DIRECT FIRED AXIAL FLOW CO-CURRENT HEATING SYSTEM FOR HOT-IN-PLACE ASPHALT RECYCLING

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ABSTRACT

A direct fired, axial flow, co-current primary heater for use in a hot in place asphalt recycling system includes internally substoichiometric inspiriting burners operating at slightly greater than the stoichiometric amount by tertiary air flow controlled by a variable speed induced draft fan. A cool down box at the end of the burner box reduces emissions exiting at the back of the system. The sides of the burner box may pivot outwardly to increase the width of coverage.
FIG. 1A

FIG. 1B

Time (minutes)

Temperature (°C)

Legend:
- 102
- 104
- 106
- 108
- 110
- 112
Asphalt Surface Heat Flux

Heat Flux (kW/m²)

Distance (ft)

FIG. 2C

Asphalt Temperatures (Top 1")

Temperature (°C)

Distance (ft)

FIG. 3
DIRECT FIRED AXIAL FLOW CO-CURRENT HEATING SYSTEM FOR HOT-IN-PLACE ASPHALT RECYCLING

CROSS REFERENCES TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/282,868, filed Apr. 13, 2010 and No. 61/272,951, filed Nov. 23, 2009, the contents of each of which are hereby incorporated by reference in their entirety.

TECHNICAL FIELD

[0002] This application relates to improvements to hot-in-place asphalt recycling systems and processes and more particularly relates to a direct fired, axial flow, co-current heater and related components and processes for use as a primary heater in hot-in-place asphalt recycling systems.

BACKGROUND

[0003] Hot-in-place asphalt recycling systems (referred to herein as “HIP”) although other acronyms are also in common use: e.g. HIP, HIPAR) refers to continuous processes by which distressed asphalt of a road or other surface is renewed by recycling the existing asphalt material. These processes typically involve:

[0004] i. Heating the upper layer (about 2 inches) to soften the bitumen binder.
[0005] ii. Lifting of this layer from the surface, in one or more ‘milling’ stages (scarification) to produce loose asphalt.
[0006] iii. Mixing rejuvenators and other additives including virgin hot-mix asphalt into the loose asphalt.

[0008] An example of a hot-in-place asphalt recycling systems and processes are described in U.S. Pat. No. 6,769,836 to Lloyd, the contents of which are incorporated by reference herein.

[0009] Current HIP operations use one or more asphalt heating devices (‘heaters’) operating in series, one behind the other in a line. The ensemble will be referred to as a “HIP train”. Each heater consists of one or more burners and, based on the maximum fuel flow and heating value of the fuel, can be assigned an installed burner rating; e.g. Btu/hr or million Btu/hr (MMBtu/hr).

[0010] In absence of any industry standard for heater terminology, this disclosure defines two categories:

[0011] (a) Primary heaters intended to play the dominant role in heating of the asphalt. In current practice, greater than 75% of the total heat supplied to the asphalt is by primary heaters.

[0012] (b) Secondary heaters intended to augment the heating process.

[0013] Primary heaters are distinguished by significantly greater installed burner ratings than secondary heaters, typically by a factor of three or greater.

[0014] Secondary heaters may be assigned names based on positioning within the HIP train; e.g. as a preheater when leading a primary heater; post-heater when following a primary heater. Again there is no industry standard for naming of secondary heaters.

[0015] Within this disclosure, heaters will be referenced by function; i.e. primary or secondary heaters.

[0016] Current prior art primary heaters employ (i) multiple (up to several hundred) radiant heater boxes or (ii) recirculated hot-gas. Within this disclosure these will be termed ‘radiant heaters’ and ‘hot-air heaters’ respectively.

[0017] Current prior art secondary heaters typically have the following configuration. Burners (usually located at the front of the device) discharge directly into the unit (i.e. direct firing). The gas flow is from front to rear (i.e. axial flow) and opposite the direction of travel; i.e. co-current to the asphalt. This configuration is referred to as a direct-fired, axial-flow, co-current (and abbreviated as “DF-AF-CC”) heater. This configuration has not been utilized for primary heaters as they are not of sufficient burner rating to operate as primary heaters.

[0018] Current prior art secondary heaters typically operate at air flows significantly in excess of that required to combust the fuel (high excess air often greater than 50%) and are characterized by little, if any, automated control. High excess air reduces the heat transfer rates achieved to the asphalt and represents an unnecessary thermal burden. These factors result in poor heating efficiency with (typically) about ½ of the heat available from combustion penetrating the asphalt, which is viewed as uneconomic for a primary heater.

[0019] Uniform heating distribution over the lane width is ensured by the use multiple burners (up to 15). The complexity of the multi-burner layout is reduced by the use of purpose-designed ‘inspiriting’ type burners to obviate the need for forced draft air supply. The term “inspiriting” refers to burners that entrain combustion air by to the interection of the high momentum fuel jet with the surrounding fluid (air). Some current secondary heaters employ this type of burner. However, inspring burners cannot be considered for primary heaters without significant improvement on current practice:

[0020] i. The maximum rating of commercially available inspiriting burners is about 350,000 BTU per hour which is too low for application as primary heaters.

[0021] ii. Inspiriting burners are known to experience difficulty maintaining stable combustion over a wide range of firing rates while simultaneously operating at consistently low (less than 15%) excess combustion air.

[0022] The criteria preferred for an inspiriting burner design in a DF-AC primary burner system are one or more of:

[0023] i. A rating of about 900,000 BTU/hour at maximum fuel flow.

[0024] ii. The ability to maintain stable combustion conditions from 100% firing down to 20% firing. This is referred to as turn-down, in this instance 5:1.

[0025] iii. The ability to maintain less than 15% excess air over the 5:1 turndown. This is important for ensuring acceptable heating efficiency.

[0026] With the aid of a purpose-built test cell, a novel burner design meeting these preferred criteria was developed.

[0027] Some preferred criteria established for the HIP process and system are one or more of:

[0028] i. Achieve high heating efficiency by maintaining excess air at less than 15%. Air in excess of that required for chemical reaction with the fuel (combustion) is a thermal burden on the system. As excess air increases beyond the minimum required for complete combustion gas temperatures within the heater are driven down...
which reduces heat transfer rates to the asphalt. The net effect is to lower heating efficiency; i.e. the percentage of the energy made available by combustion that enters the asphalt. Current DF-AF-CC secondary heaters operate at high levels of excess air (50% or greater) with heating efficiencies as low as 30%.

- **ii.** The ability to achieve less than 15% excess combustion air ensures the gas temperature over the majority of the heater box length box is sufficiently high to promote incineration of emissions evolved from the asphalt in-situ; i.e. while still under the heater box. Current DF-AF-CC secondary heaters cannot achieve efficient incineration because of operation at high excess air and the attendant depression of gas temperature.

- **iii.** Minimize emission generation at source by limiting the maximum asphalt surface temperature under the heater box to a specified maximum value. The maximum will depend on the composition of the particular asphalt being worked. This is achieved by combination of two methods: (i) a computer model of the process that relates asphalt surface temperature profiles, including the surface temperature on exit from the heater box, to firing rate and heater speed and (ii) infrared sensors reading asphalt surface linked to the fuel flow to the burners by a conventional PLC control circuit. The set point is derived initially from the model and then fine-tuned in the field to account for local conditions.

- **iv.** Incorporate an unheated cool-down box at the back-end of the heater to collect any residual emissions from the asphalt surface occurring after exiting from under the heater box. The cool-down box ensures that the surface temperature is below the level of active fume emission (~150°C) before being exposed to ambient conditions. The cool-down box is purged by inward flowing air which is passed through the tertiary incinerator unit. Because it must subsequently be heated in the incinerator, the flow of purge air is maintained at a low level.

- **v.** Incorporate the capability for heating non-standard lane widths; i.e. greater than 12 feet.

**Background Analysis of Heat Penetration into Asphalt**

**0031** Heating of the asphalt road surface involves two significant issues:

- **0032** Thermal penetration of materials of 'low' diffusivity (such as asphalt) requires substantial time to accomplish. Overly aggressive external heating will tend to accumulate thermal energy (heat) at the surface; i.e. the surface temperature increases quickly but the response at depth is sluggish.

**TABLE 1**

<table>
<thead>
<tr>
<th>C (J/kg°C)</th>
<th>ρ (kg/m³)</th>
<th>K (W/m°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200 ± 10%</td>
<td>2200 ± 10%</td>
<td>1.25 ± 30%</td>
</tr>
</tbody>
</table>

- **0037** Heating of the asphalt road surface involves two significant issues:

- **0038** Thermal penetration of materials of ‘low’ diffusivity (such as asphalt) requires substantial time to accomplish. Overly aggressive external heating will tend to accumulate thermal energy (heat) at the surface; i.e. the surface temperature increases quickly but the response at depth is sluggish.

**Heating Strategies: Desirable Characteristics**

**0040** Heat transfer to the asphalt surface can be expressed by:

\[
q = -h(T^* - T_o) \rho c_p \frac{d\theta}{dx}
\]

where: 
- \( h \) is the overall heat transfer coefficient (W/m²°C)
- \( T^* \) is the temperature of the heat source
- \( T_o \) is the surface temperature of the asphalt.

**0041** The thermal response of asphalt can be simulated using computer models for conduction within combined with the boundary condition given by formula (1) above.

**0042** To illustrate the implications, consider the passage of a heater over a fixed section of asphalt. Assuming the heater is 30 feet long and moving at 15 ft/min, the total heating time is 2 minutes. The asphalt properties are taken as those given in Table 1. If we further assume \( h=125 \text{ W/m}^2\text{C} \) we can consider two scenarios:

- **0043** i. The source temperature \( T^* \) is a constant 600°C.

- **0044** ii. The source temperature varies linearly as a function of time, starting at 900°C and finishing at 300°C.

**0045** In each scenario the average \( T^* \) is 600°C. FIG. 1a is a graphical representation of asphalt temperature over time for constant \( T^* \) of 600°C. The maximum surface temperature \( 102 \text{ (270°C) } \) occurs as the asphalt is exposed to ambient. The graph at FIG. 1a also shows lines for temperature at one inch asphalt depth 106 and average of the top one inch of asphalt depth 104.

**0046** FIG. 1b is a graphical representation of asphalt temperature over time for declining \( T^* \) starting at 900°C and finishing at 300°C with an average of 600°C. The maximum surface temperature \( 108 \text{ (350°C) } \) occurs after 1 minute and the surface temperature \( 108 \) at the time of exposure to ambient is 205°C. The graph at FIG. 1b also shows lines for temperature at one inch asphalt depth 112 and average of the top one inch of asphalt depth 110.

**0047** Emissions generated under the heater unit can be captured but emissions generated after the asphalt passes from under the unit are problematic.
[0048] FIGS. 1a and 1b demonstrate the advantages of the declining source temperature heating method (front-to-rear of the device) relative to the constant source temperature approach; i.e. reduced maximum surface temperature and reduced surface temperature at exit from the heater which leads to lower process emissions.

[0049] i. Current primary heaters employ the constant source temperature principle.


[0051] It follows that there is a need for primary heater(s) of a HIP system to operate with the DF-AF-CC configuration to take advantage of the benefits of the declining source temperature principle.

SUMMARY OF THE INVENTION

[0052] The application discloses embodiments directed to several improvements to HIP asphalt recycling systems and processes, including:

[0053] 1. The technology for operation of the DF-AF-CC configuration utilizing a novel burner system which significantly improves the heating efficiency of this configuration (to greater than 75%) permitting its use as a primary heater;

[0054] 2. A novel cool-down box to eliminate fugitive emissions;

[0055] 3. A control system to ensure consistent performance;

[0056] 4. An ensemble of DF-AF-CC primary heaters forming a HIP train.

[0057] In addition the application is directed to the following improvements:

[0058] A. A novel combustion system comprised of internally substoichiometric inspiring burner(s) operating with tertiary air flow controlled by a variable speed induced draft fan. This is accomplished using an oxygen sensor located under the heater box linked to the fan drive motor via a conventional PID or PLC control system.

[0059] Relative to current inspiring burners systems this offers improvements in:

[0060] Capacity: The system operates up to 1 million BTU/hr per burner, roughly three times that of currently available inspiring burners.

[0061] Turndown: The system maintains stable combustion between 100% of maximum fuel flow and 20% of maximum fuel flow; i.e. 5:1 turndown.

[0062] Minimizing excess air: The system is capable of maintaining less than 15% excess combustion air over the 5:1 turndown range. The ability to control excess combustion air to this level is essential to achieving heating efficiency acceptable in primary heaters.

[0063] B. The application of this novel combustion system enables the DF-AF-CC configuration to be incorporated for use in a primary heater for HIP applications. Primary being defined here as providing greater than 75% of the total heat input to the asphalt, either as a single heater or multiple heaters acting in concert. It is exemplified below that heater units of this configuration impose desirable features on the asphalt surface temperature distribution under the heater and, when operated at less than 15% excess air, achieve heating efficiency greater than 60%, while promoting in-situ incineration of emissions from the asphalt surface. An HIP train based on multiple heater units of this configuration will retain these benefits.

[0064] C. The cool-down box and purge air system for emissions collection before exposure of the heated asphalt surface to ambient. The cool-down box ensures the asphalt surface is not exposed to ambient before dropping below 150° C. This allows a significant reduction in fugitive emissions compared to current primary and secondary heaters.

[0065] D. The use of direct-fired, drop-on heater box extensions to allow operation on wider-than-standard lane widths.

Technology Included in the Application

[0066] The engineering basis for the DF-AF-CC primary heater and the enabling technology includes:

[0067] 1. The combustion system comprised of internally substoichiometric inspiring burner(s) operating with tertiary air flow controlled by a variable speed induced draft fan. This is accomplished using an oxygen sensor located under the heater box linked to the fan drive motor via a conventional PID or PLC control system.

[0068] Relative to current inspiring burners systems this offers improvements in:

[0069] Capacity: The system operates up to 1 million BTU/hr per burner, roughly three times that of currently available inspiring burners.

[0070] Turndown: The system maintains stable combustion between 100% of maximum fuel flow and 20% of maximum fuel flow; i.e. 5:1 turndown.

[0071] Minimizing excess air: The system is capable of maintaining less than 15% excess combustion air over the 5:1 turndown range. The ability to control excess combustion air to this level is essential to achieving heating efficiency acceptable in primary heaters.

[0072] 2. The application this enabling technology to the DF-AF-CC primary heater for HIP applications. In this context, “primary” is defined as providing greater than 75% of the total heat input to the asphalt, either as a single heater or multiple heaters acting in concert. It is demonstrated in the engineering discussion that heater units of this configuration impose desirable features on the asphalt surface temperature distribution under the heater and, when operated at less than 15% excess air, achieve heating efficiency greater than 60% while promoting in-situ incineration of emissions from the asphalt surface. It is further demonstrated that a train based on multiple heater units of this configuration will retain these benefits.

[0073] 3. The cool-down box and purge air system for emissions collection before exposure of the heated asphalt surface to ambient. The cool-down box ensures the asphalt surface is not exposed to ambient before dropping below 150° C. This allows a significant reduction in fugitive emissions compared to current primary and secondary heaters.

[0074] 4. The use of novel swing-out panels to allow operation on wider-than-standard lane with minimal increase in mechanical complexity.

[0075] In an embodiment of the invention a direct fired, axial flow, co-current primary heater for a hot in place asphalt
recycling system, the heater includes: (a) a heater container having front, rear, left, right and top sides for positioning over an asphalt road surface for travel over the asphalt in a first direction of travel, such that the bottom edges of the sides is positioned adjacent the asphalt to substantially prevent escape of gases from the interior of the container; (b) a burner positioned at the front of the container for heating the gas in the container, the burner including: (i) a combustion chamber; (ii) a fuel injector for injecting fuel into the combustion chamber in a direction opposite to the first direction; (iii) a first combustion gas inlet for inputting a first supply of combustion gas into the first chamber to mix with the fuel, configured to restrict the amount of gas input into the combustion chamber less than the stoichiometric amount required for complete combustion of the fuel; (iv) a combustor for igniting the mixture of fuel and gas; and (v) a second combustion gas inlet for inputting a second supply of combustion gas into the mixture downstream of the combustor; (e) a variable speed induced draft fan for drawing the flow of second combustion gas from the second combustion gas inlet; and (d) a fan controller for controlling speed of the fan responsive to the amount of oxygen in the gas stream exiting the burner to maintain the oxygen above the stoichiometric amount to fully combust the fuel.

The second combustion gas inlet of the primary heater may include an adjustable inlet for controlling the amount of second supply of combustion gas into the combustion chamber.

As an alternative, the primary heater may include a controller responsive to the pressure in the heater container to control the adjustable inlet to maintain the pressure in the heater container to a level less than the pressure outside the container. Alternatively, The second combustion gas inlet of the primary heater may input the second supply of combustion gas into the heater container.

As a further alternative the flow resistance of the first combustion gas inlet may be greater than the flow resistance of the second combustion gas inlet.

The fan controller may control the speed of the fan to maintain the amount of excess gas leaving the second combustion gas inlet at about 15% above the stoichiometric amount. The second combustion gas inlet may include an adjustable inlet for controlling the amount of second supply of combustion gas into the combustion chamber and a controller responsive to the pressure in the heater container to control the adjustable inlet to maintain the pressure in the heater container at a level less than the pressure outside the heater container. The adjustable inlet may include an annular channel and opening about the periphery of a circular cross-section combustion chamber and a slideable annular collar block movable in an axial direction to open and close the adjustable inlet.

As a further alternative, the fuel injector may be configured to inject a high momentum flow of fuel into the combustion chamber in the direction opposite to the first direction.

As yet a further alternative the burner may include a plurality of burners extending along the front side of the container in axial alignment perpendicular to the first direction.

The combustion gas may be air.

The first combustion gas inlet may be configured with respect to the fuel injector to provide about 75% of the stoichiometric gas requirements for combustion of the fuel.

The left and right sides may be extendable outwardly to increase the width of the heater container. The left and right sides may be pivotable about an axis adjacent their top to permit the bottom of the sides to extend outwardly.

A cooling container may be positioned adjacent the rear side for collecting and cooling emissions from the road surface following the passage of the heater container over the road surface. The emissions from the cooling container may be directed to mix with the emissions in the heater container. An incinerator may communicate with the heater container for receiving and combusting the emissions received from the heater container and cooling container to combust the emissions before returning residual gases to the environment. The fan is positioned to draw the emissions from the heater container and cooling container and direct them to the incinerator. The cooling container may include a first outlet from the interior of the cooling container to the heater container, a second outlet from the interior of the cooling container to the fan, and a controller for controlling the amount of emissions from the road surface travelling through one or both of the outlets to control the temperatures of the emissions entering the incinerator. An inlet may be provided to permit cooler outside gases to enter the cooling container. A sensor may be provided for sensing the amount of gaseous emissions from the asphalt surface behind the cooling container. A controller may be provided responsive to the sensor for controlling the amount of gases exiting the cooling container through the second outlet.

In a further alternative a burner for a primary heater of a hot in place asphalt recycling system positioned at the front of the container for directing heat axially co-current with the direction of travel of the asphalt recycling system includes: (a) a combustion chamber; (b) a fuel injector for injecting fuel into the combustion chamber in the co-current direction; (c) a first combustion gas inlet for inputting a first supply of combustion gas into the first chamber to mix with the fuel, configured to restrict the amount of gas input into the combustion chamber less than the stoichiometric amount required for complete combustion of the fuel; (d) a combustor for igniting the mixture of fuel and gas; and (e) a second combustion gas inlet having a flow resistance less than that of the first combustion gas inlet for inputting a second supply of combustion gas into mixture downstream of the combustor; (f) a fan for controlling the amount of combustion gas exiting the second combustion gas inlet; and (g) a controller, responsive to the amount of oxygen in the mixture downstream of the second combustion gas inlet, controlling the fan to maintain the amount of excess gas leaving the adjustable inlet at about 15% above the stoichiometric amount.

As a further alternative the primary heater is a part of a train of heaters in axial alignment for travel in the first direction and the primary heater may provide at least 75% of the total heat applied to the asphalt surface by the train. The primary heater may be the first heater of the train. The train may include four primary heaters and a pair of scarifiers for milling the asphalt from the surface, the first scarifier positioned behind the second primary heater in the train and the second scarifier positioned behind the fourth primary heater of the train.

In another alternative, a process of hot in place asphalt recycling of an asphalt surface using a primary heater in a heater box includes the steps of: (a) by combustion of a fuel air mixture by a burner, creating heat and directing the heat in the heater box in an axial direction, in direction from
the front to the rear of the box, co-current with the direction of movement over the asphalt; combustion by the burner including the steps of: (i) directing stream of fuel at high momentum in the axial co-current direction; (ii) directing a first stream of air into the stream of fuel so that first stream is entrained with the fuel, the amount of air in the first stream being insufficient to cause complete combustion of the fuel; (iii) partially combusting the fuel in the mixture of fuel and first stream of air; (iv) directing a second stream of air into the mixture, the amount of air in the second stream being sufficient, when combined with the amount of air in the first stream of air, to exceed the amount required for complete combustion of the fuel; and (v) combusting the remaining uncombusted fuel in the stream; (b) applying negative pressure in the axial co-current direction on the combustion gases and on the second stream of air; and (c) controlling the amount of excess air leaving the burner to an amount less than about 15% above the amount required for complete combustion of the fuel by controlling the amount of negative pressure applied on the second stream of air.

As an alternative, at step (a)(iv), the step of controlling the amount of second stream of air entering the mixture by increasing or decreasing the area through which the second stream of air travels to enter the mixture. Alternatively, the amount of second stream of air may be controlled to maintain the pressure in the heater box less than the pressure outside of the heater box.

DESCRIPTION OF THE DRAWINGS

FIG. 1a is a graph of Asphalt temperatures over time for T = 600°C;
FIG. 1b is a graph of Asphalt temperatures over time for T = 900°C T → 300°C, (T average = 600°C);
FIG. 2a is a graph of Asphalt temperatures over distance for the top 1" of asphalt;
FIG. 2b is a graph of Asphalt surface temperature of heater box gas and roof temperatures over distance;
FIG. 2c is a graph of Asphalt surface heat flux over distance;
FIG. 3 is a graph of Asphalt temperature at the surface, at one inch depth, and the average of the top 1 inch, over distance indicative of projected performance of a HIP train consisting of four DF-AF-CC heaters;
FIG. 4 is a schematic diagram in cross-section of the heater box, cool-down box, burner, induced draft fan, and tertiary incinerator of an embodiment of the subject embodiment;
FIG. 5 is a schematic diagram in cross-section of the detail of the cool-down box of FIG. 4;
FIG. 6 is a schematic diagram of the sub-stoichiometric burner of FIG. 4;
FIG. 7 is a schematic diagram in cross-section of the optional variable width sides of the heater box of FIG. 4; and
FIG. 7b is a close-up view of a portion of the heater box of FIG. 7a.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Computer Simulation of the DF-AF-CC Primary Heater

In order to confirm the design criteria of using DF-AF-CC primary heaters a computer model for the system (including the asphalt) was developed. The independent variables for the model are: fuel flow (which sets the energy release rate by combustion), excess combustion air, heater box length, width and depth and speed in the direction of travel.

The results of an example simulation is shown graphically in FIGS. 2a, 2b and 2c. FIG. 2a is a graph of asphalt temperatures over distance for the top 1" of asphalt, at the surface 114, at one inch asphalt depth 118 and average of the top one inch of asphalt 116.

FIG. 2b is a graph of asphalt surface temperature of heater box gas temperature 120, roof temperature 122, and asphalt temperature at one inch depth 124, over distance. FIG. 2c is a graph of asphalt surface heat flux over distance. The heater speed is 20 ft per minute and the maximum allowable surface temperature is set at 275° C. The heater box is 30 ft long and the cool-down box an additional 6 ft. Note that, in these figures, distance refers to the location of the section of asphalt being considered relative to the front of the heater box.

General features to be noted are:

1. The gas temperature 120 is highest (about 1450° C., FIG. 2b) near the front of the heater box 12 and then declines to about 600° C. at exit to the ID fan. This clearly illustrates the declining source temperature principle.
2. The maximum asphalt 20 surface temperature 114 of 275° C. (FIG. 2a) also occurs near the front of the heater box 12 and decreases to about 200° C. at exit from under the heater box 12.
3. Over the first 15 ft of the heater box 12, the gas temperature 120 is greater than 800° C. (FIG. 2b) promoting in-situ incineration of asphalt emissions generated upstream.
4. The maximum heat flux 12c to the asphalt 20 (FIG. 2c) occurs near the front end of the heater box 12 and declines over the remainder of the heater box 12 length.
5. The asphalt 20 surface temperature 114 at exit from the heater box 12 (about 180° C.) is reduced to below 150° C. at exit from the cool-down box 38 (36 ft in FIG. 2a). This significantly reduces emissions from the surface after exit from the heater box 12 where capture is problematic.

Performance of the HIP Asphalt Recycling System Train Using DF-AF-CC Primary Heaters

The projected performance of a HIP asphalt recycling train consisting of four DF-AF-CC primary heaters is shown in FIG. 3. FIG. 3 comprises a graph of asphalt temperature at the surface 128, at one inch depth 132, and the average of the top 1 inch depth 130, over distance, indicative of projected performance of a HIP asphalt recycling train consisting of four DF-AF-CC primary heaters. Train speed is 20 ft/min and 2-stage milling is employed; i.e. 1" is removed from the surface after the 2nd and 4th heaters. These results confirm the capability of such a system.

Direct-Fired, Axial-Flow, Co-Current Primary Heater

A preferred embodiment of applicant’s DF-AF-CC primary heater system and method for a HIP asphalt recycling system is shown schematically in FIG. 4.
FIG. 4 is a schematic diagram in cross section of the components of heater 10. Heater 10 includes heater box 12 made up of an inverted box structure with top member 14, front member 16, rear member 18, and a pair of opposed side members (not shown). Front and rear members 16, 18 and side members extend downwardly with bottoms configured to closely approach or contact asphalt surface 20 in order to confine gases released upon heating the asphalt by heater 10 and to provide maximum application of heat on asphalt 20 within heater box 12. Top, front, and rear members 14, 16, 18 and side members are all insulated to assist in retaining heat within heater box 12.

Heater 10 is configured for travel in the direction of arrow 22. Burner 24 extends through front member 16 oriented to direct heat axially in a direction opposite to the direction of travel 22, that is co-current with the direction of travel over asphalt 20. Burner 24 will be discussed in greater detail, with reference to FIG. 6, below.

The main gas flow exiting burner 24 is shown with reference to arrow 26, the main gas flow 26 is also in a direction co-current with the direction of asphalt 20 as heater 10 moves in the direction of travel 22.

The axial gas flow is drawn by variable speed induced draft fan 28 extending upwardly from top member 14 connected by conduit 30 to permit gases within box 12 to enter and exit fan 28 into tertiary incinerator 32. Incinerator burner 34 is a direct fired, on-demand, burner to burn off the combustible gases exiting fan 28. Incinerator 34 is positioned to direct its heat into the flow of the gas exiting fan 28 in order to combust the combustible portion of those gases. The remaining gases are then exhausted to atmosphere.

Oxygen sensor 36 is positioned within heater box 12 within the main gas flow 26. Sensor 36 reads the amount of oxygen within gas flow 26 which is used to establish the excess oxygen exiting burner 24 by controlling fan 28 speed in order to maintain less than 15% excess air exiting burner 24, that is air over and above that required for full combustion of the fuel entering burner 24.

In particular, note that:

i. Multiple burners 24 configured in the manner discussed below (up to 15) are located at the front end extending through front member 16 and discharge into an inverted box structure or heater box 12, insulated on all 5 faces. The burners 24 are aligned in the axial direction and sufficiently high on the front member 16 to ensure against direct flame impingement on the asphalt surface 20. This should be contrasted with current primary heaters which utilize either several hundred radiant heater boxes which form the roof (radiant-type heaters) or a single burner located external to the heater box (hot-air-type heaters). This is also contrasted with secondary heaters which, due to burner inefficiencies and other limitations, cannot attain the necessary heat transfer to the asphalt in order to act as primary heaters.

ii. The axial gas flow 26 is drawn by a variable speed induced draft (ID) fan 28. The axial gas flow 26 is comprised of the gaseous products of fuel combustion. Contrasted with current DF-AF-CC secondary heaters which employ multiple burners but not an ID fan. Current prior art primary heaters direct the gas flow downward onto the asphalt coupled with secondary flow inward to a central plenum (radiant heaters) or downward onto the asphalt surface then rearward for recirculation back to the burner (hot-air heaters).

iii. A direct-fired, on-demand, tertiary incinerator 32, is included in the off-gas circuit.

Cool-Down Box

At surface temperatures above about 150° C, asphalt generates significant fume emissions. Although the heater system is designed to reduce the heating rate over the length of heater box 12, this represents inefficient heating when the asphalt surface temperature is below about 200° C. To avoid this inefficiency, a separate unheated, cool-down box 38 is attached to the backend of heater box 12. Cool-down box 38 ensures that the asphalt surface 20 is not exposed to ambient before dropping below 150° C.

Cool-down box 38 will be discussed with reference to FIGS. 4 and 5. Rear member 18 acts as an insulated baffled separating heat box 12 from cavity 40 of cool-down box 38. Box 38 also includes upper insulated member 42 angled at an acute angle with respect to rear member 18 so that its rear end 44 is adjacent to asphalt 20. However, it should be noted that a narrow space exists between rear end 44 and rear end 46 of rear member 18 to permit air from outside of heater 10, including outside of cool-down box 38 to enter both cool-down 38 and heater box 12. The flow of air from outside heater 10 and cool-down 38 is shown by means of arrow 48 showing the flow of outside air into heater box 12 and arrow 50 showing the flow of air into cool-down box 38. It can be seen that the flow of air shown by arrow 48 also passes through cavity 40 of heater box 38.

Conduit 52 extends upwardly from upper member 42 to join conduit 30 which permits gas flowing in the direction of arrow 50 to enter conduit 30 drawn by induced draft fan 28. Controller 54 is positioned along conduit 52 to enable manual or automatic control of the amount of flow of air through conduit 52.

It should also be understood that air moving up along in the direction of arrows 48 and 50 also capture gases from asphalt 20 causing those gases to move through conduits 52 and 30 into incinerator 32 where the combustible portions of those gases are incinerated.

As depicted in FIG. 4, optionally infrared sensor 56 can be positioned adjacent rear end 44 to monitor the amount of transient gases, coming off asphalt 20 after heater 10 passes by.

As shown in FIGS. 4 and 5, purge air is drawn through cool-down box 38 by induced draft fan 28, some of the flow passing under the baffle, that is rear member 18, separating it from heater box 12 and the remainder passing through the conduit 52 directly connected to conduit 30 at the inlet side of induced draft fan 28. The latter path includes a damper (controller 54) to ensure the total purge flow through cool-down box 38 is just sufficient to clear emissions. Because the purge air is heated within incinerator 32, the flow is maintained at a low level to minimize the thermal burden on incinerator 32.

Burner

FIG. 6 depicts the sub-stoichiometric burner 24. Burner 24 includes three main sections, primary air tube 58, mixing tube 60 and combustor 62. Burner 24 is connected to front member 16 in axial alignment with heater box 12 and the direction of travel of heater box 12 over asphalt (FIG. 4).

Primary air tube 58 includes fuel tube and nozzle 64 through which fuel enters burner 24 and is caused to flow in
the direction of arrow 66 passing through nozzle tip 68 having inner dimensions 70, referenced as “D” herein. Fuel tube and nozzle 64 are generally circular in cross-section as is nozzle tip 68. Fuel to the nozzle 64 includes an outer wall 72 controlling the flow of fuel. Primary air tube 58 is defined by outer wall 74 also of a circular cross-section. An annular primary air inlet 76 is formed between walls 72 and 74 to permit primary air, flowing in the direction of arrows 78 to enter region 80 to mix with the fuel exiting nozzle 68. The approximate diameter of the fuel jet is defined by an outwardly extending conical region 82.

[0129] Mixing tube 60 is positioned downstream of primary air tube 58 defined by cylindrical wall 84 connected to the downstream end of outer wall 74. The diameter 86 of mixing tube 60 is defined by wall 84.

[0130] Combustor 62 is positioned downstream of mixing tube 60 and is defined by outer wall 88 which is also cylindrical with diameter 90. Outer wall 88 joins wall 84 of mixing tube by means of a lateral step region 92 with diameter 90 being greater than diameter 86. Combustor 62 includes circumferential annulus 94 extending about outer wall 88 of combustor 62. Annulus 94 defines the extent of opening 96 thought which tertiary air (a second stream of air) enters heater box 12. Annulus 94 is adjustable in an axial direction, as indicated by arrows 98 moving annulus 94 in a downstream direction moves it closer to front member 16 thereby reducing the size of opening 96. Conversely, moving annulus 94 in an upstream direction moves annulus 94 away from front member 16 thereby increasing the size of opening 96, permitting more air to enter heater box 12.

[0131] As shown in FIG. 6, combustion air is split between primary air drawn through the primary air inlet 76 of burner 24 and tertiary air drawn from around burner 24 through opening defined between front member 16 and annulus 94 with the size of opening 96 controlled through movement of annulus 94. The internal burner 24 design ensures 75% of the stoichiometric combustion air requirement is via the primary air circuit. Thus, burner 24 is classified as internally sub-stoichiometric; i.e. the air passing through burner 24 is less than the stoichiometric requirement for complete combustion of the fuel. Fuel and primary air are vigorously mixed in mixing tube 60 upstream of the combustor where ignition occurs. The tertiary air flow provides the additional air to complete the combustion process. The annular area 96 for tertiary air flow is controlled by the positioning of the sliding annulus 94.

[0132] Burner 24 is designed for gaseous fuels, typically (but not limited to) gaseous propane. As shown in FIG. 6, it consists of a fuel tube and nozzle 64 concentric with a primary air tube or primary air inlet 76 leading to a fuel-air mixing tube 60 and combustor 62 where ignition occurs. The fuel tube tapers to the exit nozzle 70 with nozzle tip of diameter 70 “D”. To ensure efficient entrainment of primary air by the fuel jet diameter 70 is sized to generate sonic velocity in the fuel at the nozzle tip 68 exit plane (termed choked flow) at fuel flows greater than 25% of maximum flow. Relative to subsonic exit velocity, the choked flow design maximizes the momentum of the fuel jet which promotes entrainment of primary air.

[0133] Tertiary air supply is an important element for achieving stable combustion over the 5:1 (maximum:minimum flow) turndown capability.

[0134] The tertiary air flow is controlled by the speed of the induced draft (ID) fan 28, which is linked to the oxygen sensor 36 (FIG. 4) signal via a PLC controller programmed to maintain 15% (or less) excess combustion air over the 5:1 turndown. The oxygen level at the sensor 36 location (after combustion) is linked to excess air (before combustion) by the combustion reaction stoichiometry; an oxygen sensor reading of about 1.5% O₂ (i.e. after combustion) corresponds to about 15% excess combustion air (the exact relationship depends on the fuel composition). Based on the oxygen level relative to the set-point value, 1.5% in this example, the PLC controller adjusts the ID fan 28 speed; e.g. increasing the fan speed increases the tertiary air flow.

[0135] As described in the foregoing, the excess air level is controlled by the speed of the ID fan 28. The purpose of the sliding annulus 94 is to control excess air but rather the pressure drop of the tertiary air passing through opening 96. This enables control of the average pressure under heater box 12 between positive (above atmospheric) and negative (sub-atmospheric). The flow resistance of the primary air circuit is designed to be significantly greater than that of the tertiary circuit; this ensures that the tertiary air flow is more responsive to the speed of the ID fan 28 than the primary air flow.

[0136] As an example, at a given fuel flow (and total combustion air flow corresponding to 15% excess) moving the annulus 24 inward or downstream of the gas flow (opposite the direction of travel 22 shown in FIG. 4) decreases the annular area of opening 96 (and hence tertiary air flow) and increases the pressure drop. The controller response is to increase the ID fan 28 speed to bring the tertiary air flow back to the level required for 15% excess air. The net result is to reduce the pressure at both the front (burner-end) and back-end (the ID fan 28 inlet end) of heater box 28; i.e. to reduce the average pressure. Control of the average pressure allows control of the infiltrate air flow (or exfiltrate gas flow) occurring due to imperfect sealing of heater box 28 to the asphalt surface 20.

[0137] The annulus 94 can be manually adjusted or, optionally, included in the PLC control system using a pressure transducer mounted under heater box 12 and an appropriate actuator.

[0138] Based on the distance of diameter 70 defined as “D” at nozzle tip 68, various preferred distances of various components of burner 24 have been identified. The diameter 86 of mixing tube 60 is preferably about 20 times distance “D” or 20D. The distance 140 of mixing tube 60 is preferably about 75D. The distance 142 between tip 68 and the downstream end of primary air tube 58 is about 50D. The length 144 of combustor 62 is about 25D and the diameter 90 of combustor 62 is about 25 D.

The Variable Width Heater Box

[0139] FIG. 7a is a schematic diagram in cross-section of the optional variable width sides of the heater box 12. FIG. 7b is a close up view of a portion of the variable width sided heater box of FIG. 7a.

[0140] In certain instances it is required to heat lane widths greater than standard (e.g. to include shoulder areas). However, it is also desirable that the unit conform to standard width regulations for transport between job sites. This avoids the necessity of special permitting, pilot cars, etc. In order to meet these needs, heater box 12 may optionally incorporate swing-out panels 100 of sides 152 of heater box 12. The design features an elevated pivot point 150 so as to maintain adequate volume for gas flow within the extension zone when sides are in their extended positions as shown with respect to
one side in FIG. 7b. In the extended position, additional burners 24 can be fitted as appropriate. Sides 152 include insulation 154 configured to be in sliding slideable engagement with insulation 156 connected to top side 14 of heater 10. Bottom ends of insulation 154 and sides 152 contact asphalt surface 20 when in use.

[0141] Although the embodiment has been shown and described with respect to a certain preferred embodiment or embodiments, it is obvious that equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed figures. For example, regard to the various functions performed by the above described elements (components, assemblies, devices, etc.), the terms used to describe such elements are intended to correspond, unless otherwise indicated, to any element that performs the specified function of the described element (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure that performs the function in the herein illustrated exemplary embodiment or embodiments of the embodiment. In addition, while a particular feature of the embodiment may have been described above with respect to only one or more of several illustrated embodiments, such feature may be combined with one or more other features of the other embodiments, as may be desired and advantageous for any given or particular application.

1. A direct fired, axial flow, co-current primary heater for a hot in place asphalt recycling system, the heater comprising:
   (a) a heater container having front, rear, left, right and top sides for positioning over an asphalt road surface for travel over the asphalt in a first direction of travel, such that the bottom edges of the sides is positioned adjacent the asphalt to substantially prevent escape of gases from the interior of the container;
   (b) a burner positioned at the front of the container for heating the gas in the container, the burner comprising:
      (i) a combustion chamber;
      (ii) a fuel injector for injecting fuel into the combustion chamber in a direction opposite to the first direction;
      (iii) a first combustion gas inlet for inputting a first supply of combustion gas into the first chamber to mix with the fuel, configured to restrict the amount of gas input into the combustion chamber less than the stoichiometric amount required for complete combustion of the fuel;
      (iv) a combustor for igniting the mixture of fuel and gas; and
      (v) a second combustion gas inlet for inputting a second supply of combustion gas into mixture downstream of the combustor;
   (c) a variable speed induced draft fan for drawing the flow of second combustion gas from the second combustion gas inlet; and
   (d) a fan controller for controlling speed of the fan responsive to the amount of oxygen in the gas stream exiting the burner to maintain the oxygen above the stoichiometric amount to fully combust the fuel.

2. The primary heater of claim 1 wherein the second combustion gas inlet comprises an adjustable inlet for controlling the amount of second supply of combustion gas into the combustion chamber.

3. The primary heater of claim 2 further comprising a controller responsive to the pressure in the heater container to control the adjustable inlet to maintain the pressure in the heater container at a level less than the pressure outside the heater container.

4. The primary heater of claim 1 wherein the second combustion gas inlet inputs the second supply of combustion gas into the heater container.

5. The primary heater of claim 1 wherein the flow resistance of the first combustion gas inlet is greater than the flow resistance of the second combustion gas inlet.

6. The primary heater of claim 5 wherein the fan controller controls the speed of the fan to maintain the amount of excess gas leaving the second combustion gas inlet at a level about 15% above the stoichiometric amount.

7. The primary heater of claim 6 wherein the second combustion gas inlet comprises an adjustable inlet for controlling the amount of second supply of combustion gas into the combustion chamber and further comprising a controller responsive to the pressure in the heater container to control the adjustable inlet to maintain the pressure in the heater container at a level less than the pressure outside the heater container.

8. The primary heater of claim 1 wherein the fuel injector is configured to inject a high momentum flow of fuel into the combustion chamber in the direction opposite to the first direction.

9. The primary heater of claim 1 wherein the burner comprises a plurality of burners extending along the front side of the container in axial alignment perpendicular to the first direction.

10. The primary heater of claim 1 wherein the combustion gas is air.

11. The primary heater of claim 7 wherein the adjustable inlet comprises an annular channel and opening about the periphery of a circular cross-section combustion chamber and wherein a slideable annular collar block is moved in a axial direction to open and close the adjustable inlet.

12. The primary heater of claim 1 wherein the first combustion gas inlet is configured with respect to the fuel injector to provide about 75% of the stoichiometric gas requirements for combustion of the fuel.

13. The primary heater of claim 1 wherein the left and right sides are extendable outwardly to increase the width of the heater container.

14. The primary heater of claim 13 wherein the left and right sides are pivotable about an axis adjacent their top to permit the bottom of the sides to extend outwardly.

15. The primary heater of claim 1 further comprising a cooling container adjacent the rear side for collecting and cooling emissions from the road surface following the passage of the heater container over the road surface.

16. The primary heater of claim 15 wherein the emissions from the cooling container are directed to mix with the emissions in the heater container.

17. The primary heater of claim 16 further comprising an incinerator communicating with the heater container for receiving and combusting the emissions received from the heater container and cooling container to combust the emissions before returning residual gases to the environment.

18. The primary heater of claim 17 wherein the fan is positioned to draw the emissions from the heater container and cooling container and direct them to the incinerator.

19. The primary heater of claim 15 wherein the cooling container comprises a first outlet from the interior of the cooling container to the heater container, a second outlet from
the interior of the cooling container to the fan, and a controller for controlling the amount of emissions from the road surface travelling through one or both of the outlets to control the temperatures of the emissions entering the incinerator.

20. The primary heater of claim 19 further comprising an inlet to permit cooler outside gases to enter the cooling container.

21. The primary heater of claim 19 further comprising a sensor for sensing the amount of gaseous emissions from the asphalt surface behind the cooling container.

22. The primary heater of claim 21 further comprising a controller responsive to the sensor for controlling the amount of gases exiting the cooling container through the second outlet.

23. A burner for a primary heater of a hot in place asphalt recycling system positioned at the front of the container for directing heat axially co-current with the direction of travel of the asphalt recycling system, the burner comprising:
   (a) a combustion chamber;
   (b) a fuel injector for injecting fuel into the combustion chamber in the co-current direction;
   (c) a first combustion gas inlet for inputting a first supply of combustion gas into the first chamber to mix with the fuel, configured to restrict the amount of gas input into the combustion chamber less than the stoichiometric amount required for complete combustion of the fuel;
   (d) a combustor for igniting the mixture of fuel and gas; and
   (e) a second combustion gas inlet having a flow resistance less than that of the first combustion gas for inputting a second supply of combustion gas into mixture downstream of the combustor;
   (f) a fan for controlling the amount of combustion gas exiting the second combustion gas inlet; and
   (g) a controller, responsive to the amount of oxygen in the mixture downstream of the second combustion gas inlet, controlling the fan to maintain the amount of excess gas leaving the adjustable inlet at below about 15% above the stoichiometric amount.

24. The primary heater of claim 1 wherein the primary heater is a part of a train of heaters in axial alignment for travel in the first direction and wherein the primary heater provides at least 75% of the total heat applied to the asphalt surface by the train.

25. The primary heater of claim 24 wherein the primary heater is the first heater of the train.

26. The primary heater of claim 24 wherein the train comprises four primary heaters, further comprising a pair of scarifiers for milling the asphalt from the surface, the first scarifier positioned behind the second primary heater in the train and the second scarifier positioned behind the fourth primary heater of the train.

27. A process of hot in place asphalt recycling of an asphalt surface using a primary heater in a heater box, comprising the steps of:
   (a) by combustion of a fuel air mixture by a burner, creating heat and directing the heat in the heater box in an axial direction, in direction from the front to the rear of the box, co-current with the direction of movement over the asphalt, combustion by the burner comprising the steps of:
      (i) directing stream of fuel at high momentum in the axial co-current direction;
      (ii) directing a first stream of air into the stream of fuel so that first stream is entrained with the fuel, the amount of air in the first stream being insufficient to cause complete combustion of the fuel;
      (iii) partially combusting the fuel in the mixture of fuel and first stream of air;
      (iv) directing a second stream of air into the mixture, the amount of air in the second stream being sufficient, when combined with the amount of air in the first stream of air, to exceed the amount required for complete combustion of the fuel; and
      (v) combusting the remaining uncombusted fuel in the stream;
   (b) applying negative pressure in the axial co-current direction on the combustion gases and on the second stream of air; and
   (c) controlling the amount of excess air leaving the burner to an amount less than about 15% above the amount required for complete combustion of the fuel by controlling the amount of negative pressure applied on the second stream of air.

28. The process described in claim 27, wherein at step (a)(iv), controlling the amount of second stream of air entering the mixture by increasing or decreasing the area through which the second stream of air travels to enter the mixture.

29. The process as described in claim 28, wherein the amount of second stream of air is controlled to maintain the pressure in the heater box less than the pressure outside of the heater box.

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