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(54) Title: COBALT CATALYSTS

(57) Abstract: A process for preparing a cobalt based catalyst precursor includes, in a support impregnation stage, impregnating a coated catalyst support comprising porous catalyst support particles coated with carbon, with a cobalt salt, and partially drying the impregnated support. Thereafter, in a calcination stage, the partially dried impregnated support is calcined, to obtain the cobalt based catalyst precursor. The cobalt based catalyst precursor can then, in a reduction stage, be reduced to obtain a cobalt based Fischer-Tropsch catalyst.

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COBALT CATALYSTS

10 THIS INVENTION relates to cobalt catalysts. In particular, the invention relates to a process for preparing a precursor of a cobalt based Fischer-Tropsch catalyst, to a process for preparing such a cobalt catalyst, and to a process for producing hydrocarbons using such a cobalt catalyst.

15 The Applicant is aware of known processes for preparing cobalt based catalyst precursors and which involve slurry phase impregnation of a catalyst support with a cobalt salt, drying of the impregnated catalyst support, and calcination of the dried impregnated catalyst support, to achieve a desired cobalt loading of the support. The resultant precursors
20 are then activated by reduction thereof, to obtain cobalt based Fischer-Tropsch catalysts. These catalysts can display good intrinsic activities when used for Fischer-Tropsch synthesis; however, catalysts having enhanced or superior intrinsic activities cannot readily be obtained using the known processes. It is thus an object of the present invention to
25 provide a cobalt based Fischer-Tropsch catalyst having enhanced initial and/or stabilized intrinsic Fischer-Tropsch synthesis activity, as well as a process for preparing such a catalyst.

According to a first aspect of the invention, there is provided a process
30 for preparing a cobalt based catalyst precursor, which process includes

in a support impregnation stage, impregnating a coated catalyst support comprising porous catalyst support particles coated with carbon, with a cobalt salt, and partially drying the impregnated support; and

in a calcination stage, calcining the partially dried impregnated support, to obtain the cobalt based catalyst precursor.

The resultant cobalt based catalyst precursor will, in practice, be reduced to obtain a cobalt based Fischer-Tropsch catalyst. It was surprisingly found that this catalyst has enhanced or superior initial as well as stabilized intrinsic Fischer-Tropsch synthesis activity.

Thus, according to a second aspect of the invention, there is provided a process for preparing a cobalt based Fischer-Tropsch catalyst, which process includes

in a support impregnation stage, impregnating a coated catalyst support comprising porous catalyst support particles coated with carbon, with a cobalt salt, and partially drying the impregnated support;

in a calcination stage, calcining the partially dried impregnated support, to obtain a cobalt based catalyst precursor; and

in a reduction stage, reducing the cobalt based catalyst precursor to obtain the cobalt based Fischer-Tropsch catalyst.

If a higher cobalt loading is required, then a second, or even a third, impregnation, drying and calcination step may thereafter be carried out after the first impregnation, drying and calcination step hereinbefore described.

In this specification, unless explicitly otherwise stated, where reference is made to catalyst mass, the mass given pertains to the calcined

catalyst mass, ie the catalyst mass before any reduction of the catalyst is effective.

The cobalt salt may, in particular, be cobalt nitrate, $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$.

5

The carbon coated catalyst support may be any commercially available porous oxidic catalyst support, such as alumina (Al_2O_3), silica (SiO_2), a silica alumina ($\text{SiO}_2 \cdot \text{Al}_2\text{O}_3$), titania (TiO_2) and magnesia (MgO), coated with carbon.

10

The support may be a protected modified catalyst support, containing, for example, silicon as a modifying component, as described in WO 99/42214 and which is hence incorporated herein by reference.

15 The processes according to the first and second aspects may, if necessary, include preparing the carbon coated catalyst support, ie they may include modifying the porous catalyst support particles by coating them with carbon.

20 In principle, the coating of the catalyst support particles can then be effected by any suitable method. For example, the carbon coated catalyst support may be prepared by coating pre-shaped spherical porous catalyst support particles with a uniform carbon based layer in accordance with the method as described in EP 0681868, which is
25 hence incorporated herein by reference.

It is to be appreciated that the maximum amount of carbon that can be used as an effective coating is determined by the influence of the carbon coating on the pore volume of the original catalyst support, as the pore
30 volume of the catalyst support determines how much cobalt can be

impregnated into the catalyst support. This is particularly important when catalysts with a relatively high cobalt loading are required. Similarly, the minimum amount of carbon that can be used as an effective coating is determined by the minimum level of carbon that still provides the required positive effect on the stabilized intrinsic Fischer-Tropsch synthesis performance of the resultant cobalt catalyst. Thus, the maximum level of carbon may be 40g C/100g support, preferably 20g C/100g support, and more preferably 10g C/100g support, while the minimum level of carbon may be 0.1g C/100g support, preferably 0.5g C/100g support, and more preferably 1.2g C/100g support.

The support impregnation with the cobalt salt may, in principle, be effected by any known impregnation method, eg incipient wetness impregnation, or slurry phase impregnation. Similarly, the calcination may be performed in any known calcination unit, eg fluidized bed, fixed bed, furnace, rotary kiln, and/or torbed calciner, preferably at temperatures between 150°C and 300°C. In particular, the calcination may be in accordance with that described in PCT/IB00/01745, and which is thus incorporated herein by reference. The calcination may thus involve fluidized bed calcination as described in PCT/IB00/01745.

The cobalt catalyst precursor may be obtained by a 2-step slurry phase impregnation, drying and calcination process. The 2-step process may include, in a first step, impregnating the carbon coated catalyst support with the cobalt salt, partially drying the impregnated support, and calcining the partially dried support, to obtain a calcined material, and thereafter, in a second step, impregnating the calcined material with the cobalt salt, partially drying the impregnated material, and calcining the partially dried material, to obtain the catalyst precursor.

The support impregnation with the cobalt salt, the drying and the calcination may, in particular, be in accordance with the process described in our copending WO 00/20116, which is thus incorporated herein by reference.

5

The support impregnation and drying may typically be effected in a conical vacuum drier with a rotating screw or in a tumbling vacuum drier.

The catalyst precursor may contain between 5gCo/100g support and
10 70g Co/100g support, preferably between 20gCo/100g support and 50g Co/100g support.

During either or both of the slurry phase impregnation steps, a water
soluble precursor salt of palladium (Pd) or platinum (Pt) or a mixture of
15 such salts may be added, as a dopant capable of enhancing the reducibility of the cobalt. Preferably, the dopant is added in a mass proportion of the palladium metal, the platinum metal or the mixture of palladium and platinum metals to the cobalt metal of between 0,01:100 to 0,3:100.

20

The invention extends also to a cobalt catalyst, when produced by the process of the second aspect of the invention, and to a cobalt catalyst precursor, when produced by the process of the first aspect of the invention.

25

According to a third aspect of the invention, there is provided a process for producing hydrocarbons, which includes contacting synthesis gas comprising hydrogen (H₂) and carbon monoxide (CO) at an elevated temperature between 180°C and 250°C and an elevated pressure
30 between 1 and 40 bar with a cobalt catalyst according to the invention,

in a slurry phase Fischer-Tropsch reaction of the hydrogen with the carbon monoxide, to obtain hydrocarbons.

The invention extends also to hydrocarbons when produced by the
5 process as hereinbefore described.

The invention will now be described in more detail with reference to the following non-limiting examples and with reference to the accompanying
10 drawing.

In the drawing,

FIGURE 1 shows the influence of carbon levels on the pore volume of the carbon-coated catalyst support.

15 EXAMPLE 1

Catalyst B (30g Co/100g Al₂O₃) (not in accordance with the invention)

Preparation

A Pt promoted catalyst was prepared on SASOL Germany GmbH's trademark product: Puralox SCCa 5/150, as a selected pre-shaped Al₂O₃
20 support, in accordance with the method of aqueous slurry phase impregnation and vacuum drying, followed by direct fluidized bed calcination, in accordance with Catalyst Example 1 of WO 00/20116, or one of Catalysts D, E, G or H of PCT/IB00/01745.

25 In preparation for laboratory scale slurry phase continuous stirred tank reactor ('CSTR') Fischer-Tropsch synthesis runs, this calcined material was reduced and wax coated in accordance with the following procedure:

27,5g of the catalyst was reduced at 1 bar pure H₂ (space velocity \geq 200mℓ_n H₂/g catalyst/h) whilst the temperature was increased from 25°C to 380°C-425°C at a rate of 1°C/min whereafter the temperature was kept constant at this temperature of 380°C-425°C for 16 hours.

5

The reduced catalyst was allowed to cool down to room temperature at which stage the hydrogen was replaced by argon, and the catalyst unloaded in molten Fischer-Tropsch wax under the protection of an argon blanket. This wax coated catalyst was then transferred to the slurry reactor.

10

CSTR Fischer-Tropsch synthesis run

An extended slurry phase CSTR Fischer-Tropsch synthesis run (number 106F) was performed on catalyst B. This run lasted about ('ca') 90 days, during which the following synthesis conditions were maintained:

15

Reactor temperature	:	220,5°C
Reactor pressure	:	20,3 bar
Catalyst inventory	:	20,8g
(H ₂ + CO) space velocity	:	2169mℓ _n /(g catalyst.h)
APG space velocity	:	2452mℓ _n /(g catalyst.h),

20

where 'APG' is an acronym for Arge Pure Gas, ie the commercial synthesis gas produced at Schümann-Sasol (Pty) Limited in Sasolburg, South Africa, according to the method of coal gasification, followed by Rectisol (trademark) purification.

25

Feed gas composition:

H ₂	:	49,1 vol%
CO	:	25,9 vol%

30

CH₄ : 9,3 vol%
 CO₂ : 0,5 vol%
 Ar : 15,2 vol%

- 5 The observed synthesis performance data of this run (i.e. 106F) is presented in Table 1.

Relative (Fischer-Tropsch) Intrinsic Activity Factor ('R.I.A.F.') is defined as follows:

10

Consider an arbitrary slurry phase cobalt Fischer-Tropsch catalyst, displaying the following observed synthesis performance in a CSTR:

15 $r_{FT} = Z$ moles CO converted to Fischer-Tropsch products per gram catalyst per second, observed at $T = \gamma$ Kelvin, at the following set of reactor partial pressures:

$$P_{H_2} = \nu \text{ bar}$$

$$P_{CO} = \tau \text{ bar}$$

then the definition of R.I.A.F. is as follows:

20
$$R.I.A.F = [Z (1 + 1.82 \tau)^2] / [49480.9e^{(-11113.4/\gamma)} \nu \tau]$$

Initial intrinsic Fischer-Tropsch activity (a_i) of a slurry phase cobalt based catalyst is defined as follows:

25 $a_i =$ the R.I.A.F. after 15 hours on stream (ie $t_i =$ time initial) of continuous exposure to the following set of gradientless slurry phase synthesis conditions:

220°C, 20 bar, %(H₂ + CO) conversion in excess of 50%,
 obtained with a feed gas of composition: ca 50 vol% H₂ and

ca 25 vol% CO, the balance consisting of Ar, N₂, CH₄ and/or CO₂.

Catalyst C (C239) (40g Co/100g Al₂O₃) (not in accordance with the invention)

5 Preparation

Catalyst C was prepared in a similar manner as catalyst B. The only difference was that catalyst C was prepared by three consecutive impregnation / drying / calcination steps and catalyst B by two steps. This was done to increase the cobalt loading from 30 to 40g/100gAl₂O₃.

10

Catalyst C was also tested for Fischer-Tropsch synthesis (run 293F) performance and the results are presented in Table 1.

TABLE 1

Catalyst	C	B
<u>Catalyst characteristics:</u>		
Composition	40gCo/0,100gPt/ 100gAl ₂ O ₃	30gCo/0,075gPt/ 100gAl ₂ O ₃
<u>Synthesis performance data:</u>		
Run analysis number	293F	106F
Time on stream (hours)	15	15,5
%(H ₂ + CO) conversion	65	73
Reactor partial pressures:		
H ₂ (bar)	5,3	3,7
CO (bar)	2,8	2,4
H ₂ O (bar)	4,7	5,0
CO ₂ (bar)	0,4	0,3
Initial Relative Intrinsic (Fischer-Tropsch) Activity Factor (i.e.: $a_i = \text{R.I.A.F. at } t_i$)	3,5	2,7

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EXAMPLE 2

EXAMPLES OF Al₂O₃ SUPPORTED COBALT SLURRY PHASE CATALYST
SAMPLES IN ACCORDANCE WITH THE INVENTION (CATALYSTS E, K,
L) THAT DISPLAYED ENHANCED INITIAL INTRINSIC FISCHER-TROPSCH
ACTIVITIES

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Catalyst E (40gCo/0.100gPt/100gAl₂O₃)

Preparation

SASOL Germany GmbH's trademark product: Puralox SCCa 5/150 (ie a
pre-shaped spherical porous Al₂O₃ catalyst support material), was coated

15

with a uniform carbon based layer at KataLeuna GmbH Catalysts (Am Haupttor; D-06236 Leuna; Germany) in accordance with a method as described in EP 0681868, incorporated herein by reference. The result of this exercise was a 12,4gC/100gAl₂O₃ modified support.

5

A 40gCo/O,100gPt/100gAl₂O₃ slurry phase Fisher-Tropsch catalyst was prepared on this modified 12,4gC/100gAl₂O₃ pre-shaped support material in accordance with the method of aqueous slurry phase impregnation and vacuum drying, followed by direct fluidized bed calcination disclosed in
10 US 5733839, WO 99/42214 and WO 00/20116, incorporated herein by reference. In particular, catalyst E was prepared as follows:

34.1g Co(NO₃)₂.6H₂O was dissolved in 40ml distilled water and 0.0185g (NH₃)₄Pt(NO₃)₂ was dissolved in 10ml distilled water. These two
15 solutions were mixed together in a 500ml round ball flask in a rotavapor at 60°C and atmospheric pressure, and 50g of the 12.4g C/100g Al₂O₃ modified support was added. Aqueous slurry phase impregnation and vacuum drying was effected via the following procedure:

20

Temperature of oil bath (°C)	Rotavapor pressure (mbar)	Time (minutes)
60	Atmospheric	10
60	240	30
70	240	90
85	240	60
85	50	240

This vacuum dried intermediate product was directly subjected to a fluidized bed calcination step, having followed the following procedure:

- Continuous air flow of $1.7 \text{ dm}^3_{\text{n}}/\text{min}$
- 5 - Temperature program:
 $25^\circ\text{C} \xrightarrow{1^\circ\text{C}/\text{min}} 250^\circ\text{C} \xrightarrow{6\text{hours}} 250^\circ\text{C}$

50g of this intermediate calcined material was subjected to the following 2nd cobalt/platinum impregnation and calcination step:

10

- 34.1g $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ was dissolved in 40ml distilled water and 0.0189g $(\text{NH}_3)_4\text{Pt}(\text{NO}_3)_2$ was dissolved in 10ml distilled water. These two solutions were mixed together in a 500ml round ball flask in a rotavapor at 60°C and atmospheric pressure, and 50g of the ex 1st impregnated and calcined intermediate was added. Aqueous slurry phase impregnation and vacuum drying was effected in the same manner as during the 1st cobalt/platinum impregnation step. This vacuum dried intermediate product was directly subjected to a fluidized bed calcination step, having followed the following procedure:

- 20 - Continuous air flow of $1.7 \text{ dm}^3_{\text{n}}/\text{min}$
- Temperature program:
 $25^\circ\text{C} \xrightarrow{1^\circ\text{C}/\text{min}} 250^\circ\text{C} \xrightarrow{6\text{hours}} 250^\circ\text{C}$

- 50g of this intermediate calcined material was subjected to the following 3rd cobalt/platinum impregnation and calcination step:

25

- 25.4g $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ was dissolved in 40ml distilled water and 0.0446g $(\text{NH}_3)_4\text{Pt}(\text{NO}_3)_2$ was dissolved in 10ml distilled water. These two solutions were mixed together in a 500ml round ball flask in a rotavapor at 60°C and atmospheric pressure, and 50g of the ex 2nd impregnated

30

and calcined intermediate was added. Aqueous slurry phase impregnation and vacuum drying was effected in the same manner as during the 1st cobalt/platinum impregnation step. This vacuum dried intermediate product was directly subjected to a fluidized bed calcination step, having followed the following procedure:

- Continuous air flow of 1.7 dm³_n/min

- Temperature program:

25 °C $\xrightarrow{1^{\circ}\text{C/min}}$ 250 °C $\xrightarrow{6\text{hours}}$ 250 °C

10

A total of three consecutive impregnation steps were thus performed as dictated by the restrictions imposed by the pore volume of the solid materials.

15 In preparation for laboratory scale slurry phase CSTR Fischer-Tropsch synthesis runs, this calcined catalyst precursor was reduced externally at 350 °C. For this purpose 22,8g of the catalyst was reduced at 1 bar pure H₂ (space velocity of 2000ml_n/g catalyst.h), whilst the temperature was increased from 25 °C to 350 °C at a rate of 1 °C/min, where-after
20 the temperature was kept constant at 350 °C for 16 hours.

The reduced catalyst was allowed to cool down to room temperature where the hydrogen was replaced by argon and the catalyst was unloaded in molten wax under the protection of an argon blanket. This
25 wax coated catalyst was then transferred to the slurry synthesis reactor.

Catalyst K (C258) (30gCo/0.075gPt/1.5gSi/100gAl₂O₃)

Preparation

SASOL Germany GmbH's trademark product: Siralox 1.5 (i.e. a pre-
30 shaped spherical porous Al₂O₃ catalyst support material, containing

1.5m% SiO₂), was coated with a uniform carbon based layer at KataLeuna GmbH Catalysts (Am Haupttor; D-06236 Leuna; Germany) in accordance with the method as described in EP 0681868, which is incorporated herein by reference. The result of this exercise was a
5 12,4gC/100gAl₂O₃ modified support.

A 30gCo/0,075gPt/1.5gSi/100gAl₂O₃ slurry phase Fischer-Tropsch catalyst was prepared on this modified 12,4gC/1.5gSi/100gAl₂O₃ pre-shaped support material in accordance with the method of aqueous slurry
10 phase impregnation and vacuum drying, followed by direct fluidized bed calcination disclosed in US 5733839, WO 99/42214 and WO 00/20116, incorporated herein by reference.

Catalyst K was thus prepared in a similar manner to Catalyst E, the only
15 difference being the lower cobalt loading of catalyst K, i.e. 30 versus 40gCo/100gAl₂O₃, which was achieved in two impregnation/drying/calcination steps.

Catalyst L (C339) (30gCo/0.075gPt/1.5gSi/100gAl₂O₃)

20 Preparation

SASOL Germany GmbH's trademark product: Siralox 1.5 (i.e. a pre-shaped spherical porous Al₂O₃ catalyst support material, containing 1.5m% SiO₂), was coated with a uniform carbon based layer at KataLeuna GmbH Catalysts (Am Haupttor; D-06236 Leuna; Germany) in
25 accordance with a method as described in EP 0681868, incorporated herein by reference. The result of this exercise was a 1.2gC/100gAl₂O₃ modified support.

A 30gCo/0,075gPt/1.5gSi/100gAl₂O₃ slurry phase Fischer-Tropsch
30 catalyst was prepared on this modified 1.2gC/1.5gSi/100gAl₂O₃ pre-

shaped support material in accordance with the method of aqueous slurry phase impregnation and vacuum drying, followed by direct fluidized bed calcination disclosed in US 5733839, WO 99/42214 and WO 00/20116, incorporated herein by reference.

5

Catalyst L was thus prepared in a similar manner to Catalyst K, the only difference being the lower carbon loading of the support used for catalyst L, i.e. 1.2gC versus 12,4gC/100gAl₂O₃.

10 The pore volumes of the (carbon coated) catalyst supports used to prepare catalysts B, C, E, K, and L are presented in Figure 1 as a function of the amount of carbon on the catalyst support. It can be seen that the pore volumes of the catalyst supports decrease with increasing levels of carbon.

15

Catalysts E, K, and L were tested for their Fischer-Tropsch synthesis performance in a similar manner to that described in Example 1. The observed results are presented in Table 2.

TABLE 2

Catalyst	E	K	L
Catalyst characteristics:			
Composition	40gCo/0,100gPt/ 100gAl ₂ O ₃	30gCo/0,075gPt/ 1.5gSi/100gAl ₂ O ₃	30gCo/0,075gPt/ 1.5gSi/100gAl ₂ O ₃
<u>Synthesis performance data:</u>			
Run analysis number	45f	55f	97f
Time on stream (hours)	15	15	15
%(H₂ + CO) conversion	76	54	72
Reactor partial pressures:			
H ₂ (bar)	4,0	6.5	
CO (bar)	2,3	3.5	4,1
H ₂ O (bar)	5,9	3.8	2,0
CO ₂ (bar)	0,5	0.3	4,5
			0,4
Initial Relative Intrinsic (Fischer-Tropsch) Activity Factor (ie: a_i = R.I.A.F. at t_i)	5,6	4.3	4.0

5

The following conclusions can be drawn from Tables 1 and 2:

Catalyst E, ie 40gCo/0.100gPt/100gAl₂O₃ prepared on an alumina support coated with carbon, displayed an initial RIAF of 5,6, which is significantly higher than the initial RIAF of 3,5 of catalyst C, i.e. 40gCo/0.100gPt/100gAl₂O₃ prepared on an alumina support without carbon coating.

Catalysts K and L, i.e. both 30gCo/0.075gPt/100g support and both prepared on an carbon coated alumina support, displayed significantly higher initial RIAF's, ie 4,3 and 4,0 respectively, than the initial RIAF of 2.7 of catalyst B, ie 30gCo/0.075gPt/100gAl₂O₃ prepared on an alumina support without carbon coating.

In this invention it was thus surprisingly found that cobalt based Fischer-Tropsch synthesis catalysts displayed an increased intrinsic catalytic performance when these catalysts were prepared on supports which were carbon coated prior to the deposition of the active cobalt phase onto and into the support during the impregnation/drying step.

CLAIMS

5 1. A process for preparing a cobalt based catalyst precursor, which process includes

in a support impregnation stage, impregnating a coated catalyst support comprising porous catalyst support particles coated with carbon, with a cobalt salt, and partially drying the impregnated support; and

10 in a calcination stage, calcining the partially dried impregnated support, to obtain the cobalt based catalyst precursor.

2. A process for preparing a cobalt based Fischer-Tropsch catalyst, which process includes

15 in a support impregnation stage, impregnating a coated catalyst support comprising porous catalyst support particles coated with carbon, with a cobalt salt, and partially drying the impregnated support;

in a calcination stage, calcining the partially dried impregnated support, to obtain a cobalt based catalyst precursor; and

20 in a reduction stage, reducing the cobalt based catalyst precursor to obtain the cobalt based Fischer-Tropsch catalyst.

3. A process according to Claim 1 or Claim 2, wherein the amount of carbon present on the support is from 0.1g carbon/100g support to 40g carbon/100g support.

4. A process according to Claim 3, wherein the amount of carbon present on the support is from 0.5g carbon/100g support to 20g carbon/100g support.

30

5. A process according to any one of Claims 1 to 4 inclusive, wherein the cobalt salt is cobalt nitrate, and wherein the porous catalyst support particles are alumina, silica, silica-alumina, titania or magnesia particles.

5

6. A process according to any one of Claims 1 to 5 inclusive, wherein the support is a protected modified catalyst support containing silicon as a modifying component.

10 7. A process according to any one of Claims 1 to 6 inclusive, wherein the cobalt catalyst precursor is obtained by a 2-step slurry phase impregnation, drying and calcination process which includes, in a first step, impregnating the carbon coated catalyst support with the cobalt salt, partially drying the impregnated support, and calcining the partially
15 dried support, to obtain a calcined material, and thereafter, in a second step, impregnating the calcined material with the cobalt salt, partially drying the impregnated material, and calcining the partially dried material, to obtain the catalyst precursor.

20 8. A process according to Claim 7 wherein, during either or both of the two slurry phase impregnation steps, a water soluble precursor salt of palladium or platinum or a mixture of such salts is added, as a dopant capable of enhancing the reducibility of the cobalt.

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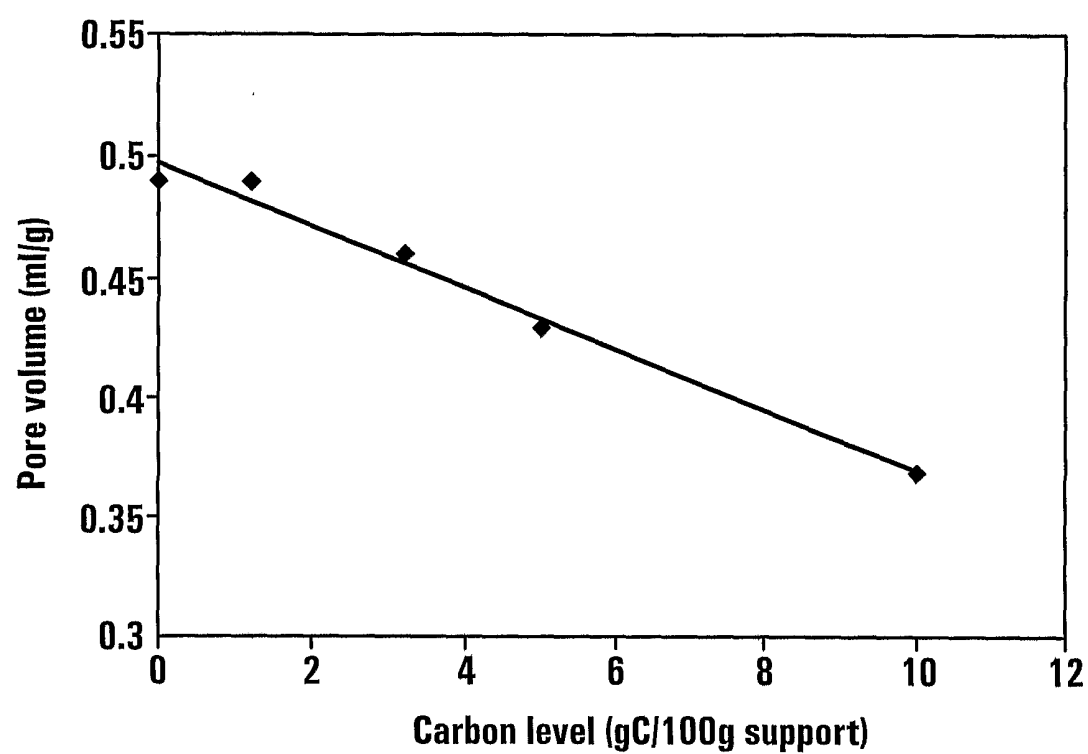


FIG 1