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ORIGINAL ARTICLE **OPEN ACCESS**

Greenhouse Gases Compliance Monitoring and Emission Characteristics Analysis

Ibrahim Altuwair*
*Department of Chemical and Materials Engineering, Northern Border University, Kingdom of Saudi Arabia (KSA)
***Corresponding Author: -** I, Altuwair
*Email: Ibrahim.Altuwair@nbu.edu.sa

ABSTRACT
The environmental concerns regarding global warming has become a controversial topic around the globe. It is becoming even more important for researchers to define vital methods and achieve efficient solutions to alleviate greenhouse gases and global warming impact. In fact, the pollution in JIC is caused from several sources, (i.e. reactors, boilers, power plants and water desalination plant). This paper highlights some environmental issues in an industrial area in Saudi Arabia (Jubail Industrial City, JIC). It estimates the greenhouse gases concentrations (i.e. CO_2, SO_2, and H_2S). Nine sites are located around the JIC for monitoring and measuring gas concentrations. The FTIR used for providing the capability to monitor a variety of criteria pollutants and VOC. For the sake of clarity, the industrial environmental issues specified into air and water and the effects of each pollutant are highlighted. Additionally, the impact of harmful pollutant into environment by industrial manufacturing activities around the Jubail Industrial City (JIC) is the main reason of growing pollution problem.
Keyword(s): *Environment, Global warming, concentration, fuel, Greenhouse gases, Impact, Pollutant.*

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INTRODUCTION

Air is a mixture of many chemicals and particulate matters. They fall into 3 categories, essentially permanent, variable and very variable. Most of the very variable components are considered as primary pollutants. Such as, Carbon monoxide (CO), Sulfur Oxides (SOx). The world health organization has defined air pollution as the presence in the outdoor atmosphere of one or more contaminants such as dust, fumes, gas, mist odour, smoke, or vapour in quantities or characteristics and of duration such as to injurious to human, plant, or animal life or to property which unreasonably.

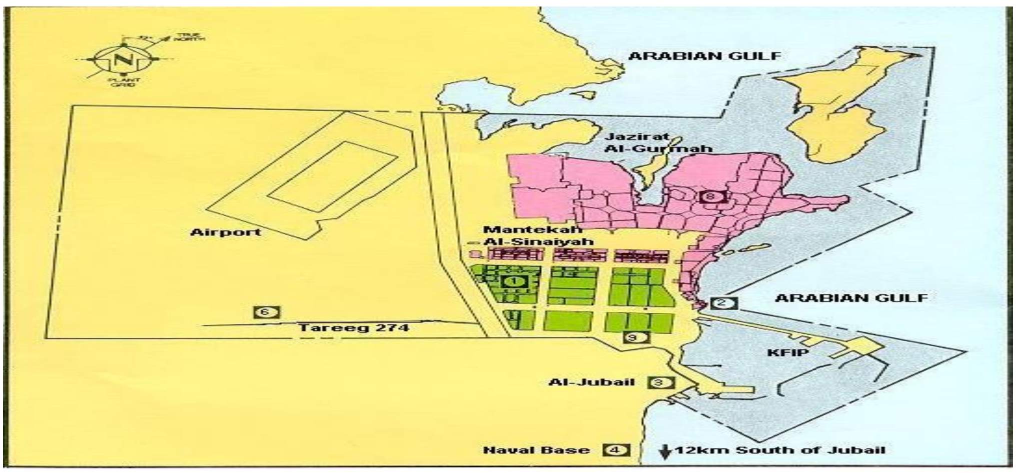

Figure 1.0: Jubail Atmospheric Monitoring Network (JAMN)

Interferes with the comfortable enjoyment of life and property. Saudi Arabia is one of the most popular industrial countries with rapid establishment of new industries. One of these industrial cities is Jubail

Industrial City (JIC) Figure 1.0. It is located near the eastern Coast (Arabian Gulf). JIC started to operate in last century including industries that potentially affect local air quality and health status of it surrounding residents. The dimension of industrial development prior to the 1970's flaring wasted resources and increased pollution.

Land use planning is a vital example for how environmental protect on has encompassed industrial development at Jubail. From the earliest concept drawings the policy was to segregate residential areas from the heavy industry, and utility plants. The industrial areas were placed in direct proximity to the industrial port facilities for easy importing and exporting. Now, however, the master Gas gathering System which is both a source of energy and supplies the NGL plants in Jubail Industrial City (JIC) has eliminated that risk. During the same period a network of environmental monitoring stations which operate 24 hours a day 7 days a week. Certain stations are dedicated to air quality monitoring. They automatically transmit data every hour on wind and dispersion characteristics. Most important, samples of particles floating in the air are collected and are analysed at the Environmental laboratory. The results are compared with reference to internationally agreed standards of safety. The daily routine work of the Environmental Laboratory also guarantees the people of Jubail, clean air and a pollution free environment. All industries are required to comply with the Royal Commission Environmental Standards (RCES).

MATERIAL AND METHODS

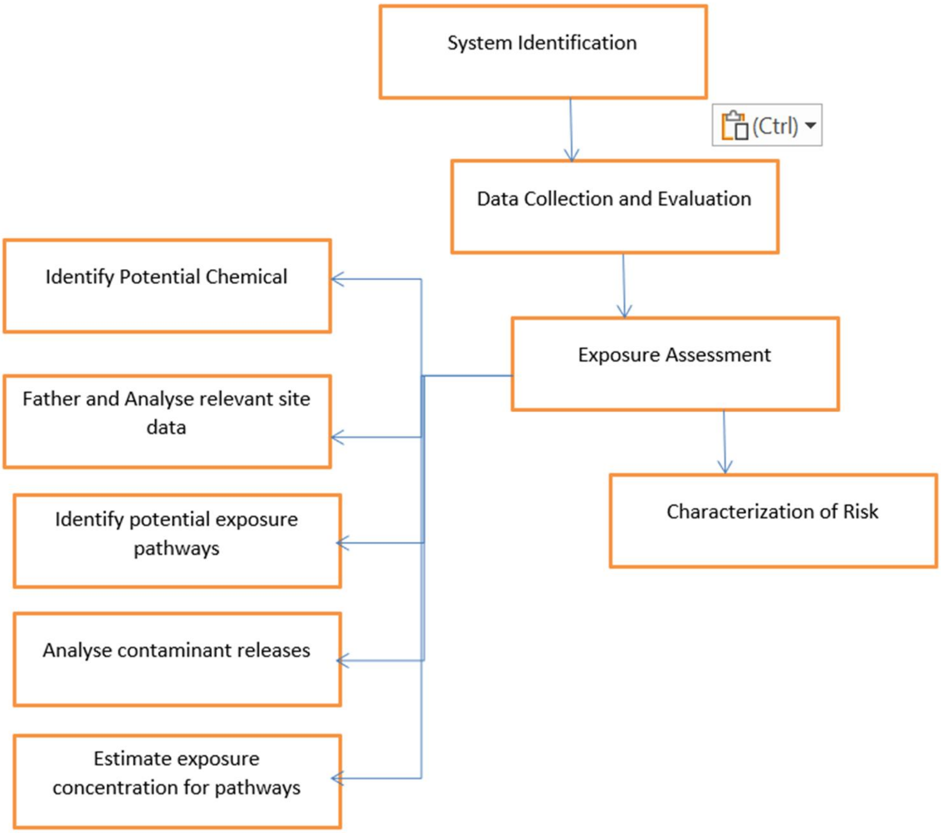

Figure 1.1: The Framework of the study experimental design

The methodology was developed to allocate limited resources (time, money, regulatory oversight, etc.) to multiple-release sites in a way that allows innovative and cost-effective decision making while ensuring that human health and environmental resources are protected. In order to meet the goal of paper, the process emphasizes the following points:

Integrates site assessment, site monitoring and remedial action selection.

Site assessment activities are focused on collecting data required to support risk-based corrective action decision. Those corrective action decisions are based on site-specific factors and compliance points directed toward cost-effective alternatives that provide a high probability of achieve an appropriate risk reduction.

Figure 1.1 illustrates the framework process diagram including data collection and evaluation. In general, it involves initial sites assessment and classification of these sites. Steps 2 and 3 involve evaluating the site using more site specific information (e.g. infiltration rate, weight.) Step 3 is likely to have more detailed site

assessment, probabilistic evaluation, and chemical fate and transport models. This is designed to be applicable for estimating receptor point concentrations as part of chemical risk assessment.
It is used average annual data and are multi-dimensional dispersion. It is very useful for engineering design problems. In addition, it can also be used to evaluate several scenarios and estimate receptor point concentrations. Thus, it provide a tool to support or/and control the maximum future concentration expected at a receptor location.

Air Quality

The air quality is one of environmental measurement tools that may indicate to the importance of air. For instance, a person whose average weight is 68 kg needs approximately 25 kg of air daily to provide his oxygen requirement. However his daily food requirement is approximately 1.5kg. This indicates his air requirement is slightly more than 15 times the food needed. This indicates why air quality is so important and any contamination needs to be so much lower in air than in food if we are to ensure that our total intake of potentially harmful substances does not put our health at risk. We can survive for a few days without food and water but not air.

Specific Details

The maximum recorded 1-hr average air temperature was 35.3°C recorded at Site 9. The minimum temperature was 15.3°C recorded at Site 6. The monthly mean temperatures ranged from 22.6°C at Site 6, to 23.8°C at Site 9. However, atmospheric Pressure and Insolation are measured at Site 1 only. Atmospheric Pressure ranged from a minimum 1011.3 mb to a maximum of 1020.1 mb with an average of the month of 1015.5 mb while solar radiation. is measured between the 6th and 17th hour of each day, throughout November. The sunniest day was the 6th with 377 Langley. The least sunny day was the 27th with 277 Langley. Total insolation for the month was recorded as 10153 Langley.In addition, the total annual rain was recorded on November 98.1 mm while total seasonal rain was 200.3 mm. Soil temperature monitored with monthly average of -5 cm soil temperature for November was 24.7 °C; but the -1 m monthly average soil temperature was 28.8 °C; and -2 m mean monthly soil temperature was 29.9 °C.
The maximum 1-hr average wind speed over the JAMN was 9.5 m/s, recorded at Site 2 on month of November. The monthly average wind speeds ranged from 1.9 m/s at Site 3 to 3.9 m/s at Site 2. The maximum 2-second wind gust was 12.8 m/s recorded at Site 4 on the 17th. The prevailing wind directions at each site were W at Site 1, 2, 4 and 6, NNW at Site 3, and N at Site 8 and Site 9. Evaporation is monitored at Site 1 only. During November 2021 total evaporation for the month was 155.9 mm. Maximum daily evaporation was recorded on the 6th with 7.7 mm and the lowest daily evaporation of 3.2 mm was recorded on the 20th.The maximum recorded 1-hr average dew point was 25.3 °C, recorded at Site 1 and the minimum 1-hr average was – 4.2 °C, recorded at Site 2. The maximum recorded 1-hr average relative humidity was 100%, recorded at Sites 1, 2 and 4 and the minimum relative humidity was 9.1 °C, recorded at Site 2. The daily horizontal visibility during the month of November remained about 10 km throughout and whole month. In our modern technological society, we need air to burn fuels for heating and for transport. To burn 0.8 litres of oil per minute needs 8.5 m3 (including excess air) of air per minute. Each mass unit of petrol needs about 15 mass units of air (stoichiometric calculation below, equation 1).

Table 1.0: Approximate composition of dry air in the troposphere

Component	vol per vol / ppm(v)	mass per vol / µgm-3	%v
nitrogen (N2)	781x103	976x106	78.1
oxygen (O2)	209.5x103	229x106	20.9
argon (Ar)	9340	16.7x106	0.934
neon (Ne)	18.36	16400	0.0018
Helium (He)	5.24	940	

$$C_8H_{16} + 12\ O_2 = 8CO_2 + 8\ H_2O \qquad (1)$$

The Jubail Air Quality Index (JAQ) is based on pollutant standards index structure that includes the following four pollutants: SO_2, O_3, and CO. A daily sub index is calculated from a segmented linear function that transforms ambient air concentrations onto a scale extending from "0" to "500", with 100 corresponding to the Royal Commission's ambient air standards, and 500 corresponding to the significant harmful levels established by the U.S. EPA. Breakpoints 200, 300, and 400 correspond to the Alert (unhealthy), Warning (very unhealthy), and Emergency (hazardous) levels used by the U.S. EPA.
A number of air quality parameters were continuously monitored at the JAMN stations during the reporting period January to December 2021. The parameters are: sulfur dioxide (SO_2), hydrogen sulfide (H_2S), ozone (O_3), carbon monoxide (CO, and atmospheric sulfates. Analyses of data from ambient air quality monitoring during

2021 are presented in the following sections including(grit, dust (diameter 1 and 76 µm)), where fume, aerosol and smoke, soot, fly ash and they are suspended in the air as solid or liquid droplets.

*According to the law of conservation of energy, solar radiation received by determining the following correlation; The E**arth = Solar energy emitted + Energy transformed into other forms**,*

S (1-A) ¶ R2 + E = 4¶R2ÓT4 (2)

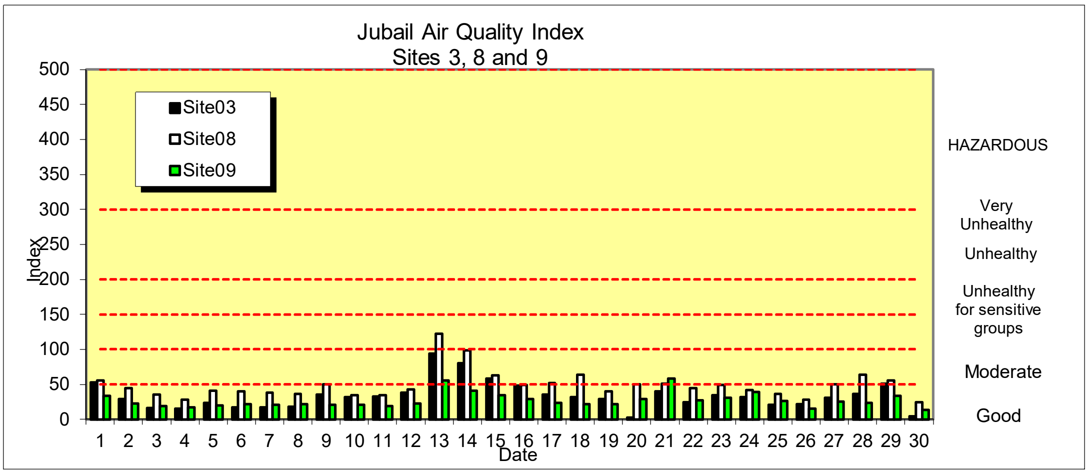

Figure 1.1a: Jubail Air Quality Index Sites 3, 8 & 9

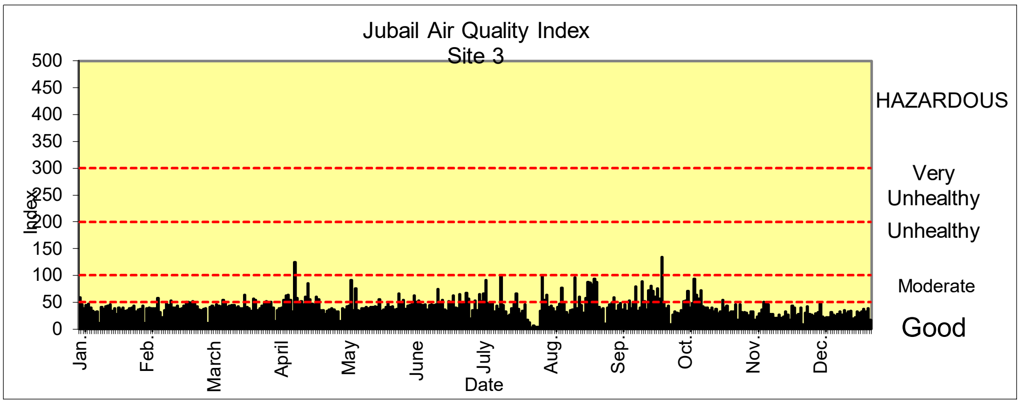

Figure 1.1b-1: Jubail Air Quality Index Sites 3

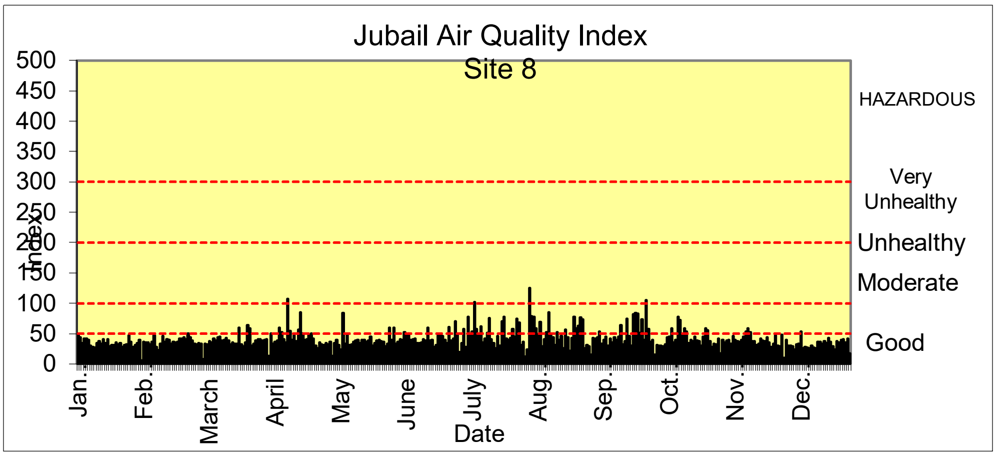

Figure 1.1b-2: Jubail Air Quality Index Sites 8

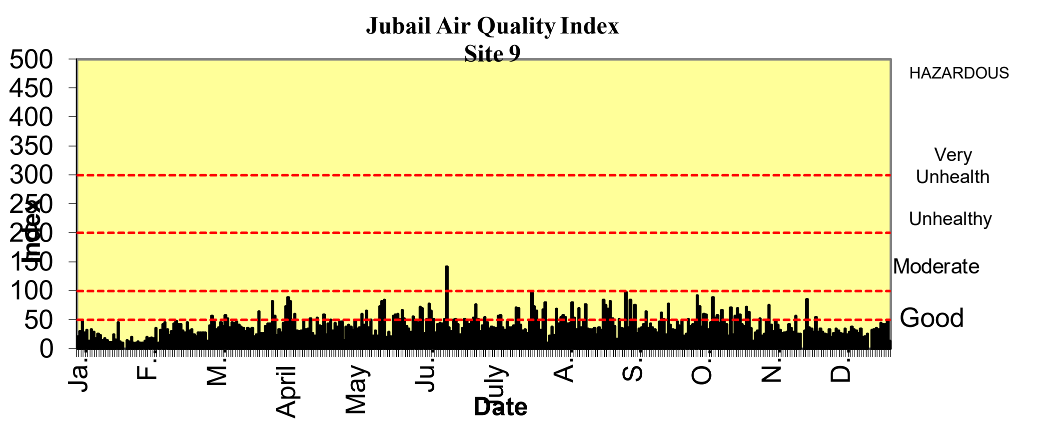

Figure 1.1b-3: Jubail Air Quality Index Sites 9

The presence of dust particles in the atmosphere may increase the temperature that lead to cause net warming or decreasing temperature that lead to net cooling on the properties of the particles and the underlying surface. However, it will also reflect heat released from earth. Thus particles with a white or grey upper surface and black lower surface would cause cooling of the earth; if this were reversed, warming of the earth would result. Table 1.1a shows typical industrial dusts and collection efficiencies for various types of gas cleaning equipment with respect to the same dust.

Table 1.1a: Typical industrial dusts classified as coarse, fine and ultra-fine

BS Sieve number	Particle Size (µm)	% by weight less than *		
		Coarse (CD)	Fine (FD)	Ultra-Fine
100 (0.06 in.)	152	-	100	-
150 (0.04 in.)	104	-	97	-
200 (0.03 in.)	76	46	90	100
	60	40	80	99
	40	32	65	97
	30	27	55	96
*	20	21	45	95
	15	16	38	94
	10	12	30	90
	7.5	9	26	85
	5.0	6	20	75
	2.5	3	12	56

Table 1.1b: Power requirements for a flow rate of various types of gas cleaning equipment

Type of equipment	Collection efficiency (%)			Approximate power requirements (kW) for a flow rate of 105 m3/h
	Coarse	Fine	Ultra-fine	
Medium efficiency cyclones	84.6	65.3	22.4	40
High efficiency cyclones	93.9	84.2	52.3	60
Self-induced spray scrubber	97.6	92.3	70.3	70
Pressure spray scrubber (medium to high energy)	99.9	99.7	99.5	150-300
Electrostatic precipitator	99.5	98.5	94.8	40
High efficiency Electrostatic precipitator	99.96	99.85	99.35	50
Venturi-scrubber (medium to high energy)	99.97	99.9	99.6	200-370
Shake type filter	99.97	99.92	99.6	50
Reverse jet filter (blow ring)	99.98	99.95	99.8	130
Reverse jet filter (nozzle)	99.98	99.95	99.8	150
Reverse pressure filter	99.98	99.95	99.8	110

A summary of the Royal Commission Environmental Guidelines (RCEG) for ambient air given in Table 1.2. Use is made of pollution roses to illustrate the direction from which the pollution originates and the amount of pollutant coming from that direction, averaged over each month of the year. Frequency distributions for all sites, for all months' data, show graphically, the mean, standard deviation, 20, 50, 80, 90 and 99 percentiles and also the maximum and minimum values attained for that parameter. Comparison data tables for manual parameters are used. Each of the monitored pollutants is discussed in details in the section below.

Table 1.2: The Environmental Guidelines for Ambient Air

Pollutant	Maximum Limit ug/m3	ppm	Average Period
CO	40,000	35.0	1 hr
	10,000	8.8	8 hrs
H2S	40	0.029	1 hr
	20	0.014	24 hrs
	50	---	1 year
	400	0.214	24 hrs
	---	0.053	1 yr
Ozone	240	0.122	1 hr
Sulphates	25	---	24 hrs
Sulphur Dioxide	1,300	0.500	1 hr
	800	0.308	3 hrs
	400	0.154	24 hrs
	85	0.033	1 yr

- 1ppm = (M / 22.4)103 µg /m3

RELEVANT STUDIES

The environmental issues caused by industrial production and pollution have stimulated scientists and professionals into atmospheric protection, including studies on air quality, monitoring chemicals and particles. Previous studies have attempted to explain side effects of some diseases result from exposure to air pollution [1]. A study of the association between long-term exposure to air pollution and particulate Ozon (O_3) [2]. According to WHO, there are more than 11 Million cases of infectious disease (e.g. Tuberculosis) worldwide related death have been reported in 2019 and 2020 [3]. A former group of researchers revealed in their study that exposure to ambient PM was significantly associated with an increased risk of monthly incidence of pulmonary tuberculosis (PTB), it increased the monthly incidence of smear-positive pulmonary tuberculosis (SPPTB) incidence per 10 µg/m3 increase [4]. However, O_3 exposure was not associated with the monthly PTB or SPPTB incidence. A study of the atmospheric patterns at a specific region and determine the long-range transport scale was revealed [5]. Using CO_2 and CH_4 levels to observe gases emission levels at specific times [5]. However, Pedro reported of wind speed influence on CO_2 and CH_4 Concentrations; a noticeable impact on pollutant concentrations has been observed [6].

In terms of collecting particulates there are several basic physical, principles which can be, and are, employed in the operation of the various types of collectors. For examples;

(1) Dry Mechanical Collectors provide a feasible technique only if one is dealing with particulates, and if there is no more than a light to moderate amount of them. Preferentially the particles are fairly large. Often, a dry mechanical collector is put ahead of a more efficient collector, on order to remove the bulk of the heavier particles and thus to increase the overall efficiency and reduce the maintenance of the system. (2) Gravity settling small particles is carried along in a moving air stream. When the velocity of that air stream is reduced many of the particles particularly the heavier ones can settle to the bottom of the collector.(3) Inertial forces as the direction of a moving air stream changes, the heavier particles have a tendency, due to their momentum, to continue in a straight line. As they leave the air stream typically collide with wall and then settle to the bottom of the collector.

(4) Filtration the air stream saturated with particulate matter passes through a porous material. The particulates are retained on the surface and then clean air is passes through. (5) Electrostatic attraction particles can be electrostatically charged. These charged particles are then attracted to objects of the opposite charge and removed from the air stream. When the two objects make physical contacts the particles are neutralized and fall to the bottom of the collector. (6) Particle enlarging when dust particles pass through a water spray a particulate -water droplet agglomerate is formed. The heavier weight of this agglomerate allows it to be more easily separated from air stream.

Table 2.1a: Air Quality Data Exceedances

Pollutant	Averaging Time	RCEG Limit	Highest Conc.	Number of Exceedances for Sites 1-9							
				1	2	3	4	6	8	9	Total
SO_2	1 hr.	500 ppb	110	0	0	0	0	0	0	0	0
	3 hrs.	308 ppb	65	0	0	0	0	0	0	0	0
	24 hrs.	154 ppb	18	0	0	0	0	0	0	0	0
H_2S	1 hr.	29 ppb	29	0	0	0	0	0	0	0	0
	24 hrs.	14 ppb	9	0	0	0	0	0	0	0	0
O_3	1 hr.	122 ppb	100	0	0	0	0	0	0	0	0
CO	1 hr.	34.8 ppm	9.4	0	0	0	0	0	0	0	0
	8 hrs.	8.8 ppm	4.1	0	0	0	0	0	0	0	0

All of these collection methods employ one or more of these principles in their operation. The efficiency of the collection tends to correspond to the size of particle; the larger, heavier particles are much more efficiently removed by all of these techniques. Additionally, these types of collectors require minimal power consumption and experience no corrosion unless a corrosive mist is incident upon them, hot and hydroscopic emissions can present problem. Also, the equipment is often large and very bulky.

Smog is most intense in the early morning and is dispersed by solar radiation. Constituents can be smoke, SO_2, unburnt hydrocarbons and NOx.

January's weather can be characterized by mild day temperatures and cool nights. The average monthly temperature ranged from 14.9 °C to 19.2 °C with an extreme maximum of 28.6 °C at Site 1. Maximum humidity was observed at Site 1 with an extreme maximum of 70.5 % for several days. The prevailing wind direction was from the west-north-west (WNW) quadrant with the average speed ranging from 12.7 m/s at Site 1 to 19.0 m/s at Site 9, gusting to a maximum of 12.8 m/s at Site 4. Daily temperature wind and rain data for Site 1 are shown in Table 2.2.

Table 2.1b: Climatological Data Summary

Site 1												
Atmospheric Temperature (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Years
Absolute Max.	28.6	34.6	37.9	43.2	45.2	47.3	49.7	48.6	46.2	45.4	37.6	31.8	2021
Mean Daily Max.	19.2	20.9	24.8	33.2	36.7	40.3	41.6	41.2	38.3	34.0	27.2	22.0	2021
Monthly Mean	14.9	16.4	19.9	25.4	30.8	33.1	35.5	34.9	31.7	27.7	21.9	17.4	2021
Mean Daily Min.	10.7	12.2	15.5	20.4	25.3	27.8	29.8	29.2	25.8	22.0	17.0	13.1	2021
Absolute Min.	5.6	2.9	7.6	10.6	19.3	20.5	25.8	25.7	20.3	16.8	7.8	6.4	2021
Relative Humidity													
Mean Relative Humidity (%)	70.5	70.2	19.5	53.9	45.0	41.1	42.2	52.1	53.7	61.4	65.1	65.8	2021
Rainfall													
Mean (mm)	23.3	3.8	6.8	1.8	0.8	0.0	0.0	0.0	0.0	0.6	24.1	10.0	2021
Wind Speed (m/s)													
Max. Gust	19.0	19.2	21.4	20.2	29.9	22.1	17.5	16.4	16.0	24.6	42.7	38.3	2021
Max. 1 Hr Avg.	12.7	12.3	15.8	12.5	13.5	13.9	12.2	11.2	11.5	11.9	17.2	11.4	2021
Monthly Mean	4.3	4.3	4.4	4.3	4.5	4.6	4.1	3.8	3.7	3.8	3.9	4.2	2021
Wind Direction													
Prevailing	WNW	NW	N	NNW	N	NNW	NNW	N	NW	NW	NW	WNW	2021

Table 2.2: Meteorology Data Summary for Site 1, November, 2021(Site # 1)

Date	Maximum Temp °C	Minimum Temp °C	Prevailing Wind Dir.	Max. Wind Sp. (m/s)	Rain Fall (mm)
1	32.0	17.2	W	4.3	0.0
2	31.5	17.3	W	4.4	0.0
3	33.4	18.5	S	4.6	0.0
4	32.1	19.5	N	5.4	0.0
5	29.9	18.9	W	7.0	0.0
6	28.8	17.9	WSW	7.4	0.0
7	28.5	16.3	W	7.3	0.0
8	30.0	15.2	W	5.1	0.0
9	31.2	14.4	SW	4.5	0.0

10	30.1	15.0	ESE	4.6	0.0
11	31.3	18.8	SSE	6.5	0.0
12	32.9	17.1	S	4.3	0.0
13	27.8	18.4	WNW	7.7	0.0
14	27.4	17.1	W	6.3	0.0
15	31.1	14.8	WSW	4.9	0.0
16	30.7	17.1	S	5.2	0.0
17	24.9	17.9	WNW	8.5	0.0
18	24.6	16.1	WNW	7.5	0.0
19	27.2	14.9	W	5.6	0.0
20	29.7	14.2	WSW	4.7	0.0
21	31.5	14.9	NNE	4.2	0.0
22	30.1	15.4	SW	4.4	0.0
23	31.9	14.0	SSW	4.4	0.0
24	32.9	16.6	S	4.2	0.0
25	33.1	16.7	S	5.4	0.0
26	30.8	16.4	S	3.4	0.0
27	26.5	16.4	NNW	4.6	0.0
28	26.8	15.1	W	5.8	0.0
29	30.5	12.4	WSW	3.6	0.0
30	29.8	15.4	S	5.9	0.0
Monthly	33.4	12.4	W	8.5	0.0

Experimental Design

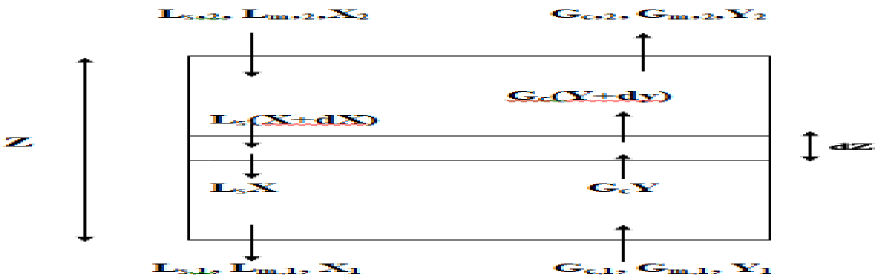

Figure 1.1: The mass transfer design of chemicals

The above figure 1.1 illustrates the mass transfer design for receptors. It is useful to describe the gas flow rates by carrier gas flow rate (G_c) the total gas flow rate (G_m)

$$G_m = G_c + G_j \qquad (3)$$

Where, G_j the molar flow rate of pollutant species j in gas phase in a similar fashion for the liquid phase

$$L_m = L_s + L_j \qquad (4)$$

Where, Lm is the total molar liquid flow rate entering or leaving the bed, Lj is the molar flow rate of pollutant species j in the liquid phase and Ls is liquid molar flow rate of the uncontaminated liquid. For the assumptions made above,

$$Ls_1 = Ls_2 = Ls \quad \text{and} \quad Gc_1 = Gc_2 = Gc \qquad (5)$$

It is useful to describe the pollutant concentration by the mol ratio X_j and Y_j, which is related to the mol fraction (x_j and y_j).

X_j mole ratio of molecular species j in liquid phase
X^* hypothetical mol ratio in liquid phase
x_j mole fraction of molecular species j in liquid phase
Y_j mole ratio of molecular species j in the gas phase
Y^* hypothetical mole ratio in gas the phase
y_j mol fraction of molecular species j in the gas phase
n_t total number of moles
n_j number of moles of molecular species j

Physically, X_J and Y_j represent the moles of molecular species j per mole of uncontaminated scrubbing liquid and uncontaminated carrier gas, respectively. Hence, for the gas phase:

$$Y_j = y_j / (1-y_j) = (n_j / n_t) / (1-n_j / n_t) \qquad (6a)$$

$$y_j = Y_j / (1+Y_j) \qquad (6b)$$

For the liquid phase

$$X_j = x_j / (1-xj) = (nj / n_t) / (1-n_j / n_t) \quad (6c)$$

$$x_j = X_j / (1+X_j) \quad (6d)$$

Since the composition variables that will be used are the mol ratios X and Y, it is necessary to express Henry's law in these variables. Using equations 1 and 6,

$$y_j = (HcL / P)x_j = H''x_j$$

$$Y_j / (1+Y_j) = H'' (X_j) / (1+X_j) \quad (7)$$

$Y_j = H''X_j (1+Y_j) / (1+X_j) = mX_j$, the absorption equilibrium line on the X-Y axes may be redrawn as

$$Y_j = mX_j \quad (8)$$

Where,

$$m = H''(1+Y_j) / (1+X_j) \cong H'', \text{ since } 0<X_j<<1 \text{ and } 0<Y_j<<1 \quad (9)$$

In this analysis it will be assumed that the equilibrium curve is linear and that its slope (m) in the X-Y coordinates can be taken as constant.

The total number of moles of pollutant lost by gas stream is equal to total number of moles of pollutant gained by the scrubbing liquid.

$$Ls (X_1-X_2) = Gc (Y_1-Y_2) \quad (10)$$

From the above the liquid to gas ratio also called the reflux ratio can be defined as

$$Ls / Gc = (Y_1-Y_2) / (X_1-X_2) \quad (11)$$

In equation (11) the reflux ratio is computed on the basis of moles. The molar flow rate of the carrier gas (Gc) and inlet pollutant concentration (Y_1) are known quantities fixed by the process to be controlled and Y_2 is dictated by the pollution regulations or company standards that needs to be satisfied. The input concentration in the liquid (X_2) is an independent parameter fixed by the performance of the treatment process. Consequently there are two unknowns in equation (11) i.e. X_1 and Ls. Designers select Ls and equation (11) determines the value of X_1.

RESULTS AND DISCUSSION

The air quality, with respect to SO_2, O_3, and CO for Site 3, were within the "Good" classification for the whole month except for eleven days when it was under the classification "Moderate" an one day under the classification of "Unhealthy" .

Site 8 and 9 also showed "Good" classifications for the whole month except for ten days when it was under the classification of "Moderate".

Nitrogen dioxide causes photochemical smog that absorbing the visible or ultra-violet energy of sunlight. It forms nitric oxide to free atoms of oxygen (O_2), which is combined with oxygen (O_2) to form the ozone (O_3). In the presence of hydrocarbons and certain other organic compounds, several chemical reactions take place identified via two stages:

Stage 1: Smog concentration is linked to both the amount of sunlight and hydrocarbons respectively.

Stage 2: The amount is dependent on the initial concentration of nitrogen oxides.

Many different substances are formed in sequence including formaldehyde, acrolein, PAN (it is one of a number of complex compounds present photochemical smog) etc. These chemicals can cause can cause severe damage to leafy plants such as tobacco, endive.

Sulfur Dioxide (SO_2)

Sulfur dioxide is one of six gaseous, sulfur compounds: the others are sulfur monoxide, sulfur trioxide, sulfur tetroxide, sulfur sesquioxide, and sulfur heptoxide. Sulfur dioxide and sulfur trioxide are the two oxides of sulfur of most interest in the study of air pollution. In the JAMN, however, only sulfur dioxide is monitored, as the effects of sulfur trioxide are considered negligible.

MAJAS Sulfur Dioxide Monitoring

The prime source of sulfur dioxide pollution in MAJAS is from the Saudi Aramco Shell Refinery Company (Sasref) Claus Sulfur Recovery. Outside the Royal Commission area, but relatively close to Jubail, are the Aramco Berri Plant to the southeast of the Madinat Al-Jubail Al-Sinaiyah (MAJAS) and the Aramco Abu Ali plant to the north. Both of these facilities are potential sources of sulfur dioxide pollution. The RCEG for sulfur dioxide specifies that the maximum 1-hour average concentration must not exceed 500 ppb more than twice in a calendar month per monitoring site. The highest 1-hour average concentration in 2021 was 288 ppb, recorded at Site 9, on the 21st of March. The highest 3-hr average concentration in MAJAS (recorded at Site 9) was 260 ppb compared to the highest allowable 3-hr average of 308 ppb, was recorded in the month of March. The highest 24-hour average was 101 ppb (RCEG maximum allowable = 154 ppb), recorded also at Site 9. The maximum allowable yearly average is 30 ppb and the highest 2021 yearly average was 6.3 ppb recorded also at Site 9.

There was no excess of the 1-hr average standard, the 3-hr average standard, or the 24-hr average standards for sulfur dioxide during 2021. The sulfur dioxide emissions from Sasref used to be chronic and whenever the wind from the NNW to N high levels of sulfur dioxide were detected by Site 9 monitoring station located about 2 km to the SE of the Sasref plant. During 2018 SO_2 excesses occurred during March only. Through the rest of the year and through 2021, the ambient air levels were within the limits. This is probably due to some modification to the Clause Sulfur Recovery Unit.

Table 2.2.1: Data summary comparison report of SO_2

	Sites							
Year	SITE01	SITE02	SITE03	SITE04	SITE06	SITE08	SITE09	
				Maximum 1-hour Sulfur Dioxide (ppb)				
2018	3.0	10.0	129.0	16.0	41.0	7.0	368.0	* *
2019	16.0	9.0	263.0	11.0	7.0	8.0	715.0	* *
2020	11.0	27.0	13.0	8.0	69.0	10.0	202.0	* *
2021	69.0	13.0	18.0	7.0	32.0	17.0	138.0	* *
				Mean Daily Maximum Sulfur Dioxide (ppb)				
2018	1.0	2.1	9.4	1.9	2.0	1.2	51.0	* *
2019	2.3	3.4	11.9	1.7	0.2	0.5	165.5	* *
2020	2.6	2.4	2.8	1.3	4.2	1.3	30.6	* *
2021	5.6	2.7	6.0	2.3	8.6	2.7	31.8	* *
	Quarterly Mean Sulfur Dioxide (ppb)							
2018	0.2	0.6	1.4	0.6	0.3	0.2	6.9	* *
2019	0.7	1.1	1.1	0.3	0.0	0.1	26.7	* *
2020	0.9	0.6	0.7	0.2	0.7	0.3	4.2	* *
2021	1.4	0.6	1.8	0.5	2.7	0.8	2.7	* *

The pollution indicates that stations in a close proximity to Sasref detect higher concentrations of sulfur dioxide. Site 9, which is down prevailing wind of Sasref, shows the highest concentrations in the NW to N sectors. This data clearly shows the main source is the Sasref plant. Figures 4.1.4 and 4.1.5 show the sulfur dioxide frequency distributions for, respectively, monthly, and yearly 2018 to date. (Site 9 distributions) shows the maximum levels of sulfur dioxide recorded were all below the maximum allowable. It shows that the yearly means for years 2018-2021 are in the region of 1 to 10 ppb for all the sites, with Site 9 recording the highest levels.

Hydrogen Sulfide (H_2S)

Hydrogen sulfide is a colorless gas having the odor of rotten eggs. The sense of smell becomes rapidly fatigued in atmospheres containing H_2S and hence cannot be relied upon to warn of the continued presence of the gas. It is a very flammable gas and can form explosive mixtures with air over a wide range of concentrations (4.3% to 45%).

Table 2.2.2 Data summary comparison report of H_2S

Year	SITE01	SITE02	SITE03	SITE04	SITE06	SITE08	SITE09	
	Maximum 1-hour Hydrogen Sulfide (ppb)							
2018	17.0	28.0	28.0	6.0	11.0	18.0	21.0	* *
2019	22.0	5.0	7.0	26.0	19.0	7.0	14.0	* *
2020	29.0	24.0	9.0	21.0	9.0	33.0	49.0	* *
2021	51.0	70.0	35.0	23.0	10.0	44.0	43.0	* *
	Mean Daily Maximum Hydrogen Sulfide (ppb)							
2018	5.4	6.6	6.0	2.1	2.3	5.7	7.2	* *
2019	3.4	2.3	4.0	3.2	3.3	3.3	4.8	* *
2020	5.3	3.6	4.4	2.9	2.9	5.8	3.5	* *
2021	27.3	29.6	29.1	20.4	7.1	29.1	26.3	* *
	Quarterly Mean Hydrogen Sulfide (ppb)							
2018	1.9	1.4	1.5	0.6	0.8	1.3	2.1	* *
2019	1.1	1.0	1.5	1.2	0.7	1.1	1.0	* *
2020	0.9	1.3	1.1	0.9	0.9	1.3	0.9	* *
2021	21.2	25.6	25.5	17.9	3.7	22.1	19.9	* *

MAJAS Hydrogen Sulfide Monitoring

The main sources of hydrogen sulfide pollution in MAJAS are emissions from the Saudi Aramco Shell Refinery Company (Sasref), wastewater treatment plants and from drainage channels.

The RCEG specifies two criteria for hydrogen sulfide. The 1-hr average criterion of 29 ppb may only be exceeded twice per calendar month per site. This standard is actually very strict, and is designed to prevent odor nuisance in the residential areas of the Industrial City. The 24-hour average maximum allowable standard of 14 ppb may not be exceeded. During 1998 there were six (6) recorded hourly averaged values greater than the RCEG maximum allowable, and no 24hour average concentrations, greater than the maximum allowable. The highest 1 hr concentration of 91 ppb was recorded at Site 3, in May. The second highest 1 hr concentration was 35 ppb recorded at Site 1 in June.

Table 2.2.2 displays the relative levels of hydrogen sulfide pollution at each monitoring station, the yearly frequency distribution, for all sites, it may be seen at a glance that Site 1 recorded the highest concentration in excess of the maximum allowable. The concentration measurement shows the yearly frequency distribution for each site and shows that mean concentrations of hydrogen sulfide have been fairly consistent over the three years period. In mitigation of the excesses of the hydrogen sulfide standard of 29 ppb maximum allowable concentration, the following information is relevant: the very strict standard of 29 ppb and 14 ppb for, 1-hr and 24-hr average respectively is designed to prevent odor nuisances. The immediately danger to life and health (IDLH) concentration of hydrogen sulfide is 300 ppm. Therefore, the occasional high concentrations of hydrogen sulfide, while they cause an odor nuisance have not been high enough to cause a health problem.

Carbon Monoxide (CO)

Carbon Monoxide is colorless, tasteless and odorless. It is chemically inert under normal conditions and has a mean life in the atmosphere of about two and a half months. On a worldwide basis, CO makes up over half of all the anthropogenic air pollutants. Carbon monoxide sources are natural as well as anthropogenic. The oxidation of methane gas from decaying vegetation and solid waste disposal is a significant source. However, the production of CO by incomplete combustion and transportation is by far the most important contributor to the CO pool.

MAJAS Carbon Monoxide Monitoring

The RCEG for CO specifies a maximum 1-hour average concentration of 35 ppm, which may only be exceeded twice per month per site. The 8-hour average is also specified, and the maximum allowable concentration for this period is 8.8 ppm. This, also, may only be exceeded twice per month per site. Any additional high values would be in violation of the guidelines.

There were no excesses of the RCEG in 2021. The maximum 1-hour average concentration was 24.6 ppm and 23.3 ppm recorded at Site 3 and site 8 in 2018 and 2020. The highest quarterly mean was 0.4 ppm also recorded at Site 3. Carbon monoxide levels can be considered as stable and occurring at very low concentrations.

Table 2.3.1: Data summary comparison report of CO

	Site							
Year	SITE01	SITE02	SITE03	SITE04	SITE06	SITE08	SITE09	
	Maximum 1-hour Carbon Monoxide (PPM)							
2018	2.6	3.4	8.9	24.6	2.1	2.9	3.1	* *
2019	2.3	2.9	5.1	4.7	1.1	2.7	2.2	* *
2020	1.3	2.6	5.3	2.9	0.7	23.3	1.7	* *
2021	1.5	2.0	4.3	2.3	0.7	5.1	2.1	* *
	Mean Daily Maximum Carbon Monoxide (PPM)							
2018	0.9	1.0	2.0	1.8	0.4	1.0	0.9	* *
2019	0.8	1.1	2.5	1.4	0.5	1.0	0.7	* *
2020	0.7	0.9	1.4	1.2	0.3	4.6	0.4	* *
2021	0.7	0.9	2.2	0.9	0.3	1.7	0.3	* *
	Quarterly Mean Carbon Monoxide (PPM)							
2018	0.3	0.3	0.3	0.3	0.2	0.3	0.3	* *
2019	0.3	0.3	0.4	0.3	0.3	0.3	0.2	* *
2020	0.3	0.2	0.2	0.2	0.1	0.5	0.1	* *
2021	0.3	0.2	0.4	0.1	0.1	0.4	0.1	* *

The CO concentrations are evenly spread throughout JAMN and at low levels. the percentile pollution rose shows higher concentrations at Site 3 primarily because of motor vehicle traffic in the Jubail town environment. it can be reaffirmed, graphically, that CO is one of the least troublesome pollutant and all the distributions are well below the RCEG 1-hr average maximum allowable level.

Atmospheric Sulfates (SO_4)

Sulfates are the water soluble fraction of suspended particulate matter containing the sulfate radical (SO_4), including but not limited to strong acids and sulfate salts as measured by the turbid metric barium sulfate method. Sulfates in the air can cause a decrease in human and animal respiratory function, aggravation of asthmatic symptoms, aggravation of cardio-pulmonary disease, damage to vegetation, degradation to visibility and property damage by corrosion.

MAJAS Atmospheric Sulfate Monitoring.

The RCEG define a maximum daily allowable concentration of sulfates in the ambient air of 25 ug/m^3. Monitoring was carried out at Site 9 only and sampling for atmospheric sulfates was conducted throughout the year and is run in conjunction with the inhalable suspended particulate sampling. A concentration of sulfates in the atmosphere is measured by taking triangular sections of each of the inhalable suspended particulate (ISP) filters and conducting laboratory analysis on them. A gravimetric value is established and divided by the volume of air, which passed through the section of ISP filter.

Table 2.4.1 Sulfate concentration (ug/m3) in ambient air at Site # 9

Date	2022	2021	2020	2019	2018
01/01	13.8	6.0	2.9	10.5	10.5
04/01	10.3	5.9	2.7	5.6	7.7
07/01	14.1	6.0	3.7	5.7	6.8
10/01	13.2	6.4	4.0	8.3	24.0
13/01	15.3	7.6	4.1	6.3	5.8
16/01	13.6	6.4	3.0	8.1	17.4
19/01	10.0	7.4	3.4	4.2	8.7
22/01	7.8	5.9	1.4	9.2	5.4
25/01	7.0	7.4	0.9	8.9	8.2
28/01	9.3	17.5	3.6	5.7	8.1
31/01	9.6	7.7	4.6	7.0	8.8
03/02	8.4	6.9	4.0	6.0	6.3
06/02	8.3	6.4	3.3	9.5	8.3
09/02	9.8	17.5	4.0	12.8	5.6
12/02	6.8	4.8	5.0	7.2	6.0
15/02	16.4	5.8	2.0	8.1	9.0
18/02	15.7	8.6	2.5	7.6	8.5
21/02	36.0	7.7	4.6	7.4	7.9
24/02	7.3	8.1	2.6	7.2	7.7
27/02	6.4	9.4	6.5	11.8	7.8
02/03	9.9	7.6	2.2	4.7	9.4
05/03	10.6	11.0	6.4	7.0	12.7
08/03	7.2	6.6	6.1	6.0	12.7
11/03	10.9	9.1	5.0	7.7	9.4

CONCLUSION

A variety of interact pollutants along with corresponding meteorological data have been investigated and discussed thoroughly in JAMN. The FTIR was used to supplement the JAMN by providing the capability to monitor a variety of criteria pollutants and VOCs, thus, the ability of FTIR to trace the VOCs being particularly useful. It was located at the RC Environmental Laboratory and Khodari Roads and Maintenance.

The Ozone exceedances can be linked almost directly to industrial production. However, the number of Ozone exceedances has risen markedly since with a 5-fold increase.

Generally there is little evidence of improvement in air quality in MAJAS. Quite the contrary there is evidence indicating deterioration, illustrated by an increase in the number of exceedances of Ozone guidelines, and increase in average NO_X and SO_2.

However, it is highly recommended to establish new sites so that the FTIR can be moved to a new site each month since there is continual industrial growth in MAJAS in all sectors. The growth has likely contributed to the increase of gases emission. Tighter scrutiny of industry will keep some emissions in check, however, self-monitoring by industry will be must effective in preventing further deterioration. For new projects and expansions and old plant also, periodic reviews of RC guidelines, against which ambient air quality can be compared.

In addition, a requirement of prospective industry applying for safe and environmentally protective location in the JIC so that any hazardous impact from the operation of the industry and appropriate remedial measures are built in the form of best available technology. The industries are also required to obtain an Environmental Permit before they commence operation.

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