TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 13, No. 2, February 2015, pp. 329 ~ 336
DOI: 10.11591/telkomnika.v13i2.6952

A New Ozone Concentration Regulator

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Abstract

Laboratory design of an ozone concentration regulator which is build on the theory of continuity equation for gas flow in parallel pipes in conjunction with the ozone elimination potentials of an ozone destructor is presented. At an initial oxygen flow rate of 33.33 cm^3s^{-1}*, ozone concentration was generated and varied between 429.30 parts per million (ppm) to 3826.60 ppm. Similarly at an initial oxygen flow rate of 25* cm^3s^{-1}*, ozone concentration was generated and varied between 387.30 ppm to 4435.20 ppm. Effect of flow meter when the ozone concentration was set to approximate 1000 ppm were investigated and reported. Fine tuning of the regulator is necessary to ensure concentration stability for long duration experimental work.*

Keywords*: flow rate, continuity, variable concentration, regulator, internal radius*

1. Introduction

Ozone application is diverse [1-8] and the requirement for each application differs from the other in terms of the required quantity. Ozone generators whose outputs are proportional to the oxygen or air flow rate input, generates very high amount of ozone at a low flow rates [9, 10]. The higher the oxygen or air flow rate the lower the amount of ozone generated and vice versa [9]. Thus, it is difficult or almost impossible to obtained lower concentrations at lower flow rates of air or oxygen. Investigation of sensing parameters such as response time which is more pronounced at lower flow rates becomes difficult at lower concentrations [11-14]. In this work we have designed and developed a laboratory based ozone concentration variable regulator which transforms a fixed ozone output generator into a variable concentration generator with available laboratory equipments and thus expanding the capability and applications of an ozone generator such that when ozone is generated at a low flow rate, varying concentrations can be obtained by means of the variable output regulator.

2. Theoretical Backgrounnd and Regulator Design

When a gas flow in a parallel network of pipes as depicted in Figure 1, by continuity [15] the volume rate of discharge Q (cm^3/s) is express as:

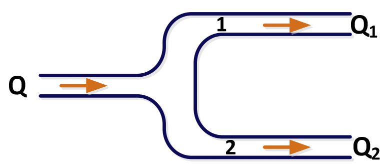


Figure 1. Flow in a parallel network of pipes

$$Q = Q_1 + Q_2 \quad (1)$$

Received November 2, 2014; Revised December 28, 2014; Accepted January 10, 2015

Where:

$$Q = \frac{V}{t} = \frac{\pi r^2 L}{t} \quad (2)$$

$$Q_1 = \frac{\pi r_1^2 L_1}{t_1} \quad (3)$$

$$Q_2 = \frac{\pi r_2^2 L_2}{t_2} \quad (4)$$

Q = Volume rate of discharge (cm^3/s)
Q_1 = Volume rate of discharge in section 1 (cm^3/s)
Q_2 = Volume rate of discharge in section 2 (cm^3/s)
V = Volume of gas with volume rate of discharge of Q (cm^3)
V_1 = Volume of gas in section 1(cm^3)
V_2 = Volume of gas in section 2 (cm^3)
r = radius of pipe section with volume rate of discharge of Q (cm)
r_1 = radius of pipe section 1(cm)
r_2 = radius of pipe section 2; for our design r_2 = 0.3cm
L = length of pipe section with volume rate of discharge of Q (cm)
L_1 = length of pipe section 1; for our design L_1 = 45.5 cm
L_2 = length of pipe section 2; for our design L_2 = 97.5 cm
t = time (s)
t_1 = time of flow in section 1 (s)
t_2 = time of flow in section 2 (s)

From equation (1) to (4) above:

$$Q_1 = Q - Q_2$$
$$Q_1 = Q - \frac{\pi r_2^2 L_2}{t_2} = Q - \frac{\pi \times r_2^2 \times 97.5}{t_2} \quad (5)$$

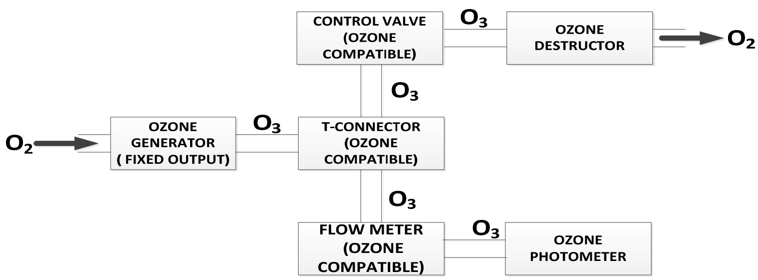


Figure 2. Block diagram of ozone concentration regulator

Q_1 or Q_2 depends on the level of freedom or resistance to gas flow which is proportional to the length and internal radius of the respective pipes [16]. In equation 5, when Q, r_1, L_1, L_2 and t_2 are kept constant; variation of the radius r_2 (between 0 and 0.3 cm) will produce a corresponding variation in the amount of flow both through sections 1 and 2 of Figure 1 and thereby varying the value of Q_1 and thus controlling the concentration in the different sections of the system [15]. The implementation of the said control for ozone gas is described in the block diagram of Figure 2. At lower concentrations requirements, excess ozone produced is eliminated by flowing it through an ozone destructor.

3. Experimental Set-up and Procedure

Figure 3 shows the experimental setup of our ozone regulator incorporated to an ozone photometer. The items in Figure 3 are described as follows: (1) Ozone destructor made in the

US by Longevity Resources Inc; (2) A silicon tube connecting a control valve to the ozone destructor; (3) A control valve that varies the flow of ozone gas to the destructor; (4) A silicone tube connecting the control valve and a T-connector; (5) Ozone compatible T-connector; (6) - A silicone tube connecting the T-connector to a flow meter; (7) A silicone tube connecting a ozone generator output into the T-connector; (8) EXT50 Ozone generator made in the US by Longevity Resources Inc; (9) Vinyl tube for connecting the flow of oxygen from the oxygen tank to the ozone generator; (10) 220V electricity supply to the ozone generator; (11) 0 to 10 LPM (0 to 166.67 cm^3s^{-1}) ozone compatible flow meter; (12) A silicone tube connecting the flow meter to ozone monitor; (13) 2B technologies 106-M model ozone monitor which can measure accurate ozone concentrations between 0 to 1000 ppm; (14) USB cable connecting the monitor to a laptop computer and (15) A DC source to power the ozone monitor.

Oxygen gas with a purity of 99.999% was delivered at a flow rate of 33.33 cm^3s^{-1} [2 liters per minute (LPM)] through a vinyl tubing to the EXT50 Ozone generator. Ozone was generated and fed into the ozone monitor at a flow rate of 33.33 cm^3s^{-1}. The control valve was completely locked so that there was no flow of ozone gas to the ozone destructor.

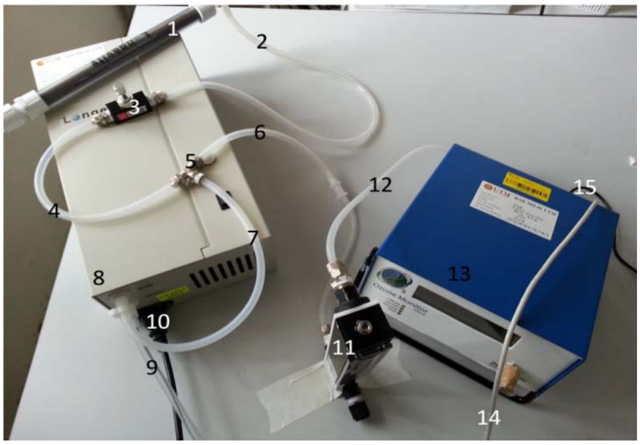


Figure 3. Experimental setup of an ozone concentration regulator

The ozone concentration in ppm were extracted from the monitor through the USB connection to the laptop. With the ozone gas flowing at a rate of 33.33 cm^3s^{-1}, the control valve was completely opened and ozone flowed into the destructor and the corresponding effect on the flow rate and the concentration were noted and recorded. With the aid of the control valve, the ozone concentration was adjusted to approximately 1000 ppm which corresponds to a flow rate of approximately 30.00 cm^3s^{-1}(1.8 LPM). The effect of the flow meter on this adjusted concentration of 1000 ppm was then investigated for a flow rate between 16.67cm^3s^{-1} (1LPM) and 166.67cm^3s^{-1} (10 LPM) at a step of 16.67cm^3s^{-1} or 1LPM. The entire process was repeated for an initial oxygen flow rate of 25 cm^3s^{-1} (1.5 LPM) and the results were obtained and analised.

4. Results and Discussion

Figure 4 shows the maximum and minimum ozone concentrations in ppm obtained at an initial oxygen flow rate of 33.33 cm^3s^{-1}(Initial oxygen flow rate is the flow rate of oxygen in the system before the ozone generator was energised electrically). The section 'A' is when oxygen was fed into the ozone generator while the ozone generator was off.

B indicates the maximum ozone concentrations 3826.60 ppm at an initial oxygen flow rate of 33.33 cm^3s^{-1} with the control valve completely locked to short out ozone from the destructor. C is the lowest ozone concentration obtained 429.30 ppm, when the control valve was completely opened thus allowing maximum flow of ozone to the destructor. Thus, the percentage regulation at a flow rate of 33.33cm^3s^{-1} is in the range of 11.22% to 100%.

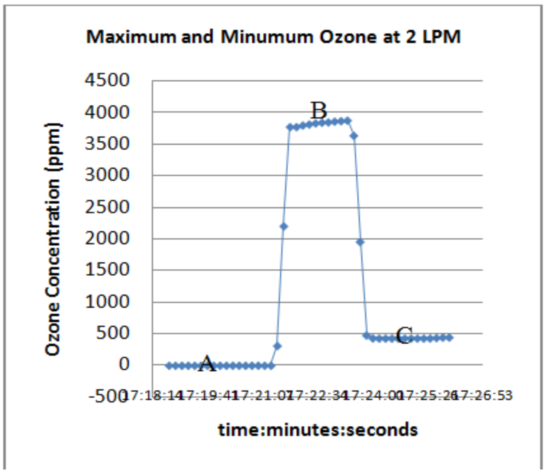


Figure 4. Maximum and minimum ozone concentrations at an oxygen flow rate of 33.33cm^{3}s^{-1} (2 LPM)

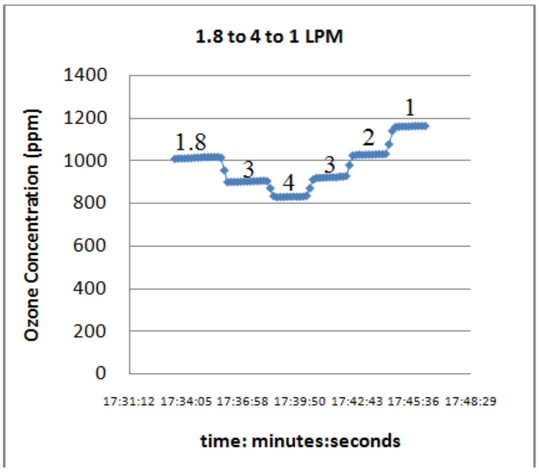


Figure 5. Effect of flow meter between 30cm^{3}s^{-1} to 66.67 cm^{3}s^{-1} to 16.67cm^{3}s^{-1} (1.8 to 4 to 1 LPM) of ozone concentrations

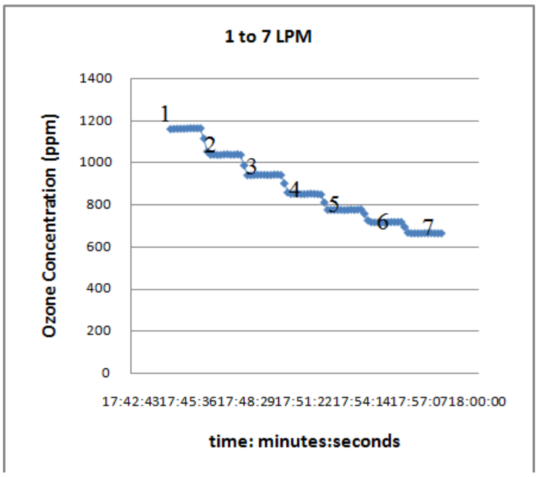


Figure 6. Effect of flow meter between 16.67 cm^{3}s^{-1} and 116.67 cm^{3}s^{-1} (1 and 7 LPM) of ozone concentrations

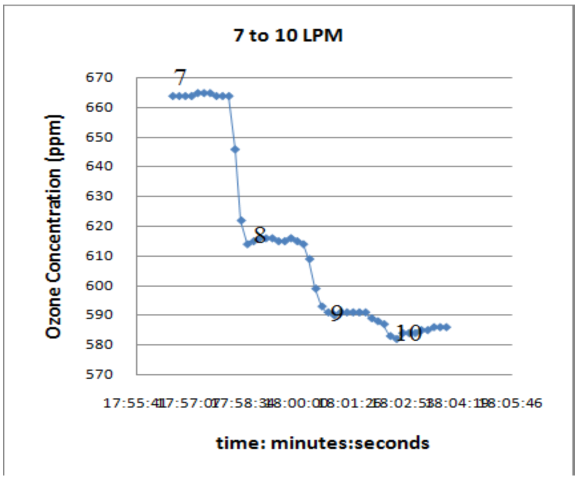


Figure 7. Effect of flow meter between 116.67 cm^{3}s^{-1} and 166.67 cm^{3}s^{-1} (7 and 10 LPM) of ozone concentrations

In Figure 5, 6, 7 and 8 the effect of the flow meter when the ozone was set to 1000 ppm approximately is shown. The concentrations in ppm obtained for ozone flow rate of 16.67cm^{3}s^{-1} to 166.67cm^{3}s^{-1} (1 to 10 LPM) respectively are 1163.60, 1039.20, 942.50, 776.10, 716.70, 664.30, 615.20, 590.60 and 584.50 ppm. Thus the higher the flow rate the lower the concentrations, this is depicted clearly in Figure 9. Figure 10 is the fluctuations in pressure at higher flow rates, which shows that the regulator is effective between 16.67cm^{3}s^{-1} to 116.67cm^{3}s^{-1} (1 to 7 LPM) since the pressure is not longer able to sustain a steady flow as from 8 LPM upwards. This can also viewed in Figure 7. At D in Figure 8, the ozone generator is switched off and ozone concentration becomes reduced to approximately zero. The results thus obtained are in agreement with the theory of gas flow in parrallel pipes as earlie shown in section 2 of this article.

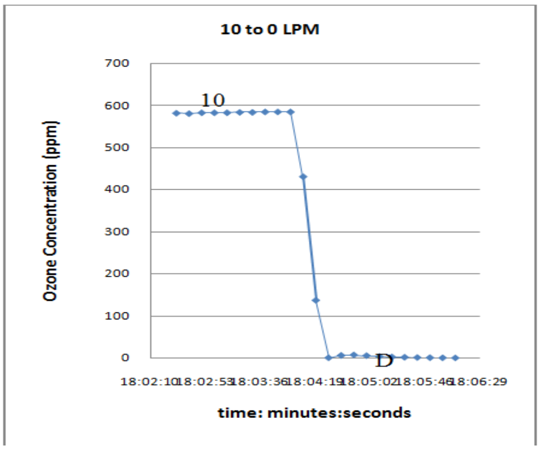


Figure 8. Effect of flow meter between 166.67 cm^3s^{-1} and 0 cm^3s^{-1} (10 and 0 LPM) of ozone concentrations

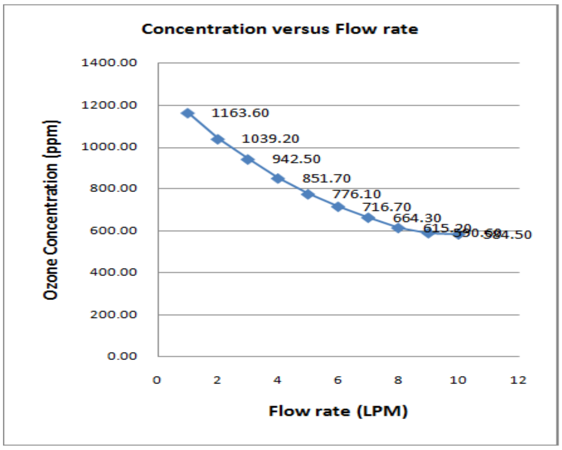
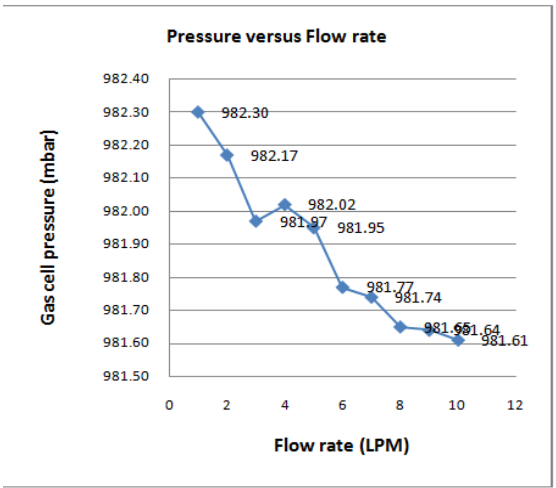


Figure 9. Effect of flow rate on ozone concentrations

Similarly, Figure 11 shows the maximum and minimum ozone concentrations in ppm obtained at an initial oxygen flow rate of *25.00* cm^3s^{-1} (1 LPM). The section E is when oxygen was fed into the ozone generator while the ozone generator was off. F is the maximum ozone concentrations 4435.20 ppm at an oxygen flow rate of *25* cm^3s^{-1} with the control valve completely locked to short out ozone from the destructor. G is the lowest ozone concentration obtained 387.30 ppm, when the control valve was completely opened thus allowing maximum flow of ozone to the destructor. Similarly, the percentage regulation at a flow rate of 25 cm^3s^{-1} is in the range of 8.37% to 100%.



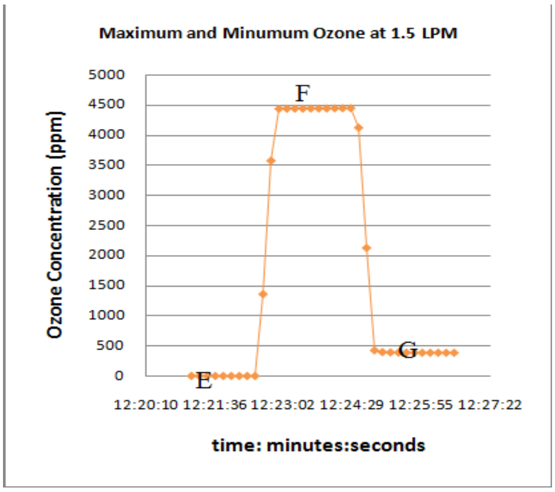


Figure 10. Effect of flow rate on the pressure of ozone gas in the gas cell

Figure 11. Maximun and Minimum ozone concentrations at an oxygen flow rate of *25.00* cm^3s^{-1}*(1.5 LPM)*

The ozone concentration was adjusted to approximately 1000 ppm at an ozone flow rate of approximately 21.67 cm^3s^{-1}(1.3 LPM). In Figure 12, 13, 14, and 15 the effect of the flow meter when the ozone was set to 1000 ppm approximately is shown. The concentrations obtained for 16.67cm^3s^{-1} to 166.67cm^3s^{-1} (1 to 10 LPM) are 1253.30, 1105.50, 976.25, 879.50, 783.50, 728.00, 663.80, 628.60, 589.00 and 563.50 ppm respectively. Similarly, the higher the flow rate the lower the concentrations, as shown in Figure 16. Figure 17 is the shows the fluctuations in pressure at higher flow rates, at in innitial oxygen flow rate of *25* cm^3s^{-1} as compared 33.33cm^3s^{-1} the fluctuation is minimal and the gas pressure in the regulator was able to sustain a steady flow between 16.67cm^3s^{-1} to 150.00cm^3s^{-1} (1 to 9 LPM), this is shown in Figure 10, fluctuations sets in at 166.67cm^3s^{-1} (10 LPM). At H in Figure 15, the ozone generator is switched off and ozone concentration to reduce to approximately zero. The results are also in agreement with gas flow theory in parallel pipes.

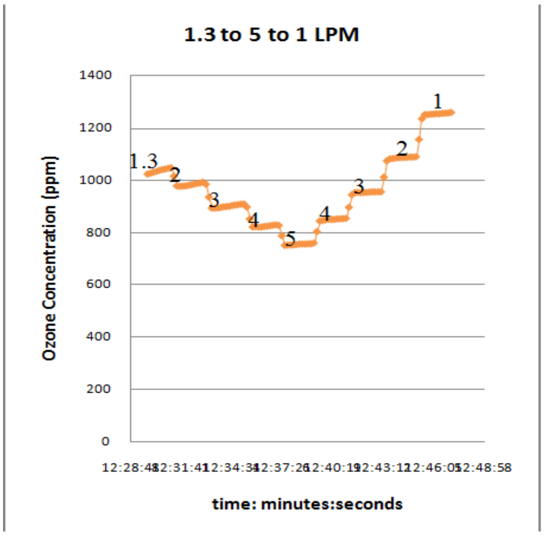


Figure 12. Effect of flow meter between 21.67cm^3s^{-1} to 83.33 cm^3s^{-1} to 16.67cm^3s^{-1}(1.3 to 5 to 1 LPM) of ozone concentrations

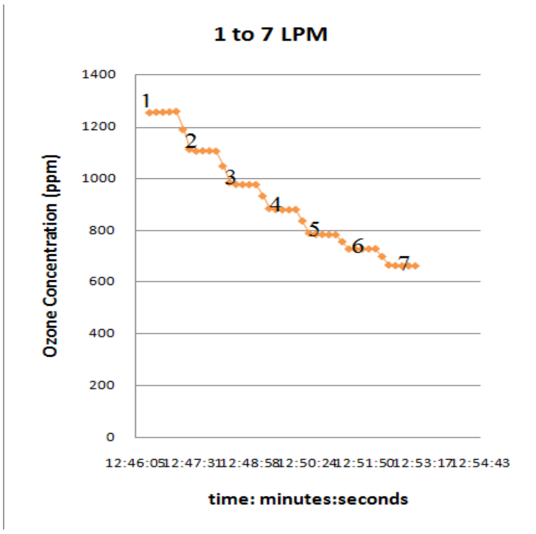


Figure 13. Effect of flow meter between 16.67 cm^3s^{-1} to 116.67cm^3s^{-1} (1 and 7 LPM) of ozone concentrations

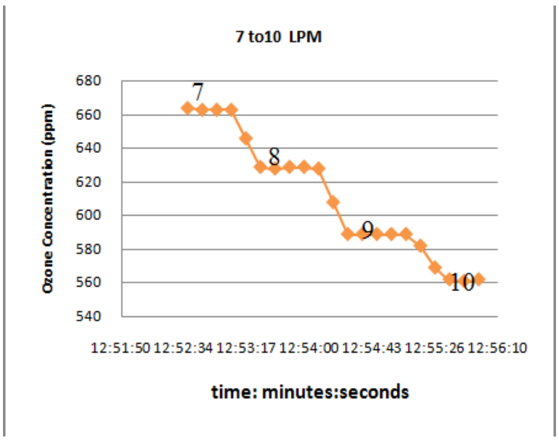


Figure 14. Effect of flow meter between 116.67 cm^3s^{-1} and166.67cm^3s^{-1} (7 and 10 LPM) of ozone concentrations

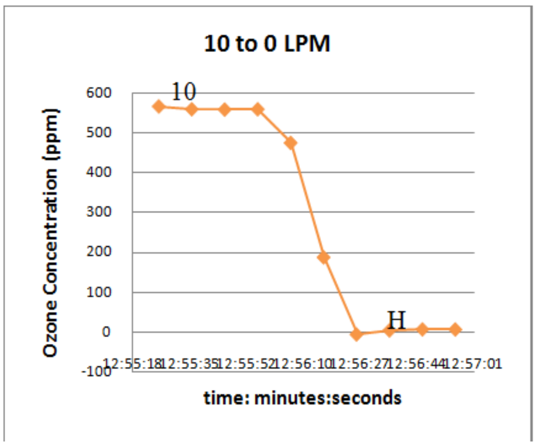


Figure 15. Effect of flow meter between 166.67 cm^3s^{-1} and 16.67cm^3s^{-1} (10 and 0 LPM) of ozone concentrations

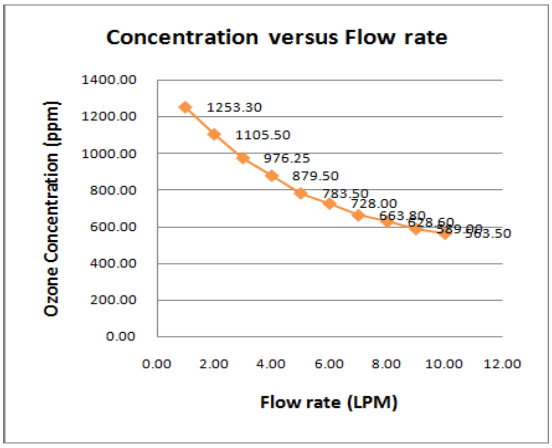


Figure 16. Effect of flow rate on ozone concentrations

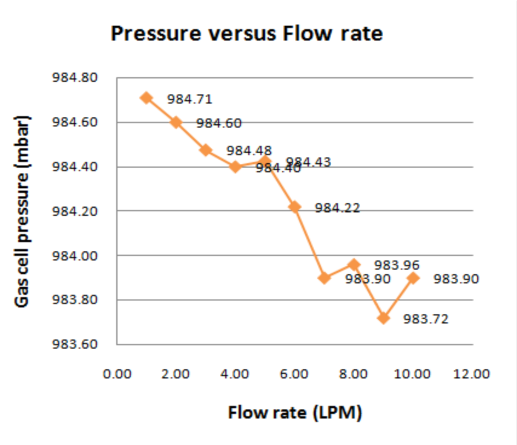


Figure 17. Effect of flow rate on the pressure of ozone gas in the gas cell

5. Conclusion

A new ozone regulator has been designed and build on the theory of continuity for gas flow in parallel pipes. The ozone regulator makes it possible to generate varying concentrations of ozone at different flow rates and thus providing for maximum flexibility in terms of concentration and flow rates. For a given flow rate varying concentrations can be obtained: at initial oxygen flow rate of 25.00 cm^3s^{-1} and 33.33cm^3s^{-1} yields an ozone flow of 50.00 cm^3s^{-1} (3 LPM) whose contration were 976.25 ppm and 942.50 LPM respectively. Similarly a specific concentration can also be generated at different flow rates taking the advantage of the regulator: approximately 1000 ppm of ozone was generated at 21.67 cm^3s^{-1} (1.3 LPM) and 30.00 cm^3s^{-1}(1.8 LPM) corresponding to initial oxygen flow rate of 25.00 cm^3s^{-1} and 33.33cm^3s^{-1}respectively. Effects of the regulator and the flow meter has also been tested and has been found to be satisfactory. The regulator has a capability of varying concentrations of ozones between 8.73% to 100%.

Acknowledgements

The authors would like to thank Universiti Teknologi Malaysia (UTM) for sponsoring this publication under Research University Grant (RUG) Scheme, grant no: 05J60 and 04H35; and Fundamental Research Grant Scheme (FRGS) grant no: 4F317 and 4F565. The Ministry of education (MOE) Malaysia is also acknowledge and the Nigerian Education Trust Fund (ETF) for the financial support giving inform of Tertiary Education Trust Fund (TET-Fund).

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