

quickly removed from the process channel for exothermic reactions, potentially preventing unwanted side reactions. The anticipated increase in surface heat flux may be more than 2× that of a corresponding flat channel that is based on a cross section that is tangent to the top of the surface features. The overall reactor volume for a homogenous reaction that includes surface features may then be up to a factor of ten smaller than the corresponding volume of a reactor that does not include surface features.

Example

Impact of Capillary Features on the Uptake and Repartition of the Catalyst

[0319] Two coupons (152 mm long×12.7 mm wide), one with capillary features (3CFC=0.76 mm or 3 mil deep capillary features). The capillary features are horizontal slots (angle of 0 degrees and 0.076 mm deep by 0.076 mm wide. The leg length is 4 mm and the other without (flat coupon, FC) were coated by dipping in a Rh acetate solution of 15% (w) Rh in DI water. The capillary features in this example were not formed as through features in thin plates, but as features machined into a thicker plate. Features so formed can be equally effective, and may have cross sections other than rectangular open channels. The surface feature cross section may also be rounded at the corners, triangular, fully rounded, etc. In this example (11), the cross section of the surface or capillary features has rounded corners. Then the coupons were dried vertically at 120° C., similar to processing within a device, and calcined horizontally at 400° C. After calcination the uptake was 2.3 mg(Rh₂O₃)/in² for FC and 5.1 mg(Rh₂O₃)/in² for the 3CFC capillary feature containing coupons.

Surface Inspection of the Two Coupons by SEM:

[0320] On the 3CFC coupon, the Rh distribution was uniform on a macro scale from top to bottom and from left to right across the coupon face; however on the flat coupon, the distribution of metal is not uniform in either the axial or lateral direction.

Coating Quality:

[0321] Cracks are observed in the coating, made with a 15% (wt) Rh solution. By using a lower concentration coating solution, cracking can be minimized. An optical photo was obtained of a coupon with capillary features that was coated two times with an 8% Rh solution. The Rh loading in the coating was 8 mg (Rh₂O₃)/in². No cracking was observed.

Model Validation of Capillary Feature from Experimental Results

[0322] The liquid retention per coat during washcoating with an aqueous precious metal salt solution was predicted using a washcoat retention model for the three capillary feature geometries. Each of these geometries was also tested experimentally for catalyst uptake. A contact angle of ~45 degrees was assumed in the model (the approximate value measured for the 8 wt. % rhodium solution on a typical surface-stabilized coupon prior to washcoating). It should be noted that the contact angle does vary somewhat over the heat treated surface and also appears to be somewhat different in the valleys of the capillary features.

[0323] Since the predicted uptake per coating was consistently low compared to the measured values, the predicted uptake was also calculated assuming that the capillary features completely fill with liquid. Both predictions are compared to measured values in FIG. 11. Note that in FIG. 11, both predictions for the 1CFC geometry assume that the groove is completely filled, since the actual geometry does not match the assumptions made in the washcoat retention model. Surprisingly, the model predictions made assuming that the capillary features completely fill with liquid better match the experimentally measured values. These results are suggestive of a higher contact angle created on the surface generated in the valleys of the capillary features. It should be noted that alumina cracks and surface roughness may also affect the catalyst uptake.

[0324] FIG. 12 shows that Rh uptake depends considerably on the capillary feature design. With respect to the Rh uptake, the coupons can be classified in the following order for efficacy: 5CFC>3CFC>1CFC>FC, where FC means flat channel (no capillary features) and CFC means capillary feature channel or surface feature channel. The number before the CFC moniker refers to the depth of feature in mils or 0.001 inch, that is a 5 CFC is a 5 mil or 0.005 inch or 125 micron deep horizontally aligned surface feature recessed into the main flow channel of the microchannel.

Example

One Sided Surface for the Enhancement of Apparent Catalyst Activity for Methane Steam Reforming

[0325] The impact of one sided surface features in a microchannel on the apparent activity of Rh/MgO catalyst was investigated in a device with a 0.006 inch flow-by gap by testing a coupon without surface features (flat) and a coupon with surface features at the same level of catalyst loading per unit area. The surface features were formed from chevrons whose arms were placed at a 45° angle to the center line of the channel in its long axis (SFG-0). The features themselves were each 10 mil deep and had a width or span of 15 mil. The tip of the chevron had a 10 mil radius round and the legs were terminated with full rounds. The presence of surface features increased the area available for catalyst retention by a factor of 1.63×. The comparison was conducted at 4.1 ms using a steam to methane ratio of 3:1 over temperatures ranging from 675° C. to 850° C. Coupons were loaded to 9.5 mg/in² (mg active metal) in the case of the featureless coupon and 10.5 mg/in² (mg active metal) in the case of the surface feature containing coupon. A computational fluid dynamics simulation was conducted using FLUENT and the inclusion of the features was found to increase the apparent kinetic activity by a factor of at least 2.1. Thus the mass transfer enhancement provided by the one sided surface features (on one side of the channel only) increased the apparent activity by approximately 31% over what would be expected based on the increased surface area alone.

Experimental—Coupons

[0326] Coupons for catalyst coating were prepared both with and without surface features. Overall the coupons were 1.4 inch in length, the surface features, on those that contained them, were deployed over a total length of 1.323