DETONATIVE CLEANING APPARATUS MOUNTING SYSTEM

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ABSTRACT
An apparatus for cleaning a surface within a vessel has an elongate combustion conduit extending from an upstream end to a downstream end. The downstream end is associated with an aperture in the wall of the vessel and is positioned to direct a shockwave toward the surface. At least one hanger supports the combustion conduit at least one location along a length of the combustion conduit. A penetration conduit is positioned between the wall aperture and an associated portion of the combustion conduit. Means couple the combustion conduit to the penetration conduit so as to accommodate relative longitudinal movement and/or relative angular movement.
DETONATIVE CLEANING APPARATUS MOUNTING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS


TECHNICAL FIELD OF THE INVENTION

[0002] The disclosure relates to industrial equipment. More particularly, the disclosure relates to the detonative cleaning of industrial equipment.

BACKGROUND OF THE INVENTION

[0003] Surface fouling is a major problem in industrial equipment. Such equipment includes furnaces (coal, oil, waste, etc.), boilers, gasifiers, reactors, heat exchangers, and the like. Typically, the equipment involves a vessel containing internal heat transfer surfaces that are subjected to fouling by accumulating particulate such as soot, ash, minerals and other products and byproducts of combustion, more integrated buildup such as slag and/or fouling, and the like. Such particulate build-up may progressively interfere with plant operation, reducing efficiency and throughput and potentially causing damage. Cleaning of the equipment is therefore highly desirable and is attended by a number of relevant considerations. Often direct access to the fouled surfaces is difficult. Additionally, to maintain revenue, it is desirable to minimize industrial equipment downtime and related costs associated with cleaning. A variety of technologies have been proposed. Such systems are often identified as “soot blowers” after an exemplary application for the technology.

[0004] Basic soot blower configuration is the scheme lance soot blower. Additionally, combustion soot blower technologies have been proposed. Recent examples include those of U.S. Pat. Nos. 7,011,047 and 7,442,034 and US Patent Publication Nos. 20050126594 and 20050130084, both now abandoned, the disclosures of which are incorporated by reference in their entirety herein as if set forth at length.

SUMMARY OF THE INVENTION

[0005] Accordingly, one aspect of the disclosure involves an apparatus for cleaning a surface within a vessel. An elongate combustion conduit extends from an upstream end to a downstream end associated with an aperture in the wall of the vessel and positioned to direct a shockwave toward the surface. One or more hangers support the combustion conduit at one or more locations along a length of the combustion conduit. A penetration conduit is positioned between the wall aperture and an associated portion of the combustion conduit. Means couple the combustion conduit to the penetration conduit so as to accommodate one or both of relative longitudinal movement and relative angular movement.

[0006] In various implementations, the means for coupling may accommodate the relative longitudinal movement via a slip fit and the relative angular movement via flexing. The slip fit may be of an aperture plate held by a bellows or expansion joint. The flexing may be of the bellows or expansion joint.

[0007] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a partially schematic side view of a soot blower associated with an industrial furnace.

[0009] FIG. 2 is a top view of the soot blower of FIG. 1.

[0010] FIG. 3 is an enlarged side view of a discharge/outlet end of the soot blower of FIG. 1.

[0011] FIG. 4 is a transverse sectional view of the soot blower of FIG. 3.

[0012] FIG. 5 is a partial vertical longitudinal sectional view of the soot blower end portion.

[0013] FIG. 6 is a view of a damper of the soot blower of FIG. 1.

[0014] FIG. 7 is a sectional view of the damper of FIG. 6.

[0015] FIG. 8 is a side view of an alternate soot blower.

[0016] FIG. 9 is a top view of the soot blower of FIG. 8.

[0017] FIG. 10 is a view of a first pair of thrust reaction plates secured to a flange joint.

[0018] FIG. 11 is an end view of the plates and joint of FIG. 10.

[0019] FIG. 12 is an X-ray view of one of the plates of FIG. 10.

[0020] FIG. 13 is a view of the plate of FIG. 12.

[0021] FIG. 14 is an end view of the plates and joints carrying devices.

[0022] FIG. 15 is an end view of plates and joints carrying first alternatively oriented devices.

[0023] FIG. 16 is an end view of plates and joints carrying second alternatively oriented devices.

[0024] FIG. 17 is a view of alternate thrust reaction plates secured to a joint.

[0025] FIG. 18 is an end view of the plates and joint of FIG. 17.

[0026] FIG. 19 is a view of a single thrust reaction plate secured between flanges of a joint.

[0027] FIG. 20 is an end view of the plate and joint of FIG. 19.

[0028] FIG. 21 is a top view of an alternate embodiment of the sootblower of FIG. 1.

[0029] FIG. 22 is a side view of the sootblower of FIG. 21.

[0030] FIG. 23 is an end view of the thrust reaction plates and joint of FIG. 22.

[0031] FIG. 24 is a perspective view of a thrust reaction plate of FIG. 23.

[0032] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0033] FIG. 1 shows a vessel (e.g., a boiler) 20 in a building 21. One or more soot blower apparatus (soot blowers) 22 are positioned to clean surfaces within the vessel interior 78. The exemplary vessel comprises a wall 24. The exemplary wall 24 may include a structural and/or insulative outer layer 26 and an inner layer 28. In high temperature locations along the wall 24, the inner layer 28 may be a heat transfer layer formed of fluid (e.g., water)-carrying tubes. Exemplary tubes are welded together to form a membrane wall. In lower temperature locations, the inner layer 28 may be a steel plate. For further structural reinforcement against internal or external pressure loads, the wall 24 may include reinforcements com-
monly known as buckstays 30. Exemplary buckstays 30 are steel I-beams secured to each other and to the remaining wall structure to form a rigid enclosure. The wall 24 is subject to thermal growth as the vessel temperature increases. The growth may be accommodated by suspending the vessel via the buckstays 30 from a relatively fixed building structure such as a ceiling 32. As the vessel heats, the wall 24 grows vertically downward.

[0034] Each soot blower 22 includes an elongate combustion conduit 36 extending from a first (e.g., an upstream/distal/inlet end) 38 away from the vessel wall 24 to a second (e.g., downstream/proximal/outlet) end 40 closely associated with the wall 24. Optionally, however, the end 40 may be well within the vessel interior 78. In operation of each soot blower 22, combustion of a fuel/oxidizer mixture within the conduit 36 is initiated proximate the upstream end 38 (e.g., within an upstreammost 10% of a conduit length) to produce a detonation wave which is expelled from the downstream end 40 as a shock wave along with associated combustion gases for cleaning surfaces within the interior volume of the furnace. Each soot blower 22 may be associated with a fuel/oxidizer source 42. Such source or one or more components thereof may be shared amongst the various soot blowers. An exemplary source includes a liquidified or compressed gaseous fuel cylinder 44 and an oxygen cylinder 46 in respective containment structures 48 and 50.

[0035] In one example, there is a single fuel (e.g., propane) and a single oxidizer (e.g., pure oxygen). In second example, the oxidizer is a first oxidizer such as essentially pure oxygen. A second oxidizer may be in the form of shop air delivered from a central air source 52. In the second example, air may be stored in an air accumulator 54. Fuel, expanded from that in the cylinder 46 may be stored in a fuel accumulator 56. Each exemplary source 42 is coupled to the associated conduit 36 by appropriate plumbing. Similarly, each soot blower 22 includes a spark box 60 coupled to an igniter 61 for initiating combustion of the fuel oxidizer 4 mixture and which, along with the source 42, is controlled by a control and monitoring system 62.

[0036] In exemplary embodiments of the second example, the fuels are hydrocarbons. In particular exemplary embodiments, both fuels are drawn from a single fuel source but mixed with distinct oxidizers: essentially pure oxygen for the predetonator mixture; and air for the main mixture. Exemplary fuels useful in such a situation are propane, MAPP gas, or mixtures thereof. Other fuels are possible, including ethylene and liquid fuels (e.g., diesel, kerosene, and jet aviation fuels). The oxidizers can include mixtures such as air/oxygen mixtures of appropriate ratios to achieve desired main and/or predetonator charge chemistries. Further, monopropellant fuels having molecularly combined fuel and oxidizer components may be options.

[0037] FIG. 1 shows further details of an exemplary soot blower 22. The exemplary conduit 36 may be formed by a series of doubly flanged conduit sections or segments arrayed from upstream to downstream and a downstream nozzle conduit section or segment 72 having a downstream portion 74 extending through an aperture 76 in the wall and in the downstream end of outlet 40 exposed to the vessel interior 78. The term nozzle is used broadly and does not require the presence of any aerodynamic contraction, expansion, or combination thereof. Exemplary conduit segment material is metallic (e.g., stainless steel). The outlet 40 may be located further within the vessel if appropriate support and cooling are provided. Within the vessel interior 78 are furnace interior tube bundles 80, the exterior surfaces of which are subject to fouling and which are to be cleaned by the soot blower 22.

[0038] A fuel/oxidizer charge may be introduced to the conduit interior in a variety of ways. As noted above, there may be one or more distinct fuel/oxidizer mixtures. Such mixture(s) may be premixed external to the detonation conduit, or may be mixed at or subsequent to introduction to the conduit. For example, there may be distinct introduction of two distinct fuel/oxidizer combinations: a predetonator combination; and a main combination. There may also be a purge gas conduit connected to a purge gas port. An end plate may be bolted to the upstream flange of the upstream segment to seal the upstream end of the combustion conduit and pass through the igniter/initiator 61 (e.g., a spark plug) having an operative end in the conduit interior.

[0039] In operation, at the beginning of a use cycle, the combustion conduit is initially empty except for the presence of air (or other purge gas or flue gas). The fuel(s) and oxidizer(s) are introduced.

[0040] With the charge(s) introduced, the spark box is triggered to provide a spark discharge of the initiator igniting charge (or the predetonator charge in a multi-charge example). The predetonator charge (or single charge) may be selected for very fast combustion chemistry, the initial deflagration quickly transitioning to a detonation producing a detonation wave. Once such a detonation wave occurs, it is effective to pass through the rest of the charge (or the main charge which, otherwise, have sufficiently slow chemistry to not detonate within the conduit of its own accord). The wave passes longitudinally downstream and emerges from the downstream end 40 as a shock wave within the furnace interior, impinging upon the surfaces to be cleaned and thermally and mechanically shocking to typically at least loosen the contamination. The wave will be followed by the expulsion of pressurized combustion products from the detonation conduit, the expelled products emerging as a jet from the downstream end 40 and further completing the cleaning process (e.g., removing the loosened material). After or overlapping such venting of combustion products, a purge gas (e.g., air from the same source providing the main oxidizer and/or nitrogen) is introduced through the purge port to drive the final combustion products out and leave the detonation conduit filled with purge gas ready to repeat the cycle (at another cycle gas conduit connected to a purge gas port). Optionally, a baseline flow of the purge gas may be maintained between charge/discharge cycles so as to prevent gas and particulate from the furnace interior from infiltrating upstream and to assist in cooling of the detonation conduit.

[0041] In various implementations, internal surface enhancements may substantially increase internal surface area beyond that provided by the nominally cylindrical and frustoconical segment interior surfaces. The enhancement may be effective to assist in the deflagration-to-detonation transition or in the maintenance of the detonation wave.

[0042] The apparatus may be used in a wide variety of applications. By way of example, just within a typical coal-fired furnace, the apparatus may be applied to: the. pods or secondary superheaters, the convective pass (primary superheaters and the economizer bundles); air preheaters; selective catalyst removers (SCR) scrubbers; the baghouse or electrostatic precipitator; economizer hoppers; ash or other heat/
accumulations whether on heat transfer surfaces or elsewhere, and the like. Similar possibilities exist within other applications including oil-fired furnaces, black liquor recovery boilers, biomass boilers, waste reclamation burners (trash burners), and the like.

To support the conduit 36, the exemplary soot blower 22 includes one or more hangers 100 and 102. The exemplary hanger 100 is positioned relatively upstream and the exemplary hanger 102 relatively downstream. The exemplary hanger 100 couples the conduit 36 to relatively fixed building structure, bypassing the vessel 20. Exemplary relatively fixed building structure is as a transverse horizontal I-beam 104 or the ceiling 32. The exemplary hanger 100 connects to a support point 106 along the conduit 36 such as a hanger eyelet and to another eyelet 108 along the I-beam 104. The exemplary hanger 100 is a spring hanger, more particularly constant load spring hanger. Exemplary spring hangers are available from LIGEIA, Inc., Newpton, Tenn.

The exemplary hanger 102 couples the conduit 36 to the vessel 20. In the exemplary embodiment, the hanger 102 is coupled to an eyelet 110 secured to one of the buckstays 30 above the conduit 36. The exemplary hanger 102 connects to a collar 112 encircling the conduit in a slip fit (discussed further below). The exemplary hanger 102 is a spring hanger (e.g., a simple spring hanger, not a constant load spring hanger).

The soot blower 22 includes means for resisting recoil of the conduit. The exemplary means for resisting recoil may couple the conduit to relatively fixed building structure to transfer recoil forces to the building structure (and not the wall 24). FIGS. 1 and 2 show means as including a pair of struts 120 (e.g., respectively to the left and right of the conduit 36) coupling the conduit to vertical posts 122. The exemplary struts 120 include an elongate shaft 124 having upstream and downstream ends. At the respective upstream and downstream ends, joints 126 and 128 are provided respectively engaging mating coupling elements 130 and 132 on the conduit 36 and posts, respectively. The exemplary joints 126 and 128 are rods each having a threaded first end mated to end caps of the shaft and having an eyelet second end carrying an apertured ball. The exemplary couplings 130 and 132 are mating devises carrying pins extending through the associated balls. As is discussed further below, the exemplary upstream coupling 130 are mounted to one or more upstream supports while the exemplary downstream coupling 132 are mounted to the right and left sides of the conduit 36. Exemplary plates 140 and 142 are respectively mounted to the right and left sides of the conduit 36. Exemplary plates 140 and 142 are mounted to a downstream face of an upstream flange of one of the sections of the conduit 36. The coupling elements 130 are, in turn, mounted to the downstream faces of the plates 140 and 142.

Upon firing of the conduit, recoil forces tend to drive the conduit away from the vessel 20. Slip fit between the collar 112 and the conduit may allow a certain amount of movement. However, the movement is resisted by tensile force transmitted through the struts 120. As is discussed further below, the struts may include resilient dampers to smoothly absorb the recoil forces and limit peak force loads transferred to the building. An exemplary recoil is limited/constrained to a value of less than about 10 cm (e.g. a value in the range of 1-6 cm, more narrowly 2.5-5 cm).

The thermally-induced vertical movement of the vessel 20 may tend to cause associated local vertical movement of the conduit. Even if this can be partially matched by compliance in the hanger 100, it may be impractical to entirely so address. The result is that the conduit will tend to rotate to a slightly outlet-down orientation. A rigid mounting of the conduit to the vessel would potentially interfere with proper conduit operation across the anticipated range of vessel vertical displacement. Also, there may be relative horizontal displacement. Accordingly, referring to FIG. 3, the exemplary apparatus includes means for coupling the conduit to the vessel so as to accommodate relative longitudinal movement (e.g., the recoil) and relative angular movement (e.g., associated with vertical thermal expansion of the vessel or other vertical or horizontal relative movements). The exemplary means includes a penetration conduit 150 which may be rigidly mounted to the wall 24. For example, the penetration conduit 150 may be in a friction fit or an interference fit with the outer layer 26 or may be secured thereto via brackets or other mounting elements. The exemplary penetration conduit 150 includes an upstream mounting flange 152 outside the vessel. A tubular portion 154 extends from the mounting flange 152 through the wall 24 to an exemplary downstream/outlet end 156 (e.g., a rim). A downstream end portion 155 of the nozzle at the outlet 40 may protrude beyond the rim 156.

Referring to FIG. 5, an annular space 160 between the interior surface 162 of the tubular portion 154 and the exterior surface 164 of the conduit downstream portion 74 may have sufficient radial span DR to accommodate relative angular movement of the combustion conduit 36 relative to the penetration conduit 150 and wall 24. The relative angular movement may include movement characterized by rotation about a horizontal transverse axis (e.g., associated with a pure vertical movement of the vessel relative to one or more upstream support locations of the conduit). The relative angular movement may include movement characterized by rotation about a vertical transverse axis (e.g., associated with a pure horizontal movement of the vessel relative to one or more upstream support locations of the conduit). In addition to these respective pitch and yaw movements, there, potentially may be a roll movement about a longitudinal axis. The span DR may also be effective to accommodate transverse translation movements of up to DR. An exemplary range of angular movement is up to 5° in any direction (for a total range of 10°) from a neutral coaxial condition (e.g., to 0.5-5° in any direction or, more narrowly, 1-4°).

The space 160 may be sufficiently sealed to limit exfiltration (outward flow of gases from the vessel interior if a positive pressure system) and/or infiltration (inward flow of air in the case of a negative pressure system). To do this, a closure plate 170 is positioned outside the vessel to provide a higher degree of relative sealing between the penetration conduit and combustion conduit than would be associated with the radial gap of span DR. Referring to FIGS. 4 and 5, in the exemplary implementation, the plate 170 has a central aperture 172 which closely accommodates the exterior surface 174 of the conduit downstream portion 74. An exemplary accommodation is a close radial sliding fit (much closer than DR). However, for a positive pressure system, in particular the gap may be closed (e.g., by a sealing/structural weld). The exemplary plate 170 is formed in two 180° segments permitting easy assembly over the combustion conduit. The close accommodation of the plate 170 to the combustion conduit requires that relative angular movement between the plate 170 and the flange 152 be accommodated. As seen in FIG. 5, this relative movement may be accommodated by a flexible member 180. An exemplary flexible member 180 is formed as an expansion joint.
An exemplary expansion joint is a single or multiple arch elastomeric expansion joint. The illustrated expansion joint is a single arch, doubly flanged expansion joint such as is available from The Mercer Rubber Company of Hauppauge, N.Y., U.S. The exemplary expansion joint 180 has a flexible arch 182 between a first flange 184 and a second flange 186. The first flange 184 is bolted to the plate 170. The second flange 186 is bolted to the flange 152. The arch may flex to accommodate the relative angular movement. In implementations including those with a fixed non-sliding fit between the plate 170 and the combustion conduit 36, the arch 182 may also accommodate relative longitudinal displacement. Metallic expansion joints may, however, be used (e.g., where advantageous due to high temperature exposure).

For insulation and further sealing, insulation material 190 is positioned within the annular space 160. Exemplary insulation material comprises fibrous material such as a batt or mat of mineral wool and/or glass fiber which also provides a degree of thermal insulation. The material may be longitudinally captured between the plate 170 and an annular clamp 192 (e.g., a stainless steel band clamp clamping an end portion of the insulation batt/mat to the conduit downstream portion 74). With sliding fit between the plate 170 and the conduit 36, relative longitudinal recoil movement of the combustion conduit 36 relative to the wall will be associated with telescoping movement of the downstream portion 74 relative to the penetration conduit 150. The initial recoil may longitudinally compress the insulation 190. A return may re-expand the insulation.

For damping recoil and providing a return force, FIGS. 6 and 7 show damper units 200 which may serve as the joints 126 and/or 128. Each damper unit has a threaded first end portion 202 and a bull-carrying second end portion 204 (i.e., for forming a ball joint). In the exemplary damper unit 200 one of the end portions forms a piston whereas the other forms a cylinder. The exemplary first end portion 202 is formed on a first shaft having an opposite end secured (e.g., threaded) into a piston head 206. The exemplary second end portion 204 is along a second shaft whose opposite end is secured to a cylinder 210. Within the cylinder 210, at opposite ends of the head 206 are resilient (e.g., rubber or elastomer) disks 212 and 214. In the exemplary configuration, extension of the damper resiliently compresses the disk 212 whereas compression resiliently compresses the disk 214. The disks 212 and 214 may be preloaded (i.e., both are under compression when there is no net compressive or tensile force across the damper unit 200). With the exemplary damper unit 200, recoil of the conduit further compresses the disk 214, absorbing the recoil energy and, then, at least partially relaxing to return the combustion conduit to its initial position.

Alternative dampers may be hydraulic snubbers as are available from Piping Technology & Products, Inc. of Houston, Tex. Other devices are available from Taylor Devices Inc. of North Tonawanda, N.Y. as are used in aircraft landing gear shock absorbers. These may be particularly relevant in systems absorbing recoil via compression rather than tension.

Referring back to FIGS. 1 and 2, the struts 120 have sufficient length to accommodate vertical movement by pivoting at axes of the coupling elements 132 while not substantially affecting the longitudinal position of the conduit 36 relative to the wall 24. FIGS. 8 and 9, however, show an alternative configuration wherein a sliding thrust joint 250 is provided. The joint 250 can vertically slide along fixed build-

FIG. 9 shows respective posts 252 and 254 on opposite sides of the conduit 36. The exemplary joint 250 includes pieces of low friction material 256 and 258 respectively sliding along the downstream faces of the downstream flanges of the posts 252 and 254. Exemplary low friction material is polytetrafluoroethylene (PTFE) or an ultra high molecular weight (UHMW) plastic material. The low friction material is sandwiched between the associated post flange and an associated robust thrust plate 260 and 262. Exemplary thrust plates may be similarly formed to the plates 140 and 142 of the first embodiment. Exemplary thrust plates are integrated with a flanged pipe joint 266 between two segments of the conduit 36. Retainer brackets 270 and 272 may capture outboard edges of the respective post flanges to help guide vertical movement.

FIGS. 10 and 11 have separate plates 260 and 262 attached to the back face of the downstream flange 280 of one of the conduit segments (mated to the upstream flange 282 of the next segment). FIGS. 12 and 13 show an individual one of the plates 260, 262 as including two through-holes 283 for bolting with the flanges along the bolt circle of the flanges and two additional holes 284 for mounting the coupling elements 130 or the low friction material 256, 258 (not shown). FIGS. 14-16 show alternate mounting configurations for the coupling elements 130 or the low friction material 256, 258.

FIGS. 17 and 18 show an alternate plate configuration wherein plates 300 and 302 replace plates 260 and 262. The plates 300 and 302 are welded to the OD of the flange 280.

FIGS. 19 and 20 show a single plate 310 having lateral portions 312 and 314 which respectively replace the plates 260 and 262. The plate 310 is shown sandwiched between the flanges 280 and 282, having a central aperture 316 and a bolt hole circle 320 corresponding to those of the flanges 280 and 282 and receiving the bolts securing the flanges 280 and 282. Each of the three exemplary configurations may have different advantages. The welded construction of FIGS. 17 and 18 allows easy retrofitting without need to remove any bolts from the flanges 280 and 282. However, the welds are directly loaded by the recoil force. Also, the loadpath of the recoil force is spaced outboard of the flange outer diameter (OD). This relatively large radial spacing may cause undesirably high bending loading on the flange 280. The FIGS. 10 and 11 plates may require only partial unbolting and without need to separate the flanges 280 and 282. The force path is brought radially inward and may act more directly against the faces of the flanges, thereby decreasing chance of damage to the flanges. The FIGS. 19 and 20 embodiment may have a radically outboard force transmission but more evenly circumferentially distributes this force to the associated moments. However, in a retrofit application, it requires full joint disassembly. It may also require use of an additional gasket and replacement of relatively short bolts with relatively longer bolts.

Referring to FIGS. 21 and 22, an alternative embodiment of the damping unit 400 is shown. The unit 400 comprises a plurality of cylindrical elastomer bumpers 491, such as model number TCB-2 supplied by EFDYN. As seen in FIGS. 21 and 22, four bumpers 491 are arranged along a rod 493 which is threaded into astandard load strut 420. Referring to FIGS. 23 and 24, the thrust plates 460 and 462 attach
to the rear flange 480 of the combustor conduit 436. The thrust plates 460 and 462 are similar to the thrust plate discussed in connection with the previous embodiments with an aperture 497 provided for the rod 493 instead of connecting elements 130 or low friction material 256, 258. Referring back to FIGS. 21 and 22, each thrust plate 460 and 462 is clamped between two of the elastomer bumpers 491. A preload is applied to the bumpers 491 by nut and washer assemblies 494 on each side. Each nut and washer assembly 494 includes two nuts 495 having a split ring style lock washer 496 between them. Tightening the two nuts 495 together locks them in place on the threaded rod 493.

[0060] The elastomer bumpers 491 arranged in this fashion act as a spring/damper system in both recoil (from the initial detonation thrust load) and in rebound as the kinetic energy absorbed by the bumpers 491 is released and pushes the combustor conduit 436 back toward the vessel wall 424.

[0061] The elastomer bumpers 491 having a wide range of load ratings may be selected for different combustor conduit diameters and thrust loads. Accordingly, this damping unit is easily scalable up and down for various combustor diameters and thrust loads.

[0062] The damping unit 400 has been demonstrated in the field and is capable of installation as a retrofit to an existing scrubber or as part of a new installation. Testing in the field for a twelve inch (12") diameter combustor conduit showed about a half inch (0.5") total recoil from the initial blast, with a sinusoidal decaying motion of the combustor that was completely damped to rest in four to five cycles of motion. The field testing showed nearly a reduction factor of four (4) in load transmitted through the struts to the vessel building structure when the elastomer bumpers 491 were utilized. This reduction is very significant as it greatly reduces the amount of local reinforcement customers must add to their vessel building structure for mounting of combustors.

[0063] One or more embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, the invention may be adapted for use with a variety of industrial equipment and with variety of scrubber technologies. Aspects of the existing equipment and technologies may influence aspects of any particular implementation. Accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. An apparatus for cleaning a surface within a vessel, the apparatus comprising:
   an elongate combustor conduit extending from an upstream end to a downstream end associated with an aperture in a wall of the vessel and positioned to direct a shock wave toward said surface;
   means for movably supporting the combustor conduit at one or more locations along a length of the combustor conduit;
   a penetration conduit between the wall aperture and an associated portion of the combustor conduit; and
   means for coupling the combustor conduit to the penetration conduit so as to accommodate at least one of relative longitudinal movement and relative angular movement.

2. The apparatus of claim 1 wherein:
   the means for coupling accommodates both said relative longitudinal movement and said relative angular movement.

3. The apparatus of claim 1 wherein:
   the means for coupling accommodates said relative longitudinal movement via a slip fit; and
   the means for coupling accommodates the relative angular movement via flexing.

4. The apparatus of claim 1 wherein:
   the means for coupling permits at least 0.1 m of said relative longitudinal movement and at least 1° of said relative angular movement, said relative angular movement being about a transverse horizontal axis.

5. The apparatus of claim 4 wherein:
   the means for coupling provides no more than 1.0 m of said relative longitudinal movement and no more than 5° of said relative angular movement.

6. The apparatus of claim 1 wherein the means for coupling comprises:
   a bellows having an upstream end and a downstream end; a plate secured to the bellows upstream end and having an aperture accommodating the combustion conduit in a slip fit; and
   an upstream end flange of said penetration conduit secured to the bellows downstream end.

7. The apparatus of claim 6 wherein:
   the plate is formed in exactly two segments.

8. The apparatus of claim 6 wherein:
   the means for coupling further comprises a fibrous layer surrounding the combustion conduit within the bellows and the penetration conduit.

9. The apparatus of claim 1 further comprising:
   means for restraining the combustion conduit against thrust movement.

10. The apparatus of claim 9 wherein the means for restraining comprises:
    at least two struts coupling the combustion conduit to a fixed building structure.

11. The apparatus of claim 10 wherein:
    each of the struts comprises a damper.

12. The apparatus of claim 11 wherein:
    the dampers are hydraulic dampers.

13. The apparatus of claim 11 wherein:
    the dampers are resilient non-hydraulic dampers.

14. The apparatus of claim 1 wherein:
    the means for movably supporting comprises one or more spring hangers.

15. The apparatus of claim 1 wherein:
    the combustor conduit comprises a plurality of segments assembled end-to-end.

16. An apparatus for cleaning a surface within a vessel, the apparatus comprising:
   an elongate combustor conduit extending from an upstream end to a downstream end associated with an aperture in a wall of the vessel and positioned to direct a shock wave toward said surface;
   one or more hangers supporting the combustor conduit at one or more locations along a length of the combustor conduit;
   a penetration conduit between the wall aperture and an adjacent portion of the combustor conduit; and
   an expansion joint coupling the combustion conduit to the penetration conduit so as to accommodate relative angular movement.

17. The apparatus of claim 16 wherein:
   the expansion joint is an elastomeric expansion joint.

18. The apparatus of claim 16 wherein:
   the expansion joint is a metallic expansion joint.
19. The apparatus of claim 17 wherein:
the expansion joint has a downstream flange secured to an
upstream flange of the penetration conduit;
the expansion device has an upstream flange secured to an
apertured plate accommodating the combustion conduit
in a slip fit having smaller clearance than a clearance
between the combustion conduit and the penetration
conduit.
20. The apparatus of claim 16 further comprising:
means for transferring a recoil force to building structure
bypassing the vessel wall.
21. The apparatus of claim 20 wherein:
the means comprise a vertically sliding engagement with
the building structure.
22. The apparatus of claim 20 wherein:
the means comprise a resilient damper.
23. The apparatus of claim 21 wherein:
the means for transferring a recoil force includes a plurality
of elastomer bumpers.

24. An apparatus for cleaning a surface within a vessel, the
apparatus comprising:
an elongate combustion conduit extending from an
upstream end to a downstream end associated with an
aperture in a wall of the vessel and positioned to direct a
shock wave toward said surface;
one or more hangers supporting the combustion conduit at
one or more locations along a length of the combustion
conduit;
a penetration conduit between the wall aperture and an
adjacent portion of the combustion conduit;
an expansion joint coupling the combustion conduit to the
penetration conduit so as to accommodate relative angular
movement; and
a damping unit for restraining the combustion conduit
against thrust movement including a plurality of elas-
tomer bumpers arranged on a rod, the rod engaging at
least two struts coupling the combustion conduit to a
fixed building structure.