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(54) HYDROTREATING OF PETROLEUM DISTILLATES USING SHAPED CATALYST PARTICLES

(71) We, AMERICAN CYANAMID COMPANY, a corporation organised and existing under the laws of the State of Maine, United States of America, of Berdan Avenue, Township of Wayne, State of New Jersey, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—
This invention relates to the hydrotreating of petroleum distillates.
In the past, catalyst materials used in hydrotreating processes were generally of spherical or cylindrical shape. Such convex catalyst particles provided desirable activity for the specific hydrotreating reactions considered at the time. Since the catalyst particles also had desirable physical properties and were readily prepared, little interest was devoted to novel catalyst shapes and sizes. The lack of interest apparently arose because it was felt that smaller particles would cause intolerable pressure drops, that distinctive shape would have adverse effect on physical properties, that no advantage in activity would arise from shape distinctions and that, in fact, any increased void fraction would reduce reactor activity because of the lesser weight of catalyst present per reactor volume, occasioned by the larger void fraction.
Recent shortages in petroleum supplies has necessitated increasing reliance on sources which require more extensive hydrotreating and are more difficult to process. Use of conventional spherical or cylindrical particles does not result in efficient hydrotreating of some sources now used. Recourse must therefore be had to more effective catalysts for hydrotreating if the shortages are to be alleviated by resource to such sources.
In United States Patent 3,674,680 to Hoekstra et al., there is disclosed a process for hydrotreating petroleum residuum by use of small catalyst particles of distinct shape, which at the same time, have a majority of pores

having a diameter in the range of 100—200 angstrom units. The catalyst is stated to provide an increased service life over conventional catalyst used in processing residuum and the extended life is thought to be due to the combination of large-pore alumina substrate and the distinctive particle size and shape. Although the reference provides a catalyst of extended service life in residuum processing, it does not provide improved initial activity. Since activity decreases with increasing service use, the extended service life is at a low level of activity.
There continues to exist, therefore, the need for hydrotreating catalysts useful in processing petroleum distillates that not only provide good service life but also provide good activity throughout service life of the catalyst particles.
In accordance with the present invention, there is provided a process for hydrotreating a petroleum distillate which process comprises contacting said distillate in the presence of hydrogen at a hydrogen flow rate of 100 to 10,000 standard cubic feet per barrel of distillate; at a temperature in the range of 500 to 800°F.; at a total pressure in the range of 100 to 3,000 pounds per square inch gauge; and at a liquid hourly space velocity of 0.5 to 25 reciprocal hour; with porous but non-hollow catalyst particles of a polylobal cross-sectional shape which is characterized by a concavity index (as herein defined) greater than 1.0, a void fraction (as herein defined) in the range of 0.25 to 0.60, and when containing more than two lobes, at least 15% of the points within the particle being greater than 0.015 inch from the particle surface; said particles each having a cross-sectional shape and size which are substantially uniform along the length thereof, a ratio of geometric volume to geometric surface in the range of 0.001 to 0.042 inch; a catalytic surface area greater than 100 square meter per gram, as measured by the method herein defined, and a catalytic pore volume of from 0.35 to 0.85 cubic centimeters per gram, said pore volume resulting from a major portion of

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pores of diameter in the range of 40 to 90 angstrom units when measured with mercury up to 50,000 pounds per square inch absolute pressure and a contact angle of 140°; and a composition comprising a major portion by weight of alumina; from 5 to 25 weight percent of molybdenum oxide and from 1 to 8 weight percent of an oxide selected from cobalt and nickel oxides and mixtures thereof.

In accordance with preferred embodiments of the present invention, there is provided hydrotreating process for petroleum distillates wherein the catalyst particle employed exhibits higher activity than is possible with conventional catalyst particles. This result is entirely unexpected in view of the fact that the activity associated with the specific catalyst shape is much greater than is attributable to its particle size and that not all shapes provide the improved activity.

In order that the size and shape characteristics of the catalyst particles may be clearly understood, the following discussion is given.

Concavity Index

A geometric solid is convex if all pairs of points lying within or on the surface of the solid can be connected by a straight line which is completely contained within the solid or surface thereof. Conversely, a geometric solid is concave if pairs of points lying within or on the surface of the solid can be connected by a straight line which is not completely contained within or on the surface of the solid. The geometric volume of a convex solid of the minimum size necessary to contain a concave solid will be greater than the geometric volume of the concave solid. Letting V_x equal the volume of the minimum convex solid specified and V_c equal the volume of the contained concave solid, the Concavity Index, C , is given by the expression:

$$C = \frac{V_x}{V_c}$$

In order for the geometric solid to be concave, the value of the Concavity Index must be greater than 1.0. Since the present invention requires concave solids, the Concavity Index must be greater than 1.0 and preferably is 1.05 to 1.15.

Void Fraction

The void fraction represents the closeness of particle packing that can be obtained with particles of a given shape. In a given geometric volume of space, a specific number of catalyst particles can be packed, the number being determined by the size and shape of the particles. Multiplying the geometric volume of an individual particle by the number of particles packed, a total geometric particle volume, V_p , is obtained. If the apparent geometric volume

of space packed is V_s , there will exist void space, V_v , not actually occupied by catalyst particles. Thus $V_s = V_p + V_v$. The void fraction, E , associated with a specific particle shape is given by the expression:

$$E = \frac{V_v}{V_v + V_p}$$

In order for a catalyst particle to be useful in accordance with the present invention, it must have a void fraction in the range of 0.25 to 0.60, preferably from 0.35 to 0.50.

Ratio of Geometric Volume to Geometric Surface

Catalyst particles of the present invention have a characteristic geometric volume and geometric surface area associated therewith as a consequence of their cross-sectional shape and length. The geometric volume and geometric surface area are readily calculated from appropriate measurements for the perfect geometric forms. Actual catalyst particles approximate these forms and their volumes and surface can be closely estimated from the appropriate geometric model. The ratio of geometric volume to geometric surface area is indicative of particle size and should be in the range of 0.001 to 0.042 inch, preferably from 0.005 to 0.025 inch.

Catalyst particles of the present invention are of polylobal cross-sectional shape. This means that the shape is composed of a series of lobes which are united together to form a unitary structure. The lobes are generally of circles of equal diameter. When two lobes are present they may be connected so as to form a "dumbbell" or a "figure eight". The dumbbell shape is that of two circles of equal diameter attached by an elongated central section that is approximately of a width equal the radius of one of the circles. The figure eight shape is that of two circles of equal diameter connected to each other by spacing of the circle centers from about 3/8 to 15/16 of the length of a circle diameter apart. When more than two lobes are employed, the lobes will be of circles of substantially the same diameter and will intersect adjacent lobes to some extent depending upon the number of lobes employed, and the center area of the cross-sectional shape will be of porous catalyst material, i.e. it will not be hollow. This requirement is essential to obtain adequate particle strength and results in an increase in the particle thickness in the intersecting region. Thus, although dilobal particles may have all points in the particle less than 0.015 inch from the surface of the particle, polylobal particles will have at least 15% of the points at a distance greater than 0.015 inch from the surface of the particle in order to provide adequate structural integrity.

In addition to the geometric considerations reflecting particle size and shape, it is also necessary for the particles to possess certain characteristics that are associated with catalytic action. These characteristics and methods of measurements are given next.

Catalytic Surface Area

The catalytic surface area is expressed in square meters per gram and is determined in accordance with the procedure described by H. W. Doeschner and F. H. Stoss in Anal. Chem., Vol. 34, page 1150, 1962. This value should be greater than 100 square meters per gram, preferably greater than 200 square meters per gram, and more preferably from 250 to 350 square meters per gram.

Catalytic Pore Volume

The catalytic pore volume of the catalyst particles represents internal cavities therein. Measurements are made by conventional procedures based on mercury penetration at up to 50,000 pounds per square inch absolute pressure using a contact angle of 140°. In this procedure, both total pore volume and pore diameter are determined. Catalyst particles of the present invention will have a total pore volume in the range of 0.35 to 0.85 cubic centimeters per gram with the majority of the pores having a diameter in the range of 40 to 90 angstrom units in accordance with the method of determination specified.

In addition to the geometric size and shape relationships, the catalyst particles will also have a specific chemical composition, which is next discussed.

The catalyst particles will comprise a major portion by weight of alumina and, in particular, small-pore alumina so as to be consistent with the catalytic characteristics specified above. The alumina will thus be the major structure-forming component of the catalyst particles. In addition to alumina the catalyst particles may contain up to 36 weight percent of silica, based on the total weight of silica and alumina. The amount of silica added as such will generally be up to 5 weight percent, same basis. When added in the form of aluminosilicate, such as a zeolite, it may be as high as 45 weight percent of zeolite, thus giving rise to 36 weight percent of silica as indicated.

The catalyst particles will also contain from 5 to 25 weight percent of molybdenum oxide and from 1 to 8 weight percent of an oxide selected from cobalt and nickel oxides and mixtures thereof. These constituents serve as promoter materials and are based on the total weight of the catalyst particle.

In preparing the catalyst particles of the present invention by the preferred technique, precipitated alumina is prepared in accordance with conventional procedures, well-known in the art. After filtration, washing, and adjust-

ment in composition as may be desired, the precipitated alumina is spray-dried in accordance with conventional procedures. The spray-dried alumina powder may then be prepared as an extrusion mix, incorporating therein, if desired, the promoter ingredients. Typically, mixing is employed in providing the extrusion mix. The extrusion mix is then extruded through a die having orifices of the desired cross-sectional shape and the extrudate is cut to the proper length to provide the desired shape characteristics specified. The extrudate is then subjected to drying and calcination in conformity with conventional procedures. If provision for promoter incorporation was not made prior to extrusion, the calcined extrudate may be suitably treated with promoter materials and again calcined, in accordance with conventional procedures. Advantageously, preparation of catalyst particles used in the present invention requires no new processing steps, but merely requires conventional processing directed to the combination of geometric, catalytic and compositional features of the catalyst particles as described.

In addition to extrusion, catalyst particles used in the present invention may be prepared by other procedures. For example, the shaped particles can be obtained by tabletizing, pelletizing, or molding.

The catalyst particles prepared as described after preliminary sulfiding are useful in hydrotreating petroleum distillates. In hydrotreating reactions, three effects are observed. Primarily, hydrosulfurization is accomplished. Saturation and nitrogen removal, to limited extents, may also occur. Accordingly, hydrotreating is the preferred term used to described the catalytic reactions effected since it is generic as to the effects observed.

In carrying out the process of the present invention a petroleum distillate is contacted with the catalyst particles described in the presence of hydrogen gas at specified values of temperature, pressure, and space velocity. The catalyst particles are normally present in the form of a fixed bed and generally several beds in series are employed. The hydrogen gas and distillate are mixed and fed downward through the catalyst bed. Catalyst bed size and distillate flow rate are adjusted to provide a liquid hourly space velocity in the range of 0.5 to 25 reciprocal hour. Hydrogen flow rate is from about 100 to 10,000 standard cubic feet, preferably 200—2,000 per barrel of distillate. The reaction temperature is in the range of 500 to 800°F. and the total pressure is from 100 to 3,000 pounds per square inch gauge.

By using preferred catalyst particles in the hydrotreatment of petroleum distillates according to the process described, improved hydrosulfurization activity compared to prior art procedures using conventional catalysts may be demonstrated. In addition, the catalyst particles

used in the present invention generally provide reduced pressure drops across the catalyst bed thereby improving process operability.

The invention will be further described in conjunction with the accompanying drawings in which:

Figure 1 is a graph comparing the Average Relative Volume Activities of shaped catalyst particles contemplated by the present invention with conventional catalyst particles of the prior art;

Figure 2 is a graph comparing the average Relative Weight Activities of the same catalyst particles considered in Figure 1;

Figure 3 is a graph comparing the Relative Activities of catalyst particles contemplated by the present invention with those of catalyst particles of the same composition having conventional configuration, the comparison being under prescribed conditions;

Figure 4 is a graph comparing the Average Relative Weight Activities of catalyst particles contemplated by the present invention with conventional catalyst particles of like composition;

Figure 5 is a "plate", a convex catalyst not contemplated by this invention, wherein the dimensions are $L = 0.186$ inch, $D = 0.094$ inch, and $d = 0.056$ inch;

Figure 6 is a "dumbbell" configuration contemplated by this invention wherein the dimensions are $L = 0.202$ inch, $D = 0.0473$ inch, and $d = 0.0532$ inch;

Figure 7 is a "figure eight" configuration contemplated by this invention wherein the dimensions are $L = 0.1814$ inch, $D = 0.092$ inch and $d = 0.0541$ inch;

Figure 8 is a "three-leaf clover" polylobal configuration contemplated by this invention wherein the dimensions are $L = 0.212$ inch, $D = 0.0919$ inch, $d = 0.0477$ inch, $T = 0.0442$ inch, and $T = 60^\circ$;

Figure 9 is an undimensioned oval convex configuration not contemplated by this invention;

Figure 10 is an undimensioned tetralobal configuration contemplated by this invention;

Figure 11 is a ring or "donut" configuration not contemplated by this invention.

In the Examples which follow, all parts and percentages are by weight unless otherwise specifically designated.

Examples 1 and 2.

A series of shaped particles were made as follows:

One thousand and thirty gallons of water were charged to an agitated tank. Over a period of about 45 minutes, 3,940 pounds of sodium aluminate solution (28% Al_2O_3 , and about 15% excess Na_2O) and 5,430 pounds of aluminum sulfate solution (7.8% Al_2O_3) were metered into the water. The rates were adjusted so as to hold the pH at about 8.5. When the aluminum sulfate solution was used

up, the sodium aluminate solution flow was continued to bring the pH up to 10.5. The batch temperature was about 120°F. when the final pH was reached.

The resulting alumina slurry above was filtered and washed (using water to pH 9.0) over a rotary vacuum to remove the sulfate. Nitric acid was added to the repulped washed cake to adjust the pH down to 7.0—7.5. The pH adjusted slurry was washed over another filter to remove the Na_2O .

The resulting washed slurry above was spray dried to give a coarse powder.

The spray dried alumina powder (363 pounds) was charged to a muller along with 425 pounds of water. Thereafter 285 pounds of ammonium molybdenate solution (28% MoO_3) followed by 108 pounds of cobalt nitrate solution (16% CoO) were added to the mix.

The batch was mixed for a period of about 10—15 minutes, then 75 pounds (ignited basis) of alumina powder is added to the mix. The mix was then muller for an additional 10—15 minutes.

Using the desired die (shape of extrudate), the muller mix was extruded through an extruder (Welding Engineer Extruder 2010). The extrudates were cut, dried, in an oven to about 20% loss on ignition, and then calcined at a temperature of 1200°F. for one hour. The extrudates had a promoter content of 3% cobalt oxide and 15% molybdenum oxide by weight based on the weight of the catalyst composition. Four separate batches of extrudates were obtained by use of four different dies, the extrudates differing only in shape since the same muller mix was employed in each instance. Two batches, A and B, represented prior art cylindrical shapes of 1/16 and 1/8 inch diameters, respectively. Two additional batches, Examples 1 and 2, represented dumbbell and three-leaf clover shapes of the present invention, respectively, and there latter batches also had the required catalytic pore volume, void fraction, catalytic surface area and pore size distribution characteristics. Activities of the various shaped extrudates were obtained on a Heating Oil Test described below.

Heating Oil Test

Heating Oil Description	
Gravity	34.2° API
Boiling Range	435—628°F.
Sulfur Content	1.4%
Basic Nitrogen	35 ppm

The catalyst particles were charged to the reactor on a volume basis. Two 25 cc. catalyst beds were used in series. Each of these beds was diluted with glass beads to a total of 55 cc. The beads were separated with a glass wool plug.

The catalyst beds were then presulfided via the following scheme:

1. The catalyst was heated from room temperature to 700°F. in a mixture of 10% H₂S plus 90% H₂ by volume flowing at 5 standard cubic feet per hour at atmospheric pressure.
2. The catalyst was then held at 700°F. in this mixture for 1 hour.
3. The reactor temperature was then lowered under flowing hydrogen to 600°F.

The process conditions employed were as follows:

- | | |
|-----------------------|----------------|
| Temperature | = 600, 700°F. |
| Pressure | = 500 psig |
| Space Velocity | = 4LHSV |
| Hydrogen Recycle Rate | = 1000 SCF/Bbl |

Three samples were collected at each temperature. These samples were scrubbed with caustic, then water, then caustic and finally water again. The samples were then analyzed for sulfur in accordance with the Dohrmann Sulfur Method. The activity results are shown in Table I. Some physical properties are given in Table II.

The reaction is influenced by diffusion and, accordingly, the size of the catalyst particle

affects its activity. Results obtained with the cylindrical particles (1/16 and 1/8 inch extrudates A and B) are used to establish the diffusion curve. Activities obtained with the shaped particles are then compared to the diffusion curve at equal particle size. In order that different particles can be readily compared, particle size is defined in terms of the ratio of geometric volume to geometric surface, V_p/S_p .

In this study, two shapes other than cylinders were made. One of these has been designated as the "dumbbell", which is illustrated in Figure 6 of the accompanying drawings. The other has been designated as the "three-leaf clover", which is illustrated in Figure 8 of the accompanying drawings.

The relative activities are defined as the ratio of second order rate constants (catalyst activity) for the catalyst of interest to that of the reference catalyst. The 1/16 inch cylinder is defined to be 100 activity. Relative activities are the percentage of activity of the reference catalyst (1/16 inch cylinder).

The results show an advantage for particles of cross-sectional shape as described by the present invention. A graphical presentation of the data is given in Figure 3 for the 700°F. runs. Activities of the shaped particles are above the standard diffusion curve.

TABLE I
Heating Oil Results

Catalyst ID Example	Description	% Sulfur Removal					% Relative Activities			
		600°F	700°F	600°F	700°F	700°F	Volume			
							600°F	700°F	600°F	700°F
A	"1/16" inch cylinder	46.1	86.5	100	100	100	100	100	100	100
1	Dumbbell	43.0	87.3	88	107	106	106	106	106	128
2	3 Leaf Clover	49.6	88.1	115	116	115	115	116	115	116
B	1/8" cylinder	44.0	85.0	92	88	87	88	88	87	83

TABLE II
Physical Properties

Example	Description	Length (in.)	Dia. (in.)	Volume particle	Surface particle	$\frac{V_p}{Sp}$ (in.) ²	Pore Volume (PV) (cc/g)	Apparent Bulk Density (ABD) g/cc	Compacted Bulk Density (CBD) g/cc	Crush Strength (CS) lbs.	(CS/L) lbs./in.
				Geometric Volume (Vp) (in.) ³	Geometric Surface (Sp) (in.) ²						
A	1/16" inch Cylinder	.142	.053	.000316	.0282	.0112	.50	.71	.76	12.3	93
1	Dumbbell	.177	—	.000838	.0704	.0119	.50	.60	—	—	—
2	3 Leaf Clover	.180	—	.000933	.0695	.0134	.51	.70	.74	23.3	174
B	1/8" Cylinder	.201	.115	.00209	.0934	.0224	.51	.74	.78	27.7	223

Examples 3—6.

Additional extrudates were prepared following the procedure of Examples 1 and 2, except that the content of promoter materials was adjusted to provide 6% CoO and 12% MoO₃ by weight based on the weight of the catalyst composition. The extrudates were tested in two series using the following described Gas Oil Test for desulfurization and denitrogenation.

Gas Oil Test

Gas Oil Description

Gravity = 23.3° API
Boiling Range = 490—847°F.
Sulfur Content = 1.0%
Basic Nitrogen Content = 515 ppm

The catalyst was charged into the reactor on a volume basis. Two 25 cc. catalyst beds were used in series. Each of these beds was diluted with glass beads to a total of 100 cc. The beds were separated by a glass wool plug. The catalyst was then presulfided as follows:

1. The reactor was heated to 600°F. in flowing nitrogen at atmospheric pressure.
2. At 600°F. the nitrogen was stopped and a mixture of 90% H₂ and 10% H₂S by volume was passed over the catalyst at 0.85 SCF/hr. for 30 minutes.
3. The reactor temperature was then raised to 700°F. and held for 2 hours with H₂/H₂S mixture as in 2 above.
4. After 2 hours the reactor temperature was reduced to 450°F. with H₂/H₂S flowing. This completed the presulfiding.
- Processing was then carried out under the following conditions:

Temperature — 650 and 725°F.
Pressure — 750 psig
Space Velocity — 2LHSV
Hydrogen Recycle Rate — 6000 SCF/Bbl

Three samples were collected at each temperature. These samples were scrubbed with nitrogen and then a portion was analyzed for basic nitrogen by U.O.P. method 269—59. The remaining portion of the sample was washed with distilled water three times, then analyzed for sulfur by the Dohrmann Method.

In Table III set forth below activity results for these catalysts are shown. Equal volumes of the catalysts are charged and both sulfur and nitrogen removals are measured at two temperatures as described above. Calculations have shown that at both 650°F. and 725°F., the reactor operates in the "trickle" phase (hydrocarbon exists as both liquid and vapor). In Series I (Catalysts C, D, 3 and 4) the catalysts were muffle calcined in a common batch. In Series II (Catalysts E, 5, and 6) the catalysts were muffle calcined in a common

batches. Activity results are given in terms of percentage removals and relative activities on both a weight and volume basis.

In Series I both the relative weight and volume sulfur activities of the shaped particles of the invention are greater than the 1/16 inch cylinder. In Series II, with the exception of one data point which is not believed to be statistically significant, a similar advantage for sulfur removal is evident. Although the two series do not agree exactly (possible due to differences in the method of calcination) their average results show that the shaped particles have more sulfur removal activity on both a weight and volume basis.

In Table IV there are given for Examples 3 and 4 certain physical properties of the catalysts. The void fraction, catalytic surface area and pore size distribution characteristics also met the requirements hereinabove identified. The significant dimension in terms of generalized particle size is the V_p/S_p ratio. This ratio shows that the order of increasing size is:

1/16" cyl. < dumbbell < 3-leaf clover < 1/8" cyl. With respect to reactions wherein diffusion into catalyst particles is important, the relative activities should increase with decreasing ratios of V_p/S_p . The Gas Oil Test results, however, show an unexpected advantage for shaped particles, that is their activity is greater than that attributable to their ratio of V_p/S_p . If another mode of action such as bulk mass transfer is affecting activity, then the Gas Oil Test results would be expected to correlate with total geometric surface (total surface in Table IV). However, no such correlation is evident and again an unexpected advantage arises for shaped particles. The ABD (Apparent Bulk Density) values show that the dumbbells pack much more loosely than do the other particles.

In Figure 1 of the accompanying drawings, the average relative volume activities are plotted versus particle size as expressed by the ratio of V_p/S_p . The straight line shown in the diffusion curve obtained from the two cylinder sizes and agrees well with theory. The activity values for both the dumbbell and the 3-leaf clover are well above this curve, a highly unexpected result. The dumbbell-shaped catalyst particle is not as active as that of the 3-leaf clover shape on this volume basis but this is felt to be due at least in part to its lower apparent bulk density (ABD).

A similar graph for weight activities is shown in Figure 2. Both shapes are responsible for activities which are significantly above the diffusion curve and of approximately the same value. Again the results are highly unexpected.

Finally, in Table V data are given for pressure drop for the shaped particles of the invention (Examples 5 and 6) compared to the 1/16 inch cylinders. The catalysts of Examples 5 and 6 both had all the properties de-

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5 fined above for use in the invention. Both absolute and relative pressure drops as a function of flow rate are given. In this test 50 cc. of catalyst are loaded into a tube and the pressure drop from flowing air is measured. Both shaped particles of this invention show about the same pressure drops and a considerable advantage compared to the 1/16 inch cylinder (about 40% lower at the more important flow condition). For the dumbbell, the lower pressure drop is a direct result of its low ABD. For the 3-leaf clover, the lower pressure drop is a result of its increased size (V_p/S_p) and slightly lower ABD.

Example 7.

Using the same catalyst material as was used in Examples 3 and 4 and the same test, additional catalyst particles in accordance with this invention were prepared. The catalyst particles were rotary calcined as were the Series II catalysts in Table III. Results are given in Tables VI and VII.

Example F.

The procedure of Example 7 is followed except for catalyst cross-sectional shape. Results are given in Tables VI and VII.

TABLE III
Gas Oil Test Activity Results

Catalyst	Description	% Removals				Volume Basis				Weight Basis			
		Sulfur		Nitrogen		Sulfur		Nitrogen		Sulfur		Nitrogen	
		650F	725F	650F	725F	650F	725F	650F	725F	650F	725F	650F	725F
<u>SERIES I</u>													
<u>Example</u>													
C	1/16" Cylinder	85.6	97.5	0	30.6	100	100	100	100	100	100	100	100
3	Dumbbell	86.8	98.1	0	25.2	111	133	130	133	79	130	159	93
4	3 Leaf Clover	86.3	97.8	1.6	33.2	106	114	109	114	110	109	117	—
D	1/8" Cylinder	71.6	95.2	—	—	42	51	41	51	—	41	49	—
<u>SERIES II</u>													
<u>Example</u>													
E	1/16" Cylinder	82.2	97.6	—	—	100	100	100	100	—	100	100	—
5	Dumbbell	85.8	97.2	—	—	131	85	159	85	—	159	103	—
6	3 Leaf Clover	88.2	98.5	—	—	162	161	164	161	—	164	163	—
<u>AVERAGE I & II</u>													
	1/16" Cylinder	—	—	—	—	100	100	100	100	—	100	100	—
	Dumbbell	—	—	—	—	121	109	145	109	—	145	131	—
	3 Leaf Clover	—	—	—	—	134	137	137	137	—	137	140	—
	1/8" Cylinder	—	—	—	—	42	51	41	51	—	41	49	—

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TABLE IV

Physical Properties

Example	Catalyst Description	Length (in)	Dia. (in)	Volume		Vp/Sp (in)	Total Surface area (in) ²	PV cc/g	AED g/cc	CBD g/cc	CS lbs.	CS/L lbs./in.
				Particle Vp ₃ (in)	Surface Particle Sp ₃ (in)							
C	1/16" Cylinder	0.216	0.052	0.00046	0.0398	0.0117	178	0.55	0.66	0.72	21.5	172
3	Dumbbell	0.202	—	0.00096	0.0798	0.0121	124	0.56	0.57	0.60	—	—
4	3 Leaf Clover	0.212	—	0.00111	0.0782	0.0142	128	0.57	0.65	0.69	31.3	250
D	1/8" Cylinder	0.225	0.123	0.00262	0.1084	0.0241	—	.57	.67	.73	29	232

TABLE V

Pressure Drop

Nominal Air Flow SCFM	C					
	1/16" Cylinder			3 Leaf Clover		
	ΔP "H ₂ O	Relative ΔP , %	ΔP "H ₂ O	Relative ΔP , %	ΔP "H ₂ O	Relative ΔP , %
0 ⁺	1.5	100	0.94	61	0.98	64
1	4.0	100	2.6	64	2.6	64
2	15.7	100	11.2	71	11.1	71
3	36.4	100	27.0	75	26.3	72

TABLE VI
Gas Oil Test Activity Results

Example	Catalyst Description	% Sulfur Removal 650F	% Relative Activities			Vp/Sp in.	Concavity C
			Volume 650F	Weight 725F	Weight 650F		
7	Figure Eight	86.2	117	112	120	.0139	1.04
F	Flat Plate	85.3	110	78	104	.0154	1.00

TABLE VII

Physical Properties

Example	Description	Length (in.)	Dia. (in.)	Vp (in) ³	Sp (in) ²	Vp/Sp in.	PV cc/g	ABD g/cc	CBD g/cc	CS lbs.	CS/L lbs./in.
7	Figure Eight (Fig. 1 Drawings)	.181	—	.000756	.0544	.0139	.55	.64	.71	52	415
F	Flat Plate (Fig. 5 Drawings)	.187	—	.000874	.0567	.0154	.56	.68	.72	57	455

In Examples 7 and F above, the shapes studied were a figure eight with a small amount of concavity, $C = 1.04$, and a flat plate which is convex $C = 1.00$, but with a non-circular cross-section and not of the present invention. These results are shown in Table VI. The average results from catalyst A and Catalyst B were used to calculate the relative activities in Table VI. To simplify the data interpretation the average relative weight activities (650°F. and 725°F.) is plotted as a function of particle size in Figure 4. In general those particles with a concavity index, C , equal to 1.00 fall on the diffusion curve. The figure eight with $C = 1.04$ falls above the diffusion curve but not as high as those with $C = 1.10$ or greater. These data tend to support the hypothesis that C must be greater than 1.00. Figure 4 demonstrates that. Preferably, C should be in the neighborhood of 1.10.

It will be apparent that the above described invention and parameters relates to freshly prepared catalyst particles of unique size and shape and does not contemplate conventional catalyst shapes and size having imperfections therein of the type that may be described as knicks, chips, abrasions, bends and the like.

WHAT WE CLAIM IS:—

1. A process for hydrotreating a petroleum distillate, which process comprises contacting said distillate in the presence of hydrogen at a hydrogen flow rate of 100 to 10,000 standard cubic feet per barrel of distillate, a liquid hourly space velocity of 0.5 to 25 reciprocal hour, a temperature in the range of 500° to 800°F., and a total pressure in the range of 100 to 3,000 pounds per square inch gauge; with porous but non-hollow catalyst particles of a polylobal cross-sectional shape characterized by a concavity index (as herein defined) of greater than 1.0, a void fraction (as herein defined) in the range of 0.25 to 0.60, and when containing more than two lobes at least 15% of the points within said particles being greater than 0.015 inch from the particle surface; said particles each having a ratio of geometric volume to geometric surface in the range of 0.001 to 0.042 inch; a catalytic surface area greater than 100 square meters per gram, as measured by the method herein defined; and a catalytic pore volume of from 0.35 to 0.85 cubic centimeters per gram, said pore volume resulting from a major portion of pores of diameter in the range of 40 to 90 angstrom units when measured with mercury up to 50,000 pounds per square inch absolute pressure and a contact angle of 140°, and a composition comprising a major portion by weight of alumina, from 5 to 25 weight per-

cent of molybdenum oxide and from 1 to 8 weight percent of an oxide selected from cobalt and nickel oxides and mixtures thereof.

2. A process according to claim 1, wherein said concavity index is from 1.05 to 1.15.

3. A process according to claim 1 or claim 2, wherein said void fraction is from 0.35 to 0.50.

4. A process according to any preceding claim, wherein said ratio of geometric volume to geometric surface area is from 0.005 to 0.025 inch.

5. A process according to any preceding claim, wherein said catalytic surface area is from 250 to 350 square meters per gram.

6. A process according to any preceding claim, wherein said catalyst particle is of three-leaf clover cross-sectional shape.

7. A process according to any one of claims 1 to 5, wherein said catalyst particle is of dumbbell cross-sectional shape.

8. A process according to any preceding claim, wherein the hydrogen flow rate is 200—2,000 standard cubic feet per barrel of distillate.

9. A process according to any preceding claim, wherein the liquid hourly space velocity is 2 reciprocal hours.

10. A process according to any preceding claim, wherein the temperature is 650°F.

11. A process according to any one of claims 1 to 9, wherein the temperature is 725°F.

12. A process according to any preceding claim, wherein the total pressure is 750 pounds per square inch gauge.

13. A process according to any one of claims 1 to 5, wherein the hydrogen flow rate is 6,000 standard cubic feet per barrel of distillate, the liquid hourly space velocity is 2 reciprocal hours, the temperature is 625°F., and the total pressure is 750 pounds per square inch gauge.

14. A process according to any one of claims 1 to 5, wherein the hydrogen flow rate is 6,000 standard cubic feet per barrel of distillate, the liquid hourly space velocity is 2 reciprocal hours, the temperature is 725°F., and the total pressure is 750 pounds per square inch gauge.

15. A process for hydrotreating a petroleum distillate, according to claim 1 and substantially as described in any one of the Examples herein.

16. A product of a hydrotreating process according to any preceding claim.

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