

HYDROGENOPYROLYSIS OF COAL AND COAL DERIVATIVES

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1. INTRODUCTION

Coal hydrolysis is now developing as one of the third generation processes for coal gasification or partial liquefaction. The advantages of coal hydrolysis are : rapid primary devolatilisation of the coal, with production of more volatile matter than what is determined by standard methods; desulfurization of the char; simultaneous hydrocracking of the primary tar. General reviews on the subject have been published recently (1)(2)(3)(4) Present paper deals with three aspects of fixed bed hydrolysis : the increased formation of methane and light monocyclic aromatics and phenols; the desulfurization process and yield, with regard to the composition of the mineral constituents of the coal; the mechanism of thermal cracking of hydro- and perhydrocyclic hydrocarbons.

2. POSTCRACKING OF THE PRIMARY VOLATILE MATTER

During pyrolysis of coal under H_2 pressure, the primary volatile matter are submitted to hydrocracking. This postcracking is shown by the variation, compared to what happens in inert atmosphere, of the methane concentration in the gas and of the light aromatics (B.T.X. : benzene, toluene and xylene) and phenols (P.C.X. : phenol, cresols and xylenols) in the liquid phase.

Experiments have been made with a 32,8% V.M. coal from Beringen, sized < 500 μm , between 480 and 850°C at a fixed H_2 pressure of 30 bar. One run was made with 30 bar He pressure at 580°C. Residence time of carrier gas was about 60 s. Yields in gas, oil, water and char are given in table I.

T (°C)	H_2					He
	485	580	650	780	850	580
Char	75.7	70.9	66.7	61.6	60.6	75.0
Oil	9.5	9.2	8.8	6.4	5.5	6.4
Gas	9.1	10.2	15.1	24.2	28.3	7.9
Water	4.4	6.9	8.9	10.1	9.2	4.7

Table I : Yields (% maf) (30 bar H_2 pressure)

Above 700°C, coal devolatilisation is higher than the volatile matter content, determined following standard methods.

Hydrogen pressure influence at 580°C between 1 and 50 bar has been studied on the same coal. Yields obtained are given in table II.

H ₂ pressure-bar	H ₂					He
	0	10	20	30	50	30
Char	76.6	72.4	70.6	70.9	69.0	75.0
Oil	7.4	10.3	9.8	9.2	8.9	6.4
Gas	5.3	10.0	10.3	10.2	9.9	7.9
Water	5.3	6.0	7.0	6.9	6.1	4.7

Table II : Yields (% maf) at 580°C.

Fig. 1 gives the variation of CH₄ and C₂H₆ content in the gas at 30 bar H₂ pressure compared with conventional carbonisation, as a function of temperature. CH₄ content increases from 45% at 500°C to 80% at 850°C. Under conventional atmospheric carbonisation the known reverse evolution occurs. CH₄ formation is due to hydrodealkylation of higher hydrocarbons.

The change in composition of B.T.X., P.C.X. and naphthalenes is given on fig. 2 as a function of carbonisation temperature. Light aromatics are steadily increasing. Phenols, on the contrary, are at their highest concentration in the low temperature oil. Phenols dehydroxylation occurs only above 700°C. Water content shows an increase parallel to the decrease of P.C.X. (phenol, cresols, xylenols) content. The speed of cresols disappearance is equal to the speed of their formation by dealkylation of the xylenols. Phenol increase is a result of both processes. The optimal phenol production is at about 750°C. The dehydroxylation of P.C.X. contributes to the B.T.X. increase between 600 and 800°C.

Naphthalenes yields are increasing with temperature as a result of known formation of di- and polycyclic aromatics from cracking fragments. Under hydrogen pressure these reactions are markedly slowed down but nevertheless still present.

Fig. 3 shows that, for the light aromatics, hydrogen pressure influence at 580°C is important between 1 and 20 bar. This is not the case for the phenols. Naphthalenes increase with the pressure from 1,2% at 1 bar to 3,6% at 50 bar.

3. DESULFURIZATION OF THE COAL DURING HYDROGENOPYROLYSIS

It is known that high temperature hydrolysis leads to partially desulfurized char. In this paper, this hydrodesulfurization was considered regarding the nature of the sulfurous minerals present in the coal. As an example a high S containing Italian coal was submitted to a fixed bed hydrocarbonisation at 30 bar H₂ pressure. Experiments were performed at 580°C, 700° and 850°C. Pyrite is reduced by H₂ to an extent depending mainly upon pyrolysis temperature. The reduction of pure pyrite and mixtures of pyrite and pitch coke under hydrogen pressure has been studied by thermogravimetry between 1 and 50 bar up to 950°C. It can be seen on fig. 4 that the first loss of S, corresponding to the conversion of FeS₂ to FeS_x (pyrrhotite) is complete around 500°C.

The reduction to Fe is only complete at much higher temperature. At 950°C, under 50 bar, total reduction is achieved within 10 minutes, whereas at 1 bar, it needs 40 minutes. The same behaviour is observed for pyrite in the coal. The higher the pyrolysis temperature is, the more important is the pyritic sulfur elimination.

Scanning electron microscopy photographs show the distribution of S, Ca and Fe in the coal and in the char. The pyritic sulfur

is well localised in the coal, whereas the organic sulfur is uniformly distributed in the bulk of the sample. The calcium content of this Italian coal is high, mostly as CaCO_3 but also some CaSO_4 (Fig.5).

In the char, after hydrogen treatment, it can be observed on Fig.6 that FeS_2 has been reduced. At low temperature, reduction is limited to pyrrhotite (FeS_x), at high temperature, to iron. But where Ca is detected it is associated with S, probably in the form of CaS and some unreduced CaSO_4 . The experimental results are summarized in table III. They show in this case of a high calcium containing coal, that the higher the pyrolysis temperature is, the more sulfur remains in the char. It seems to be due to increased decomposition of CaCO_3 into CaO , which is more active to fix the volatile sulfur compounds. CaCO_3 from the ash would have the same effect under hydrocarbonisation conditions, as limestone or dolomite, added to coal, in combustion, as to reduce atmospheric SO_2 pollution. As a conclusion of this, it can be said that high calcium containing coals, will not be desulfurized in the same ratio as pyritic coals and that an increase of their hydrocarbonisation temperature will leave more sulfur in the char.

SULCIS COAL					
Proximate analysis		Ultimate analysis (Mf)			
Moisture	6,0	C	63,24	S, pyritic	0,83
Ash (Mf)	12,9	H	3,71	sulfate	0,05
Volatile Matter (% Maf)	56,4	O	14,11	organic	3,57
		N	1,77		
		S	4,45		
		Ash	12,9		
		Total	100,28	Total	4,45
HYDROGENOPYROLYSIS $p_{\text{H}_2} = 30 \text{ bar}$					
T°C		580	700	850	
Devolatilisation (% Maf)		51,6	61,1	61,9	
Gas		19,2	36,2	39,7	
Oil		14,8	10,3	8,2	
Water		16,4	18,8	14,1	
Char		48,4	38,9	38,1	
S balance in					
Char		34,1	35,6	41,9	
Oil		7,0	6,0	4,7	
Gas		59,1	58,4	53,4	

Table III : Sulcis coal and chars.

THERMAL CRACKING OF DI- AND POLYHYDROAROMATICS AT ATMOSPHERIC PRESSURE OF INERT GAS

In connection with the high content of hydropolyaromatic compounds present in coal liquids produced by several industrial processes, due to partial hydrogenation, the thermal cracking in inert gas

at atmospheric pressure of di- and polycyclic compounds, partially and totally hydrogenated was studied in view of their conversion to monocyclic aromatic hydrocarbons.

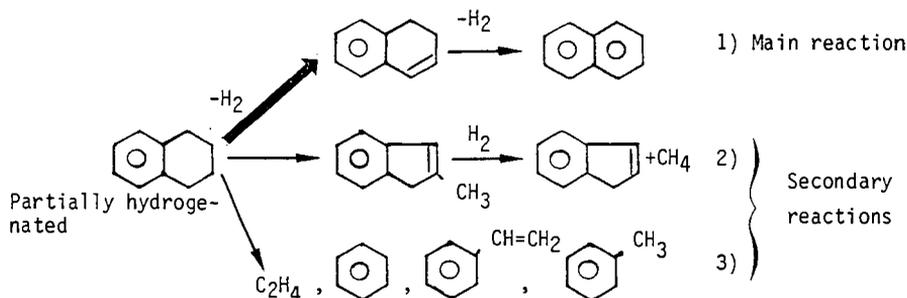
Korosi (5) has shown that steam cracking of decaline, with a steam to hydrocarbon ration of 16/1 at 854°C and nearly atmospheric pressure leads to 18 W% benzene and up to 19 W% C₂H₄ in the gas phase.

We made thermal cracking at atmospheric pressure in inert gas and without any catalyst of the following di- and polycyclic compounds:

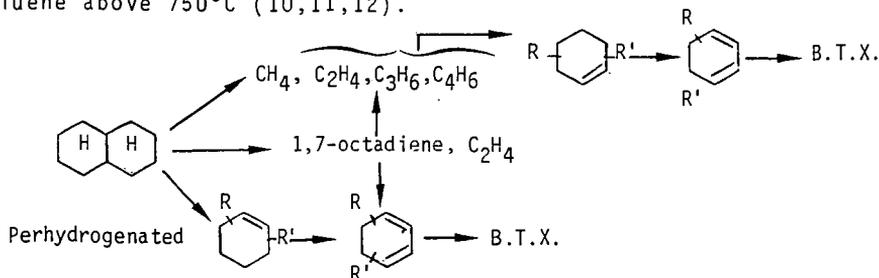
1,2-dihydronaphthalene, 1,2,3,4-tetrahydronaphthalene (tetraline), decahydronaphthalene (decaline), 1- and 2-naphtols, 1,2,3,4-tetrahydro-1-naphtol, 5,6,7,8-tetrahydro-1-naphtol, cisdecahydro-1-naphtol, perhydroindane, perhydrofluorene, perhydropyrene, 9,10-dihydrophenanthrene, 1,2,3,4,5,6,7,8-octahydrophenanthrene, perhydrophenanthrene and phenanthrene.

The experimental devices and results of some of those studies were already published (6,7,8,9).

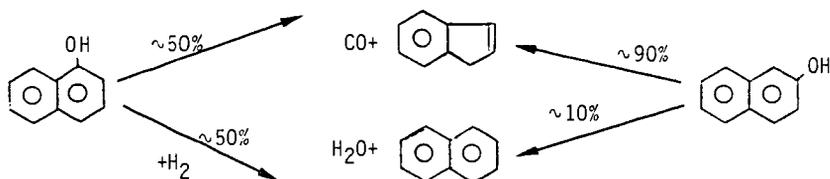
Comparison between B.T.X. and ethylene yields obtained by thermal cracking of tetraline and decaline is given in fig.7. It was demonstrated that cracking mechanism of partially hydrogenated naphthalene is completely different of what happens with decaline. In the first case the main cracking reaction is dehydrogenation leading back to naphthalene (Equation 1). Two other pathways, less important, occur at the same time. They can explain the formation of indene and of the small amounts of monocyclic aromatic (Eq. 2 and 3).



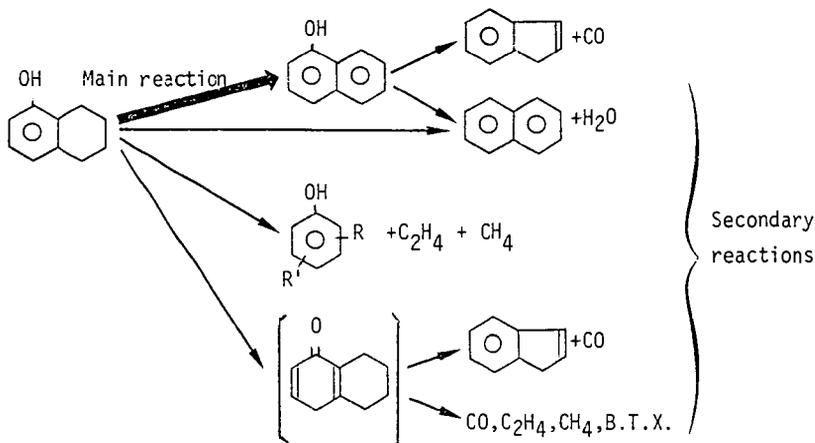
For the perhydrocompounds, on the contrary, the main reaction is the opening of one or two cycles with formation of alkylmonocyclic compounds whose subsequent dehydrogenation gives the corresponding aromatics. At the same time, C₂H₄ and H₂ are the major constituents of the gas phase. Smaller amounts of 1,3-C₄H₆, 1,7-octadiene, C₃H₆ and C₄H₈ are also observed. It was shown in previous work that the light olefines react to give benzene and toluene above 750°C (10,11,12).



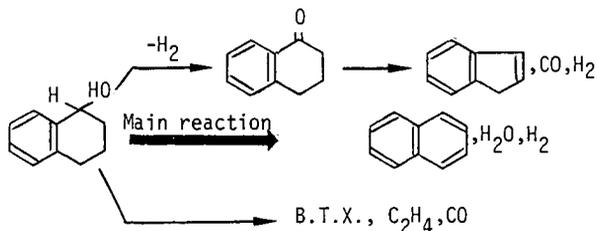
The influence of an hydroxyl group on thermal behaviour of dicyclic compounds was studied by cracking the naphthols, the tetrahydronaphthols and decahydro-1-naphthol. Results obtained show that two cracking mechanisms can be considered for naphthols. The first one is decarbonylation, similar to what was demonstrated to happen with phenol (13). Indene is formed. The second one is a dehydroxylation leading to naphthalene. The hydroxyl group position has a relative importance on the contribution of both of them.



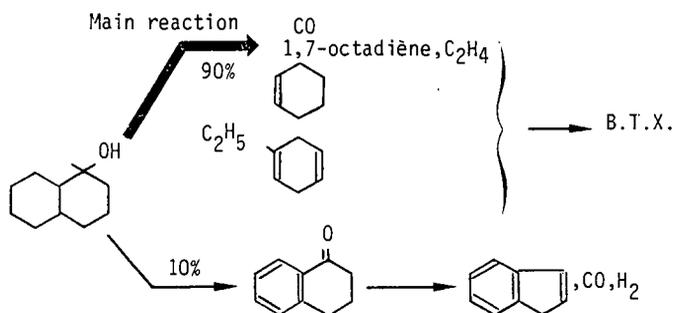
In the case of naphthol partially hydrogenated, the OH group can be located either on the aromatic ring or on the saturated one. Therefore, thermal cracking of 5,6,7,8-tetrahydro-1-naphthol and 1,2,3,4-tetrahydro-1-naphthol was performed. The main thermal degradation reaction was, in the first case, dehydrogenation into 1-naphthol, undergoing subsequently the above described reactions. B.T.X. and C₂H₄ production is low. Those different degradation pathways of 5,6,7,8-tetrahydro-1-naphthol can be summarized as follow :



Concerning 1,2,3,4-tetrahydro-1-naphthol, the main degradation reaction is a dehydroxylation with subsequent dehydrogenation into naphthalene. The presence of an hydroxyl group located on the saturated ring makes the rupture of the C-C bond easier, increasing the B.T.X. production. The different mechanisms are summarized as follow.



The main cracking reaction of decahydro-1-naphthol is similar to that of decahydro-naphthalene: C-C bond ruptures leading to olefines and cycloolefines, together, in this case, with CO elimination. The obtained olefines give easily B.T.X. A secondary reaction of partial dehydrogenation leading to indene formation occurs simultaneously and explains the lower B.T.X. yield compared with decahydronaphthalene.



Comparison between B.T.X. and ethylene yields obtained by thermal cracking of the hydrogenated naphthols is given in fig. 8.

It can be seen that the dicyclic perhydrocompounds lead to much higher B.T.X. yields than those of the partially hydrogenated products. The influence of the hydroxyl group is apparent when comparing tetrahydronaphthols and tetrahydronaphthalene. The B.T.X. yield of the two tetrahydronaphthols are higher than that of tetrahydronaphthalene. The hydroxyl position has also a marked effect. Located on the saturated ring, the B.T.X. yield is higher than when the OH group is on the aromatic ring.

Decahydronaphthol gives again higher B.T.X. yield but, due to a secondary dehydrodecarbonylation reaction, it reaches 24 W% against 34 W% for decahydronaphthalene.

As polycyclic model substances, phenanthrene and 3 hydrogenated derivatives (di-, octa- and perhydrophenanthrene), perhydrofluorene, perhydroindane and perhydropyrene have been cracked in the same conditions. Detailed results are available but not given in this paper for lack of time. The maximum yields of B.T.X. and ethylene are given for all of them in table IV.

It can be seen that all the perhydrocompounds give excellent yields of monocyclic aromatics and of ethylene, whereas the corresponding partially hydrogenated compounds show predominantly dehydrogenation, leading back to the aromatic starting hydrocarbon. The hydrogen saturation of all the polycyclic compounds mentioned, even in the case of pyrene with his 4 condensed aromatic rings, weakens the C-C bonds. It makes possible the rupture of the cycles, with light olefines production. Above 750°C, they contribute to an additional benzene formation as demonstrated in earlier work.

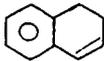
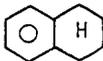
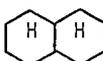
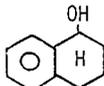
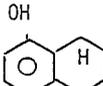
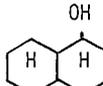
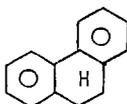
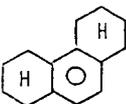
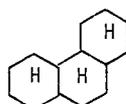
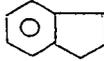
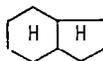
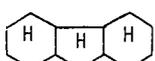
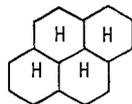
 B.T.X. 1,1 C ₂ H ₄ -	 3,8 2,9	 34,0 18,9
 B.T.X. 15,6 C ₂ H ₄ 2,6	 8,2 2,5	 23,9 17,6
 B.T.X. 1,3 C ₂ H ₄ 0,8	 1,3 3,6	 38,3 18
 B.T.X. - C ₂ H ₄ -	 33,6 ~ 15	 30,2 33
B.T.X. C ₂ H ₄	 27,3 17	

Table IV : Optimum B.T.X. and C₂H₄ yields (in W% of injected compounds) obtained by thermal cracking of di- and polyhydroaromatics.

As to show in which position of the starting molecule, cracking occurs first, polycyclic compounds labelled in specific position with ^{14}C and ^3H have been used. The radioactivity of the cracking products is measured by radiochromatography. Phenanthrene and perhydrophenanthrene are labelled in position 9 with ^3H , and in positions 9 and 10 with ^{14}C .

The radioactive ^3H or ^{14}C content in the cracking products is expressed as :

$$\frac{\text{molar specific activity of a given compound}}{\text{molar specific activity of the starting labelled compound}} \text{ in } \left(\frac{\text{mCi/mmole}}{\text{mCi/mmole}} \right)$$

Cracking of phenanthrene-9- ^3H and of phenanthrene-9,10- ^{14}C

Table V gives composition and tritium content of the cracking products.

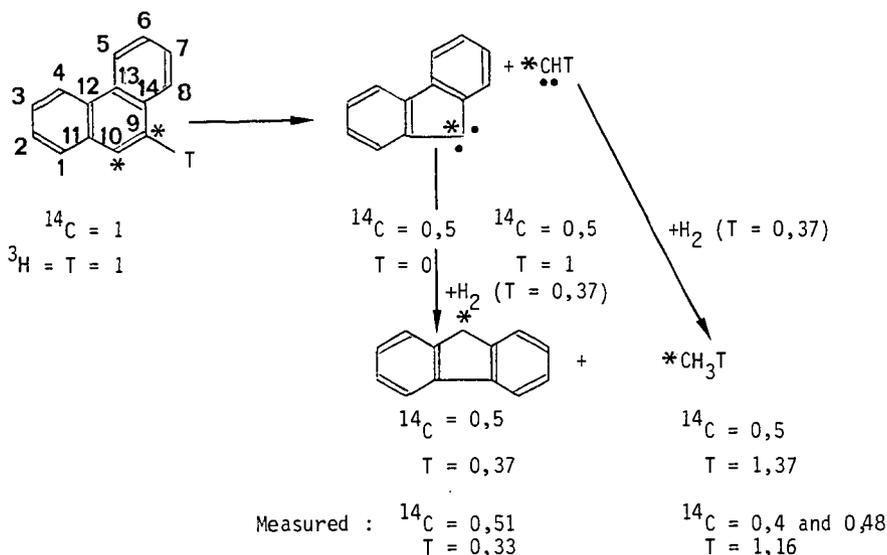
Gas phase	Composition (M %)			^3H content		
	875°C/2s	890°C/2s	900°C/2s	875°C/2s	890°C/2s	900°C/2s
Hydrogen	92,5	92,3	93,6	0,37	0,27	0,21
Methane	6,9	7,3	6,2	1,16	0,85	0,76
Ethylene	0,4	0,3	0,2	0,82	0,51	0,39
Ethane	0,05	0,07	0,03	1,36	0,66	0,57
Acetylene	Tr.	Tr.	Tr.			
Propene	-	Tr.	Tr.			
Liquid phase	850°C/2,5s		875°C/2s	850°C/2,5s		875°C/2s
Benzene	0,7		0,1	0,57		-
Indene	0,5		0,3	0,99		0,47
Naphthalene	3,6		1,6	0,77		0,90
Fluorene	0,5		0,5	0,39		0,32
Phenanthrene	91,6		95,0	1,02		1
Pyrene	0,3		0,4	-		1,70

Table V : Composition and tritium content of cracking of phenanthrene 9- ^3H

The tritium content in hydrogen is higher for low cracking yield. This means that there is preferential rupture of C-H bond in position 9. This is in agreement with what is admitted in literature where Beckwith and Thompson (14) give the following reactivity position sequence in phenanthrene : $9 > 1 > 3 = 2$. With increasing pyrolysis temperature the formation of 1-phenanthryl radical and even 2- and 3-phenanthryl radicals leads to a reduction of ^3H content in hydrogen. The ^3H content of methane is high, what demonstrates an important contribution of the ^3H located on C9.

Cracking of phenanthrene-9,10- ^{14}C at 885°C give ^{14}C content of 0,39 in CH_4 , 0,52 in naphthalene, 0,5 in fluorene and 1 for the uncracked phenanthrene.

The fluorene and methane formation, the only considered here, starts with the elimination of one C and two H in position 9. The hypothetical intermediate would be a fluorenyl biradical.



The intermediate fluorenyl biradical is hydrogenated by the hydrogen of the gas phase, whose tritium content is 0,37. Thus, the theoretical tritium content of the fluorene should be 0,37, as 1 mole H_2 is needed. The measured values are in very good agreement with this as ^3H content found was 0,33 and ^{14}C 0,51. For CH_4 , measured content was 1,16 for ^3H , and 0,4-0,48 for ^{14}C . The $::\text{CHT}$ biradical has taken one of the two radioactive carbon and all the tritium. His ^{14}C content is 0,5 and ^3H content 1. Hydrogenation of $::\text{CHT}$ to $::\text{CH}_3\text{T}$ needs one mole H_2 whose ^3H content is again 0,37. Thus, the total content is 1,37. This value is to compare with 1,16 measured. This lower value is due to the fact that not all the CH_4 is originated in this way.

Similar mechanisms were elaborated for some of the other minor constituents of the liquid phase : naphthalene and benzene. They will be available in more detailed publications.

- Cracking of perhydrophenanthrene -9,10 ^{14}C

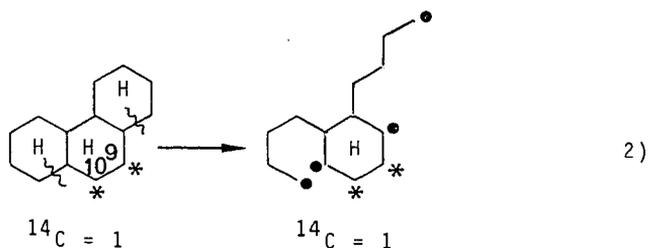
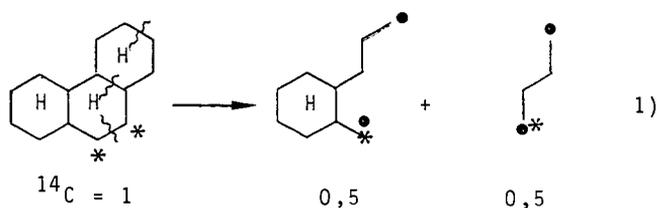
Table VI shows the composition, yields of cracking gaseous and liquid phases, and the respective ^{14}C content of the cracking compounds obtained at 750°C and 2s for perhydrophenanthrene -9,10 ^{14}C .

Experimental results show that no phenanthrene nor hydrophenanthrene are formed : there is no direct dehydrogenation of perhydrophenanthrene as is observed for the hydrophenanthrene. The C-C rupture happens before the C-H rupture. The H_2 production is due to subsequent dehydrogenation of the monocyclicperhydro-or hydrocaromatics.

	Composition(M%)	Yields	^{14}C content
	Gas phase	(M%)	$\frac{(\text{mCi/mM})}{(\text{mCi/mM})}$
H ₂	25,7	103,5	-
CH ₄	26,8	109,5	0,14
C ₂ H ₄	32,1	131,1	0,12
C ₂ H ₆	5,8	23,8	0,17
C ₃ H ₆	5,9	24,0	0,18
C ₃ H ₈	0,4	1,5	-
C ₄ H ₈	3,7	15,1	-
	Liquid phase	(M%)	$\frac{(\text{mCi/mM})}{(\text{mCi/mM})}$
Benzene	33,4	33,8	0,36
Toluene	18,3	18,4	0,60
Ethylbenzene	0,9	0,9	0,71
m,p-xylenes	2,8	2,8	0,74
o-xylene	0,6	0,6	0,74
Styrene	6,2	6,3	0,77
Naphthalene	9,6	9,7	0,87
Perhydrophenant.	-	-	1
Other compounds	28,2	28,6	

Table VI : Composition, yields and ^{14}C content obtained by cracking of perhydrophenanthrene -9,10 ^{14}C ($T^\circ 750^\circ\text{C}$, $t = 2\text{s}$)

Considering also that C₂ and C₃ olefins are detected in the gas phase as soon as the cracking begins two possible pathways can be considered.



The ^{14}C contents of the intermediate species are indicated. Let us consider benzene and toluene formation. Mechanism 1), followed by dealkylation and dehydrogenation of the remaining cycle, leads to inactive benzene and active CH_4 ($^{14}\text{C}=0,5$). Mechanism 2) leads to a benzene with a ^{14}C content of 1. The benzene ^{14}C content measured was 0,36. Thus pathways 1) and 2) contribute respectively for 2/3 and 1/3 to the benzene formation. This leads to the conclusion that in this perhydrocompound there is a preferential rupture between the carbons, in 9 and 10 position.

For toluene, the ^{14}C content measured was 0,6, twice that of benzene. This is in good agreement with what was said for the benzene formation. Pathway 1) is giving toluene with ^{14}C content of 0,5, after elimination of a C_3 radical from the intermediate. Pathway 2) gives as for benzene, toluene with ^{14}C content of 1, after a C_3 and a C_4 elimination and dehydrogenation of the cycle. Considering that as found for benzene, pathway 1) contributes for 2/3 and pathway 2) for 1/3 to the first step of the reaction, the theoretical activity of toluene should be a ^{14}C content of $(2/3 \times 0,5) + (1/3 \times 1) = 0,66$. as to compare with the measured content of 0,60.

Concerning the radioactivity in ethylene which is one of the major products in the gases, the measured ^{14}C content was 0,12. This demonstrates that ethylene is not formed by preferential elimination of the carbon atom in the 9 position.

5. CONCLUSIONS

During hydrocarbonisation of coal, the main reaction below 750°C is hydrodealkylation. This makes possible to optimize the B.T.X. and low boiling phenols formation. Dehydroxylation of the phenols is only important above 750°C giving an increase in water and additional light aromatics. The oxygen content of the coal, corresponding to the hydroxyl group is not hydrogen consuming below 750°C , as it is the case at high temperature where conversion to methane is the goal of the process. Dealkylation of alkylphenols and alkylaromatics explains the almost linear increase with temperature of methane. Hydrogen pressure prevents reassociation of free radicals, not only in the pyrolysis of coal itself, but also in the postcracking process. Due to this fact, naphthalene and other heavy polycyclic aromatics yields remain low, compared to what is found when carbonisation is performed under pressure of an inert gas.

The sulfur elimination in the char depends of the nature of the mineral constituents of the coal. CaCO_3 and MgCO_3 under hydrogen pressure react with sulfur compounds to form CaS . Calcium is not associated with sulfur in the coal, except for some CaSO_4 . But in the char, on the contrary, calcium is combined with the sulfur. The concentration of CaCO_3 is however not sufficient to fix all the sulfur. Pyritic sulfur is eliminated at high temperature. But it seems possible that this sulfur is trapped on CaCO_3 . High sulfur containing coals will only be well desulfurized under hydrolysis conditions if their ashes are poor in CaO and MgO .

Thermal pyrolysis at atmospheric pressure under inert gas demonstrates that all perhydrocyclic hydrocarbons are easily cracked into monocyclic aromatics and ethylene. The mechanism of the ring opening, in the case of perhydrophenanthrene, labelled with carbon 14 in 9 and 10 position, is a rupture of the C-C bond between 9 and 10. This conclusion is in good agreement with the perhydrocompounds cracking results. No formation of naphthalene was observed at low conversion yields of tricyclic perhydrocompounds, what would be the case if opening of the external ring would be the main reaction pathway. Hydrocyclic aromatics

undergo mainly dehydrogenation leading back to the corresponding aromatic starting compound.

The low stability of the perhydropolycyclic compound makes possible to convert industrially the hydropolycyclic compounds, abundant in coal liquid hydrogenates, into benzene and ethylene, two compounds of major importance in industrial organic chemistry. The polycyclic aromatics have to be saturated by additional hydrogenation to the corresponding perhydrocompounds, which can then be directly cracked at 800-850°C for 0,5s residence time, into benzene, ethylene, methane and hydrogen. The process is hydrogen self sufficient.

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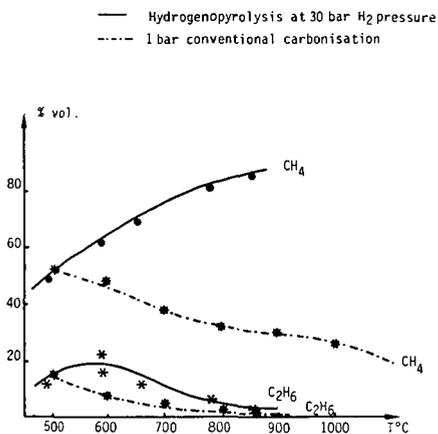


FIG. 1 : GAS COMPOSITION AS FUNCTION OF TEMPERATURE.

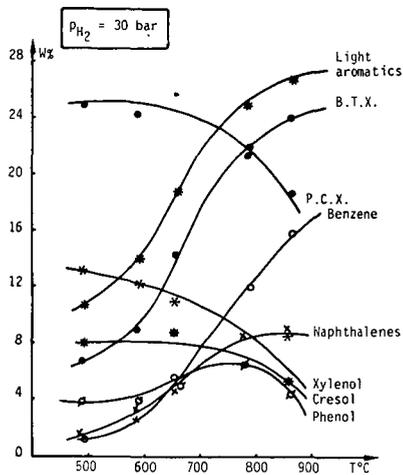


FIG. 2 : OIL COMPOSITION AS A FUNCTION OF TEMPERATURE.
 $\tau = 60s, < 500 \mu m$

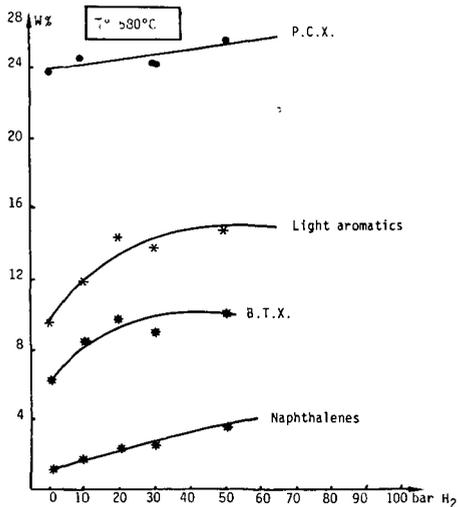


FIG. 3 : B.T.X. AND NAPHTHALENES YIELDS AS A FUNCTION OF H₂ PRESSURE (W% OF DIL)
 $\tau = 60s, < 500 \mu m$

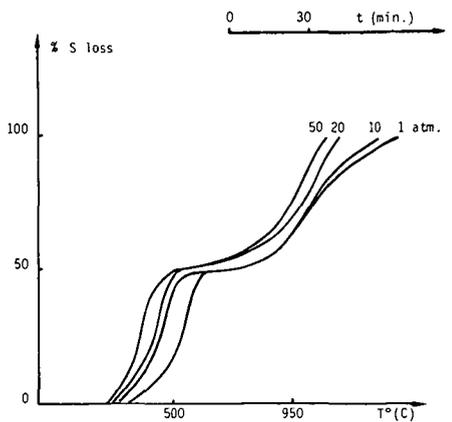


FIG. 4 : REDUCTION OF FeS₂ UNDER H₂ PRESSURE

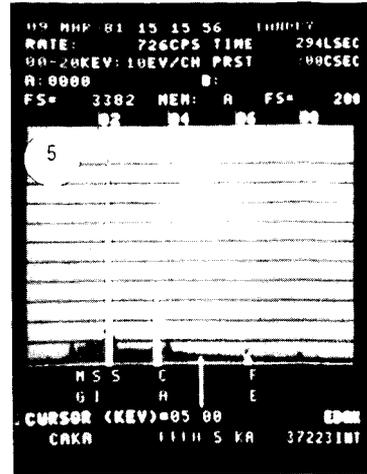
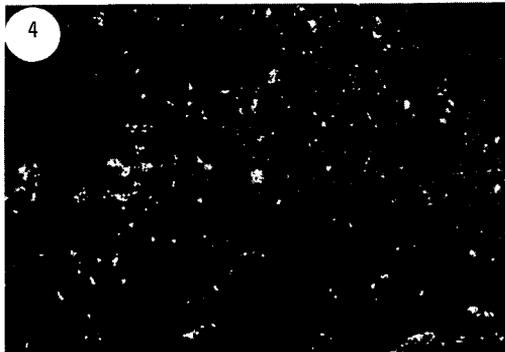
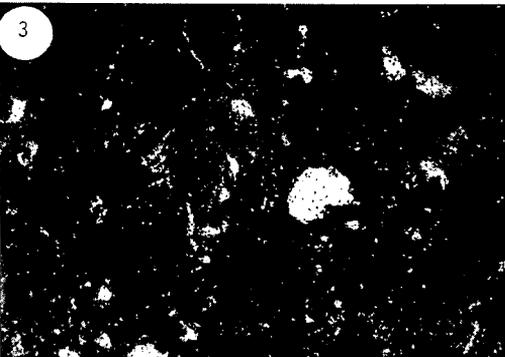
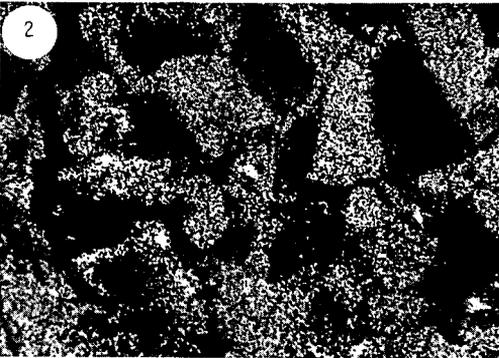


Fig.5 : SEM images

SULCIS COAL (56,4% VM, 12,9% ASH,
4,45% S_t)
before pyrolysis

1. Coal
2. S x-ray distribution image
3. Ca x-ray distribution image
4. Fe x-ray distribution image
5. x-ray spectrum

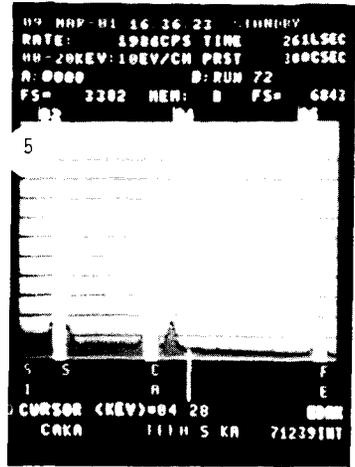
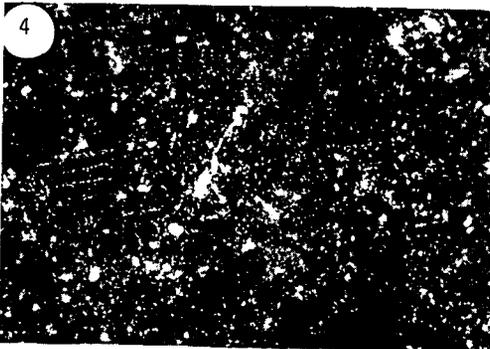
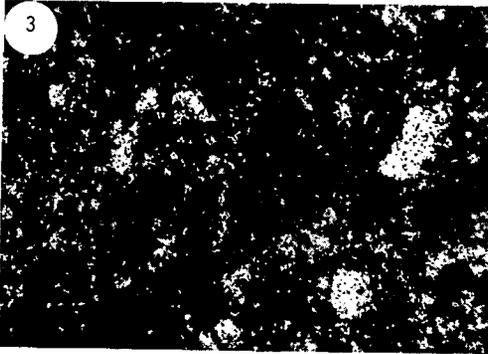
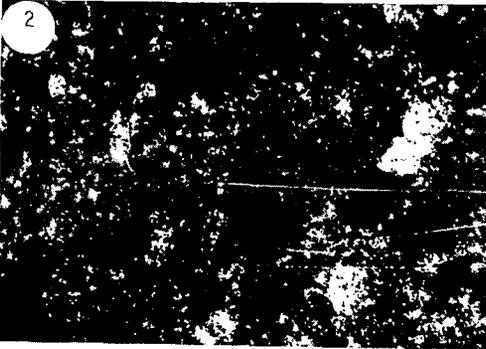
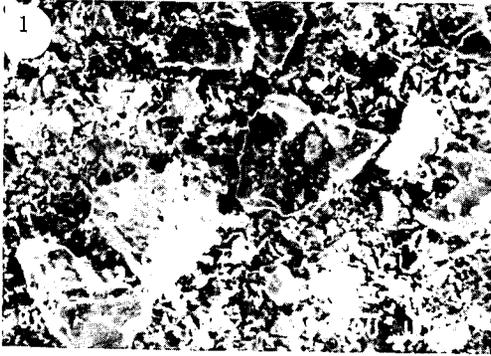


Fig. 6 : SEM images

SULCIS after Hydrogenopyrolysis
850°C - 30 bar H₂

1. Char
2. S x-ray distribution image
3. Ca x-ray distribution image
4. Fe x-ray distribution image
5. x-ray spectrum

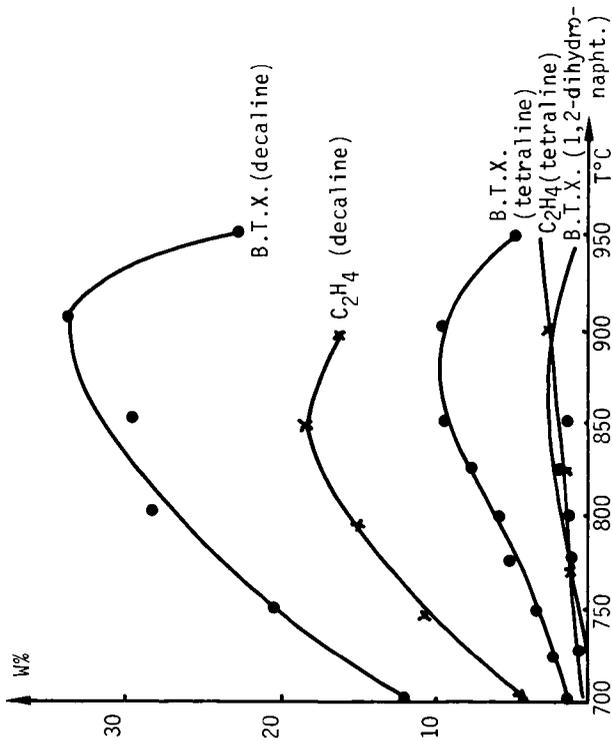


FIG. 7 : PYROLYSIS OF HYDRONAPHTHALENES
W% YIELDS IN B.T.X. AND ETHYLENE

1. B.T.X. (5,6,7,8 -tetrahydro-1-naphthol)
- 1'. C₂H₄ (5,6,7,8 -tetrahydro-1-naphthol)
2. B.T.X. (1,2,3,4 -tetrahydro-1-naphthol)
- 2'. C₂H₄ (1,2,3,4 -tetrahydro-1-naphthol)
3. B.T.X. (cis-1-decalol)
- 3'. C₂H₄ (cis-1-decalol)

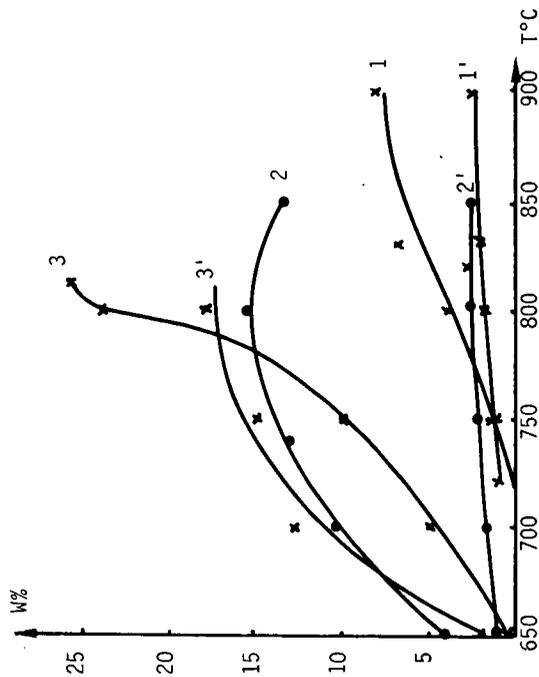


FIG. 8 : PYROLYSIS OF HYDRONAPHTOLS
B.T.X. AND ETHYLENE YIELDS (W%)