

The Magnitude and Source of Air Emissions from Asphalt Blowing Operations

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The US EPA has developed emission factors for estimating the emissions of filterable particulate, total organic compounds, and carbon monoxide from asphalt blowing operations. These are published by the EPA in a series called AP-42, which contain factors for many manufacturing processes. The emission factors for asphalt blowing are acknowledged by the EPA to be of poor quality. Owens Corning has taken extensive data in various manufacturing facilities and an asphalt Pilot Plant to provide more information on air emissions from these operations. The results of that work clearly show that the current AP-42 emission factors for asphalt processed by air blowing are deficient in that they omit significant emissions of SO_x and HCl, overestimate particulate and CO emissions, and potentially underestimate both VOC and NO_x emissions. In fact, SO_x, which is not addressed by AP-42, is the major air emission contributed by the fumes from the asphalt blowing process when those fumes are incinerated. The sources of SO_x from air blowing are discussed in detail in this paper. The impact of incineration temperature on carbon monoxide is also illustrated. With the exception of HCl, the hazardous air pollutants encountered in the asphalt blowing process are minimal.

INTRODUCTION

The use of asphalt as a material is prevalent throughout recorded history. The commercial use of air blown asphalt, also known as oxidized asphalt, dates from the late 19th century [1]. Oxidized asphalt is produced by blowing air through hot petroleum residuum, which can come from vacuum distillation towers, atmospheric towers or solvent extraction units. At the start of the batch, input residuum is typically pumped through a direct fired non-contact preheater to achieve temperatures over 400°F(204°C), and into reaction vessels called oxidizers, or alternately, stills or convertors. Air is injected into the oxidizer and dispersed through perforated pipes. Air flow is typically in the range of 15 to 50 cfm/ton (0.008 to 0.026 m³/sec/Mg) of asphalt and the oxidizer is typically operated between 400 and 550°F (between 204 and 288°C) [2]. Oxygen is consumed by the reaction of air with the petroleum

residuum, resulting in fumes exiting the oxidizer at less than 10% oxygen content. Many theories exist as to the specific chemistry of the asphalt blowing reaction, with no consensus as to what is really happening. It is clear that in the asphalt blowing reaction oxygen functionality is added to the asphalt molecules; the apparent molecular weight of the asphalt increases; and compounds like hydrogen sulfide, methane, water, carbon monoxide, and carbon dioxide are released [3,4,5]. In addition to the gases formed, the high air flows both evaporate and entrain oily materials from the residuum, which can condense further down the process. These are referred to in this article as process oils. Fumes from asphalt blowing processes are typically treated with a variety of separation devices to remove condensing or entrained process oil, and then are incinerated. The most commonly used catalyst for the reaction is ferric chloride, although most oxidized asphalt is produced without any catalyst.

Air blowing of residuum results in an increase in Ring and Ball Softening Point (ASTM D36) and Brookfield Viscosity (ASTM D4402), and a decrease in Penetration (ASTM D5). The product is unique in that its combination of properties cannot be produced by any other refinery process. That is, if the softening point of the residuum is raised by distillation or solvent extraction the material is far more brittle than if the softening point is raised by air blowing. Oxidized asphalt is used for the manufacture of asphalt shingles; and in built-up roof construction, adhesives, corrosion protection, waterproofing, and a wide variety of specialty applications. The two highest volume products made using this process, shingle coating and BURA Type III asphalt, typically see a softening point increase during the blowing process from an initial value of less than 100°F (38°C) to a final value of 200°F (93°C) or higher.

Title V of the 1990 Clean Air Act required the accurate estimation of emissions from all U.S. manufacturing processes, and placed the burden of proof for that estimate on the process owner. In response to Title V, Owens Corning (OC) analyzed existing data and conducted extensive testing of their asphalt blowing processes in plant and pilot plant scale to develop the best possible emission factors. This paper is the result of that work, and it is our hope that it will lead to improved AP-42 emission factors for the asphalt blowing process.

Table 1. Test Methods Used in Sampling Air Blowing Emissions

EPA Method #	Items Measured Using Method
1	Sample and velocity traverses
2	Stack gas velocity & flow
3	Dry molecular weight
3A	Oxygen & Carbon dioxide
4	Stack moisture
5	Particulate
5A	Particulates
6C	Sulfur oxides
7E	Nitrogen oxides
10	Carbon Monoxide
25A	Total gaseous organic (VOCs)
26	Hydrogen chloride
26A	Hydrogen chloride
29	Inorganic compounds
202	Condensable particulate
0010	Semi-volatile HAPs

TEST METHODS

Testing of emissions from Owens Corning's asphalt blowing processes was done using the EPA test methods outlined in Table 1.

AP-42 Emission Factors

The Emission Factor and Inventory Group (EFIG) in the U. S. Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards (OAQPS) develops and maintains a database of emission factors for manufacturing processes. These emission factors are published in a series known as AP-42 [6]. As part of this process the emission factors have been assigned a quality rating. AP-42 emission factors for limited pollutants exist for the asphalt blowing process [7]. The factors are available for filterable particulates (PM), total organic compounds (VOC), and carbon monoxide (CO). They are summarized in Table 2. These emission factors have been assigned "D" or "E" ratings, indicating they are no better than "Engineering Judgment" in accuracy. More specifically a "D" rating indicates below average quality based on a small number of possibly non-random facilities with evidence of test variation. An "E" rating indicates poor quality based on unproved test methods, and issues with a low number of data points, ran-

domness, and variability. An "E" rating is the lowest rating given to emission factors by AP-42 [6]. The asphalt blowing AP-42 factors are for both saturant and coating asphalt manufacture. The rest of this article only addresses the coating factors, which are larger in proportion to their longer processing times.

Owens Corning Plant Testing Results

The results of emission testing for Criteria Pollutants done on 33 different occasions in 14 different Owens Corning plant locations are shown in Table 3. The processes shared common process conditions: 15 to 30 cfm/ton (0.008 to 0.016 m³/sec/Mg) air injection and 460 to 510°F (238 to 266°C) reaction temperature, common control equipment (fumes bubbled through a liquid seal in a knock out tank followed by gas fired incineration in an incineration chamber designed for adequate turbulence), and were processed to a common end point (coating asphalt). Widely variable input petroleum residuum were used in the tests. There was no catalyst used in any of the tests reported in Table 3. In all but one case, each data point is the average of three determinations, taken during three separate process times, with the same input residuum, under as similar as possible process conditions. The exception to that is the case of the PM data for plant J from 1984 to 1994. In this case an average of 83 different determinations were used to avoid skewing the overall PM data for only one plant configuration.

Averages and other statistics for each criteria pollutant are given at the bottom of Table 3. The arithmetic mean and median are included for each pollutant. The geometric mean is also included in Table 3, and could in some cases be appropriate because of the exponential nature of the dependence of the emissions data on some process conditions. As can be seen in Table 3, the arithmetic mean is the most conservative estimate and all further analyses in this paper use it as the most representative value of the data set. These data are the basis of what we believe to be improved emission factors for asphalt blowing, and in lieu of other available data, we recommend the arithmetic means be accepted as new emission factors for asphalt blowing with gas incineration. When used to estimate emissions, the emission factors are adjusted depending on the configuration and the amount of data existing for that particular plant. For example, the average value plus two or three standard deviations are often used to ensure that the estimate is greater than the actual emission.

CONTRIBUTION OF INCINERATION FUEL TO EMISSIONS

To apply the data of Table 3 to processes using fuel oil, rather than natural gas, for incineration requires that the contribution of the fuel burned be recognized. This is done by calculating the incremental emissions from the

Table 2. US EPA Emission Factors for Asphalt Blowing Emissions from AP-42 (7)

Pollutant	Method	Control Equipment	Saturant Asphalt	Coating Asphalt	Emission Factor Rating
Filterable PM	EPA 5A	none	6.6 lb/ton ¹	24 lb/ton	E
Filterable PM	EPA 5A	incineration	0.27 lb/ton	0.81 lb/ton	D
Total Organic Compounds	EPA 25A	none	1.3 lb/ton	3.4 lb/ton	E
Total Organic Compounds	EPA 25A	incineration	0.0043 lb/ton	0.017 lb/ton	D
Carbon Monoxide		none		0.27 lb/ton ²	E
Carbon Monoxide		incineration		3.7 lb/ton ²	E

¹1 lb/ton = 0.5 kg/Mg

²unclear what product was manufactured.

Table 3. Emission Factor Data for Asphalt Blowing to Coating with Gas Incineration

Plant	SOx (lb/ton) ¹	CO (lb/ton)	NOx (lb/ton)	VOC (lb/ton)	PM (lb/ton)	Comments	Year Tested
A	0.63	0.43	0.06	0.08		2 oxidizers	1996
A					0.02	2 oxidizers	1996
B		0.72		0.002	0.17		1996
C		0.07					1988
C	0.88	0.11	0.08	0.02	0.06		1994
C					0.08	Incinerator @ 1500F ¹	1992
D		0.95			0.07		1988
F					0.07		1990
F					0.07		1990
F					0.06		1990
H	0.84	0.09	0.02	0.01	0.18	2 oxidizers	1994
I					0.05		1993
I	0.66	0.002	0.08	0.10	0.14	Incinerator @ 1625F	1993
J					0.11	average of 83 PM tests	1984-1994
J		0.01			0.18	Incinerator @ 1550F	1992
J					0.02		1995
K					0.08		1986
L	0.86	0.34	0.10	0.002	0.12	Incinerator @ 1550F	1993
L	0.95	0.77	0.02	0.02	0.11	Incinerator @ 1550F	1994
L	0.65	0.33	0.05	0.001			1997
M					0.23		1992
M					0.25		1988
M	1.03	3.2	0.03	0.04		3 oxidizers	1994
M	0.76				0.03	2 oxidizers	1995
M					0.06	2 oxidizers	1996
M					0.07		1995
M		1.15				Incinerator @ 1400F	1995
M		0.17				Incinerator @ 1450F	1995
M		0.12				Incinerator @ 1500F	1995
N	0.95	0.01	0.02	0.07	0.04		1996
P					0.03	2 oxidizers	1984
P	0.93	0.21	0.12	0.002			1993
S	1.15	2.00	0.04	0.06		4 oxidizers	1993
Summary	SOx	<u>CO</u>	<u>NOx</u>	<u>VOC</u>	PM		
Arithmetic Mean	0.86	0.59	0.05	0.03	0.10		
Geometric Mean	0.84	0.18	0.04	0.01	0.08		
Median	0.87	0.27	0.05	0.02	0.07		
Std Dev	0.16	0.83	0.03	0.03	0.06		
Arith. Mean+3s	1.34	3.09	0.16	0.14	0.29		
Minimum	0.63	0.002	0.02	0.001	0.02		
Maximum	1.15	3.20	0.12	0.10	0.25		
Number	12	18	11	12	24		

¹ 1 lb/ton = 0.5 kg/Mg, °C = (°F-32)*5/9

alternate fuel by using AP-42 emissions factors for combustion [8,9] and adding that source of emissions to the data in Table 3 for gas incineration. The incremental emissions subtract the gas combustion emissions from the fuel oil combustion emissions. Table 4 contains asphalt blowing emission

factor data measured in four plants using heavy fuel oil. To illustrate the technique described above, the average of the measurements in these plants is compared to an average predicted by adjusting the gas incineration average from Table 3 with fuel oil emissions for a typical fuel oil usage rate.

Table 4. Evaluation of Emission Factors for Air Blowing Coating Asphalt with Heavy Fuel Oil Incineration

Plant	SO _x (lb/ton) ¹	CO (lb/ton)	NO _x (lb/ton)	VOC (lb/ton)	PM (lb/ton)	Year
F		0.31			0.03	1985
Q					0.28	1989
Q	1.38	0.02	0.12	0.01	0.30	1994
Q	1.14	0.00	0.19	0.01	0.35	1994
X	1.50	1.25	0.04	0.01	0.09	1993
P	2.87	0.37	0.15	0.00		1993
Average	1.72	0.39	0.13	0.01	0.21	

¹1lb/ton = 0.5 kg/Mg

Gas Data Averages from Table 3 Adjusted for Fuel Oil Emissions.

SO _x (lb/ton) ¹	CO (lb/ton)	NO _x (lb/ton)	VOC (lb/ton)	PM (lb/ton)
1.53	0.60	0.14	0.03	0.14

CRITERIA POLLUTANT SUMMARY

Table 5 summarizes the comparisons between current AP-42 emission factors for asphalt blowing, the data gathered by Owens Corning on 33 occasions in 14 plants using gas incineration, and estimated values for the contribution of the gas fuel that is burned in the incinerator.

The key conclusions from this comparison follow:

1. It is clear from the data in Table 5 that the omission of a sulfur oxide (SO_x) emission factor for the asphalt blowing process from AP-42 ignores what is usually the largest criteria pollutant from this process. The average value in all our testing is 0.86 lb SO_x/ton asphalt (0.43 kg/Mg) with gas fueled incinerators without using catalysts. This represents a significant source of SO_x that should be accounted for in all asphalt blowing operations.

2. The AP-42 factor for carbon monoxide (CO) of 3.7 lb/ton (1.85 kg/Mg) is obviously based on poor incineration as it is excessively high for normal processes. In all of our testing on gas systems with adequate incineration turbulence and without any catalyst the average CO factor was 0.59 lb/ton (0.295 kg/Mg). Our one value close to AP-42, 3.2 lb/ton (1.6 kg/Mg) in plant M, was reduced to less than 0.2 lb/ton (0.1 kg/Mg) by raising the incineration temperature 100 °F (38°C). The sensitivity of CO to

incineration temperature will be discussed below.

3. The AP-42 factor for volatile organic compounds (VOC) of 0.017 lb/ton (0.0085 kg/Mg) is achievable (5 out of 12 measurements we took were less than that value), but is approximately one half of the average measured value. This factor should be increased.

4. The AP-42 value for particulate material (PM) is much too high. Our largest reading in 24 tests was still less than 1/3 the AP-42 value and our average was 1/8 the AP-42 value.

5. The contribution of fuel burning to nitrogen oxide (NO_x) emissions gives an order of magnitude estimate of NO_x emissions in the asphalt blowing process. Some additive emissions appear to be warranted from the data, but this omission from the AP-42 factors is not a serious one.

6. Based on comparisons in Table 4, asphalt blowing emission factors based on gas incineration systems can be used as approximate estimates for systems using alternate fuels by adding the emission contribution of the alternate fuel calculated using AP-42 for combustion.

SOURCES OF SPECIFIC ASPHALT BLOWING EMISSIONS

Sulfur Oxides

SO_x emissions in the asphalt blowing process come from three sources:

1. The fuel used to incinerate the asphalt blowing fumes contains sulfur compounds which are oxidized on incineration to produce SO_x emissions.

2. Some process oil is carried over as condensable vapor or droplets in the fume stream and, when burned, the sulfur, which exists primarily as thiophenes, is oxidized to produce SO_x emissions.

3. Hydrogen sulfide (H₂S) is formed in the asphalt blowing process and that material oxidizes in the fume stream and in the incinerator to produce SO_x emissions.

The incineration fuel component is quite small when using natural gas, as shown in Table 5. Estimates of the magnitude of the other two components can be made from observations of results of experiments to reduce these emissions. The use of H₂S scavengers in the asphalt blowing process to tie up the H₂S component of the emission has been seen to give a maximum reduction in SO_x emissions of about 70 to 80% in a gas incineration situation [10]. This would indicate that the contribution of the release of H₂S in the process is about 70 to 80% of the emission in a gas incineration system. Similarly, unpublished work with filtration of pilot scale asphalt blowing fumes indicated that completely eliminating droplet carryover in an asphalt blowing process with gas incineration reduced SO_x emissions by 20 to 30%. Therefore, in a gas incineration system the contributions to SO_x emissions could reasonably be estimated as indicated in Table 6.

Table 5. Summary of Emission Factors for Asphalt Blowing Process Making Coating

	SO _x (lb/ton) ¹	CO (lb/ton)	NO _x (lb/ton)	VOC (lb/ton)	PM (lb/ton)
AP-42 Factor (Table 2)	omitted	3.7	omitted	0.017	0.81
Average OC Emission for Gas Incineration (Table 3)	0.86	0.59	0.05	0.03	0.10
Range of OC Values (Table 3)	0.63 to 1.15	0.002 to 3.2	0.02 to 0.12	0.001 to 0.10	0.02 to 0.25
Contribution from gas fuel estimated with AP-42 (8)	0.0002	0.007	0.03	0.002	0.004

¹1 lb/ton = 0.5 kg/Mg

Table 6. Sources of SO_x in Asphalt Blowing - Typical Values

Source of SO _x	Typical Contribution
Gas fuel for incinerator	< 0.1% of the total SO _x
H ₂ S release from Asphalt	
During Blowing	70 to 80% of the total SO _x
Carryover of process oil containing thiophene sulfur	20 to 30% of the total SO _x

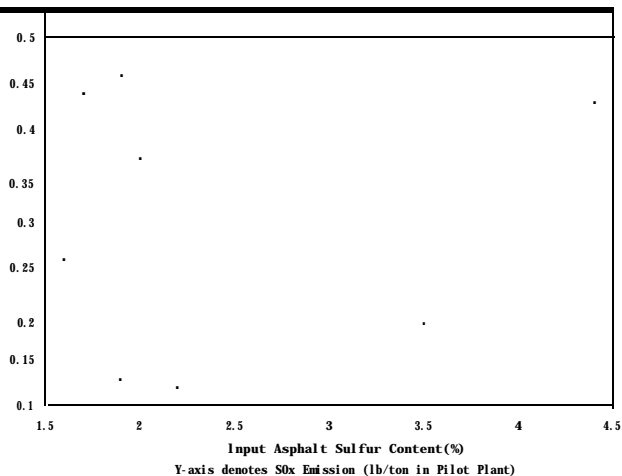


FIGURE 1. Correlation of input asphalt sulfur content With SO_x emissions. Eight different crude sources used in study. Correlation coefficient = 0.09 (1lb/ton = 0.5 kg/Mg).

Because of the strong contribution of some input petroleum residuum sulfur to SO_x, an investigation was done to determine if the total sulfur content of input residuum, which is easily measured, would correlate with SO_x emissions. To determine this a series of input residuum made with different crude oils were brought to Owens Corning's asphalt blowing pilot plant and oxidized under identical conditions, with determination of emission factors for SO_x. The results of these tests are shown in Figure 1, a plot of pilot plant SO_x emissions versus total sulfur content of the input asphalt. It is clear that no correlation exists, implying that only a small, unidentified, component of the sulfur in the asphalt is responsible for the H₂S release and subsequent SO_x emission.

Table 7. Effect of Incineration Temperature on Carbon Monoxide Emissions

Plant	CO Emission Factor (lb/ton) ¹	Incineration Temperature (°F) ¹
M	1.15	1400
M	0.17	1450
M	0.12	1500
L ²	2.15	1450
L	0.17	1550

¹ 1 lb/ton = 0.5 kg/Mg, °C = (°F-32)*5/9

² The L plant data was taken with ferric chloride as a catalyst and is therefore not included in the Table 1 data set.

Carbon Monoxide

Large amounts of carbon monoxide can be emitted from the asphalt blowing process when the incineration conditions are less than optimum in terms of residence time, incineration temperature and fume turbulence. In Table 7 the effect of incineration temperature is shown for two asphalt blowing processes where the incineration residence time and turbulence are acceptable. As can be seen, the emission of carbon monoxide is very sensitive to a relatively small change in temperature. In general, we have found that for incinerators with more than 0.5 seconds of residence time and chambers designed to promote turbulence, incineration temperatures in the 1450 to 1550°F (788 to 843°C) range are necessary to achieve very low CO levels. From the data in Table 7, plant M needs to run at least 1450°F (788°C) while plant L needs to run 1550°F (843°C) to achieve emission factors under 0.2 lb/ton (0.1 kg/Mg).

A small amount of CO is detectable in the fumes prior to the incinerator, but the major source for CO emissions is incomplete combustion of hydrocarbons to carbon dioxide (CO₂).

Hydrocarbon Emission - Particulate and VOCs

From the description of the asphalt blowing process, it is not surprising that the fumes entering the incinerator contain significant amounts of hydrocarbons. The reactions that occur in the process create lower molecular weight hydrocarbons that remain as vapor or condense at some point in the fume system. The incineration process does a good job of combusting these

Table 8. Measured Incineration Destruction Efficiencies for Hydrocarbons in the Air Blowing Process

Plant	# Samples Averaged	Residence Time (seconds)	Incineration Temperature (°F) ¹	Destruction Efficiency
C	3	1.8	1500	98.9%
S	4	1.9	1500	98.1%
S	4	1	1500	97.9%
S	5	0.7	1500	98.7%
S	4	0.5	1500	99.2%

¹ °C = (°F-32)*5/9

Table 9. Sampling Data for HAPs Emissions from Asphalt Blowing (1 lb/ton = 0.5 kg/Mg).

Plant	C	O	P	L	L	Q	Q	M	M
Year	1992	1990	1984	1994	1994	1994	1994	1995	1995
Fuel	gas	gas	gas	gas	gas	BD Oil	#5 Fuel	gas	gas
Comments				Ferric	No Ferric			Ferric	No Ferric
Hazardous Air Pollutant	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)
Hydrogen chloride			8.2E-03	2.5E-01	3.6E-02	8.4E-03	7.7E-03	1.9E-01	4.0E-02
<u>General Inorganic HAPS</u>									
Antimony				1.0E-06	7.7E-07				
Arsenic		0.0E+00		8.5E-07	2.8E-06	6.3E-07	6.3E-07		
Beryllium				8.5E-09	6.2E-09				
Cadmium		0.0E+00		5.7E-07	6.2E-09				
Chromium				3.2E-05	4.3E-06	4.1E-06	7.3E-06		
Cobalt						7.4E-07	8.9E-06		
Lead				3.2E-06	2.2E-06	1.3E-05	4.7E-05		
Manganese				5.5E-06	4.1E-06	9.9E-05	2.4E-04		
Nickel		4.2E-05		2.8E-04	6.3E-06				
Phosphorus				4.1E-06	2.2E-06				
Selenium		0.0E+00		8.1E-07	2.5E-06	6.3E-07	6.3E-07		
<u>General Organic HAPS</u>									
Benzene	2.6E-04	1.3E-02		8.2E-04	1.5E-03	9.0E-04	1.2E-05		
Toluene				1.3E-04	8.8E-05	3.4E-04	1.2E-05		
Ethyl Benzene						1.0E-02	1.2E-02		
Xylene						1.7E-04	9.0E-06		
1,1,1 TCE						2.1E-05	2.2E-05		
methyl chloride				2.1E-04	7.9E-04				
vinyl chloride				8.7E-05	9.7E-05				
ethyl chloride				5.5E-05	7.7E-05				
methylene chloride				1.3E-03	1.3E-03				
chloroform				1.0E-04	1.2E-04				
Di-n-butylphthalate				2.5E-06	3.0E-06				
Dibenzofuran				3.8E-05	6.1E-06				
bis(2-ethylhexyl)phthalate				9.6E-06	8.4E-06				
isophorone				3.0E-06	2.5E-06				
4-nitrophenol				1.6E-05	1.1E-05				
phenol				1.4E-05	7.4E-06				
o-cresol				2.4E-06	2.5E-06				
p-cresol				8.7E-06	5.7E-06				
<u>Polycyclic Organic Matter</u>									
2-methylnaphthalene				2.1E-05	4.7E-06	4.6E-08	8.2E-08		
Acenaphthene (ACEP)	0.0E+00			3.6E-05	2.5E-06	2.7E-07	8.4E-08		
Acenaphthylene (ACEY)	6.7E-09					2.5E-08	6.7E-09		
Anthracene (ANTH)	0.0E+00					2.5E-09	5.6E-08		
Benz (A) anthracene (BENA)	0.0E+00					8.0E-09	6.2E-09		
Benzo (B) Fluoranthene (BENB)	0.0E+00					7.1E-09	7.9E-09		
Benzo(G,H,I) Preylene (BENG)	0.0E+00								
Benzo (K) Floouranthene (BENK)	0.0E+00								
Benzo (A) Pyrene (BEZA)	0.0E+00								
Benzo(e)pyrene						2.0E-08	2.2E-08		
Chrysene (CHRY)	0.0E+00					1.0E-08	1.4E-08		
Dibenz (A,H) Anthracene (DIBN)	0.0E+00								
Fluoranthene (FLUO)	0.0E+00			1.3E-05	2.5E-06	6.5E-09	2.0E-08		
Indeno (1,2,3-C,D) Pyrene (INDE)	0.0E+00								
Naphthalene (NAPH)	5.9E-06			5.3E-05	2.5E-05	8.9E-07	9.9E-07		
Phenathrene (PHEA)	0.0E+00			8.0E-05	6.9E-06	6.4E-08	6.4E-07		
Pyrene (PYRE)	0.0E+00			7.3E-06	2.5E-06	7.8E-09	1.8E-08		

to CO and CO₂ as indicated by the data in Table 8, which was taken by measuring total hydrocarbons entering the incinerator and total leaving to get a destruction efficiency. Because of the nature of the process there is an insignificant amount of inorganic components in the particulate emissions.

HAZARDOUS AIR POLLUTANTS TEST RESULTS

In addition to testing on criteria pollutants, Owens Corning has done extensive testing on the emissions of hazardous air pollutants (HAPs) from the asphalt blowing process. This testing, done in six plants on nine occasions, is summarized in Table 9. On different occasions four basic classes of HAPs have been measured: 1. hydrogen chloride, 2. general inorganic HAPs, 3. general organic HAPs, and 4. polycyclic organic matter (POM). Table 9 is organized around those groupings.

The data show that the use of ferric chloride as a catalyst significantly increases hydrogen chloride emissions from the 0.007 to 0.04 lb/ton (0.0035 to 0.02 kg/Mg) emission factor level without ferric chloride use to 0.19 to 0.25 lb/ton (0.095 to 0.125 kg/Mg) with the catalyst. This is an important omission from AP-42 and should be added for ferric chloride catalyzed asphalt blowing. The source of this chloride is free HCl in the ferric solution and the reaction of ferric chloride to ferrous chloride as part of the mechanism of catalysis [11]. Only a fraction of the HCl available from these two sources is actually evolved. The rest takes part in as yet unidentified reactions in the asphalt.

Emissions of general inorganic materials can be seen to be very small, in the range of 0.00000006 to 0.0002 lb/ton (0.00000003 to 0.0001 kg/Mg).

Emissions of general organic materials were very low with the exception of ethyl benzene and one measurement of benzene, which were in the range of 0.01 to 0.013 lb/ton (0.005 to 0.0065 kg/Mg). Clearly more severe incineration conditions can reduce these values, and this is indicated in other measurements of benzene emissions which were as low as 0.000012 lb/ton (0.000006 kg/Mg).

Emissions of POM were all extremely low ranging in measurement from 0.000000005 to 0.00008 lb/ton (0.0000000025 to 0.00004 kg/Mg).

CONCLUSIONS

From the data presented in this paper the following conclusions have been reached:

1. Current AP-42 emission factors for asphalt blowing ignore important emissions of sulfur oxides. This is usually the largest emission from the process. The emission of sulfur oxides are not correlated with total sulfur in the input residuum. In a gas incineration system the source of sulfur oxides are approximately 70 to 80% from H₂S released in the asphalt blowing reaction, 20 to 30% from entrained or condensing oils, and almost no contribution from the fuel used for incineration.

2. Current AP-42 emission factors for asphalt blowing ignore hydrogen chloride emissions, which are important when ferric chloride is used as a catalyst in the process.

3. Current AP-42 emission factors for asphalt blowing overestimate the emissions of particulate and carbon monoxide in a well designed process. Carbon monoxide emissions can be dramatically reduced with small increases in incineration temperature above a certain threshold temperature,

in an incinerator with adequate residence time and turbulence. In our experience that threshold temperature is approximately 1400 to 1500°F (760 to 816 °C).

4. Emissions of hazardous air pollutants, other than hydrogen chloride, from the asphalt blowing process are insignificant.

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