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Evaluation of Electricity Generation from Wastewater by Microbial Fuel Cell

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Abstract

Combined systems for wastewater treatment and resource recovery have been developed in many countries. However, systems for energy generation are still underdeveloped. This research was conducted to evaluate the possibility of electric potential generation from wastewater using a microbial fuel cell system (MFC). The simple two-chamber apparatus (2 liters) was fed with wastewater collected from dormitory discharge. Three batch experiments were carried out with 2 liters of wastewater with an influent concentration of 518 mg L^{-1} BOD_5 and 750 mg L^{-1} COD. The results showed that the microbial fuel cell system generated a potential from 0.29 to 0.45 V for 7 days in the presence of 1.0-1.5% (v/v) *Bacillus subtilis* while this potential was not obtained in the case when microbes were not added. The highest removal efficiencies of BOD_5 and COD reached 56% and 63%, respectively. It was found that the potential dropped to almost zero in all of the treatments while the ratio of BOD:COD was 0.83 and the concentration of BOD was around 230 mg L^{-1}, indicating that other governing factors may have an impact on potential electricity generation. Therefore, further studies on the effects of the operating conditions and equipment should be comprehensively studied.

Keywords

Microbial fuel cell, domestic wastewater, renewable energy, electricity generation, *Bacillus subtilis*

Introduction

In Vietnam, it has been reported that domestic wastewater generated throughout the country has significantly increased, with Hanoi and Ho Chi Minh City reaching approximately 900,000 m^3 day^{-1} and 2.67 million m^3 day^{-1}, respectively (Ministry of Natural Resources and Environment, 2016). However, municipal wastewater treatment plants only process 14% of the total amount generated, and up to 86% of untreated urban wastewater is directly discharged into the environment (World Bank, 2013). A general characteristic of

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domestic wastewater is that it often contains many organic substances and nutritional components such as nitrogen, phosphorus, and pathogenic microorganisms (Son *et al.*, 2020). The large amounts of wastewater discharged into the environment have significant impacts on the receiving source but recoverable resources could be extracted from the wastewater. Domestic wastewater discharges in rural areas are commonly mixed with livestock wastewater, and therefore contain significant amounts of nitrogen and have a high biochemical oxygen demand (BOD) (Vo Huu Cong & Phung Thi Hang, 2019). On the other hand, domestic wastewater treatment focuses on the application of biochemical and chemical technologies to minimize the concentration of pollutants but does not yet incorporate energy recovery technologies into the treatment system.

Microbial fuel cells (MFCs) are bio-electrochemical systems capable of degrading organic compounds through microbial activities, while simultaneously releasing electrons (e^-) and protons (H^+), thereby generating electricity (Pandit & Das, 2018). The initial application of MFCs was to decompose glucose in an aqueous solution using *Escherichia coli* and obtain an electric potential of 500mV at 1000ohms (Ω) for 1 hour (Davis & Yarbrough, 1962). In the 1980s, several researchers discovered that adding electron mediators could enhance the current density and power output (Vega & Fernández, 1987; Allen & Bennetto, 1993; Park & Zeikus, 2000; Ikeda & Kano, 2003; Ieropoulos *et al.*, 2005). During the early stages of MFC research and development, much effort was paid to the investigation of microbes, substrates, and the configuration of electrode materials. It was reported that the microorganisms capable of transferring electrons directly to the anode stably and highly efficiently without electron mediators were *Shewanella putrefaciens* (Kim *et al.*, 1999), *Geobacteraceae sulferreducens* (Bond & Lovley, 2003), *Rhodoferax ferrireducens* (Chaudhuri & Lovley, 2003), and *Geobacter metallicireducens* (Min *et al.*, 2005). Substrates play an important role in the system as carbon sources. In addition to glucose, starch, substrates such as lactate, molasses (Niessen *et al.*, 2004), acetate, and sucrose (Park & Zeikus, 2000) have all been studied. The concept of bioelectricity has been used commonly when culturing *Escherichia coli* and *Saccharomyces* on platinum electrodes (Du *et al.*, 2007). Since then, there has been a significant increase in the application of MFCs technology for renewable energy, especially, the generation of electricity from wastewater.

For the application of an MFC system, it is important to use strong and affordable microbial strains. The aerobic Gram-positive species *Bacillus subtilis*, for example, is able to grow anaerobically and produce a biofilm in a microbial fuel cell, which can generate long-term power output. This species is one of the most commonly used hosts in fermentation production. It is also simple to cultivate and compatible with various culturing environments (Nimje *et al.*, 2009).

The research on microbial fuel cell systems in Vietnam has focused on selecting electrode materials for MFCs and using biosensors in assessing water quality (Nong Minh Tuan, 2014). However, these findings are covered in the field of biosensors. Other research has focused on the effects of chloride on the performance of microbial fuel cells for wastewater treatment (Duyen *et al*., 2021). Recently developed microbial fuel cell systems can be catalyzed by various microbial strains. It was reported that an MFC inoculated with *Bacillus subtilis* generated a potential of 0.45V against an external resistance of 125Ω (Ismail & Jaeel, 2013), or a maximum voltage of 0.52V with a 5% concentration of glucose (Yoganathan & Ganesh, 2015). This research was conducted to assess the electricity generated from domestic wastewater employing a simple design of an MFC and to evaluate the possibility of organic matter reduction via the electricity generation process.

Methodology

Wastewater

The wastewater and water samples for the experiment were collected and analyzed following the national standard methods for water analysis (TCVN 6663-1:2011).

Wastewater was collected at the discharge point from the dormitory of a university in suburban Hanoi. Wastewater was then separated for the experimental run and initial conditions analysis. The water quality parameters, namely pH, TSS, BOD_5, COD, NO_3^-, PO_4^{3-}, and coliform, were analyzed and compared with the national regulations for domestic wastewater quality (QCVN14-MT:2015).

The water samples were collected from the chamber with a syringe (50mL). The pH values were measured by a portable pH meter; biological oxygen demand (BOD_5) was measured following TCVN 6001- 1:2008 (ISO 5815-1:2003) - determination of biochemical oxygen demand after n days (BOD_n); chemical oxygen demand (COD) was measured following TCVN 6491:1999 (ISO 6060:1989) - determination of the chemical oxygen demand; total suspended solids (TSS) were measured following SMEWW 2540 water quality - determination of TSS; nitrate (NO_3^-) was measured following TCVN 7323-2:2004 water quality - determination of nitrate; phosphate (PO_4^{3-}) was measured following TCVN 6202:2008 water quality- determination of phosphorus; and coliform was counted following TCVN 6187-1:2009 water quality - detection and enumeration of Escherichia coli and coliform bacteria.

Experimental apparatus

The microbial fuel cell was designed as a two-chamber MFC system with each chamber holding 2000mL. The cathode chamber was fed with tap water whereas the anode chamber was fed with domestic wastewater. To facilitate the proton exchange, the anode and cathode chambers were connected by a 3% KCl salt bridge through a cylindrical pipe with a diameter of 2cm and a length of 7cm. Each chamber was fixed with a graphite electrode (2cm × 2cm × 0.5cm). This size was suitable with the size of the electrodes' surface area. The graphite electrodes were connected through a Victor VC 890D potentiometer for potential measurement (**Figure 1**).

Experimental operation conditions

This research was conducted in a batch experiment in anaerobic conditions with three runs (**Table 1**). The *Bacillus subtilis* strain was selected as the catalyst for the biological conversion of organic contents because it has been reported as having a high potential for bioelectricity generation (Nimje *et al.*, 2009; Ismail & Jaeel, 2013). In this study, a pure *Bacillus subtilis* inoculant was provided by the Department of Microbiology (VNUA). The *Bacillus subtilis* was propagated at level 1 in a specialized environment (0.4g meat broth, 1g peptone, 0.5g NaCl, 2g jelly, and 100mL distilled water) in the laboratory. The original amount of culture inoculant was 11.1 x 10^{10} (CFU/100mL). The voltage produced by the MFCs was measured with a Victor VC 890D meter at 0, 6, 24, 30, 48, 54, 72, 78,… hours until the potential approached zero. The BOD_5 and COD were measured before and at the end of each batch experiment.

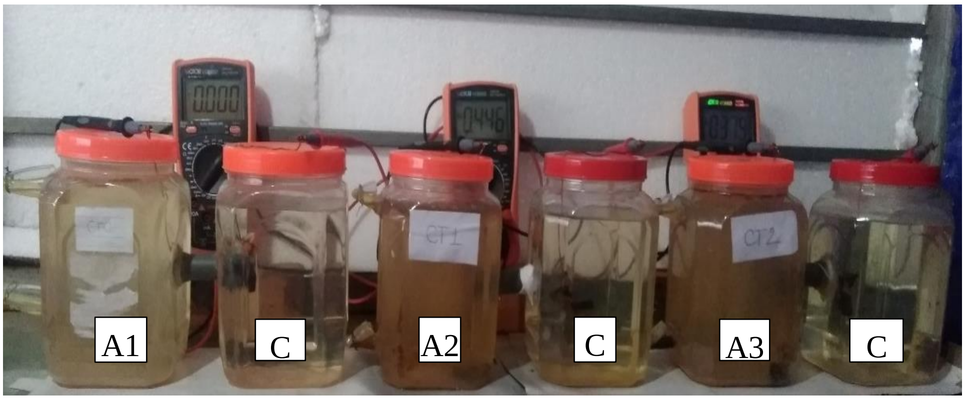

Figure 1. Experimental apparatus. A1, A2, and A3 represent the anode chambers of CT0, CT1, and CT2, respectively; C represents the cathode chamber

Table 1. Experimental operation conditions

Run	Treatment volume	Supplement of microbe
CT0- Control	2000mL	No addition of microbe
CT1	2000mL	1.0% (v/v) of *Bacillus subtilis*
CT2	2000mL	1.5% (v/v) of *Bacillus subtilis*

Results and Discussion

Wastewater characterization

The wastewater generation was estimated at 62-75 liters/person/day and was collected from a dormitory of 10,000 students. **Table 2** shows the wastewater quality via pH, BOD_5, TSS, COD, N-NO_3^-, P-PO_4^{3-}, and coliform. The initial concentration of COD was observed at 750 mg L^{-1} and the concentration of BOD_5 was 518 mg L^{-1}. The COD concentration was about six times higher than that of the limited value (125 mg/L) regulated by QCVN 14-MT:2015/BTNMT (category B - limit of the regulated value for the discharge of wastewater into a receiving water body not used for domestic water recycling purposes). The BOD concentration was also almost ten times higher compared to the upper limit of the regulated values. These results are similar to the general characteristics of the organic content in domestic wastewater published elsewhere (Hoa, 2017). The concentrations of N-NO_3^- and P-PO_4^{3-} were still within the permitted limits of QCVN 14-MT:2015. It was obtained that the concentration of coliforms was 133,630 CFU/100 mL, much higher than the regulation value (5000 CFU/100mL).

In wastewater treatment with indication for resources recovery or energy recovery, the COD and BOD are components indicating the potential for microbial degradation and are associated with electricity generation. In this research, the ratio of BOD/COD was 0.69, indicating a high level of biodegradable organic contents. The proper ratio of BOD:N:P is necessary to maintain suitable conditions for aerobic or anaerobic treatment by microorganisms. The optimal ratio for BOD:N:P has been reported at 100:5:1 for aerobic digestion and 350:5:1 for anaerobic digestion. In this research, the ratio of BOD:N:P of the domestic wastewater was 77:0.1:1.

Electricity generation efficiency

The efficiency of electricity generation was assessed by the voltage produced during the time course changes of the MFC's operation. The results of 216 hours of operation show that the presence of *B. subtilis* bacteria increased electricity production compared to that of water without supplementation (CT0) (**Figure 2**). When the contents of *B. subtilis* were increased from 1% (v/v) (CT1) to 1.5% (v/v) (CT2), the voltage appeared and increased earlier and was maintained after 32 hours (from 36 to 168 hours). In formula 1 (CT1) with 1% of *B. subtilis*, the voltage was almost zero during the first 24 hours. The potential appeared from 30-54 hours after the operation began, then sharply increased and reached peak value (0.44V) after 78 hours. However, the potential decreased substantially to around 0.265V at 150 hours then continued its downward trend to roughly 0.091V at 168 hours.

The control formula without supplemental *B. subtilis* indicated that the voltage was nearly below the detection value of the device. When the content of *B. subtilis* was set at 1.5% (v/v), the electric potential appeared quite early, within 6 hours of the beginning of the operation. The potential was maintained around 0.3-0.4V for 168 hours, then decreased at the time similar to treatment 1. The potential obtained in this research was similar to that reported in other research papers (Nimje *et al.*, 2009; Ismail & Jaeel, 2013) when *B. subtilis* was added to generate a higher and more stable electric current. In another research article (Liu *et al.*, 2011), when operating an MFC system with domestic wastewater with a COD of 415 ± 50 mg L^{-1}, the generated electricity remained stable after 270 hours to reach more than 200mV and continued to generate electricity until the end of the experiment for 1200 hours. It was observed that the potential reaching zero within 200 hours

Table 2. Characteristics dormitory wastewater

No.	Indicator	Unit	Measured value	QCVN 14-MT: 2015 (B)
1	pH	-	7.07	5-9
2	BOD_5	*mg L⁻¹*	518	50
3	TSS	*mg L⁻¹*	76	100
4	COD	*mg L⁻¹*	750	150
5	$N\text{-}NO_3^-$	*mg L⁻¹*	0.49	50
6	$P\text{-}PO_4^{3-}$	*mg L⁻¹*	6.68	10
7	Coliforms	*CFU 100mL⁻¹*	133,630	5,000

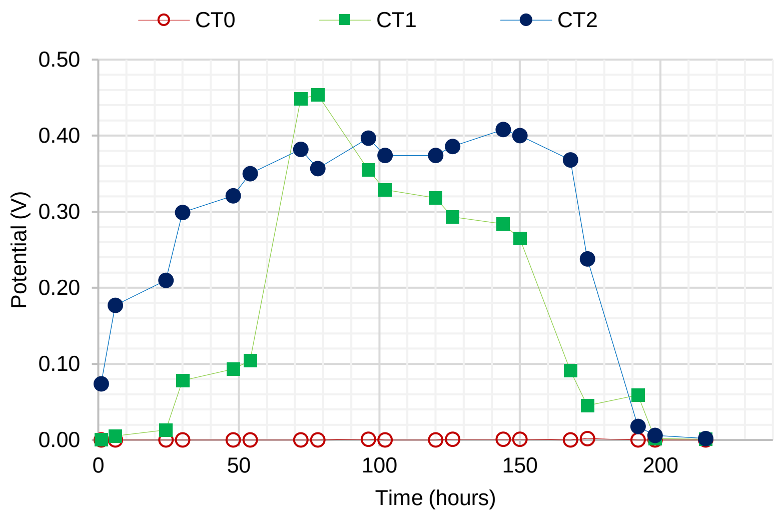

Figure 2. Electricity generation within 216 hours. CT0 is the control experiment without added *B. subtilis*, CT1 is the treatment with 1.0% *B. subtilis*, and CT2 is the treatment with 1.5% *B. subtilis* (v/v).

of all operations may indicate the limitations of the operating conditions in regards to organic contents (carbon source), nutrients (N, P), or microbes.

The observed data may indicate that without adding a microbial strain, less potential is produced by the microbial fuel cell regardless of the existence of an indigenous microbial community in the wastewater. Adding a microbial strain showed a potential up to 0.4V. The reduction of potential after 200 hours may have been due to the weakening of the microbial strain due to detergent from washing activities. Therefore, further studies should be conducted with wastewater from other sources and under different operating conditions.

Figure 3 shows the potential use of domestic wastewater as carbon sources for biodegradation to produce electric potential by a microbial fuel cell. It was obtained that an electric potential was generated while the concentration of the organic content declined significantly. The concentrations of the BOD_5 and COD values represent a downward trend in all of the formulas. The obtained removal efficiencies were 34%, 49%, and 56% for BOD_5 in CT0, CT1, and CT2, respectively. The COD removal efficiency also reached the highest efficiency in CT2, with 63% of the COD content removed after 216 hours. These results are similar to the research by Min and Logan (2004), who treated domestic wastewater with flat plate MFC. The COD treatment efficiency ranged from 42-79% when the retention time and flow capacity were changed, and electricity was generated reaching 7.2 ± 1 mW m^{-2} to 43 ± 1 mW m^{-2}.

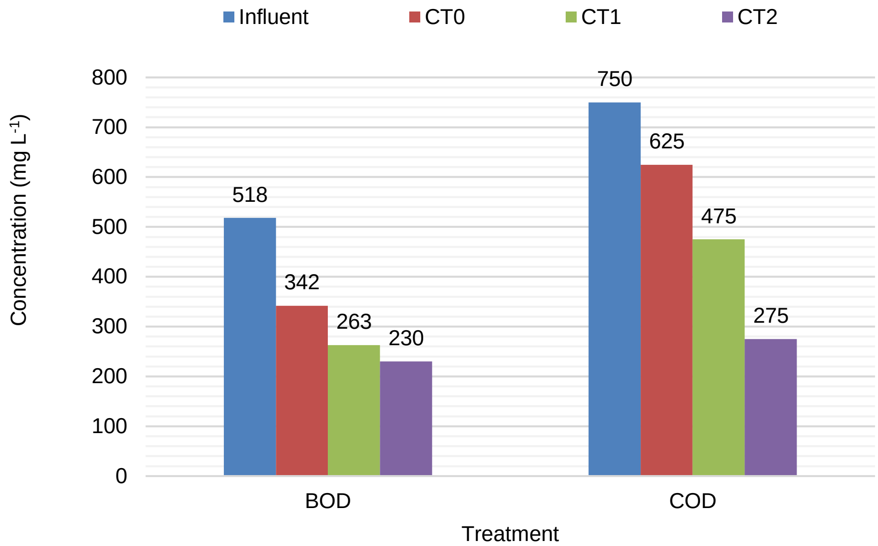

Figure 3. Removal of BOD and COD after the operation. CT0 is the control experiment without added *B. subtilis*, CT1 is the treatment with 1.0% *B. subtilis*, and CT2 is the treatment with 1.5% *B. subtilis* (v/v).

This research confirmed that electricity generation was possible while the organic content removal rate achieved significant results. It was interesting that at the point when no potential was obtained, the ratio of BOD/COD was around 0.84 in CT2 and 0.55 in CT0 and CT1, indicating that other operating conditions (i.e. nutrient supply or regeneration of microbes) should be considered as governing factors. This phenomenon may indicate the ratio of BOD:N:P of the influent of wastewater acquired from the dormitory discharge has an impact on the generation of electricity.

Conclusions

The microbial fuel cell system was applied to treat domestic wastewater by adding 1.0% and 1.5% (v/v) of *Bacillus subtilis*. The MFC system produced a potential in the range of 300-500mV during 3-7 days (168 hours) of operation. The potential then reached zero within 200 hours (8 days).

The BOD_5 removal efficiency was about 30-50% whereas the COD removal was 63%. However, the remaining BOD and COD in the chamber were still high. The results indicated further stabilization of the MFC system could be achieved with the involvement of other controlling parameters such as pH, BOD:N:P rate, and microbial strains.

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References

Allen R. M. & Bennetto H. P. (1993). Microbial Fuel-Cells electricity production from Carbohydrates. Applied Biochemistry and Biotechnology. 39/40: 27-40.

Bond D. R. & Lovley D. R. (2003). Electricity production by Geobacter sulfurreducens attached to electrodes. Applied and Environmental Microbiology. 69(3): 1548-1555.

Chaudhuri S. K. & Lovley D. R. (2003). Electricity generation by direct oxidation of glucose in mediatorless microbial fuel cells. Nature Biotechnology. 21(10): 1229-1232.

Davis J. B. & Yarbrough H. F. J. (1962). Preliminary Experiments on a Microbial Fuel Cell. Science. 137: 615-616.

Du Z., Li H. & Gu T. (2007). A state of the art review on microbial fuel cells: A promising technology for wastewater treatment and bioenergy. Biotechnology Advances. 25(5): 464-482.

Hoa T. T. H. (2017). Study on ammonium removal in domestic wastewater from dormitory of National University of Civil Engineering. Journal of Science and Technology in Civil Engineering. 11(6): 191-197.

Ieropoulos I. A., Greenman J., Melhuish C. & Hart J. (2005). Comparative study of three types of microbial fuel cell. Enzyme and Microbial Technology. 37(2): 238-245.

Ikeda T. & Kano K. (2003). Bioelectrocatalysis-based application of quinoproteins and quinoprotein-containing bacterial cells in biosensors and biofuel cells. Biochimica et Biophysica Acta (BBA) - Proteins and Proteomics. 1647(1-2): 121-126.

Ismail Z. Z. & Jaeel A. J. (2013). Sustainable power generation in continuous flow microbial fuel cell treating actual wastewater: influence of biocatalyst type on electricity production. Scientific World Journal. 2013: 713515.

Kim B. H., Ikeda T., Park H. S., Kim H. J., Hyu M. S., Kano K., Takagi K. & Tatsumi H. (1999). Electrochemical activity of an Fe(III)-reducing bacterium, Shewanella putrefaciens IR-1, in the presence of alternative electron acceptors. Biotechnology Techniques. 13: 475-478.

Liu G., Yates M. D., Cheng S., Call D. F., Sun D. & Logan B. E. (2011). Examination of microbial fuel cell start-up times with domestic wastewater and additional amendments. Bioresources Technology. 102(15): 7301-7306.

Min B., Cheng S. & Logan B. E. (2005). Electricity generation using membrane and salt bridge microbial fuel cells. Water Research. 39(9): 1675-1686.

Min B. & Logan B. (2004). Continuous Electricity Generation from Domestic Wastewater and Organic Substrates in a Flat Plate Microbial Fuel Cell. Environmental Science and Technology. 38: 5809-5814.

Ministry of Natural Resources and Environment (2016). Special issue: Urban Environment. National Environmental Status Report. Retrieved from https://www.worldbank.org/content/dam/Worldbank/document/EAP/Vietnam/vn-urbanwastewater-summary-EN-final.pdf on December 5, 2022.

Niessen J., Schroder U. & Scholz F. (2004). Exploiting complex carbohydrates for microbial electricity generation ? a bacterial fuel cell operating on starch. Electrochemistry Communications. 6(9): 955-958.

Nimje V. R., Chen C.-Y., Chen C.-C., Jean J.-S., Reddy A. S., Fan C.-W., Pan K.-Y., Liu H.-T. & Chen J.-L. (2009). Stable and high energy generation by a strain of *Bacillus subtilis* in a microbial fuel cell. Journal of Power Sources. 190(2): 258-263.

Nong Minh Tuan (2014). Research and development of microbial fuel cells used as biosensors to assess wastewater quality, Master thesis, Vietnam National University (in Vietnamese).

Pandit S. & Das D. (2018). Principles of Microbial Fuel Cell for the Power Generation. 2: 21-41. DOI: 10.1007/978-3-319-66793-5.

Park D. H. & Zeikus J. G. (2000). Electricity Generation in Microbial Fuel Cells Using Neutral Red as an Electronophore. Applied and Environmental Microbiology. 66(4): 1292-1297.

Son C. T., Giang N. T. H., Nui N. H., Thao T. P., Lam N. T. & Cong V. H. (2020). Assessment of Cau River water quality assessment using a combination of water quality and pollution indices. Journal of Water Supply: Research and Technology-Aqua. 69(2): 160-172.

Duyen T. M. T., Ngoc P. & Hoa T. P. (2021). Evaluating the effects of chloride on the performance of microbial fuel cells for wastewater treatment. Environmental Sciences. 64: 99-104.

Vega C. A. & Fernández I. (1987). Mediating effect of ferric chelate compounds in microbial fuel cells with *Lactobacillus plantarum*, *Streptococcus lactis*, and *Erwinia dissolvens*. Bioelectrochemistry and Bioenergetics. 17(2): 217-222.

Vo Huu Cong & Phung Thi Hang (2019). Waste audit of cattle production in Minh Chau commune, Ba Vi district, Hanoi. TNU Journal of Science and Technology. 207(14): 129-134.

World Bank (2013). Vietnam Urban Wastewater Review Executive Summary. Retrieved from https://www.worldbank.org/content/dam/Worldbank/document/EAP/Vietnam/vn-urbanwastewater-summary-EN-final.pdf on December 1, 2022.

Yoganathan K. & Ganesh P. (2015). Electrogenicity assessment of Bacillus subtilis and *Bacillus megaterium* using Microbial Fuel Cell technology. International Journal of Applied Research. 1(13): 435-438.