Abstract: A thin channel flow cell system for the corrosion study of flowing systems that is designed based on the flow between two substantially parallel flat walls is presented. The small scale equipment used in the system eliminates the effect of the centrifugal force encountered in the rotating cylinder electrode system and avoids large volumes of fluid and expense associated with large scale equipment. Multiple corrosion measurement techniques, which include electrical resistance, linear polarization resistance, weight loss and quartz crystal microbalance, can be used in the thin channel flow cell system to provide real time information on the corrosion process. Visual observation of the corroding surface is possible in situ. The in situ observation capability makes the thin channel flow cell system ideal for the study of the initiation and propagation of localized corrosion.
Published:  
— with international search report  
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments
THIN CHANNEL CORROSION FLOW CELL

The present disclosure generally relates to small scale corrosion study of flowing systems and, in particular, to a small scale thin channel corrosion flow cell system used to investigate corrosion in flowing systems.

Typically, in corrosion studies, both small scale and large scale equipment are used. The rotating cylinder electrode (RCE) system is the most commonly used small scale apparatus. Flow loops are the typical large scale types of equipment used. The correlation between the small scale RCE system and the large scale pipeline has already been studied by many researchers with some success. However, the effect of the centrifugal forces encountered in the RCE system is unexplored and difficult to scale from one system to another. The large scale equipment, flow loops, can replicate flow regimes and conditions found in larger pipelines. However, the cost for operation of these systems is usually very expensive. In either case, in situ visual observation of the corrosion coupons is almost impossible.

Therefore, there is a need for a new and different piece of small scale equipment, here called the Thin Channel Flow Cell (TCFC) system, that can be designed to provide easy and accurate in situ visual observation of the corrosion process in under realistic single-phase flow conditions. This can be especially useful for localized corrosion study, as mechanical and chemical effects on corrosion product films can be easy to control and observe in real time. Moreover, the flow condition in a thin channel can be compared with pipe flow. In situ observation by a microscope and simultaneous corrosion measurements using various techniques can be a major benefit of the TCFC system.

Various corrosion monitoring techniques can be used in the TCFC, including those that can monitor corrosion both actively and passively. Suitable corrosion measurement devices can include, for example, corrosion monitoring probes that can measure corrosion produced by, for example, a corrosion
coupon. Additionally, the various corrosion measurement devices can measure, for example, weight loss (WL), electrical resistance (ER), linear polarization resistance (LPR). A quartz crystal microbalance (QCM) monitoring device can also be used to monitor the corrosion process. These corrosion monitoring techniques allow film formation and removal to be studied in real time by imaging, online measurements and subsequently by weight gain/loss and surface analysis.

According to the present disclosure, a thin channel flow cell system designed for corrosion study based on the flow between two substantially parallel flat walls is presented. The thin channel flow cell can enable easy and accurate testing for the effects of corrosion in flowing systems such as, for example, both laminar and turbulent flow. The effect of additives, such as corrosion inhibitors, can also be easily studied. The small scale equipment of the thin channel flow cell system can eliminate the effect of the centrifugal force typically encountered in the RCE system. The thin channel flow cell system can also avoid the large volumes of fluid and expense associated with large scale equipment. The TCFC can enable the insertion of multiple corrosion monitoring devices, such as, for example, corrosion coupon, ER, LPR, WL and QCM probes. These monitoring devices can be used in the TCFC system to provide real time information on the corrosion process. Additionally, visual observation of the corroding surface can be possible in situ. The in situ observation capability can make the system ideal for the study of the initiation and propagation of localized corrosion. These corrosion monitoring techniques can allow scale formation and removal to be studied in real time by imaging, online measurements and weight gain/loss.

In accordance with one embodiment of the present disclosure, the in situ observation capabilities can allow for the study of the initiation and propagation of localized corrosion in real time.
In accordance with another embodiment of the present disclosure, corrosion monitoring techniques can allow film formation and removal to be studied in real time by imaging, online measurements and weight gain/loss. It is a feature of the embodiments of the present disclosure to study corrosion under realistic flow conditions while avoiding the large volumes of fluid and expense of large scale equipment.

It is another feature of the embodiments of the present disclosure to study film formation and removal during turbulent flow in real time by imaging, online measurements and weight gain/loss using various corrosion monitoring devices. Other features of the embodiments of the present disclosure will be apparent in light of the description of the disclosure embodied herein.

The following detailed description of specific embodiments of the present disclosure can be best understood when read in conjunction with the following drawings, where like structure is indicated with like reference numerals and in which:

Fig. 1 illustrates the channel flow according to one embodiment.

Fig. 2 illustrates a mock-up of the thin channel flow cell system according to one embodiment.

Fig. 3 illustrates exploded view of a thin channel flow cell according to one embodiment.

Fig. 4 illustrates a cross section of the flow cell according to one embodiment.

Fig. 5 illustrates diametric cross-sectional cut away view of a thin channel flow cell according to one embodiment.

Fig. 6 illustrates a thin channel flow cell with probes according to one embodiment.
Fig. 7 illustrates a quartz crystal microbalance probe according to one embodiment.

In the following detailed description of the embodiments, reference is made to the accompanying drawings that form a part hereof, and in which are shown by way of illustration, and not by way of limitation, specific embodiments in which the disclosure may be practiced. It is to be understood that other embodiments may be utilized and that logical, mechanical and electrical changes may be made without departing from the spirit and scope of the present disclosure.

A thin channel flow cell (TCFC) system 100 can be based on thin channel flow cell 10. The thin channel flow cell 10 can comprises a top surface 50, a bottom surface 20, a fluid input end 45, a fluid output end 40, two substantially flat parallel walls 15 positioned on opposite longitudinal sides of the bottom surface 20 to form a flow channel 5. The flow channel 5 is illustrated in Figure 1. The thin channel flow cell 10 can further comprises a series of corrosion measurement devices 200 (as shown in Figure 2) that can be incorporated into the bottom surface 20 of the thin channel flow cell 10. In one embodiment, the series of corrosion measurement devices 200 do not extend into the flow channel 5 itself and can comprise diagnostic surfaces that can be flush with the bottom surface 20 of the thin channel flow cell 10. A fluid can flow from the fluid input end 45 to the fluid output end 40 as represented by the arrow A. The fluid can be pumped into the thin channel flow cell 10 at the fluid input end 445 by a water pump or by any other method known in the art. Flow between two substantially parallel flat walls 15 can be characterized by using the hydraulic diameter equation:

\[ D_H = \frac{2Dh}{D + h} \]  

Where:

\( D_H \) = hydraulic diameter (mm)
5 \( D \) = width of the channel (mm)
\( h \) = height of the channel (mm), i.e., the distance between the top surface 50 and the bottom surface 20.

Referring to Figure 1, in order to have a fully developed flow in the flow channel 5, the length 35 of the flow channel 5, \( L \), should be much larger than the width 25 of the flow channel 5, \( D \). And in order to eliminate the "edge effect," the height 30 of the flow channel 5, \( h \), needs to be much smaller than the width 25. Therefore, these dimensions in Figure 1 can relate to the open space of the flow channel 5 available for fluid flow, or in other words:

\[ L \gg D \gg h \quad (2) \]

For Laminar flow, the wall shear stress can be calculated by:

\[ \tau = \frac{2}{3} \beta \frac{\mu}{Wd^2} \quad (3) \]

Where:
\( \tau \) = wall shear stress (Pa)
\( \beta \) = wall shear stress (Pa)
\( \mu \) = viscosity of the fluid (Pa*s)
\( Q \) = flow rate of the channel (m\(^3\)/s)
\( d \) = depth or height of the channel (m)
\( W \) = width of the channel (m)

In turbulent flow, shear stress can be calculated by using the Fanning friction factor:

\[ \lambda = \frac{D \Delta P}{2 \rho V^2 L} \quad (4) \]

\( D \) = hydraulic diameter (m)
\( \Delta P \) = drop in pressure due to friction (Pa)
\( \rho \) = density of the fluid (kg/m\(^3\))
\( V \) = velocity (m/s)
\( L \) = length (m)
One objective of the flow channel 5 design can be to be able to achieve a wall shear stress range from about 1 to about 200 Pa which covers most practical situations. The wall shear stress can be influenced by the fluid flow velocity, the viscosity of the fluid, as well as the slope of the flow channel 5.

Figure 2 illustrates one embodiment of a TCFC system 100, which can include the thin channel flow cell 10, a microscope system 140, a processor 110 and various other parts such as, for example, a fluid pump 120, a heat exchanger 150 and other temperature controllers, a flow meter, pressure gauge, a pH meter, an ion exchanger, and a manifold 160 to sample the fluid flow and to add corrosion inhibitors to the fluid. However, the thin channel flow cell 10 can be the main part of the design. The series of corrosion measurement devices 200 can include, for example, a corrosion coupon measurement device. The corrosion coupon measurement device can comprise a corrosion coupon that can be flush with the bottom surface 20 of thin channel flow cell 10. The corrosion coupon can be comprised of a metal disk or any other suitable material used in the art.

Figure 3 shows the exploded view of the thin channel flow cell 10. A series of corrosion measurement devices 200 can be incorporated into the bottom surface 220 of the thin channel flow cell 10. In one embodiment, the series of corrosion measurement devices 200 can be flush with the bottom surface 220 of the thin channel flow cell 10 so as to avoid interfering with the fluid flow in flow channel 5. In another embodiment, the series of corrosion measurement devices 200 can be integrated into the bottom surface 220 of the thin channel flow cell 10. In yet another embodiment, the series of corrosion measurement devices 200 can be integrated and flush with the bottom surface 220 of the thin channel flow cell 10. The bottom surface 220 can be formed by a measurement device holding block 270 and the thin channel flow cell 10. In one embodiment, the measurement device holding block 270 can have a standard hole size that can be used to hold all of the corrosion measurement
devices 200 flush with the bottom surface 220 of the thin channel flow cell 10. Using the measurement device holding block 270 can help make the corrosion measurement devices 200 directly exchangeable with flow loops and other large scale facilities.

In one embodiment, the thin channel flow cell 10 can have the overall outer length (L) of 800 mm, an overall outer width (W) of 140 mm, and overall outer height (H) of 85 mm. In this embodiment, the dimensions of the thin channel flow cell 10 can be designed for fully developed turbulent flow within the thin channel flow cell 10. For visualization of the fluid flow and of the inside corrosion coupons, a microscope system can be used. To optimize the working distance of the microscope system and the quality of the image that needs to be generated by the microscope system, the interior height of the thin channel flow cell 10 can be designed to be about 3 mm to about 6 mm.

\[ h = 3.0 \times 10^{-3} \text{ m} \sim 6.0 \times 10^{-3} \text{ m} \] (5)

The variable interior height of the thin channel flow cell 10 can help determine the volumetric flow rate necessary to achieve the desired shear stress. A peripheral support 265 can be used to adjust the interior height of the thin channel flow cell 10 by placing or removing the peripheral support 265 from on top of the measurement device holding block 270. In one embodiment, the diameter of the upper surface 210 of the corrosion measurement devices 200 to be incorporated into the bottom surface 220 can typically be about 1.25 inches, or 31.75 mm. Taking this corrosion measurement device 200 diameter dimension into account, in order to get a fully developed turbulent flow and to eliminate the edge effect within the thin channel flow cell 10, the interior width of the thin channel flow cell 10 can be set to be about 100 mm.

\[ D = 0.1 \text{ m} \] (6)
The interior length of the thin channel flow cell 10 can be determined by the number of corrosion measurement devices 200 that are going to be incorporated into the bottom surface 220 of the thin channel flow cell 10. In this example, four corrosion measurement devices 200 can be used in the thin channel flow cell 10 design. However, more corrosion measurement devices 200 can be used by simply extending the interior length of the thin channel flow cell 10. The distance between fluid inlet 225 and first corrosion measurement device 205 can be set to be about 10 cm to enable a desired flow pattern development. The distance between the individual corrosion measurement devices 200 can be set to about 15 cm for mechanical purposes (distance between fittings of the corrosion measurement devices 200) but can be set to other distances with different corrosion measurement devices and/or different embodiments. The distance between the last corrosion measurement device 208 and the fluid outlet 230 can be set to about 10 cm as well. Therefore, the overall interior length of the thin channel flow cell 10 can be set to about 78 cm for this example.

\[ L = 7.8 \times 10^{-1} \text{ m} \]  

(7)

Therefore, in this embodiment, the open space 260 available for the channel fluid flow can be set to about 10 cm wide, about 0.3 cm to about 0.6 cm deep and about 78 cm long. The characteristics of the fluid flow in the 0.3 cm high channel are shown in Table 1.

<table>
<thead>
<tr>
<th>Flow velocity (m/s)</th>
<th>Volumetric flow rate (gallon/min)</th>
<th>Shear Stress (Pa)</th>
<th>Flow type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 - 9</td>
<td>2 - 42</td>
<td>1 - 200</td>
<td>Turbulent</td>
</tr>
</tbody>
</table>

Table 1. Characteristics of flow in 3mm high channel

The bottom surface 220 of the measurement device holding block 270 of the thin channel flow cell 10 can be comprised of stainless steel, where the flush mounted and incorporated corrosion measurement devices 200 can
be added. The top surface of the thin channel flow cell 10 can be a clear window 240, on top of which a reinforcing steel plate 250 can be added. The material that can comprise the clear window 240 can be dependent on the operational temperature and pressure within the thin channel flow cell 10. The typical operational temperature conditions for the thin channel flow cell 10 can range from about room temperature (i.e., about 20 to about 25° C) to about 90° C and the typical operational pressure conditions for the thin channel flow cell 10 can range from about ambient pressure (i.e., approximately 0 psi) to approximately 200 psi.

In one embodiment for operational conditions where the operational pressure is not to exceed about 5 psi and where the operational temperature is not to exceed about 55° C, the clear window 240 can be comprised of optical grade polycarbonate. The tensile strength of polycarbonate can be 6.3-10^7 Pa at room temperature. The thickness of the polycarbonate can determine the size of the exposed window 255 possible without added support. The size of the exposed window 255 can be calculated by using the standard stress (S) expression given for polycarbonate:

\[ S = \frac{K_1 \omega L^2}{t^2} \]  

(8)

And the vertical deflection \( y \) in inches can be calculated by:

\[ y = \frac{K \omega L^4}{Et^3} \]  

(9)

Where:

\( \omega \) = unit applied load (psi)
\( K \) = loading-support factor for deflection (dimensionless)
\( K_1 \) = loading-support factor for stress (dimensionless)
\( E \) = modulus of elasticity (psi)
\( L \) = length (inch)
\( t \) = plate thickness (inch)
The loading-support factor for deflection and the loading-support factor for stress can depend only on the geometry of the clear window 240 for a rectangular shape (a: length, b: width). For example, according to the calculation, the relationship between the thickness of the polycarbonate and the size of the exposed window 255 is shown in Table 2. The exposed window 255 can be designed for an operational bar total pressure of about 2.5. In order to observe the whole surface of the corrosion coupon in the thin channel flow cell 10, about 0.6 cm thick polycarbonate can be used to give the largest exposed window size 255.

Table 2 Relationship between thickness of polycarbonate and window size

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>Exposed Window Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>75</td>
</tr>
<tr>
<td>6</td>
<td>95</td>
</tr>
</tbody>
</table>

In another embodiment, the clear window 240 can be comprised of two layers optical grade polycarbonate as illustrated in Figure 5. The two-layered clear window 240 can be used for situations when there is higher operational pressures within the thin channel flow cell 10. The bottom layer of the two-layered clear window 240 can be comprised of a solid layer of optical grade polycarbonate. The top layer of the two-layered clear window 240 can be comprised of polycarbonate with circular cut-outs in the polycarbonate which can be positioned above the corrosion measurement devices 200 for enhanced in situ observation.

In another embodiment with an operational pressure that exceeds about 5 psi and an operational temperature that exceeds about 55° C, the clear window 240 can be comprised of quartz, sapphire, or any other suitable material able to withstand such operational temperature and pressure considerations.
Figure 4 shows a cross section view of the thin channel flow cell 10 according to one embodiment. In another embodiment, illustrated in Figure 5, heaters 280 can be positioned proximately to the corrosion measurement devices 200 in the thin channel flow cell 10 below the open channel space 260. In other words, the heaters 280 can be positioned within the measurement device holding block 270. The heaters 280 can be in thermal communication with the bottom surface of the thin channel flow cell 10. In one embodiment, the heaters 280 can be positioned between each of the corrosion measurement devices 200. For example, if four corrosion measurement devices 200 are used, three heaters 280 can be used between the individual corrosion measurement devices 200. However, any number of heaters 280 can be used to maintain the temperature of the fluid flow. In one embodiment, the heaters 280 can be controlled by a processor 110. In another embodiment, the heaters 280 can be controller by an independent heater controller.

In one embodiment, four kinds of corrosion measurement devices 200 for corrosion measurements can be installed into the thin channel flow cell 10 for corrosion study. The corrosion measurement devices 200 can include Electrical Resistance (ER), Linear Polarization Resistance (LPR), Weight Loss (WL) measurement probes as well as a Quartz Crystal Microbalance (QCM) probe. Additionally, at least one corrosion measurement devices 200 can be a corrosion coupon measurement device. The use of multiple corrosion measurement devices 200 can allow a variety of methods to observe the corrosion process. Figure 6 illustrates the thin channel flow cell 10 with the corrosion measurement devices 200 installed between the fluid input 225 and the fluid output 230.

In one embodiment, a quartz crystal microbalance (QCM) corrosion measurement device (illustrated in Fig. 7) can be used to measure the mass change occurring at the quartz crystal 700 surface during the test. The surface 710 of the quartz crystal 700 can be exposed into the fluid flow. The resonant frequency of the quartz crystal 700 can change as a linear function of the mass
of material deposited on the quartz crystal 700 surface. The QCM corrosion
measurement device can have the same shape as other corrosion
measurement devices 200, which can ensure that all the holes in the
measurement device holding block 270 for the corrosion measurement devices
200 can be exchangeable. The quartz crystal 700 can be fixed on into and
flush with the top of the measurement device holding block 270 and exposed
to the fluid flow.

Returning to Fig. 2, in one embodiment, in order to visually observe
the surface of the samples in situ, a microscope system 140 can be used. The
microscope system 140 can be positioned near the exposed window 255 at
the upper surface 210 of the thin channel flow cell 10. The microscope system
140 can have a magnification from about 100X to about 1000X by using a long
working distance objective lens. In addition, the microscope system 140 also
can have three-dimensional analysis capability, which can allow the three-
dimensional analysis of the sample surface of the thin channel flow cell 10
after the test. Three-dimensional analysis can be especially useful for localized
corrosion studies.

Additionally, the TCFC system 100 can have two temperature
controllers, one for the thin channel flow cell 10 and one for a fluid tank, that
can be controlled by the processor 110. In one embodiment, one of the two
temperature controllers can be a heater exchanger 150. These temperature
controllers can help to ensure a stable temperature for the TCFC system 100
as well as to maintain the desired operational temperature for the TCFC
system 100. A flow meter can be used to control the volumetric flow rate
accurately. The flow meter can also under control of the processor 110. A
manifold 160 can be available in order to sample the fluid flow as well as to
add corrosion inhibitors to the fluid flow. Additionally, the processor 110 can
control a pressure gauge to be used to control the operational pressure of the
TCFC system 100. Further, a pH meter and probe can be used to monitor and
aid in the adjustment of the fluid solution pH and an ion exchanger can be
used to remove extra iron ions (Fe\(^{2+}\)) to aid in the control of the water chemistry of the TCFC system 100. The pH meter and ion exchanger can be controlled by the processor 110 as well.

It is noted that terms like "preferably," "commonly," and "typically" are not utilized herein to limit the scope of the present disclosure or to imply that certain features are critical, essential, or even important to the structure or function of the present disclosure. Rather, these terms are merely intended to highlight alternative or additional features that may or may not be utilized in a particular embodiment of the present disclosure.

For the purposes of describing and defining the present disclosure it is noted that the term "substantially" is utilized herein to represent the inherent degree of uncertainty that may be attributed to any quantitative comparison, value, measurement, or other representation. The term "substantially" is also utilized herein to represent the degree by which a quantitative representation may vary from a stated reference without resulting in a change in the basic function of the subject matter at issue.

Having described the present disclosure in detail and by reference to specific embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the present disclosure defined in the appended claims. More specifically, although some aspects of the present disclosure are identified herein as preferred or particularly advantageous, it is contemplated that the present disclosure is not necessarily limited to these preferred aspects of the present disclosure.
CLAIMS

1. A thin channel flow cell comprising a bottom surface, a fluid input end, a fluid output end, two substantially flat parallel walls positioned on opposite longitudinal sides of the bottom surface, a top surface, and a series of corrosion measurement devices incorporated into the bottom surface, wherein: a flow channel is formed by the top surface, the bottom surface, and the two substantially flat parallel walls for flowing a fluid from the fluid input end to the fluid output end; the distance between the fluid input end and the fluid output end is greater than the distance between the two substantially flat parallel walls and the distance between the top surface and the bottom surface is less than the distance between the two substantially flat parallel walls in order to create turbulent flow of the fluid within the flow cell; and the series of corrosion measurement devices measure the corrosion process within the thin channel flow cell.

2. The thin channel flow cell of claim 1, wherein the series of corrosion measurement devices do not extend into the flow channel and comprise diagnostic surfaces that are flush with the bottom surface of the thin channel flow cell.

3. The thin channel flow cell of claim 1, wherein the top surface is comprised of optical grade polycarbonate for operational pressures not exceeding about 5 psi and operational temperatures not exceeding 55° C.

4. The thin channel flow cell of claim 1, wherein the top surface is comprised of quartz or sapphire for operational pressures exceeding about 5 psi and operational temperatures exceeding 55° C.

5. The thin channel flow cell of claim 1, wherein the distance between the top surface and the bottom surface is between about 3 mm to about 6 mm.
6. The thin channel flow cell of claim 1, further comprising:
   at least one temperature controller for maintaining an operational
temperature of the thin channel flow cell system in the range of
between about 20°C to about 90°C.

7. The thin channel flow cell of claim 1, further comprising:
   a pressure gauge controlled by a processor for maintaining an
   operational pressure range of the thin channel flow cell system in
   the range of between approximately 0 psi to approximately 200 psi.

8. The thin channel flow cell of claim 1, wherein the thin channel flow cell
   is configured such that a fluid flowing from the fluid input end to the fluid output
   end has a wall shear stress of between about 1 Pa to about 200 Pa.

9. The thin channel flow cell of claim 8, wherein the wall shear stress is
determined by velocity of the fluid, viscosity of the fluid and slope of the
   channel flow cell.

10. The thin channel flow cell of claim 1, wherein the series of corrosion
    measurement devices measure weight loss, electrical resistance, linear
    polarization resistance or combinations thereof.

11. The thin channel flow cell of claim 1, wherein one of the series of
corrosion measurement devices is a quartz crystal microbalance.

12. The thin channel flow cell of claim 11, wherein the quartz crystal
    microbalance corrosion measurement device measures mass changes
    occurring on a surface of the quartz crystal microbalance corrosion
    measurement device.

13. The thin channel flow cell of claim 1, wherein one of the series of
corrosion measurement devices is a corrosion coupon measurement device.

14. The thin channel flow cell of claim 1, further comprising:
    a microscope system for visually observing *in situ* the corrosion process
    in real time.
15. The thin channel flow cell of claim 1, further comprising:
   a peripheral support to adjust the distance between the top surface and
   the bottom surface.
16. The thin channel flow cell of claim 1, further comprising:
   a processor to control temperature of the fluid, volumetric flow rate, and
   pressure inside the channel flow cell.
17. The thin channel flow cell of claim 1, wherein the bottom surface is
   formed by a measurement device holding block and the thin channel flow cell
   further comprises:
      at least one heater positioned in the measurement device holding block.
18. The thin channel flow cell of claim 1, wherein one of the series of
   corrosion measurement devices monitors the pH of the fluid in the thin channel
   flow cell.
19. The thin channel flow cell of claim 1, further comprising:
   an ion exchanger to remove extra iron ions in order to control water
   chemistry of the fluid in the thin channel flow cell.
20. A thin channel flow cell system for the \textit{in situ} observation of a corrosion
   process, the thin channel flow cell comprising a bottom surface, a fluid input
   end, a fluid output end, two substantially flat parallel walls positioned on
   opposite longitudinal sides of the bottom surface, a top surface, a series of
   corrosion measurement devices incorporated into the bottom surface, wherein:
      a flow channel is formed by the top surface, the bottom surface, and the
      two substantially flat parallel walls for flowing a fluid from the fluid
      input end to the fluid output end;
      the distance between the fluid input end and the fluid output end is
      greater than the distance between the two substantially flat
      parallel walls and the distance between the top surface and the
      bottom surface is less than the distance between the two
      substantially flat parallel walls in order to create turbulent flow of
      the fluid within the flow cell; and
the series of corrosion measurement devices do not extend into the flow channel and comprise diagnostic surfaces that are flush with the bottom surface and measure the corrosion process within the thin channel flow cell.

21. A method of *in situ* observing a corrosion process in a channel flow cell, the thin channel flow cell comprising a bottom surface, a fluid input end, a fluid output end, two substantially flat parallel walls positioned on opposite longitudinal sides of the bottom surface, a top surface, a series of corrosion measurement devices incorporated into the bottom surface, the method comprising:

- flowing a fluid in a channel formed by the top surface, the bottom surface, and two substantially flat parallel walls of the thin channel flow cell between the fluid input end and fluid output end;
- creating turbulent flow within the thin channel flow cell by setting the distance between the fluid input end and the fluid output end greater than the distance between the top surface and the bottom surface and setting the distance between the top surface and the bottom surface less than the distance between the two substantially flat parallel walls; and
- measuring the corrosion process with the series of corrosion measurement device.

22. The method of claim 21, further comprising:
- adding corrosion inhibitors into the fluid.

23. The method of claim 21, further comprising:
- adjusting the distance between the top surface and the bottom surface to control the turbulent flow.
**INTERNATIONAL SEARCH REPORT**

International application No
PCT/US2008/01131

**A. CLASSIFICATION OF SUBJECT MATTER**

INV. GO1N17/00 GO1N5/02 GO1N7/02 GO1N27/00

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)

GO1N

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

Electronic database consulted during the international search (name of data base and where practical, search terms used)

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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<td>US 5 275 704 A (YANG BO [US]) 4 January 1994 (1994-01-04) abstract; figures column 3, line 15 - column 4, line 2 column 9, lines 15-60 -----</td>
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<td>A</td>
<td>WO 2006/030226 A (BP OIL INT [GB]; BUTLER GRAHAM [GB]; COUVES JOHN WILLIAM [GB]; GREENOU) 23 March 2006 (2006-03-23) page 7 abstract; figures ----- /--</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

**Date of the actual completion of the international search**
29 October 2008

**Date of mailing of the International search report**
21.12.08

Name and mailing address of the ISA/Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV RUISWOLK Tel. (+31-70) 340-2040 Fax: (+31-70) 340-3016

Smith-Hewitt, Laura
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