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Effect of Differences in Fluid Pressure Passing Through Venturi on Dissolved Oxygen Level in Medical Waste Water

Zainuri Anwar*, Muhammad Irfan Dzaky, Aldony Reco Putra, Fajri Bayu Saputra, Mohammad Roihan, Muhammad Audhi Natanegara

Jurusan Teknik Mesin Politeknik Negeri Sriwijaya, Jl, Srijaya Negara, Bukit Besar, Kota Palembang, Indonesia
*Corresponding author: zainuri.anwar@polsri.ac.id

ABSTRACT

Medical wastewater is characterised by a high organic load, which can deplete Dissolved Oxygen (DO) levels in receiving waters. One effective method to mechanically increase DO levels is through the aeration process using a venturi injector-based microbubble generator (MBG). This study aims to analyse the effect of fluid pressure variations through the venturi on DO levels in medical wastewater. The research was conducted experimentally by varying the fluid input pressure to 1 bar, 2 bar, 3 bar, and 4 bar to observe the effectiveness of ambient air suction via venturi injection. DO levels were measured over 15–60 minutes using a DO meter. The results indicated an increase in DO levels at an inlet pressure of 3 bar, reaching approximately 9 mg/L. However, DO levels decreased to 6.1 mg/L at 4 bar. This was due to excessive velocity, which caused turbulence in the divergent zone, leading to bubble collisions and coalescence.

Keyword: Wastewater; Dissolved Oxygen; Pressure; Velocity; Microbubble

1. INTRODUCTION

Water is a basic necessity for life on Earth. Water must meet several criteria, including chemical, physical, bacteriological, and radioactive properties. Contamination from various chemicals reduces water quality, potentially damaging the environment. Wastewater treatment is a critical challenge in maintaining this environmental quality, particularly in the healthcare sector, which generates medical wastewater (Rahmi et al., 2024). Liquid waste that is not properly processed can contain various organic and inorganic substances that reduce dissolved oxygen levels and pollute receiving waters. (Sumangando et al., 2022). Therefore, improving dissolved oxygen efficiency is very important in treating medical liquid waste to ensure compliance with environmental safety standards before disposal. (Maharani, 2020).

One widely used method to increase dissolved oxygen levels in wastewater is aeration. (Shah et al., 2024). The aeration process is a wastewater treatment method that utilises oxygen. Economically, this method is more cost-effective and environmentally friendly. To increase the oxygen supply used by a new technology, the Microbubble Generator (MBG) (Rofik, 2020). This technology provides oxygen, helping maintain the activity of microorganisms in the waste so they can decompose wastewater effectively. (Yao et al., 2016). Microbubbles are extremely small gas bubbles with diameters ranging from 10 to 100 μm. In addition to their small size, microbubbles possess unique properties such as slow floating speed, a large contact area between gas and liquid, and highly efficient mass transfer capabilities. (Qin et al., 2023).

The most commonly used microbubble is the Venturi type. Venturis operate on the principle of pressure differences resulting from changes in fluid flow velocity across a narrowing cross-section, transferring oxygen from the air to the water until it reaches the surface and bursts into bubbles based on Bernoulli's principle (Li et al., 2023). The effectiveness of a venturi as an aeration device depends heavily on its geometry and the flow conditions within it. A venturi tube consists of a convergent section, a throat section, and a divergent section. (Deddy et al., 2024) (Wilson et al., 2021).

Several previous studies have evaluated the effects of venturi geometry, fluid flow rate, and air pressure on the performance of microbubble generators. (Oro & Carmona, 2022). The bubble size is greatly influenced by the ratio of air pressure to the variation in water flow through the venturi. (Anugrah et al., 2023). Meanwhile, several studies have shown that the combination of high liquid fluid velocity and optimal air discharge pressure can significantly increase dissolved oxygen content (Wells & Sharifian, 2024).

Research specifically focused on testing venturi fluids at high pressures in medical wastewater treatment remains relatively limited. Several previous studies have focused more on venturi dimensions, including throat diameter and length, convergence and divergence angles, and airflow rate passing through the throat. Given these conditions, it is important to examine the effect of pressure on microbubble formation. In principle, pressure increases directly with the velocity through the venturi. High velocities create vacuum pressure in the throat and turbulence in the divergent region. This condition is an important factor in determining fluid pressure to obtain appropriate design parameters for microbubble formation. which influences microbubble formation. These conditions are crucial for determining the fluid pressure and velocity through the venturi, thereby defining the appropriate design parameters for microbubble formation.

Based on these problems, researchers focused on the effect of variations in fluid pressure on increasing dissolved oxygen in medical liquid waste using a venturi-based microbubble generator.

2. MATERIAL AND METHODS

The research was conducted using experimental methods in the Mechanical Engineering Laboratory of Politeknik Negeri Sriwijaya in collaboration with PT. Ratna Hapsari Mahakarya Cendekia, which operates in the field of hospital waste processing. This study aims to determine the effect of pressure differences on dissolved oxygen levels in medical wastewater using a Microbubble Generator (MBG). The fluid pressure passing through the venturi was varied from 1 bar, 2 bar, 3 bar, and 4 bar. The fluid velocity will adjust as the pressure changes.

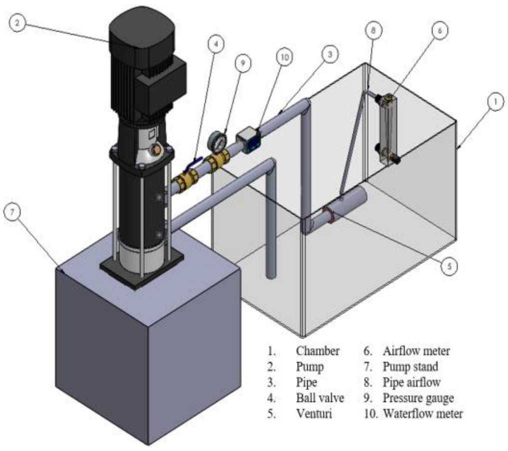

Figure 1. Test scheme of the microbubble generator

The test used a tank measuring 590 mm long, 360 mm wide, and 290 mm high, filled with medical wastewater. The liquid waste was pumped through a venturi by regulating the pump pressure variation using a control valve. The pump used is a vertical multistage pump capable of reaching 8 bar.

The air passing through the venturi can be controlled by adjusting the valve on the airflow meter.

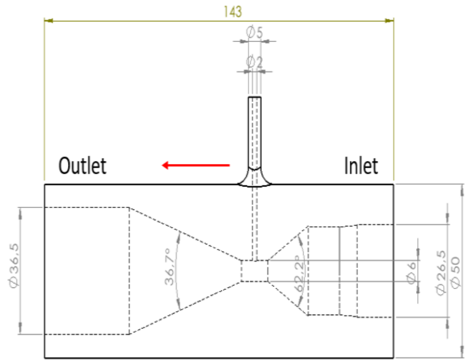

Figure 2. Design of venturi injector

The venturi has an inlet diameter of 26.5 mm and an outlet diameter of 36.5 mm. The throat section has a 2 mm-diameter air hole with a constant inlet air flow rate of approximately 0.2 L/min.

Table 1. The dimension of the venturi

Ventury Part	Dimension
Inlet diameter	26.5 mm
Outlet diameter	36.5 mm
Throat diameter	6 mm
Throat lenght	20 mm
Nozzle convergent angle	62.2°
Diffuser divergent angle	36.7°

This design was chosen to increase outlet pressure, allowing for greater air intake. The sucked air forms small bubbles and exits through the venturi outlet. The flow rate through the venturi is measured by a flowmeter installed upstream of it. The following table shows the velocity and Reynolds number values passing through the throat.

Table 2. Velocity and Reynolds number in the throat

Pressure	Velocity (v)	Reynolds (Re)
1 bar	15,693 m/s	105.359
2 bar	22,085 m/s	148.243
3 bar	24,628 m/s	165.312
4 bar	27,306 m/s	183.287

Dissolved oxygen levels are measured using a DO meter after the flow has been fully developed for 60 minutes.

Figure 3. The calibration of dissolved oxygen

The DO meter has been calibrated using the zero calibration method, where the probe is inserted into a zero solution, and the test results show 0 mg/L. Linear regression tests and one-way ANOVA were conducted to determine the strength of the relationship between pressure increases and DO levels.

3. RESULTS AND DISCUSSION

Initial dissolved oxygen (DO) measurements in medical wastewater samples were 0.4 mg/L. This value indicates that the wastewater oxygen content was very low before aeration, requiring treatment with a microbubble generator to increase oxygen levels to meet water quality standards.

Figure 4. DO level before treatment

Based on the tests carried out with three repetitions at each pressure and time variation, an increase in Dissolved Oxygen (DO) levels was obtained, which is shown in the following graph:

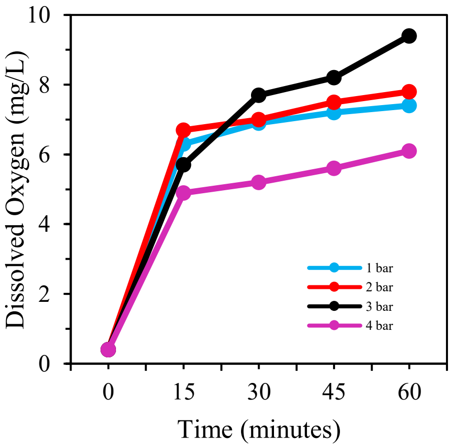

Figure 5. Result of dissolved oxygen

Figure 4 shows that, overall, DO increased over time at each pressure. The lowest dissolved oxygen levels occurred at 4 bar, around 6 mg/L, while the greatest DO increase occurred at 3 bar, reaching 9.4 mg/L at the 60th minute. The one-way

ANOVA analysis focused on the 45th and 60th minutes, where the system had reached a more stable condition (steady state).

Table 3. Dissolved oxygen on the pressure difference

Pressure	DO (Minute 45)	DO (Minute 60)	Average mg/L
1 bar	7,2	7,4	7,30
2 bar	7,5	7,8	7,65
3 bar	8,2	9,4	8,80
4 bar	5,6	6,1	5,85

By removing the initial data (minutes 0-15), whose values are still very low and uniform, we can more sharply see the difference in performance between pressures.

Table 4. ANOVA result

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9,33	3	3,11	12,74	0,016	6,59
Within Groups	0,98	4	0,24			
Total	10,31	7				

The statistical analysis results for the steady-state phase (minutes 45 to 60) showed a P-value of 0.016 (<0.05). This demonstrates that pressure variations have a statistically significant effect on the efficiency of increasing DO levels in the fluid.

The best pressure parameter was 3 bar. This pressure produced the most progressive oxygen transfer rate, with the highest DO value reaching 9.4 mg/L and a final average of 8.80 mg/L. This performance far outperformed the other pressure groups.

Increasing the pressure from 1 bar to 3 bar is directly proportional to the increase in dissolved oxygen levels. This can be explained by Bernoulli's Law and the Principle of Continuity. When the inlet pressure is increased, the flow velocity at the venturi's throat increases drastically, thereby breaking up the bubbles. (Çengel & Cimbala, 2018).

Figure 6. DO level at 3 bar pressure

The increased velocity in the throat results in a very low pressure drop (a vacuum). The higher the operating pressure, the stronger the suction force of outside air into the medical wastewater stream. However, if the fluid velocity through the venturi is too high, bubbles will not form at the microscopic level. Instead, the ruptured bubbles will bind together and be pushed out of the venturi, making it difficult for dissolved oxygen to increase.

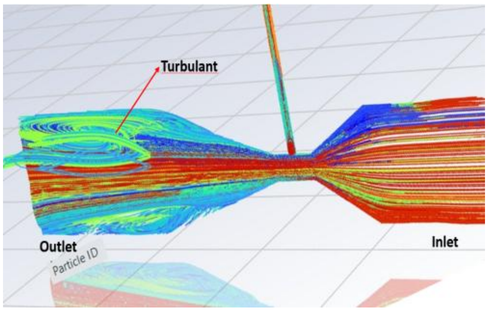

Figure 7. CFD streamline at 4 bar

Based on CFD simulations of the streamline, higher turbulence occurs within the venturi at 4 bar. At very high velocities, the turbulence within the outlet pipe (divergent section) becomes so chaotic that it produces unstable microbubbles. This extreme turbulence can cause small bubbles to collide with each other with high energy and coalesce into larger bubbles (coalescence). Consequently, the surface area of contact between the air and the wastewater is reduced, resulting in suboptimal oxygen transfer.

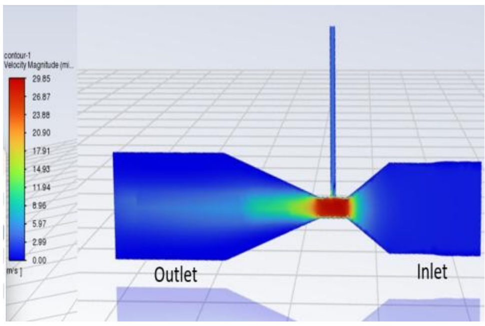

Figure 8. Velocity contour at 4 bar

The significant inlet-to-throat diameter ratio of 1:5 increases the velocity in the throat region. Mathematical calculations and CFD analysis show that the fluid velocity in the throat region reaches 29.85 m/s at an inlet pressure of 4 bar. Conversely, the pressure in the throat region is lower than in the convergent region, from 86.8 kPa to 4331.1 kPa. The sudden pressure change causes unstable flow and turbulence, as seen in the flow lines. This condition influences bubble formation.

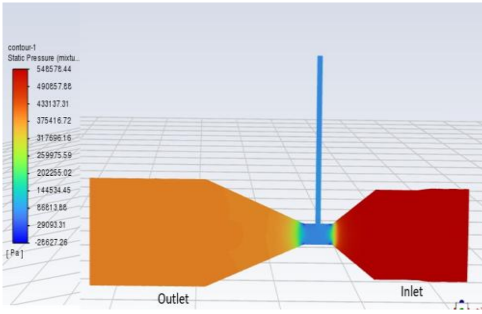

Figure 9. Pressure contour at 4 bar

Medical wastewater contains organic and chemical substances that can alter the water's surface tension. At a high pressure of 3 bar, oxygen mixing is more effective at degrading compounds that cause anaerobic conditions in wastewater, as indicated by a change in odour, becoming more neutral after the venturi aeration process.

4. CONCLUSION

There is a significant influence between variations in fluid pressure and dissolved oxygen levels. A pressure of 3 bar was optimal in this study, yielding the highest DO levels that meet wastewater quality standards before discharge into the environment or further treatment. High fluid pressure and velocity do not always yield the best results for microbubble formation, but depend on the pressure-velocity ratio. Flow turbulence can cause bubbles to collide and coalesce.

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