transport. However, if a longer section of this surface feature pattern were simulated, one or more core flows might develop within which little interaction with the active surface features would occur.

[0203] For the case of a reactor channel with a larger gap, the importance of the perpendicular flow velocity will become more pronounced. As the gap increases, the contribution to external mass transfer in a flat channel with a laminar flow profile fluid becomes more significant as the increase in diffusion time increases with the square of the diffusion distance (or half gap). The use of surface features to create perpendicular flow will increase the initial enhancement factor. For gas-phase reactions, the importance of surface features as it relates to gap size will also be dependent upon how fast the reactions are progressing relative to the time spent in the reaction channel and the time required for diffusion. As an example, an SMR reaction operated near 1 ms contact time would have an external mass transport effect even at 25 to 50 microns (micron=one thousandth inch) gap. An SMR reaction operated near 10 ms contact time would likely not have an external mass transfer resistance until the gap approaches 500 microns. A liquid phase reaction would have significant mass transfer limitations even for fluid gaps below 500 microns. The inventive features are expected to be advantageous for liquid phase reactions in addition to gas phase reactions, as liquid phase reactions are more likely to exhibit external mass transport limitations.

E) Surface Grooves at an Oblique Angle with the Flow Direction—Asymmetric Pattern on Single Side—Different Orientation on Opposite Walls of the Channel

A wide range of design parameters are examined in term of the reactor performance enhancement. Among them are:

[0204] Surface feature depth

[0205] Catalyst activity level

[0206] Main channel gap size

[0207] Process flow rate

[0208] The analyzed design is illustrated in FIG. 6; dark lines show recesses on the top surface and lighter lines show recesses on the bottom surface.

TABLE

Reactor enhancement for different depth of the features at 700 C. and 25 atm for SMR kinetics (equilibrium conversion ~44%)

full activity	Methane conversion	E_factor	dP, psi	relative increase in dP
Baseline	41.4%		0.0517	
0.005" SF	42.8%	3.4%	0.0634	22.6%
0.01" SF	43.7%	5.7%	0.0832	60.8%
0.015" SF	44.2%	6.8%	0.0957	85.0%

[0209] In all these simulations, full SMR catalyst activity specified at the beginning of this section is applied. As shown in the above Table, a small enhancement in term of methane conversion is seen. It should be pointed out that the methane conversion achieved for all the cases approches the equilibrium conversion at the temperature of 700 C. The pressure drop from the inlet to the outlet of the reactor increases as the depth of the surface features increases. This reflects more momentum loss in the surface features of larger depth. However, the pressure drop increases at a slower rate as the surface features are deeper.

TABLE

Reactor enhancement for different depth of the features (lower catalyst activity level - 20%)

20% activity	Methane conversion	E_factor	dP, psi	relative increase in dP
Baseline	19.8%		0.0459	
0.005" SF	22.6%	14.0%	0.0571	24.4%
0.01" SF	25.1%	26.6%	0.0755	64.6%
0.015" SF	27.3%	37.5%	0.0872	90.1%

A much higher degree of enhancement is seen as the catalyst activity is reduced. For the cases summarized in the above Table, the baseline kinetics as described previously were reduced to 20% of the original baseline. Surprisingly, the deeper features gave better performance. The deeper features have both more surface area but also more distance from the bulk flow path to the reactor wall. The extra surface area outweighs a mass transport issue because of the perpendicular flow velocity both in the bulk channel and within the surface features themselves.

[0210] Activity level is defined as a percentage reduction in the pre-exponential factor used for the previusly described kinetic expression. In general, the impact of active surface features is more pronounced as the rate of reaction or kinetics are slower. This is a result of the increased time spent within an active surface feature becoming more important as the catalyst activity is reduced.

TABLE

Impact of activity level on the rector performance with 0.01" deep features at 700 C and 25 atm for methane reforming

Activity Level		Methane conversion	E_factor
100%	Baseline	41.4%	
(Full)	With SF	42.8%	3.4%
75%	Baseline	38.9%	
	With SF	43.2%	11.0%
50%	Baseline	33.8%	
	With SF	40.4%	19.5%
20%	Baseline	19.8%	
	With SF	22.6%	14.0%

[0211] The relative enhancement afforded by the surface features goes through an optimum with catalyst activity. If the kinetics are very fast and the microchannel gap small (<0.015" for a gas phase reaction run less than 10 ms contact time), then the added transverse and perpendicular flow within the channel offers little added advantage and most of the impact arises from the increase in surface area. If the kinetics are too slow then the short contact time environment of the microchannel dominates in that the reactants are swept out of the reactor before appreciable conversion occurs.