[0039] Laminar flow means that layers of air are stratified and run parallel to each other. This indicates that the air near the surface will continue to be near the surface as it travels along a heat transfer sheet. Once the air near the surface reaches the temperature of the surface, there is little heat transfer between them. Any heat transfer for other layers must now pass through the layer near the surface, since they do not come in direct contact with the heat transfer sheet 50. Transfer of heat from laminar layer of air to an adjacent layer of air is not as efficient as heat transfer from air to the metal surface

[0040] As is shown in Figures 5 to 7, undulating surface 71 has parallel undulations ridges 75 and valleys 77 make an acute first angle A1 with respect to separation ribs 59. Undulation surface 81 also has parallel ridges 85 and valleys 87 make an obtuse second angle A2 with respect to separation ribs 59. The repeated pattern is identified as "R". In this embodiment, as air passes along the surface, it is directed alternatively in opposite directions along the heat transfer sheet 70.

[0041] It is believed that the passageways 79 between ridges 75, 85 of adjacent plates constantly redirect the flowing air first to the right, then left, then back right, etc. This constant redirection is believed to break up the laminar flow and cause more turbulence than the embodiment shown in Figure 4. Therefore, different layers of air will now come in direct contact with the metal surface of the sheet 70. This is believed to increase heat transfer.

[0042] The angles shown in the figures are only for illustrative purposes. It is to be understood that the invention encompasses a wide variety of angles.

[0043] Even though only two undulation surfaces are shown here, it is understood that a number of undulation surfaces with different angles may also be added and fall under the scope of this invention.

[0044] There are sections in Figures 6 and 7 where the passageway is straight. One can further increase heat transfer by providing a design that has no straight sections and exhibits constant redirection to increase efficiency.

[0045] Figures 8 and 9 show another embodiment of a heat transfer sheet 90 having a first end 52 and a second end 53 and a longitudinal axis 60 extending from the first end 52 to the second end 53, according to the present invention. Heat transfer sheet 90 has at least one undulation surface 91. The undulation surface 91 has a plurality of ridges 95 and valleys 97. As viewed from above, the ridges 95 and valleys 97 have a sinusoidal shape or pattern 94 extending from a first side 51 to a second

side. Some sinusoidal patterns 94 compete one or more periods T. Sinusoidal patterns 94 on opposite sides of the separation ribs 59 are 180 degrees out of phase. Other phases and periods may be also be used and are within the scope of the present invention.

[0046] These ridges 95 and valleys 97 create sinusoidal passageways 99 when the heat transfer sheets 90 are placed against each other in the basket. The constant redirection of the air as it passes through the sinusoidal passageways 99 reduces laminar flow, thereby increasing turbulence and increasing heat transfer efficiency.

[0047] In some locations, only partial sinusoidal shapes 98 are formed. The sinusoidal patterns 94 are not limited to having a constant period T for all patterns 94 and having each section being 180 degrees out of phase with respect to the next section. The offset (phase angle) of the sinusoidal patterns may also differ from each other.

[0048] While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for heat transfer sheets thereof without departing from the scope of the invention. In addition, many modifications will be appreciated by those skilled in the art to adapt a particular instrument, situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS

What is claimed is:

1. A heat transfer sheet for a rotary regenerative heat exchanger that receives hot flue gas stream and an air stream and transfers heat from the hot flue gas stream to the air stream, the heat transfer sheet comprising:

a plurality of sheet spacing features extending along the heat sheet substantially parallel to a direction of the hot flue gas stream, the sheet spacing features defining a portion of a flow passage between an adjacent heat sheet and

a plurality of undulating surfaces disposed between each pair of adjacent sheet spacing features the plurality of undulating surfaces including:

a first undulating surface formed by a plurality of elongated ridges extending along the heat transfer sheet parallel to each other at a first angle A_1 relative to the sheet spacing features, and

a second undulating surface formed by a plurality of elongated ridges extending along the heat transfer sheet parallel to each other at a second angle A_2 relative to the sheet spacing features, the first angle A_1 being different from the second angle A_2.

2. The heat transfer sheet of claim 1, wherein first undulation surface is connected to the second undulation surface and the flow passages formed by the undulation surfaces are fluidically continuous.

3. The heat transfer sheet of claim 1, wherein the first angle A_1 is an acute angle and the second angle A_2 is an obtuse angle.

4. A heat transfer sheet comprising:

a plurality of ridges and valleys are shaped as at least a partial sinusoidal pattern, extending from a first end to a second end, oriented such that a fluid passing from the first end to the second end is at least partially redirected in an alternating manner between a first direction and a second direction.

5. The heat transfer sheet of claim 4 wherein the sinusoidal pattern is comprised of several periods, T.

6. The heat transfer sheet of claim 4 wherein at least a portion of ridges trace out less than a full sinusoidal period, T.

7. The heat transfer sheet of claim 4 wherein there are at least two sinusoidal patterns that are out of phase with respect to each other.

8. The heat transfer sheet of claim 7 wherein the at least two sinusoidal patterns are a full period T out of phase.

9. The heat transfer sheet of claim 7 wherein at least one sinusoidal pattern has a period T that is different from that of at least one other sinusoidal pattern.

10. The heat transfer sheet of claim 4 wherein passageways are created under the ridges of the undulation surfaces when placed against another undulation surface of another heat transfer sheet.

11. A basket for a rotary regenerative heat exchanger, the basket comprising:
a frame; and
at least one heat transfer sheet comprising:
a plurality of ridges and valleys having at least a partial sinusoidal pattern, extending from a first end to a second end, oriented such that a fluid passing from the first end to the second end is at least partially redirected in an alternating manner from side to side.

12. The basket of claim 11 wherein sinusoidal pattern of the heat transfer sheet comprises several periods, T.

13. The basket of claim 11 wherein sinusoidal pattern of the heat transfer sheet comprises less than a full sinusoidal period, T.

14. The basket of claim 11 wherein the heat transfer sheet has several sinusoidal patterns that are out of phase with respect to each other.

15. The basket of claim 11 wherein the heat transfer sheet has at least two sinusoidal patterns having a different sinusoidal period T.

[0039] Laminar flow means that layers of air are stratified and run parallel to each other. This indicates that the air near the surface will continue to be near the surface as it travels along a heat transfer sheet. Once the air near the surface reaches the temperature of the surface, there is little heat transfer between them. Any heat transfer for other layers must now pass through the layer near the surface, since they do not come in direct contact with the heat transfer sheet 50. Transfer of heat from laminar layer of air to an adjacent layer of air is not as efficient as heat transfer from air to the metal surface

[0040] As is shown in Figures 5 to 7, undulating surface 71 has parallel undulations ridges 75 and valleys 77 make an acute first angle A1 with respect to separation ribs 59. Undulation surface 81 also has parallel ridges 85 and valleys 87 make an obtuse second angle A2 with respect to separation ribs 59. The repeated pattern is identified as "R". In this embodiment, as air passes along the surface, it is directed alternatively in opposite directions along the heat transfer sheet 70.

[0041] It is believed that the passageways 79 between ridges 75, 85 of adjacent plates constantly redirect the flowing air first to the right, then left, then back right, etc. This constant redirection is believed to break up the laminar flow and cause more turbulence than the embodiment shown in Figure 4. Therefore, different layers of air will now come in direct contact with the metal surface of the sheet 70. This is believed to increase heat transfer.

[0042] The angles shown in the figures are only for illustrative purposes. It is to be understood that the invention encompasses a wide variety of angles.

[0043] Even though only two undulation surfaces are shown here, it is understood that a number of undulation surfaces with different angles may also be added and fall under the scope of this invention.

[0044] There are sections in Figures 6 and 7 where the passageway is straight. One can further increase heat transfer by providing a design that has no straight sections and exhibits constant redirection to increase efficiency.

[0045] Figures 8 and 9 show another embodiment of a heat transfer sheet 90 having a first end 52 and a second end 53 and a longitudinal axis 60 extending from the first longitudinal end 52 to the second longitudinal end 53, according to the present invention. Heat transfer sheet 90 has at least one undulation surface 91. The undulation surface 91 has a plurality of ridges 95 and valleys 97. As viewed from above, the ridges 95 and valleys 97 have a sinusoidal shape or pattern 94 extending

from a first side 51 to a second side. In one embodiment, the heat transfer sheet includes a plurality of sections of undulations 91 having a cross-section defined by ridges 95 and valleys 97 which undulate laterally. In a longitudinal direction 60 the undulations 91 are shaped in an at least a partial sinusoidal pattern. The at least partial sinusoidal pattern extending in the longitudinal direction 60 from the first longitudinal end 52 to a second longitudinal end 53 of the sheet. The at least partial sinusoidal pattern is oriented such that a fluid passing from the first longitudinal end 52 to the second longitudinal end 53 is at least partially and continuously redirected laterally in an alternating manner. Some sinusoidal patterns 94 compete one or more periods T. Sinusoidal patterns 94 on opposite sides of the separation ribs 59 are 180 degrees out of phase. Other phases and periods may be also be used and are within the scope of the present invention.

[0046] These ridges 95 and valleys 97 create sinusoidal passageways 99 when the heat transfer sheets 90 are placed against each other in the basket. The constant redirection of the air as it passes through the sinusoidal passageways 99 reduces laminar flow, thereby increasing turbulence and increasing heat transfer efficiency.

[0047] In some locations, only partial sinusoidal shapes 98 are formed. The sinusoidal patterns 94 are not limited to having a constant period T for all patterns 94 and having each section being 180 degrees out of phase with respect to the next section. The offset (phase angle) of the sinusoidal patterns may also differ from each other.

[0048] While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for heat transfer sheets thereof without departing from the scope of the invention. In addition, many modifications will be appreciated by those skilled in the art to adapt a particular instrument, situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS

1. A heat transfer sheet comprising:

a plurality of sections of undulations having a cross-section defined by ridges and valleys which undulate laterally, in a longitudinal direction said undulations are shaped in at least a partial sinusoidal pattern, said at least partial sinusoidal pattern extending in the longitudinal direction from a first longitudinal end to a second longitudinal end of the sheet, said at least partial sinusoidal pattern being oriented such that a fluid passing from the first longitudinal end to the second longitudinal end is at least partially and continuously redirected laterally in an alternating manner.

2. The heat transfer sheet of claim 1 wherein the sinusoidal pattern is comprised of several periods, T.

3. The heat transfer sheet of claim 1 wherein at least a portion of ridges trace out less than a full sinusoidal period, T.

4. The heat transfer sheet of claim 1 wherein there are at least two sinusoidal patterns that are out of phase with respect to each other.

5. The heat transfer sheet of claim 4 wherein the at least two sinusoidal patterns are a full period T out of phase.

6. The heat transfer sheet of claim 1 wherein passageways are created under the ridges formed in an undulation surface of a heat transfer sheet when placed against another undulation surface of another heat transfer sheet.

7. A basket for a rotary regenerative heat exchanger, the basket comprising:

a frame; and

at least one heat transfer sheet comprising:

a plurality of sections of undulations having a cross-section defined by ridges and valleys which extend laterally, in a longitudinal direction said undulations are shaped in at least a partial sinusoidal pattern, said at least partial sinusoidal pattern extending in the longitudinal direction from a first longitudinal end to a second longitudinal end of the sheet, said at least partial sinusoidal pattern being oriented such that a fluid passing from the first end to the second end is at least partially and continuously redirected laterally in an alternating manner.

8. The basket of claim 7 wherein the sinusoidal pattern of the heat transfer sheet comprises several periods, T.

9. The basket of claim 7 wherein the sinusoidal pattern of the heat transfer sheet comprises less than a full sinusoidal period, T.

10. The basket of claim 7 wherein the heat transfer sheet has several sinusoidal patterns that are out of phase with respect to each other.