A continuous mode reactor design for industrial textile wastewater treatment through catalytic ozonation

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Abstract. A rapid catalytic process with low energy requirements gives catalytic ozone the potential to treat industrial textile wastewater in a full-scale application. However, until today, this catalytic ozone technology remains energy-consuming and, as a consequence, expensive. Thus, to overcome the bottleneck related to energy needs, this research aims to design a continuous mode reactor design to treat industrial textile wastewater through catalytic ozone, which integrated solar power plants (PLTS). In this work, a constant mode reactor design combined with an integrated sensor is investigated for industrial textile wastewater. Combining the autonomous and continuous removal of the impurities makes this continuous mode reactor excellent for the treated wastewater on the industrial textile scale.

1. Introduction

Environmental pollution caused by industrial wastewater, especially in big cities today, has reached an alarming stage. The burden of pollutants dumped into water bodies or rivers has reached the limit while nature or the environment can no longer purify naturally. The impact can be seen from the degree of impurities of rivers in Indonesia, from upstream to estuary. One source of polluters is industrial activities as a cause of environmental destruction, apart from domestic activities [1].

Some industries are experiencing a shortage in the fulfillment of water needs for the production process due to restrictive permits of water utilization from sources issued by local governments. Meanwhile, there is a shortage of new water sources due to its smaller discharge. Although the industry already has a wastewater treatment plant (WWTP), the processed wastewater effluent still cannot be reused to meet the industry's needs. Therefore, WWT effluent water quality needs to be improved, and the reuse unit needs to be efficiently installed to meet the requirements for reuse [2].

Wastewater is a resource that still allows it to be utilized again. Wastewater has wasted value/money. Wastewater treatment is a process of degradation of wastewater that requires energy. Wastewater treatment costs money. By controlling these two things, it is possible to reuse wastewater to bring material advantages and the environmental side [3].

The textile industry is one of the industries that require a large amount of water in its production process. A textile production process includes scouring, bleaching, dyeing, printing, and finishing. In this process, a high quantity of water, chemicals, and energy are required. Textile generates a large volume of wastewater that contains color, salinity, biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total nitrogen (TN), total phosphorus (TP), and
heavy metals (chromium (Cr)). Among those parameters, the most problematic parameters that hindered textile wastewater's potential reuse are color and organic pollutants (COD).

Generally, textile industries use a combination of chemical and biological technology. The most common technology used by textile industries is coagulation-flocculation, biological activated sludge, and filtration. Drawbacks of those combination technologies are extensive energy processes, an enormous quantity of chemical used, and effluent inability to meet quality reuse standards.

Catalytic ozone methods have proven effective for eliminating organic contamination in wastewater, to the extent could reach the effluent standard for reuse (Permenkes 32/2017, clean water standard). The installation of catalytic ozone as an advanced treatment in the final of effluent discharge could improve the volume of reusable water and enhanced the effluent quality in terms of color, residual organic pollutants of the complex, and the destruction of microorganisms in WWT processed water. The bottlenecks of full-scale application of catalytic ozone are the need for extensive electricity energy for an ozone generator. Thus, the integration of catalytic ozone technology with an abundant external electricity source becomes a critical need to apply catalytic ozone on a full scale successfully.

This research study the potential of catalytic ozone in eliminating organic pollutants in textile wastewater to the level the effluent could be reused in the production process and decrease energy consumption. A continuous mode reactor design for the treatment of industrial textile wastewater through catalytic ozone with a processing capacity of 50 m$^3$ per day is designed to provide information to the industry regarding system performance. Catalytic ozone methods proved useful for eliminating organic contamination in wastewater. The combination of catalytic ozone and sensor integration in real-time can produce good quality water for the industry. But the mixture became a relatively expensive process for the industry due to the need for energy/electricity from fossil fuel-based electricity derived from National Grid Electricity Factory (PLN). Thus, to lower the demand for fossil fuel-based electricity, the renewable electricity derived from Solar Panel was integrated into the catalytic ozone machine. Furthermore, wastewater real-time monitoring controller was also installed. Aims to monitor the catalytic ozone machine's performance in effluent parameters (i.e., TOC, color, turbidity, conductivity Chlorine, Hydrocarbons, Algae, Fluoride, Ammonia, and pH) and flow in real-time condition.

It is expected that water output reuse meets industry water quality standards with improved energy efficiency, the percentage of wastewater can be reused, and the effectiveness of reuse water use. The industry can benefit economically from the added value of reuse water and save the use of clean water from sources. Textile industry wastewater pollution control and water resource management will positively impact water resource conservation and the environment.

2. Methodology
The reactor consists of 4 main parts: a continuous mode catalytic ozone reactor, a filtration unit, a solar panel for electricity supply, and a wastewater real time monitoring controller to analyze flow and effluent parameters. The processing capacity of the reactor was 50 m$^3$ per day.

Real-time process control includes the development or use of sensors to observe, monitor, and manage catalytic process performance. Instruments used in reuse units include catalytic ozone, microfiltration, solar panel, and real-time control. Real-time controls include pressure sensors, flow, levels, temperature sensors, and analyzers such as Oxygen Reduction Potential (ORP) sensors, Turbidity, Conductivity, pH, O$_3$, total organic carbon (TOC), Chlorine, Hydrocarbons, Algae, Fluoride, and Ammonia. It becomes the most critical variables that must be controlled to obtain a safe and efficient process (as shown in figure 1).
3. Results and discussions

3.1. The general approach to wastewater effluent reuse

Wastewater treatment aims to eliminate the parameters of pollutants in wastewater to the extent that it is allowed to be disposed to the surface water and environment following the standard requirements of the acceptable quality or until it meets certain qualities for reuse. Wastewater treatment is mostly a solid-liquid separation of colloidal compounds and removal of dissolved pollutant compounds [5].

The reliability of the treatment process used to reuse industrial wastewater can be known from the stability and consistency of process water that can be received according to its use. There are two main factors to note that can affect the wastewater reuse process's performance and reliability. The first is the operation of the reuse unit, and the second is the characteristic of wastewater. The reuse unit will be operated to monitor and control water quality input and output in real-time to increase the effectiveness and efficiency of the reuse process results that meet effluent quality requirements. The integration is critical and needs to be done in the best possible way for the reuse process to be optimized, effectively, and efficiently. The pilot of the WWT outlet reuse unit project is planned with a capacity of 50 m$^3$/day.

Catalytic ozone methods for eliminating wastewater contamination have proven effective in creating the industrial water sources needed to increase wastewater benefits for industries with difficulty obtaining water sources. Catalytic ozone can produce good quality water and is feasible for industrial purposes. The combination of catalytic ozone and filtration can be a relatively expensive process. Estimation for the reuse unit's operation requires 75 kWh to produce 50 m$^3$ clean water. Electricity supply becomes the largest cost component from the fossil fuel needed.

On the other hand, the integrated catalytic ozone combination unit sensor becomes relatively expensive to build. Although most industries have investment costs of building WWT, its operating costs are not always available for an industry or industrial center. The price is relatively high, so some industries avoid developing integrated catalytic ozone combination technology because they cannot afford the initial investment and operational costs. The use of solar power plants (PLTS) is expected to reduce energy consumption in reuse units so that the operating expenses of WWT do not burden the industry.

3.2. Catalytic ozone approach

Ozone has been used in many industries to apply surface sanitation and piping, raw water purification, air treatment and odor control, wastewater treatment, and more. Ozone has proven to be a promising eco-friendly technology [6].

Hydroxyl radicals, the primary oxidants for removing organic pollutants, were created through the AOP (Advanced Oxidation Process) method, using proven catalytic ozone technology (ozone and catalysts). Hydroxyl radicals have a much higher oxidation potential than chlorine, ozone, or industry peroxide, which provides an advantage in shorter contact times and processes [7].

Ozone is attractive as a substitute oxidizer for chemical processes such as chlorine, which potentially risks significant safety challenges. Ozone exposure has not been shown to cause long-term health problems. The USDA and FDA have approved ozone for use in foods intended for human consumption [8].

Some factors that affect the ozone decomposition of catalytic ozone include the type of catalyst, retention time, acidity (pH), the chemical composition of wastewater, competition between water, and contaminants [9]. Effectiveness and efficiency of the application of catalytic ozonation show in textiles wastewater treatment technology [10]. Previous research on this technology also proved that catalytic ozonation results could meet textile wastewater criteria based on PermenLHK No. 5/2014 and Perda Jateng No. 5/2012 [11]. Advanced technology with improved catalysts and reactors will be added to achieve a higher standard for reuse purposes.
3.3. Realtime WWT control and monitoring
During the application of integrated ozone catalytic devices, real-time WWT control and monitoring are essential. The wastewater real-time monitoring controller ensures the effluent characteristic data to be monitored fast as a mechanism for process control and monitoring the process's effectiveness. Real-time control and monitoring also can reduce cost and time regarding sample collections and analysis to the accredited laboratory.

The industry should always take regular sampling. If there is a rogue industry in disposing of wastewater safely or at night, officers will have difficulty monitoring continuously for 24 hours. To address field power shortages in monitoring and rapidly detecting industrial wastewater pollution, a continuous and efficient monitoring unit is needed to solve the problem.

Real-time monitoring and control of water quality through operational control of WWTP in the industry will be displayed information resulting from rapid, direct, and integrated water quality monitoring. It requires a database that can store water quality monitoring and control data from WWTP in real-time. Industries or companies that dump their waste into rivers must install water quality sensors as stipulated in National Environmental Board Regulation PermenLHK No. 93/2018. Realtime monitoring of water quality and WWT requires some water quality sensor components monitored in real-time. The sensors are placed in the production channel of the wastewater.

3.4. Design approach
Catalytic ozone combinations in real-time can produce good quality water for the industry. High operational costs come from the use of necessary fossil fuels or PLN. It demands high energy costs. This design utilizes solar power plants (PLTS) to reduce energy consumption in catalytic ozone reuse units in real-time with a processing capacity of 50 m$^3$ per day in the textile industry. There are two different solutions to be done; the first is the solar powerplant (PLTS) used, and the second is catalytic ozone in real-time online. The instrument in real-time controls the process. It is expected that the reuse water output meets industry water quality standards with improved energy efficiency, the percentage of wastewater can be reused, and the effectiveness of reuse water use as in figure 1.

![Realtime and online control and monitoring](https://example.com/fig1.png)

**Figure 1.** Continuous mode reactor design.
3.5. Features, benefits, and advantages of catalytic ozone straight mode reactor design
The wastewater treatment process in the textile industry produces wastewater that is directly disposed of into the environment. Generally, the treatment process still uses conventional systems that are less efficient in color removal and other contamination. The water always does not meet the standard quality of wastewater. On the other hand, the industry must meet environmental regulatory requirements so that there needs to be innovation in wastewater treatment technology to ensure pollution prevention while lowering operational costs.

The reuse unit uses the concept of real-time green integrated product treatment. Using catalytic ozone technology and integrated sensors with PLTS energy sources without the use of chemicals, eliminating contamination, easy/cheap, and does not cause by-products and preventing the impact of environmental pollution of the waters. Reuse unit as a multi-function wastewater treatment component that is a wastewater processing and industrial process water supply. The reuse unit is "All in One Product," meaning that only 1 (one) reuse unit can be applied to various types of industrial wastewater such as food, beverages, pharmaceuticals, health, cosmetics, and others. In terms of use, it is also relatively more accessible compared to similar products. The system will also help reduce production costs in the textile industry as it can lower the cost of providing clean water.

The industry today is increasingly aware that the use of energy or chemical chemicals will impact soil quality, health, and the environment. Even some industries have turned to environmentally friendly technology that exists today. The application of reuse units in the industry will improve the water quality of the process and maintain and maintain the environment. Also, the reuse unit is minimal in noise; the process is swift, faster, and not over a shift. The industry has the opportunity to benefit economically from the added value of reuse water. The industry saves the use of clean water from the sources. Textile industry wastewater pollution control and water resource management will positively impact water resource conservation and the environment.

3.6. Expected results
The design of this WWT air outlet reuse unit is planned with a capacity of 50 m$^3$/day expected to support the sustainable textile industry's growth. The application of reuse unit design will lower the industry's operational costs in providing water needs. The industry is currently burdened by the value of offering process water and wastewater treatment costs. If the percentage of wastewater that can be reused reaches 80%, then the industry benefits from an 80% reduction in the price of providing process water. Also, the impact of environmental pollution at risk can be prevented because it excretes less wastewater. Also, the industry benefits from lower WWT operating costs using PLTS.

4. Conclusion
A continuous mode reactor design for industrial textile wastewater treatment through catalytic ozone will provide many benefits for the textile industry. Catalytic ozone as the leading technology is an environmentally friendly technology so that it will have a positive impact on the conservation of water resources and the environment. Furthermore, the design can be utilized to construct prototype and pilot project units to reuse the textile industry wastewater. Later, test documents/simulation (implementation) pilot project unit reuse in an industrial environment. The final output to be achieved is full-scale unit reuse as standardized technology (Eco-Friendly Technology) based on ISO 14034:2016 Environmental Management - Environmental Technology Verification (ETV).

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