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MODELING AIR POLLUTION DUE TO OPEN BURNING OF SCRAP TIRES IN RHINEHART USA

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ABSTRACT

With approximately one scrap tire being generated per person each year in the USA, scrap tires present a disposal problem. Uncontrolled open burning of tires produces many toxic products of incomplete combustion into the atmosphere. Air emissions from open burning of tires have been shown to be more toxic than those from a combustor regardless of the fuel. Emissions from open tire fire include pollutants such as particulates, carbon monoxide, sulfur oxides, volatile organic compounds (VOCs), polynuclear aromatic hydrocarbons (PAHs) and metals including arsenic and lead. These emissions from an open tire fire can post significant acute and chronic health hazards to firefighters and nearby residents. Therefore the ability to simulate air pollution scenarios that may arise from this source of open burning of tires is urgently needed in order to provide a means for mitigation and protection. This paper will present the application of a suite of air pollution models known as ISC-AERMOD View, which is developed by Lakes Environmental Software in collaboration with the United States Environmental Protection Agency (USEPA). This package combines three of the most versatile air dispersion models available, namely The Industrial Source Complex - Short Term regulatory air dispersion model (ISCST3), "AERMOD" and The Industrial Source Complex - Plume Rise Model Enhancements (ISC-PRIME). A case study on simulating the air pollution scenarios due to the uncontrolled open tire burning known as the Rhinehart Tire fire in Virginia, USA will be presented. A total of five million scrap tires burned continuously for eight months from 31 October 1983 to 4 July 1984, contributing severe air pollution over an extended period. Good agreement between simulated air pollutant concentrations and concentrations measured by USEPA provides an indication of confidence in the robustness of ISC-AERMOD. It is hoped that application of this air pollution suite in Malaysia will be possible soon.

INTRODUTION

Open burning can pose to be more dangerous due to the material burned such as scrap tires and inorganic agricultural waste such as agricultural plastic film which may release more deadly toxic chemicals. It can be done in open drums or baskets, in fields and yards, and in large open dumps or pits. Materials commonly disposed of in this manner include municipal waste, auto body components, landscape refuse, agricultural field refuse, wood refuse, bulky industrial refuse, and leaves.

USEPA's current regulations prohibit open burning of hazardous waste. One exception is for open burning and detonation of explosives, particularly waste explosives that have the potential to detonate, and bulk military propellants which cannot safely be disposed of through other modes of treatment.

Ground-level open burning emissions are affected by many variables, including wind, ambient temperature, composition and moisture content of the debris burned, and compactness of the pile. In general, the relatively low temperatures associated with open burning increase emissions of particulate matter, carbon monoxide, and hydrocarbons and suppress emissions of nitrogen oxides since it cannot achieve a complete combustion. This section will only concentrate on the open burning of scrap tires.

Approximately 240 million vehicle tires are scrapped annually in the United States. Although viable methods of reclamation exist, less than 25 percent are re-used or re-processed. The remaining scrap tires are discarded in illegal dumps, above ground stockpiles, or landfills. However, in the past few years, many landfills have refused to accept tires because they present not only a disposal problem (statute prohibited the disposal of whole tires after 1993 in permitted solid waste disposal site) but health related problems. Therefore, facilities disposing of tires have increased their fees, resulting in the creation of tire stockpiles and illegal dumps. These stockpiles present a significant risk to the environment and public health if managed improperly.

Tires are highly combustible. They generate a large amount of heat when burned which makes them extremely difficult to extinguish. Some tire fires can even continue to burn for months. An example is the Rhinehart fire in Winchester, Virginia which burned for nearly nine months. This uncontrolled burning of tire piles produces smoke and toxic air pollutants such as benzene and polycyclic aromatic hydrocarbons (PAH). The intense heat leads to the generation of pyrolytic oil that mixes with extinguishing material, contaminating surrounding soils, surface waters and groundwater. Table 1 depicts the typical composition of a passenger tire.

Table 1: Typical tire composition: passenger tire recipe

Material	Percentage	Material	Percentage
Styrene Butadiene	46.78%	Stearic Acid	0.94%
Carbon Black	45.49%	Antioxidant 6C	1.40%
Aromatic Oil	1.74%	Wax	0.23%
Zinc Oxide	1.40%	Accelerator CZ	0.75%
Sulfur	1.17%		

(Source: LEA Advisory, 1997)

In order to prevent uncontrolled open tire burning, the Scrap Tire Management Council has recommended a few guidelines for the tire storage site. Table 2 shows the guidelines which were developed with the contribution of over a dozen experienced fire chiefs and emergency response personnel.

Table 2: Guidelines set by the Scrap Tire Management Council for controlled open tire burning

No.	Guidelines
1.	tire piles be limited to 6m in height with maximum outside dimensions of 76m by 6m.
2.	the edges of the pile should be at least 15m from the perimeter fence and the area should be free of debris and vegetation
3.	interior fire breaks should be at least 18m
4.	the area extending 60m from the outside perimeter of the piles should be devoid of any vegetation
5.	buildings, vehicles, etc. should be at least 60m from the piles
6.	the site should be flat, with a concrete or hard clay surface and should be designed to capture and contain water run-off
7.	scrap tire storage should not be on wetlands, floodplains, ravines, canyons or on any steeply-graded surfaces
8.	any open-air burning should be at least 305m from the tire piles
9.	heat generating devices (e.g. welders) should not be within 60m of the pile and
10.	lightning rods should be installed, but away from the tire piles

METHODOLOGY

ISC-AERMOD View was developed by Lakes Environmental Software and since then its superiority was recognized by consultants and academics. It had been selected as the tool of choice for air dispersion modeling across all of the 39 regions in China. It was also announced that the U.K. Meteorological Office will be teaming up with Lakes to provide software, services, meteorological data, and training using ISC-AERMOD View.

ISC-AERMOD View is a complete and powerful Windows air dispersion modeling system which seamlessly incorporates three popular U.S. EPA models into one interface: ISCST3, AERMOD and ISC PRIME.

(i) The Industrial Source Complex - Short Term regulatory air dispersion model (ISCST3) is a Gaussian plume model and is widely used to assess pollution concentration and/or deposition flux on receptors from a wide variety of sources.

(ii) AERMOD is the next generation air dispersion model which incorporates planetary boundary layer concepts.

(iii) The Industrial Source Complex - Plume Rise Model Enhancements (ISC-PRIME) dispersion model is similar to the ISCST3 model but contains enhanced building downwash analysis.

Since this paper won't involve any building downwash, ISC-PRIME won't be used in our simulation. Both ISCST3 and AERMOD models are based on the Gaussian Plume Model. For a steady-state Gaussian plume, the hourly concentration at downwind distance x (m) and crosswind distance y (m) is given by (USEPA 1995b):

$$\chi = \frac{QKVD}{2\pi u_s \sigma_y \sigma_z} \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right] \qquad (1)$$

where:

Q = pollutant emission rate (mass per unit time)
K = a scaling coefficient to convert calculated concentrations to desired units (default value of 1x 10^6 for Q in gs^{-1} and concentration in μgm^{-3})
V = vertical term
D = decay term
σ_y, σ_z = standard deviation of lateral and vertical concentration distribution (m)
u_s = mean wind speed (ms^{-1}) at release height

Equation (1) is a basic formula of the model for point sources, examples of which are chimney and smokestacks in ISCST3 model. In the case of the AERMOD model, it contains new or improved algorithms from the ISCST3 model.

The area source model is based on a numerical integration over the area in the downwind and crosswind directions of the Gaussian point source plume formula given in equation (1). The ground-level concentration at a receptor located downwind of the source area is given by a double integral in the downwind (x) and crosswind (y) directions as follows:

$$\chi = \frac{Q_A K}{2\pi u_s} \int_x \frac{VD}{\sigma_y \sigma_z} \left(\int_y \exp\left[-0.5\left(\frac{y}{\sigma_y} \right)^2 \right] dy \right) dx \qquad (2)$$

where:

Q_A = area source emission rate (mass per unit area per unit time, $gs^{-1}m^{-2}$)
K = units scaling coefficient (Equation (1))
V = vertical term
D = decay term as a function of x.

The ISC-AERMOD View model user's guide (Thé et al., 2002) may be consulted for additional information on how to use the model. Even though the ISC-AERMOD View is very flexible, there are limitations and uncertainties because of some assumptions and constraints in its calculations.

CASE STUDY

This section will present some simple preliminary applications of ISC-AERMOD View by using the area source approach in the burning of scrap tires in a conceptual case and an actual scenario. The estimation of source parameters will be discussed in this section. The concentrations of lead will be estimated for averaging period of 1 hour.

Conceptual Case Study

A controlled burning of scrap tires will be discussed in this section. The size of the tire pile is chosen as $456m^2$ which is a maximum area set by the Scrap Tire Management Council for controlled scrap tires burning (76m*6m) as mentioned in Table 2. Rectangular area sources will be used in this case study during the simulation. Two rectangular area sources are used with each area size $228m^2$ (38m*6m) instead of one area source with the area of 76m*6m to make sure the ratio of rectangular area source is 10 to 1.

Qualitative data on the open burning of scrap tires is limited to one recent study funded by the USEPA's Air and Energy Engineering Research Laboratory (AEERL). The study identified and quantified the emissions of organic and inorganic compounds from the simulated open burning of tires comprised of rubber only. Steel belted tires were not tested. Emission factors were developed in the report for large "chunks" of tires that are burned, and for smaller slices or "shredded" tires.

It should be kept in mind that emissions from burning tires are generally dependent on the burn rate of the tire. A greater potential for emissions exists at lower burn rates, such as when a tire is smoldering, rather than burning out of control. Although there are many chemicals released during the burning of tires, we will only consider the emission of lead in this study. Several emission factors for the chemical released are shown in Table 3.

From Table 3, it can be seen that 0.34 mg of lead will be released into the air when 1 kg of tire is burned in the form of "chunks". It is assumed we have a burning rate of 400 kg tires $hour^{-1}$. Therefore, the emission rate for this case is estimated at around $3.78*10^{-5}$ gs^{-1}. The emission flux is required for area source. Therefore, the emission flux is around $1.66*10^{-7}$ $gs^{-1}m^{-2}$ for each area. Single wind direction is used with a wind speed of $3ms^{-1}$ and mixing height of 100m.

Table 3: Emission factors from open burning of tires

Tire Condition	Chunk [a]		Shredded [a]	
Pollutant	$\frac{mg}{kg tire}$	$\frac{lb}{1000 tons tire}$	$\frac{mg}{kg tire}$	$\frac{lb}{1000 tons tire}$
Aluminum	3.07	6.14	2.37	4.73
Antimony [b]	2.94	5.88	2.37	4.73
Arsenic [b]	0.05	0.10	0.20	0.40
Barium	1.46	2.92	1.18	2.35
Calcium	7.15	14.30	4.73	9.47
Chromium [b]	1.97	3.94	1.72	3.43
Copper	0.31	0.62	0.29	0.58
Iron	11.80	23.61	8.00	15.99
Lead [b]	0.34	0.67	0.10	0.20
Magnesium	1.04	2.07	0.75	1.49
Nickel [b]	2.37	4.74	1.08	2.15
Selenium [b]	0.06	0.13	0.20	0.40
Silicon	41.00	82.00	27.52	55.04
Sodium	7.68	15.36	5.82	11.63
Titanium	7.35	14.70	5.92	11.83
Vanadium	7.35	14.70	5.92	11.83
Zinc	44.96	89.92	24.75	49.51

[a] Values are weighted averages
[b] Hazardous air pollutants listed in the *Clean Air Act.*
(Source: USEPA, 1995a)

Actual Case Study – Rhinehart Tire Fire

A fire of unknown origin began on October 31, 1983 in a dump in Winchester, Virginia, USA. This event became known as the Rhinehart Tire Fire. The dump contained approximately 5 million scrap tires over a 1.6-hectare [16000 m^2] site situated in a sparsely populated rural area. The fire broke out in the tire storage area and burned until July 4, 1984 (USEPA, 1997). The dispersion pattern of the pollutant namely lead will be simulated in this scenario. The tire condition is assumed to be in chunk.

Since the total area size is approximately 16000m^2. The area is assumed to be rectangular with the length of 128m and the width of 125m. The total days of burning are around 246 days whilst the total tire burned is approximately 5 million. The average weight of a tire is 7 kg (USEPA, 1995a). Therefore it is assumed that the total weight of the burned tire is around 35 million kg. The burning rate of the fire is calculated as 5928.2kg tires $hour^{-1}$.

$$\text{The emission rate of lead} = \frac{0.34\text{mg}}{1\,\text{kg tire}} * 5928.2\,\text{kg tires hour}^{-1}$$

$$= 5.6*10^{-4}\,gs^{-1}$$

The emission flux of lead in the area = $3.5*10^{-8}\,gs^{-1}m^{-2}$

It is assumed that the fire to be smoldering. Therefore, the release height is set at zero.

The actual meteorological parameters were taken from the Meteorological Resource Center website (WebMET, 2002) in "Samson" format. This website is the largest online meteorological center with compiled meteorological data of USA in many different file formats. The weather station selected is the Washington DC Dulles international airport. The anemometer height of this station is 6.1m. Since the fire ranged from the year of 1983 to 1984, two scenarios will be simulated with meteorological data of the year of 1983 and 1984. These "Samson" meteorological data are then inserted into a program called Rammet View – a precursor software for ISC-AERMOD View to estimate the mixing height and then generate the required meteorological data format for ISC-AERMOD View. More information about this software can be view at PCRammet User's Guide (USEPA, 1999). Figure 1 shows the annual wind rose of the year of 1983 and 1984 of the site. These wind rose diagrams are simulated by using WRPLOT View, another sub-software of ISC-AERMOD View. As seen in Figure 3.1, the wind rose patterns in both years are very similar where majority of the winds are blowing from north west.

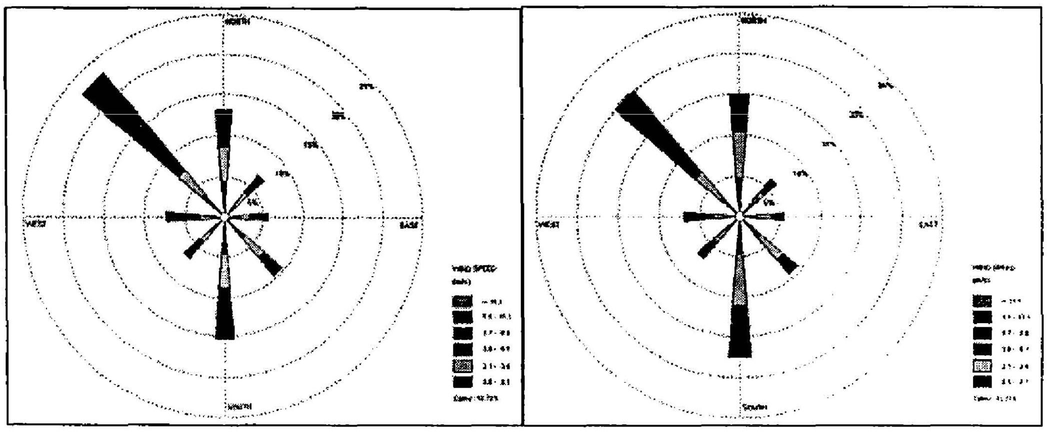

Figure 1: Wind rose summary from the Washington DC Dulles international airport, Virginia in the year of (a) 1983 and (b) 1984

RESULTS AND DISCUSSIONS

An average tire is produced from about 2.5 gallons of petroleum, making it a good source of heat energy. Shredded or chipped tires, without their steel belts, have an energy content ranging from 14,800 to 15,800 kJ which is higher than the energy content of coal. The fire burn rate can be affected by the material size. For example, shredded tires will burn at a much lower rate than chunk tires. Therefore, the concentrations simulated in these case studies in 'chunks' may tend to be higher than those tires in the form of 'shredded'.

Conceptual Case Study

After manipulating the data into ISC-AERMOD View, the maximum concentration of lead estimated is 0.10μgm^{-3} with the wind direction blowing away from the length of the tire pile and 0.25μgm^{-3} when the wind is blowing away from the width of the pile. It is below the limitation set by the WHO for lead which is 0.5μm^{-3}. Figure 2 shows the dispersion pattern of the pollutant in both cases. The dotted red polygon in the figure indicates the venue where the tires being burned.

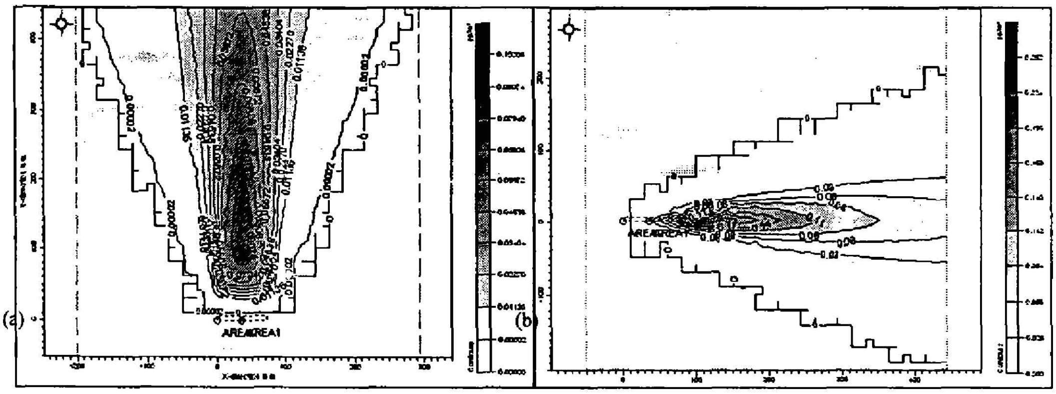

Figure 2: Concentrations of lead of the conceptual case study in a single wind direction (a) to north and (b) to east

Actual Case Study – Rhinehart Tire Fire

The maximum concentrations simulated for the actual scenario for the Rhinehart tire fire are approximately 10.3 μgm^{-3} and 4.3 μgm^{-3} by using the meteorological data from the year of 1983 and 1984 respectively. It is very clear that these concentrations far exceed the limitation set by the WHO for lead which is 0.5μgm^{-3} for 24 hour averaging period. Figure 3 shows the dispersion pattern of the pollutant. The concentrations are all gather around the south east area since very strong wind is blowing from the north west which cancels out other alternative route of the dispersion in other directions. At a high level of concentration in this case, the health of populations at the particular area are at risk.

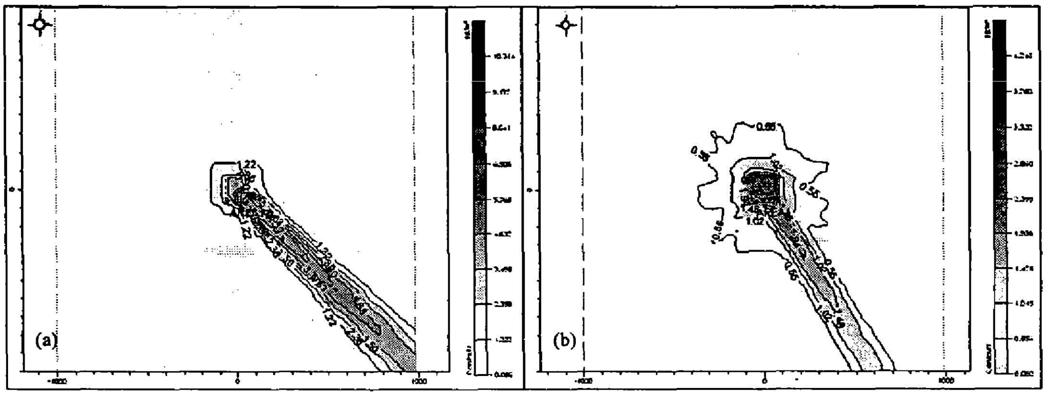

Figure 3.11: Contour plot of the pollutant concentrations of Rhinehart Tire Fire in the year of (a) 1983 and (b) 1984

Figure 4 depicts the comparison of the simulated concentrations and the WHO standards for lead for 24 hour averaging period in the year 1983 and 1984 with the downwind distance (from north-west). It can be seen that in 1983, the concentrations are only safe for area 15000m downwind distance from the burned site. The concentrations of lead also pose health hazards for those within 500m radius of the said site other than the downwind distance. As for the year 1984, the concentrations remain dangerous for the area within 400m radius and the concentrations for the downwind distance are also within safety limit 400m away from the burned site.

This particular fire was so serious until the USEPA requested immediate technical assistance from the National Institute for Occupational Safety and Health (NIOSH) to evaluate site safety and worker exposure to potentially hazardous emissions from the tire fire during the fire. NIOSH industrial hygienists collected air samples on November 4 and 9, 1983 (NIOSH, 1984) and the concentrations of lead in the plume was sampled at 11 μgm^{-3}. This was sampled at a stationary location in the plume. The sampling method employed included the use of a low-volume sampling pump (flow rate of 1.0 liter per minute) and a cellulose ester membrane filter. The analytical method was low temperature ashing nitric acid digestion followed by inductively coupled argon plasmography, atomic emission spectroscopy (although no specific method was cited, the procedures are consistent with NIOSH Method 7300). This sampled concentration is consistent with our simulated result for the year of 1983.

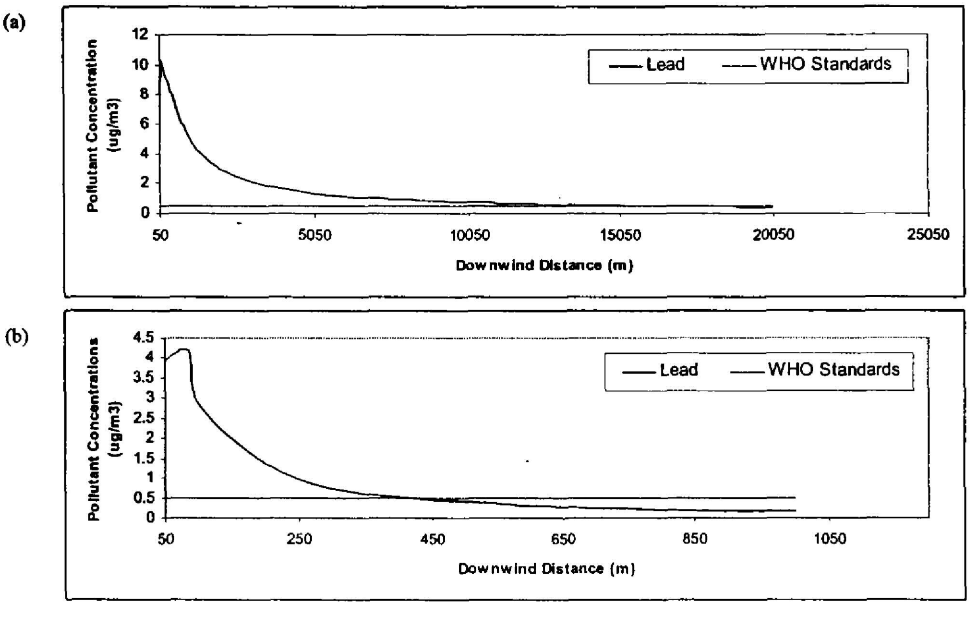

Figure 4: Comparison of the WHO Standards (24 hour averaging period) and lead concentrations along downwind direction (from north-west) for (a) 1983 and (b) 1984

CONCLUSION

Open burning of scrap tires is a very dangerous source of pollution. It not only pollutes the air but it also produces oily-tar which ultimately contaminated sediment and surface water of an adjacent stream. Air emissions from these fires have shown to be more toxic than those of a combustor, regardless of the fuel. They not only produce criteria pollutants such as CO, Sox, NOx and VOCs but also non-criteria hazardous air pollutants (HAPs) such as polynuclear aromatic hydrocarbons (PAHs) and metals such as lead, arsenic, mercury etc. Both criteria and HAP emissions from an open tire fire can represent significant acute (short-term) and chronic (long-term) health hazards to firefighters and nearby residents. Depending on the length and degree of exposure, these health effects could include irritation of the skin, eyes and mucous membranes, respiratory effects, central nervous system depression, and cancer. A throughout scrap tire management in every stage such as pre-fire, fire prevention, control, suppression tactics must be planned for a tire pile site to avoid or minimum the damage of tire burning. More information can be found in 'The Prevention and Management of Scrap Tire Fires' (Hebert, 2000).

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