surface feature channel, but that the increase over a flat wall for a given geometry will be independent of fluid at equal Reynolds number.

Example

Varying Depth and Width of Surface Features

[0300] For this study, the surface feature depth and width were varied. CFD models were developed in Fluent-6.0 to study the effect of the depth and width of the surface features. The effect of depth and width were measured qualitatively by looking at the pathlines. For quantitative measurement, a surface reaction was applied on the surface of the features and the composition of gas at the outlet was measured. It was found that the depth of surface features has more impact of flow mixing compared to the width of the surface features.

[0301] The description of CFD models for this study is given in the following Table.

TABLE

Model description for Case 1	
Kinetics pre-exponential factor(s)	282.3
Case number	1, 2, 3
Surface feature geometry type	SFG-0-60°
Flow direction	Cis-A
Surface feature width (mm)	0.381
Surface feature depth (mm)	0.508
Surface feature pitch or tangent to tangent spacing (mm)	0.381
Surface feature angle (degrees relative to width direction, or orthogonal to bulk flow)	60°
Channel gap modeled (mm)	0.597
Full channel gap (mm)	1.194
Channel width modeled (mm)	2.032
Full channel width (mm)	4.064
Channel length upstream of features (cm)	0.381
Channel length with surface features (cm)	5.588
Channel length downstream of features (cm)	0.381
Total number of surface features per surface feature containing wall	33
Total number of walls containing surface features	2
Number of cells	126,975
Model symmetry	quarter
Wall boundary condition	870° C. wall temperature
Inlet fluid temperature (° C.)	870° C.
Inlet mass flow for modeled portion (kg/s)	4.975E−5 kg/s
Inlet velocity profile	uniform
Outlet pressure (bar)	1.26
Reaction enabled?	Yes
Fluid properties	
Density (kg/m3)	Ideal Gas
Heat capacity (J/kg-K)	Mixing Law
Thermal conductivity (W/m-K)	Mass-weighted-mixing-law
Viscosity (kg/m-sec)	Mass-weighted-mixing-law
Inlet Fluid Composition	
O_2 (mass %)	0.03240
CO_2 (mass %)	0.31480
CH_4 (mass %)	0.00263
H_2O (mass %)	0.09184
H_2 (mass %)	0.00000
CO (mass %)	0.00000
N_2 (mass %)	0.55833
Balances	
Mass ([out − in]/in)	0
Energy ([out − in]/in)	0

[0302] Case 2 was the same as case 1 except surface feature width was 0.508 mm. Case 3 was the same as case 1 except surface feature depth was 0.762 mm.

[0303] Assumptions for these CFD analyses include: the flow was considered to be fully laminar; the entire flow-field was adiabatic; and the flow was steady-state.

[0304] When the depth of the surface features is increased from 0.508 mm to 0.762 mm at a constant main channel gap of 0.597 mm, the frequency of flow moving to the edges and then to the center increases significantly compared to wider surface features.

[0305] One of the purposes of introducing surface features in the channel is to break the laminar boundary layer to enhance heat and mass transport properties. The efficacy of increasing width and depth was studied by applying a surface reaction of methane combustion on the surface feature walls and comparing the outlet concentration of methane and overall pressure drop in the channel. The table below lists the inlet/outlet methane concentration and pressure drop for Cases 1, 2 and 3 with surface reaction applied.

TABLE

Methane concentration and pressure drop

	Inlet methane concentration (PPM)	Outlet methane concentration (PPM)	Pressure drop (psi)
Case 1	4902	937	1.81
Case 2	4899	1036	1.85
Case 3	4902	679	2.13

As we can see from the Table, Case 3 (with the increased feature depth) provided the minimum methane concentration at the outlet. This is attributed to more movement of flow in the channel and better bringing the fluid in contact with the surface reactive wall. However the movement of the flow results in higher pressure drop in the channel. Also visually looking at pathlines, case 2 looked better than case 1 in flow movement and mixing inside the channel. But the methane outlet concentration comparison between Case 1 and Case 2 showed that the fluid is not brought to the reacting wall as much as in Case 1.

[0306] It should be noted that the catalyst kinetics used in this study were somewhat slower (by a factor of 4.5) than those used in previous combustion examples. As such, the resulting outlet prediction of methane ppm is much higher.

Example

Features on Opposing Sides

[0307] A comparison of mixing behavior between a channel with surface features on only one wall and a channel with surface features on two opposing walls in a "cis" orientation was evaluated with a main channel having dimensions of 0.0125 inch by 0.160 inch by 2.5 inch. The surface features were of type SFG-0, having a span of 0.015 inch wide and a depth of 0.01 inch and separated from each other by a spacing of 0.015 inch. The surface feature angle for the SFG-0 geometry was 45°. For the particular case considered here it was found that one-sided features with an "A" flow orientation provided the best mixing in a direction perpen-