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Air Pollution Control for a Hot Mix Asphalt Plant

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Abstract: *The report explores how to reduce pollution by improving the emission control system in Hot Mix Asphalt (HMA) plants. The majority of emissions come from the combustion of fuel and particulate matter (PM) diffusion. The key finding is that combining a wet scrubber system and baghouse system will reduce the major pollutants significantly. Thousands of HMA plants across the country are in operation every day in rural, suburban, and urban areas, affecting all neighbors in their local communities. How an asphalt plant impacts the neighborhood and the environment mainly depends on their sustainable operation. Asphalt plant emissions are very low and getting lower due to innovative control systems and manufacturing technology. The objective of this report is to exppore the emission control system of a Hot Mix Asphalt plant. The main point is how to improve the scrubber system and baghouse filter for controlling criteria pollutants in the Hot Mix Asphalt plant during production to reduce the emissions.*

Keywords: *Hot Mix Asphalt, Wet scrubber, Baghouse Filter, Particulate Matter, Emissions, Sulfur Dioxide, Environmental.*

1. Introduction

The objective of this report is to improve the emission control system of a Hot Mix Asphalt (HMA) plant. If a HMA plant has no emission control system, it could cause many problems because the main pollutants are particulate matter, including fly ash and stone dust, and other acid gas, including Nitrogen oxides (NOx), Sulfur dioxide (SO_2), Carbon monoxide (CO), Volatile organic compound (VOCs), Methane (CH_4), Carbon dioxide (CO_2) and various Hazardous Air Pollutant (HAPs) (Missouri Dept. of Natural Resources, 2004). These emissions result in many unhealthy effects for humans and the environment, such as lung cancer, acid rain aggravation of asthma and other cardiovascular and respiratory diseases.

According to Myers (2004), manufacturing facilities produce the hot mix asphalt primarily used as paving material for highways; it consists of a mixture of aggregate and liquid asphalt cement, which is heated and mixed in measured quantities. Emissions from HMA plants may be divided into ducted production emissions, pre-production fugitive dust emissions, and other production-related fugitive emissions (Myers, 2004).

This report will focus on how to improve the wet scrubber and baghouse filter controls for controlling particulate matter and Sulfur Dioxide (SO_2) in the HMA plant site during production to reduce the emission charges. After improving the control equipment to control pollution from combustion sources, such as the wet scrubber and baghouse filters, the amount of air pollution will be reduced significantly (McGowan, 2016). The details of the emission control system for the wet scrubber and baghouse filter control will be discussed in this report, especially how much reduction could be expected.

Two typical HMA facilities widely applied are drum mix plants and batch mix plants according to the process by which the raw materials are mixed (Myers, 2004). The standards and permits for the hot mix asphalt must be applied. Currently, the discharge of the particulate matter and the SO_2 will go through the primary collector with the scrubber and the secondary collector with the baghouse filter, in order to limit emissions according to the applicable standards.

The four common types of wet scrubbing systems are the tray scrubber, packed tower, venture scrubber and spray tower (Wang, Taricska, Hung, Eldridge, & Li, 2004). This report aims to find the best wet scrubber to control and remove pollutants in the waste gas stream. Moreover, there are three main types of baghouse filters: shaker, reverse-air, and pulse jet baghouse (Cooper & Alley, 2011). After considering the main effects during the baghouse reaction, the report will also decide on the most effective way to reduce Particulate matter (PM) emissions.

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2. Background: Hot Mix Asphalt Plant Background and Plant Operation

HMA plants differ by their type of mixing operation, such as batch plants, parallel flow drum mix, continuous mix plants, and the counter flow drum mix plants. The world's two most common types of mixing operation, discussed in this report, are batch plants and drum mix plants.

2.1 Batch plants

A HMA batch plant is designed to run with some major components including the primary collector, secondary collector, batch tower, storage silo, dry(er), Rap Bin and asphalt storage tanks. Figure 1 displays a typical HMA batch plant (Asphalt mixture plant operations, 2015). All batch plants utilize certain basic operations such as aggregate storage and cold feeding, aggregate drying and heating, screening and storage of hot aggregates, storage and heating of binder, measuring and mixing of binder and aggregate and recycled materials and loading of finished asphalt mixture.

Each batch plant must maintain air pollution control devices due to EPA requirements, which are recognized worldwide. The equipment usually consists of wet collectors, a baghouse filter and a combination of other devices for particulate matter.

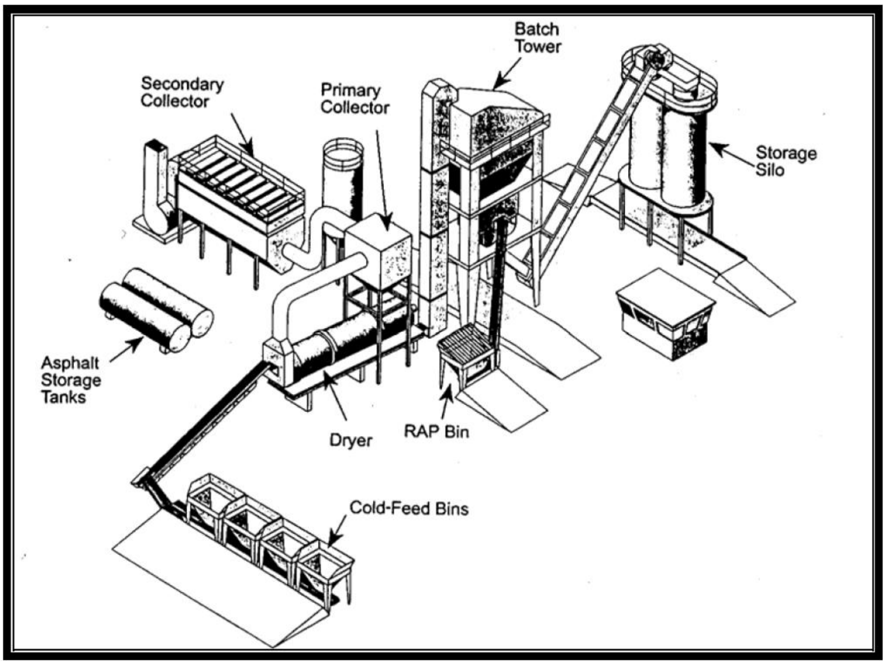

Figure 1: Typical Batch Plant (Asphalt mixture plant operations, 2015)

2.2 Batch plant operation

Figure 2 presents the process of producing the hot mix asphalt in a batch plant operation base on 2000 Emission Assessment Report. The process begins when the cold aggregate feeder bins supply cold aggregates to the drying drum. Then the drying drum removes moisture from the aggregates. Therefore, they easily can bind with bituminous material.

Once the aggregates are heated and leave the drum, they are transferred to the vibrating screen where they are separated by size and stored in separate compartments called hot bins. At the same time, the bitumen and filler material are weighed separately before they get introduced into the mixing unit. This mixing unit is a twin shaft batch mixer designed to homogenously mix the weighed aggregates, bitumen and filler material.

At the end of this mixing process, the gate at the bottom of the mixer opens and the materials fall into the waiting trucks or into the storage silos (Emission Assessment Report, 2000).

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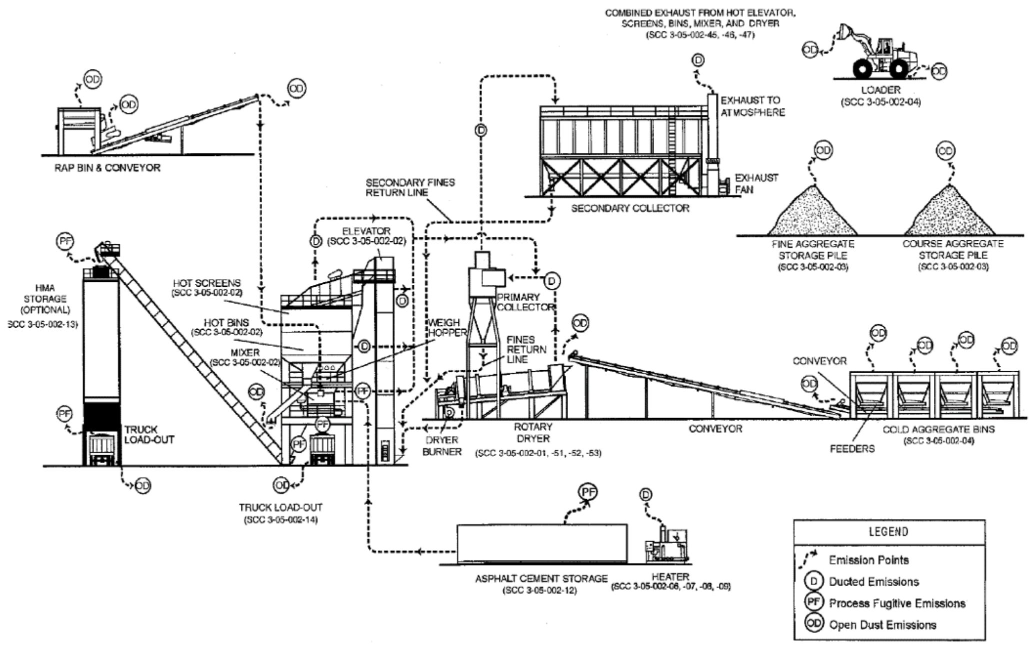

Figure 2: General process flow diagram for batch mix asphalt plants (Emission Assessment Report, 2000)

2.3 Drum mix plant

The process in a drum mix plant consists of three major operations, such as handling the aggregate system, controlling the asphalt cement binder system, and processing the blend of materials system. Each of the main components is discussed below.

The aggregate handling system consists of the cold feed bins, gathering conveyors, charging conveyor, weigh bridge and belt speed sensor, and mineral filler system. If reclaimed material is fed into the plant, a separate cold feed system will be required in order to handle the additional aggregate flow. The components of the asphalt cement binder system are used to control and store the asphalt cement. A heated storage tank is necessary to hold the asphalt cement until it is needed. The main component of the blending materials system is the drum mixer itself. A pump and meter are used to transfer the binder to the plant and to proportion the asphalt cement with respect to the correct amount of aggregate, which needs to be introduced into the drum mixer (Kennedy, Scherocman, & Tahmoressi, 1986).

Some plants also contain additional plant components involving the asphalt mixture, which include the hot mix charging conveyor, the hot mix surge silo and the plant dust collection system.

For the emission control, that is the amount of particulate carryout from the mixing process to be controlled, the drum mix plant can be equipped with a variety of air pollution control systems, such as a dry collector, a wet collector or a fabric filter (Kennedy, Scherocman, & Tahmoressi, 1986).

The main parts of the drum mix plant are the dryer/mixer, secondary collector, slat conveyor, rap bin, cold-feed bin and asphalt supply tanks noted in Figure 3 (Asphalt mixture plant operations, 2015).

2.4 Drum mix plant operation

The major difference between this process and the batch process is that the dryer is used not only to dry the material but also to mix the heated and dried aggregates with the liquid asphalt cement. This process is one type of continuous mixing process (Cooper & Alley, 2011). Drum mix plants can utilize either a parallel flow drum mixer or a counter flow drum mixer.

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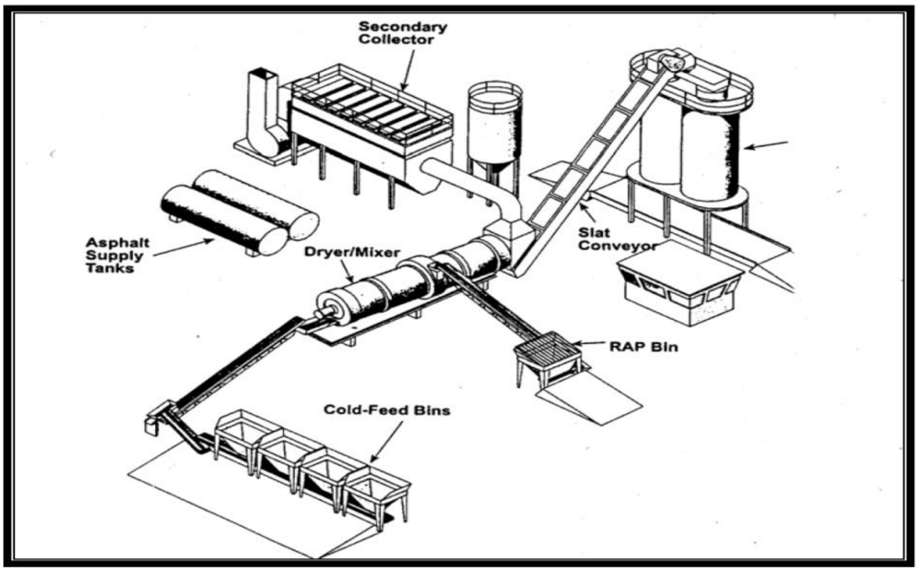

Figure 3: Typical Drum Mix Plant (Asphalt mixture plant operations, 2015)

In a parallel flow drum mixer, when the burning ends, the aggregate is introduced to the drum (Kennedy, Scherocman & Tahmoressi, 1986). The aggregate and combustion products from the burning move toward the other end of the drum in parallel while the drum rotates. And then liquid asphalt cement with any reclaimed asphalt pavement (RAP) and particulate matter (PM) from collectors is pulled in the mixing zone. The exhaust gases with the main pollutants exit the end of the drum process and pass into the emission collection system (Hot Mix Asphalt Plants, 2000).

In a counter-flow drum mixer, counter-flow means the material flows into the drum from the opposite direction as the exhaust gases. The mixing process is also different. The liquid asphalt cement mixing zone is located behind the burner flame zone. The hot exhaust gases directly contact the materials. After mixing, the mixture is completed at the end of the drum, and then the mixture is conveyed to either a surge bin or HMA storage silos. Figure 4 illustrates a normal drum mix plant operation (Hot Mix Asphalt Plants, 2000).

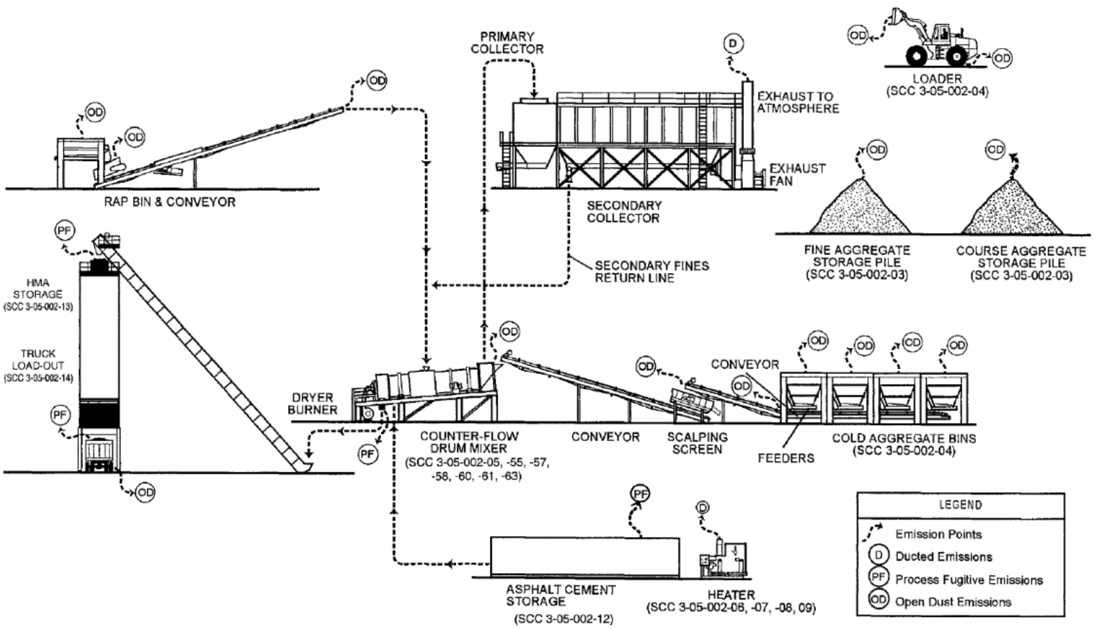

Figure 4: General process flow diagram for counter-flow drum mix asphalt plants (Emission Assessment Report, 2000)

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3. Emissions

As mentioned previously, the main operation components in batch and drum mix plants produce the emissions from the drum dryers, load-out operations, asphalt storage, yard, diesel exhaust, paved and unpaved road dust, and aggregate processing, such as screening, conveyor transfer, and reclaimed asphalt pavement crushing.

Table 1 lists the source of the emissions, criteria pollutants and HAPs, and other pollutants from the batch mix plant and drum mix plant. Both plant types generate PM, SO_2, NOx, VOCs, CO and other pollutants, such as CO_2 organics and metals. A variety of organic and metal HAPs are produced during different phases of operation.

Table 2 (for a typical HMA batch mix plant) and Table 3 (for a typical drum mix HMA plant) summarize annual emissions by using the emission factors estimates from one or more HMA facilities.

Table 1: Matrix of Emission Factors Developed for HMA Sources (Emission Assessment Report, 2000 Are these the most recent data available?).

Plant type	Source	Criteria pollutants	HAPs	Other pollutants
Batch mix	Dryer, hot screens, and mixer	PM-10, NO_x, CO, SO_2, VOC	24 organic HAPs 9 metal HAPs	CO_2 4 other organics 3 other metals
	Hot oil heaters		22 organic HAPs	
	Load-out	PM, CO, VOC,	41 organic HAPs	3 other organics
	Yard emissions	VOC	19 organic HAPs	
Drum mix	Dryer	PM-10, NO_x, CO, SO_2, VOC	58 organic HAPs 11 metal HAPs	CO_2 15 other organics, 6 other metals
	Hot oil heaters		22 organic HAPs	
	Load-out	PM, CO, VOC	41 organic HAPs	3 other organics
	Silo filling	PM, CO, VOC	28 organic HAPs	3 other organics
	Yard emissions	VOC	19 organic HAPs	

Annual emissions for a facility can be estimated by summing up the emissions from each emission source over the course of a year. The estimates are based on the assumptions listed below the tables. The accounts presented in Table 2 and 3 are for the identified annual emissions for each source at each type of facility.

Table 2: Estimated annual emissions for a typical batch mix HMA facility (Emission Assessment Report, 2000).

Pollutant	Annual emissions by source, pounds per year								
	Mobile sources (diesel exhaust)	Material handling and road dust	No. 2 fuel oil-fired dryer, hot screens, and mixer[b]	Natural gas-fired dryer, hot screens, and mixer[c]	Load-out[d]	Asphalt Storage[e]	Yard[f]	Total[g] (oil-fired)	Total[g] (gas-fired)
Criteria air pollutants									
Particulate matter less than 10 micrometers (PM-10)	46	7,900	2,700	2,700	52			10,700	10,700
Volatile organic compounds (VOC)	100		820	820	391	32	110	1,500	1,500
Carbon monoxide (CO)	700		40,000	40,000	135	3	35	41,000	41,000
Sulfur dioxide (SO_2)	22		8,800	460				8,800	480
Nitrogen oxides (NO_x)	380		12,000	2,500				12,400	2,900
Hazardous air pollutants (HAPs)									
Polycyclic aromatic hydrocarbons (PAHs)	0.035		11	11	2.0	0.12		13	13
Phenol					0.40			0.40	0.40
Volatile HAPs	1.9		751	751	6.2	140	1.6	760	760
Metal HAPs			1.4	1.4				1.4	1.4
Total HAPs[g]	1.9		760	760	8.6	140	1.6	770	770

[a] Based on an annual HMA production rate of 100,000 tons per year.
[b] Between 10 and 30 percent of the HMA is produced using fuel oil.
[c] Between 70 and 90 percent of the HMA is produced using natural gas.
[d] Loading of HMA into haul trucks.
[e] Includes emissions from oil-fired hot oil heaters.
[f] Fugitive emissions from loaded trucks prior to departure to the job site.
[g] Total expressed using two significant figures.

Table 3: Estimated annual emissions for a typical drum mix HMA facility (Emission Assessment Report, 2000)

Pollutant	Annual emissions by source, pounds per year									
	Mobile sources (diesel exhaust)	Material handling and road dust	No. 2 fuel oil-fired dryer[b]	Natural gas-fired dryer[c]	Load-out[d]	Silo filling[e]	Asphalt storage[f]	Yard[g]	Total[h] (oil-fired)	Total[h] (gas-fired)
Criteria air pollutants										
Particulate matter less than 10 micrometers (PM-10)	220	26,000	4,600	4,600	104	117			31,000	31,000
Volatile organic compounds (VOC)	190		6,400	6,400	782	2,440	64	220	10,000	10,000
Carbon monoxide (CO)	1,200		26,000	26,000	270	236	6	72	28,000	28,000
Sulfur dioxide (SO_2)	26		2,200	680					2,200	710
Nitrogen oxides (NO_x)	560		11,000	5,200					12,000	5,800
Hazardous air pollutants (HAPs)										
Polycyclic aromatic hydrocarbons (PAHs)	0.13		176	37	4.0	5.8	0.12		190	50
Phenol					0.80				0.80	0.80
Volatile HAPs	6.6		1,560	1,020	12.4	31	140	3.3	1,800	1,200
Metal HAPs			19	16					19	16
Total HAPs[h]	6.7		1,800	1,100	17	37	140	3.3	2,000	1,300

[a] Based on an annual HMA production rate of 200,000 tons per year.
[b] Between 10 and 30 percent of the HMA is produced using fuel oil.
[c] Between 70 and 90 percent of the HMA is produced using natural gas.
[d] Loading of HMA into haul trucks
[e] Filling of temporary storage silo prior to load-out.
[f] Includes emissions from oil-fired hot oil heaters.
[g] Fugitive emissions from loaded trucks prior to departure to the job site.
[h] Total expressed using two significant figures.

Based on the emission factors and assumptions, the estimate of annual emissions can be calculated. For example, if both batch plants and drum mix plants use oil as fuel, in the batch plant, the top four specific pollutants are CO, NOx, PM and SO_2 which is 41,000 pounds/year, 12,400 pounds/year, 10,700 pounds/year and 8800 pounds/year, respectively. In the drum mix plant, the top four specific pollutants are PM, CO, NO_x and VOCs, which is 31,000 pounds/year, 28,000 pounds/year, 12,000 pounds/year and 10,000 pounds/year. In addition, the estimate amount of SO_2 discharge is 2,200pounds/year in the drum mix plant. For the gas-fired plants, the situation is similar.

Comparing the results in the tables for both plants shows that the batch plant produced a larger amount of gas acid including CO, NO_x, and SO_2, more than the drum mix plant. But the drum plant produced much more PM than the batch plant. Therefore, an emission control system in a batch plant has to emphasize controlling pollutants with acid gas. However, the emission control system in the drum plant must enhance the ability to control for PM. For the PM emissions, both batch mix and drum mix HMA plants create pre-production fugitive dust emissions, ducted production emissions, and other production-related fugitive emissions (Myers, 2004). The ducted production emissions include the largest number of pollutants. In both types of HMA plants, drum dryers are the most significant sources of ducted emissions.

These emissions have a very serious impact for humans and the environment. Carbon monoxide (CO) can be life-threatening in high concentrations, or lead to heart disease over after long periods of exposure time because it is odorless and colorless, essentially undetectable. Sulfur dioxide (SO_2) corrodes the skin and eyes, can harm the respiratory system and contributes to acid rain. Particulate matter (PM) can cause lung cancer, asthma and other respiratory diseases (The Environmental Impact of Asphalt Plants, 2002).

For environmental protection and human health, National Ambient Air Quality Standards (NAAQS) limit the concentrations of PM, SO_2, NOx, and CO into the air to protect public health (A Guide to Environmental Compliance and Pollution Prevention for Asphalt Plants in Missouri, 2004).

4. Emission Control Technology

4.1 Scrubber system

During the scrubbing process, a wet or dry absorbent removes one or more components of a gas stream. Scrubbing focuses on gas streams polluted by acid gases, particulates, heavy metals, trace organics, and odors (Wang, Taricska, Hung, Eldridge, & Li, 2004). In HMA plants, the scrubber system

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is always installed between the drum dryer and baghouse.

The absorbent can either be wet or dry. In general, HMA plants choose wet absorbents as a primary emission control to efficiently remove acid gases. Although there are four types of wet scrubbing systems, packed tower wet scrubbers are the most common. Water is the most common absorbent in wet scrubbing. In other special cases, another relatively nonvolatile liquid may be used as the absorbent too. (Wang, Taricska, Hung, Eldridge, & Li, 2004).

4.1.1 Packed tower wet scrubber

A packed tower wet scrubber can remove inorganic fumes, vapors, volatile organic compounds (VOC), particulate matter (PM), and gases, such as chromic acid, hydrogen sulfide, ammonia, chlorides, fluorides, and sulfur dioxide. Figure 5 shows a typical Packed Tower Wet Scrubber. A general unit consists of a column shell, mist eliminator, liquid distributors, packed bed, packing materials, packing support, and may include a packing restrainer. Corrosion resistant alloys or plastic materials protect internal column surfaces from corrosive solvents or gases (Vatavuk, 1995).

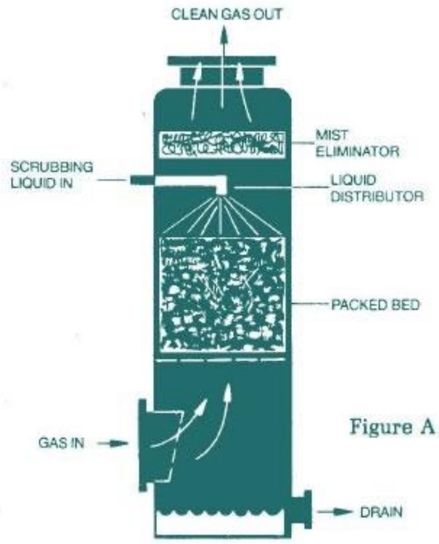

Figure 5: Typical Packed Tower Wet Scrubber (Packed Tower Gas Scrubber, 2015)

In general, a packed tower wet scrubber system absorbs the gas steam contaminants in two steps. In the first step the absorbent captures the contaminants. Then the liquid droplets are separated from the gas stream before them leave the scrubber (Packed Tower Gas Scrubber, 2015).

The most common packed tower scrubber designs are countercurrent. As the waste gas flows up the packed column the pressure decreases. This pressure decrease creates a large surface area for the liquid to absorb the waste emissions. A high powered fan drives the gas through the packed tower. (Brauer & Varma, 1981).

The packed tower wet scrubber system reduces the pollutants released. When the waste gas stream exits the wet scrubber, SO_2content will be reduced by 99%, VOC by 99%, PM by 95% NOx by 97% and other pollutants will also be removed (Packed-Bed/Packed-Tower Wet Scrubber, 1993).

4.1.2 Cyclone dust collector

In most HMA plants, the emission control systems use a cyclone dust collector combined with a wet scrubber. The cyclone can collect coarser materials such as fugitive dust.

Figure 6 shows the exhaust fan at the top of the dryer drawing the smoke and fine materials into the cyclone where they are spiraled (Vatavuk, 1995). Larger particles hit the outside wall and drop to the bottom of the cyclone. A dust return auger collects the fines at the bottom of the cyclone. Dust and smoke are discharged through the top of the collector. (Hot mix asphalt plant operations, 2015). The fines collected at the bottom of the cyclone are picked up by a dust-return auger and may be returned to the plant or wasted.

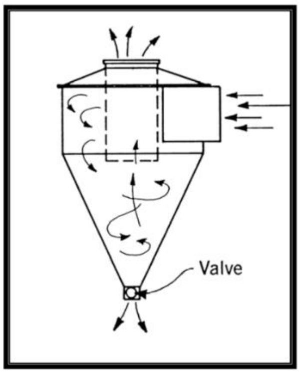

Figure 6: Cyclone Dust Collector (Vatavuk, 1995).

4.1.3 Mist eliminator

All wet scrubber designs incorporate mist eliminators to remove entrained droplets from the emission stream. These entrained droplets contain the contaminants or particulate matter (PM), and the mist eliminator returns them to the packed bed. Figure 7 shows the Chevron Mist Eliminator (Mist Eliminator, 2015).

The most common mist eliminators are chevrons, mesh pads, and cyclones. Chevrons offer the highest reliability and efficiency, often removing close to 100% of contaminants. Chevrons are simply zig-zag shaped baffles that cause the gas stream (and entrained droplets) to turn several times as the stream rises. On each turn, gravity pulls the droplets toward the blades of the chevron where the droplets collect and then drain back into the packed bed (Wet Scrubber for Particulate Matter, 2015).

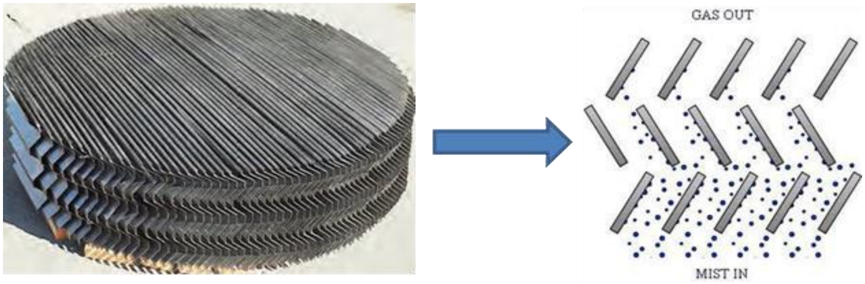

Figure 7: Chevron Mist Eliminator (Mist Eliminator, 2015)

4.1.4 Wastewater

The wastewater needs to be recycled. The recycling process uses a limestone water system to remove the remaining acid gas and dust in the last step of processing. The limestone reacts with the SO_2 in the flue gas to create insoluble calcium sulfite ($CaSO_3$) as in the equations below. The resultant calcium sulfite may be further reacted with oxygen to produce gypsum (Feng, Liu, & Ringer, 2015). According to the article Lime / Limestone Wet Scrubbing System for Flue Gas Desulfurization (2014), the reaction equations were shown below.

Limestone: $CaCO_3 + SO_2 \rightarrow CaSO_3 + CO_2$

Lime: $CaSO_3 + \frac{1}{2} O_2 + 2H_2O \rightarrow CaSO_4 \cdot 2(H_2O)$

In industry, the spent scrubbing liquids are sent to a clarifier, where much of the water is reused. Spent solids are removed in heavy slurry to a settling pond. The water (combined with fresh water, as needed) is returned to the scrubber. The inlet solvent limestone is roughly neutral and the system is always controlled around pH 6. The liquid stream outlet of the wet scrubber usually has a pH range 5 to 7, so the waste water disposal on this plant is not a big issue (Lime / Limestone Wet Scrubbing System for Flue Gas Desulfurization, 2014).

4.2 Baghouses and filters

The primary device for handling particulate matter (PM) for the HMA plants is the baghouse filter. Four collection mechanisms, including inertial collection, interception, Brownian movement, and electrostatic forces, are used to collect particulate matter. Baghouse filters intercept a wide range of

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particulate sizes and can operate under a wide range of volumetric flow rates while only requiring low pressure drops. Baghouse filters are very commonly used due to their high efficiency rating, typically in excess of 99% to 99.9% (Turner, 2015).

The baghouse filter device works by passing particulate-burdened air through a series of fabric bags. During filtering the particulate matter collects in the bags until the point when the accumulated dust must be removed from the fabric surface. Three different cleaning methods distinguish different baghouse filters: shaker, reverse-air, and pulse jet baghouses (Cooper & Alley, 2011). Cost is the main consideration among the three cleaning methods.

In shaker baghouses, the bags are suspended from a motor-driven framework that oscillates (hence “shaking”), allowing the dust to fall free into a hopper in the bottom of the compartment (Cooper & Alley, 2011). Reverse air baghouses blow particulate-free air from the top to the bottom of the filtering stream to free the dust from the filters. This cleaning method reduces the cost of baghouse operation.

Neither shaker nor reserve-air baghouse simultaneously filter and clean as the pulse-jet can. However, since HMA plants do not operate 24/7, cleaning time can be accomplished without interruption to the operation of the plant. Furthermore, reverse-air baghouses often utilize parallel filter stacks so that one can be taken offline to clean while the others continue to filter (Doss, Sunderland, & Hoya, 1980).

4.2.1 A reverse-air baghouse

A reverse-air baghouse filter’s advantages include low cost, high temperature tolerance, lower expected maintenance cost and time, and a low pressure drop for the system.

Figure 8 shows the processing of the air flow in a reverse air baghouse. In a reverse air baghouse, the dirty air flows from the inside-to-outside, so that the dust collects on the inside of the filter bag. The filter bags are tubular, open at the bottom and connected to a tube sheet. The gas flow is reversed to initiate filter bag cleaning (Menardi Filters, 2016).

Figure 8: Reverse Air Baghouse (Reverse Air Baghouse, 2015)

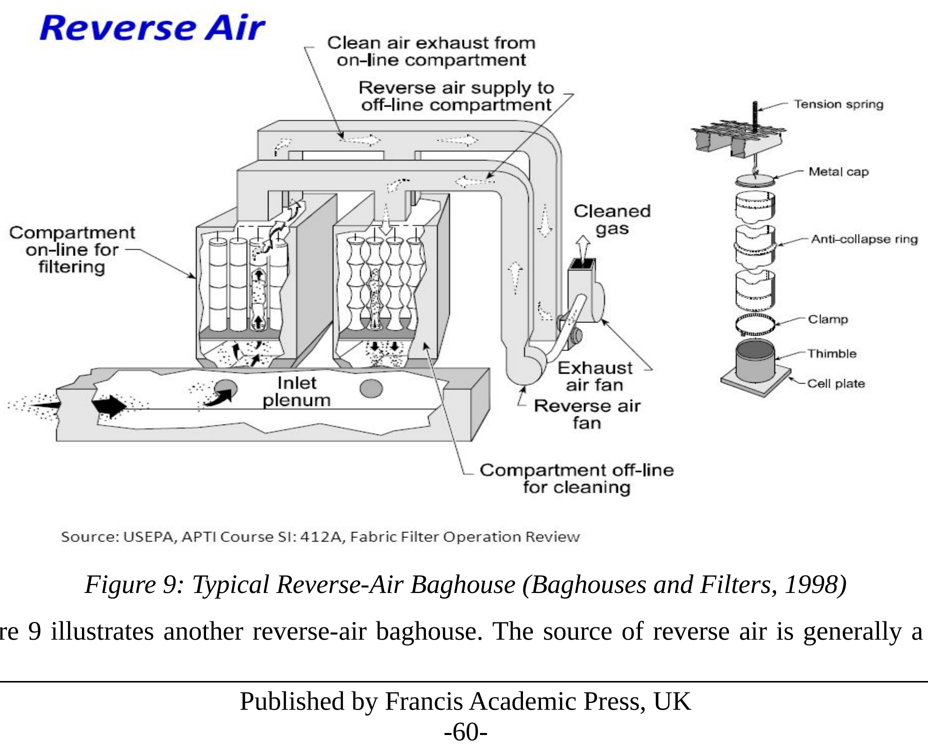

Figure 9: Typical Reverse-Air Baghouse (Baghouses and Filters, 1998)

Figure 9 illustrates another reverse-air baghouse. The source of reverse air is generally a separate

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system fan for supplying cleaning air. The dirty gas flows into the baghouse by inlet plenum, reverse air supply to an off-line compartment reverse air fan. The clean air exhaust from the on-line compartment flows out as cleaned gas (Turner, Mckenna, Mycock, Num & Vatuvak 1998). Figure 9 also shows the flow diagram for an on-line compartment filtering particulate matter and an off-line compartment being cleaned. During operating, reverse air generally has a separate system fan to supply flow power (Baghouse Filter Bags, 2015).

4.2.2 Fabric Filter

Fabric filtration is one of the most common air pollution control techniques used to collect particulate matter. The choice of fabric material simply depends on the emission gas and PM characteristics (Baghouse Filter Bags, 2015).

Fabric filters are used where high efficiency particle collection is required. The material of the fabric filter is a crucial variable to consider. Polyphenylene sulfide is commonly used in hot mix asphalt applications because Polyphenylene sulfide has a high maximum service temperature of 375 ℉, excellent resistance to acids and alkalis, and works well in high moisture content applications (Polyphenylene Sulfide (PPS) Typical Properties Generic PPS, 2016).

4.2.3 Sizing of the baghouse filter

To determine the size of the filters, important process variables include particle characteristics, gas characteristics, and fabric properties. The design procedure of size of filter requires estimating air-to-cloth or gas-to-cloth ratio compatible with the material and cleaning method (Kandhal, 1999).

Table 4: Gas-to-Cloth Ratios for Baghouse/Fabric Combinations (actual ft3/min) / (ft2 of net cloth area) (Particulate Matter Controls, 1998)

Dust	Shaker/Woven Fabric Reverse-Air/Woven Fabric	Pulse Jet/Felt Fabric Reverse-Air/Felt Fabric
Alumina	2.5	8
Asbestos	3.0	10
Bauxite	2.5	8
Carbon Black	1.5	5
Coal	2.5	8
Cocoa, Chocolate	2.8	12
Clay	2.5	9
Cement	2.0	8
Cosmetics	1.5	10
Enamel Frit	2.5	9
Feeds, Grain	3.5	14
Feldspar	2.2	9
Fertilizer	3.0	8
Flour	3.0	12
Fly Ash	2.5	5
Graphite	2.0	5
Gypsum	2.0	10
Iron Ore	3.0	11
Iron Oxide	2.5	7
Iron Sulfate	2.0	6
Lead Oxide	2.0	6
Leather Dust	3.5	12
Lime	2.5	10
Limestone	2.7	8
Mica	2.7	9
Paint Pigments	2.5	7
Paper	3.5	10
Plastics	2.5	7
Quartz	2.8	9
Rock Dust	3.0	9
Sand	2.5	10
Sawdust (Wood)	3.5	12
Silica	2.5	7
Slate	3.5	12
Soap, Detergents	2.0	5
Spices	2.7	10
Starch	3.0	8
Sugar	2.0	13
Talc	2.5	5
Tobacco	3.5	
Zinc Oxide	2.0	

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The air-to-cloth ratio is defined as the ratio between the volumetric flow rate and total cloth area, $(ft^3/min)/(ft^2)$ and the gas-to-cloth ratio is defined as the ratio between the actual volumetric flow rate and net cloth area, $(ft^3/min)/(ft^2)$. The air-to-cloth/gas-to-cloth ratio is one of the main control variables for design of baghouse filters. The air-to-cloth/gas-to-cloth ratio is difficult to estimate without computer models, or manufacturer data. (Turner, 2015). Major factors that influence the gas-to-cloth ratio are particle and fabric characteristics and gas temperature. The gas-to-cloth ratios for numerous particulate matters are listed in Table 4.

Baghouse filters of HMA plants mainly handle fly ash and stone dust, emitted from the drum dyer and burner (Davis, 2000). The gas-to-cloth ratios for fly ash fly and stone dust could be found on table 4. For example, fly ash has a gas-to-cloth ratio of 2.5 $(ft^3/min)/(ft^2)$ and stone dust has a gas-to-cloth ratio of 3.0 $(ft^3/min)/(ft^2)$. This indicates an a composite gas-to-cloth ratio of 2.75 $(ft^3/min)/(ft^2)$.

If the gas-to-cloth ratio is too high (please define too high) pressure increases, collection efficiency decreases and more frequent cleaning is required, leading to reduced fabric life. If the gas-to-cloth ratio is too low, the additional cloth is wasted. Unfortunately, the gas-to-cloth ratio is difficult to estimate from first principles. (Turner, McKenna, Mycock, Nunn & Vatavuk, 1998). Other factors also influence the size of filter, such as pressure drop across the filter system, input flow rate (cfm), number of compartments and average fabric area(ft^2/bag).

4.3 Exhaust Systems Emission Control

An HMA plant's emission control system relies on the effectiveness of the exhaust system that brings emissions from the drum dryer through the wet scrubber, baghouse, and into the stack. The fans and stack most influence the effectiveness of this system. Because each of these elements is different, both in appearance and function, each must be designed separately. These elements comprise a system, which is governed by certain physical laws that serve to unite elements in "common cause" (Vatavuk, 1995). In the calculation, before the individual design procedures for hoods, ductwork, and stacks are described, ventilation fundamentals must be presented. For applied air pollution control ventilation systems, some fundamentals cover basic fluid flow concepts (Vatavuk, 1995). The flow chart and fans positions are shown in the Figure 10.

Any gains from increasing the efficiency of the exhaust system can be thwarted if the plant doesn't control dust in the yard or during conveyance of dry materials, so separate systems must be created and maintained there as well.

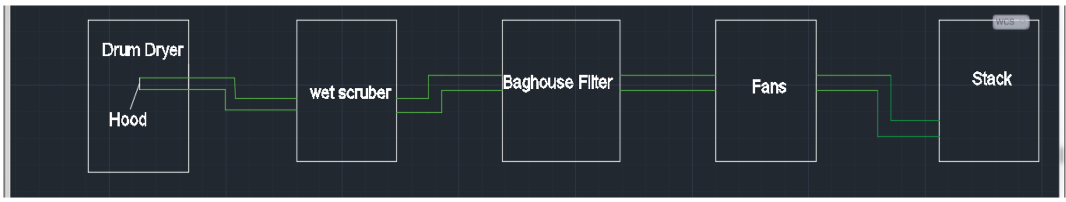

Figure 10: Position of Fans at HMA plants

4.3.1 Fans

An induced draft fan maintains a constant drum vacuum pressure by drawing exhaust air from the mixing drum through the baghouse system and wet scrubber system. The capacity of the fan is a controlling factor in heating and drying of the aggregate in the drum dryer/burner. The fan in HMA plants also delivers the gas to the stack in order to release it to the ambient air.

The centrifugal induced draft (ID) fans provide the most effective means of generating relatively high pressures. They have a track record of use in material handling applications that produces dirty air-streams with high moisture and particulate content under temperatures above 235 ℉ (Benson, 2003).

Figure 11 shows some components included in the centrifugal induced draft fan, such as the base frame, motor pedestal, motor, fan casing and outlet, impeller, impeller cone, fan casing section removable, inlet vane control and inlet box (Centrifugal Fan-Exploded View, 2015).

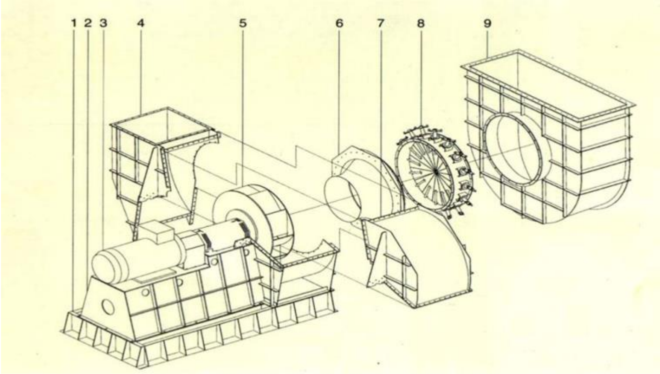

Figure 11: Induced Draft Fan (Centrifugal Fan-Exploded View, 2015)

Centrifugal fans use various blade types including forward curved blades, radial blades, backward inclined blades, and air foil blades (Fan Performance Characteristics of Centrifugal Fans, 2014). Radial-blades are best suited for HMA plants because they are effective under conditions of low to medium airflow rates at high pressures. These fans can handle high-particulate air-streams, which include dust, wood chips, and metal scrap (Benson, 2003).

4.3.2 Stack

A stack vents the emission into the atmosphere, and the pressure difference created by the stack's height is essential to efficient air flow. In general, the gas temperature inside the flue is around 325 ℉ and the outside ambient air temperature is around 86 ° F. The temperature difference causes a pressure difference between the base of the stack and the tip. On the upper level, the air is cold with heavy density, so the hot gas with low density will be pushed up causing the pressure difference in the stack (Vatavuk, 1995).

Figure 12: Stack in HMA plant (Emissions into the environment, 2016)

Dust sources are a major category of emissions for most facilities in the mineral products industry. The dust sources are usually vented to the atmosphere through some type of stack, vent, or pipe. Dusted emissions are usually collected and transported by an industrial ventilation system which has one or more fans or air movers, eventually to be emitted to the atmosphere through some type of stacks (Reducing Atmospheric Emissions from Asphalt Plants, 2016).

According to the Section 2, Generic Equipment and Devices from EPA (2002), GEP is defined as "the height necessary to insure that emissions from the stack do not result in excessive concentrations of any air pollutant in the immediate vicinity of the source as a result of atmospheric downwash, eddies, or wakes which may be created by the source itself, nearby structures, or nearby terrain obstacles". Although an emission control system can remove 99% of air pollutants, to satisfy the regulation and promote the flow of emissions from the drum dryer, the stack should be set up.

Two main factors affect the stack efficiency: the height of the stack and the diameter. The diameter of the stack at the bottom is typically larger than the diameter of the stack at the tip for stability. But for HMA plants, a constant diameter is selected because the stack is not so tall and the metal material has good stability. To reach the maximum efficiency and lowest cost, the height and diameter of the stack

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need to be designed and calculated, as explained in Appendix A: Factors calculation of the stack efficiency.

4.3.3 Yard dust control

Any gains from increasing the efficiency of the exhaust system can be thwarted if the plant doesn't control dust in the yard or during conveyance of dry materials. An integrated dust control system should be considered for the yard. Often the production materials are left in the yard without being covered. Wind can move the material which is conveyed to the drum dryer, casting dust into the air. As Figure 13 shows, the amount of dust can sometimes obscure vision and requires employees to shield their eyes and mouths (Reducing Atmospheric Emissions from Asphalt Plants, 2016).

Figure 13: Dust on HMA yard (Emissions into the environment, 2016)

A simple, economic and effective way to solve this problem is to cover materials during storage and cover all conveyors and feeding systems.

5. Conclusions

This report discusses the design of HMA plants and recommends several best practices to improve an HMA plant's emission control system. Together these practices can remove 99% -99.9% of CO, NOx, PM, VOCs and SO_2.

A packed tower model is the most efficient wet scrubber available. The gas absorbers in a packed tower scrubber achieve efficiencies as high as 99.9 percent because the acid gas steam contacts a high surface area of solvent. Packed tower wet scrubbers commonly use water to remove inorganic and organic contaminants to avoid chemical reactions with the gas steam that would cause additional pollutants.

The cyclone dust collector is combined with a wet scrubber to collect coarser materials such as fugitive dust. In this model, a Chevrons mist eliminator was used in the wet scrubber system because Chevrons offer the highest reliability and efficiency and removes contaminants close to 100%. A limestone water system decontaminates waste water, allowing for safe disposal.

The other major improvement is to use a reverse-air baghouse filter. With Polyphenylene Sulfide fabric filters and the correct sizing of the filter, baghouse filters collect particulate matter (PM) with sizes ranging from submicron to several hundred microns in diameter at efficiencies generally in excess of 99 or 99.9 percent. The reverse-air cleaning method yields a layer of dust or dust cake that contains the dust for easy disposal.

The exhaust system also contributes to the effectiveness of the emission control system. The centrifugal induced draft fan (radial-blade types) drives air through the system to ensure that every component, including hoods and duct, work unimpeded. The height and diameter of the stack are the main factors affecting stack efficiency. Two equations applied to design the height and diameter of the stack allow it to reach maximum efficiency and low cost. There is not too much emission exhaust because the effective emission control systems are already in plants, so the stack exhaust gas is a negligible emission.

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The quality of a plant's material transmission system covers that are over the conveyors reduce dust diffusion. Finally, the simple covers over other materials stored in the yard and over the conveyors transferring materials in the plant also reduce dust diffusion.

Ideally all HMA plants would immediately switch to these methods. In actuality, each plant will need to judge the cost efficiency of the different recommendations based on their existing setup and current emission system effectiveness. This report did not attempt to calculate costs because the cost varies so much due to the individual characteristics of HMA plants around the country. However, as costs are reduced, harmful emissions can be reduced even further.

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