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Design and Fabrication of a Micro-respirometer to Measure the Short-Term Respiratory Quotient (RQ) of Wastewater Samples

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Abstract - *The main objective of the study is to develop a low-cost wastewater micro-respirometer to determine some important bioactivity performance indicators such as oxygen consumption rate (OCR), carbon dioxide evolution rate (CER) and respiratory quotient (RQ) of wastewater samples collected from effluent treatment plants (ETPs) and other wastewater sources. The developed apparatus was comprised of two major parts, a reaction chamber and a measuring unit facilitated with a well type vertical volumeter. Validation of the newly fabricated respirometer was done by checking the repeatability of the test results using standard sodium sulfite deoxygenation method. The qualities of the wastewater collected from different sources of Sylhet city area of Bangladesh were characterized in terms of pH, total solid (TS), total dissolved solid (TDS) and chemical oxygen demand (COD). Finally, five wastewater samples (both municipal and industrial type) covering low range COD were tested for three hours of incubation period to obtain respirograms for calculating OCR, CER and RQ under room temperature. Similar fashion of experiments were conducted with another five wastewater samples covering high range COD. Samples originated from a pharmaceutical industry under high range COD category had shown highest value of CER (4.1 mg/L.min) and the corresponding RQ was constantly above one. Under low range category mixed type wastewater samples had shown the highest RQ (3.5). However, using the device ETP personnel could make a rough idea about the type of influent wastewater and subsequent follow-up steps could be formulated and maintained during plant operation.*

Key Words: **Oxygen consumption rate, Carbon dioxide evolution rate, Effluent treatment plant, Low-cost, Manometer, Respirometer, Respirogram, Respiratory quotient, Wastewater**.

1. INTRODUCTION

In our country, biochemical oxygen demand (BOD) is being used as a unique wastewater quality index from academic to industrial level for both design and operation of effluent treatment plants (ETPs). Therefore, it is very important to develop a relatively faster and cost-effective way for understanding the biodegradation phenomena that are taken placed in a reaction tank of an ETP [1, 2, 3]. Respiration is generally considered as a general measure of the microbial activity [4, 5]. Therefore, the respiration process and its qualitative and quantitative phenomena could be an effective indicator of the on-going condition of a typical biodegradation process. Respirometric parameters such as cumulative oxygen consumption (COC), oxygen consumption rate (OCR), cumulative carbon-dioxide evolution (CCE), carbon dioxide evolution rate (CER) and respiratory quotient (RQ) can ascertain the presence of organic matters, microbes and respiration type present in wastewater by observing microbial activities [4, 5, 6]. These parameters can provide a reliable and scientifically sound assessment of biodegradable criteria. Oxygen consumption and carbon dioxide emission are directly associated with both biomass growth and substrate removal [7, 8]. It can be considered as one of the most important information sources in activated sludge process modelling and process control. Respirometry is used to assess wastewater toxicity to heterotrophic and nitrifying bacteria in activated sludge [9]. Respirometry is a direct method for measuring sludge activity and thus toxicity to sludge [10]. The method for analysing wastewater based on Respirometry and COD is comparatively new to the dominant part of higher educational institutions in Bangladesh. From this research different parameters as stated earlier like OCR, COC, CER, CCE, RQ and COD can be known which will give a clear picture about the concentration of organic matters and biodegradation status of wastewater under some treatment. Thus, the main objective of the study is to develop a low-cost wastewater micro-respirometer (named as **'Waste respirometer'**) to determine some important respirometric parameters such as oxygen consumption rate (OCR), carbon dioxide evolution rate (CER) and respiratory quotient (RQ) of wastewater samples. This study can present an improved quick test protocol for analysing wastewater with locally available materials and technology.

2. RESEARCH METHODOLOGY

Before starting design and fabrication of the present respirometer, a survey was done to find the existing devices in the market and nearby laboratories. After that a prototype device was built to test the feasibility of the concept and device as well (Figure 1). Then final fabrication of the device was done following standard fabrication process (Figure 2 and Figure 3).

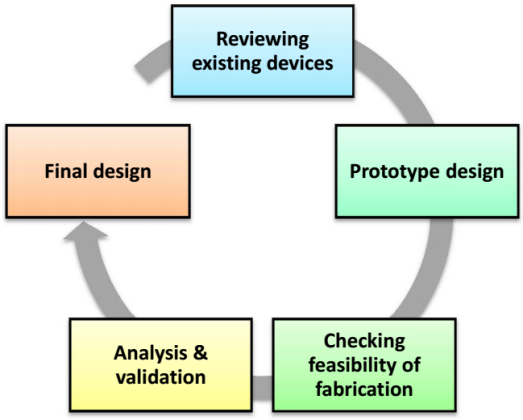


Fig -1: Design approach for the fabrication of the device

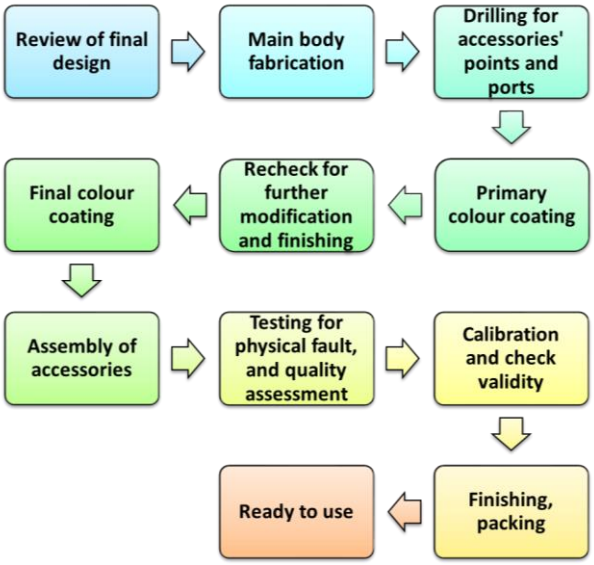
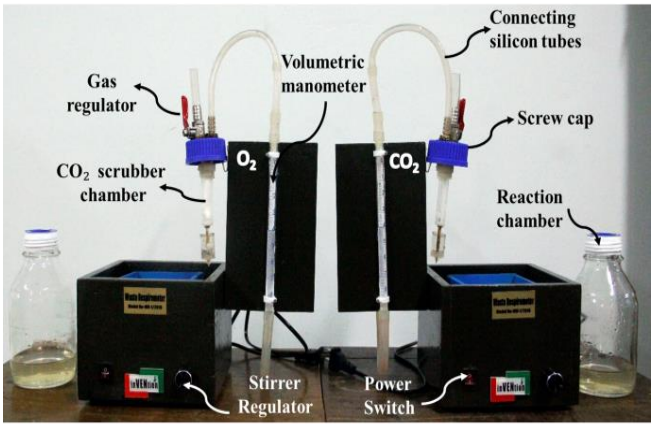


Fig -2: Fabrication approach of the device



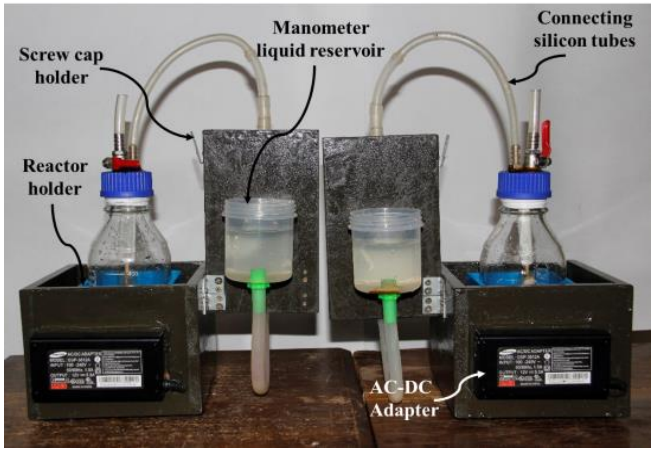


Fig -3: Fabricated 'Waste Respirometer'

2.1 Technical specifications

Technical provisions that were embedded in the model are pointed out in the following Table 1.

Table -1: Technical specifications of the present device 'Waste Respirometer'

Features	Description
Measuring principle	Volumetric and/ or manometric
Reactor volume	600 ml
Power supply	110-220 V (AC), 50/60 Hz [12 V DC]
Stirrer speed	0-4100 rpm
Weight	3 kg (Approx.)
Manometric liquid	Diluted methyl orange

2.2 Validation of the 'Waste Respirometer'

Validation of the test results obtained from different experiments was done by repeatability test and expressed in terms of standard deviations. Repeatability is the measurement of variability found when the same sample is tested by the same operator. The current device satisfactorily produced repeated data with a good precision for a set of experiments performed. A control test with sodium sulfite (Na_2SO_3) solution in presence of cobalt chloride ($CoCl_2$) was done to assess the precision of the instrument [11]. Sodium sulfite functions as oxygen scavenger in presence of cobalt chloride within the reactor of the respirometer and total oxygen consumption was monitored from the manometer readings. The results of such a precision test are presented in Table 2. From the test results it is found that the relative standard deviation is only 3.44% and 3.15% respectively, which fairly proves the preciseness of the machine data.

Table -2: Repeatability checks of the test results obtain from the present device

Respiro-meter No.	Test no.	Total Oxygen Uptake, mL	Mean	Standard deviation	Relative Standard deviation, %
No. 1	1	4.3	4.275	0.147	3.44
	2	4.5			
	3	4.2			
	4	4.1			
No. 2	1	4.2	4.125	0.129	3.15
	2	4.3			
	3	4			
	4	4			

2.3 Operation of the device

The following steps were generally followed to run a test sample using this '**Waste respirometer**'.

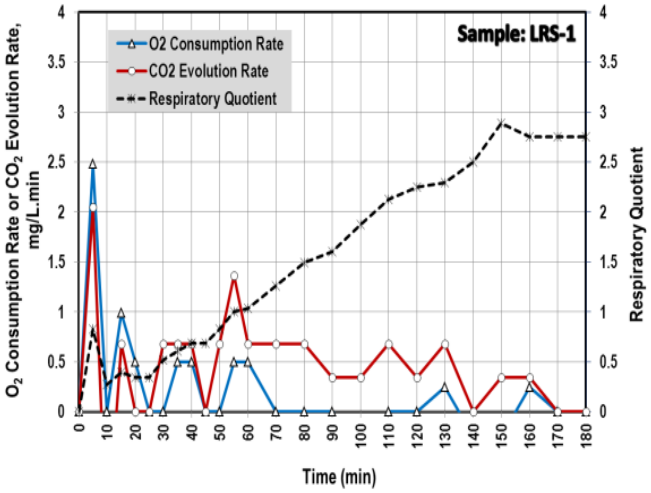
1. At first, all joints and connections were made perfectly airtight.
2. Then leakage test was performed to check any leakage in the system.
3. Weight and volume of sample were determined.
4. Then sample was placed in the reactor.
5. Remaining air volume of reactor was determined.
6. Magnetic stirrer bar was placed in reactor.
7. 10-20 pellets of KOH were placed in CO_2 scrubber chamber.
8. The gas stopper was adjusted in such a way so that the reactor was directly connected to the manometer.
9. The magnetic stirrer was turned on.
10. Manometer readings were observed and tabulated for further analysis.
11. OUR, COU, RQ, CCE, CER was calculated using different working formula as stated in the inside of the report.

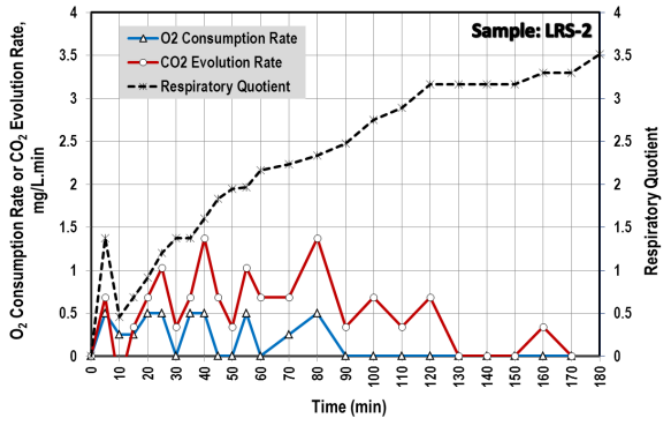
Along with the above steps, room temperature, sample temperature and humidity were also measured. For the characterization of the wastewater samples some specific parameters such as the total solid, dissolved solid, pH, COD of the samples were measured at the starting time of experiment.

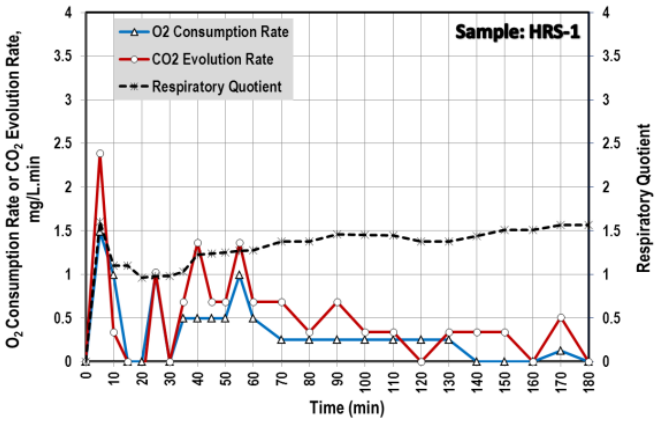
3. Results and Discussions

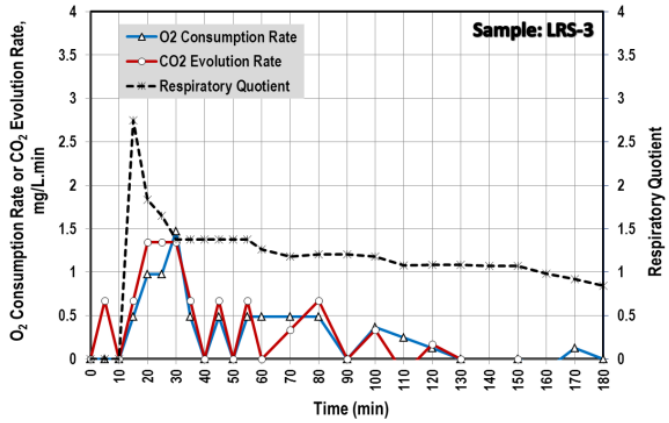
The qualities of the wastewater collected from different municipal and industrial sources were characterized in terms of pH, total solid (TS), total dissolved solid (TDS) and chemical oxygen demand (COD) according to the standard analytical methods. Finally, five wastewater samples (both municipal and industrial type) covering low range COD were tested in the respirometer for three hours of incubation period to obtain respirograms for calculating OCR, CER and RQ under room temperature. Similar fashion of experiments was conducted with another five wastewater samples covering high range COD. Low range samples were collected from different sources within the SUST campus because of the greater possibility of getting low range COD value. All these five samples were marked as LRS-1, LRS-2, LRS-3, LRS-4 and LRS-5. On the other hand, high range samples were collected from different sources around the BSCIC area Khadim Nagar, Sylhet because of the greater possibility of getting high range COD value. All these five samples were marked as HRS-1, HRS-2, HRS-3, HRS-4 and HRS-5.

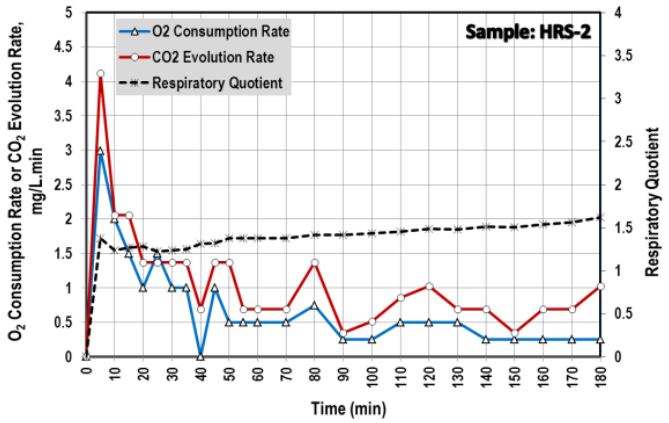
All the output respirograms of the tested wastewater samples for both low range COD and high range COD category is presented in the Figure 4. It is seen that the first peaks were detected at early stage of experiment in both case of OCR and CER. These peaks indicate that the respiration rates of samples were high in these points. Gradually, with the increase of time, the respiration rates were decreased. Sometimes OCR and CER value had shown some small peaks which indicate that respiration activity of the samples were intermittent type. Sometimes respiration was at high rate and some other time at lower rate. Since, there was sufficient amount of oxygen inside the reactor at the initial time, therefore respiration response in the beginning of the test was high. But as long as inside oxygen dropped down, the respiration rate also decreased.

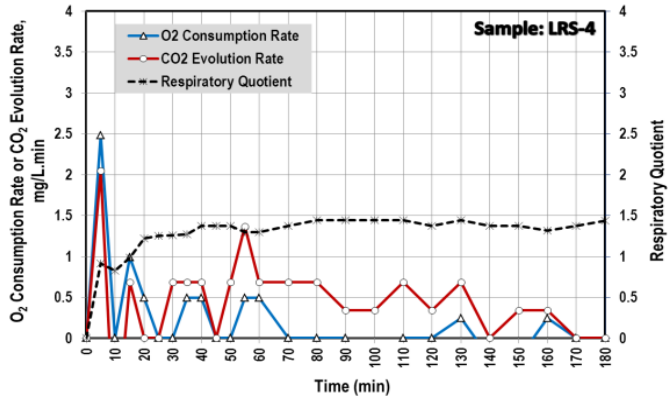


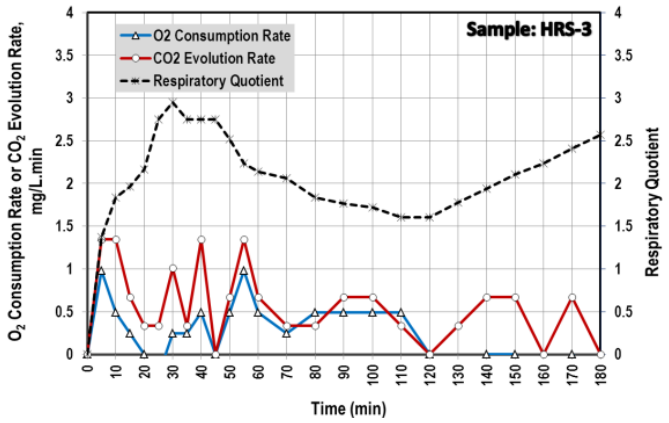

Sample: LRS-2
O2 Consumption Rate
CO2 Evolution Rate
Respiratory Quotient
O2 Consumption Rate or CO2 Evolution Rate, mg/L.min
Respiratory Quotient
Time (min)

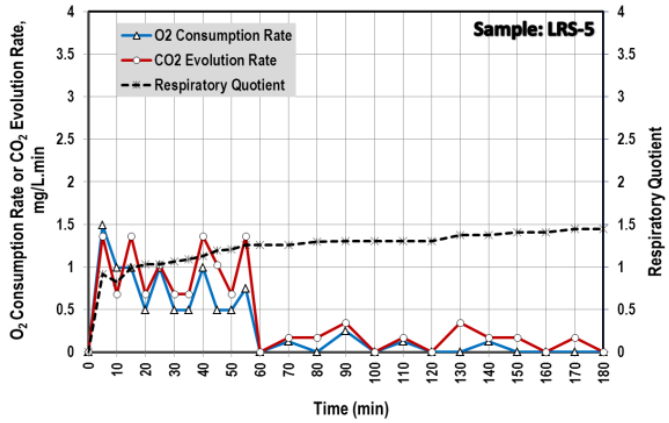

Sample: HRS-1
O2 Consumption Rate
CO2 Evolution Rate
Respiratory Quotient
O2 Consumption Rate or CO2 Evolution Rate, mg/L.min
Respiratory Quotient
Time (min)

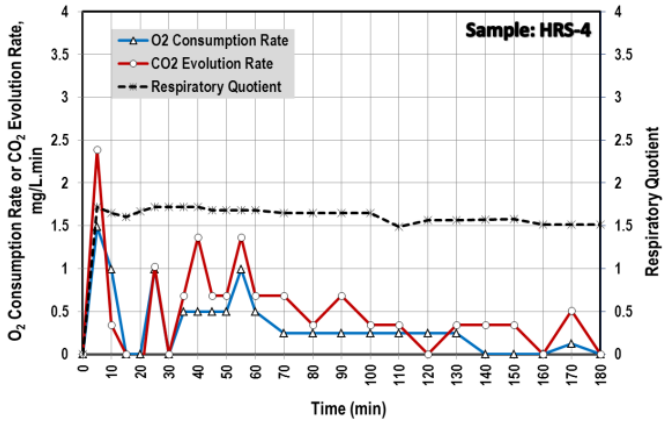

Sample: LRS-3
O2 Consumption Rate
CO2 Evolution Rate
Respiratory Quotient
O2 Consumption Rate or CO2 Evolution Rate, mg/L.min
Respiratory Quotient
Time (min)


Sample: HRS-2
O2 Consumption Rate
CO2 Evolution Rate
Respiratory Quotient
O2 Consumption Rate or CO2 Evolution Rate, mg/L.min
Respiratory Quotient
Time (min)


Sample: LRS-4
O2 Consumption Rate
CO2 Evolution Rate
Respiratory Quotient
O2 Consumption Rate or CO2 Evolution Rate, mg/L.min
Respiratory Quotient
Time (min)


Sample: HRS-3
O2 Consumption Rate
CO2 Evolution Rate
Respiratory Quotient
O2 Consumption Rate or CO2 Evolution Rate, mg/L.min
Respiratory Quotient
Time (min)


Sample: LRS-5
O2 Consumption Rate
CO2 Evolution Rate
Respiratory Quotient
O2 Consumption Rate or CO2 Evolution Rate, mg/L.min
Respiratory Quotient
Time (min)


Sample: HRS-4
O2 Consumption Rate
CO2 Evolution Rate
Respiratory Quotient
O2 Consumption Rate or CO2 Evolution Rate, mg/L.min
Respiratory Quotient
Time (min)

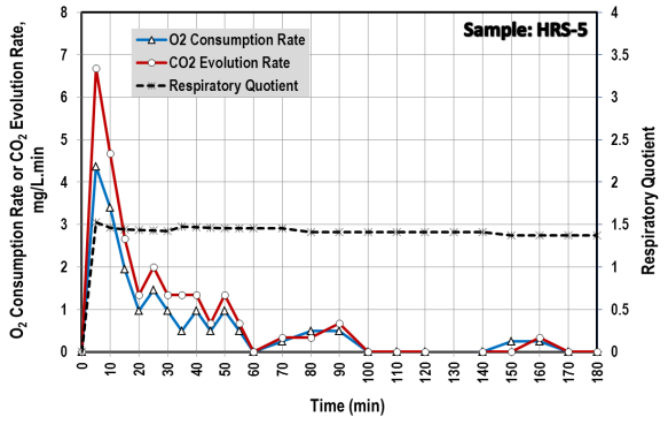


Chart -1: Respirograms of the wastewater samples for low range COD and high range COD

Samples originated from a pharmaceutical industry (HRS-2) under high range COD category had shown highest value of CER (4..1 mg/L.min) and the corresponding RQ was constantly above one. Under low range category wastewater samples collected from the canal behind the academic building 'B' (LRS-2 mixed type) had shown the highest RQ value (3.5). However, irregular pattern of RQ for some samples revealed that these samples were composed of mixed type substrates. In most analyses CER was found higher than OCR because of the presence of anaerobic micro-organisms which regulated anaerobic respiration. During the ending period of experiment LRS-1, LRS-2, LRS-4, HRS-3, HRS-5 had only CER response, OCR was around zero. Because after consuming the whole oxygen available in the reactor aerobic respiration stops, only anaerobic respiration prevailed.

It may be concluded from the above scenario that for low range COD category the cumulative oxygen consumption (COC) due to degradation of the biodegradable organic matters was found about 12-43% of the total chemical oxygen demand (Table 3). This reveals that the samples were deficient in viable biomass. On the other hand, for high range COD category this percentage was very much lower, only 0.05-11.50%. It means that these samples were in huge deficiency of viable biomass in comparison to their organic load in the sample. Moreover, it also indicates that if sufficient supply of oxygen could ensure then the biodegradability of the wastewater may also be increased.

Table -3: Percent biodegradability in 3 hrs of incubation degraded by inborn microbes

Sample no.	Sample ID	$COD_{initial}$ (mg/L)	COC (mg/L)	Biodegradability (%)
1	LRS-1	177	28	15.82
2	LRS-2	189	23	12.17
3	LRS-3	161	44	27.33
4	LRS-4	130	57	43.85
5	LRS-5	196	50	25.51
1	HRS-1	11038	53	0.05
2	HRS-2	6617	112	1.69
3	HRS-3	322	37	11.50
4	HRS-4	4510	25	0.55
5	HRS-5	3850	97	2.52

However, respirometric outcomes achieved in the study were satisfactorily found in the same order as those by previous authors [3, 4, 5].

4. CONCLUSION

This work proposed a unique idea to design cost-effective, good performance respirometer in the laboratory from locally available materials. The developed 'Waste Respirometer' could trace both the oxygen consumption and carbon dioxide evolution at the same time in a typical biodegradation process. The biomonitoring parameters (COC, CCE, OCR, CER and RQ) proposed in the study could be used in various decision and policy making activities concerning biodegradation of different test substrates and design, operation and management of ETP. However, using the device ETP personnel could make a rough idea about the type of influent wastewater and subsequent follow-up steps could be formulated and maintained through the continuous monitoring of respiratory quotient of the representing test samples collected from the plant.

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BIOGRAPHIES

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