Effect of Using Waste Oil As a Source of Energy in Cement Plant on Ambient Air Quality- Case Study for Al-Rashadeya Factory

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ABSTRACT
Al-Rashadeya Cement Plant is planning to use waste oils resulting from the industrial process and vehicles as an auxiliary source of energy. This study was initiated to assess the environmental impacts of burning waste oil in Al-Rashadeya cement kilns on ambient air quality. Surveys were carried out to obtain data on emission rates, area of study and metrological data. Gaussian air quality model was used to predict the effect of burning waste oil on ambient air concentrations of SO$_2$, NO$_2$ and CO. The results show that SO$_2$ and CO ambient air concentrations at ground level did not exceed the Jordanian standards in any month and at any distance from the factory. However, during the prevailing west wind, NO$_2$ concentration at ground level exceeded the allowable limits in most of the months. The populated areas around the plant will be affected by NO$_2$ emissions in case of south and north wind. In order to decrease the effect of burning process on air quality, it is recommended to increase the stack height, conduct continuous monitoring of emissions and weather conditions, and/or stopping one of the production lines for 14 days/ year during the stable conditions only.

Keywords: Air Pollution, Gaussian Model, Cement Plants, Waste Oils, Recycle, Jordan.

1. INTRODUCTION
Used oil is defined as any oil that has been refined from crude oil, or any synthetic hydrocarbon oil, that has been used, and as a result of such use, has become unsuitable for its original purpose due to the presence of impurities or the loss of original properties (Woodward, 2000). It includes used crankcase oil from automobiles and trucks, used industrial lubricating oils (such as metal working oils), and other used industrial oils (such as heat transfer fluids).

In virtually, due lubricating and industrial applications, the performance of the oil deteriorates over time as oil additives break down and as contaminants build up in the oil. Eventually, the oil must be removed from service and replaced (Karvelas et al., 1993).

The contaminants in used oil can induce a variety of illnesses and diseases for humans and other mammals through inhalation, ingestion or skin contact (Woodward, 2000). Studies have shown that a small quantity of used oil can cover a small lake and destroy the aquatic life in the lake. In large quantities, it can make water sources unfit for drinking purposes (Bamiro et al., 2004, EPA, 2008). Significant growth inhibitions and growth pattern alterations as well as susceptibility to bacterial attack were observed in the dominant diatom species in a river, which is contaminated by used oil (Ekom et al., 2003).

Used oil has been subject of concern over recent years. Issues of concern included the effectiveness of used oil recovery systems, safety and handling issues, and the appropriateness of putting used oil on roads as a dust suppressant and burning it at low temperatures (Karvelas et al., 1993, Woodward, 2000). The benefits of recycling applications are: less waste, less pollution and a more prudent utilization of precious natural resources (Harrison, 1994).

The management options for used oil include re-refining, reprocessing, burning, road oiling, and disposal (Karvelas et al., 1993, Woodward, 2000). Since the used...
oil has a great effect on human health and environment, the recycle and management of used oil is the focus of much ongoing researches.

Regeneration and reuse of waste oil as a source of energy was investigated by many researchers (Karvelas et al., 1993; Woodward, 2000; Khelifi et al., 2006). Other researchers investigated the possibility of using it in concrete mixes and they found that the used engine oil increased the slump and percentage of entrained air of the fresh concrete mix, and did not adversely affect the strength properties of hardened concrete (Hamad et al., 2003). Oil intended for disposal was used to impregnate wood shavings at room temperature and atmospheric pressure. Experimental results showed a sizable decrease of 48% (JMD, 2006).

Based on the study – carried out by Woodward Clyde Company – used oil can be combusted with minimal environmental effects if the combustion process are properly controlled (Woodward, 2000). Waste oil can be burned in variety of combustion systems including industrial boilers, space heaters, asphalt plants, steel production blast furnaces, cement and lime kilns (Aul et al., 1993). The combustion of used oil in cement kilns may have many environmental and economical benefits.

Al-Rashadeya Cement Plant (RCP) intends to use waste oils resulting from the industrial process and vehicles as an auxiliary source of energy. Waste oil will be mixed with heavy fuel oil, in order to reduce the cost of energy and to save the cost of waste disposal. RCP used to purchase about 25 ton/day of used oil and mix it with heavy fuel in the main storage tanks. The cost of waste oil is about $90/ton while the price of the heavy fuel is $250/ton, so this practice saved money and reduced the operation cost. However, upon the request of the Jordanian Ministry of Environment, this practice was stopped until an EIA study is carried out (JCF, 2006). In Jordan, the management and disposal of waste oil is controlled by regulations that aim to reduce its effects on the environment. However, since there are no environmental impact assessment studies that identify the effects of burning waste oil in cement kilns on the surrounding populated areas, this reuse alternative is always rejected by inhabitants, and by environmental pressure groups (JFC, 2006).

The purpose of this study is to evaluate the effects of burning waste oil in Al-Rashadeya cement plant on ambient air quality and to determine the required mitigation measures to reduce these effects.

2. DESCRIPTION OF THE STUDY AREA

The factory lies in south of Jordan at about 200 km south of Amman as shown in Figure (1). The plant produces an estimated amount of two million tons of cement annually by two production lines (A and B), and consumes about 1140 ton/day of heavy fuel.

The climate at the plant area is classified as arid with hot summer and mild to cold winter. The average monthly wind speed ranges from 2.7 - 5.0 m/s. The average rainfall is about 166 mm/y with average humidity of 48% (JMD, 2006).

The factory site is surrounded by several settlements, these are, Al-Rashadeya and employees housing to the north of the site, and Al-Qadisyah to the south, while Dana natural reserve and Dana village are located on the west of the factory site. The populations of the major settlements within the study area are presented in Table (1) (DOS, 2006).

3. MODELING OF POLLUTANTS EMISSIONS

The most popular and commonly used model for regulatory purposes is the Gaussian steady-state model. It provides a steady-state solution to the transport and diffusion equations. Many practical models were based on Gaussian assumptions and were recommended by EPA such as Complex Terrain Dispersion Model and Offshore and Coastal Dispersion Model (EPA, 2005).

Many studies were carried out to compare the results of Gaussian model with the measured ambient contaminants. The reported results proved that Gaussian model was capable of accurately predicting the ground-level concentration profile for ground level and elevated sources (Shieh et al., 1972; Melli et al., 1979; Islamm, 1999; Haan et al., 2001, Kimmel et al., 2003, Baroutian et al., 2006, Sriram et al., 2006).

According to the Gaussian model, the spatial dynamics of pollution dispersion is described by the following equation (Vesilind, 1983):

\[ C_{(x,y,z)} = \frac{Q}{2\pi\sigma_y\sigma_z} \left[ e^{-0.5\frac{(y-\mu_y)^2}{\sigma_y^2}} + e^{-0.5\frac{(Z-H)^2}{\sigma_z^2}} \right] \]

(1)
Where:

\( C(x,y,z) \): Concentration at the interest point in the \( x, y, \) and \( z \) coordinates space, in g/m\(^3\), \( x \) is downwind, \( y \) is the horizontal cross wind, and \( z \) is in the vertical direction.

\( Q \): Emissions rate from the stack, g/sec.

\( H \): Effective stack height (stack's height plus plume rise)

\( u \): Average wind speed at stack level, m/sec.

\( \sigma_y \) and \( \sigma_z \): Standard deviation of the dispersion in \( y \) and \( z \) directions respectively.

When the plant used waste oil as a source of energy, the emissions rates of sulfur dioxide (SO\(_2\)), carbon monoxide (CO), and nitrogen dioxide (NO\(_2\)) were measured directly from the two stacks (A and B) (JCF, 2006). The obtained emission rate for each month was used to estimate the air quality in the surrounding areas by applying Gaussian model. Average flow rate of gases effluent of 600,000 m\(^3\)/hr (167 m\(^3\)/sec) for each stack was used in the modeling. To determine the plume rise, many if not most of the air dispersion models developed between the late 1960s and the early 2000s used what are known as the Briggs equations (Beychok, 2005). Briggs' equations are recommended to estimate the plume rise, so these equations were used in this model as shown in equation 2 and 3 (Stern et al., 1994):

\[
H = h' + \frac{38.71 F^{3/5}}{u} \tag{2}
\]

For \( F \) equals or greater than 55, and

\[
H = h' + \frac{21.425 F^{3/4}}{u} \tag{3}
\]

For \( F \) less than 55,

Where:

\( H \): Effective stack height (m),

\( h' \): Physical stack height (m),

\( u \): Monthly average wind speed (m/s).

\( F \): Buoyancy flux parameter (m\(^4\)/s\(^3\)), and is calculated as:

\[
F = \frac{g \cdot V_s \cdot d^2 \cdot (T_s - T_a)}{4 \cdot T_s} = 2.45 V_s \cdot d^2 \cdot (T_s - T_a) / T_s \tag{4}
\]

g: acceleration due to gravity (9.8 m/s\(^2\)).

\( T_s \): Stack gas temperature in (K).

\( T_a \): Ambient air temperature (K).

\( V_s \): Stack gas exit velocity (m/s).

\( d \): Stack exit diameter (m).

The terms \( \frac{38.71 F^{3/5}}{u} \) and \( \frac{21.425 F^{3/4}}{u} \) in equations 2 and 3 represent the plume rise vertical height.

The stacks gas temperatures (92 °C and 101°C for stack A and B respectively) determined by the Royal Scientific Society (RSS), were used in the model. The physical stack height of 62 m was used to calculate the effective stack height according to equations 2 and 3.

All Climatic data that include wind speed, wind direction, rainfall, temperature, solar intensity, and humidity for all months were obtained from Jordan Meteorological Department (JMD, 2006). In order to determine the prevailing wind, and other wind directions, the available data listed in Table (2) was used to draw the wind rose for the study area.

Stability classes were defined for different meteorological situations, characterized by wind speed and solar radiation during day time and cloud cover during night time. Based on the stability conditions, dispersion coefficients were determined using Pasquill-Gifford method (Stern et al., 1994).

The stability condition was class B during April, May, June, July, August, September, and October, and was class C during January, February and December, while it was class B-C during March and November.

4. RESULTS AND DISCUSSIONS

4.1 Stacks Emissions

The maximum total concentration of SO\(_2\) (18 mg / m\(^3\)) from the two stacks was measured in July (Fig. 2). This value is below the limit of 6500 mg/m\(^3\) specified in the Jordanian standards (JS 1189/1999).

For carbon monoxide (CO), the emissions ranged from 446 mg/m\(^3\) in October to 1751 mg/m\(^3\) in August (Fig. 3). The sum of emissions from both stacks was higher than the allowable limits except in March and October.

Figure (4) shows that the total emissions of NO\(_2\) from both stacks ranged from 449 mg/m\(^3\) in March to 1802 mg/m\(^3\) in June, which are below the Jordanian standards (1800 mg/m\(^3\)) except in June.

The variation in emission rates between the different months is attributed to the variation in the production quantities, which vary in response to the demand. The same reason explains the differences in emission rates between the two production lines.

4.2 Model Results

During January, February and December, the concentration of NO\(_2\) was zero at distance up to 750 m
away from the stack location, while in the other months the concentration was zero at a distance up to 500 m. The difference in NO\textsubscript{2} concentrations during these months is related to two factors: the difference in the stability conditions, and the emission rates from the stacks. Low ground level concentration in March and July (Fig. 5) was attributed to the low emissions rate of NO\textsubscript{2} from the stacks during these months. It was noticed that the ambient air concentration was higher at the plume center (y=0) and decreased as the crosswind distance (y) increased.

The maximum NO\textsubscript{2} ambient air concentration (897 µg/m\textsuperscript{3}) occurred in June at about 1.5 km away from the stack location, while the lowest maximum value (198 µg/m\textsuperscript{3}) occurred in March at about 1 km away from the stack location (Fig. 5). The maximum ground level concentration exceeded the allowable Jordanian standards during most of the months. However at 4 km downwind of the stack location, the concentration decreased to lower than the standard limit in all months.

The maximum SO\textsubscript{2} ambient air concentration (7.91µg/m\textsuperscript{3}) was found in July at downwind distance of 1.25 km (Fig. 6). Obviously it is below the Jordanian standards limit for an exposure of one hour duration (786µg/m\textsuperscript{3}).

The maximum CO ambient air concentration at ground level (885µg/m\textsuperscript{3}) occurred in August at a downwind distance of about 1.5 km (Fig. 7). The value is below the Jordanian standards. The SO\textsubscript{2} and CO concentrations were always less than the Jordanian standards during all months and at all distances.

### 4.3 Effects of Gases Emission on the Surrounding Communities:

The plant site is surrounded by the villages of Al-Rashadeya, Al-Qadisiyah and Dana, in addition to the employees housing.

Al-Rashadeya village and the employees housing are located at the northern side of the factory and therefore subject to the effect of the emissions in case of south winds only. From the wind rose characteristics, about 3% of the annual wind will carry pollutants to the employees housing and Al-Rashadeya village. The results of the model indicated that the concentrations of SO\textsubscript{2} and CO were lower than the Jordanian standards. Consequently these pollutants are not expected to cause any environmental problems to the surrounding communities.

The resulting calculations for air pollutant concentrations are often expressed as an air pollutant concentration contour map in order to show the spatial variation in contaminant levels over a wide area under study. In this way the contour lines can overlay sensitive receptor locations and reveal the spatial relationship of air pollutants to areas of interest.

Figure (8) shows NO\textsubscript{2} concentrations plotted on contour maps in case of south wind direction; it shows also the location of Al-Rashadeya and employee's houses.

In case of south winds, the employees housing will be affected by NO\textsubscript{2} emissions during May, June, August and November. During these months the concentration was higher than the maximum allowable limit according to the Jordanian standards for 1 hour exposure (400µg/m\textsuperscript{3}). Al-Rashadeya village will be affected only during February and April for the same wind direction. It is worthy to point out that only about 3% (11 days) of the annual wind (S and SSW) is blowing towards Al-Rashadeya and the Employees houses.

Al-Qadisiyah, which is the largest village in the area with about 7000 inhabitants, is located at the south of the factory. The distance between the cement factory and the northern side of the village is only about 2.4 km. From the wind rose characteristics, about 1% of the wind blows from the north direction. This means that Al-Qadisiyah village, which is located in the downwind direction will be subject to the effect of the factory for about 3 days during the whole year.

Figure (9) shows the ambient air concentrations of NO\textsubscript{2} in case of north wind during all months. The concentration in Al-Qadisiyah village seems to exceed the Jordanian standards only during February, June, August and December.

According to the Jordanian standards, three violations are permitted during 30 successive days.

Dana reserve is located at the southwest direction of the factory. The distance between the factory and the village is about 3 km. From the wind rose data, Dana village is always upwind and most likely will not be affected by emissions from the cement plant during the period of the prevailing west wind. The distance between Dana location and the plume centerline (x-axis) is about 520 m (y), and therefore it will not be affected by the east winds also.

### 4.5 Required Measures to Reduce the Emissions:

Based on the obtained results, the plant is expected to
affects on the populated areas during the north and south wind directions. In order to decrease the concentration of the emitted gases in the atmosphere of this area to the limit of the Jordanian standards, two solutions are suggested.

1. Raising of the stack height will decrease the ground level concentration. By applying Gaussian model, it was found that raising the stack height to 151 m is sufficient to achieve the standard limits.

2. Stopping one of the production lines during north and south winds will reduce the emissions to about 50%, so that the ambient NO₂ concentration will not exceed the standards. The required stopping period will be about 14 days/year.

The managers and / or decision makers of the plant might choose one of the two suggested solutions based on economical and social considerations.

5. CONCLUSIONS

From the analysis of the obtained results, it is predicted that burning of used oil in the cement kilns at Al- Rashadeya is an attractive option as it will reduce its effects on human health and the local environment. Burning this toxic substance in well controlled conditions will leave no residues and will save the cost of disposal. In comparison with other management and disposal options, this suggested practice will be the most suitable environmental and economical solution. Proper operational controls, adequate stack height, and continuous monitoring of emissions and weather conditions will minimize the effect of burning process on the ambient air quality.

Stability condition could be used as a control parameter to decrease the concentration of pollutants caused by the burning process. To achieve this purpose, it was recommended to stop one of the production lines for 14 days / year during the time of north and south wind only.

<table>
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<tr>
<th>Location</th>
<th>Population</th>
<th>Distance to the cement factory (km)</th>
<th>Direction</th>
<th>Elevation above sea level (m)</th>
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<tr>
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<td>North</td>
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<tr>
<td>Employees Housing</td>
<td>Not available</td>
<td>1.0</td>
<td>North</td>
<td>1570</td>
</tr>
<tr>
<td>Al-Qadisiya</td>
<td>6933</td>
<td>2.4</td>
<td>South</td>
<td>1480</td>
</tr>
<tr>
<td>Dana Village</td>
<td>250</td>
<td>2.2</td>
<td>West</td>
<td>1270</td>
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</table>

Source (DOS, 2006).

<table>
<thead>
<tr>
<th>Direction</th>
<th>Percentage of time %</th>
<th>Direction</th>
<th>Percentage of time %</th>
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<tr>
<td>Total</td>
<td>100%</td>
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</tr>
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</table>

Source (JMD, 2006).
Figure 1: location map of the cement plant at Al-Rashadeya
Figure 2: SO\textsubscript{2} Emissions from the stacks

Figure 3: CO emissions from the stacks
Figure 4: NO$_2$ emissions from the stacks

Figure 5: Maximum ground level concentration of NO$_2$. 
Figure 6: Maximum ground level concentration of SO₂

Figure 7: Maximum ground level concentration of CO
Figure 8a: NO$_2$ ambient air concentration during south wind in January

Figure 8b: NO$_2$ ambient air concentration during south wind in February

Figure 8c: NO$_2$ ambient air concentration during south wind in March
Figure 8d: NO$_2$ ambient air concentration during south wind in April

Figure 8e: NO$_2$ ambient air concentration during south wind in May

Figure 8f: NO$_2$ ambient air concentration during south wind in June
Figure 8g: NO₂ ambient air concentration during south wind in July

Figure 8h: NO₂ ambient air concentration during south wind in August

Figure 8i: NO₂ ambient air concentration during south wind in September
Figure 8j: NO$_2$ ambient air concentration during south wind in October

Figure 8k: NO$_2$ ambient air concentration during south wind in November

Figure 8L: NO$_2$ ambient air concentration during south direction in December
Figure 9-a: NO$_2$ ambient air concentration during north wind in January

Figure 9-b: NO$_2$ ambient air concentration during north wind in February

Figure 9-c: NO$_2$ ambient air concentration during north wind in March
Figure 9-d: NO$_2$ ambient air concentration during north wind in April

Figure 9-e: NO$_2$ ambient air concentration during north wind in May

Figure 9-f: NO$_2$ ambient air concentration during north wind in June
Figure 9-g: NO$_2$ ambient air concentration during north wind in July

Figure 9-h: NO$_2$ ambient air concentration during north wind in August

Figure 9-i: NO$_2$ ambient air concentration during north wind in September
Figure 9-j: NO$_2$ ambient air concentration during north wind in October

Figure 9-k: NO$_2$ ambient air concentration during north wind in November

Figure 9-L: NO$_2$ ambient air concentration during north wind in December
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* Osmanlı صناعية: تأثيرات الأليوت في عملية التسميد

تَأَدَّبَتْ

قُصُورُ الكَوَازِمُ لِلدِّيْنَةِ، ودَافِعَتْ عَنْ الرِّجَالِ، وقَدْ بَلَغَتْهَا الدُّلْجَةُ وَالقَدْرُ، وَالسَّحْرُ.

* لَهَا صَنُّوْرُ: تأثيرات الأليوت في عملية التسميد

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