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Prototype of Eco-Friendly Indoor Air Purifier to Reduce Concentrations of CO_2, SO_2 and NO_2

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ABSTRACT

Urbanization and industrialization lead to the increased usage of fossil fuels for running various types of automobiles and industries in developing countries. The rapid growth of automobiles usage in major cities causes air pollution and its direct impact on public health. This impact is alarming the worsening of the health of urban dwellers. But this impact can be reduced by breathing the filtered air. Filtering of air can be done in multiple ways. Among all, filters prepared from natural materials have become popular. In this study, an attempt has been made to find the novel approach to reduce the pollutants' level in the air by preparing prototype indoor air purifier which is designed, fabricated and tested with eco-friendly materials and adsorbents prepared from plant extractions. The three pollutants considered were CO_2, SO_2 and NO_2. Activated carbon was used as an adsorbent for CO_2 and NO_2 removal, whereas Neem bark, Mango bark, Orange peel powder and Neem leaf powder were used for SO_2 removal. The prototype was designed for Hyderabad city, Telangana State of India and tested at houses of five different locations (Balanagar, Jeedimetla, Zoo Park, MGBS and JNTU) which are major traffic intersections in the city. The level of pollution before and after the installation of the instrument was measured for three months (January, February, March) and analysed. Results indicate the improvement of air quality after filtration.

INTRODUCTION

In the urbanized world, lifestyle is automated and dependency on automobiles is increasing enormously. The sudden lifestyle change resulted in increasing automobiles decade after decade. This massive shift is damaging the ambient air quality which is impacting the millions of urban dwellers (Kura et al. 2013, Gurjar & Nagpure 2015). Next to industrial and power plants, the gigantic automobile growth rate of two, three and four-wheelers, passenger buses and multi-axle trucks, etc. are burning fossil fuel leading to permanent damage to air and atmosphere. The problem is aggravating in developing countries like India. The economic growth and industrialization are the two fundamental factors producing regional pockets of heavy pollutants especially, in metro-cities which have seen a rapid rise in the fleet of vehicles in the last decade (CMIE 1998, Garg et al. 2001).

The causes of rapid growth of automobile increase include but not limited to (i) increasing human dependency on the automobiles, transport of commercial goods etc., (ii) marketing tactics include lot of attractive finances availability even for common man to buy a vehicle according to one's interest and (iii) the frequent old vehicle exchange offers from suppliers exhilarating the existing users to go for new vehicles etc.

Increase in the number of vehicles producing large amounts of pollution into the air which leads to multiple impacts. Impact on human health is quite alarming news nowadays (Gurjar & Nagpure 2015, Jain & Khare 2009). UNEP (2010) reports that urban air pollution is linked to about 1 million premature deaths and 1 million pre-native deaths each year. It is believed that diesel vehicle fumes can cause cancer than petrol vehicles in India. Diesel vehicles also have high risk in causing non-cancerous effects like allergy, asthma and other respiratory problems (Bhandarkar 2013). According to Vannan Kandi Vijayan et al. (2015), the recent data on the amount of exposure to indoor and outdoor air pollution further revealed a strong reason for cardiovascular diseases, such as strokes and ischemic heart disease.

The main pollutants such as CO_2, SO_2 and NO_2 present in the air cause health problems. Carbon dioxide is emitted when carbon compounds go through combustion. Nitrogen dioxide is the main source of nitrate aerosols. This is mainly released during heating, power generation and engines in vehicles and ships. It causes severe respiratory problems, lowering the immune system, especially in children. It is also responsible for the formation of surface-level ozone, toxic nitrates, etc. Sulphur dioxide is released when any organic matter is burned. Sulphur dioxide causes several diseases like asthma, inflammation of respiratory organs, chronic bronchitis, etc.

Reducing the concentration of these pollutants is very much important for healthy living in the urbanized world. To breathe air free from pollutants, there is a need to purify surrounding air using an air purifier. The British Thoracic Society on Asthma Management recommended the use of air filters for removal of the pet and other allergens (Vannan Kandi Vijayan et al. 2015). USEPA (2009) recommends the usage of gas-phase air filters to remove gaseous pollutants by using a material called a sorbent, such as activated carbon to adsorb pollutants. Reshma et al. (2017) have presented the review of literature discussing the importance of using the ornamental plants, weedy trees, and green space as natural filters of air pollution reduces respiratory illness mortality rates and reducing visits to the hospitals. Many species of ornamental shrubs and herbaceous landscape plants have been identified for phytoremediation to improve indoor and outdoor air quality. The research on the removal of air pollutants using natural materials and natural methods is scanty in the literature.

The objective of the present study is to reduce the pollutants' level in the air by preparing a physical prototype indoor air purifier which is designed, fabricated and tested with eco-friendly materials and adsorbents prepared from plant extractions. Selection of the natural materials is inspired by the culture and customs in the age-old traditions of India, in which Neem tree, Tulasi and *Ficus religiosa* considered as holy plants and Mango leaves. These age-old practices inspired us to test these plant materials concerning air purification. The physical model developed with these plant materials works on the principle of adsorption and suction of pollutants. The three pollutants considered were CO_2, SO_2 and NO_2. Activated carbon was used as an adsorbent for CO_2 and NO_2 removal, whereas Neem bark, Mango bark, Orange peel powder and Neem leaf powder were used for SO_2 removal. The adsorbents were considered in four different sizes. The sizes were considered in such a way that the parameters can be distinguished.

For the case study, the Hyderabad, metropolitan city of Telangana State, India was selected which is witnessing the rapid growth of the number of two-wheelers and four-wheelers in the past two decades due to over-population and migration from rural to urban areas. According to Sood (2012), both the two-wheelers and four-wheelers together contributing more than 80 per cent of the vehicle population in Hyderabad city. Sarath & Rakesh (2009) investigated using the data, the contribution of various pollutants in Hyderabad City. Overall, the transport sector is expected to contribute particulate matter (PM) direct emission of about 50%, PM indirect emission of 30%, and high contributions to ozone and CO along the main activity corridors. Considering the importance of reducing the air pollution at a major junction of the city, the prototype is tested at houses of five different locations such as Balanagar, Jeedimetla, Zoo Park, Mahatma Gandhi Bus Station (MGBS) and Jawaharlal Nehru Technological University (JNTU), Kukatpally which are major traffic intersections in the city. The level of pollution before and after the installation of the instrument was measured for three months (January, February and March) and analysed.

MATERIALS AND METHODS

The major components of the air purifier were made of eco-friendly materials. The body of the purifier was made up of a wood called Novopan. It was designed in a cuboidal shaped box with four inlets and one outlet. This prototype works on the principle of adsorption and suction. The workflow is shown in Fig. 1.

The four exits consist of filters made of jute, a strong durable natural fibre. It has properties like UV protection, heat insulation, sound insulation, anti-static properties, high tensile strength, low extensibility, and low thermal conduction, carbon dioxide neutral and also naturally decomposable. It can be recycled once and also bio-degradable. It is an eco-friendly and low-cost fibre extracted from the plant's stem. Artificial polymer filters were also prepared to test the efficiency and compared with natural filters. The exhaust fan with properties of Volts 230 AC: 50Hz 1Phase, 2800Rpm, Sweep of 150 mm was inserted on the fifth side. The adsorbents were prepared from plant extractions of neem bark powder, mango bark powder, neem leaf powder, orange peel powder and also activated carbon. The adsorbing media based on the pollutants are categorized in Table 1.

The compartments are made in the filters with an ascending of size towards the outlet fan. These compartments are filled with four different sizes of adsorbents as mentioned in Table 2.

Fabrication

Novopan wood material was used for the body of the air purifier. Cuboid shaped box with five side openings was designed to place the filters at the four sides for inlet purpose and one for insertion of a suction fan of 2800rpm speed. Filters were made with both natural and artificial fibres to

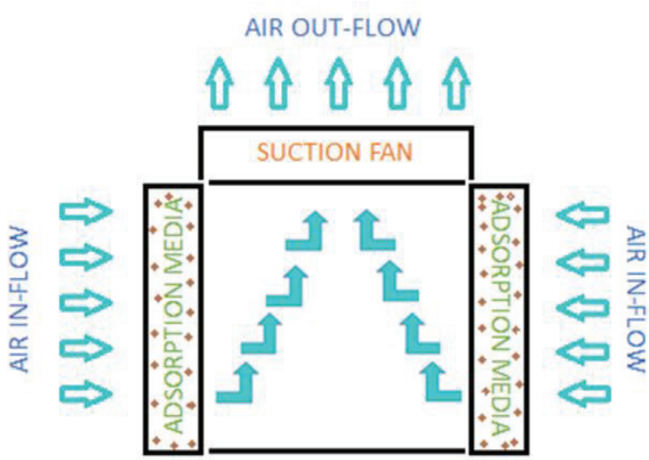

Fig. 1: Workflow of prototype air purifier.

compare the efficiency between them. Natural fibre as jute and artificial fibre as polymer were used. Filters were divided into three horizontal compartments to the adsorbing material in increasing order as the suction pressure varies with the distance from the fan. Adsorption material was inserted in the filters. The male part of Velcro was attached to the four openings of inlet and female to the filters (both natural and artificial). A suction fan was attached to the body of the purifier at the opening provided for the insertion. It was fixed tightly in such a way that the body does not vibrate while it works. Filters were attached to the purifier and measured the concentrations of pollutants at inlet and outlet. The values were tabulated. The procedure of measuring concentrations of pollutants with varying sizes of absorbing materials was repeated and the filters with natural and artificial fibres were interchanged.

Table 1: Adsorbent allotment to pollutants.

Pollutants	Adsorbing Media
CO_2	Activated carbon
NO_2	Activated carbon
SO2	Neem bark powder
	Mango bark powder
	Neem leaf powder
	Orange peel powder

Table 2: The adsorbents used in filters and their sizes.

Adsorbents Used	Sizes
Neem bark powder	>1.18 mm, 1.18-2.36 mm, 2.36-4.75 mm, >4.75 mm
Mango bark powder	>1.18 mm, 1.18-2.36 mm, 2.36-4.75 mm, >4.75 mm
Neem leaf powder	<300 microns, 300-425 microns, 425-600 microns, >600 microns
Orange peel powder	>1.18 mm, 1.18-2.36 mm, 2.36-4.75 mm, >4.75 mm
Activated carbon for carbon dioxide	>1.18 mm, 1.18-2.36 mm, 2.36-4.75 mm, >4.75 mm
Activated carbon for nitrogen dioxide	>1.18 mm, 1.18-2.36 mm, 2.36-4.75 mm, >4.75 mm

The Experiment

The prototype prepared was installed in the houses in the selected locations. Then the concentrations of pollutants were measured before installation and after installation at the air outlet of the purifier. The SO_2 and NO_2 values were measured with the respiratory dust sampler followed by spectrophotometer, and carbon dioxide by CO_2 analyser. A similar number of experiments were conducted with varying the size of adsorbents and also all the five adsorbents. The experiment was conducted for the three months of January, February and March in the year 2016. Then the sampling recordings were analysed after conducting an on-site experiment with respiratory dust sampler. The concentrations of SO_2, NO_2 and CO_2 were calculated in the laboratory.

Sampling and Analysis of SO_2

The Modified West and Geake method was used for the measurement of sulphur dioxide in the air. The concentration of sulphur dioxide (μg/m³) was calculated using the calibration graph. The SO_2 concentration was calculated using equation 1 and equation 2.

$$C = \frac{(V1-V2) \times N \times K}{V} \quad ...(1)$$

Where,
C = Sulphite concentration (mg/mL)
V1 = Volume of thiosulfate for blank (mL)
V2 = Volume of thiosulfate for sample (mL)
N = Normality of thiosulfate
K = 32000 (Milli-equivalent weight SO_2/μg)
V = Volume of standard sulphite solution (mL)

$$C\ (S0_2\ \mu g/m^3) = (As-Ab) \times CF \times (Vs/Va) \times Vt \quad ...(2)$$

Where,
C (SO_2) = Concentration of sulphur dioxide (μg/m^3)
As = Absorbance of sample
Ab = Absorbance of the reagent blank
CF = Calibration factor
Va = Volume of air sampled (m^3)
Vs = Volume of sample (mL)
Vt = Volume of aliquot taken for analysis (mL)

Sampling and Analysis of NO_2

Modified Jacobs and Hochheiser method was used for the measurement of nitrogen dioxide in the air. The concentration of nitrogen dioxide (μg/m³) was measured using the calibration graph. The concentration of NO_2 was calculated using equation 3.

$$C\ (NO_2\ \mu g/m^3) = (As-Ab) \times CF \times (Vs/Va) \times Vt \times 0.82 \quad ...(3)$$

Where,
C (NO_2) = Concentration of nitrogen dioxide (μg/m^3)
As = Absorbance of sample
Ab = Absorbance of the reagent blank
CF = Calibration factor
Va = Volume of air sampled (m^3)
Vs = Volume of sample (mL)
Vt = Volume of aliquot taken for analysis (mL)
0.82 = Sampling efficiency

Sampling and Analysis of CO_2

Handheld carbon dioxide analyser of the model 1205B gas analyser was used. This accurately measures the concentration of carbon dioxide in a duct. It has a two-line LCD to display the concentrations of carbon dioxide before installation and at the outlet of the purifier after installation with a sampling probe. 225 sets of readings can be stored simultaneously measuring the concentrations at intervals from 1 to 10 minutes. The readings were recorded with varying adsorbent sizes. The maximum limits for the recordings were at temperatures 32°F to 104°F, relative humidity limits of 10 to 90 % with 1 ppm resolution.

RESULTS AND DISCUSSION

The final concentration of the pollutants was measured after installation of this prototype at five major locations in the city to estimate the maximum efficiency of adsorbents under practical working conditions. The initial and final mean concentrations of the pollutants in the three months from January to March with varying sizes of adsorbents are shown in Fig. 2 to Fig. 17.

Change of adsorbent size indirectly means the change of surface area. The pattern observed is the increase in surface area increases the rate of adsorption through which maximum efficiencies are achieved. Particles with the size less than 1.18 mm have greater efficiency than the particles with the size greater than 4.75 mm irrespective of the absorbents used in this research. These four natural adsorbents were used only for sulphur dioxide removal. Among them, neem leaf powder has the least efficiency and mango bark powder has the highest efficiency. But in the case of carbon dioxide and nitrogen dioxide, activated carbon was found to be more efficient. The eco-friendly components used in fabrication have high stability factors towards the environment. The purifier is portable and can easily fit in windows. This helped us in performing the experiments at different locations.

All the laboratory experiments mentioned in this study were carried out at room temperature (25 ± 5°C) at 1 atm pressure. All the instruments (respiratory dust sampler, CO_2 gas analyser, spectrophotometer) used in this research were

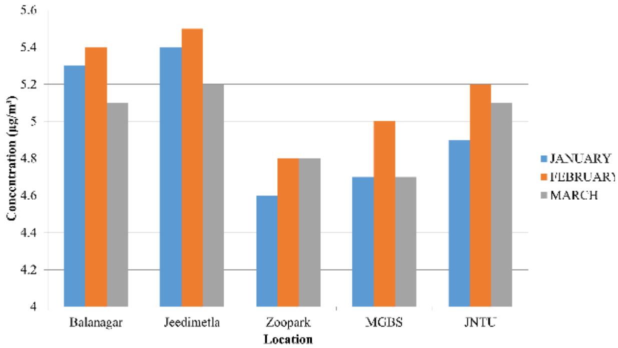

Fig. 2: Initial readings of SO_2 in selected areas.

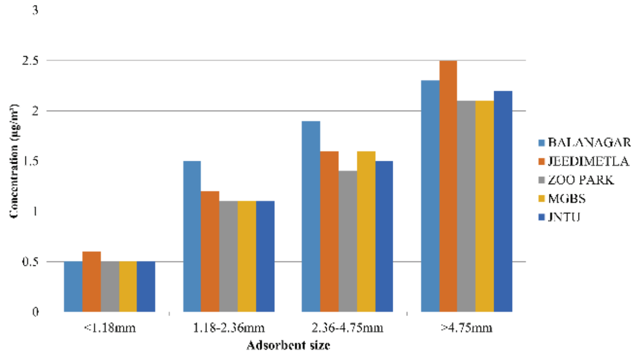

Fig. 3: Concentrations of SO_2 at the outlet of purifier using neem bark powder.

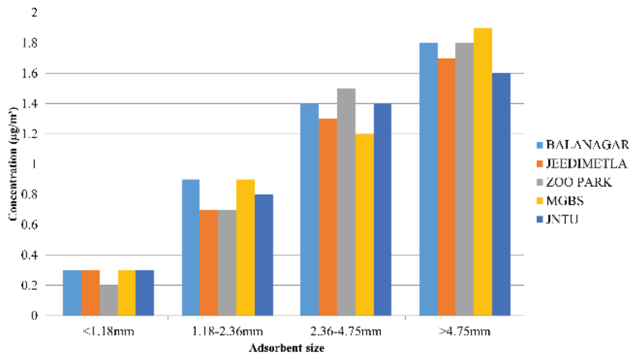

Fig. 4: Concentrations of SO_2 at the outlet of purifier using mango bark.

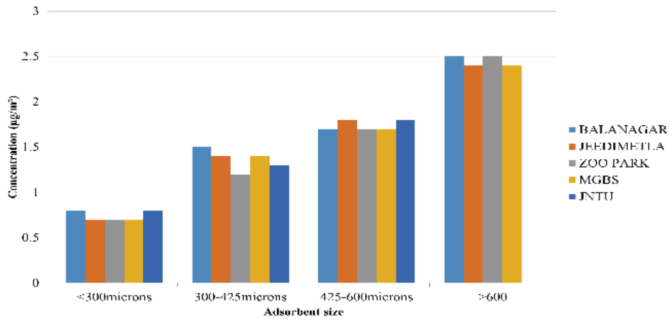

Fig. 5: Concentrations of SO_2 at the outlet of purifier using neem leaf powder.

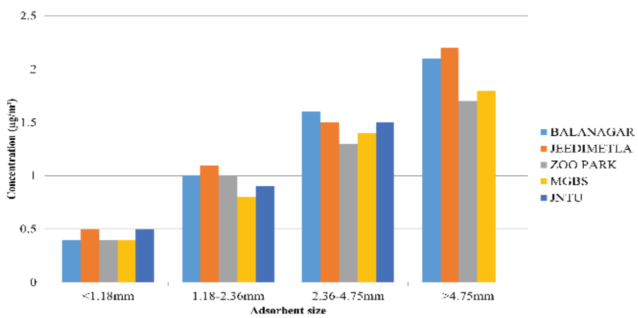

Fig. 6: Concentrations of SO_2 at the outlet of purifier using orange peel powder.

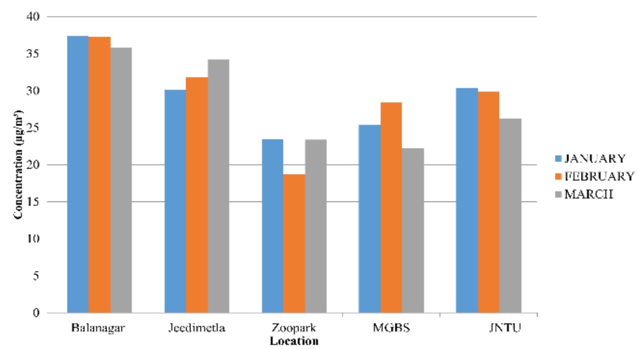

Fig. 7: Initial readings of NO_2 at selected locations.

calibrated for respective readings. All the materials used for fabricating the prototype were eco-friendly. No chemicals or any hazardous substances were used in this prototype. The adsorbents used in the study, after they reach the saturation point, can be disposed off through incineration.

CONCLUSIONS

In the present study, five different locations were selected (i) Balanagar (Industrialized area), (ii) Jeedimetla (Industrial and residential area), (iii) MGBS (Main bus station), (iv) JNTU (High population density) and (v) Zoo park area (Tourist place) in Hyderabad city.

- The reading of SO_2 was measured in three months (January, February and March) in Balanagar, Jeedimetla, Zoo-park, JNTU, MGBS, and results are 5.3, 5.4, 5.1 µg/m^3 in Balanagar; 5.4, 5.5, 5.2 µg/m^3 in Jeedimetla,

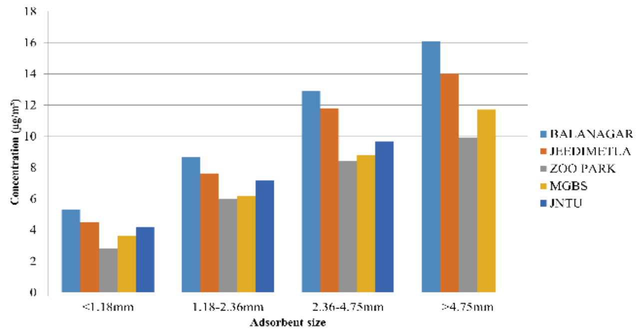

Fig. 8: Concentrations of NO_2 at the outlet of the purifier.

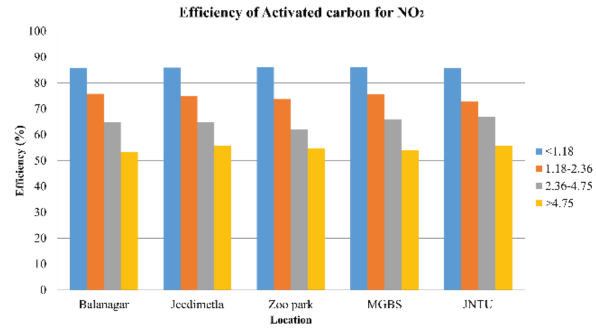

Fig. 9: The efficiency of activated carbon for NO_2.

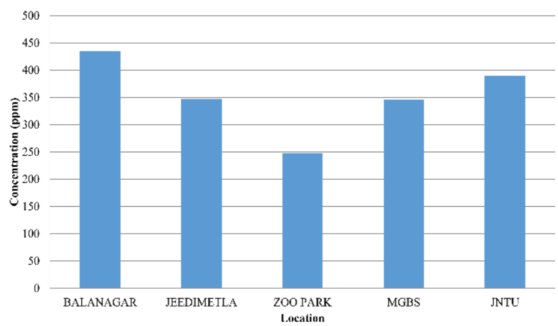

Fig. 10: Initial concentrations of CO_2 at various locations.

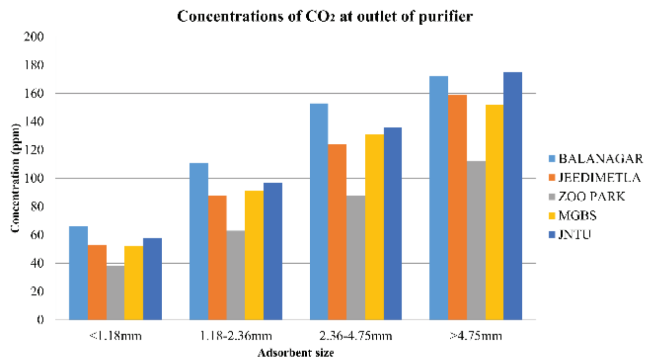

Fig. 11: Concentrations of CO_2 at the outlet of the purifier.

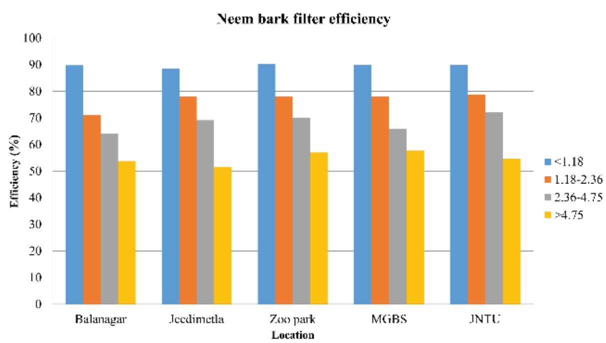

Fig. 12: The efficiency of neem bark filter.

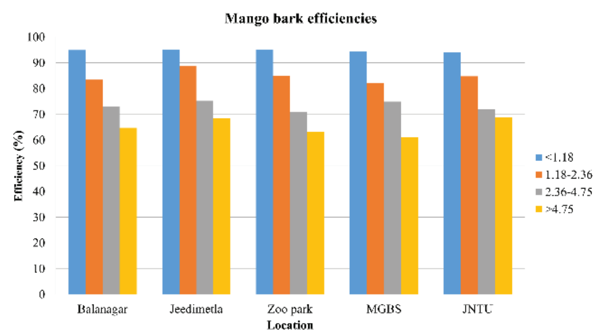

Fig. 13: The efficiency of mango bark.

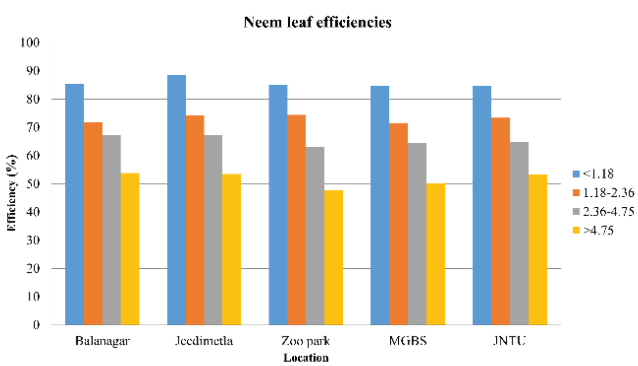

Fig. 14: The efficiency of neem leaf powder.

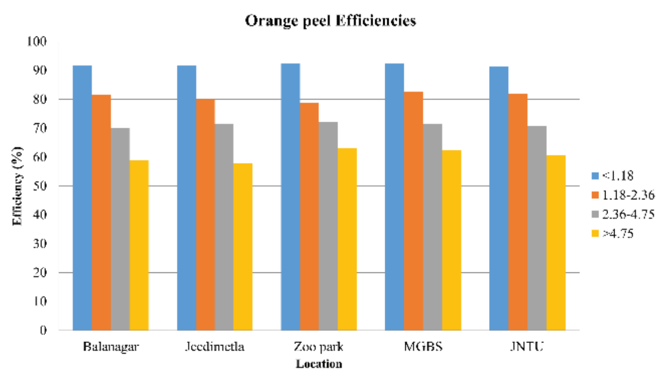

Fig. 15: The efficiency of orange peel powder.

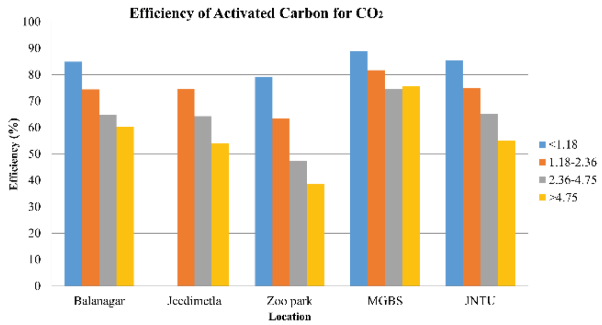

Fig. 16: The efficiency of activated carbon for CO_2.

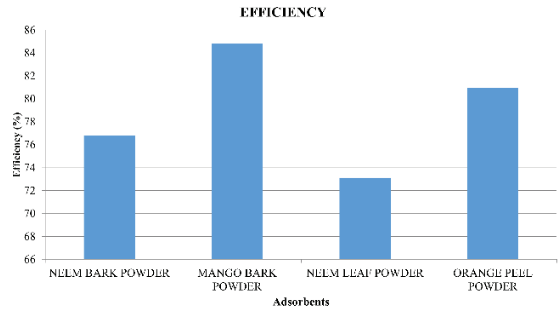

Fig. 17: The overall efficiency of the adsorbing materials.

4.6, 4.8, 4.8 μg/m^3 in Zoo park area, 4.7, 5, 4.7 μg/m^3 in MGBS and 4.9, 5.2, 5.1 μg/m^3 in JNTU.

- The adsorbents used were neem bark powder, mango bark powder, neem leaf powder, orange peel powder of sizes 1.18 mm, 1.18-2.36 mm, 2.36-4.75 mm, and >4.75 mm.
- In the study, it was identified that mango bark powder adsorbs more SO_2 as compared to other materials.
- As the size of adsorbents increases, the adsorption capacity decreases.
- It was observed that activated carbon is more efficient for NO_2 as compared to other materials.
- It was observed that activated carbon is quite efficient in the removal of CO_2.

For the present study, only a few materials were considered for the adsorption of CO_2, SO_2 and NO_2 for indoor purpose. But it is possible to use other materials or a combination of materials for multi pollutants and to even operate at outdoors by changing the functionality of the purifier.

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