

A FLOW CONTROL METHOD AND APPARATUS

SUMMARY

[0001] An apparatus for redirecting fluid flow in a plenum provides flow performance (quality), structural, and economic advantages by using an array of flat blades that is mounted at an angle with respect to the inlet (upstream) fluid flow, such that the blades are tilted with respect to that flow and correspondingly redirect the flow in a desired direction. The apparatus, also referred to as a "GSG" or "graduated straightening grid," has a range of applications, and offers a number of performance, structural, and economic advantages in large-scale applications. As a particular, but non-limiting example, one or more embodiments of the flow-redirecting apparatus taught herein are configured for use in selective catalytic reactors (SCRs), such as used for scrubbing industrial flue gases.

[0002] In at least one embodiment, an apparatus for redirecting fluid flow in a plenum from a first flow direction to a second flow direction comprises a transverse array of flat blades positioned at an angle oblique to the first flow direction to redirect the fluid flow from the first flow direction to the second flow direction. In this sense, "transverse" denotes that the blades are lengthwise transverse to the direction of the flow being redirected. The oblique angle thus presents an inclined, graduated surface to the inlet/upstream flow, such that the windward face of each blade in the array redirects a portion of the flow in the desired direction.

[0003] In another embodiment, a method of designing a transverse array of flat blades for use in redirecting fluid flow in a plenum from a first flow direction to a second flow direction comprises defining a transverse blade length as a function of an interior cross section at a position within the plenum where the transverse array is to be mounted, and adjusting at least one of a blade height, blade spacing, and blade angle as needed to achieve a desired flow quality for the fluid flow. The method may include adjusting the blade angle by adjusting a planned mounting angle of the transverse array within the plenum.

[0004] In one or more such embodiments, adjusting at least one of a blade height, blade spacing, and blade angle as needed to achieve a desired flow quality for the fluid flow comprises simulating fluid flow in a simulation model of the transverse array, assessing a modeled flow quality against one or more quality requirements, and adjusting one or more of a modeled blade height, modeled blade spacing, and modeled blade angle until the modeled flow quality meets the one or more flow quality requirements. Such processing may be automated partially or wholly, such as by configuring a simulation model with design requirements and designating preferred design tradeoffs (such as blade height-to-spacing adjustment ranges), and configuring the simulation to tune the array design against flow quality requirements. The design requirements may include structural details, including dimensions, allowable array weights, structural fastening/support details, stiffness, etc.

[0005] Of course, those skilled in the art will recognize additional features and advantages upon reading the following detailed description, and upon viewing the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Fig. 1 is a simplified side view of one embodiment of a transverse array for flow redirection, shown within a plenum.

[0007] Fig. 2 is a simplified side view of blade details for one or more embodiments of the array shown in Fig. 1.

[0008] Fig. 3 is a simplified perspective view of one embodiment of a transverse array, particularly illustrating the flat blades used for flow redirection.

[0009] Fig. 4 is a simplified plan view of one embodiment of a transverse array.

[0010] Figs. 5 and 6 are logic flow diagrams illustrating processing logic such as may be implemented on a computer system, for one or more embodiments of a method of designing a transverse array for flow redirecting.

[0011] Figs. 7-9 are installation illustrations, showing various embodiments of transverse arrays as installed in plenums for selective catalytic reactors (SCRs).

DETAILED DESCRIPTION

[0012] Fig. 1 illustrates a transverse array 10, which is also referred to as a “graduated straightening grid” or simply as “array 10.” From the illustration, one sees that the array 10 comprises a plurality of spaced-apart flat blades 12. The array 10 is configured for fixed mounting within a plenum 14, for redirecting a fluid flow from a first flow direction to a second flow direction. In particular, it should be appreciated that the illustrated, novel arrangement for redirecting the fluid flow provides high downstream flow quality in the second flow direction, without need for supplemental straightening vanes downstream of the array 10.

[0013] The illustration depicts a side view of the array 10 and it will be appreciated that the viewer sees an “end view” of the blades 12, and that the blades 12 are lengthwise oriented transverse to the first flow direction. Further, as shown in the illustration, one example installation of the array 10 is at a corner position or junction of the plenum 14, where a first plenum section 16 is oriented in the first flow direction and a second plenum section 18 is oriented in the second flow direction. Thus, the array 10 in this example is configured for redirecting the fluid flow at the corner junction between first and second plenum sections 16 and 18.

[0014] One sees that an exemplary oblique angle for mounting the array 10 with respect to the first flow direction is the “corner angle” of the corner junction between plenum sections 16 and 18. One sees that the upstream blade edges of the blades 12 define a plane and, in at least some design applications, it is preferred to align that plane along the corner diagonal line 20 running from the inside plenum corner 22 to the outside plenum corner 24.

[0015] Of course, it should be understood that other alignments may be used, and the array 10 can be raised or lowered relative to the corner centerline as a “tuning” parameter for

achieving desired flow quality, mounting convenience, etc. Further, the angle of the array 10 relative to the first flow direction may be increased or decreased as a performance tuning parameter, and the oblique angle thus does not necessarily track inside-to-outside corner angles. Still further, it should be understood that the array 10 may be configured for directional changes other than 90 degrees, e.g., corners at less than 90 degrees, and the mounting angles and corner positioning can be varied as needed for flow quality and mechanical considerations.

[0016] Turning to Fig. 2, one sees a magnified side view of a few blades 12 comprising a given embodiment of the array 10. In particular, for ease of reference rather than limitation, one sees that the transverse faces of each blade 12 can be identified as a windward face 30 that faces looking into the fluid flowing in the first flow direction and an opposite, leeward face 32. For further reference, each blade 12 is considered to have an upstream (transverse) edge 34 associated with the inlet/upstream first flow direction and a downstream (transverse edge) 36 associated with the outlet/downstream second flow direction. These upstream and downstream blade edges 34 and 36 may or may not be machined or formed into an aerodynamic profile. Indeed, unfinished square edges such as those associated with plate steel generally provide acceptable performance. However, some installations having higher flow rates, thicker blades, etc., may benefit from shaped blade edges.

[0017] In overall respect to array configurations, one or more embodiments of the array 10 are based a blade height “h” as measured from the upstream blade edge 34 to the downstream blade edge 36 being in a range from about six inches to about eighteen inches, and a blade spacing “c” between adjacent blades 12 in the array 10 being in a range from about three inches to about twenty-four inches. Further, the oblique angle—mounting angle of the array 10 relative to the first flow direction—may be selected to place the blades 12 in the array 10 at a blade angle θ in a range from about minus twenty-five degrees to about plus twenty-five degrees.

[0018] Of course, whether the parameters are set within the above ranges, it should be understood that the array 10 may be “tuned” as needed for given installation requirements by

adjusting one or more such parameters. Such tuning may fix one or more such parameters and vary one or more others in an iterative fashion to arrive at a design solution that yields acceptable flow quality, while meeting all practical cost and mechanical considerations.

[0019] In at least one embodiment, a preferred blade height "h" is at or about twelve inches, and a preferred blade spacing "c" is at or about six inches, and a preferred blade angle θ is at or about nineteen degrees. (One sees in Fig. 2 that the blade angle is measured between a line running from upstream blade edge 34 to downstream blade edge 36 and a line parallel with the second flow direction. Thus, if the second flow direction is vertical, then the preferred blade angle is at or about nineteen degrees off of the vertical. More broadly, the oblique angle of the array 10 is selected to position each blade 12 in the array 10 at a blade angle θ of between -25 degrees to +25 degrees (inclusive) with respect to the second flow direction, wherein the blade angle θ is, as explained, measured relative to the second flow direction using a line connecting the upstream and downstream blade edges 34 and 36.

[0020] Further regarding array design considerations, in one embodiment the blade height as measured from the upstream blade edge 34 to the downstream blade edge 36 is configured to be about two times the blade spacing as measured between adjacent blades 12 the array 10. Mathematically, $h = 2c$. In another embodiment, the ratio is set to 2.5 times, i.e., $h = 2.5c$. For at least some installations, the 2x ratio is preferred, but it should be understood that the height-to-spacing ratio is a candidate tuning parameter and may be manipulated as part of the array design process. For example, weight and/or cost restrictions may call for a reduced blade count, meaning that blade spacing increases for given array dimensions. In such cases, for example, the overall array mounting angle can be changed and/or the blade height can be changed to compensate for the reduced blade count.

[0021] Turning to Fig. 3, one sees a simplified perspective view of the blades 12 in a given array 10, emphasizing the lengthwise transverse orientation of the blades 12, and further

illustrating the deflection by the windward blade faces 30 of the flowing fluid from the first flow direction to the second flow direction. While the leeward face 32 is not visible in Fig. 3, one or more embodiments contemplated herein include a structural stiffener integrated or otherwise mounted on the leeward faces 32 of the blade 12. (Such structural stiffening is shown later herein, for a large scale SCR application.)

[0022] As for other mechanical and structural considerations, one should note that the term “plenum” is to be given broad construction herein. For example, the definition contemplated herein encompasses but is not limited to a fluid-filled space in a structure (e.g., gas, air, etc.), and particularly a conduit or other passage carrying a flowing fluid. Further, unless otherwise noted, the term does not necessarily connote a continuous conduit. For example, a first closed structure (e.g., conduit) may open into a second closed structure (e.g., the space above an SCR stack), and all or part of the first and second structures may be considered as the plenum 14 in which the array 10 is mounted.

[0023] Further, it should be understood that mounting features of the array 10 may be tailored as needed to the particulars of the plenum 14 in which it is installed. For example, Fig. 4 depicts a plan view of a given array 10, illustrating not only the transverse orientation of the blades 12, but also showing a perimeter frame 40, which serves as a carrier for the blades 12 and which may be used to fix the array 10 within the plenum 14. Thus, in one or more embodiments, the array 10 includes at least a partial perimeter frame 40 for structurally fixing the array 10 within the plenum 14. Also, it should be understood that the array 10 may comprise two or more sub-arrays. For example, for very large plenum cross-sections, a number of smaller arrays 10 may be used to form a larger array spanning the required interior space. Doing so may provide, for example, greater structural integrity, as well as limiting individual blade lengths to more practical values.

[0024] Still further, it should be understood that the blades 12 are uniformly spaced within the array 10 in one or more embodiments. However, in one or more other embodiments, the

blades 12 are non-uniformly spaced within the array 10. In still other embodiments, a portion of the blades 12 may be uniformly spaced and another portion may be non-uniformly spaced. Such variations may be adopted to allow for structural mounts, to accommodate obstructions, etc.

[0025] Of course, all design parameters can be set and adjusted as needed for a given installation. Indeed, one aspect of the teachings herein comprises a design methodology whereby computer simulation (and/or experimental scale modeling) and parameter adjustment yield an array 10 that is configured given particular installation requirements. Such simulation may be based on computational fluid dynamics (CFD) modeling and/or experimental scale modeling, and may be implemented in whole or in part on a computer system, e.g., a PC, having a computer readable medium embodying program instructions for carrying out the array tuning method within a flow simulation environment.

[0026] Fig. 5 illustrates one embodiment of such a method, wherein processing “begins” with inputting design requirements (Block 100). Such requirements may be desired flow quality in the second direction, which may be expressed in terms of laminar quality, turbulence values, etc. Such requirements generally will include basic plenum dimensions, flow volumes, velocities, etc. With basic design requirements in place, a method of designing the array 10 includes defining a transverse blade length “L” as a function of an interior cross section at a position within the plenum 14 where the array 10 is to be mounted (Block 102). Processing continues with adjusting at least one of a blade height, blade spacing, and blade angle as needed to achieve a desired flow quality for the fluid flow (Block 104).

[0027] Such processing may be iterative and may use or be driven by scripts or other programmatic controls that step through a range of design parameter choices for any one or more array tuning parameters (e.g., blade height, spacing, angle, overall blade count, etc.), until the design requirements are met. Again, such processing may be carried out via computer simulation in a flow modeling simulation environment or in experimental scale modeling.

[0028] Fig. 6 illustrates one embodiment of iterative array tuning. Such processing may represent details for Block 104 of Fig. 5. The array design may be initialized using default or nominal array parameters, such as default blade height, spacing, and angle (Block 110). Processing continues with adjusting any one or more parameters based on known overrides, such as a mandated blade spacing (Block 112). Processing continues with running/evaluating the corresponding simulation model (Block 114).

[0029] Evaluation comprises, for example, comparing the simulated flow qualities against design requirements. If design criteria are met (within some acceptable range of variations) (Block 116), processing “ends.” If design criteria are not met, and if an iteration limit or other processing constraint is not exceeded (Block 118), processing continues with tuning one or more array parameters and re-running/re-evaluating the re-tuned simulation model (Block 120). Such iterative tuning continues as needed or until an iteration constraint is exceeded.

[0030] In one or more embodiments, tuning the array 10 includes adjusting the blade angle by adjusting a planned mounting angle of the array 10 within the plenum 14. Tuning alternatively or additionally includes adjusting at least one of a blade height, blade spacing, and blade angle as needed to achieve a desired flow quality for the fluid flow. Again, such tuning may comprise simulating fluid flow in a simulation model of the array 10, assessing a modeled flow quality against one or more quality requirements, and adjusting one or more of a modeled blade height, modeled blade spacing, and modeled blade angle until the modeled flow quality meets the one or more flow quality requirements. Also, as noted, adjusting at least one of a blade height, blade spacing, and blade angle as needed to achieve a desired flow quality for the fluid flow may include initializing a transverse array design using a default blade height, a default blade spacing, and a default blade angle, and then adjusting one or more of those default values.

[0031] Such defaults may be based on setting the default blade height and the default blade spacing according to a blade height to blade spacing ratio of about two-to-one. Further, the

tuning ranges of one or more tuning variables may be constrained to lie in the earlier mentioned ranges for blade height, spacing, and angle.

[0032] With such design flexibility in mind, Figs. 7, 8, and 9 illustrate application examples where the array 10 is configured for various SCR applications. In particular, Fig. 7 highlights leeward side structural stiffeners on the blades 12, and illustrates mechanical mounting features. The plenum 14 in these illustrations comprises an upstream element of a selective catalytic reactor (SCR) 50, and the array 10 is configured for redirecting a gas flow into the SCR 50.

[0033] However, the array 10 is not limited to these illustrated examples. More generally, it should be understood that the foregoing description and the accompanying drawings represent non-limiting examples of the methods, systems, and individual apparatuses taught herein. As such, the present invention is not limited by the foregoing description and accompanying drawings. Instead, the present invention is limited only by the following claims and their legal equivalents.

CLAIMS

What is claimed is:

1. An apparatus for redirecting fluid flow in a plenum from a first flow direction to a second flow direction, said apparatus comprising a transverse array of flat blades positioned at an angle oblique to the first flow direction to redirect the fluid flow from the first flow direction to the second flow direction.
2. The apparatus of claim 1, wherein the apparatus is configured for redirecting the fluid flow at corner junction between first and second plenum sections, said first plenum section conveying the fluid flow in the first flow direction and said second plenum section conveying the fluid flow in the second flow direction, and wherein a plane defined by the transverse array is aligned along a diagonal line of the corner junction.
3. The apparatus of claim 2, wherein the plane is defined by upstream edges of the blades in the transverse array and wherein the oblique angle represents a measure of the angle between the first flow direction and the plane.
4. The apparatus of claim 3, wherein the transverse array is positioned with the plane aligned on a diagonal line extending from inside to outside corners of the corner junction.
5. The apparatus of claim 3, wherein a blade height as measured from an upstream blade edge to a downstream blade edge is in a range from about six inches to about eighteen inches and a blade spacing between adjacent blades in the transverse array is in a range from about three inches to about twenty-four inches, and wherein the oblique angle is selected to place the blades in the transverse array at a blade angle in a range from about fifteen degrees to about twenty-five degrees.

6. The apparatus of claim 5, wherein the blade height is at or about twelve inches, the blade spacing is at or about six inches, and the blade angle is at or about nineteen degrees.
7. The apparatus of claim 1, wherein a blade height as measured from an upstream blade edge to a downstream blade edge is configured to be about two times a blade spacing as measured between adjacent blades in the transverse array.
8. The apparatus of claim 7, wherein the oblique angle is selected to position each blade in the transverse array at a blade angle of between minus twenty-five degrees and plus twenty-five degrees with respect to the second flow direction, wherein the blade angle is measured relative to the second flow direction using a line connecting the upstream and downstream blade edges.
9. The apparatus of claim 1, wherein one or more of the blades includes a structural stiffener integrated or otherwise mounted on a leeward face of the blade, wherein the leeward face of the blade is the side of the blade away from the first flow direction.
10. The apparatus of claim 1, wherein the transverse array includes at least a partial perimeter frame for structurally fixing the transverse array within the plenum.
11. The apparatus of claim 1, wherein the transverse array comprises two or more sub-arrays.
12. The apparatus of claim 1, wherein the blades are uniformly spaced within the transverse array.

13. The apparatus of claim 1, wherein the blades are non-uniformly spaced within the transverse array.
14. The apparatus of claim 1, wherein the plenum comprises an upstream element of a selective catalytic reactor (SCR), and wherein the transverse array is configured for redirecting a gas flow into the SCR.
15. A method of designing a transverse array of flat blades for use in redirecting fluid flow in a plenum from a first flow direction to a second flow direction, said method comprising:
- defining a transverse blade length as a function of an interior cross section at a position within the plenum where the transverse array is to be mounted; and
 - adjusting at least one of a blade height, blade spacing, and blade angle as needed to achieve a desired flow quality for the fluid flow.
16. The method of claim 15, further comprising adjusting the blade angle by adjusting a planned mounting angle of the transverse array within the plenum.
17. The method of claim 15, wherein adjusting at least one of a blade height, blade spacing, and blade angle as needed to achieve a desired flow quality for the fluid flow comprises simulating fluid flow in a simulation model of the transverse array, assessing a modeled flow quality against one or more quality requirements, and adjusting one or more of a modeled blade height, modeled blade spacing, and modeled blade angle until the modeled flow quality meets the one or more flow quality requirements.
18. The method of claim 17, wherein adjusting at least one of a blade height, blade spacing, and blade angle as needed to achieve a desired flow quality for the fluid flow comprises

initializing a transverse array design using a default blade height, a default blade spacing, and a default blade angle.

19. The method of claim 18, further comprising setting the default blade height and the default blade spacing according to a blade height to blade spacing ratio of about two-to-one.

20. The method of claim 18, further comprising setting the default blade height to about twelve inches and correspondingly setting the default blade spacing to about six inches.

21. The method of claim 18, further comprising setting the default blade angle to about nineteen degrees relative to the second flow direction.

22. The method of claim 17, wherein initializing the transverse array design using a default blade height, a default blade spacing, and a default blade angle comprises setting the default blade height to a value in a range from six inches to eighteen inches, setting the default blade spacing in a range from three inches to about twenty-four inches, and setting the default blade angle from about minus twenty-five degrees to about plus twenty-five degrees.

23. The method of claim 15, further comprising adjusting the actual blade spacing away from a default blade spacing to reduce an aggregate blade count for the transverse array, while compensating for the increased blade spacing by correspondingly adjusting one or both of the blade height and blade angle.