A catalytic ozonation reactor design for reuse large scale industrial wastewater: laundry

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Abstract. Large-scale industrial wastewater is a longstanding problem, but considerations of the industrial wastewater treatment progress are unusual, and the design of wastewater treatment required by industry is severely deficient. To make industrial wastewater an economically viable source of clean water, we propose a logical approach towards designing a large scale catalytic ozonation reactor for reuse large scale industrial wastewater. ANSYS software is used as a primary tool to estimate the ozone transfer and catalytic performance of the reactor, and the effects of reactor design are investigated. The ozone transfer of 100 g/h, energy consumption rate of 3 kWh and a catalytic time of 120 seconds are all within acceptable ranges typical to industrial wastewater. It is estimated that a double catalytic ozonation reactor of 5 m³ can supply the clean water demand of 100 m³/day.

1. Introduction
The laundry industry's growth in Indonesia is increasingly in line with the increasing need for laundry per kg, laundry per pcs, hotel laundry, hospital laundry, laundry workers who need clothes with hygiene standards, and others. Indonesia's wastewater laundry industry is currently in the range of 50 L to 200 L for each washing process. This discharge of wastewater is determined by the type of washing machine, detergent, and washing remedy.

Patil et al. (2020) mention that the primary contamination of laundry wastewater is detergents, namely surfactants, such as linear alkylbenzene sulfonates, dodecyl sulfates and sulfonates, olefin sulfonates, alkyl amides, polyoxyethylene ether sulfates, and buffers, such as sodium tripolyphosphate, as well as firn from washed clothes [1]. The COD concentration of laundry wastewater in the range of 500 – 2000 ppm.

Currently, most of the laundry industry wastewater in Indonesia is directly discharged to the body of water without processing. Surfactant contamination in water can damage aquatic ecosystems, and surfactant consumption above 0.5 ppm can harm the health of living things. The government and stakeholders need to encourage the creation of an environmentally friendly laundry business ecosystem to thrive while maintaining environmental sustainability.

Various treatment technologies have been developed for wastewater with surfactant content such as aerobic and anaerobic, coagulation and flotation, membrane separation, ion exchange, and Advanced Oxidation Processes (AOP). Today the AOP approach is an attractive alternative to conventional technology, as it allows the mineralization of surfactants without incurring mud residue.

Catalytic ozone is one of the AOP technologies utilized in the Wastewater Treatment Plant (WWT). There are two main reasons why this technology is the top choice, firstly regarding catalytic ozone
performance in the mineralization of all types of organic contamination into H$_2$O and CO$_2$, both potential reuse and recycle. Catalytic ozone technology has been utilized in various industrial WWT, such as textiles, pulp and paper, distilleries and pharmaceuticals [2].

Various publications have been published on catalytic ozone applications to suppress toxic organic contamination, such as phenols, pesticides, dyes, pharmaceuticals, and other toxic organic contamination [3]. Research conducted by Patil et al. (2020) shows the efficiency of laundry wastewater treatment using catalytic ozone with ZnO and CuO catalysts [1]. The catalytic ozone system produces hydroxyl radicals as oxidation for the degradation and mineralization of organic contamination.

Zhang et al. (2016) research successfully utilized homogeneous catalysts in hybrid catalytic ozone membrane reactor (COMR) nonbiodegradable organic contamination processing resulting in a total decrease in organic carbon (TOC) to 98.6%, mineral elimination of nearly 100%, and recovery of catalyst metal ions by up to 100% [4]. Another promising solution is filtration in the catalytic ozone system to increase hydroxyl radicals and organic contamination minerals in the water. This approach enables the profit generated from the filtration and profit of catalytic ozone [5].

2. Methodology
The selection of laundry industry wastewater treatment to be used is based on the publication of catalytic ozonation and some environmentally friendly criteria that support the green industry, among others: new technological innovations; reusable water; the resulting mud is as small as possible (reduce); can remove detergent well; processing efficiency can meet the prevailing quality standards; can lower COD large enough to achieve the overall quality standard; operating costs and energy consumption are low; the price of investment and land required is not very high; operation and maintenance are easy and straightforward.

Based on the above criteria, the laundry industry wastewater treatment uses Catalytic Ozone technology. The investment costs, operational costs, aesthetics, and added value are the primary considerations in designing the proposed catalytic ozone reactor design.

1. Location and time
   The catalytic ozonation reactor's design was carried out at the Center of Industrial Pollution Prevention Technology and was carried out for approximately three months from July 2020 to September 2020.

2. Data collection
   The data used is secondary data, which comes from several references. This data is useful as a reference in determining the discharge of waste to be processed and the desired quality standard.

3. Data processing and design
   Discharge data is useful for calculating the size of the tool to be designed. The detailed design process can be seen in figure 1.
3. Results and discussions

3.1. Process flow chart

All laundry industry wastewater resulting from laundry activities, namely washer wastewater and drying wastewater, flowed into the container. Furthermore, wastewater in the container is pumped into the Wastewater Treatment Plant (WWT) unit.

Inside the Wastewater Treatment Plant (WWT) unit, the first wastewater has flowed into the catalytic reactor tube (A/B). Furthermore, wastewater is pumped (C) into venturi injector tubes (D) to distribute ozone gas into wastewater. Wastewater from venturi injector tubes has then flowed to the catalyst tube (E) with the parallel flow direction.

Inside the catalyst, the tube is filled with special media from a mixture of several types of tablet-shaped catalyst metal. Ozone contact, catalysts, and water will produce hydroxyl radicals as catalytic ozonation processes. This hydroxyl radical will decipher organic contamination that has not yet been decomposed by ozone in the venturi injector tube. Total decomposition (mineralization into H$_2$O and CO$_2$) of organic contamination in wastewater is carried out indirectly by hydroxyl radicals and directly by ozone.

Wastewater from catalyst tubes has flowed into filtration tubes (F). Inside this filtration tube is filled with two layers of filters so that the inorganic minerals in the wastewater will get stuck on the surface of the first filter or the space between the first filter (F1) and the second filter (F2). Thus, the mineralization of wastewater is possible to occur before, during, and after filtration. This filtration configuration can improve the efficiency of organic contamination degradation and accelerate the catalytic ozone process, resulting in greater detergents/surfactants’ greater mineralization efficiency.

From the filtration tube, water has flowed back into the container. Degradation by ozone still occurs in the container because wastewater still contains ozone. Next, the water is pumped back into the venturi injector tube section. According to the specified time, the circulation of wastewater through venturi injector tubes, catalyst tubes, and filtration tubes is carried out.

Water in the container can be reused for the laundry (recycle) or reused for other purposes (reuse). Besides being able to decipher organic contamination, bacteria, viruses, and others, the catalytic ozone
system's design can also be significantly destroyed. The laundry wastewater treatment process with a catalytic ozone system can be seen in figure 2.

![Figure 2. Laundry wastewater-treatment-process diagram with catalytic ozonation process.](image)

### 3.2. Land use

The land required for the placement of the Wastewater Treatment Plant (WWT) is not very large. Wastewater Treatment Plant (WWT) can be separated into two parts. The first part serves for wastewater mineralization with dimensions of 90 x 54 x 52 cm (0.5 m$^3$). In contrast, the second part works for ozone production with dimensions of 30 x 50 x 15 cm (0.15 m$^3$). A designed image of the Catalytic Ozone Ozone Treatment Plant (WWT) can be seen in front in figure 3, front view in figure 4, front view in figure 5. Relatively low energy consumption coming from the pump. Wastewater Treatment Plant (WWT) is equipped with four wheels at each lower end for easy transfer. The placement of the Wastewater Treatment Plant (WWT) can be adapted to the available location. Treatment of Wastewater Treatment Plant (WWT) is relatively easy and straightforward.

Each unit of Wastewater Treatment Plant (WWT) has a processing capacity of up to 15 m$^3$/day. But technical considerations then will only use capacity up to 10 m$^3$/day. Wastewater treatment 100 m$^3$/day requires ten units of Wastewater Treatment Plant (WWT), then the necessary for the placement of the entire Wastewater Treatment Plant (WWT) is 10 x 90 x 54 x 52 cm (5 m$^3$).

![Figure 3. Image of wastewater treatment plant design (WWT) front view.](image)
3.3. Use of construction materials
Construction materials use PVC for catalytic reactor tubes and pipe systems. In comparison, the catalyst tube uses stainless steel material 316. Stainless steel materials are used for the frame and installation of cars. All ingredients are local/domestic products.

3.4. Investment costs
The investment fee is calculated based on the amount of wastewater treatment plant (WWT) procurement cost for processing capacity of 10 m$^3$ per day, namely the Oxygen engine unit of Rp.12,000,000,-; Ozone engine unit of Rp.15,000,000,-; Cooling unit of Rp.3,000,000,-; Catalytic reactor unit of Rp. 6,000,000,-; A container of Rp.2,000,000,-; and a Catalyst of Rp.5,000,000,-. So the investment cost of one unit of Wastewater Treatment Plant (WWT) is Rp.43,000,000,-.

The wastewater treatment plant (WWT) unit's technical balance will only be used capacity up to 10 m$^3$/day. Wastewater treatment 100 m$^3$/day requires ten units of wastewater treatment plant (WWT), then the total investment cost required for builders the entire Wastewater Treatment Plant (WWT) is 10 x Rp. 43,000,000,- (Rp. 430,000,000,- /100 m$^3$/day).

Figure 4. Image of wastewater treatment plant design (WWT) is pictured above.

Figure 5. Image of wastewater treatment plant design (WWT) side view.
3.5. Operating expenses

Operating costs are calculated based on the amount of electrical equipment used, namely pumps. The estimated operating cost of a wastewater treatment plant (WWT) can be simulated as follows: one wastewater pump of 350 watts and 350 watts of power consumption for O$_2$/O$_3$ generators. The amount of kWh/hour is 0.77 kWh. While the price of electric/kWh is Rp. 513,-. The operational cost of one unit of Wastewater Treatment Plant (WWT) is Rp. 2,052,- per m$^3$ of wastewater.

3.6. Aesthetic

A proposed catalytic ozone reactor design has relatively small, light, and portable dimensions. Display a proposed catalytic ozone reactor design that is easy to adjust to placement conditions or locations. Also, it looks relatively attractive with interesting colors and shapes. A proposed catalytic ozone reactor design does not cause a disturbing odor, so it is comfortable for the surrounding environment.

3.7. Added value proposed catalytic ozone reactor design

The laundry industry can meet the standard quality requirements following regulations based on Regulation of the Minister of Environment No. 5 of 2014 on Wastewater Quality Standards in annex on raw wastewater quality for businesses and/or domestic activities showing the highest parameters and content of water in the laundry industry as seen in table 1 [6]. The laundry industry must also comply with the regulation of the Minister of Environment and Forestry Regulation Number P.68/Menhk/Setjen/Kum.1/8/2016 on Domestic Wastewater Quality Standards in Appendix I on Separate Domestic Wastewater Quality Standards as shown in table 2 [7].

| Parameter   | Unit  | Highest Rated |
|-------------|-------|---------------|
| pH          |       | 6-9           |
| BOD         | mg/L  | 100           |
| TSS         | mg/L  | 100           |
| Oils and Fats | mg/L | 10            |

| Parameter   | Unit            | Maximum content |
|-------------|-----------------|-----------------|
| pH          |                 | 6-9             |
| BOD         | mg/L            | 30              |
| COD         | mg/L            | 100             |
| TSS         | mg/L            | 30              |
| Oils & Fats | mg/L            | 5               |
| Ammonia     | mg/L            | 10              |
| Total Coliform | total/100 mL | 3000            |
| Debit       | L/person/day    | 100             |

Catalytic Ozone Treatment Plant (WWT) is expected to help the laundry industry meet wastewater quality standards, improve wastewater quality into clean water, and obtain alternative solutions for recycling/reuse technology to enhance production efficiency industrial pollution prevention.

4. Conclusion

A proposed catalytic ozone reactor design has relatively small, light, and portable dimensions and is easy to adjust to placement conditions or location. Catalytic ozonation technology enables the process to be recycled for laundry and reuse for other purposes, thus supporting the sustainable green industry. It is estimated that wastewater treatment of 100 m$^3$/day only uses the land of 5 m$^2$, the investment cost of Rp. 430,000,000,- and operating cost Rp. 2,052,- per m$^3$ of wastewater. But the parameter value may
be very different from the implementation conditions in the industry. However, this paper's output can be considered in the selection of WWT technology and its application.

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