are $3.37°C$ for the AcryShield product and $3.44°C$ for the NXT product (calculations done utilizing the process detailed in Section

1).

Part IV

Analysis and Conclusions

The AcryShield High Reflectance A590 and the NXT Cool Zone Gloss White products would both reduce the possible influent water temperature increase to $3.37°C$ and $3.44°C$, down from $9.84°C$. The lowered temperature increase would reduce required backwash of the filtration system and improve sedimentation tank performance (which is highly temperature dependent).

3 AcryShield High Reflectance A590 Pricing

National Coatings suggests utilizing 3 gallons of the A590 product to cover $100\,ft^2$; covering the approximately $23,000\,ft^2$ of exposed pipeline would therefore require 696 gallons. At a price of $30 per gallon, the total cost of coating the entire 4.5 km of exposed pipeline would be approximately $21,000.

4 NXT Cool Zone Gloss White Pricing

Nutech Paint requires two coats of the NXT product and one coat of a specialized primer, where the coverage is $825\,ft^2$ per 5 gallons for the NXT product and $1,000\,ft^2$ per 5 gallons for the primer. The respective required volumes of paint to cover the entire pipeline are 285 gallons and 120 gallons. At a price of $287.50 per 5 gallons for the NXT product and $243.50 per 5 gallons for the primer, total cost is approximately $22,000.

5 Minimizing Paint Volume Utilized

While the cost of covering the entire pipeline with either coating researched is very high, it is possible that the area of the pipeline is being over-estimated because only the top half of the pipe exposed to the sun would have to be coated. If this approach were taken, the cost would be approximately $10,000 for either product. Given the relatively high cost of painting the pipeline, this alternative must be compared with other alternatives including no action, covering the pipeline with thatch, encouraging growth of shade plants, and modifications to the sedimentation tank to reduce the negative impact of the temperature gradients.

Part V

Future Work

Future work could include evaluating other cool coating products and researching other possible solutions to either prevent heating of influent raw water in the exposed pipeline or improve the performance of the sedimentation tanks. However, before any significant investment in reducing the temperature gain in the pipeline is made, further research is required to determine the relationship between temperature gradient and sedimentation tank performance.

The pipeline for San Nicolas is approximately 15 km long, with 4.5 km exposed, and thus temperature changes due to warming of the air and warming of the top layer of soil where the pipe is buried may also contribute to water temperature changes. Although it would be possible to reduce the temperature fluctuations, it is likely that even small temperature changes would cause sedimentation tank performance to deteriorate. Investigating adjustments in plate settler design to reduce flow circulation should be pursued if the water temperature increase cannot be curbed.