The centerline flow molecules do not enter the active surface feature region at least 1 time.

[0364] A comparison case was done for a flat channel operating in a turbulent regime. The flat or smooth channel was taken as the same geometry

[0365] 0.0125" (0.32 mm) main channel gap

[0366] 2.5" (63.5 mm) long

[0367] 0.160" (4.1 mm) wide main channel

[0368] Surface features of 0.015" (0.38 mm) span, 0.010" (0.25 mm) depth, and 0.015" (0.38 mm) separation

[0369] 30 m/s inlet flow rate (or 3× the flowrate of the previous case)

[0370] 350 psig (25.1 bar) outlet

[0371] 3 parts steam to 1 part methane

[0372] Reynolds number ~4360, and well within the laminar regime.

[0373] The peak vorticity in the surface feature channel at a lower Reynolds number was surprisingly higher than that found in a flat channel at a much higher Reynolds number (4360). For 3 times the flowrate, the peak vorticity near the wall was 551000 hz as compared to 628000 hz for the surface feature channel with a Reynolds number of 1450. Furthermore, the increase in vorticity penetrates the bulk flow path more in the surface feature channel than in the flat microchannel operated with 3× the flowrate or 3× the Reynolds number. The flat channel localized the maximum vorticity near the wall rather than creating more flow rotation and movement in the bulk flow channel.

[0374] The pressure drop for the flat channel operated at a Reynolds number of 4360 was 0.47 psig as calculated by Fluent under the conditions described above, and a corresponding flat channel operating at a Reynolds number of 1450 was 0.2 psig. The pressure drop through the microchannel with surface features has been modeled and measured as 2× the flat channel for a Reynolds number near 1500 and gives roughly 0.4 psig pressure drop. The net result is more mixing at the lower Reynolds number and with a lower net pressure drop by the use of active surface features than by taking the same channel into the turbulent flow regime.

Example

Heat Transfer

[0375] A test device was fabricated to demonstrate heat transfer enhancement using channels with surface features. The body of the device contained a slot such that two coupons were inserted in the slot and the gap between the inserted coupons formed a microchannel for the fluid to flow in. The device body was made of a 12.7 mm diameter rod and the openings for the coupons, part of slot made in the device body, was 5.59 mm×2.54 mm and was located 0.64 mm off the center of the cross section of the rod. When the coupons were inserted in the openings, a microchannel with a nominal 1.27 mm gap was formed. The width of the microchannel was 4.06 mm. The overall length of the body was 88.39 mm. Wells for thermocouples were placed 25.4 mm from of each end of the device main body. The thermocouple wells were 3.81 mm deep and had a diameter of 0.89 mm. Overall both the smooth wall and surface feature coupons were 88.39 mm in length. For the surface features coupons, the total length of surface features was 86.36 mm. The coupons were 5.46 mm in width. The coupons were 2.41 mm thick and made of Inconel 617.

[0376] The reactor with coupons with surface features is shown in FIG. 13. The surface features were in the form of "V" shape whose arms were placed at a 75° angle (where a 90 degree angle is essentially parallel with the main direction of flow and a 0 degree angle is essentially horizontal to the main flow path. The features themselves were each 0.51 mm deep and had width or opening of 0.38 mm. The tip of the surface feature was a 0.20 mm' round and the arms were terminated with full rounds. Each surface feature was separated from the next by 0.38 mm.

[0377] Nitrogen was heated to desired temperature in the heater and then entered the device. The device was kept in a constant temperature bath. The nitrogen gas exited from the other end of the device to ambient. All the connections in the flow circuit were using stainless steel swagelok fittings and tubes. During experiments, the constant temperature water bath was continuously circulated to maintain uniform temperature. Two thermocouples were also located on the pioneer pellet surface, each 3.25" from the end of the pellet. A thermocouple was located ~6.3 mm off the surface of the pellet to measure the water temperature. The gas was preheated coming into the device. The device was kept submerged under water at all times to maintain temperature. Watlow Watlube, a thermal conductive slurry, was used between the coupon and main body.

[0378] Experiments were run for various flow rates and inlet temperature. The nomenclature used for different thermocouples and pressure transducers is listed below:

TC1: Average gas inlet temperature, 3.2 mm before the entrance to device, ° C.

TC2: Average temperature of thermocouple in the thermocouple hole (near inlet of the device), ° C.

TC3: Average temperature of thermocouple in the thermocouple hole (near outlet of the device), ° C.

TC4: Average gas inlet temperature, 3.2 mm after the exit to device, ° C.

TC5: Average water bath temperature, ° C.

PT1: Average inlet pressure, kPa

PT2: Average outlet pressure, kPa

[0379] Two orientations were defined for surface feature channel testing. Orientation 1 was defined as when the flow moves in the direction pointed by the surface feature apex. Orientation 2 was defined as when the flow moves opposite to the direction pointed by the surface feature apex. The experimental results for surface features geometry in both orientation and smooth channel geometry are listed below: