

**FIRE SUPPRESSION SYSTEM USING HIGH VELOCITY LOW
PRESSURE EMITTERS**

Cross-Reference to Related Applications

This application is based on and claims priority to U.S. Provisional Application No. 60/689,864, filed June 13, 2005 and U.S. Provisional Application No. 60/776,407, filed February 24, 2006.

Field of the Invention

This invention concerns fire suppression systems using devices for emitting atomized liquid, the device injecting the liquid into a gas flow stream where the liquid is atomized and projected away from the device onto a fire.

Background of the Invention

Fire control and suppression sprinkler systems generally include a plurality of individual sprinkler heads which are usually ceiling mounted about the area to be protected. The sprinkler heads are normally maintained in a closed condition and include a

thermally responsive sensing member to determine when a fire condition has occurred. Upon actuation of the thermally responsive member, the sprinkler head is opened, permitting pressurized water at each of the individual sprinkler heads to freely flow therethrough for extinguishing the fire. The individual sprinkler heads are spaced apart from each other by distances determined by the type of protection they are intended to provide (e.g., light or ordinary hazard conditions) and the ratings of the individual sprinklers, as determined by industry accepted rating agencies such as Underwriters Laboratories, Inc., Factory Mutual Research Corp. and/or the National Fire Protection Association.

In order to minimize the delay between thermal actuation and proper dispensing of water by the sprinkler head, the piping that connects the sprinkler heads to the water source is, in many instances, at all times filled with water. This is known as a wet system, with the water being immediately available at the sprinkler head upon its thermal actuation. However, there are many situations in which the sprinkler system is installed in an unheated area, such as warehouses. In those situations, if a wet system is used, and in particular, since the water is not flowing within the piping system over long periods of time, there is a danger of the water within the pipes freezing. This will not only adversely affect the operation of the sprinkler system should the sprinkler heads be thermally actuated while there may be ice

blockage within the pipes but, such freezing, if extensive, can result in the bursting of the pipes, thereby destroying the sprinkler system. Accordingly, in those situations, it is the conventional practice to have the piping devoid of any water during its non-activated condition. This is known as a dry fire protection system.

When actuated, traditional sprinkler heads release a spray of fire suppressing liquid, such as water, onto the area of the fire. The water spray, while somewhat effective, has several disadvantages. The water droplets comprising the spray are relatively large and will cause water damage to the furnishings or goods in the burning region. The water spray also exhibits limited modes of fire suppression. For example, the spray, being composed of relatively large droplets providing a small total surface area, does not readily absorb heat and, therefore, cannot operate efficiently to prevent spread of the fire by lowering the temperature of the ambient air around the fire. Large droplets also do not block radiative heat transfer effectively, thereby allowing the fire to spread by this mode. The spray furthermore does not displace oxygen from the ambient air around the fire, nor is there usually sufficient downward momentum of the droplets to overcome the smoke plume and attack the base of the fire.

With these disadvantages in mind, devices, such as resonance tubes, which atomize a fire suppressing

liquid, have been considered as replacements for traditional sprinkler heads. Resonance tubes use acoustic energy, generated by an oscillatory pressure wave interaction between a gas jet and a cavity, to atomize a liquid that is injected into the region near the resonance tube where the acoustic energy is present.

Unfortunately, resonance tubes of known design and operational mode generally do not have the fluid flow characteristics required to be effective in fire protection applications. The volume of flow from the resonance tube tends to be inadequate, and the water particles generated by the atomization process have relatively low velocities. As a result, these water particles are decelerated significantly within about 8 to 16 inches of the sprinkler head and cannot overcome the plume of rising combustion gas generated by a fire. Thus, the water particles cannot get to the fire source for effective fire suppression. Furthermore, the water particle size generated by the atomization is ineffective at reducing the oxygen content to suppress a fire if the ambient temperature is below 55°C. Additionally, known resonance tubes require relatively large gas volumes delivered at high pressure. This produces unstable gas flow which generates significant acoustic energy and separates from deflector surfaces across which it travels, leading to inefficient atomization of the water.

There is clearly a need for a fire suppression system having an atomizing emitter that operates more efficiently than known resonance tubes. Such an emitter would ideally use smaller volumes of gas at lower pressures to produce sufficient volume of atomized water particles having a smaller size distribution while maintaining significant momentum upon discharge so that the water particles may overcome the fire smoke plume and be more effective at fire suppression.

Brief Description of the Drawings

Figure 1 is a schematic diagram illustrating an exemplary fire suppression system according to the invention;

Figure 2 is a longitudinal sectional view of a high velocity low pressure emitter used in the fire suppression system shown in Figure 1;

Figure 3 is a longitudinal sectional view showing a component of the emitter depicted in Figure 2;

Figure 4 is a longitudinal sectional view showing a component of the emitter depicted in Figure 2;

Figure 5 is a longitudinal sectional view showing a component of the emitter depicted in Figure 2;

Figure 6 is a longitudinal sectional view showing a component of the emitter depicted in Figure 2; and

Figure 7 is a diagram depicting fluid flow from the emitter based upon a Schlieren photograph of the emitter shown in Figure 2 in operation.

Figure 8 is a diagram depicting predicted fluid flow from another embodiment of the emitter.

Detailed Description of the Embodiments

Figure 1 illustrates, in schematic form, an example fire suppression system 11 according to the invention. System 11 includes a plurality of high velocity low pressure emitters 10, described in detail below. Emitters 10 are arranged in a potential fire hazard zone 13, the system comprising one or more such zones, each zone having its own bank of emitters. For clarity, only one zone is described herein, it being understood that the description is applicable to additional fire hazard zones as shown.

The emitters 10 are connected via a piping network 15 to a source of pressurized water 17. A water control valve 19 controls the flow of water from the source 17 to the emitters 10. The emitters are also in fluid communication with a source of pressurized gas 21 through a gas conduit network 23. The pressurized gas is preferably an inert gas such as nitrogen, and is maintained in banks of high-pressure cylinders 25. Cylinders 25 may be pressurized up to 2,500 psig. For large systems which require large volumes of gas, one or more lower pressure tanks (about 350 psig) having volumes on the order of 30,000 gallons may be used.

Valves 27 of cylinders 25 are preferably maintained in an open state in communication with a high pressure manifold 29. Gas flow rate and pressure from the manifold to the gas conduit 23 are controlled by a high pressure gas control valve 31. Pressure in the conduit 23 downstream of the high pressure control valve 31 is monitored by a pressure transducer 33. Flow of gas to the emitters 10 in each fire hazard zone 13 is further controlled by a low pressure valve 35 downstream of the pressure transducer.

Each fire hazard zone 13 is monitored by one or more fire detection devices 37. These detection devices operate in any of the various known modes for fire detection, such as sensing of flame, heat, rate of temperature rise, smoke detection or combinations thereof.

The system components thus described are coordinated and controlled by a control system 39, which comprises a control panel 41 and a programmable logic controller 43. The control system communicates with the system components to receive information and issue control commands as follows.

Each cylinder valve 27 is monitored as to its status (open or closed) by a supervisory loop 45 that communicates with the system control panel 41, which provides a visual indication of the cylinder valve status. Water control valve 19 is also in communication with control panel 41 via a communication

line 47, which allows the valve 19 to be monitored and controlled (opened and closed) by the control system. Similarly, gas control valve 35 communicates with the control system via a communication line 49, and the fire detection devices 37 also communicate with the control system via communication lines 51. The pressure transducer 35 provides its signals to the programmable logic controller 43 over communication line 53. The programmable logic controller is also in communication with the high pressure gas valve 31 over communication line 55, and with the control panel 41 over communication line 57.

In operation, fire detectors 37 sense a fire event and provide a signal to the control panel 41 over communication line 51. The control panel actuates the logic controller 43. Note that controller 43 may be a separate controller or an integral part of the high pressure control valve 31. The logic controller 43 receives a signal from the pressure transducer 33 via communication line 53 indicative of the pressure in the gas conduit 23. The logic controller 43 opens the high pressure gas valve 31 while the control panel 41 opens the gas control valve 35 and the water control valve 19 using respective communication lines 49 and 47. Nitrogen from tanks 25 and water from source 17 are thus permitted to flow through gas conduit 23 and water piping network 15 respectively. Preferred water pressure for proper operation of the emitters 10 is between about 1 psig and about 50 psig as described below. The logic controller 43 operates valve 31 to

maintain the correct gas pressure (between about 29 psia and about 45 psia) and flow rate to operate the emitters 10 within the parameters as described below. Upon sensing that the fire is extinguished, the control panel 41 closes the gas and water valves 35 and 19, and the logic controller 43 closes the high pressure control valve 31. The control system 39 continues to monitor all the fire hazard zones 13, and in the event of another fire or the re-flashing of the initial fire the above described sequence is repeated.

Figure 2 shows a longitudinal sectional view of a high velocity low pressure emitter 10 according to the invention. Emitter 10 comprises a convergent nozzle 12 having an inlet 14 and an outlet 16. Outlet 16 may range in diameter between about 0.125 inches to about 1 inch for many applications. Inlet 14 is in fluid communication with a pressurized gas supply 18 that provides gas to the nozzle at a predetermined pressure and flow rate. It is advantageous that the nozzle 12 have a curved convergent inner surface 20, although other shapes, such as a linear tapered surface, are also feasible.

A deflector surface 22 is positioned in spaced apart relation with the nozzle 12, a gap 24 being established between the deflector surface and the nozzle outlet. The gap may range in size between about 0.1 inches to about 0.75 inches. The deflector surface 22 is held in spaced relation from the nozzle by one or more support legs 26.

Preferably, deflector surface 22 comprises a flat surface portion 28 substantially aligned with the nozzle outlet 16, and an angled surface portion 30 contiguous with and surrounding the flat portion. Flat portion 28 is substantially perpendicular to the gas flow from nozzle 12, and has a minimum diameter of about 0.1 inches larger than the diameter of the outlet 16. The angled portion 30 is oriented at a sweep back angle 32 from the flat portion. The sweep back angle may range between about 15° and about 45° and, along with the size of gap 24, determines the dispersion pattern of the flow from the emitter.

Deflector surface 22 may have other shapes, such as the curved upper edge 34 shown in Figure 3 and the curved edge 36 shown in Figure 4. As shown in Figures 5 and 6, the deflector surface 22 may also include a closed end resonance tube 38 surrounded by a flat portion 40 and a swept back, angled portion 42 (Figure 5) or a curved portion 44 (Figure 6). The diameter and depth of the resonance cavity may be approximately equal to the diameter of outlet 16.

With reference again to Figure 2, an annular chamber 46 surrounds nozzle 12. Chamber 46 is in fluid communication with a pressurized liquid supply 48 that provides a liquid to the chamber at a predetermined pressure and flow rate. A plurality of ducts 50 extend from the chamber 46. Each duct has an exit orifice 52 positioned adjacent to nozzle outlet 16. The exit

orifices have a diameter of about 0.0625 inches. Preferred distances between the nozzle outlet 16 and the exit orifices 52 range between about 0.015 inches to about 0.125 inches as measured along a radius line from the edge of the nozzle outlet to the closest edge of the exit orifice. Liquid, for example, water for fire suppression, flows from the pressurized supply 48 into the chamber 46 and through the ducts 50, exiting from each orifice 52 where it is atomized by the gas flow from the pressurized gas supply that flows through the nozzle 12 and exits through the nozzle outlet 16 as described in detail below.

Emitter 10, when configured for use in a fire suppression system, is designed to operate with a preferred gas pressure between about 29 psia to about 45 psia at the nozzle inlet 14 and a preferred water pressure between about 1 psig and about 50 psig in chamber 46. The preferred gas is nitrogen.

Operation of the emitter 10 is described with reference to Figure 7 which is a drawing based upon Schlieren photographic analysis of an operating emitter.

Gas 45 exits the nozzle outlet 16 at about Mach 1.5 and impinges on the deflector surface 22. Simultaneously, water 47 is discharged from exit orifices 52.

Interaction between the gas 45 and the deflector surface 22 establishes a first shock front 54 between the nozzle outlet 16 and the deflector surface 22. A shock front is a region of flow transition from supersonic to subsonic velocity. Water 47 exiting the orifices 52 does not enter the region of the first shock front 54.

A second shock front 56 forms proximate to the deflector surface at the border between the flat surface portion 28 and the angled surface portion 30. Furthermore, shock diamonds 58 form in a region along the angled portion 30, the shock diamonds initially defining the liquid-gas stream 60 which projects outwardly and downwardly from the emitter. The shock diamonds are also transition regions between super and subsonic flow velocity and are the result of the gas flow being overexpanded as it exits the nozzle. Overexpanded flow describes a flow regime wherein the external pressure (i.e., the ambient atmospheric pressure in this case) is higher than the gas exit pressure at the nozzle. This produces oblique shock waves which reflect from the free jet boundary 49 marking the limit between the liquid-gas stream 60 and the ambient atmosphere. The oblique shock waves are reflected toward one another to create the shock diamonds.

Significant shear forces are produced in the liquid-gas stream 60, which ideally does not separate from the deflector surface, although the emitter is

still effective if separation occurs as shown at 60a. Water discharged from the orifices 52 is entrained with the gas jet 45 at the second shock front 56 forming the liquid-gas stream 60 where the shear forces developed therein are the primary mechanism for atomization. The water also encounters the shock diamonds 58, which are a secondary source of water atomization.

Thus, the emitter 10 operates with multiple mechanisms of atomization which produce water particles 62 less than 20 μm in diameter, the majority of the particles being measured at less than 5 μm . Furthermore, the particles maintain significant downward momentum, allowing the liquid-gas stream 60 to overcome the rising plume of combustion gases resulting from a fire. The flow from the emitter is observed to impinge on the floor of the room in which it is operated. The sweep back angle 32 of the angled portion 30 of the deflector surface 22 provides significant control over the included angle 64 of the liquid-gas stream 60. Included angles of about 120° are achievable. Additional control over the dispersion pattern of the flow is accomplished by adjusting the gap 24 between the nozzle outlet 16 and the deflector surface.

During emitter operation it is further observed that the smoke layer that accumulates at the ceiling of a room during a fire is drawn into the gas stream 45 exiting the nozzle and is entrained in the flow 60.

This adds to the multiple modes of extinguishment characteristic of the emitter as described below.

The emitter causes a temperature drop due to the atomization of the water into the extremely small particle sizes described above. This robs the fire of heat and helps mitigate spread of combustion. The nitrogen gas flow and the water entrained in the flow replace the oxygen in the room with gases that cannot support combustion. Further oxygen depleted gases in the form of the smoke layer that is entrained in the flow also contributes to the oxygen starvation of the fire. It is observed, however, that the oxygen level in the room where the emitter is deployed does not drop below about 16%. The water particles and the entrained smoke create a fog that blocks radiative heat transfer from the fire, thus mitigating spread of combustion by this mode of heat transfer. Because of the extraordinary large surface area resulting from the extremely small water particle size, the water readily absorbs energy and forms steam which further displaces oxygen, absorbs heat from the fire and helps maintain a stable temperature typically associated with a phase transition. The mixing and the turbulence created by the emitter also helps lower the temperature in the region around the fire.

The emitter is unlike resonance tubes in that it does not produce significant acoustic energy. Jet noise (the sound generated by air moving over an object) is the only acoustic output from the emitter.

The emitter's jet noise has no significant frequency components higher than about 6 kHz (half the operating frequency of well known types of resonance tubes) and does not contribute significantly to water atomization.

Furthermore, the flow from the emitter is stable and does not separate from the deflector surface (or experiences delayed separation as shown at 60a) unlike the flow from resonance tubes, which is unstable and separates from the deflector surface, thus leading to inefficient atomization or even loss of atomization.

Fire suppression systems according to the invention using emitters as described herein achieve multiple fire extinguishment modes which are well suited to control the spread of fire while using less gas and water than known systems.

Another emitter embodiment 101 is shown in Figure 8. Emitter 101 has ducts 50 that are angularly oriented toward the nozzle 12. The ducts are angularly oriented to direct the water or other liquid 87 toward the gas 85 so as to entrain the liquid in the gas proximate to the first shock front 54. It is believed that this arrangement will add yet another region of atomization in the creation of the liquid-gas stream 60 oprojected from the emitter 11.

What is claimed is:

1. A method of operating a fire suppression system, said system having an emitter comprising:
 - a nozzle having an unobstructed bore positioned between an inlet and an outlet, said nozzle inlet being connected in fluid communication with a pressurized gas source, said outlet having a diameter;
 - a duct, separate from said nozzle and connected in fluid communication with a pressurized liquid source, said duct having an exit orifice positioned adjacent to said nozzle outlet;
 - a deflector surface positioned facing said nozzle outlet in spaced relation thereto, said deflector surface comprising a flat surface oriented substantially perpendicularly to said nozzle, said flat surface having a wetted area defined by a minimum diameter approximately equal to said outlet diameter;
 said method comprising:
 - discharging said liquid from said exit orifice;
 - discharging said gas from said nozzle outlet, said gas achieving supersonic speed;
 - establishing a first shock front between said outlet and said deflector surface wherein said gas slows to subsonic speed and then impinges on said wetted area;
 - establishing a second shock front proximate to said deflector surface, said gas moving across said wetted area and increasing to supersonic speed between said first shock front and said second shock front, and decreasing in speed after passing through said second shock front;
 - entraining said liquid in said gas proximate to said second shock front to form a liquid-gas stream; and
 - projecting said liquid-gas stream from said emitter.

2. A method according to claim 1, wherein said system comprises:
 - a plurality of compressed gas tanks forming said source of pressurized gas; a plurality of control valves, each one being associated with one of said compressed gas tanks;

a supervisory loop in communication with said control valves for monitoring the open and closed status of said control valves; and

said method comprising monitoring the status of said control valves and maintaining said control valves in an open configuration during operation of said system.

3. A method according to claim 1, comprising establishing a plurality of shock diamonds in said liquid-gas stream.

4. A method according to claim 1, comprising creating an overexpanded gas flow jet after exiting from said nozzle.

5. A method according to claim 1, comprising supplying gas to said inlet at a pressure between about 29 psia and about 60 psia.

6. A method according to claim 1, comprising supplying liquid to said duct at a pressure between about 1 psig and about 50 psig.

7. A method according to claim 1, further comprising entraining said liquid with said gas proximate to said first shock front.

8. A method according to claim 1, wherein said fluid stream does not separate from said deflector surface.

9. A method according to claim 1, comprising creating no significant acoustic energy from said emitter other than jet noise.

10. A method according to claim 1, further comprising generating momentum in said gas flow jet.

11. A method according to claim 1, further comprising projecting said liquid-gas stream at a velocity of about 1,200 ft/min at a distance of about 18 inches from said emitter.

12. A method according to claim 1, further comprising projecting said

liquid-gas stream at a velocity of about 700 ft/min at a distance of about 8 feet from said emitter.

13. A method according to claim 1, further comprising establishing flow pattern from said emitter having a predetermined included angle by providing an angled portion of said deflector surface surrounding said flat surface.

14. A method according to claim 1, comprising drawing said liquid into said gas using a pressure differential between the pressure in said gas and the ambient.

15. A method according to claim 1, comprising entraining said liquid into said gas and atomizing said liquid into drops less than 20 μm in diameter.

16. A method according to claim 1, comprising drawing an oxygen depleted smoke layer into said gas and entraining said smoke layer with said liquid-gas stream of said emitter.

17. A method according to claim 1, comprising discharging an inert gas from said outlet.

18. A method according to claim 1, comprising discharging a mixture of inert and chemically active gases from said outlet.

19. A method according to claim 18, wherein said gas mixture comprises air.

20. A method of operating a fire suppression system, said system having an emitter comprising:
a nozzle having an unobstructed bore positioned between an inlet and an outlet, said nozzle inlet being connected in fluid communication with a pressurized gas source, said outlet having a diameter;
a duct, separate from said nozzle and connected in fluid communication with a pressurized liquid source, said duct having an exit orifice positioned adjacent to said nozzle outlet;

a deflector surface positioned facing said nozzle outlet in spaced relation thereto, said deflector surface comprising a flat surface oriented substantially perpendicularly to said nozzle, said flat surface having a wetted area defined by a minimum diameter approximately equal to said outlet diameter;

said method comprising:

discharging said liquid from said exit orifice;

discharging said gas from said nozzle outlet, said gas achieving supersonic speed;

establishing a first shock front between said outlet and said deflector surface wherein said gas slows to subsonic speed and then impinges on said wetted surface;

establishing a second shock front proximate to said deflector surface, said gas moving across said wetted area and increasing to supersonic speed between said first shock front and said second shock front, and decreasing in speed after passing through said second shock front;

entraining said liquid in said gas at at least one of said shock fronts to form a liquid-gas stream; and

projecting said liquid-gas stream from said emitter.

21. A method according to claim 20, further comprising entraining said liquid with said gas proximate to said second shock front.

22. A method according to claim 20, further comprising entraining said liquid with said gas proximate to said first shock front.

23. A fire suppression system, comprising:

a source of pressurized gas;

a source of pressurized liquid;

at least one emitter for atomizing and discharging said liquid entrained in said gas on a fire;

a gas conduit providing fluid communication between said pressurized gas source and said emitter;

a piping network, separate from said gas conduit, said piping network providing fluid communication between said pressurized liquid source and said emitter;

a first valve in said gas conduit controlling pressure and flow rate of said gas to said emitter;

a second valve in said piping network controlling pressure and flow rate of said liquid to said emitter;

a pressure transducer measuring pressure within said gas conduit;

a fire detection device positioned proximate to said emitter;

said emitter comprising:

a nozzle having an inlet and an outlet and an unobstructed bore therebetween, said inlet being connected in fluid communication with said first valve, said outlet having a diameter;

a duct, separate from said nozzle and connected in fluid communication with said second valve, said duct having an exit orifice separate from and positioned adjacent to said nozzle outlet;

a deflector surface positioned facing said nozzle outlet, said deflector surface being positioned in spaced relation to said nozzle outlet and having a first surface portion comprising a flat surface oriented substantially perpendicularly to said nozzle and a second surface portion comprising an angled surface surrounding said flat surface, said flat surface having a wetted area defined by a minimum diameter approximately equal to said outlet diameter; and

a control system in communication with said first and second valves, said pressure transducer and said fire detection device, said control system receiving signals from said pressure transducer and said fire detection device and opening said valves in response to a signal indicative of a fire from said fire detection device.

24. A system according to claim 23, further comprising:

a plurality of compressed gas tanks comprising said source of pressurized gas; and

a high pressure manifold providing fluid communication between said compressed gas tanks and said first valve.

25. A system according to claim 24, further comprising:
a plurality of control valves, each one being associated with one of said compressed gas tanks; and
a supervisory loop in communication with said control system and said control valves for monitoring the status of said control valves.
26. A system according to claim 23, wherein said nozzle is a convergent nozzle.
27. A system according to claim 23, wherein said outlet has a diameter between about 1/8 and about 1 inch.
28. A system according to claim 23, wherein said orifice has a diameter between about 1/32 and about 1/8 inch.
29. A system according to claim 23, wherein said deflector surface is spaced from said outlet by a distance between about 1/10 and about 3/4 of an inch.
30. A system according to claim 23, wherein said angled surface has a sweep back angle between about 15° and about 45° measured from said flat surface.
31. A system according to claim 23, wherein said exit orifice is spaced from said outlet by a distance between about 1/64 and 1/8 of an inch.
32. A system according to claim 23, wherein said nozzle is adapted to operate over a gas pressure range between about 29 psia and about 60 psia.
33. A system according to claim 23, wherein said duct is adapted to operate over a liquid pressure range between about 1 psig and about 50 psig.

34. A system according to claim 23, wherein said duct is angularly oriented toward said nozzle.

35. A system according to Claim 23, further comprising a plurality of said exit orifices.

36. A fire suppression system, comprising:

a source of pressurized gas;

a source of pressurized liquid;

at least one emitter for atomizing and discharging said liquid entrained in said gas on a fire;

a gas conduit providing fluid communication between said pressurized gas source and said emitter;

a piping network, separate from said gas conduit, said piping network providing fluid communication between said pressurized liquid source and said emitter;

a first valve in said gas conduit controlling pressure and flow rate of said gas to said emitter;

a second valve in said piping network controlling pressure and flow rate of said liquid to said emitter;

a pressure transducer measuring pressure within said gas conduit;

a fire detection device positioned proximate to said emitter;

said emitter comprising:

a nozzle having an inlet and an outlet and an unobstructed bore therebetween, said inlet being connected in fluid communication with said first valve, said outlet having a diameter;

a duct, separate from said nozzle and connected in fluid communication with said second valve, said duct having an exit orifice separate from and positioned adjacent to said nozzle outlet;

a deflector surface positioned facing said nozzle outlet, said deflector surface being positioned in spaced relation to said nozzle outlet and having a first surface portion comprising a flat surface oriented substantially perpendicularly to said nozzle and a second surface portion comprising a curved surface surrounding said flat surface, said flat surface

having a wetted area defined by a minimum diameter approximately equal to said outlet diameter; and

a control system in communication with said first and second valves, said pressure transducer and said fire detection device, said control system receiving signals from said pressure transducer and said fire detection device and opening said valves in response to a signal indicative of a fire from said fire detection device.

37. A method according to Claim 20, further comprising drawing an oxygen depleted smoke layer into said gas flow and entraining said smoke layer with said liquid-gas stream.