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The Effect of Contact Time and Concentration of Oxygen on the Efficiency of the Catalytic Reduction of Dissolved Oxygen

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Abstract: In this work, removal of dissolved Oxygen in water through a reduction catalytic method was studied. The effect of contact time and Oxygen concentration were investigated on the efficiency of the catalytic reduction of dissolved Oxygen. In steam power plants that dissolved Oxygen levels should be less than 5 ppb, the required contact time for this process is at least about 45 seconds. Also in a fixed volume of the catalyst at a low amount of dissolved Oxygen in inlet water, a higher rate of water could flows through the catalyst bed and the Hydrogen injection rate would be lower.

Key words: Dissolved Oxygen • Reduction Catalytic • Contact Time • Steam Power Plant

INTRODUCTION

Water is used for different purpose such as system cooling and warming in many industries. Dissolved oxygen (DO) in water causes some problems in the industrial systems, for example, in boilers and steel pipes DO causes pitting corrosion, poor heat transfer and in pumps it causes cavitations and fins corrosion [1, 2]. So in boilers, deoxygenation of feed water is an important step. Oxygen solubility in water is about 8 mg/L at surrounding conditions; However, acceptable level of DO is dependent on the process [3, 4]. Various physical and chemical methods are applied to remove DO. Physical methods include thermal degassing, vacuum degassing, nitrogen bubbling and degassing through a membrane module [2, 5]. Chemical methods for scavenging of DO include the addition of reducing agents such as hydrazine, sodium sulfite, carbohydrazide, β-ketogluconate and gallic acid [3, 5].

Sodium sulfite reacts with DO to form sodium sulfate. But in high pressures, sodium sulfite increases the ionic content of water and decomposes to H_2S and SO_2 that are corrosive [6]. Hydrazine is another oxygen scavenger which provides some advantages to the physical methods and sodium sulfite; but it is undesirable due to its toxicity. Another drawback of hydrazine is its low rate of reaction with DO at ambient temperature so the reductive removal of DO by hydrazine needs a highly active catalyst [7]. Another method is using the Pd and Pt-resin base catalysts [8,9]. Experimental studies show the performance of this method using hydrogen gas as a reducing agent [10]. In this study removal of dissolved oxygen in water through a reduction catalytic method, was investigated. Also the effect of the operation conditions such as temperature, pressure and flow rate of water on the efficiency of the catalytic reduction of dissolved oxygen was studied.

MATERIALS AND METHODS

In the process of catalytic reduction of dissolved oxygen, hydrogen and oxygen react in the presence of a catalyst to produce water:

$$O_2 + 2H_2 \rightarrow 2H_2O \qquad \Delta H = -68.3\,kcal/\text{mol}$$

The production of reaction is water that has no adverse effect on the system. An experimental setup was constructed to investigate the effective parameters in the catalytic reduction of dissolved oxygen. Figure (1) shows

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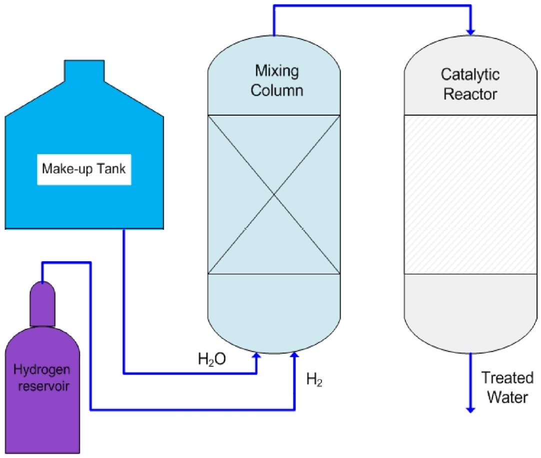

Fig. 1: Overview of the catalytic process to remove dissolved Oxygen

the overview of this process. Water was pumped from the water tank to the Hydrogen/water mixer. The mixer was a concurrent gas–liquid up flow packed bed. The water saturated both with Oxygen and Hydrogen then entered the catalytic resin vessel where the Hydrogen and Oxygen reacted in presence of the catalyst. The reaction was catalyzed using 1.5 liter of K6333 resin catalyst (Lanxess Co. Germany) [11]. All results were obtained under the following conditions:

- Operating pressure: 2- 3 bar
- For determination of remaining Oxygen in the product, ASTM D888-81 was used.
- Hydrogen gas with 99.99% purity

RESULTS AND DISCUSSION

Effect of Contact Time: An important parameter to control the process is the contact time that was influenced by column dimensions, volume of resin and the linear velocity of water. In fact the contact time is fluid residence time in the catalyst column in which DO on the catalyst surface reacted with Hydrogen. The results of experiments in different conditions were shown in figure (2) and Tables (1-4). In all tables efficiency was the oxygen absorption relative to the input of dissolved oxygen in water.

Table 1: Remaining Oxygen in 45 lit/hr flow rate (contact time: 120 seconds)

Efficiency %	Remaining dissolved Oxygen (ppb)	Water flow rate (lit/hr)	Hydrogen Injection Pressure (bar)	Mixing Column Pressure (bar)	Mixing Column Temperature (°C)	Catalytic Reactor Temperature (°C)	Inlet Dissolved Oxygen (ppm)	Sampling Time (min)
27.5	5000	45	2.5	2	18	18	6.9	5
91	600	45	2.5	1.9	19	19	6.8	10
95.5	300	45	2.5	1.8	19	19	6.7	15
98.8	80	45	2.5	1.9	20	20	6.7	20
99.8	10	45	2.5	2	19	19	6.8	25
99.9	8	45	2.5	1.9	20	20	6.9	30
99.9	4	45	2.5	1.8	18	18	6.7	30
99.9	2	45	2.5	2	20	20	6.7	40
99.95	2	45	2.5	2	21	21	6.7	50
99.95	2	45	2.5	1.9	20	20	6.8	60

Table 2: Remaining Oxygen in 90 lit/hr flow rate (contact time: 60 seconds)

Efficiency %	Remaining dissolved Oxygen (ppb)	Water flow rate (lit/hr)	Hydrogen Injection Pressure (bar)	Mixing Column Pressure (bar)	Mixing Column Temperature (°C)	Catalytic Reactor Temperature (°C)	Inlet Dissolved Oxygen (ppm)	Sampling Time (min)
11.6	6000	90	2.5	2	20	20	6.8	8
85.5	1000	90	2.5	1.9	19	19	6.9	12
91	600	90	2.5	19	18	18	6.7	15
97	200	90	2.5	1.8	20	20	6.8	20
99.9	50	90	2.5	2	17	17	6.7	25
99.9	10	90	2.5	1.9	18	18	6.9	30
99.9	6	90	2.5	1.7	21	21	6.7	35
99.95	3	90	2.5	1.9	19	19	6.7	40
99.96	2	90	2.5	2	19	19	6.7	45
99.97	2	90	2.5	1.9	21	21	6.9	60

Table 3: Remaining Oxygen in 120 lit/hr flow rate (contact time: 45 seconds)

Efficiency %	Remaining dissolved Oxygen (ppb)	Water flow rate (lit/hr)	Hydrogen Injection Pressure (bar)	Mixing Column Pressure (bar)	Mixing Column Temperature (°C)	Catalytic Reactor Temperature (°C)	Inlet Dissolved Oxygen (ppm)	Sampling Time (min)
11.7	6000	120	2.5	2	20	20	6.8	10
71	2000	120	2.5	1.9	18	18	6.9	15
87	900	120	2.5	1.8	19	19	6.9	18
92.6	500	120	2.5	1.9	20	20	6.8	20
98.5	100	120	2.5	2	18	18	6.8	22
98.8	80	120	2.5	1.8	20	20	6.9	25
99.4	40	120	2.5	1.9	19	19	7	30
99.8	10	120	2.5	1.9	20	20	6.9	35
99.9	8	120	2.5	2	20	20	6.8	40
99.9	6	120	2.5	1.8	19	19	6.8	50

Table 4: Remaining Oxygen in 240 lit/hr flow rate (contact time: 22 seconds)

Efficiency %	Remaining dissolved Oxygen (ppb)	Water flow rate (lit/hr)	Hydrogen Injection Pressure (bar)	Mixing Column Pressure (bar)	Mixing Column Temperature (°C)	Catalytic Reactor Temperature (°C)	Inlet Dissolved Oxygen (ppm)	Sampling Time (min)
13	6100	240	2.5	2	20	20	6.9	10
51	3400	240	2.5	1.8	18	18	7	15
70	2100	240	2.5	1.7	19	19	7.1	18
85.5	900	240	2.5	1.8	19	19	6.8	21
92.7	500	240	2.5	1.9	21	21	6.9	25
97	200	240	2.5	1.9	20	20	6.9	30
98.6	100	240	2.5	1.8	19	19	7.1	40
98.9	70	240	2.5	1.9	18	18	6.9	50
99.2	50	240	2.5	2	18	18	6.8	60
99.4	40	240	2.5	1.8	19	19	6.9	70

Table 5: The effect of dissolved Oxygen concentration (DO: 0.5 ppm, contact time: 30 seconds)

Efficiency %	Remaining dissolved Oxygen (ppb)	Water flow rate (lit/hr)	Hydrogen Injection Pressure (bar)	Mixing Column Pressure (bar)	Mixing Column Temperature (°C)	Catalytic Reactor Temperature (°C)	Inlet Dissolved Oxygen (ppm)	Sampling Time (min)
80	100	180	2.5	2	25	25	0.5	10
98	10	180	2.5	2	25	25	0.5	20
99	5	180	2.5	2	25	25	0.5	30
99.9	4	180	2.5	2	25	25	0.5	40
99.9	4	180	2.5	2	25	25	0.5	50
99.9	4	180	2.5	2	25	25	0.5	60

Table 6: The effect of dissolved Oxygen concentration (DO: 2 ppm, contact time: 30 seconds)

Efficiency %	Remaining dissolved Oxygen (ppb)	Water flow rate (lit/hr)	Hydrogen Injection Pressure (bar)	Mixing Column Pressure (bar)	Mixing Column Temperature (°C)	Catalytic Reactor Temperature (°C)	Inlet Dissolved Oxygen (ppm)	Sampling Time (min)
50	1000	180	2.5	2	25	25	2	10
62.5	750	180	2.5	2	25	25	2	20
82.5	350	180	2.5	2	25	25	2	30
97.5	50	180	2.5	2	25	25	2	40
99.5	10	180	2.5	2	25	25	2	50
99.85	2	180	2.5	2	25	25	2	75

Table 7: The effect of dissolved Oxygen concentration (DO: 4 ppm, contact time: 30 seconds)

Efficiency %	Remaining dissolved Oxygen (ppb)	Water flow rate (lit/hr)	Hydrogen Injection Pressure (bar)	Mixing Column Pressure (bar)	Mixing Column Temperature (°C)	Catalytic Reactor Temperature (°C)	Inlet Dissolved Oxygen (ppm)	Sampling Time (min)
20	3200	180	2.5	2	25	25	4	10
80	800	180	2.5	2	25	25	4	20
98.8	45	180	2.5	2	25	25	4	30
99.8	7	180	2.5	2	25	25	4	40
99.95	2	180	2.5	2	25	25	4	50
99.97	2	180	2.5	2	25	25	4	75

Table 8: The effect of dissolved Oxygen concentration (DO: 8 ppm, contact time: 30 seconds)

Efficiency %	Remaining dissolved Oxygen (ppb)	Water flow rate (lit/hr)	Hydrogen Injection Pressure (bar)	Mixing Column Pressure (bar)	Mixing Column Temperature (°C)	Catalytic Reactor Temperature (°C)	Inlet Dissolved Oxygen (ppm)	Sampling Time (min)
10	1000	180	2.5	2	25	25	8	10
73	750	180	2.5	2	25	25	8	20
98	350	180	2.5	2	25	25	8	30
99.7	50	180	2.5	2	25	25	8	40
99.92	10	180	2.5	2	25	25	8	50
99.97	2	180	2.5	2	25	25	8	75

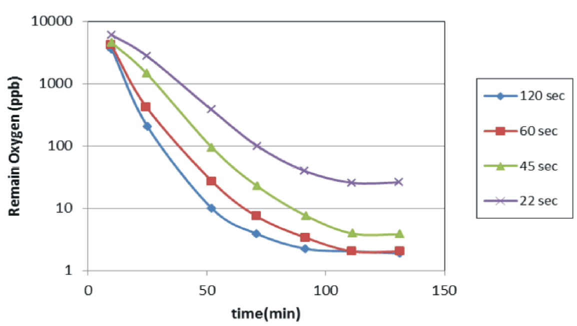

Fig. 2: The effect of contact time on remaining Oxygen

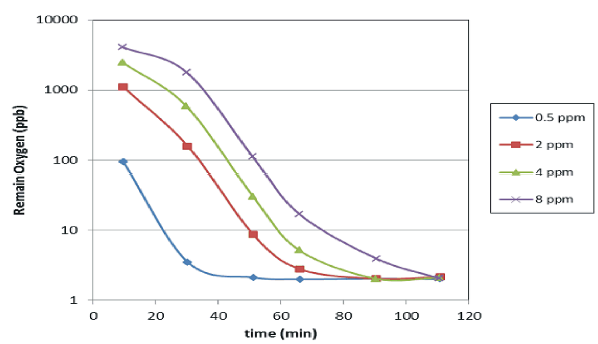

Fig. 3: The effect of different concentrations of dissolved Oxygen

As seen in Figure 2; at contact time of less than 45 seconds, the decrease in dissolved oxygen levels below 5 ppb was not possible. It was hard to reduce the dissolved oxygen level of less than 10 ppb when the exposure time was less than 30 seconds. Therefore, the ideal time should be considered based on desired reduction of dissolved oxygen. For use in steam power plants that dissolved oxygen levels should be less than 5 ppb, time is at least about 45 seconds.

Effect of Inlet Dissolved Oxygen Concentration: The amount of dissolved Oxygen in the water inlet at the start time of the system was effective on the operating time. In other words, the time required to reach the limit concentration for the remaining Oxygen in the outlet water of the catalytic column, was influenced by the dissolved Oxygen in water input. In a fixed volume of catalyst, the less amount of dissolved Oxygen in water, a higher amount of the water flew through the catalyst bed. In this condition the desired results would be achieved and the Hydrogen injection rate would be lower. The results of experiments in different concentrations of dissolved Oxygen were shown in Tables (5-8) and in Figure (3). For example when the input of dissolved Oxygen was 0.5 ppm, the time needed to reach to the desired point of 5 ppb of remaining DO was short even at the contact time of 30 seconds.

The contact time and Oxygen concentration are the most important parameters that influence on the efficiency of the catalytic reduction of dissolved Oxygen. In steam power plants that dissolved oxygen levels should be less than 5ppb, time is at least about 45 seconds. Also In a fixed volume of a catalyst, at low amount of dissolved Oxygen in water inlet, it would be possible to increase water flow rate and decrease the Hydrogen injection to reach to desired outlet Oxygen concentration.

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