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COST-BENEFIT ANALYSIS OF COOLING WATER TREATMENT BY OZONATION*

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ABSTRACT

A cost-benefit analysis of the treatment of cooling water by ozonation was performed for a cogeneration plant of a large cement company. The economic viability of the ozonation process was assessed by comparing the cost of the new cooling water treatment system with that of the conventional chemical treatment process. It was found that the payback of the ozonation treatment is highly dependent on the cycle of concentration of the cooling water system. The ozonation treatment system was found to be economically attractive for the cycle of concentration exceeding ten, a level easily realizable in practice. In the extreme case, with complete elimination of all treatment chemicals, the payback period of the ozonation treatment system is merely thirteen months. Besides the economic advantages, the ozonation treatment process also has other operational and environmental benefits which are not easy to quantify, and are not considered in the analysis.

INTRODUCTION

Cooling towers are widely used in all types of chemical processes and in large office buildings for water temperature control of closed cooling water systems. The majority of large-scale cooling towers use the direct-contact method (evaporative cooling) for water temperature control. Figure 1 shows a typical direct-contact cooling system. Hot process water enters the system from the top through a sprayer. The water trickles down the tower over the internal wood or plastic baffles in countercurrent to the air flow, which is sucked from the bottom

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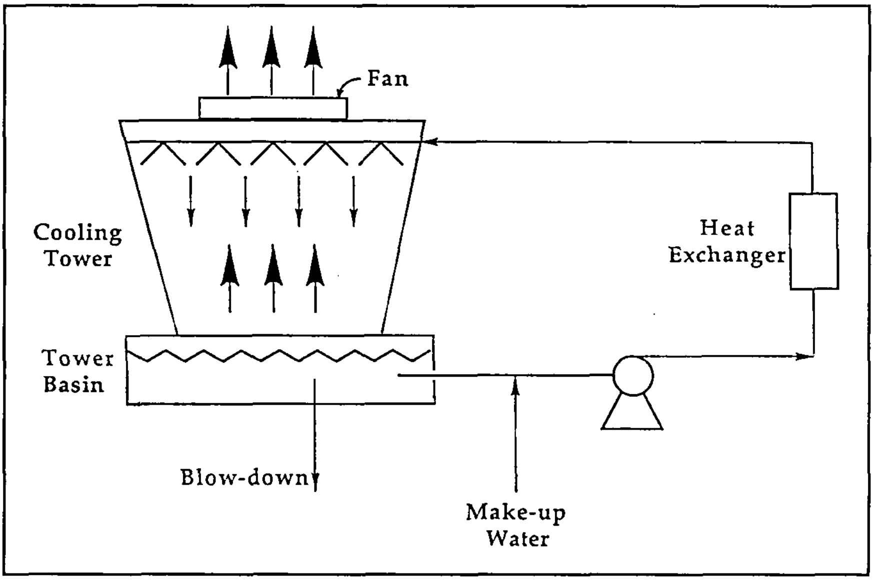

Figure 1. Schematic of direct contact cooling system.

and sides by large fans fitted on top of the tower. Direct contact between water and air flows accomplishes heat removal from the water by partial evaporation. Such a direct air/water contact, although providing a very effective means of controlling the temperature of the cooling water, traps fine air-borne particles and bacteria, thereby upsetting the quality of water in the closed circulation system. Therefore, treatment of the cooling water is necessary in order to maintain water quality at an acceptable level [1, 2].

The main problems arising from the direct air/water contact in the cooling water system include corrosion, scaling, and biofouling [1, 2]. Conventional methods of cooling water treatment consist of pH control for scale prevention, addition of chromates for corrosion control, and chlorination by chlorine gas or hypochlorites for biofouling (sliming) control. Due to increasingly stringent regulations governing the chlorine and chromate residues in cooling water, finding satisfactory substitutes is imperative [3]. In fact, the U.S. Environmental Protection Agency (EPA) banned the use of chromates in cooling water treatment in 1989; the current substitutes are costing industrial users much more than did the earlier treatment chemicals. For this reason, ozonation appears to offer an attractive alternative.

Cooling water treatment by ozonation was first investigated by the National Aeronautics and Space Administration (NASA) when the Jet Propulsion Laboratory, of the California Institute of Technology, first tried this method on several medium size cooling towers in 1977 [4]. The project was very successful. Ozone, a very strong oxidant, was found capable of controlling the corrosion, scaling and biofouling problems in a single treatment. Best of all, ozonation does not cause pollution problems in the treated cooling water such as those of the conventional multiple-chemical method. Since the NASA studies, many investigations have been conducted [5-10], and the process is gaining wide acceptance in the chemical process industry as an alternative to the conventional method.

Most of the previous investigations were primarily concerned with the technical aspects of the ozone treatment process [4-10]. One important issue not clearly addressed in the previous studies is the economic assessment of the ozonation process. The purpose of this study is to undertake an economic evaluation of this ozonation treatment method. The economic factor is in fact as important as the technical aspects in assessing the feasibility of this ozonation cooling water treatment technology.

COOLING WATER TREATMENT BY OZONATION

There are different configurations of ozone injection in the cooling water treatment system [6, 8]. Ozone can be added directly to the cooling water in the cooling tower basin. It can also be added to the hot cooling water before the water enters the top sprayers. But by far the most popular method of ozonation cooling water treatment is by injecting ozone to the returning cooling water line before the heat exchange [6, 8, 10], as shown in Figure 2. The details of the ozone injection system are illustrated in Figure 3. The system usually utilizes a Venturi tube mixer, which can provide excellent mixing efficiency at low cost.

The single most important parameter in the design of the ozonation water treatment system is the amount of ozone required for a given cooling duty of the cooling tower. This quantity is difficult to determine precisely primarily, because of its strong dependence on the cooling water quality, which varies widely from system to system. Therefore, the required amounts of ozone recommended by various investigators differ significantly. Edwards reported that an ozone concentration range between 0.02 and 0.05 mg/l needs to be maintained in the cooling water [6]. An ozone concentration below 0.02 mg/l would render the treatment insufficient. Above 0.05 mg/l, the residual ozone in the cooling water could cause corrosion to the piping of the cooling water system. Echols and Mayne recommended that for every 100 cooling tons of the tower capacity, 20 to 40 grams of ozone is required [8]. Ozonair International, a well known American manufacturer of ozone generator, recommended the required amount of ozone as a function of the total amount of cooling water in the system as given in Figure 4 [11]. According to the information reported previously and the author's own experience, the required ozone concentration in the cooling water for efficient treatment would be in the range between 0.02 and 0.1 mg/l. For sake of safe operation, an ozone concentration near the higher end of this range is usually recommended.

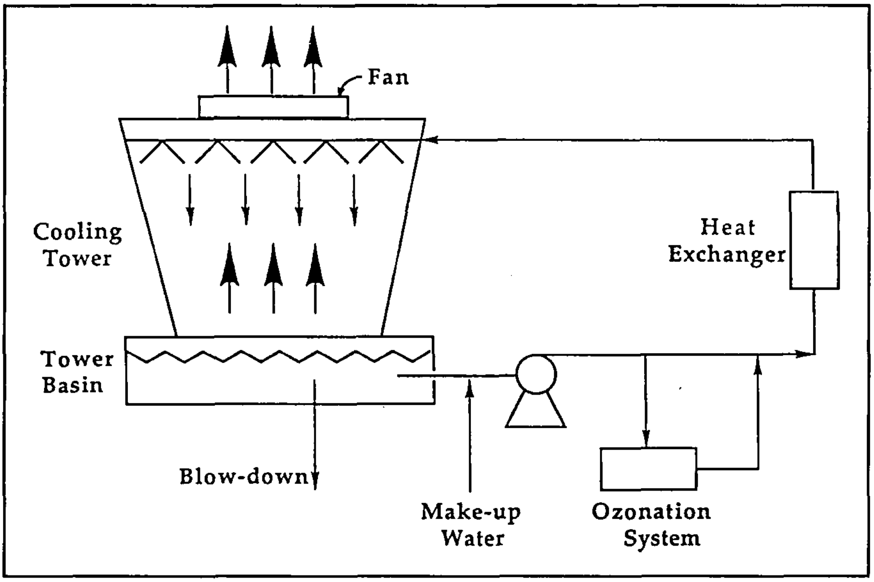

Figure 2. Cooling water treatment by ozonation.

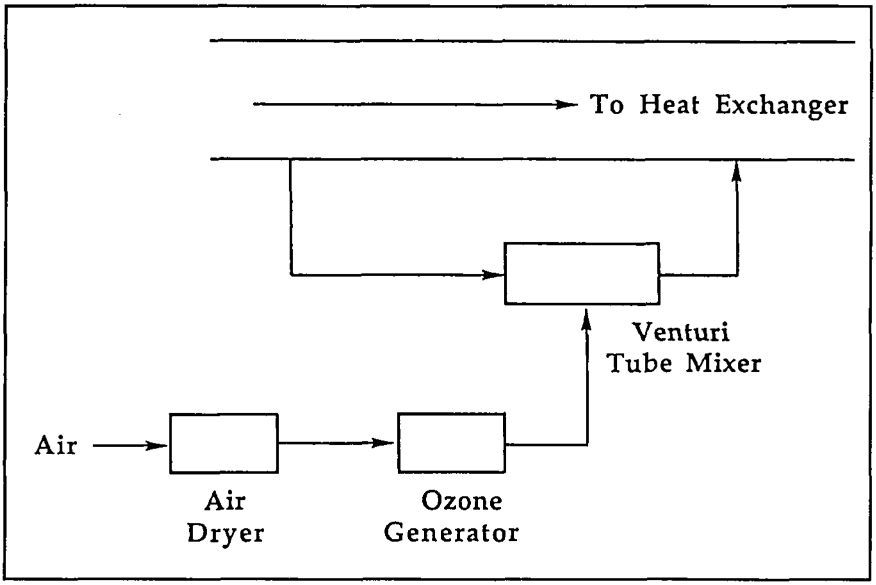

Figure 3. Detail of ozone injection system.

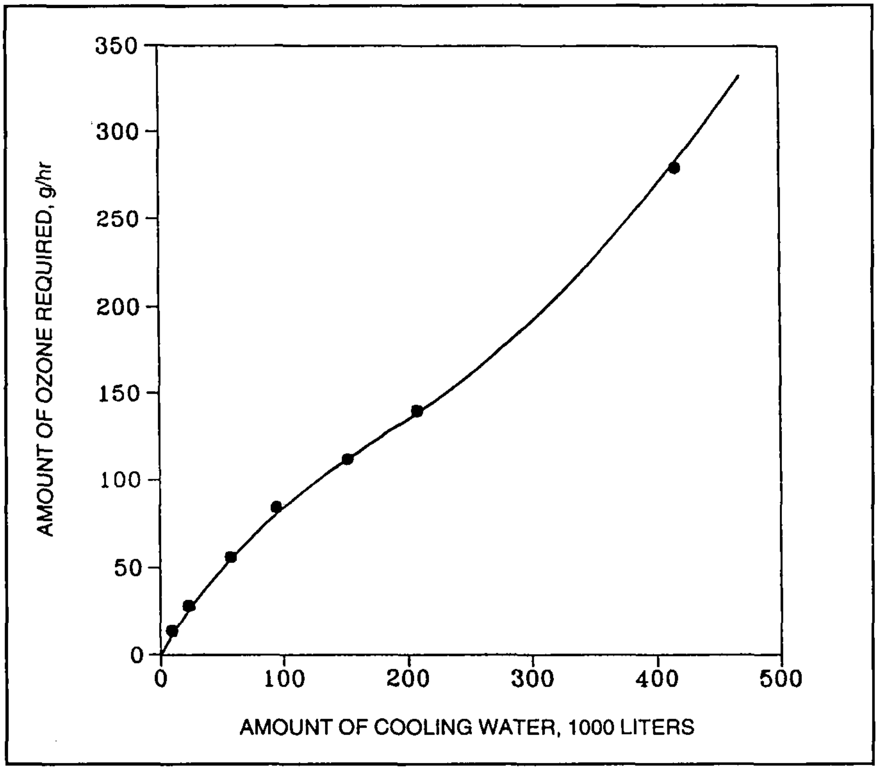

Figure 4. Ozone requirement as a function of cooling water flow rate.

COST-BENEFIT ANALYSIS OF OZONATION SYSTEM

To illustrate the principle of cost analysis of the ozonation treatment process in comparison to the conventional chemical treatment process, a cooling tower for a cogeneration plant of a big cement company was adopted [12]. The average water flow rate of the cooling tower was about 2300 tons/hr with mild fluctuation. Assuming the required ozone concentration to be 0.075 mg/l, the total amount of ozone generation required would be 172.5 g/hr. The price for the ozone generator of this capacity, as supplied by a large manufacturer, was about $75,000 (all cost figures are in U.S. currency). The total cost of capital investment of the ozone generation facilities is listed in Table 1.

According to the manufacturer, the ozone generator consumes 16 kW of power. The average cost of electricity (peak and off-peak) is about $0.07/kWh. Assuming the ozone generator is operated 340 days a year, the total cost of electricity comes to $9,100/yr. The life of the ozone generator is about eight years and hence the

Table 1. Capital Investment of the Ozonation Cooling Water Treatment System

Ozone generator:	$75,000
Venturi mixer:	500
Circulation pump:	3,800
Piping cost:	9,000
Accessory cost (10% of the above):	8,800
Total	$97,100

annual equipment depreciation is $12,100. The annual maintenance cost is about $3,800. The total annualization cost of the ozonation treatment system amounts to $25,000, of which $12,900 is the operating cost.

The cooling water of the cogeneration plant had been treated using several chemicals for pH control and biofouling, corrosion, and scale prevention. The chemical treatment is sufficient to maintain a cycle of concentration at 3.45 which is just about the average for a conventional chemical treatment process [1, 2]. The cycle of concentration is defined as the ratio of the calcium ion concentration in the blowdown to that in the makeup. It represents the calcium ion concentration level that can be safely maintained in the cooling water without causing scale formation and fouling on the metal surface of the heat exchanger. Hence the higher the cycle of concentration is, the more effective the cooling water treatment. Cooling water treatment by ozonation is intended primarily for complete replacement of all treatment chemicals [5-10]. Hence, the cycle of concentration could be raised to as high as 30 or even higher, as reported in the literature. However, it is usually deemed not practical to raise the cycle of concentration to the extreme. For the present economic analysis of the cooling water treatment system, the cycle of concentration was varied between current 3.45 and 30. An increase in the cycle of concentration can lead to a reduction of the treatment chemicals according to the empirical equation

$$C_i = C_0 \frac{N_0 - 1}{N_i - 1} \tag{1}$$

where N_0 and N_i are the original and new cycles of concentration, and C_0 and C_i the corresponding costs of treatment chemicals. An increase in the cycle of concentration also can significantly reduce the amount of blowdown. The amount of blowdown is related to the cycle of concentration by the following empirical equation

$$B = \frac{E}{N - 1} \tag{2}$$

in which B is the blowdown, E the evaporation loss of cooling water and N the cycle of concentration. The sum of the evaporation loss and the blowdown is the makeup requirement of the cooling water treatment system. The makeup comes either from the public water or underground water supply. The cost of the makeup water from either source is about $0.38/ton, which is the basis for calculating the value of water saved. Since the evaporation loss of the cooling water system is fixed, a decrease in the blowdown translates directly to a makeup water saving.

As noted, the conventional method uses chemicals for scale, fouling, and corrosion prevention, including sulfuric acid for pH control and chlorine for algal control. Ozone is an excellent bactericide and thus a very good substitute for chlorine. But it is assumed here that ozone can only partially replace the treatment chemicals depending on the cycle of concentration of the cooling water treatment system. Currently, the annual costs of treatment chemicals and chlorine amount to $40,000 and $8,400, respectively [12]. Implementation of ozonation treatment therefore leads to a complete saving of $8,400 of chlorine plus a partial saving of $40,000 by an amount computed by Equation (1). However, ozonation incurs an annual operating expense of $12,900. The return of the ozonation cooling water treatment system hence is equal to the sum of the chemical and water savings less the operating cost of the ozonation system. The payback is finally computed by dividing the sum of the return and the equipment depreciation on the total capital investment of the system, which is $97,100. All calculations were performed as outlined and were listed in Table 2 for four cycles of concentration, i.e., 6, 10, 15, 30 and ∞.

Table 2. Cost-Benefit Analysis of Ozonation Cooling Water Treatment

Cycle of concentration	3.45	6	10	15	30	∞
Evaporation loss, T/hr	33	33	33	33	33	33
Blowdown, T/hr	13.47	6.6	3.67	2.36	2.36	0
Makeup, T/hr	46.47	39.6	36.67	35.36	34.14	33
Water saving, T/yr	—	56,000	80,000	90,700	100,600	111,100
Water saving worth, $/yr	—	21,500	30,800	34,900	38,700	42,300
Chemical cost, $/yr	40,000	19,600	10,900	7,000	3,400	0
Chlorine, $/yr	8,400	—	—	—	—	—
Chemical saving, $/yr	—	28,800	37,500	41,400	45,000	48,400
Operating cost, $/yr	—	12,900	12,900	12,900	12,900	12,900
Total treatment cost, $/yr	48,400	35,200	23,800	19,900	16,300	12,900
Return, $/yr	—	15,100	44,500	56,400	67,400	77,800
Payback, yr	—	3.57	1.72	1.42	1.22	1.08

Scrutiny of Figure 5 reveals that the cycle of concentration is a highly critical factor in the economical evaluation of the ozonation treatment viability. It is apparent that there is a sharp decrease in the payback period as the cycle of concentration is elevated from 3.45 to 10. The trend of payback then tapers off until it asymptotically reaches the extreme case of 1.08 years when the treatment chemicals are totally replaced. The improvement in the payback is only 0.68 year as the cycle of concentration increases from 10 to infinite. In reality, according to the past experiences [5-10], a cycle of concentration above 10 is fairly easy to achieve by the ozonation treatment process. Hence the new process is economically viable. It should be further noted that the conclusion drawn is based solely on the economic evaluation. In fact, there are other operational and environmental

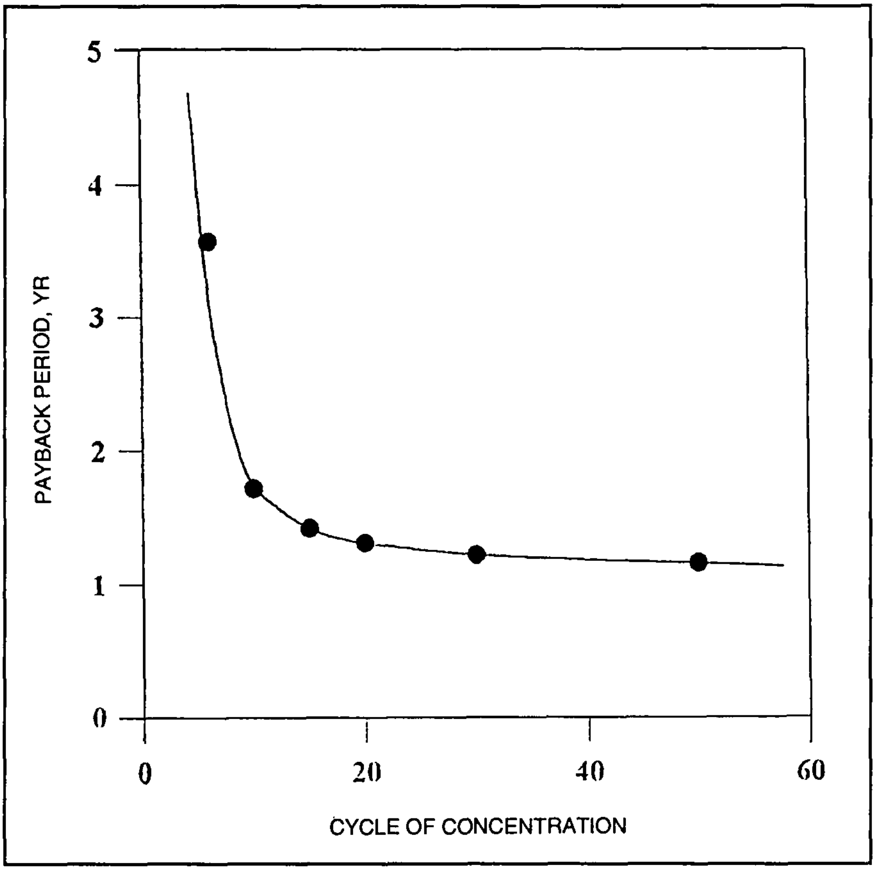

Figure 5. Payback of the ozonation cooling water treatment as a function of the cycle of concentration.

benefits which are difficult to quantify precisely. These include the reduced cost of blowdown treatment, much better cooling water quality in terms of the water chemical content, much safer operation due to elimination of chlorine hazards and ease of operation, and thus a further saving of labor cost. Therefore, from all practical standpoint, the cooling water treatment by ozonation is a very viable process.

CONCLUSIONS

Cost-benefit analysis of the cooling water treatment by ozonation for corrosion, scale, and biofouling control is considered in this present study. The present evaluation is solely based on the economic factors. A cooling water treatment system for a cogeneration plant of a large cement company is employed to illustrate the principle. It has been found that by comparing the cost of the ozonation treatment system with that of the conventional chemical treatment system for various cycles of concentration, the payback of the ozonation system can be as short as thirteen months which is extremely attractive indeed. The payback was found to be highly dependent on the cycle of concentration. The ozonation treatment system was found to become acceptable as long as the cycle of concentration of the cooling water treatment system is maintained above 10, which is very easily realizable in practice. Furthermore, the ozonation treatment brings about other benefits which are difficult to quantify *per se*. Considering the economic advantages and the operational and environmental benefits, the ozonation cooling water treatment system is decidedly viable.

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