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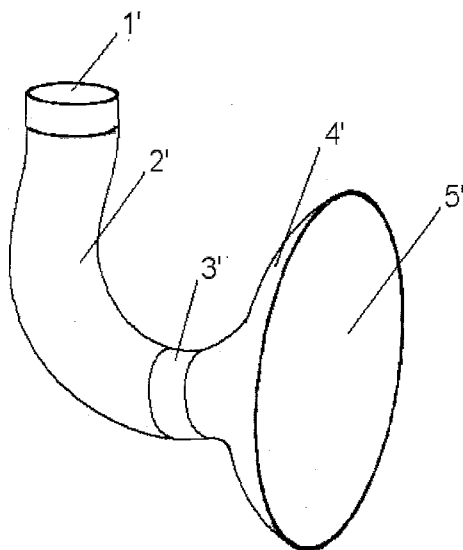
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[Continued on next page]

(54) Title: TRANSFER LINE EXCHANGER

Fig. 5



(57) Abstract: The present invention provides a transfer line exchanger which is optimized for one or more objective functions of interest such as pressure drop, erosion rate, fouling, coke deposition and operating costs. The transfer line exchanger is designed by computer modeling a transfer line exchanger in which the cross section of flow path is essentially circular and modeling the operation of the transfer line under industrial conditions to validate the model design and its operation. Then iteratively the model design is deformed and the operation of the deformed part is modeled and compared to values obtained with other deformed models until the value of the objective function is optimized (e.g. at an extreme) or the change in the objective function is approaching zero.

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TRANSFER LINE EXCHANGER

5

TECHNICAL FIELD

The present invention relates to the transfer line in furnaces for cracking paraffins to olefins, particularly for the production of ethylene. In the cracking of paraffins to produce olefins, and particularly alpha olefins, a feed stock, typically a lower paraffin such as ethane or naphtha, is heated to a temperature of at least about 850°C, typically from about 900°C to 1000°C. In the process the molecules in the feed stock loose hydrogen and become olefins. This process takes place in the heater coils inside the furnace in the radiant box of the ethylene cracker. The hot gases leaving the furnace are quickly fed to a quench exchanger. The line from the exit of the furnace tubes to the quench exchanger tube sheet or cooling section entrance is a transfer line. Due to the configuration of most plants the transfer line contains an elbow typically having about a 90° bend. The transfer line may include a diffuser to transition the diameter of the flow from that of the furnace pipe or tube to the diameter of the tubesheet of the quench exchanger (e.g. the external surface of the quench exchanger). There may also be several sections or fittings in the transfer line so that it may not be a unitary piece of pipe. In the quench exchanger the gasses are quickly cooled to a temperature below which they will no longer react.

BACKGROUND ART

To date the transfer lines have been circular in cross-section. The consideration of the cost of manufacture relative to efficiency of the transfer line in terms of pressure drop and erosion rate has been largely weighted to minimize the cost of manufacturing. Hence the transfer lines have circular tubular pipes. With the increase in the price of feedstocks both for the cracking process and the furnace and the concern about greenhouse gas emissions the weighting of the factors in the design of a transfer line exchanger is starting to move toward the efficiency of the process. Several factors to be considered in the efficiency of the furnace include the pressure drop across (i.e. along the length of) the transfer line, the erosion rate of the transfer line and the degree of recirculation of the flow which relates to fouling (e.g. coke deposition).

United States Patent 6,041,171 issued March 21, 2000 to Blaisdell et al. discloses a method for designing a material handling system. A computer is used to

select parts from a catalogue or inventory of parts. The program is more directed at assembling pre-existing parts than designing new parts.

United States Patent 6,778,871 issued August 17, 2004 teaches a method to use computer assisted design (CAD) to initially generate drawings for a pipe network.

5 The system “designs” and fabricates pipe networks but it appears that this is based on a standard pipe sizes (Col. 4 line 50). The system does not appear to design “custom” pipe or a custom elbow.

United States Patent 7,398,193 issued July 8, 2008 to Araki et al. discloses a method to “estimate” the wall thinning of a pipe at a “not measured location” to plan
10 piping maintenance work. The reference is helpful in demonstrating that there are computer programs to estimate “wall thinning”. The process is based on actual measurements of pipe erosion and modeling the fluid flow throughout the entire pipe network or system to predict the rate of wall thinning at a point distant from the actual measurement. This is then used to predict the locations of potential pipe failure and to
15 schedule maintenance of the pipe network to minimize “down time”. Again the program is not directed to designing individual components for the pipe network to minimize pressure drop and erosion.

There are a number of patents in the names of Oballa, and Benum assigned to NOVA Chemicals relating to surfaces on furnace tubes and methods for making them
20 including U.S. Patents 6,824,883 issued Nov. 30, 2004; 6,899,966 issued May 31, 2005; and 7,488,392 issued Feb. 10, 2009.

As far as applicants have been able to determine there is no art suggesting a non-circular cross section for a transfer line.

The present invention seeks to provide a transfer line for an olefin cracker which
25 is fabricated to minimize any one of or combinations of pressure drop, fouling, recirculation, erosion in the transfer line and cost (operating, capital or both).

DISCLOSURE OF INVENTION

The present invention provides a transfer line from an olefins cracking furnace to a quench exchanger said transfer line having an internal flow passage having a
30 continuously smooth and differentiable perimeter and centerline and a smoothly varying cross-section along the flow passage such that in the 5 % of the flow passage from the inlet and the outlet the ARQ is from 1.0 to 1.02 and over the remaining 90% of the length of the flow passage not less than 5% of the flow passage has an ARQ is from 1.02 to 1.5.

In a further embodiment the ARQ over said remaining 90% of the length of the flow passage does not change by more than 7% over a 5% length of the flow path.

In a further embodiment the ARQ at one or more sections over said remaining 90% of the length of the flow passage is from 1.02 and 1.30.

5 In a further embodiment the ARQ over said remaining 80% of the length of the flow passage does not change by more than 5% over a 5% length of the flow path.

In a further embodiment the calculated total pressure drop across the transfer line is decreased by not less than 10% compared to the calculated pressure drop for transfer line having an ARQ along its length from 1.00 to 1.02.

10 In a further embodiment the ARQ at one or more sections over said remaining 80% of the length of the flow passage is from 1.02 and 1.15.

In a further embodiment the normalized calculated erosion rate of the transfer line is decreased by not less than 10% compared to the normalized erosion rate for transfer line having an ARQ along its length from 1.00 to 1.02.

15 In a further embodiment the transfer line has an increasing cross sectional area in the direction of flow such that the angle between the transverse normal vector and the pipe walls range from 0° to 85°.

In a further embodiment the transfer line has, a smooth curve in its longitudinal direction which although may change rapidly, does not include abrupt, sharp changes of internal section (steps) has a radius of curvature on the internal surface of the curve from unbound (straight) to half the vertical of the section radius. Typically the radius of curvature on the internal surface of the curve may be from 1 internal pipe diameters to 5 internal pipe diameters.

20 In a further embodiment the transfer line comprises from 20 to 50 weight % of chromium, 25 to 50 weight % of Ni, from 1.0 to 2.5 weight % of Mn less than 1.0 weight % of niobium, less than 1.5 weight % of silicon, less than 3 weight % of titanium and all other trace metals and carbon in an amount less than 0.75 weight % and from 0 to 6 weight % of aluminum.

30 The present invention provides a method to optimize one or more of the operating characteristics selected from the group consisting of pressure drop, erosion rate, fouling rate, and cost (capital, operating or both) of a fixed industrial flow path defined by a continuous metal and/or ceramic envelope, comprising:

1. building a computational model comprising not less than 5,000, preferably more than 100,000, computational cells for all or a portion of the flow channel from 5%

of the length of the flow channel downstream of the inlet to from 5% of the length of the flow channel upstream of the outlet of the initial design of said industrial flow path;

2. using computer software that solves the fundamental laws of fluid and energy dynamics for each cell simulating and summing the results the operation of the model design from step 1 under the industrial pressure, temperature, and flow rate conditions of operation to verify one or more objective functions of interest (e.g. pressure drop, erosion rate, fouling, coke deposition and cost) to match operating conditions;

3. iteratively

a) deforming said computational model comprising not less 5,000 computational cells so that the resulting ARQ of one or more sections of the flow path is greater than 1.02;

b) applying the same computer software as in step 2, that solves the fundamental laws of fluid and energy dynamics for each cell simulating and summing the results of the operation of the deformed model from step 3a) under the industrial pressure, temperature, and flow rate conditions of operation used in step 2 to predict one or more objective functions of interest (e.g. pressure drop, erosion rate, fouling, coke deposition and cost) for the operation of the deformed model;

c) storing the predicted results from step 3b);

d) using some or all of the stored results from step 3c) with an optimization algorithm to estimate a deformation that will improve the objective function;

e) repeating steps a), b), c), and d) until one or both of the following conditions are met:

i) the objective function of interest goes through a beneficial local extrema; or

ii) the rate of change of all of the all the functions of interest starts to approach 0.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, benefits and aspects of the present invention are best understood in the context of the attached figures in which like parts or features are designated by like numbers.

Figure 1 shows different cross sections of a flow path having an ARQ greater than 1.

Figure 2 shows a series of overlays of equal perimeter ellipses having different ARQ equal to or greater than 1.

Figure 3 is an isometric view of a transfer line of the prior art.

Figure 4 is a sectional view along the flow path of Figure 3 and cross sections A, B, and C.

Figure 5 is an isometric view of a transfer line in accordance with the present invention.

Figure 6 is a sectional view along the flow path of Figure 5 and cross sections at A', B', and C'.

Figure 7 is an isometric view of a transfer line designed in accordance with example 1.

Figure 8 is a sectional view along the flow path of Figure 7 and cross sections at A", B", C", D", E", F" and G".

BEST MODE FOR CARRYING OUT THE INVENTION

As used in this specification relatively smoothly in relation to the ARQ means the quotient does not change by more than 7% over a 5% length of the flow path.

As used in this specification smooth in relation to the perimeter of the flow passage means the perimeter at an angle perpendicular to the flow is a differentiable continuous smooth line (i.e. having no kinks or discontinuities). As a result the perimeter of the flow passage will not be a geometric shape having straight sides and "corners" or "angles" such as a square, a parallelogram or a triangle. Rather the perimeter of the flow passage is defined by a continuous smooth curved line.

As used in this specification smooth in relation to the center line of the flow passage means the center line of the flow passage is a differentiable continuous smooth line (i.e. having no kinks or discontinuities). While the center line of the flow passage may change rapidly, it will not include abrupt, sharp changes of internal section (steps).

As used in this specification building a computational model means creating a virtual three dimensional geometric model of the transfer line exchanger and filling it with a three dimensional computational mesh to create cells (e.g. 5,000 cells to greater than 100,000 cells).

ARQ is defined as the ratio of aspect ratio (AR) to isoperimetric quotient (Q) of a section or segment of the flow passage perpendicular to the direction of flow (AR/Q). The aspect ratio (AR) is defined as the ratio of long to short side of the smallest-area

rectangle into which a particular section can be circumscribed. This ratio, for the case of a convex ovoid section symmetric about one axis, is equal to the ratio of the major chord to minor chord. The major chord is the length of the longest straight line between two points in the perimeter of a closed section which may or may not cross the centroid of the section. The minor chord for such a section is the longest distance perpendicular to the major chord between two points along the perimeter of the section. It will appear clear to those skilled in the art that thus defined the aspect ratio is greater than one.

$$AR = \text{Long/Short}$$

The isoperimetric quotient is defined as four times Pi (π) times the Area of the section of the flow path divided by the square of that section's perimeter. At a cross section of the flow path if the area of the cross section is A and the perimeter is L, then the isoperimetric quotient Q, is defined by

$$Q = \frac{4\pi A}{L^2}$$

The isoperimetric quotient is a measure of circularity. This is illustrated in Figure 1 and Figure 2.

A circle is the only cross-sectional shape with an isoperimetric quotient of one, and all other cross-sectional shapes have an isoperimetric quotient less than one.

Since the ARQ ratio is the aspect ratio (AR) divided by the isoperimetric quotient (Q) and as defined AR is always greater than one and Q is always less than one, ARQ is also always greater than one and greater than or equal to the aspect ratio.

Figures 1 and 2 demonstrate that even an ARQ near but not equal to 1 can be noticeably non-circular.

Sample calculation of an ARQ ratio:

An ellipse with a major radius "a" and a minor radius "b" has a cross sectional area $A = \pi \cdot a \cdot b$. The perimeter of such an ellipse can be approximated by Ramanujan's formula which states the perimeter of an ellipse being approximately:

$$L \approx \pi \left[3(a + b) - \sqrt{(3a + b)(3b + a)} \right]$$

For a particular example of an ellipse having a major radius "a" equals four times the minor radius "b", it would have an Area $A = 4 \cdot \pi \cdot b^2$. This four-to-one ellipse has a perimeter L

$$L \approx \pi \left[3(5b) - \sqrt{(12b + b)(3b + 4b)} \right]$$

$$L \approx \pi \left[15b - \sqrt{91b^2} \right] \approx 5.461\pi b$$

So a four-to-one ellipse has an isoperimetric quotient Q equal

$$Q \approx \frac{16\pi^2 b^2}{29.822\pi^2 b^2} \approx 0.537$$

And since the aspect ratio of this section is 4, the ARQ of such a section is 7.45

In comparison, standard pipe has an out-of round tolerance of plus or minus 1.5% and as such, the maximum ARQ of a nominally round section is approximately
5 1.0151.

Figure 3 is an isometric drawing of a prior art transfer line up to the tubesheet of the transfer line exchanger. The exchanger comprises an inlet 1, an elbow (a bend) 2 a body 3, a diffuser 4 and an outlet or exit 5. The hot gas from the cracker enters at the inlet 1, the smaller circular end of the transfer line, passes through the elbow 2, the
10 body 3, the diffuser 4 and passes through the exit 5 at the broader or flared end of diffuser end 4.

In Figure 4 cross sections are shown at A-A, B-B and C-C. In the transfer line exchangers of the prior art the flow path was circular along its entire length albeit expanding as described below and the ARQ along the transfer line is essentially 1 (e.g.
15 from 1.0 to 1.02).

The cross sectional area of the flow path varies smoothly from a minimum to a maximum area along the length of the transfer line exchanger in the direction of flow of the gas but all cross-sections are substantially round with an ARQ of 1 other than by unintentional variations of tolerance plus or minus 2% (Maximum ARQ of 1.02). The
20 walls of the diffuser are diverging to convert momentum energy into pressure. It also allows for the connection from a smaller diameter flow passage (e.g. the furnace tube) to the larger diameter of the heat exchanger tubesheet. The angle of the taper along the center line of the flow path is the angle between a line normal to the cross section and the flow path walls. For maximum pressure recovery the angle will be between
25 about 0° and 15°, preferably between 3° and 10°, typically between 4° and 7°. However, as this results in long transition regions, larger expansion angles are often preferred to maintain a shorter, less costly heat exchanger entrance. Pressure loss, fouling and erosion are normally increased in this case.

The transfer line has, a smooth curve in its longitudinal direction, the elbow
30 which although it changes rapidly, does not include abrupt, sharp changes of internal section has a radius of curvature on the internal surface of the curve from unbound (straight) to half the vertical of the section radius. In a further embodiment the transfer

line has a smooth curve in its flow direction which has a radius of curvature on the internal surface of the curve from 1 internal pipe diameters to 5 internal pipe diameters

Figure 5 is an isometric view of a transfer line in accordance with the present invention comprising an inlet 1', an elbow (a bend) 2' a body 3', a diffuser 4' and an exit 5'. The hot gas from the cracker enters at the inlet 1', the smaller circular end of the transfer line, passes through the elbow 2', body 3, the diffuser 4' and exits at the exit 5 at the broader or flared end of the diffuser. The exit 5' of the diffuser is circular or substantially circular.

Figure 6 shows sectional views of transfer line in accordance with the present invention. The cross sections at A'-A', B'-B', and C'-C' as well as the inlet and outlet are also shown. Cross sections A'-A', B'-B' and C'-C' in Figure 6 are at the same or comparable location as A-A, B-B and C-C in Figure 4. The cross section at the inlet 1 and exit 5 of the transfer line exchanger are essentially circular. However, the cross sections as A'-A', B'-B', C'-C' and D'-D' are not circular and have an ARQ substantially higher than 1.

In this embodiment the ARQ varies smoothly from 1 at either end (inlet 1 and exit 5 (round furnace pipe connected to a round tubesheet)) but reaches a maximum non-roundness with a maximum ARQ of 1.39.

The shape of the cross section of the flow path may be elliptical, ovoid, segmented or asymmetric in nature. The area of the cross-section may also be held constant, increase or decrease according to the function to be achieved. A twist may optionally be imposed on adjacent cross sections either by means of interior swirling vanes or beads (e.g. a welded bead on the interior of the pipe) within the transfer line exchanger or by the bulk twisting of the cross sections relative to each other.

However, it should be noted that different shapes may have a comparable ARQ and that a low change in the quotient may in fact result in a significant change in the cross section shape of the flow path such as from a near ellipse to a "flattened egg shape". This is demonstrated in Figures 1 and 2. A 1% change in ARQ can have a profound effect on the flow characteristics as indicated by pressure drop, for example.

The cross section of the transfer line exchanger within the last 5% of the flow path from the inlet and exit or outlet of the transfer line exchanger have an ARQ approaching unity from above, typically from 1.02 to 1.0, preferably from 1.01 to 1.

In the remaining 90% of the flow path there are one or more sections where the ARQ is from 1.02 to 1.50, preferably from 1.02 to 1.3 most preferably from 1.02 to 1.12.

The interior of the flow path is "smooth" in the sense that the change in the ARQ in 5% sections of the remaining flow path does not change by more than 7%, preferably less than 5%.

The shape of the cross sections of the flow path is optimized to obtain a local
5 beneficial minimum or maximum (known collectively as extrema) of an objective function. Such objective function may be any parameter affecting the economics of the operation of the transfer line including the cost (capital and or operating) itself include but is not limited to pressure drop, erosion rate of the fluid-contacting surfaces, weight of the component, temperature profile, residence time and rate of fouling (or coke
10 deposition).

There are a number of software applications available which are useful in the present invention. These include SolidWorks for the creation and parametric manipulation of the flow geometry, ANSYS Mechanical for the calculation of material stress and ANSYS Fluent to determine the flow pattern, pressure drop and erosion rate
15 used in calculating the objective function corresponding to a particular geometry.

Procedurally, one way to find a local objective function extremum is by sequentially applying a small perturbation to a parameter affecting the shape of the transfer line and determining the resulting value of the objective function by either analytical techniques, experiments or numerical computation. A deformation parameter
20 is defined as a value which can be uniquely mapped to a change in geometry by means of scaling, offsetting or deforming any or all of the sections in a deterministic fashion. Each parameter may also be bounded to prevent geometric singularities, unphysical geometries or to remain within the boundaries of a physical solution space. After each of a finite and arbitrary number of parameters has been perturbed, any one of a series
25 of mathematical techniques may be used to find the local extremum. In one such technique a vector of steepest approach to the objective function extremum is determined as a linear combination of parameter changes. The geometry is progressively deformed in the direction of steepest approach and the value of the objective function determined for each deformation until a local extremum is found. The
30 process is then restarted with a new set of perturbations of the parameter set. Other techniques that may be used to advance the search for a local extremum include Multi objective genetic algorithms, Metamodeling techniques, the Monte Carlo Simulation method or Artificial Neural Networks.

For example a model of the original design is built. That is a three dimensional finite model of the transfer line is created. The model must include the internal flow passage (void) within the transfer line exchanger. The model may also include the external surface of the transfer line exchanger. The model is then divided into (filled with) cells, typically from 5,000 to more than 100,000 (e.g. 150,000). To some extent this is dependent on computing power available and how long it will take to run the programs for each deformation of the original model. There are a number of computer programs which may be used to build the original model such as for example finite element analysis software (e.g. ANSYS Mechanical).

Then the model needs to be "initialized". That is a fluid dynamics and energy (of mass, energy and momentum, etc.) dynamics computer program is applied to each cell of the model to solve the operation of that cell at given operating conditions for the transfer line exchanger (e.g. mass of gas passing through the transfer line exchanger, flow velocity, temperature, and pressure, erosion rate, fouling rate, recirculation rate, etc.) to calculate one or more objective functions. The sum of the results of each cell operation describes the overall operation of the transfer line exchanger. This is run iteratively until the model and its operation approach, or closely match actual plant data. Generally the model should be initialized so that for one or more of objective functions, the simulation is within 5%, preferably within 2%, most preferably within 1.5% of the actual plant operating data for that objective function of the transfer line exchanger. One fluid and /or energy dynamics program which is suitable for the simulation is ANSYS Fluent

Once the design of the transfer line and its operation is initialized the model of the transfer line is iteratively deformed, preferably in a small manner but incremental manner and the simulated operation of the deformed part is run to determine the one or more objective functions for the deformed transfer line exchanger (for the cells and the sum of the cells or even cells in specified location or regions (at the internal radius of curvature of a bend). Typically the deformation is applied to all of part of the flow channel of the transfer line exchanger within 5% of the flow channel downstream of the inlet to 5% of the flow channel upstream of the exit (i.e. 90% of the transfer line is available for deformation). In some instances the deformation may occur in one or more sections or parts within 10% of the flow channel downstream of the inlet to 10% of the flow channel upstream of the exit (i.e. 80% of the transfer line is available for deformation). While the deformation could be applied to the whole length of transfer

line available for deformation it may be useful to apply the deformation to sections or portions of the transfer line. For example the last or first half, third or quarter or combinations thereof could be deformed. The results (e.g. one or more objective functions and the sum of each such objective function) of the simulated operation of the deformed transfer line exchanger are stored in the computer.

The deformation of the transfer line may be accomplished by applying a further computer program to the design which incrementally deforms the part. One such commercially available deformation and optimization software is sold under the trademark Sculptor. However, it may be desirable to use a neural network to optimize the location and degree of deformation to speed up or focus the iterative process.

The stored calculated objective function(s) for the operation of the deformed transfer line are then compared until either:

- 1) an extrema of one or more objective functions is reached; or
- 2) the rate of change in the one or more objective functions is approaching zero.

More generally the present invention provides a method to optimize one or more of the operating characteristics of a fixed industrial flow path defined by a continuous metal envelope, selected from the group consisting of pressure drop, erosion rate, and coke deposition rate comprising:

1. building a numerical model comprising not less than 5,000, preferably more than 100,000, computational cells of the portion of the flow channel typically from 5% of the flow channel downstream of the inlet and to 5% of the flow channel upstream of the outlet (e.g. 90% of the of the flow channel of the transfer line) of the initial design;
2. simulating (on a computational cell level and summed) the operation of the model design from step 1 using fluid and energy dynamics software under the industrial pressure, temperature, and flow rate conditions of operation to numerically determine one or more of the functions of interest (pressure drop, erosion rate, fouling rate and cost (capital and operating)) approach (within 5%) or match actual operating conditions;
3. iteratively
 - a) deforming said numerical model comprising not less 5,000 computational cells by deforming the geometry such that the resulting ARQ of the section is materially greater than 1.02;

b) simulating the operation of the deformed model under the plant operating conditions used in step 2 to determine one or more objective functions of interest (e.g. pressure drop, erosion rate, fouling rate, and cost (capital and / or operating);

5 c) calculating and storing said one or more of functions of interest calculated in step b);

d) using some or all of the stored results from step 3c) with an optimization algorithm to estimate a deformation that will improve the objective function;

e) comparing the stored objective functions of interest until one or both of the following conditions are met:

- 10 i) the objective function reaches a desirable local extrema; or
ii) the objective function ceases to change in the parametrized direction.

Some objective function value, for example pressure drop and erosion rate, at each evaluation stage in the process of finding the local extremum can be obtained via
15 Computational Fluid Dynamics. If the change in transfer line cross-sections along the flow path is selected so that the calculated total pressure drop across the line decreases by 10% from the baseline condition made of standard components (i.e. where the ARQ is from 1 to 1.02 along the 90% or 80% of transfer line flow path) which is used as a comparison benchmark and the erosion rate of the line is decreased by
20 more than 5% compared to the baseline calculated using a combination of structural finite element analysis software; computational fluid dynamics simulation of the flow rate and a geometry manipulating software that alters the shape of the transfer line in a parametric fashion.

Typically the models will be run until the change in objective function between
25 successive iterations is less than 10% or preferably less than 1%. In one embodiment when compared to a baseline of a conventionally designed transfer line made of standard components, the present invention has a decrease in total pressure drop of over 10% and the subsequent erosion rate and fouling rate of the transfer line is also affected and decreased when compared to the baseline conditions. This decrease is at
30 least in the order of magnitude of the total pressure drop. In an optional embodiment the fouling (e.g. coke deposition) rate of the transfer line is also determined. The fouling rate as noted below is also a function of the metallurgy of the transfer line and the surface coating in the transfer line.

The fouling rate for the transfer line exchanger and optionally the quench exchanger should be less than 0.1 mg/cm²/hr, preferably less than 0.07 mg/cm²/hr, desirably less than 0.05 mg/cm²/hr, more desirably less than 0.03 mg/cm²/hr, most preferably less than 0.02 mg/cm²/hr. The coke rate may be affected by a number of factors including the cross sectional shape of the transfer line exchanger and the metallurgy of the transfer line exchanger. For computer simulations the metallurgy of the transfer line may be considered constant and after the preferred shape is determined the metallurgy of the transfer line may be selected.

Due to space constraints the transfer line typically "bends" prior to entering the quench exchanger. The radius of curvature taken at the inside of the curve in the transfer line is typically from 1 to 10 pipe inner diameters preferably from 3 to 5 pipe inner diameters.

The transfer line and the quench exchanger are typically constructed from stainless steel. Preferably the steel has a surface which tends to mitigate the formation of coke such as that disclosed in United States Patent 6,824,883 issued Nov. 30, 2004 to Benum et al. assigned to NOVA Chemicals (International) S.A.

The steel should have a high nickel and chrome content.

In one embodiment the stainless steel comprises from 20 to 50, preferably from 20 to 38 weight % of chromium and at least 1.0 weight %, up to 2.5 weight % preferably not more than 2 weight % of manganese. The stainless steel should contain less than 1.0, preferably less than 0.9 weight % of niobium and less than 1.5, preferably less than 1.4 weight % of silicon. The stainless steel may further comprise from 25 to 50 weight % of nickel, from 1.0 to 2.5 weight % of manganese and less than 3 weight % of titanium and all other trace metals, and carbon in an amount of less than 0.75 weight %.

The steel may comprise from about 25 to 50, preferably from about 30 to 45 weight % nickel and generally less than 1.4 weight % of silicon. The balance of the stainless steel is substantially iron. In a further embodiment the stainless steel may contain from 0 up to about 6 weight %, typically from about 3 to 6 weight % of aluminum.

The present invention may also be used with nickel and/or cobalt based extreme austenitic high temperature alloys (HTAs). Typically the alloys comprise a major amount of nickel or cobalt. Typically the high temperature nickel based alloys comprise from about 50 to 70, preferably from about 55 to 65 weight % of Ni; from about 20 to 10 weight % of Cr; from about 20 to 10 weight % of Co; and from about 5 to 9 weight % of Fe and the balance one or more of the trace elements noted below to bring the

composition up to 100 weight %. Typically the high temperature cobalt based alloys comprise from 40 to 65 weight % of Co; from 15 to 20 weight % of Cr; from 20 to 13 weight % of Ni; less than 4 weight % of Fe and the balance one or more trace elements as set out below and up to 20 weight % of W. The sum of the components adding up to
5 100 weight %.

Newer alloys may be used which contain up to about 12% Al, typically less than 7 weight %, generally about 2.5 to 3 weight % aluminum as disclosed for example in United States Patent 7,278,828 issued October 9, 2007 to Steplewski et al., assigned to General Electric Company. Typically in the high cobalt and high nickel steels the
10 aluminum may be present in an amount up to 3 weight %, typically between 2.5 and 3 weight %. In the high chrome high nickel alloys (e.g. 13 to 50, preferably 20 to 50, weight % of Cr and from 20 to 50 weight % of Ni) the aluminum content may range up to 10, preferably less than about 7, typically from about 2 to 7 weight %.

In some embodiments of the invention the steel may further comprise a number
15 of trace elements including at least 0.2 weight %, up to 3 weight % typically 1.0 weight %, up to 2.5 weight % preferably not more than 2 weight % of manganese; from 0.3 to 2, preferably 0.8 to 1.6 typically less than 1.9 weight % of Si; less than 3, typically less than 2 weight % of titanium, niobium (typically less than 2.0, preferably less than 1.5 weight % of niobium) and all other trace metals; and carbon in an amount of less than
20 2.0 weight %. The trace elements are present in amounts so that the composition of the steel totals 100 weight %.

The transfer line (and the quench exchanger) may be treated to create a spinel surface on the internal surface. There appear to be a number of treatments which may create a spinel surface. One treatment comprises (i) heating the stainless steel in a
25 reducing atmosphere comprising from 50 to 100 weight % of hydrogen and from 0 to 50 weight % of one or more inert gases at rate of 100°C to 150°C per hour to a temperature from 800°C to 1100°C; (ii) then subjecting the stainless steel to an oxidizing environment having an oxidizing potential equivalent to a mixture of from 30 to 50 weight % of air and from 70 to 50 weight % of one or more inert gases at a
30 temperature from 800°C to 1100°C for a period of time from 5 to 40 hours; and (iii) cooling the resulting stainless steel to room temperature at a rate of less than 200°C per hour.

This treatment should be carried out until there is an internal surface on the transfer line (and optionally the quench exchanger) having a thickness greater than 2

microns, typically from 2 to 25, preferably from 2 to 15 microns desirably from 2 to 10 microns and substantially comprising a spinel of the formula $Mn_xCr_{3-x}O_4$ where x is a number from 0.5 to 2, typically from 0.8 to 1.2. Most preferably X is 1 and the spinel has the formula $MnCr_2O_4$.

- 5 Typically the spinel surface covers not less than 55%, preferably not less than 60%, most preferably not less than 80%, desirably not less than 95% of the stainless steel.

In a further embodiment there may be a chromia (Cr_2O_3) layer intermediate the surface spinel and the substrate stainless steel. The chromia layer may have a
10 thickness up to 30 microns generally from 5 to 24, preferably from 7 to 15 microns. As noted above the spinel overcoats the chromia geometrical surface area. There may be very small portions of the surface which may only be chromia and do not have the spinel overlayer. In this sense the layered surface may be non-uniform. Preferably, the chromia layer underlies or is adjacent not less than 80, preferably not less than 95,
15 most preferably not less than 99% of the spinel.

In a further embodiment the internal surface of the transfer line and the optionally the quench exchanger may comprise from 15 to 85 weight %, preferably from 40 to 60 weight % of compounds of the formula $Mn_xCr_{3-x}O_4$ wherein x is from 0.5 to 2 and from 85 to 15 weight %, preferably from 60 to 40 weight % of oxides of Mn and Si selected
20 from the group consisting of MnO , $MnSiO_3$, Mn_2SiO_4 and mixtures thereof provided that the surface contains less than 5 weight % of Cr_2O_3 .

Demonstration:

The present invention will now be demonstrated with reference to Figures 3 and 4 and 7 and 8. Figures 3 and 4 are the conventional transfer line exchanger and
25 Figures 7 and 8 are a modified design in accordance with the present invention.

The finite element analysis software and computational fluid dynamic software have been used to model NOVA Chemicals commercial ethylene cracking furnace piping at Joffre and Corunna. The models are sufficiently accurate to generally predict the commercial operation of industrial plants.

30 A numerical model of the conventional transfer line as shown in Figures 3 and 4, a circular tapered tube with a 90° bend and trumpet-like diffuser connecting to the heat exchanger tubesheet was created using a commercial finite element software program. A computational fluid dynamics program was also applied for the analysis of the conventional transfer line for gas at a temperature of greater than 600°C and a flow rate

of 3.97 Kg/s. The pressure drop and erosion rate were determined using ANSYS Fluent.

Using the shape deformation and optimization software Sculptor the circular cross section of the conventional pipe computational or numerical model was deformed into an asymmetric and arbitrary shape independently at several transverse planes of the original connecting pipe to generate a “deformed” shape based on a series of deformation parameters per section. The ARQ of the resulting sections having a maximum ARQ substantially greater than 1.02. The metallurgy of the pipe was maintained constant for these models. The pressure drop and erosion rate were also calculated for the “deformed” pipe.

The process was applied iteratively until no further improvements in pressure drop or erosion rate were found. The resulting geometry and ARQ values are shown in Figure 7 and Figure 8.

Table 1 is a summary of representative data from the computer modeling.

TABLE 1

Simulation or Iteration Number	Normalized Pressure Drop	Reduction in Pressure Drop	Normalized Erosion Rate	Reduction in Erosion Rate
1 (Base design in Figure 1)	1.0	0%	1.0	0%
2	0.98	1%	0.99	1%
4	0.92	8%	0.96	4%
8	0.89	11%	0.94	6%
14	0.85	15%	0.90	10%
16	0.85	15%	0.89	11%
21	0.82	18%	0.87	13%

Table 1 and Figure 8 show:

Although the change in ARQ appears to be moderate, the resulting change in transfer line performance has been dramatic. In terms of time in service until the unit needs to be decoked, the present invention increased the run time from a plant average of 90 days to an initial run of 290 days, or a 220% increase in run time. The factors that

determine the end of a run include pressure drop across the transfer line and temperature increase at the entrance of the exchanger.

INDUSTRIAL APPLICABILITY

- 5 The present invention provides a method to optimize the internal shape of sections of a transfer line exchanger in a cracker to reduces pressure drop and improve efficiency.

CLAIMS

1. A transfer line from an olefins cracking furnace to a quench exchanger said transfer line having an internal flow passage having a continuously smooth and differentiable perimeter and centerline and a smoothly varying cross-section along the flow passage such that in the 5% of the flow passage from the inlet and the outlet the ARQ is from 1.0 to 1.02 and over the remaining 90% of the length of the flow passage not less than 5% of the flow passage has an ARQ is from 1.02 to 1.15.
2. The transfer line according to claim 1, wherein over said remaining 90% of the length of the flow passage does not change by more than 7% over a 5% length of the flow path.
3. The transfer line according to claim 2, wherein the ARQ at one or more sections over said remaining 90% of the length of the flow passage is from 1.02 and 1.12.
4. The transfer line according to claim 3, wherein the ARQ over said remaining 80% of the length of the flow passage does not change by more than 5% over a 5% length of the flow path.
5. The transfer line according to claim 4, wherein the calculated total pressure drop across the transfer line is decreased by not less than 10% compared to the calculated pressure drop for transfer line having an ARQ along its length from 1.00 to 1.02.
6. The transfer line according to claim 5, wherein the ARQ at one or more sections over said remaining 90% of the length of the flow passage is from 1.02 and 1.15.
7. The transfer line according to claim 6, wherein normalized calculated erosion rate of the transfer line is decreased by not less than 10% compared to the normalized erosion rate for transfer line having an ARQ along its length from 1.00 to 1.02.
8. The transfer line according to claim 7, wherein the transfer line has an increasing cross sectional area in the direction of flow such that the angle between the transverse normal vector and the pipe walls range from 0° to 85°.
9. The transfer line according to claim 8, having a smooth curve in its longitudinal direction which although may change rapidly, does not include abrupt, sharp changes of internal section (steps) and a radius of curvature on the internal surface of the curve from unbound (straight) to half the vertical of the section radius.
10. The transfer line according to claim 10, comprising from 20 to 50 weight % of chromium, 25 to 50 weight % of Ni, from 1.0 to 2.5 weight % of Mn less than 1.0 weight % of niobium, less than 1.5 weight % of silicon, less than 3 weight % of titanium and all

other trace metals and carbon in an amount less than 0.75 weight % and from 0 to 6 weight % of aluminum.

11. The transfer line according to claim 8, comprising from 40 to 65 weight % of Co; from 15 to 20 weight % of Cr; from 20 to 13 weight % of Ni; less than 4 weight % of Fe and the balance of one or more trace elements and up to 20 weight % of W the sum of the components adding up to 100 weight %.

12. The transfer line according to claim 8, comprising from about 55 to 65 weight % of Ni; from about 20 to 10 weight % of Cr; from about 20 to 10 weight % of Co; and from about 5 to 9 weight % of Fe and the balance one or more of the trace elements.

13. A method to optimize one or more of the operating characteristics selected from the group consisting of pressure drop, erosion rate, fouling rate, and cost (capital, operating, or both) of a fixed industrial flow path defined by a continuous metal and/or ceramic envelope, comprising:

1. building a computational model comprising not less than 5,000, computational cells of the portion of the flow channel from 5% of the length of the flow channel downstream of the inlet to from 5% of the length of the flow channel upstream of the outlet of the initial design of said industrial flow path;

2. using computer software that solves the fundamental laws of fluid and energy dynamics for each cell simulating and summing the results the operation of the model design from step 1 under the industrial pressure, temperature, and flow rate conditions of operation to verify one or more objective functions of interest;

3. iteratively

a) deforming said computational model comprising not less 5,000 computational cells so that the resulting ARQ of one or more sections of the flow path is greater than 1.02;

b) applying the same computer software as in step 2, that solves the fundamental laws of fluid and energy dynamics for each cell simulating and summing the results of the operation of the deformed model from step 3a) under the industrial pressure, temperature, and flow rate conditions of operation used in step 2 to predict one or more objective functions of interest for the operation of the deformed model;

c) storing the predicted results from step 3b);

d) using some or all of the stored results from step 3c) with an optimization algorithm to estimate a deformation that will improve the objective function;

e) repeating steps a), b), c), and d) until one or both of the following conditions are met:

i) the objective function of interest goes through a beneficial local extrema; or

5 ii) the rate of change of all of the all the functions of interest starts to approach 0.

14. The method according to claim 13, wherein the computational model has from 10,000 to 100,000 computational cells.

Fig. 1

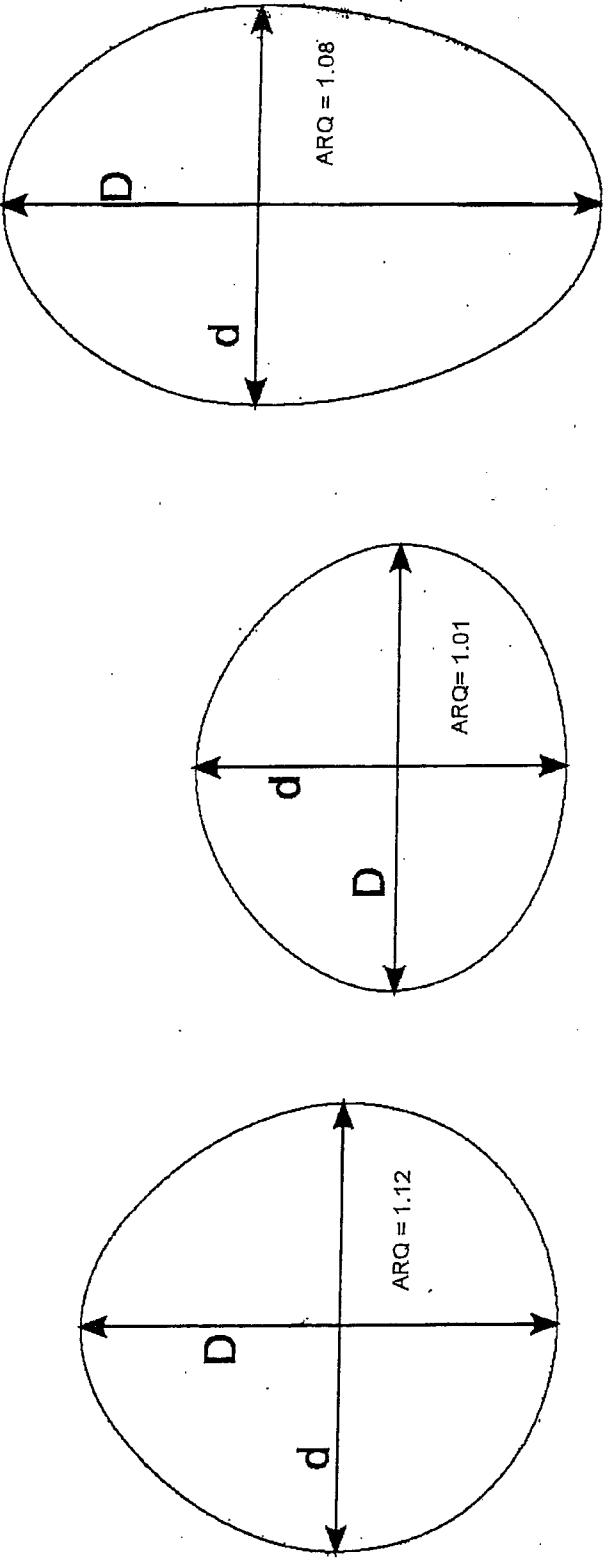


Fig. 2

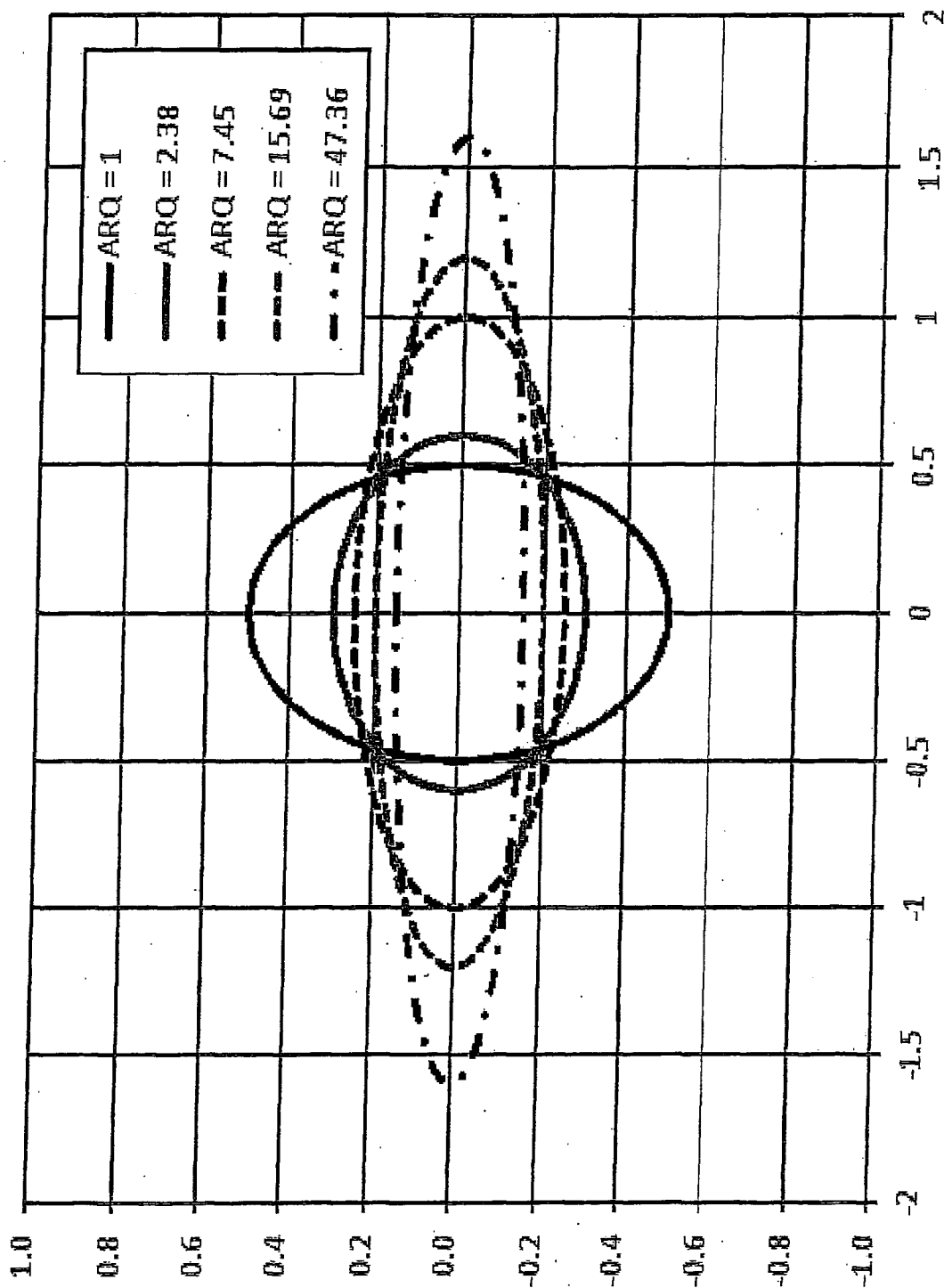


Fig. 3

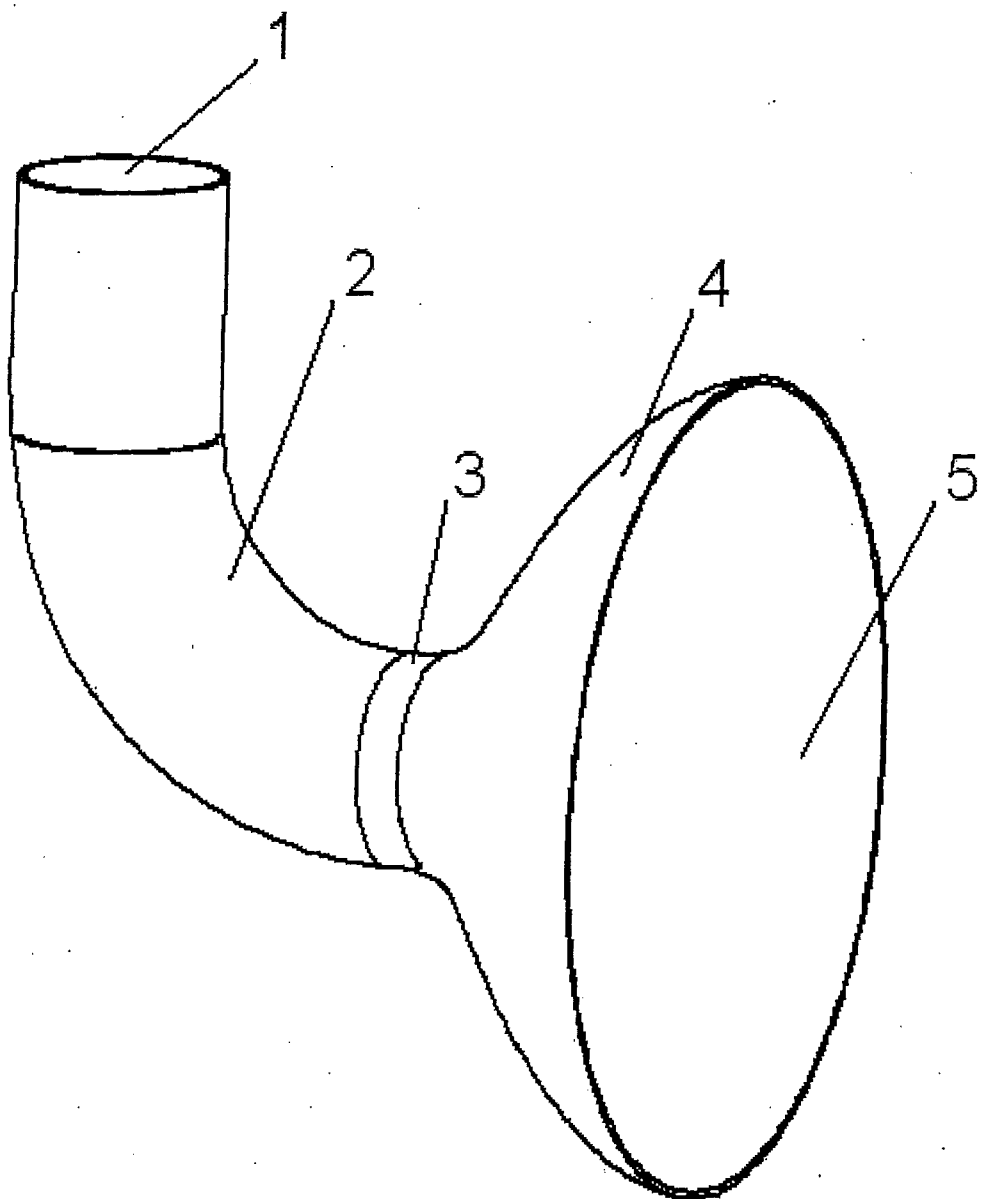


Fig. 4

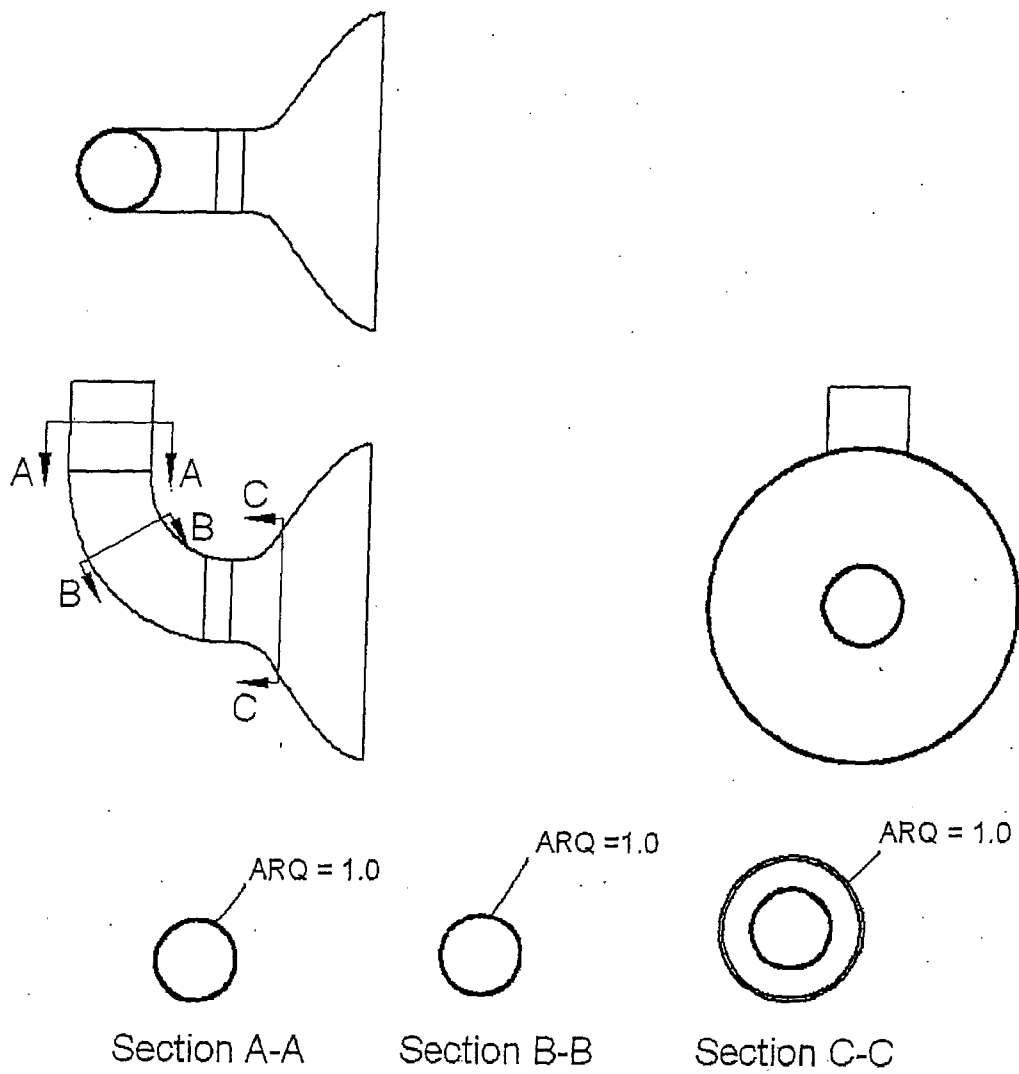


Fig. 5

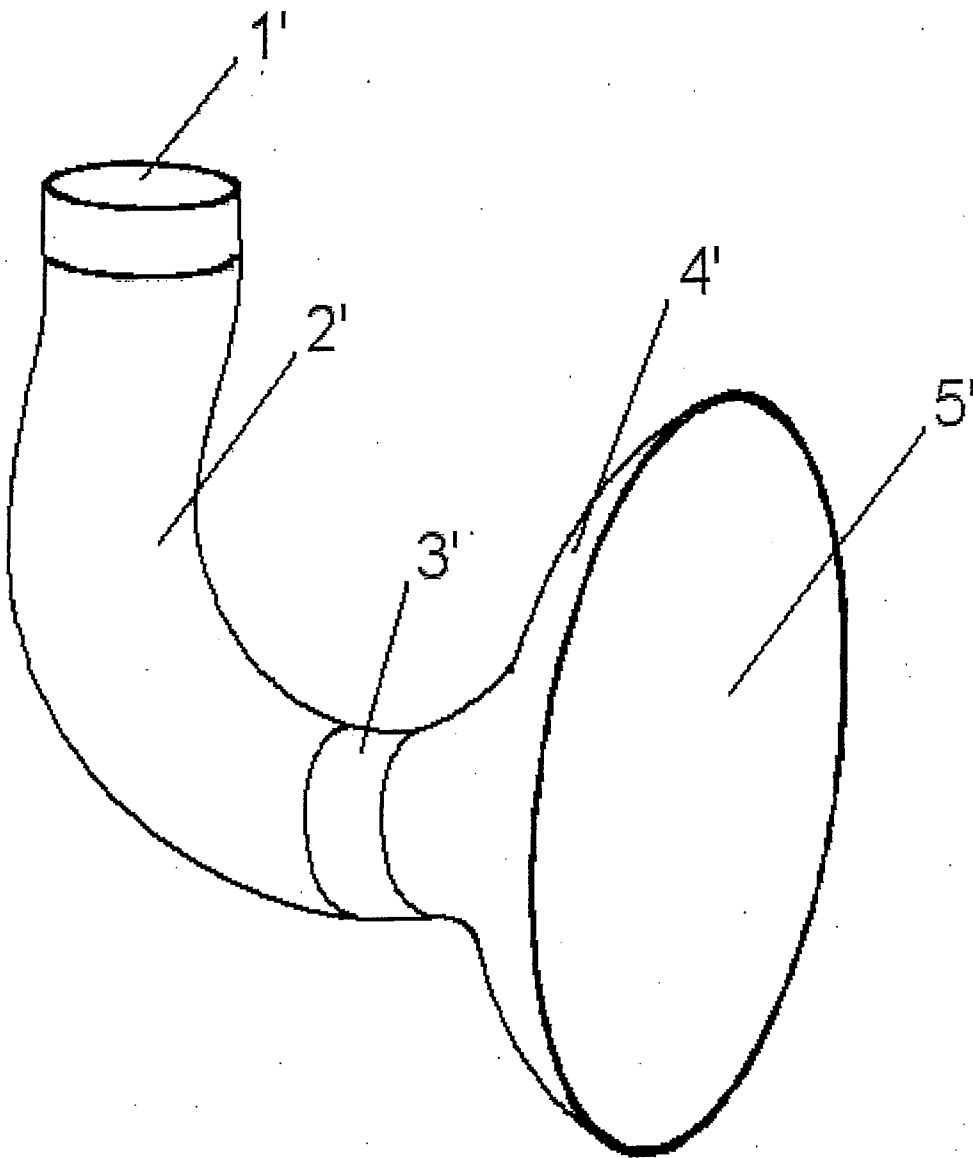


Fig. 6

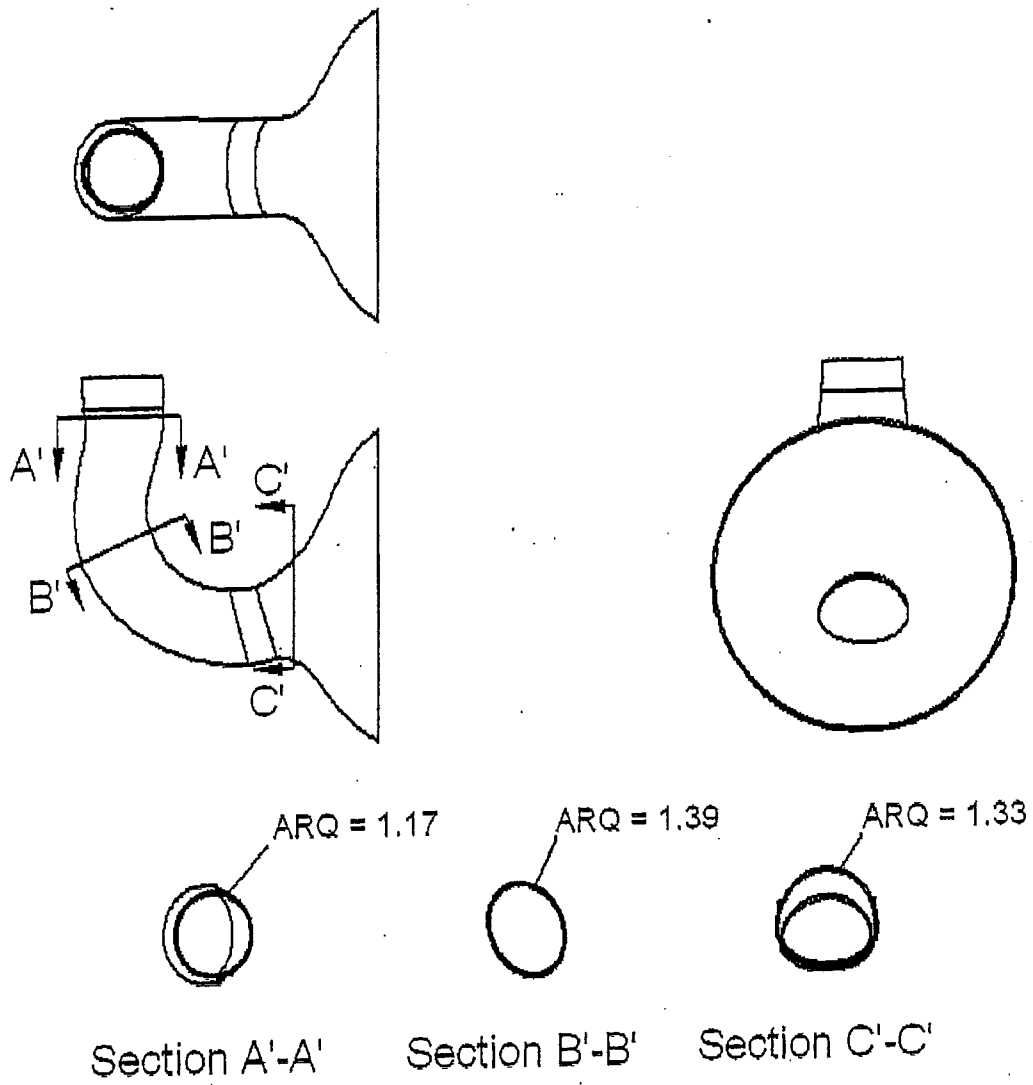


Fig. 7

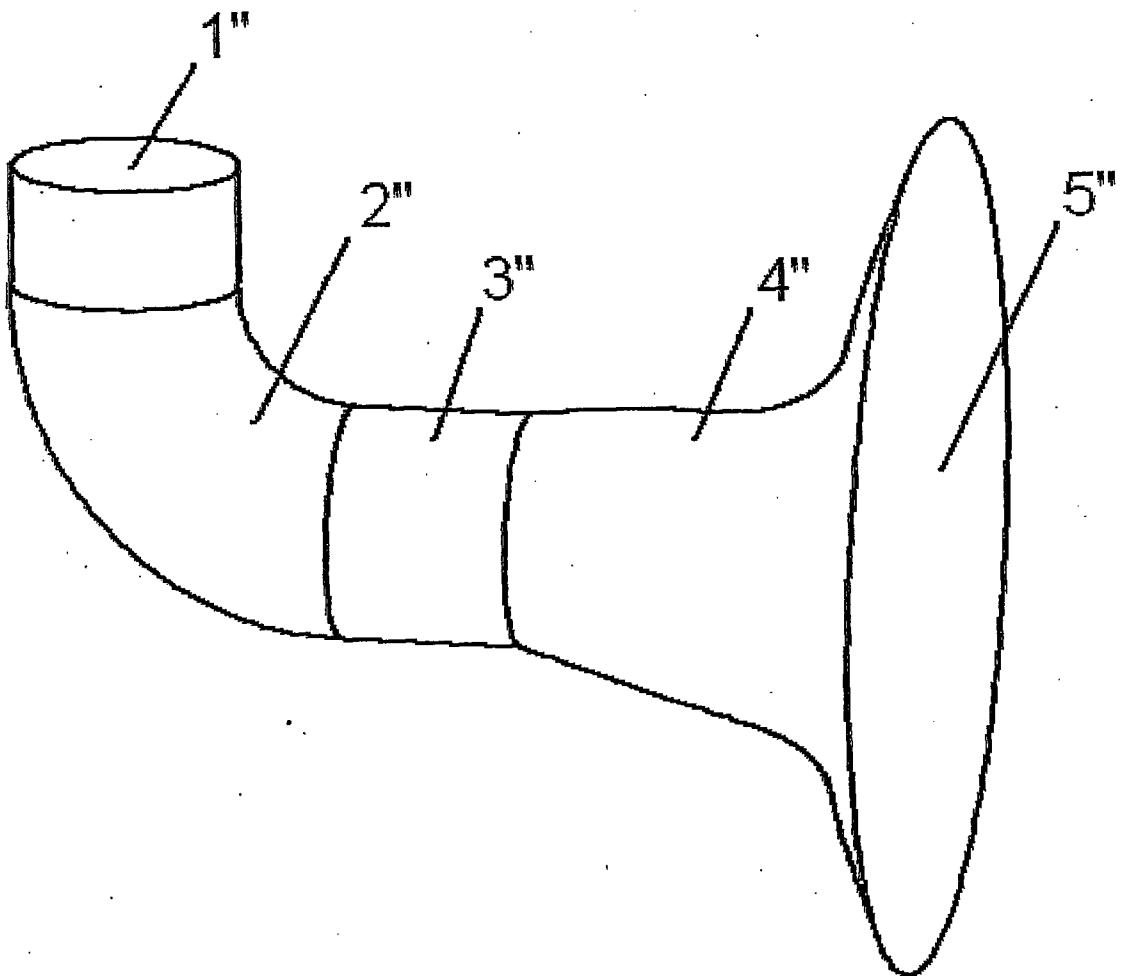
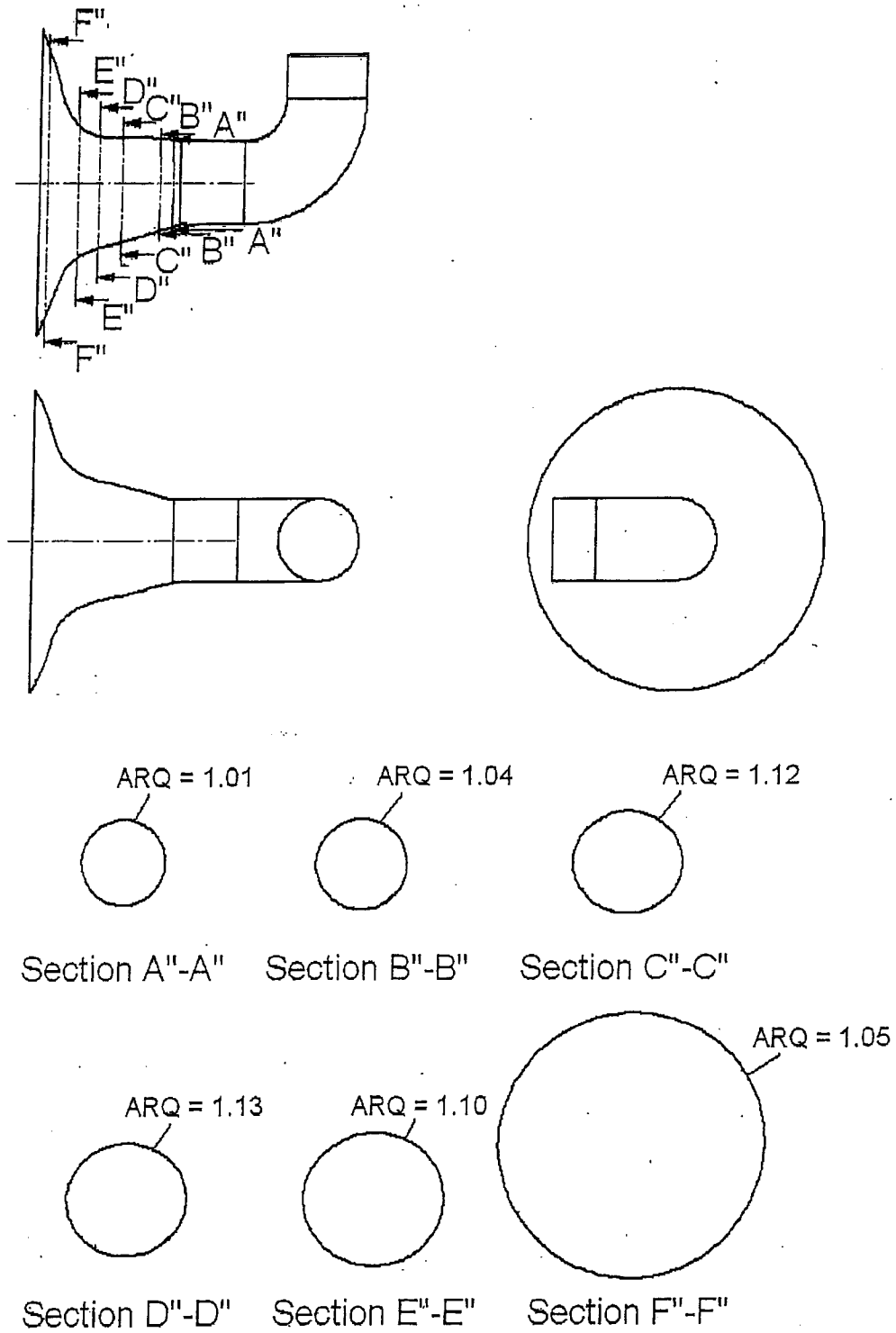


Fig. 8



INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2013/000934

A. CLASSIFICATION OF SUBJECT MATTER

IPC: *C10G 9/00* (2006.01) , *G06Q 10/04* (2012.01), *G06F 17/11*, *G06F 17/50*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C10G 9/00 (2006.01) , *G06Q 10/04* (2012.01), *G06F 17/11*, *G06F 17/50*

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Canadian Patent Database, TotalPatent, Duckduckgo, Google Scholar (ARQ, cracking furnace, manufacture, cracker, furnace, reactor, transfer pipe, transfer line, cross-section, oval or circular or ovoid or elliptic, isoperimetric quotient)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3574781 A (Racine, W.J. et al.) 13 April 1971 (13-04-1971)	1-12
A	WO 2011094169 A1 (Baumgartner, A.J. et al.) 4 August 2011 (04-08-2011) * See abstract; page 3, point (c); page 4, last line to page 5, point (c); page 9, last paragraph; page 10, 4th paragraph to page 13, 2nd paragraph *	13-14

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

18 February 2014 (18-02-2014)

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2013/000934

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of the first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons :

1. ☐ Claim Nos. :
because they relate to subject matter not required to be searched by this Authority, namely :

2. ☐ Claim Nos. :
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically :

3. ☐ Claim Nos. :
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows :

Group A - Claims 1-12

A transfer line from an olefins cracking furnace to a quench exchanger having an internal flow passage having a continuously smooth and differentiable perimeter and centerline and a smoothly varying cross-section along the flow passage such that in the 5% of the flow passage from the inlet and the outlet the ARQ is from 1.0 to 1.02 and over the remaining 90% of the length of the flow passage not less than 5% of the flow passage has an ARQ from 1.02 to 1.15.

Group B - Claims 13-14

A method to optimize one or more of the operating characteristics selected from the group consisting of pressure drop, erosion rate, fouling rate, and cost of a fixed industrial flow path defined by a continuous metal and/or ceramic envelope.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos. :
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim Nos. :

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2013/000934

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US3574781A	13 April 1971 (13-04-1971)	BE728379A CA920617A1 DE1906956A1 FR2001872A7 NL6902410A	13 August 1969 (13-08-1969) 06 February 1973 (06-02-1973) 02 October 1969 (02-10-1969) 03 October 1969 (03-10-1969) 18 August 1969 (18-08-1969)
WO2011094169A1	04 August 2011 (04-08-2011)	CN102725381A EP2528997A1 SG182402A1 US2013001132A1	10 October 2012 (10-10-2012) 05 December 2012 (05-12-2012) 30 August 2012 (30-08-2012) 03 January 2013 (03-01-2013)