Bio-Scrubber Performance Equipped with Airlift Parallel Bioreactors (APB's) for BTX Biodegradation by Wastewater Sludge

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ABSTRACT: *A new approach in this work was the biodegradation of Benzene, Toluene, and Xylene (BTX) using Airlift Parallel Bioreactors (APB's) connected to the Plexiglas Bio-Scrubber (PBS) Modulated with Polyurethane Foam (MPF) as modified sort in the use of mineral pumice as a porous filler Lava rock media. The aeration bioreactors were set up with a microbial consortium of refinery Sludge Effluent Sewer (SES) treatment and nutrient solution. The performance of PBS for BTX removal by APB's filled with Activated Sludge Effluent Sewer (ASES) in the range of inlet BTX concentrations from 180.7 to 881.8 ppmv in different air pollution flow rates was tried for two rates: 2.5 & 3.5 L/min at 30 days Mean Residence Time Distribution (MRTD) for each treatment. The results showed that at inlet pollutant concentrations of [B] = 180.7 ppmv, [T] = 327.4 ppmv & [X] = 297.5 ppmv, the removal efficiency in flow rates 2.5 L/min was 90.7, 88, and 83.6(%) for benzene, toluene and xylene, respectively. The amount of removal in a flow rate 2.5 L/min was better than the removal efficiency at 3.5 L/min due to lower pollution concentration.*

KEYWORDS: *Biodegradation; Bio-scrubber; Mineral pumice; Microbial consortium; Sludge effluent sewer.*

INTRODUCTION

Benzene, Toluene, and Xylene (BTX) are known as cyclic aromatics and are derived from the vapors of petrochemical complexes, the chimneys of aromatic chemical plants, air-conditioning plants, airborne toxins and inks, or transferred from industrial effluents into open, surface and groundwater which can be included in the category of Volatile Organic Compounds (VOC's) [1, 2]. Skin-to-skin contact of humans and other living organisms with BTX causes renal, blood, liver and neurological complications or in some cases is a major cause of bone marrow cancers [3, 4]. Chronic kidney disease is a global health problem for many populations in developing,

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due to hydrocarbon pollution in domestic freshwater [5]. Biotechnology provides technical solutions when environmental damage has already been done [6]. The problems caused by exposure to BTX have increased the attention of the Environmental Protection Agency (EPA) and researchers to remove it [2, 3, 7]. Degradation or removal of BTX has been studied using different methods by several researchers. Among the different methods for removing aromatic pollutants from the air are adsorption, enzymatic, physical, membrane, catalytic (zeolite, clinoptilolite), and biological methods may be mentioned [8, 9]. As a result, to remove harmful BTX vapors and not release more of these pollutants into the environment; it is necessary to design and use biological removal methods and associated technologies. Biological methods are very effective, low cost, clean, and do not have a destructive effect and pollution on the environment. They can be used to remove different concentrations of BTX [10]. Many biological methods, such as biological filters, biological washing columns, and every sort of bio-trickling filter, and bio-scrubber, have been used in landfill zones to remove odor and VOC treatment as biodegradation [11]. It's clear that although the choice of a pure culture strain for VOC degradation leads to better removal efficiencies, the use of industrial sludge is preferred because of the robust diversity of microorganisms, the optimal treatment effect of these microorganisms is very important, due to the synergistic effect of microorganisms in sludge and industrial or refinery effluents [12]. A novel bioactive foam emulsion bioreactor has been developed by *Ghorbani Shahna et al.* to increase the elimination capacity of BTX. They studied the effect of several parameters on bioreactor performance i.e. organic phase concentration, oxygen content, and gas residence time. Their experimental results showed that the developed bioreactor can be very effective for BTX removal [13]. In several studies, bio-scrubbers were used to remove ammonia [14, 15]. Bio-Trickling Filter (BTF) is a packed bed bio-scrubber that is filled by the spatial sort of packing materials; equipped with a bioreactor recirculation system operating in counter-current style with the gas streamline. After many times loading or EBRT then biomass will grow on the surfaces of packing materials and form a biofilm [16, 17] of benzene, toluene, and xylene too [18, 19]. The rate of aeration often leads to high circulation rates and back-mixing, and affect the sludge particle size and its distribution in the reactor [20] Biodegradation of such intricate systems and processes can be examined using the residual time technique [21]. Conventional residual time models such as airlift bioreactor, and axial dispersion model reported in the literature fail to provide a comprehensive view of the performance of bio scrubber [22]. In bio-scrubber methods, they can be filled, modified, and connected with an airlift bioreactor, and have more efficient performance compared to traditional methods with bio-filters. *Gopinath et al*. have studied a new bio-filtration system containing packing material from aerated municipal sewage water attached with coil for toluene degradation in batch and up flow packed bed reactor [23]. Recent studies have shown that considering the main mechanisms of oil consumption (emulsion adsorption and direct interfacial) in the performance of air transfer bioreactors because the mass transfer phenomena of hydrocarbons to the aqueous phase cannot explain the total oil consumption. Therefore, studies on the hydrodynamics of multiphase bioreactors related to the dominant mechanism of hydrocarbon uptake by microorganisms in an airborne air bioreactor are needed [24-26]. In an airlift bioreactor, the mass transfer limit can be due to the low solubility of hexadecane in water ($5.2*10^{-5}$ mg/L). However, microorganisms that use alkanes as an energy source are able to produce bio-emulsifiers. These molecules can dissolve hydrocarbons in microscopic droplets, which increase the bioavailability of the immiscible substrate. This can lead to improved biomass production [24]. A two-stage bio-trickling filter and bio-filter series with water scrubbing pre-treatment have been developed by *Raboni et al.* for the treatment of airborne BTEX using bacterial and fungal consortia. Removal efficiency was achieved at about 96.1% by the whole treatment [27]. In our present study, the elimination of BTX as qn environmental pollutant is main goal using the biological method. Due to the low operating costs, the industrial implementation costs of this project are considered low. The aim is to design specific dimensions of the bio-scrubber as well as a process bag by connecting the airlift bioreactors in parallel to increase the efficiency of the bio-scrubber filled with a specific type of packing. In this case, BTX degrading microorganisms can rapidly grow, and using the carbon source they can increase the efficiency of removal efficiency. Another objective of this study was to analyze the Biological and Packed Bed (PBS) performance

for removal of BTX with Activated Sludge Effluent Sewer (ASES) that filmed on lava rock pumice which is connected to the Airlift Parallel Bioreactors (APB's) at Different Mean Residence Time Distribution (MRTD).

EXPERIMENTAL SECTION

BTX measurement

Measurement of BTX was by gas chromatography model (MODEL-MICHRO 9100 GC) with HPS column (30m × 0.249mm × 0.25mm film thickness) and FID detector; with a flame ionization detector. Oven and detector temperatures were regulated at 210°C and 60°C, respectively. The hydrogen gas was used as the fuel and nitrogen gas as the carrier at a flow rate of 20 ml/min [14]. The Pressure measurements were made using a Dwyer inclined and vertical portable manometer (Dwyer Instruments, Michigan) with 0-3 mmH_2O ranges. The pressure differences between the inlet and outlet of the column were measured by connecting the two tees at the inlet and outlet of the bio-filter system with the Dwyer Manometer [28]. The calibration curve was prepared by injecting known amounts of the BTX into a scrubber tower, according to the standard procedure. The spectrophotometer (model UV 210 Shimadzu, Japan) was used for the measurement of biomass concentration and optical density of the culture at 600 nm. In order to obtain the biomass weight, samples were centrifuged at 5000 rpm for 10 min and the pellets were then washed twice with distilled water and dried at 80°C till constant weight and weighed [28]. Calibration diagrams for BTX composition were investigated and drawn. The produced CO_2 was also measured by the CO_2 infrared analyzer connected to the fermenter. For this purpose, a part of the treated airflow enters the chamber of the device which contains granulated particles of $CUSO_4$ (copper sulfate) and air passes through the granulated particles which absorb the baking soda inside the cylinder connected to the analyzer and measure the CO_2 produced [29].

Enrichment of BTX degrading bacteria in sludge

The sludge was fresh aerobic ASES from the aerobic sludge pool (effluent sewer) of an industrial refinery wastewater treatment plant in the southern airflow part of Iran and was used as a source of decomposing microorganisms. The specifications of this sludge ae as follows Table. 1.

In order to increase the number of BTX-degrading microorganisms, an enrichment medium containing the compounds of Table. 2 were used. After preparation, the pH of the enrichment medium was adjusted to 7 and after sterilization in an autoclave at 121°C for 15 min, 5% by volume of sludge was added to the culture medium and in a shaker at 50 rpm for 5 days. The environment was exposed. Then 5% by volume of enrichment medium supernatant was used for injection into the bioreactor. The fermenter used sterile broth neutrophil culture medium at 121°C and 15 atmospheres.

Table 1: Characteristics and composition of sludge for BTX degrading enrichment medium from effluent sewer.

Specification	Characteristic
PH	8.1
EC	1212 (ms/cm)
TS	10.5%
VS	56%
BOD	12600 (mg O_2/lit)
COD	24000 (mg O_2/lit)
Oil	50 - 500 ppm max
Suspended Solids	30 - 100 ppm max
Caustic soda	1 wt % max
Propane	less than 500 ppmwt
Butane	less than 200 ppmwt
Caustic	12 - 15 wt %
Na_2S & Na_2CO_3	up to 2-4 wt % of salts
Disulfides	200 ppm wt
Mercaptans/Mercaptides	traces
LCPS-30 catalyst	traces
Dissolved LPG	less than 500 ppmwt
Caustic solution	4 wt %
H_2S	5 ppm

Apparatus

Bioreactor's (CSTbR-PFbR)

In the BTX removal process, by designing and operating a continuous bioreactor, an airlift stirrer was used in parallel with a plug-in glass bioreactor of the airlift type. The efficiency of the bench-scale Continuously Stirrer Tank Bio-Reactor (CSTbR) can be attributed to mixing in the enriched bacterial strain environment to complete

Table 2: Nutrients and micronutrients of BTX degrading enrichment medium.

Component	Value (g/lit)
$(NH_4)_2SO_4$	2
$Na_2S_2O_3$	2
K_2HPO_4	1
$MgSO_4$	0.1
Fe_2O_3	0.02
Yeast extract	0.5
$CaCl_2$	0.1
$NaHCO_3$	0.5
Benzene	1
Toluene	1
Xylene	1

the regeneration process of RICH strains and to assist i n the formation of the LEAN strain, as well as integrated air bubbles and acidity control and regulation of heating and heating conditions. Through the plug bioreactor, the bacterial strain can be applied to the bio-scrubber and create a reciprocating current with the aim of distancing itself from the Plug Flow Bio-Reactor (PFbR) state in the second bioreactor by maximum reflux current as well as temperature control, which ultimately improves the efficiency of the bioreactor. Plugs can be referred to as a secondary treatment to maximize the removal of polluted air. The agitator-type bioreactor as CSTbR, consists of a glassware tank with 5 L volume, 30 cm length, and 10 cm diameter, and filled with only 2 lit of the culture medium (Fig. 1). Also a Plexiglas bioreactor was fabricated with dimension $15\times15\times30$ cm^3 and a total volume 6.75 L [30]. Inside this bioreactor are four steel baffles (blades) with 15 cm as size of height. The CSTbR was used to enable: (1) the dispersion of bubbles resulting from the injection of CO_2 gas by means of an airlift distributor installed in the bottom of the bioreactor tank, (2) the Mixing of nutrients and micronutrients for regeneration (varied reach strain to lean strain) in CSTbR, (3) Prevention of the vortex mode in the regenerating solvent.

The CSTbR bioreactor has 5 inlet and 3 outlet flow as streamlines paths. The inlet lines include:

(1) Antifoam injection path,
(2) Biological fluid from plug bioreactor,
(3) CO_2 gas flow injection,
(4) Acid and base injection flow for control the pH,
(5) Fresh nutrient loading.

The outlet lines include:

(1) CO_2 output to the analyzer,
(2) Liquid sent to top of the bio-scrubber column,
(3) Biological fluid recycles to the plug bioreactor (Fig. 3).

High temperature of the inlet solution and also higher flow of the input pollutant and also, high mixing of the solution as well as increasing the flow of circulating microorganisms in the whole of cycle, causes foaming, so In this regard, antifoam liquid with low concentration is used, (increasing the concentration of the injected antifoam causes double fumigation). Other advantages of a stirrer bioreactor include mixing to prevent dead spots and to prevent the formation of sludge residue at the bottom of the container and easy cleaning and loading. The airlift plug bioreactor used is 5 L with a length of 30 cm and a diameter of 10 cm from which the regenerated bacterial solution enters the mixed bioreactor. In order to increase the contact between gas and liquid, improve the adsorption operation, and also increase the residence time, plug bioreactors were used in the process. The semi-polluted air stream exits from the top of the bio-scrubber into the liquid inside the plug bioreactor, although some of its BTX contamination is taken up in the bio-scrubber. The reciprocating flow relationship between the agitator and plug bioreactors is through two pumps, one pump transmits the bacterial solution from the agitator to the plug and the other from the plug to the bio-scrubber and the agitator bioreactor Fig. 1. The bacterial culture medium enters the second PFbR while regenerating in the agitator bioreactor and removes BTX from the semi-polluted air again. The semi-polluted air flow is extensively filtered inside the bioreactor by a diffuser installed deep in the liquid of the plug bioreactor, forming a bubble and increasing the contact surface between the two phases. Connection of the agitator bioreactor with the plug in the reciprocating flow causes: (1) a change of state from the plug to the mixed bioreactor, (2) increased inlet reflux flow to the plug bioreactor, (3) continuous regeneration of bacterial strains of the sludge sample. The changes made in the plug bioreactor are such that the creation of circulation and mixing to prevent sedimentation in its floor with the help of peristaltic pumps is associated with the function of establishing a reciprocating circulation. The plug bioreactor

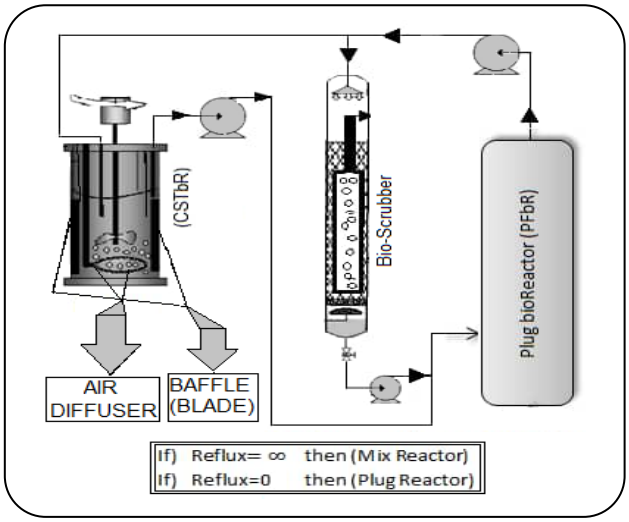

Fig. 1: Schematic of CSTbR and PFbR bioreactors and how to establish reverse flow and reflux effect

has 2 outlet and 3 inlet flow streamline paths Fig. 3.

The inlet currents include:

(1) Residual drained from the bottom of the bio-scrubber tower,

(2)The regenerated biological fluid entering from the CSTbR

(3)Semi-polluted air

The output currents include:

(1)Outlet air to the analyzer and the atmosphere,

(2)Biological fluid transferred to the agitator bioreactor for continuous regeneration.

Bio-scrubber

The PBS tower has a demister condition above and an inlet gas Spurger below, with uneven flow entering the tower, which are distributed Fig. 2 [31]. It was used as a single step and spray stream. A small particle called packing was used to increase the contact surface between the two phases and to increase the residence time of the incoming polluted air. The packing is made of Lava rock mineral pumice by spraying a strain solution of sludge on its surfaces over time with the formation of a thin biofilm on the packing's facilitates the process of contaminant removal.

Packing size

In general, the largest size of packing that is suitable for the size of column should be used; up to 50 mm. Small sizes are appreciably more expensive than the larger sizes. Above 50 mm the lower cost per cubic meter does not normally compensate for the lower mass transfer efficiency. Use of too large a size in a small column can cause poor liquid distribution. Recommended size ranges are [32]:

Table 3: Column diameter and packing size relation

Column diameter	Use packing size
<0.3 m (1 ft.)	<25 mm (1 in.)
0.3 to 0.9 m (1 to 3 ft.)	25 to 38 mm (1 to 1.5 in.)
>0.9 m	50 to 75 mm (2 to 3 in.)

Installing packing

Lava rock packing is normally dumped into the column "wet", to ensure a truly random distribution and prevent damage to the packing. The column is partially filled with water and the packing dumped into the water. A height of water must be kept above the packing at all times. If the columns must be packed dry, for instance to avoid contamination of process fluids with water, the packing can be lowered into the column in buckets or other containers. Lava rock packing should not be dropped from a height of more than half a meter.

The PBS tower is made of Plexiglas with (height of 75 cm and a diameter of 12.5 cm with 3 taps) and a diffuser shower Fig. 2. The first valve is for the sludge to come out of the floor, the second valve is connected to a Spurger to enter and distribute the BTX contaminated air from the bottom up and the third valve is at the top to exit the purified air to the plug bioreactor. The diffuser shower was installed for continuous rainfall and spreading the bacterial solution on the surfaces of the packing's and increasing the contact surface of the contaminated air for mass exchange between the two phases (air with microbial solution) Fig. 2. A vertical mesh grille module coated with polyurethane foam (MPF) was used inside the bio-scrubber tower, which increased the contact surface by increasing the retention time of the contaminant flow inside the bio-scrubber from the outlet of the polyurethane foam module at the top of the bio-scrubber to the regenerated liquid inside the plug bioreactor while creating a bubble. The air passing through the module, after passing the liquid inside the plug bioreactor, enters the GC chromatography analyzer gas on the one hand through another path (two-way) and on the other hand to measure the CO_2 produced. The best inert additive in the bacterial medium to increase the viscosity of the silicone oil with specifications (grade 3, viscosity 350 ppm and heat resistance 50°C to 350°C), 10% by volume of solution in CSTbR bioreactor.

Height of column based on conditions in the gas film

If G_m = moles of inert gas/(unit time) (unit cross-section of the tower), L_m = moles of solute-free liquor/(unit time) (unit cross-section of the tower), Y = moles of solute gas **A**/mole of inert gas **B** in gas phase, and X = moles of solute **A**/mole of inert solvent in liquid phase, and at any plane at which the molar ratios of the diffusing material in the gas and liquid phases are Y and X, then over a small height dZ, the moles of gas leaving the gas phase will equal the moles taken up by the liquid.

$$\text{Thus:} \qquad AG_m dY = AL_m dX \tag{1}$$

$$\text{But:} \quad G_m A dY = N_A(a\ dV) = k_G a(P_{Ai} - P_{AG})A\ dZ \tag{2}$$

It may be noted that, in a gas absorption process, gas and liquid concentrations will decrease in the upwards direction and both dX and dY will be negative.

$$\text{Since:} \qquad P_{AG} = P \tag{3}$$

$$G_m dY = K_G aP\left[\frac{Y_i}{1+Y_i} - \frac{Y}{1+Y}\right]dZ \tag{4}$$

$$G_m dY = K_G aP\left[\frac{Y_i - Y}{(1+Y)(1+Y_i)}\right]dZ \tag{5}$$

Hence the height of column Z required to achieve a change in Y from Y_1 at the bottom to Y_2 at the top of the column is given by:

$$\int_0^z dZ = Z = \frac{G_m}{K_G aP}\int_{Y1}^{Y2}\frac{(1+Y)(1+Y_i)}{Y_i - Y}dY \tag{6}$$

Which for dilute mixtures may be written as:

$$Z = \frac{G_m}{K_G aP}\int_{Y1}^{Y2}\frac{dY}{Y_i - Y} \tag{7}$$

In this analysis it has been assumed that K_G is a constant throughout the column, and provided the concentration changes are not too large this will be reasonably true [32].

The process of designed system

First, in order to start the CSTbR agitator bioreactor, 3.3 L of nutrient liquid culture medium was loaded for the growth of microorganisms on the sample of refinery

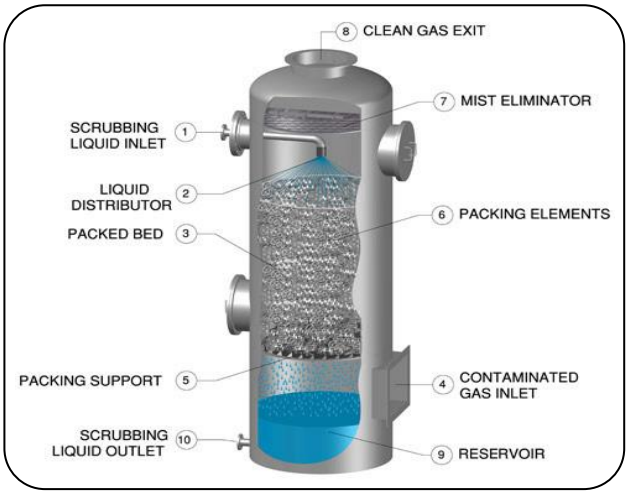

Fig. 2: Modify PBS as counter-current flow.

effluent sludge with a stirrer at 140 rpm. The liquid BTX mixture was then injected with a 60 ml gavage syringe into a syringe pump (ASCOR Germany) with a maximum flow rate of 200 ml/hr and a capacity of up to 100 ml/72hr in the inlet air flow path to PBS from bottom to top. The air flow of the compressor was adjusted to 2.5 & 3.5 L/min, depending on the type of treatment, and the reciprocating and reflux flow peristaltic pumps were serviced at 65 rpm, and the flow rate was controlled by the minimum flow Fig. 3. The glass tank of the agitator bioreactor was charged to the initial designed volume of 3 L and controlling the thermal jacket conditions with 3.3 L of cultured sludge supernatant solution to increase the viscosity of the strain of our ASES sample, silicone oil was added to it by 10% by volume of the liquid inside the bioreactor. While continuously mixing the strain and additives into the bioreactor, carbon dioxide gas was injected into the liquid from the Spurger area of the bioreactor to help the autotrophic bacteria in the sludge grow and multiply and get accustomed. It should be noted that to prevent inactivation of other non-autotrophic microorganisms, the amount of carbon dioxide injected during continuous mixing should not exceed 1 ml/min line-up. Given that our goal was to further strengthen the autotrophic system, reducing the activity of heterotrophic bacteria was not important to us and the results are based on the same set-up mentioned. The processor used in the whole process has the ability to draw growth charts of the growth and recovery process while removing contaminants and also equipped with special alarm point and trip points, used in sudden decrease and increase of liquid level and temperature and critical pressure inside

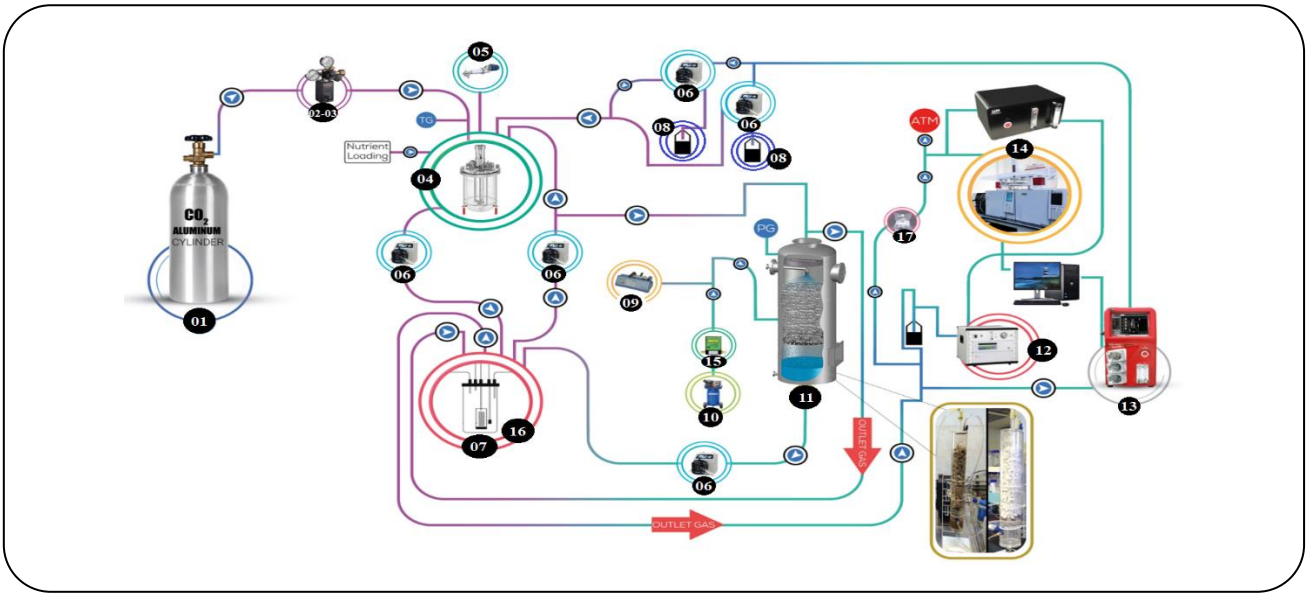

Fig. 3: Process flow diagram in the designed system and BTX removal steps. The various parts of the above diagram include: (1) Co2 Cylinder, (2,3) Preheated manometer, (4) Endothermic mix bioreactor CSTbR, (5) Agitator, (6) Peristaltic pump's, (7,16) Exothermal airlift bioreactor PFBR with Nano filter, (8) pH controller, (9) Syringe pump, (10) Air compressor, (11) Packed tower bio scrubber with modulated polyurethane, (12) Co2 analyzer, (13) Fermenter, (14) GC analyzer, (15) Mass flow-meter, (17) Tedlar bag.

the equipment connected to The fermenter is for controlling temperature, surface, pH and pressure. While charging Lava rock porous fillers irregularly inside the PBS and turning on the transfer pump, it entered the circulating phase of the solution from the stirred bioreactor to the plug bioreactor and after rolling by the circulating pump The second solution containing the bacterial sample was continuously reduced and enriched in the top of the tower, line-up and demister while regenerating and enriching. While distributing the solution in all parts of the tower continuously and increasing the level of solution in the liquids collected in the bottom of the tower, the end path of the bottom of the tower became drained towards the second bioreactor by increasing the liquid level too much. The minimum flow path of the second pump is for supplying and controlling the feed of the microorganism solution loop and also for continuous reduction of the rich bacterial solution from a plug reactor from agitator bioreactor to produce a lean bacterial solution in it, while controlling the temperature conditions of using the produced heat of whole process for reducing the heat of solution. The agitator bioreactor reservoir was moved and the process was rotated to maintain steady state conditions. Then, the semi-treated exhaust air for wet treatment and removal of more aromatic contaminants and also passing through the micro-filtration installed inside the air outlet path from the top of the tower entered the plug bioreactor and after contacting again with the Lean bacterial strain to analyze the composition. The percentage of possible BTX components remaining in the air was sampled by the Tedlar pack from the outlet of the plug bioreactor and analyzed and the results were discussed while calibrating the GC gas chromatography apparatus Fig. 3.

Calculation method

To calculate the removal efficiency (%RE) and elimination capacity (EC) of the PBS, formula shown below are used, where C_{in} and C_{out} are input and output VOC's pollutant concentration of air treated, respectively; V is its volume, and the measured data are related to BTX removal in (Tables 3 to 4…) stated respectively [9].

$$\%RE = \frac{C_{in-}C_{out}}{C_{in}} \times 100 \quad (1)$$

$$EC = \frac{C_{in-}C_{out}}{V} \times 100 \quad (2)$$

Sludge Age means a length of time that a pound of solid is maintained under aeration in system [33].

$$\text{Sludge Age (day's)} = \frac{\text{Mixed liquor suspended solids in aerator (lbs)}}{\text{Suspended solids in primary Effluent (lbs/day)}} \quad (3)$$

This calculation is used in a way similar to the Sludge Density Index (SDI) to indicate the settle ability of sludge in a secondary clarifier or effluent. The weight in grams of one milliliter of sludge after settling for 30 minutes [34, 35].

$$\mathrm{SDI} = \frac{100}{\mathrm{SVI}} \quad (4)$$

A calculation that indicates the tendency of activated sludge solids (aerated solids) to thicken or to become concentrated during the sedimentation/thickening process. Sludge Volume Index (SVI) is calculated in the following manner:

1. Allow a mixed liquor sample from the aeration basin to settle for 30 minutes; 2. Determine the suspended solids concentration for a sample of the same mixed liquor; 3. calculate SVI by dividing the measured (or observed) wet volume (mLl/L) of the settled sludge by the dry weight concentration of Mixed Liquor Suspended Solids (MLSS) in grams/L, (MLSS is the amount (mg/L) of suspended solids in the mixed liquor of an aeration tank and Mixed Liquor Volatile Suspended Solids (MLVSS) is the amount (mg/L) of organic or volatile suspended solids in the mixed liquor of an aeration tank. This volatile portion is used as a measure or indication of the microorganisms present) [34, 35].

$$\mathrm{SVI}\left(\frac{\mathrm{mL}}{\mathrm{gm}}\right) = \frac{\text{Settled Sludge Volume/Sample Volume(mL/L)}}{\text{Suspended solids concentration (mg/L)}} \quad (5)$$

RESULTS & DISCUSSION

Results of BTX removal in incoming airflow mode with flow rate (2.5 & 3.5 L/min)

BTX removal at Empty Bed Retention Time (EBRT) low flow in (low, medium and high) concentrations each separately is shown in (Table 3 & 4).

BTX removal at EBRT of flow rate 2.5 L/min

BTX removals at EBRT of low flow rate (2.5 L/min) are tabulated in Table 3. Looking through, the removal efficiency at EBRT of benzene, toluene and xylene at low concentration are 90.7, 88 and 83.6%, respectively by activated sludge. In addition, at low BTX concentration the highest elimination capacity of benzene, toluene and xylene were 9.8, 17.3 and 14.9 g/m³.hr, in turn. Therefore, the best removal efficiencies at EBRT and elimination capacity were related to benzene and toluene in low concentration of BTX. In addition to the ability of the microorganism, the attractiveness in the removal of toluene, the selectivity of the solution containing the sludge sample to decompose contaminants in the fastest possible time to the specific prioritization of the microorganism in dealing with a mixture of contaminants and their adaptive behavior must have contributed. This percentage of elimination capacity in a 15-day period for benzene compared to toluene (highest removal efficiency percentage), probably is related to the ability of microorganisms and attractiveness of overtaking to remove benzene over xylene. The removal process of all three compounds shows that due to the time required MRDT for the bacteria to multiply and adapt to the environment, the removal rate was negligible in the first week. As the number of nutrient bacteria in the PBS increases, the amount of removal rises as well. The elimination rate of compounds began to grow dramatically in the second week, and in some cases an increase in removal growth was seen in the third week after compromise. The highest removal rates of benzene, toluene and xylene reached a peak on days 20, 15 and 15 in low BTX concentration, respectively. At medium BTX concentration, the removal efficiencies of benzene, toluene and xylene were 78.8, 73.1 and 75%, respectively. The maximum removal capacity of benzene, toluene and xylene to the order was 21.1, 43.6 and 29.6 g/m³.h.

BTX removal at EBRT of flow rate 3.5 L/min

BTX removal at EBRT of high flow rate (3.5 L/min) is shown in Table 4. As regards, in low concentration of BTX the best removal efficiency at EBRT of benzene, toluene and xylene were 80.5, 67.6 and 68.2%, and elimination capacity achieved 8.8, 13.3 and 12.2 g/m³.hr in turn, at input concentrations 181.8, 328.3 and 297.7 mg/m³, respectively. Therefore, the best removal efficiency at EBRT and elimination capacity belonged to benzene and toluene, respectively. According to the removal trend of all three compounds, the removal rate was very small in the first week, the same as for the other flow rate (2.5 L/min). The removal rate began to improve in the second week, and in some cases an upward trend in the removal growth was seen in the third week. The highest removal rates of benzene, toluene and xylene were obtained on days 25, 25 and 15, respectively. The ratio of the thickness of the film layers formed on the packing increases RDT

Table 3: PBS Performance in Airflow 2.5 L/min with 10% Silicon Oil & Low/Medium/High Concentration of Inlet BTX.

				Time (Day)						
Compound	Parameter	Flow rate	L/M/H- Inlet Concentration (mg/m³)	1	5	10	15	20	25	30
Benzene	Outlet concentration (mg/m³)	Low	180.7±0.3	178.4	102.6	66	40.1	17	16.8	18.8
		Medium	446.1±0.3	442.6	278.4	212.3	134.3	101.3	94.6	113.8
		High	870.6±0.3	868	632.9	585	514.5	484.1	516.3	511
	Removal Efficiency (%RE)	Low	180.7±0.3	1.3	43.2	63.5	77.8	90.6	90.7	89.6
		Medium	446.1±0.3	0.8	37.6	52.4	69.9	77.3	78.8	74.5
		High	870.6±0.3	0.3	27.3	32.8	40.9	44.4	40.7	41.3
	Elimination Capacity EC (g/m³.hr)	Low	180.7±0.3	0.1	4.7	6.9	8.4	9.8	9.8	9.7
		Medium	446.1±0.3	0.2	10.1	14	18.7	20.7	21.1	19.9
		High	870.6±0.3	0.2	14.3	17.1	21.4	23.2	21.3	21.6
Toluene	Outlet concentration (mg/m³)	Low	327.4±0.2	325.1	210.5	116.6	39.3	46.2	43.5	41.6
		Medium	994.6±0.2	987.7	670.4	413.8	267.5	286.4	292.4	294.4
		High	1947.1±0.2	1943.3	1534.3	1407.8	1347.4	1275.4	1287	1283.1
	Removal Efficiency (%RE)	Low	327.4±0.2	0.7	35.7	64.4	88	85.9	86.7	87.3
		Medium	994.6±0.2	0.7	32.6	58.4	73.1	71.2	70.6	70.4
		High	1947.1±0.2	0.2	21.2	27.7	30.8	34.5	33.9	34.1
	Elimination Capacity EC (g/m³.hr)	Low	327.4±0.2	0.1	7	12.7	17.3	16.9	17	17.1
		Medium	994.6±0.2	0.4	19.5	34.9	43.6	42.5	42.1	42
		High	1947.1±0.2	0.2	24.8	32.4	36	40.3	39.6	39.8
Xylene	Outlet concentration (mg/m³)	Low	297.5±0.4	294.9	180	73.2	49.7	55.9	48.8	53
		Medium	658.3±0.4	655.5	402.9	248.8	187	164.6	169.8	179.7
		High	1410.3±0.4	1407.5	1060.5	906.8	840.5	758.7	740.4	747.5
	Removal Efficiency (%RE)	Low	297.5±0.4	0.9	39.5	75.4	83.3	81.2	83.6	82.2
		Medium	658.3±0.4	0.4	38.8	62.2	71.6	75	74.2	72.7
		High	1410.3±0.4	0.2	24.8	35.7	40.4	46.2	47.5	47
	Elimination Capacity EC (g/m³.hr)	Low	297.5±0.4	0.2	7.1	13.5	14.9	14.5	14.9	14.7
		Medium	658.3±0.4	0.2	15.3	24.6	28.3	29.6	29.3	28.7
		High	1410.3±0.4	0.2	21	30.2	34.2	39.1	40.2	39.8

Table 4: PBS Performance in Airflow 3.5 L/min with 10% Silicon Oil & Low/Medium/High Concentration of Inlet BTX.

				Time (Day)						
Compound	Parameter	Flow rate	L/M/H- Inlet Concentration (mg/m³)	1	5	10	15	20	25	30
Benzene	Outlet concentration (mg/m³)	Low	181.8±0.2	181.6	133.1	85.8	65.4	38.5	35.5	36.7
		Medium	450.6±0.2	447.1	311.4	266.8	210.4	200.1	219.9	215.8
		High	881.8±0.2	873.1	711.6	654.3	624.3	585.5	581.1	580.2
	Removal Efficiency (%RE)	Low	181.8±0.2	1.5	26.8	52.8	64	78.8	80.5	79.8
		Medium	450.6±0.2	0.8	30.9	40.8	53.3	55.6	51.2	52.1
		High	881.8±0.2	0.1	19.3	25.8	29.2	33.6	34.1	34.2
	Elimination Capacity EC (g/m³.hr)	Low	181.8±0.2	0	2.9	5.8	7	8.6	8.8	8.7
		Medium	450.6±0.2	-0.1	8.1	10.8	14.1	14.8	13.6	13.8
		High	881.8±0.2	0.5	10.2	13.7	15.4	17.8	18	18.1
Toluene	Outlet concentration (mg/m³)	Low	328.3±0.3	326.4	226.9	165.1	114.2	111.3	106.4	109
		Medium	995.8±0.3	990.9	780.7	6553.2	745.7	538.7	246.7	546.7
		High	1950.5±0.3	1950.5	1607.2	1476.5	1390.7	1359.5	1355.6	1369.3
	Removal Efficiency (%RE)	Low	328.3±0.3	0.6	30.9	49.7	65.2	66.1	67.6	66.8
		Medium	995.8±0.3	0.5	21.6	34.4	45.2	45.9	45.1	45.1
		High	1950.5±0.3	0	17.6	24.3	28.7	30.3	30.5	29.8
	Elimination Capacity EC (g/m³.hr)	Low	328.3±0.3	0.1	6	9.7	12.8	13	13.3	13.1
		Medium	995.8±0.3	0.2	12.8	20.5	26.9	27.4	26.9	26.9
		High	1950.5±0.3	0	20.6	28.4	33.6	35.5	35.7	34.9
	Outlet concentration (mg/m³)	Low	297.7±0.4	296	186.4	142.6	94.7	107.5	111.3	110.1
		Medium	660.5±0.4	659.2	506.6	293.9	253.6	258.9	250.3	258.3
		High	1411.1±0.4	1411.1	1135.9	1028.7	965.2	939.8	979.3	953.9
	Removal Efficiency (%RE)	Low	297.7±0.4	0.6	37.4	52.1	68.2	63.9	62.6	63
Xylene		Medium	660.5±0.4	0.2	23.3	55.5	61.6	60.8	62.1	60.9
		High	1411.1±0.4	0	19.5	27.1	31.6	33.4	30.6	32.4
	Elimination Capacity EC (g/m³.hr)	Low	297.7±0.4	0.1	6.7	9.3	12.2	11.4	11.2	11.2
		Medium	660.5±0.4	-0.1	9.1	21.9	24.3	24	24.5	24
		High	1411.1±0.4	0	16.5	22.9	26.8	28.3	25.9	27.4

increases RDT over the time (visually observation), which may indicate that the acclimatization of the sludge microorganisms was directly related to the thickening of the thin film and percentage of biodegradation. The procedure is another disadvantage in increasing efficiency compared to the low inlet airflow mode. Also, at the minimum input concentration up to 180.7 mg/m^3, the removal efficiency and removal capacity and the percentage of carbon mineralization of the produced biomass increase, but after this concentration, after 25 days, all four parameters have decreased, which means bacterial poisoning and too much BTX is input to the bio-scrubber. In fact, with the entry of pollutants into the air and the pressure of the tower, the pollutants penetrate into the pores of a thick film of microorganisms, trapping and including in biodegradation. As regards, in treatments of medium BTX concentration, best results in output air, for benzene, 55.6% removal efficiency and 14.8 g/m^3.h elimination capacity achieved. About toluene, 62.1% removal efficiency 27.4 g/m^3.hr elimination capacity, and in case of xylene, 45.9% removal efficiency and 24.5 g/m^3.h elimination capacity were reported. The highest removal rates were obtained on day 20 for all compounds. At high concentration of BTX, less efficiency but higher elimination capacity for all compounds was achieved compared with two other concentrations in 3.5 L/min flow rate. Therefore, the best removal efficiency and elimination capacity were related to benzene and toluene, respectively. The removal process of all three compounds shows that the removal rate was very marginal in the first week, mainly due to the time required for bacteria replication and adapt to the environment. The removal rate of compounds saw a noticeable increase in the second week, not surprisingly a similar trend was seen over the third week. The highest removal rates of benzene, toluene and xylene have been noticed on days 30, 25 and 30, respectively. One of the important parameters in the removal of air pollutants is flow rate of polluted air in removing systems. The amount of flow rate in the system determines the reaction time and contact between water particles and molecules of contaminants and sludge's bacteria in biological removal processes is the lower amount of polluted air flow with the higher removal rate [36]. The reason for the quantitative differences in results of flow rate 2.5 and 3.5 L/min is related to the difference in the amount of inlet compounds, which are certainly due to the higher inlet compounds in the flow rate of 3.5 L/min in summarizing the results of this section, it should be noted that with increasing the concentration of input compounds, the removal efficiency in all three compounds decreases, but the elimination capacity increases. This is exactly the same results that were obtained in EBRT of flow rate (2.5 L/min).

In the work reported by *Torkaman et al.*, template free MFI type zeolite membranes were prepared by seeded growth method in order to minimize defects and inter-crystalline gaps that form during the calcinations step required for template BTX removal. The effect of seed size on the morphology and quality of MFI membranes were also investigated. The concentrations of benzene, Toluene, and xylene were reduced to 70ppm, 81ppm and 93 ppm respectively. The overall selectivity of MFI membrane is as following; benzene > toluene > xylene. Further purification of the wastewater stream is possible but it needs a much longer time of the process due to the negligible driving force over this concentration range [16]. These values, despite the use of zeolite membranes to remove BTX and inlet & outlet concentrations, provided small target efficiency values compared to our research which are one order of magnitude lower than our results in Table 3, However, they were able to point out that the use of zeolite membranes, like the use of sludge effluent samples in the BTX removal has selectivity property in different inlet concentration.

One of the most important equipment used in chemical production process is reactor. In the past, mixed reactors were commonly used in disruptive processes, but there were factors such as manufacturing problems, high energy costs and water cooling. Also, high shear stress limited the use of mechanical agitation reactors. In addition, due to the fact that in the industry, increasing production capacity on one hand and reducing costs on the other hand are considered, so high volume reactors are needed, so with the evolution of reactors, newer models such as bubble column reactors, airlift reactors with flow loops internal (IALR) or external (EALR) replaced the basic models [37, 38] Airlifts, like bubble columns, are reactors in which mixing takes place due to the movement of air bubbles in the liquid which helps the mixing operation more. Airlift reactors are modified bubble columns and have been widely used in recent decades in biotechnological processes, including aerobic fermentation to produce

a variety of food products, wastewater treatment, and other similar operations. These types of reactors are suitable for processes in which uniform and rapid distribution of reactive components is necessary, as well as for multiphase systems (liquid-gas-solid) that require high mass and heat transfer [39,40]. *Merchuk et al*. showed that the production of a model bacterium with 41% wt growth in an airlift bio-reactor was more than the mix bio-reactor. This increase of growth in the airlift bio-reactor compared to the mix bio-reactor was with a 50% reduction in input energy, so biomass production in the airlift reactor has been achieved with up to 50% cost reduction [41]. In various researches in the field of hydrodynamics of airlift bioreactors, it has been concluded that with increasing gas volume velocity, there are gas retention and mass transfer coefficient increase [6, 42, 43]. *Bakhtiari et al.* studied the hydrodynamics and mass transfers in an external ring-shaped airlift reactor in both beds and no bed conditions. The results showed that the gas volumetric velocity increased in both cases. With and without a gas storage bed, the rotation speed of the liquid and the overall mass transfer coefficient increase However, the increase in fluid velocity is greater in the bed-less state, while the filled bed reactor has higher gas retention than in the bed-less state [46]. *Siqueira et al*. examined the biological properties of activated sludge in radiant airlift bio-reactors and stated that the viscosity of activated sludge plays an important role in oxygen and mass transfer as viscosity increased exponentially with increasing shade of activated sludge and decreased exponentially with increasing shear rate and temperature compared to conventional reactors [47]. *Otenio et al*. investigated the effect of electrolyte on the mass transfer of airlift reactors through the inner tube and found that as the salt concentration increased, the bubble cohesion decreased and kLa increased [48]. In general, the results of research show that the physical properties of liquid and solid, the characteristics of gas flow, including gas velocity, gas bubble size and also operational variables such as gas flow affect the performance of the airlift bioreactor.

Studies by various scientists on the biological removal of BTX from the air in different bioreactors and the application of dominant microorganisms on the removal process are acceptable and proven. Studies by different researchers show that different microbial strains have different removal power in removing each of the three compounds benzene, xylene and toluene. For example, in some studies, the *p.putida* strain was predominant in bioreactors, and this microbial species is able to degrade xylene. *Ralstonia pickettii* is also used in studies to remove benzene contaminants, but its role is not as prominent as *p.putida*. All of which indicate that each microbial strain has a greater effect on the removal of one of the contaminants [49-51]. To increase the removal efficiency and also the availability of different microbial strains with high removal power, in this study, enriched sludge was used instead of isolated strains. Bubble column and airlift bioreactors are reactors in which the mixing operation is done by the movement of air bubbles in the liquid, and the rotational movement of the return flow of the liquid inside the reactor helps the mixing operation. The most important advantages of airlift are low and gentle shear stress, low operating cost, good mass transfer, no contamination of the culture medium and so on [31]. In some research on the removal of BTX from the air, a double-tube airlift bioreactor was used to mix the liquid inside the bioreactor, which causes vortexing in the walls of the two tubes, but this research used this type of agitator bioreactor with baffle blades to prevent vortexing and dead spots, which also has the advantage of reducing tension in the walls and preventing energy wastage and preventing gas entrapment, as well as reducing costs [4, 31, 45, 50]. The PBS, according to previous researchers, has been shown to be very efficient for biological BTX removal when compared with individual bioreactors. In this research, adding a plug bioreactor with a reflux flow during mixing provides a stream cooling and a regenerative sludge source to control the reaction conditions inside the cycle. This controls the increased heating, overheating and much continuous refluxing flow which can damage some of the main strains of the bacterium in the sludge sample. Only the airlift bioreactor was used to contact the gas stream. Of course, the MRTD was only generally achieved but there was no increase in efficiency and the creation of bubbles in their different diameters caused the amount of gas inside the bubble to be trapped and no additional contact was made in the amount of gas inside the bubble. To initially remove and reduce the concentration of pollutants in the air, it was first passed through PBS. The bioreactor was airlifted so that even with the bubble at least a small concentration of the contaminant remained to be removed. The predominant microorganisms

in bioreactors used to treat Volatile Organic Compounds (VOCs) are heterotrophs and are mainly fungi or bacteria [52]. They are also strong removers. Carbon dioxide was used to stimulate the growth of possible autotrophic microorganisms present in the sludge. Activated sludge from the secondary purifier of municipal wastewater treatment plant (Nesapakam, Tamil Nadu, and India) was used to prepare seeds for sowing. B, T and X were used as the only mixed carbon source. Prior to the continuation of the batch analysis experiments, this process was consistently adapted to benzene, toluene, and xylene for 3 weeks through a series of repetitive transitions. For continuous testing, municipal wastewater was precipitated for 4 hours and then the excess liquid was discarded to obtain thick sludge [29]. Biological treatment of BTX-contaminated air using enrichment of the sludge sample and the microorganisms in them has been considered by many researchers [31]. Reminiscences of BTEX removal were examined by a type of fungus [53, 54]. In a study, *pseudomonas putida* was used to decompose toluene, which was equivalent to 67% removal of toluene and only a small amount of 1.5% silicone oil [55]. This study also used silicon oil to increase the shelf life of microbial strains. Silicone oil increases the viscosity of the stimulus fluid in the cycle and also reduces the speed of movement and frustration on the packing's and the wall of the tower, so the use of silicone oil was very important. The study used 30% silicon oil to biodegrade xylene and butyl acetate in a two-phase system, which left too much air in the environment, reduced bacterial efficiency, and required more carbon sources [4] In the study, as a two-phase bioreactor of the agitator type was used. It was observed that better conditions were provided for this type of bacterium and it showed better efficiency in removing toluene from the air stream and the organic phase used a two-phase bioreactor that loads Pollution equivalent to 748 g/m^3h with 98% efficiency [18]. In this study, in addition to using a two-phase agitator bioreactor, it was removed from a continuous bio-scrubber with a second bioreactor to increase retention time, increase efficiency, and an increase in the amount of biomass produced was used. The results of the present study show that despite the presence of 3 contaminants, the rate of toluene removal in the best treatment was 88%. In the research conducted, a hybrid bioreactor was used on a laboratory scale and consisted of two regions. One area to stop the bacteria and other containing substances classified for bacterial growth. Xylene was decomposed in a bioreactor containing a 100 cm vertical Plexiglas column in it, column was 30 cm high area include suspended bacteria with 70 cm area that filled by 1 cm^3 packing so with these structure provides a substrate static porous for bacterial growth. In the present study, to provide better conditions for growth and biofilm formation by bacteria, the introduction of carbon dioxide to stimulate growth and a new porous agent called mineral pumice was used [31, 44]. Bacteria can adhere to surfaces by producing different bio surfactants or by means of adhesion and adsorption mechanisms, and therefore cause the decomposition or removal of hydrocarbons from soil and air [56] and therefore the use of mineral pumice increases the surface-to-volume ratio and provides the space needed for microorganisms to bind and adhere. Lava rock mineral pumice package was used due to its high adsorbent, porous surface, many pores, and the ability of bacteria to form biofilms on its surfaces, and the cost of cleaning, maintenance, and low purchase. It has not been reported so far and the present study is the first report of their use as a packing. [4]. Certainly, the MRTD in general path was increases the ability of phases contact and mass transfer between two phases (polluted air and ASES sample), so this can be considered as the presence of constantly porous packing that there was in the path of bacterial flow while microorganism became constant on porosity media as film layer before start up and start of removal process. While remaining, it causes a film with different thicknesses on the fillers and the environment inside the bio-scrubber is completely applied to the diffusion phenomenon, and also dead spots or channeling is not formed for the ineffective movement of the incoming gas flow. The pure yeast strain *Candida tropicalis* was immobilized on a powder matrix of powdered activated carbon, sodium alginate and polyethylene glycol (PSP granules). Immobilized grains were used as a liquid material in a biological reactor to remove toluene from the gas stream. The toluene loads applied in stage 1 and stage 2 were 15.4 and 29.8 g/m^3, respectively, and the removal of toluene during the whole operation was higher than 89% [18]. Various studies on the removal of benzene, toluene and xylene are listed in (Table 5).

This table shows comparison and the type of Contamination, the flow rate, used the type of microbial source, the method used, the running time of the system for removal and the volume tested.

Comparison of the researches shows the use of sludge samples along with the use of optimal process flow paths while controlling heating and scorching and also selecting the type of equipment.

These include Bio-scrubber filled with a special and distinctive type of Lava rock packing, bioreactor continuous mixer with bioreactor non-stirred airlift, the movement of air bubbles through the liquid, which is used as a plug and airlift bioreactor for air passes through inside it, so plays the role of adsorption operation. Comparing the maximum inlet airflow into the bio-scrubber (2.5 L/min) and the highest inlet concentration to the maximum removal front of and lowest pollutants concentration in the outlet, all of these became compared with other rather similar tasks (Table 5). The biodegradation removal efficiencies obtained in the present study were a bit similar to or better than the results reported by *Tzintzun et al.* (2014) using a microbial consortium and hexadecane as a source of carbon, reaching BTX removal efficiency of 69% [61].

In general, microorganisms present in bio-filter medium absorb the biodegradable pollutants and convert it into carbon dioxide, water, and salts [57]. The reliability of biofiltration for the treatment of VOCs has been proven as it is more suitable to treat low concentration (even < 1000ppm) and the high volume of VOCs. It is also a cost-effective technology to remove toxic air pollutants because of the low temperature oxidation of the system that eliminates the high costs associated with the combustion and of very less moving parts cut-off its maintenance cost [57]. The metabolic mechanism of the organism, present in the system, failing to synthesize would influence energy production in cells by uncoupling electron transport from oxidative phosphorylation. Hence it is expected to uptake more substrate (biodegradable contaminants) to survive because of its maintenance energy demand. Under steady state conditions, it was reported that traditional bio-filters showed 91%, 90%, 84%, and 34% of removal efficiency for xylene, benzene, ethyl benzene and toluene respectively. Therefore, in accordance with all other pollutants of BTEX, concentration of toluene in the polluted region is immense and the same was not treated potentially by traditional bio-filtration method**.** Hence toluene is chosen as a model pollutant for the current study [57]. In this process, while completing the new stages of the removal process and presenting practical suggestions, a new and more efficient solution was created for industrial designers to control and design software, input paths, flow rate, concentration and removal control, as well as material restoration. Present study offers the bio-scrubber while integrating with parallel airlift bioreactors and optimizing the bio-scrubber with packing and bioreactor type have a great effect on their efficiency and should be considered for the design of these types of systems. In addition, the effect of carbon dioxide injection seems to have had a good effect on removal efficiency and needs to investigate more closely in another research in this basin. This process, as well as the addition of the organic phase (10% silicone oil) and use of polyurethane foam module and control to regenerate and absorb the thermal process of the process itself, is a process to increase the residence of benzene-contaminated air in the removal path. Therefore, has been able to increase the removal efficiency at a higher level than the treatment of environmental polluted air.

Medina-Moreno et al. (2014) demonstrated that BTX biodegradation is not possible to overcome levels of removal higher than 75% (assuming a total removal of aliphatic and aromatics) [60]. But in our work, we showed that if use the PBS with specified BTX concentration like (low/medium/high) then degradation by ASES in the best MRTD across the APB's, so we can claim that it is possible and available to overcome levels of removal higher than 75%.

An available explanation for the differences observed could be found in the work of *Maroto-Arroyo et al.* (2002); indicated that the transformation rate of VOC's is influenced by various factors, such as: temperature, nutrient sort, pH, and sludge sample chemical structure [62].

In addition, according to the other studies, high pollutant density is the most important factor limiting the efficiency of bio-scrubber, because at higher concentrations the input tends to the specified failure values and the microbial substrate becomes toxic, which can be removed in high industrial concentrations. It raised the bio-scrubber tower and also added volume to the bioreactor. In (Table 5) as the background of researches conducted in the field of aromatic biological removal under different operating conditions and designed processes and the number of consumables and other parameters, the present study PBS-APB's method compares favorably. In addition, this study's results compare well in the highest amount of polluted air flow

Table 5: Some BTX biodegradation researches.

Pollution	BTX	T	BTX	B	TX	BTX	BTX	BTEX	X	BTX	Microorganism
Flow Rate (L/min)	0.5	0.02	0.0012	-	0.5	1.5	1	0.2	1	2.5 & 3.5	Activated Sludge effluent sewer ASES
System type	zeolite membrane/Alfa alumina substrate	*Pseudomonas putida MTCC 10617-metabolic uncouples involves uncoupling electron transport from oxidative phosphorylation reactions*	*Achromobacter* and *Burkholderia*	-	compost and perlite 5% phenylmethyl silcone	-	*Pseudomonas putida*	*Bacillus sphaericus*	*Ralstonia* & *Pseudomonas putida* ، Chryseobacterium	PBS /APBs	PBS /APBs
Time	morphology	Bio-filter reactor	Bio-trickling filters	Trickle bed air bio-filter	Bio-filtration	Nano-filter FE & CU	Bio-trickling filter	Bio-filter bioreactor	Two phases mix bioreactor	15- to 25 day	15- to 25 day
PH	48-96 hr.	28 day	300 hr.	100 day	18 day	20 min.	10 day	72 hr.	432 hr.	6-7	6-7
Working Volume (lit)	-	7	-	4	7	-	7	6-8	7	3.3	3.3
Working Temp. (°C)	-	0.02	4	2.7	9.8.10-4	2	1	0.5	1.77	28-30	28-30
Biomass Generation (mg/L)	30-70	40	30	-	22	40	-	25-30	25±2	28-30	28-30
Removal efficiency (%)	-	non-growth system	-	-	-	-	-	-	11~58	600-5200	600-5200
Concentration limit (mg/m^3)	30-19-7	87	90	90	85	67-39-80	82	90	87.8	90.7	90.7
Inlet Concentration (mg/m^3)	70-100	25 ~ 50	20-450	355-800	500 ±50 of both toluene and xylene (1:1 ratio).	-	[B] & [X]:150 [T]:200	25-500	551~3330	[B]:180.7~881.8 [T]:327.4~1950.5 [X]:297.5~1411.1	[B]:180.7~881.8 [T]:327.4~1950.5 [X]:297.5~1411.1
Outlet Concentration (mg/m^3)	100	255	216580	666	-	-	5900–24400	200	2756	[B]:180.7 [T]:327.4 [X]:297.5	[B]:180.7 [T]:327.4 [X]:297.5
Reference	[B]:70 [T]:81 [X]:93	[37]	[57]	[18]	[56]	[2]	[58]	[50]	[12]	[51]	[B]:16.8 [T]:39.3 [X]:48.8
Present study	26950	[59]	cultural bacteria, and fungi	combined bioreactor	150 day	4-8	24	20-40	-	79.88	4.58-45.39

in higher concentrations than other studies, the highest efficiency of BTX removal by sludge loading in the process of parallel bioreactors to the lowest concentration of exhaust pollutant during the treatment of polluted air. Basically, in ASES, which is a very rich and diverse microbial consortium, there are bacteria that remove various compounds, and when this ASES is placed in conditions with high load of a certain compound, those removing bacteria prevail. And because they use that organic compound as a source of carbon and energy, they remove that compound, and after a while, these bacteria completely dominate the system, and other bacteria that are not able to remove these VOCs due to lack of having a suitable carbon source for their growth are automatically removed from the system. In principle, ASES is used to enrich and isolate bacteria that remove various compounds, and this is a routine matter in biological work and research, and even in industry, the same method is used to treat waste air.

Changes of biomass generation during the experiments

In (Fig. 4) biomass produced (a, b, c) in two air passages 3.5 and 2.5 L/min and three modes of pollutant input concentration are compared with each other. Biodegradation of xylene by mix bioreactor with *Ralstonia & Pseudomonas putida*, *Chryseobacterium*, with just 1 L/min air flow rate so the biomass production at 2756 mg/m^3 as inlet concentration report about 11~58 mg/L then %RE was 87.8% [51]. This compares favorably with our results (air flow rate 2.5 L/min), because the main reason would be the use of sludge sample for the biodegradation of BTX in polluted air. The amount of biomass in the bioreactor increased from 1.8 (g/L) on the first day to 8.6 (g/L) on the 25th day, which shows a direct relationship with the removal of compounds. In fact, the higher biomass is the greater removal rate. The exponential growth of biomass has been from the first day to the 20th day and after entering its growth dormancy phase, the highest removal rate has been recorded since (Table 5) then (Fig. 4 (A.)). The results of biomass amount are correlated positively with the rate of removal of compounds. In fact, as the amount of biomass increases, so does the amount of removal, which makes perfect sense. The logarithmic growth phase of biomass has been from the first day to the 16~20 to 30 day and after entering to its stationary phase in all treatments, which is also consistent with the slight cessation and reduction of the removal of compounds. On the other hand, the rate of removal of compounds was directly related to the formation of biofilm on packing pores. The highest removal rate has been recorded at logarithmic phase of sludge growth curve. So that, the higher the biomass, the greater the removal rate. After a period of about 16 to 30 days in different treatments, the removal of compounds decreases, which for various reasons, including the arrival of microbial sludge in the stationary phase, increase toxic compounds resulting from microorganism bacterial metabolism due to the breakdown of BTX concentration. In general, it shows the removal of BTX by ASES in higher concentrations, which shows the time of bacteria activation period until they reach acclimatization based on biomass production in a constant and uniform amount, and also in concentration. Below this range, the bacteria will become semi-dynamic and weak in the microorganism sample.

CONCLUSIONS

According to the results obtained in this study, the effectiveness of BTX bio-removal ability of refinery sludge species has been increased, so that the integration of agro-organic two-phase bioreactors with PBS is a product of new technology. The best treatment was in flow rate 2.5 L/min and %RE 90.7, 88 and 83.6(%) at inlet pollutant concentrations of 180.7, 327.4 and 297.5 ppmv, for benzene, toluene and xylene, respectively. In these conditions, the possibility of better activity of microorganisms and the opportunity for more elimination provided better results and it can be concluded that in the industry, the issue of gas flow should be given much attention. The results obtained in the %RE show that the use of this amount of injected carbon dioxide has a significant effect. This study proved that APB's have a great effect on their efficiency while integrating with the design dimensions of PBS-MPF. Compared to traditional bioremediation methods, the use of this PBS-MFP with a Lavarock porous bed while moving in stirrer inside the APB's is a newer method exhibiting. This process and the addition of organic phase (10% silicone oil) as well as the use of mineral pumice to increase the surface to volume ratio and create a porous space is a process to increase the Residence Time Distribution (RTD) of air contaminated with BTX in the path of removing pollutants. All of these steps increased the efficiency and showed a more effective

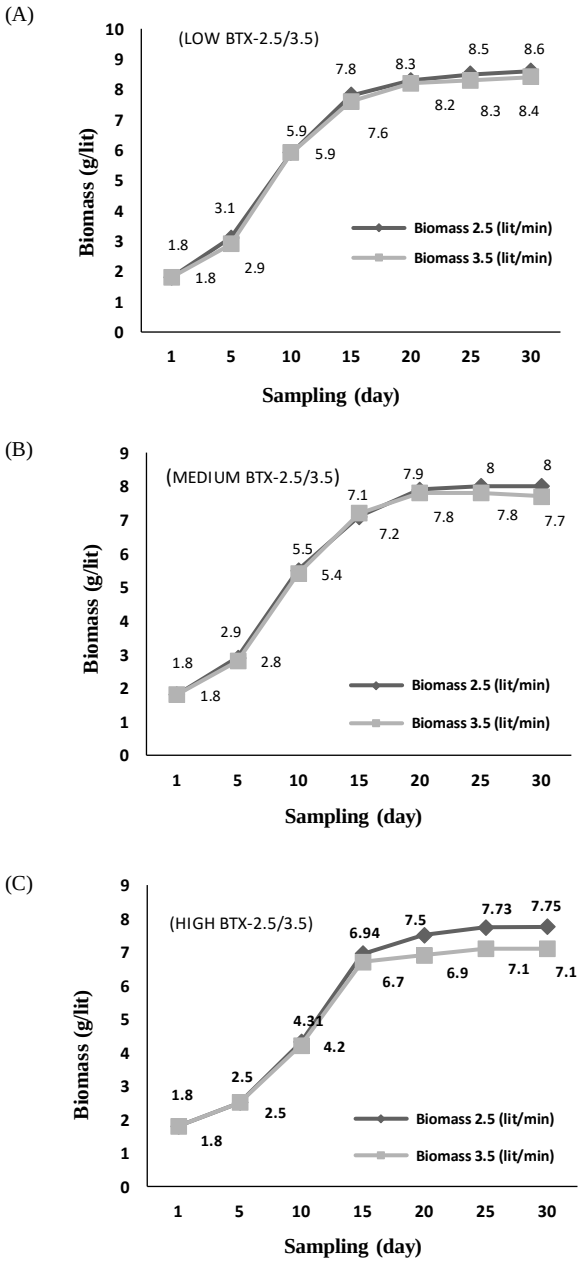

Fig. 4: Efficiency of ASES sample containing microorganisms in the most biomass produced with (minimum, medium, maximum) concentration of BTX inlet compared to 3.5 and 2.5 L/min vents with 10% silicone oil

method in polluted air treatment than the other chemical or biological removal. Finally, according to the studied conditions, high density of pollutants is the most important factor limiting the efficiency of PBS and APB's, because at concentrations higher than the specified failure values, the ASES as microbial substrate is poisoned and also removes a large dependence on the available surface of microorganisms and to increase the EC in terms of inlet air flow, it may be necessary to increase the volume and height of the PBS.

Nomenclature

A	Cross-sectional area of column, m^2
G_m	Molar rate of flow of inert gas per unit cross-section, $kmol/m^2s$
L_m	Molar rate of flow of solute-free liquor per unit cross-section, $kmol/sm^2$
N_A, N_B	Molar rate of absorption of **A**, **B** per unit Area, kmol/sm
KG	Overall gas-phase transfer coefficient, s/m
a	Surface area of interface per unit volume of column, m^2/m^3
G	Denotes gas phase
LG, OG, L, OL	Refer to gas film, overall gas, liquid film, and overall liquid transfer
i	Number of moles of **B** reacting with 1 mole of **A**
P	Total pressure, N/m^2
P_{AG}	Partial pressure of **A** in bulk of gas phase, N/m^2
P_{Ai}	Partial pressure of **A** at interface, N/m^2
Y	Molar ratio of solute gas **A** to inert gas **B** in gas phase
Z	Height of packed column, m
1	Denotes conditions at bottom of packed column, or at plane 1
2	Denotes conditions at top of packed column, or at plane 2
A	Denotes soluble gas
i	Denotes value at interface

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