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Improvement of Indoor Air Quality Using Local Fabricated Activated Carbon from Date Stones

(Penambahbaikan Kualiti Udara Dalaman Menggunakan Fabrikasi Karbon Aktif Tempatan daripada Biji Kurma)

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ABSTRACT

Indoor air quality assessment in residential areas of Al-Hofuf city/Eastern region of Saudi Arabia is investigated through a multi-week multiple sites sampling survey. Critical air pollution indicators, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), carbon dioxide (CO_2) and total volatile organic compounds (TVOC) as well as temperatures were measured and analyzed during the study period from January to May 2014. Three site-types - roadside, urban and rural - were selected and within each site type, six locations were selected to study the varying indoor/outdoor air quality. The results indicated that NO_2 and CO concentrations increased at the starting hours of the day. SO_2 concentrations were relatively low and constant. In addition, a strong association between outdoor and indoor air quality was found. Measurements showed that indoor/outdoor ratio for TVOC ranged from 0.8 to 0.99. For CO_2, NO_2 and SO_2, this was 0.92-1.15, 0.5-0.7 and 0.52-0.9, respectively. Finally, the effects of activated carbon (AC) were investigated to assess the extent of the improvement in the indoor air quality. The analysis of data obtained indicated that using locally prepared AC from date stones was an effective way to reduce the indoor air pollution with an overall efficiency of 85.5, while the use of industrial granular AC reduced the air pollutants with an efficiency of less than 0.6. In addition, AC was exposed to an exhaust gas flow to evaluate its elimination potential for high concentrated pollutants. The obtained results demonstrated that AC was also functioning as an efficient absorbent with an overall removal efficiency of 77.8%, even when it was exposed to high concentrations.

Keywords: Activated carbon; air pollution; date stones; indoor/outdoor concentrations and ratios; Saudi Arabia

ABSTRAK

Penilaian kualiti udara dalaman di kawasan perumahan bandar Al-Hofuf rantau/bahagian Timur Arab Saudi dikaji selama beberapa minggu di beberapa tapak kajian persampelan. Penunjuk pencemaran udara kritikal termasuk nitrogen dioksida (NO_2), sulfur dioksida (SO_2), karbon monoksida (CO), karbon dioksida (CO_2) dan jumlah sebatian organik meruap (TVOC) dan juga suhu diukur dan dianalisis dalam tempoh kajian daripada Januari-Mei 2014. Tiga jenis tapak - sisi jalan, bandar dan luar bandar telah dipilih dan dalam setiap jenis tapak, enam lokasi dipilih untuk mengkaji kualiti udara dalaman/luaran yang berbeza. Keputusan menunjukkan bahawa kepekatan NO_2 dan CO meningkat pada permulaan hari. Kepekatan SO_2 secara relatifnya rendah dan tetap. Di samping itu, perkaitan yang kuat antara kualiti udara luaran dan dalaman telah diperoleh. Pengukuran menunjukkan bahawa nisbah dalaman/luaran untuk TVOC adalah antara nisbah 0.8-0.99. Untuk CO_2, NO_2 dan SO_2, pula masing-masing adalah 0.92-1.15, 0.5 -0.7 dan 0.52-0.9. Akhirnya, kesan karbon diaktifkan (AC) telah dikaji untuk menilai sejauh mana peningkatan kualiti udara dalaman. Analisis data yang diperoleh menunjukkan bahawa penggunaan AC tempatan yang diperbuat daripada biji kurma adalah cara yang berkesan untuk mengurangkan pencemaran udara dalaman dengan kecekapan keseluruhan 85.5, manakala penggunaan perindustrian berbutir AC mengurangkan pencemaran udara dengan kecekapan kurang daripada 0.6. Di samping itu, AC juga terdedah kepada aliran gas ekzos untuk menilai potensi penyingkiran untuk pencemar tertumpu tinggi. Keputusan yang diperoleh menunjukkan bahawa AC juga berfungsi sebagai penyerap yang cekap dengan kecekapan penyingkiran keseluruhan 77.8%, walaupun ia telah didedahkan kepada kepekatan yang tinggi.

Kata kunci: Arab Saudi; biji kurma; karbon diaktifkan; kepekatan dalaman/luaran dan nisbah; pencemaran udara

INTRODUCTION

Air pollution in Saudi Arabia and in neighboring regions is a major concern. The air quality in urban area becomes worse year by year due to the release of pollutants from industrial plants and heavy vehicle traffic and constitutes a serious hazard to human health and the environment. Harmful emissions into the air represent an environmental pressure that reflects negatively on man's health and productivity; thus leading to a real loss in the national economy (El-Sharkawy & Zaki 2012; Qureshi et al. 2015). Until recently, the health effects of indoor air pollution have received relatively little attention from scientific community and governmental institutions worldwide. And while most people are aware that outdoor air pollution can damage their health, many do not know that indoor air pollutants can also do the same. Indeed, studies of human exposure to air pollutants (Montgomery & Kalman 1989; Rasheed et al. 2015) indicate that indoor levels of pollutants may be 2 to 5 times – and occasionally more than 100 times – higher than outdoor pollutant levels. Indoor air pollutants have been ranked among the top five environmental risks to public health. The problems they cause can be subtle and do not always produce easily recognized or immediate impacts on health.

The biggest reason for air pollution in Saudi Arabia at the moment is vehicles. Recent studies have indicated that the Gulf Cooperation Council (GCC) countries emit about 50% of the total of Arab Countries' (254 million metric tons of carbon) emissions of CO_2 (Yeatts et al. 2012). In terms of per capita carbon emissions, Saudi Arabia is still the regional leader.

Air pollution in Saudi Arabia is now recognized as a significant environmental impact of intensive anthropogenic activities. Heavy traffic in the streets of urban areas increases emissions of surface ozone (O_3) as a result of the increased emissions of precursors ($NOx=NO + NO_2$ and VOCs). Also, the local climatic conditions (high temperature, intense solar radiation, clear sky) lead to the enhanced formation of photochemical pollutants. Therefore, special attention to monitoring and reducing such emissions through concerted efforts should be immediately undertaken at both national and international levels alike. These conclusions are supported by several investigations (Al-Jeelani 2009; Chaloulakou et al. 2003; El-Sharkawy & Noweir 2014; Ho et al. 2014). The present research comes out to help in the efforts of using and utilizing scientific techniques using local materials to contribute in the efforts for the reduction of indoor air pollution.

Activated carbon (AC) has been widely used as low-cost adsorbent for quickly and effectively controlling the air pollutants like VOCs and NO (de la Puente & Menéndez 1998; Goncalves & Figueiredo 2004; Illán-Gómez et al. 1995; Kayani et al., 2014). Both granular AC and AC filters have been used intensively to improve the indoor air quality with AC filter exhibiting better performance than granular AC (Bastani et al. 2010; Das et al. 2004; Fisk 2007; Gallegoa et al. 2013; Haghighat et al. 2008; Lorimier et al. 2005). In this study, the effects of using locally prepared AC from date stones in improving the air quality by reducing the critical indoor air pollutants were investigated.

METHODS

SITE SELECTION

Three site-types – roadside (RS), urban (UR) and rural (RU) – were selected for this study to carry out the air quality measurements and to assess the varying indoor/outdoor air quality. All the selected sites were residential areas. Two locations were assigned to represent each site type and further three points were assigned and selected at each location. At each assigned point, three measurements were randomly taken for indoor and three measurements for outdoor air quality. RS sites were selected in heavy traffic areas (Riyad road, RS1 and Qayssariah Market, RS2) in Al-Hofuf downtown. Two urban sites (UR1 and UR2) were selected near Village Market, which is a rapidly developing area outside the dense populated old city. Rural sites (RU1 and RU2) were selected far away from the roadside and urban areas. Detailed description of the selected six sites is shown in Table 1. All the homes and residences were using classical AC ventilation (window or split unit types).

AIR QUALITY INDICATORS

Five of air pollution indicators, together with relevant meteorological parameters were simultaneously monitored for indoor and outdoor air quality at each site within a period of four months. The particularly important

TABLE 1. Description of sites assigned for air quality (outdoor and indoor) monitoring scattered throughout the Al-Hofuf city

Site	Description of site	Building type	Age yrs	Living area	No. of occupants	No. of smoking occupants	Type of oven
RS1	Near main road with heavy traffic flow	Residen.+ Commer.	30	70	3	0	Nat. gas
RS2	Down Town, shopping Centre	Residen.+ Commer.	35	60	1	1	Nat. gas
UR1	Near construction site and road with medium traffic flow	Private residential building	5	150	4	1	Nat. gas
UR2	Near road with medium traffic flow	Private residential building	5	120	3	3	Nat. gas
RU1	Far from road side	Private residential building	20	200	8	2	Nat. gas
RU2	Near Park (Garten)	Private residential building	5	250	6	0	Nat. gas

air quality indicators includes: Total volatile organic compounds (TVOCs), CO and CO_2 were recorded in parts per million (ppm) while SO_2 and nitric oxide (NO_2) were measured in μg/m³. The directSense IAQ meter (Gray Wolf sensing solutions) was used for measurements.

Average hourly measurements were taken over the sampling period (January-April 2014). In order to consider the effect of the traffic density on the air quality, the data have been collected over different periods of time, t1: 15-20 January, t2: 30 January-04 February, t3: 15-20 February, t4: 30 February-04 March, t5: 15-20 March, t6: 30 March-04 April. All measurements were conducted on daily basis from 10 am to 8 pm (for about 10 h per day). The concentrations of air pollutants were recorded in real time at 20 min intervals. During the measurements, indoor air was supplied directly from the outdoor air so that the air pollutants found in indoor air were resulted from outdoor emissions only.

GRANULAR ACTIVATED CARBON (GAC)

GAC was prepared in the laboratory (Environmental Lab at King Faisal University, Al-Hofuf, Saudi Arabia) from local selected date stones. The preparation of AC from date stones was achieved by following exactly the same steps explained thoroughly in Haimour and Emeish (2006), which includes pretreatment of the dates' stones, impregnation of the dates' stones with the activator, carbonization of the impregnated stones and finally the removal of activator. The pits of Khalas originate from Dates Packaging Factory in Al-Hasa Region, Saudi Arabia and were collected at the tamer stage (fruit ripeness). GAC was produced from dates' stones by the chemical activation method using Phosphorous Acid H_3PO_4 (M = 85%) as an activator. A series of experiments were designed and carried out to assess the efficiency of AC on reducing the critical air pollutants.

For assessing the absorption efficiency of AC filters in removing air pollutants, a system was developed (Figure 1). It consisted of two chambers, inlet chamber and the outlet chamber. The exhaust gas that enters the inlet chamber was forced to pass through a filter filled with AC. The measuring sensor was fixed to the inlet orifice.

For measurements of gas concentrations (entering and leaving the system), Applus + AutoLogic Inc. (Air Fuel and Lambda) was used which can measure HC, CO, CO_2, O_2, NOx (5 gas version). The system was connected to a diesel motor so that the exhaust gases that enter the system were allowed to pass through the filter. The measuring instrument was installed at the outlet of the system (Figure 1(a)). This was a closed system experiment. Before starting recording the results, the initial exhaust gases (CO_2, CO, HC) were measured and the results were presented in Table 4(a), 4(b) and 4(c). These results demonstrate the values of exhaust gases after passing the AC filters. In this experiment, two types of AC were tested, the industrial charcoal and the date stones AC that was prepared in the Lab.

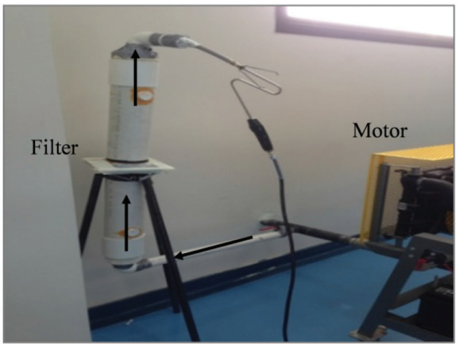
RESULTS AND DISCUSSION

ASSESSMENT OF AIR QUALITY

The daily range and the average concentrations of the measured pollution indicators during the periods of study for all assigned locations (RS1, RS2, UR1, UR2, RU1 and RU2) are shown in Table 2. In addition, the indoor/outdoor ratio of the measured concentrations is also presented. From Table 2, it can be predicted that each pollutant has almost the same daily trend during the different periods of measurements.

TVOC

Table 2 shows that the hourly recorded concentrations of TVOC for indoor air at all locations (RS1, RS2, UR1, UR2, RU1 and RU2) ranged between the lowest value of 15.00 ppb and the maximum (max.) value of 69 ppb. For outdoor air, the values fluctuated between 21 and 84 ppb. The overall average of indoor readings equals 27.56 ppb and for all outdoor values 34.16 ppb. The indoor/outdoor (I/O) ratio ranged from 0.739 to 1.000 with an overall average of 0.0.813. In general, it was to notice that measured values were high at the sites RS1 and RS2 and low at the sites UR1 and UR2. The magnitude of air pollution with TVOC could



(a)

(b)

FIGURE 1. (a) System setup and components and (b) Filter filling with AC

TABLE 2. Min, max and the average concentrations of measured air pollutants as well as the I/O ratio of pollutants at each location

Gas (units)		TVOC (ppb)			CO_2 (ppm)			CO (ppm)			NO_2 (μg/m^3)			SO_2 (μg/m^3)		
Location	Relation	I	O	I/O	I	O	I/O	I	O	I/O	I	O	I/O	I	O	I/O
	Min.	37.00	38.00	0.74	351.00	345.00	0.65	1.20	1.80	0.29	12.50	22.60	0.31	134.70	234.70	0.38
RS1	Max.	69.00	84.00	1.00	430.00	571.00	1.17	3.10	5.10	1.00	31.70	54.50	1.00	284.70	456.60	1.00
	Avg.	41.62	45.53	0.93	383.32	413.15	0.94	2.14	3.74	0.61	18.83	37.33	0.52	198.86	330.89	0.61
	Min.	29.00	38.00	0.62	301.00	331.00	0.81	1.20	2.80	0.29	14.50	23.70	0.42	166.10	244.70	0.44
RS2	Max.	42.00	59.00	0.95	531.00	571.00	1.17	3.40	5.40	0.97	38.40	63.20	1.00	376.10	466.60	1.00
	Avg.	32.68	41.77	0.78	363.23	397.16	0.92	2.15	3.94	0.56	25.82	40.31	0.67	236.27	380.37	0.63
	Min.	24.00	27.00	0.71	261.00	339.00	0.65	1.60	3.20	0.34	18.10	28.40	0.62	166.10	297.80	0.44
UR1	Max.	37.00	37.00	1.07	386.00	430.00	0.93	2.40	5.30	0.69	43.20	53.20	1.00	376.60	426.00	1.00
	Avg.	27.03	32.13	0.85	330.39	381.42	0.87	2.00	3.93	0.52	31.42	41.09	0.76	286.07	380.45	0.75
	Min.	18.00	22.00	0.51	261.00	362.00	0.64	1.60	1.20	0.39	24.50	28.40	0.46	216.60	297.80	0.52
UR2	Max.	26.00	36.00	1.13	386.00	503.00	1.02	2.30	5.30	1.33	37.40	68.40	1.00	346.00	426.00	1.00
	Avg.	21.94	30.10	0.77	335.55	422.26	0.80	1.98	3.67	0.58	31.37	46.42	0.70	291.97	384.05	0.77
	Min.	21.00	22.00	0.62	185.00	206.00	0.83	1.30	1.60	0.34	24.50	34.50	0.47	179.50	297.80	0.48
RU1	Max.	27.00	36.00	1.09	325.00	385.00	1.01	2.70	4.70	1.25	48.40	68.40	1.00	326.10	446.00	1.01
	Avg.	23.65	32.90	0.74	269.43	294.60	0.92	1.77	2.41	0.78	36.30	49.36	0.76	257.47	382.76	0.68
	Min.	15.00	21.00	0.65	200.00	240.00	0.78	2.30	1.30	0.62	31.40	34.50	0.56	197.80	276.10	0.51
RU2	Max.	22.00	27.00	1.00	234.00	275.00	0.95	3.60	4.20	1.77	48.40	68.40	1.00	356.00	476.10	1.00
	Avg.	18.48	22.55	0.82	218.48	255.52	0.86	2.74	3.36	0.85	39.81	51.13	0.80	274.45	379.33	0.73
All	Avg.	27.57	34.16	0.81	316.73	360.68	0.88	2.13	3.51	0.65	30.59	44.27	0.70	257.52	372.97	0.70

CO: 1 ppm = 1.15 mg/m^3, NO_2: 1 ppm = 378.5 ppb = 1880 μg/m^3, SO_2: 1 ppb = 2.6 μg/m^3 and 1ppm = 2860 μg/m^3 , CO_2: 1 ppm = 1.83 mg/m^3

not be evaluated because there are no standards for TOVC to compare with.

CO CONCENTRATIONS

The lowest recorded hourly outdoor CO concentration was 1.2 ppm at both RS1 and RS2, while the highest recorded concentration of 5.3 ppm was found at the urban sites (UR1 and UR2). The average for all outdoor readings and for all sites was 3.5 ppm, while the allover average for indoor readings was 2.13 ppm. The I/O ratio for all readings ranged from 0.286 to 1.77 with an overall average of 0.649.

It is clear from the results that all indoor as well outdoor values recorded were below 5.3 ppm. Similar values of I/O ratios for CO were also reported in Al-Rehaili (2002), Crump et al. (2004) and NìRiain et al. (2003). Comparing all the recorded measurements with the available standards presented in Table 3, it is clear that all concentrations of CO for both indoor and outdoor were below the 1 h average standards (ranged between 13 ppm of Alberta guidelines and 35 ppm of both PME standard and NAAQSs, USA).

NO_2 CONCENTRATIONS

The recorded hourly concentrations of NO_2 for outdoor air fluctuated between the lowest value of 22.6 μg/m^3= 0.012 ppm which was recorded at RS1 and the highest value (68.4 μg/m^3 = 0.036 ppm) was found at UR2, RU1 and RU2. The overall average for outdoor values was 44.7 μg/m^3 (0.023 ppm). For indoor air, concentrations lie between the minimum (min.) value of 12.5 μg/m^3 (0.007 ppm) recorded at RS1 and the max. concentration of 48.4 μg/m^3 (0.045 ppm) was found at both urban locations, UR1 and UR2, with an overall average of 30.59 μg/m^3 (0.016 ppm). The I/O ratio ranged from 0.306 to 1.00 with an overall average of 0.702. Comparatively, similar values of I/O ratios for NO_2 were reported in previous investigations (Chowdhury et al. 2011; Coward & Ross 2001; Crump et al. 2004; Dimitroulopoulou et al. 2005; Drakou et al. 1998; Kousa et al. 2001).

The recorded concentrations for both outdoor and indoor show an increasing trend starting with low values in the early hours of the day with an increase during the late hours. Comparing the results of 1 h averages with the available standards presented in Table 3, it can be seen that all the 1 h results of the current study were below the standards. Comparing the results of 24 h min and max averages with the available standards, it can be observed that the results of the current study were below the available standards (Noor et al. 2014).

SO_2 CONCENTRATIONS

From Table 2, it can be seen that the hourly indoor SO_2 concentration ranged from 134.7 μg/m^3 (0.047 ppm) to 284.7 μg/m^3 (0.1 ppm) with an overall average of 257.51 μg/m^3 (0.09 ppm) and that the outdoor concentrations ranged from 234.7 μg/m^3 (0.08 ppm) to 456.6 μg/m^3 (0.16 ppm) with an overall average of 372.97 μg/m^3 (0.13 ppm). The I/O of all readings ranged from 0.38 to 1.00 with an overall average of 0.696. It has been noticed that all the recorded results were fluctuating in a narrow range. Comparing the results with the available standards presented in Table 3, it is clear that all the results of the current study for 1 and 24 h were below the standards for most of the time. The NAAQs and WHO standards were violated only once throughout the year.

TABLE 3. Air quality standards in different countries (ppm)

Standards	CO	NO_2	O_3	SO_2
NAAQSs (USA) 1 h average	35	0.246		0.12
NAAQSs (USA) 1-8 h average	9			
NAAQSs (USA) 3 h average				0.5
NAAQSs (USA) 24 h average				0.14
NAAQSs (USA) annual average				0.14
NAAQSs (Canada) Desirable 1 h average	13.1		0.051	0.172
NAAQSs (Canada) Desirable 24 h average			0.051	0.057
NAAQSs (Canada) Acceptable 1 h average	30.6	0.213	0.082	0.334
NAAQSs (Canada) Acceptable 24 h average		0.106		
WHO 1 h average	26	0.07	0.5-0.1	0.13
WHO 24 h average				0.038- 0.058
WHO annual average		0.014		
EU guidelines 1 h average	0.14			0.28
EU guidelines 24 h average	0.028			0.017
Alberta Guidelines 1 h average	13	0.21	0.082	0.17
Alberta Guidelines 24 h average		0.11	0.025	0.06
NAAQSs (Korea) 1 h average	25	0.15	0.1	0.015
NAAQSs (Korea) 24 h average	35	0.35	0.15	0.14
PME (MEPA) 1 h average	35	0.35	0.15	0.28
PME (MEPA) 24 h average				0.14

THE ABSORPTION EFFICIENCY OF THE AC FILTERS

Table 4(a), 4(b) and 4(c) demonstrates the initial concentrations of pollutants (CO_2, CO and HC) as measured from the exhaust of motor when in operation and their concentrations after passing through the AC filters. The related Figure 2(a), 2(b) and 2(c) shows the efficiency of both AC filters on the reduction of exhaust gases. As per Table 4(a) and Figure 2(a), both types of AC were behaving

TABLE 4(a). Initial concentration of CO_2 (ppm) in exhaust gas and after passing through the filters

Gas	Initial concentration	Concentration after passing through the Industrial AC Filter		Concentration after passing through the Date Stone AC Filter	
	ppm	ppm	η1 %	ppm	η2 %
CO_2	147123	30226	79.46	30122	79.53
	145724	3109	97.87	29967	79.44
	148856	32023	78.49	31887	78.58
	148087	30678	79.28	32188	78.26
	146756	29867	79.65	30025	79.54
	147895	31896	78.43	31958	78.39
	146686	32256	78.01	33145	77.40
	147646	32967	77.67	33234	77.49
	148012	33284	77.51	34155	76.92
	148235	32587	78.02	32986	77.75
Average	147502.00	28889.30	80.44	31966.70	78.33

TABLE 4(b). Initial concentration of CO (ppm) in exhaust gas and after passing through filters

Gas	Initial concentration	Concentration after passing through the Industrial AC Filter		Concentration after passing through the Date Stone AC Filter	
	ppm	ppm	η1 %	ppm	η2 %
CO	3654	455	87.55	423	88.42
	6813	428	93.72	432	93.66
	9645	406	95.79	452	95.31
	10246	384	96.25	446	95.65
	10867	345	96.83	401	96.31
	11023	326	97.04	398	96.39
	10976	285	97.40	396	96.39
	10676	293	97.26	377	96.47
	11056	304	97.25	359	96.75
	10968	267	97.57	423	96.14
Average	9592.40	349.30	95.67	410.70	95.15

TABLE 4(c). Initial concentration of HC (ppm) in exhaust gas and after passing through filters

Gas	Initial concentration	Concentration after passing through the industrial AC Filter		Concentration after passing through the date stone AC Filter	
HC	ppm	ppm	η1 %	ppm	η2 %
	52	17	67.31	22	57.69
	97	21	78.35	23	76.29
	123	24	80.49	19	84.55
	143	26	81.82	18	87.41
	134	19	85.82	25	81.34
	128	22	82.81	23	82.03
	131	23	82.44	28	78.63
	141	26	81.56	27	80.85
	134	25	81.34	31	76.87
	132	24	81.82	32	75.76
Average	121.50	22.70	80.38	24.80	78.14

identically good upon the absorption of exhaust gases. Ignoring the one time peak value, the retention efficiency of both AC types ranged from 77.5-79.6% with and overall average of 77.8%.

THE EFFECTS OF AC ON THE INDOOR AIR QUALITY

Simple AC filter was designed and installed at the air conditioning unit, through which the outdoor air will enter inside homes and residences. In order to eliminate the effects of emissions from personal use (cooking and smoking) and the effect of electrical instruments and furniture, the experiments were conducted in new and empty rooms. Windows and doors were kept closed and the rooms without artificial ventilation were selected so that the pollutants remain mainly in the outdoor air. The concentrations of pollutants in indoor air were first measured to adjust concentrations prior to installation of AC filters. There was no production or deliberate removal

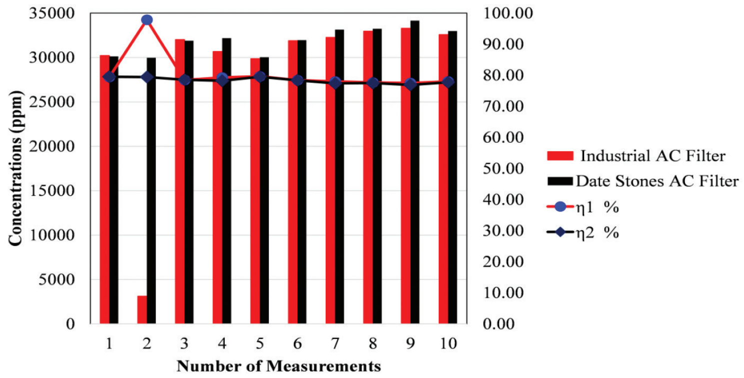


FIGURE 2a. Efficiency of AC filters for removal of CO_2 gas

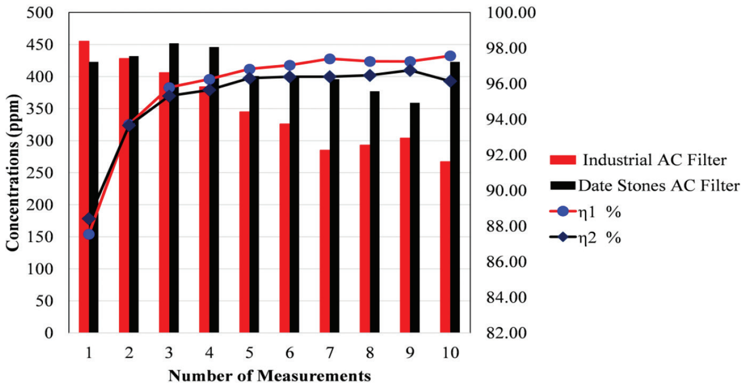


FIGURE 2b. Efficiency of AC filters for removal of CO gas

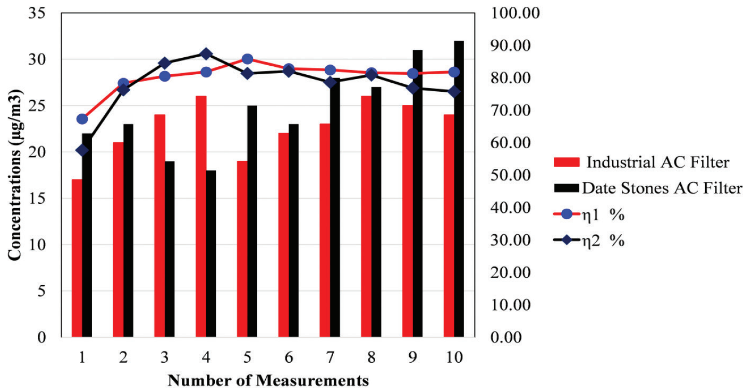


FIGURE 2c. Efficiency of AC filters for removal of HC

of pollutants within the room, so it seems reasonable to assume that the differences recorded between pollutants outdoors and indoors were mainly due to the effect of the AC filters.

The system operated 12 h prior to commence of taking measurements to ensure that most of the old indoor air is changed. As shown in Figure 3, filters containing AC were attached directly to the air conditioning unit so that the entering outdoor air must pass through these filters. As mentioned earlier, two types of AC were used, industrial activated charcoal and lab prepared AC.

TVOC CONCENTRATIONS

Figure 4 shows the concentrations of TVOC in outdoor air prior to entering inside the room, as well as the concentrations of indoor air after passing through the AC filters. From Figure 4 it is clear that the indoor concentrations of TVOC reduced after passing through AC filters compared to their initial concentrations in outdoor air. The overall efficiency of date stoned AC in eliminating TVOC fluctuated between 70 and 80%, while the efficiency of industrial charcoal lied between 20 and 60%.

CO CONCENTRATIONS

As Figure 5 demonstrates, the overall efficiencies of both industrial charcoal and date stoned AC have the same trend in eliminating CO. Both types show efficient application with an overall efficiency between 70 and 90%.

The behavior of both AC types towards reducing CO_2 concentration was very similar to that of CO, as shown in Figure 6. The overall efficiency of date stones AC ranged between 80 and 85%, while the overall efficiency of industrial charcoal was between 65 and 80%.

NO_2 CONCENTRATIONS

From Figure 7, it was obvious that both AC types were efficient in reducing NO_2 concentrations. The overall efficiency of date stones AC ranged between 40 and 80% while the values for industrial AC ranged between 40 and 70%.

SO_2 CONCENTRATIONS

As shown in Figure 8, it was clear that both AC types were less efficient in eliminating SO_2 concentrations. The overall efficiency of date stones AC ranged between 32 and

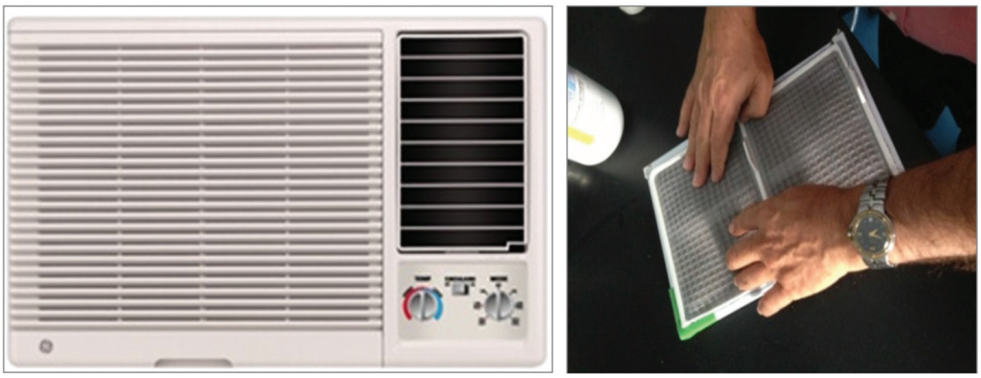


FIGURE 3. The attachment of AC filter to the air conditioning unit

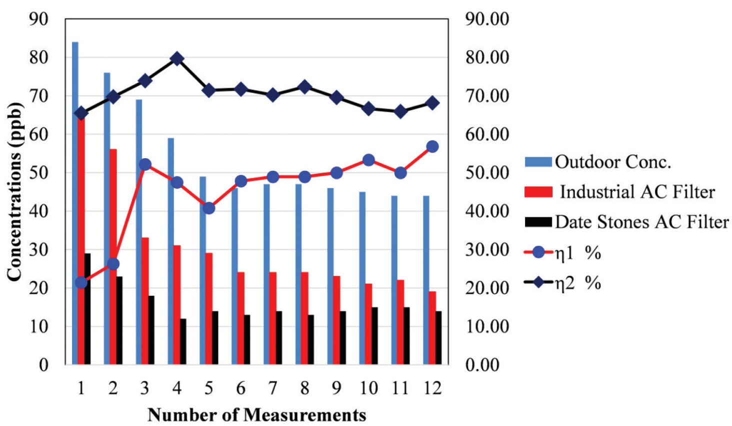


FIGURE 4. Removal efficiency of AC for TVOC

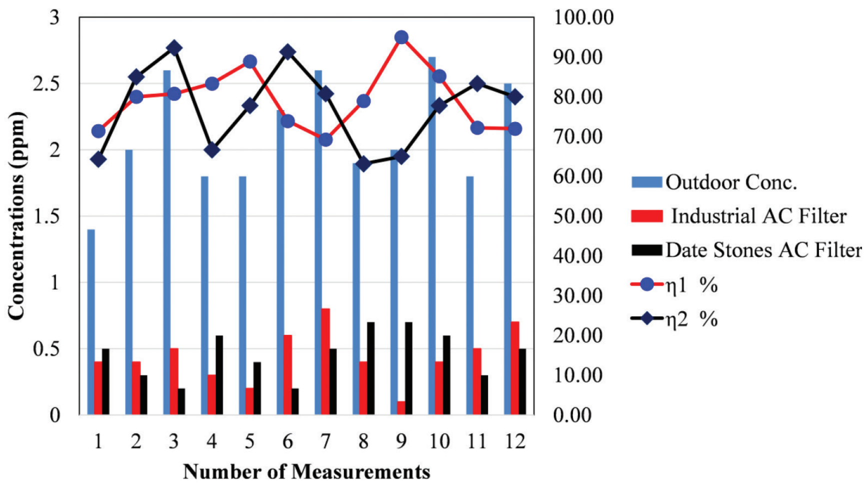


FIGURE 5. Removal efficiency of AC for CO

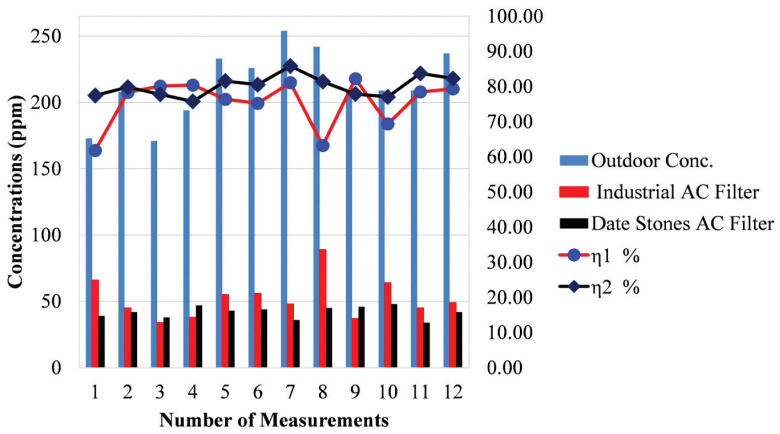


FIGURE 6. Removal efficiency of AC for CO_2

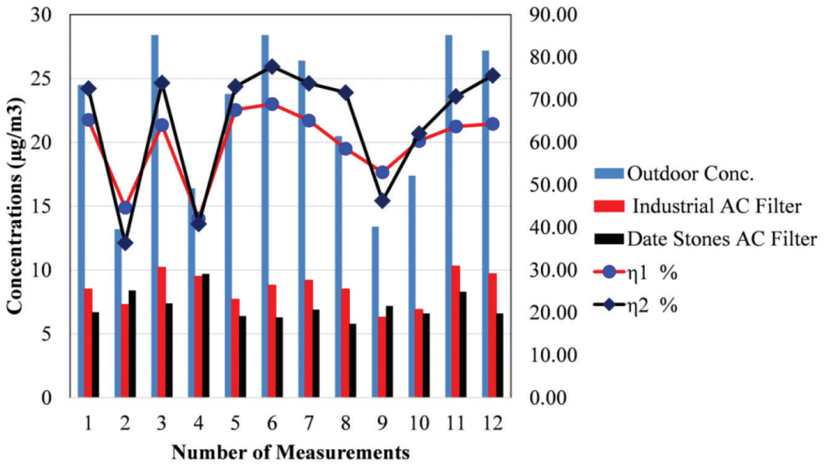


FIGURE 7. Removal efficiency of AC for CO

50% while the values for industrial AC were between 15 and 43%. The peak efficiencies resulted when the initial concentrations were high.

CONCLUSION

The results of this study have confirmed the importance of ambient air in determining the quality of indoor air and that

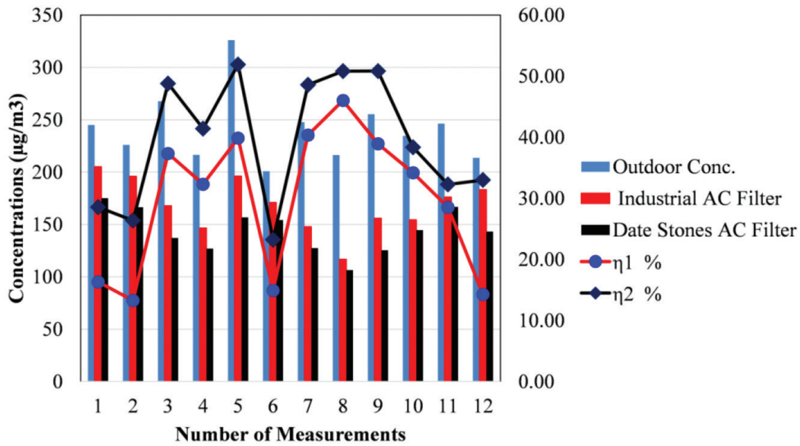


FIGURE 8. Removal efficiency of AC for CO

there is a strong correlation between outdoor and indoor air quality. Although the magnitude of existing concentrations for the critical air pollutants in outdoor/indoor air of Al-Hofuf city did not exceed the allowable limits described in national and international standards, the existing pollution is significant and cannot be ignored. Nitrogen oxides and carbon monoxide concentrations increased at the starting hours of the day, then, they fluctuated within a limited range of concentrations during the remaining hours of the day, but with decreasing trend. The reason of reduction can be attributed to the effect of the meteorological conditions. Sulfur dioxide showed a relatively constant and low concentration. AC prepared from date stones represents an effective way to control indoor air pollution caused by outdoor emissions.

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