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Fundamental Studies of Catalytic Gasification: Quarterly Report, October 1 - December 31, 1987

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QUARTERLY REPORT

October 1, 1987 - December 31, 1987

FUNDAMENTAL STUDIES OF CATALYTIC GASIFICATION

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I. Task Description for FY 1988

In the past this program has investigated the role of catalysts in relatively low temperature steam gasification. New mechanisms have been demonstrated and it has been shown that combinations of alkali hydroxide with transition metal oxides form compounds which act as the true catalyst to produce mostly hydrogen and carbon dioxide. This has further been confirmed by surface science studies and by transmission electron microscopy. At the lower temperatures (~800 K) used, hydrogen and CO₂ are the products formed, but the effect of temperature and of the exact composition of the NiO/KOH catalyst that has been studied in the greatest detail on the CO₂/CO ratio remains to be defined. Similarly, a clear definition of the advantages of different alkali-transition metal oxide compositions is required. It appears possible that with the right catalyst and conditions, either syn-gas or H₂ + CO₂ can be produced. Inexpensive transition metal oxide-alkali catalysts will be evaluated as will be the effect of mineral matter in chars and coke and the role of different partial pressures of H₂, CO and H₂S.

II. Introduction

In previous reports it has been shown that potassium-nickel mixtures have distinct catalytic activity for steam gasification of graphite. It has been concluded that a cooperative effect between the components is responsible for this activity. It has further been shown that the mixture has higher activity than potassium alone, and that it is more resistant to deactivation than nickel alone. Electron microscopy studies previously reported highlight the excellent dispersion and mobility of the catalyst. In addition, X-ray photoelectron spectroscopy studies show that the nickel-potassium interaction stabilizes potassium on the surface, and favors the presence of nickel as an oxide.

These results indicate that the nickel-potassium system is a promising new type of catalyst for steam gasification of graphite. Its

industrial application, however, requires that these properties can be expanded to gasification of other carbon solids, like chars and coke derived from coals and petroleum oil. For the gasification of these carbon sources, it is important to evaluate the stability of the catalyst and the potential deactivation by sulfur poisoning, inclusion in micropores, reaction with mineral content, and sintering.

The present report presents a kinetic study on the catalytic properties of the nickel-potassium mixture for gasification of a coal-derived char of high mineral content and compares the results with those obtained with potassium-alone and nickel-alone catalysts. This char was chosen to clarify the potential interaction of catalyst and ash components.

III. Highlights

- o In the catalytic steam gasification of chars, North Dakota lignite char was selected for an investigation of ash component-catalyst interaction because of its high mineral content.
- o Both nickel and potassium seem to react with minerals in the ash, greatly reducing catalytic activity of the nickel-potassium catalyst.
- o Ash components initially catalyze gasification in the absence of an added catalyst, but this activity rapidly declines with time.
- o When a nickel-potassium catalyst is added to the char after its gasification activity has ceased, gasification resumes with good activity and steady state gas production until almost all carbonaceous matter has been gasified.
- o Demineralization of the char by HCl/HF treatment resulted in a char which had no catalytic activity of its own, but which was

easily gasified after impregnation with Ni/K catalyst. Gasification proceeded at steady state and without the poisoning of activity observed in the presence of mineral matter.

- o Potassium appears to interact with calcium in the ash giving an eutecticum which wets the carbon and acts as a gasification catalyst, which is superior to either potassium or calcium alone in the absence of ash. Alkali earth-alkali mixtures must therefore be investigated as potential catalysts.

- o Nickel alone is very sensitive to the ash content of the char, apparently due to interaction between nickel and either calcium and/or sulfur. It has almost no activity for gasifying the North Dakota char in contrast to a short lived high level activity in the gasification of graphite and of low ash chars.

IV. Progress of Studies

A) Experimental

1) Thermal Steam Gasification of North Dakota Char.

The parent coal of the char chosen for this study is a lignite from North Dakota. The char, as received, had been prepared by partial steam gasification at 1196 K. Its elemental analysis is given in table 1. The organic content of the char is composed mainly of carbon, oxygen and hydrogen ($H/C_{at.ratio}=0.18$ and $O/C_{at.ratio}=0.07$). The inorganic content is very high (24.95 wt.%), and the ash analysis indicates the presence of mainly Al_2O_3 , SiO_2 , CaO and Fe_2O_3 .

The ash components of this char have catalytic activity for the steam gasification of carbon. Figure 1 shows that the char, as received, without addition of any external catalyst is active for reaction with steam at 893 K. The rate of steam gasification of the raw char, however, decreases rapidly with carbon conversion and time. For the particular experiment presented in this figure, the reaction rate was halved after

Table 1 Compositional data for the North Dakota-lignite char, as received.

Proximate Analysis wt. %	^a Ultimate Analysis wt. %	^b Ash Analysis wt. %
Moisture 3.32		
Loss on ignition ^c 71.76	C 89.63 H 1.33 N 0.51 S 0.0 Cl 0.1 O 8.42	
Ash 24.95		SiO ₂ 26.06 Al ₂ O ₃ 13.71 TiO ₂ 0.62 Fe ₂ O ₃ 6.55 CaO 22.40 MgO 8.14 K ₂ O 0.59 Na ₂ O 1.82 SO ₃ 18.10 P ₂ O ₅ 0.23 SrO 0.56 BaO 0.36 Mn ₃ O ₄ 0.13 total 99.27

^aOxygen by difference.

^bMineral results are reported on an ignited basis.

^cLoss after ignition at 1023 K.

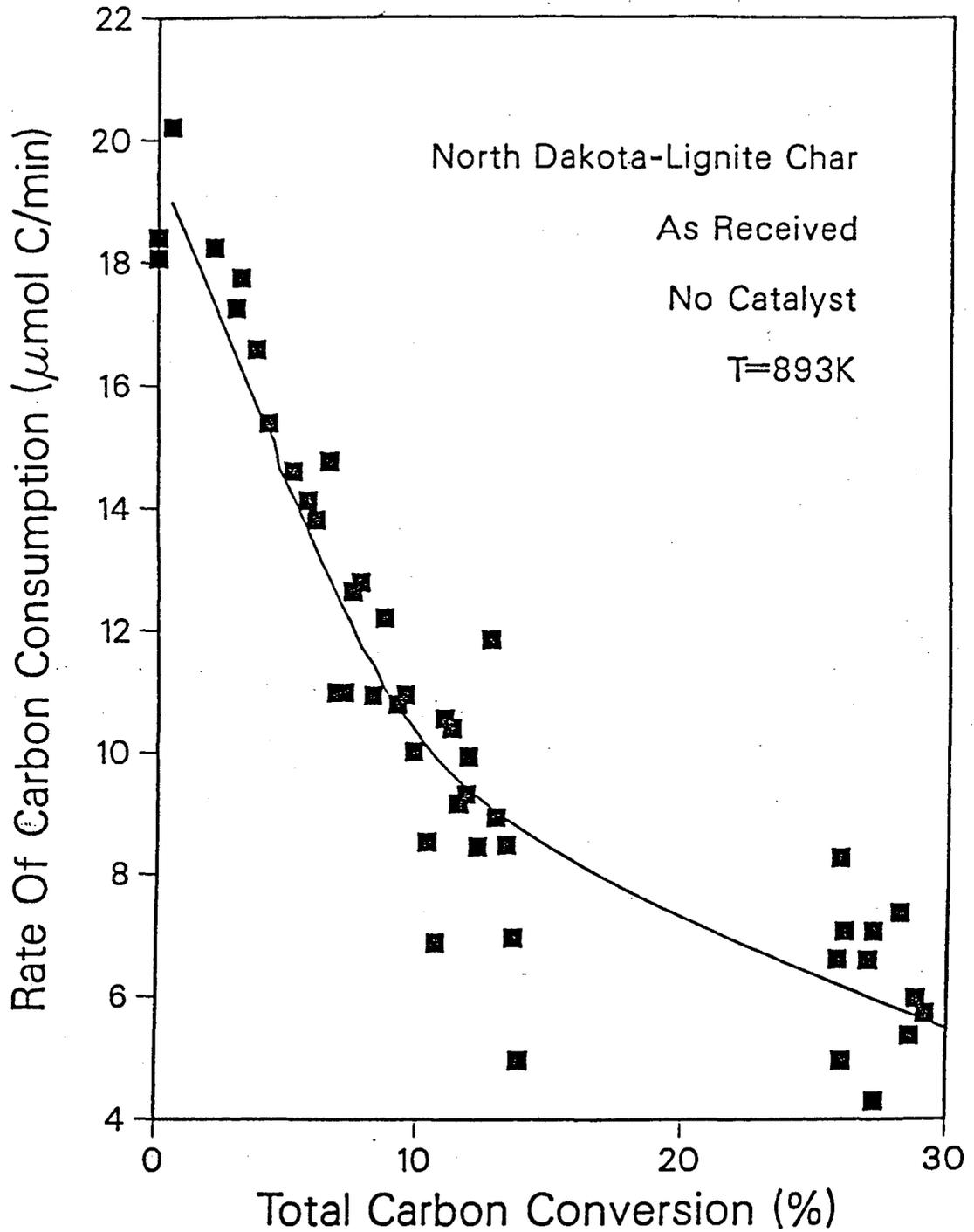


Figure 1 Variations of the rate of carbon gasification by steam at 893 K, with total carbon conversion, for North Dakota-lignite char, as received, without addition of any catalyst.

10% carbon conversion and was almost zero after 30% carbon conversion (reached after 10 hours in steam).

During the steam gasification of the raw char at 893 K, H_2 and CO_2 are the main gas products, along with a small amount of CO ($p_{CO}/p_{CO_2}=0.04$). The ratio of CH_4 to H_2 in the collected gases is only slightly above the detection limit of the apparatus ($p_{CH_4}/p_{H_2}<2\times 10^{-3}$).

Figure 2 shows that the rates of steam gasification of the char after addition of potassium and/or nickel salts, are comparable to those observed with the char alone. From these experiments, however, it is difficult to determine the catalytic properties of these compounds. Fluctuations in the total rate observed, possibly due to inhomogeneity in the char composition, could mask changes in the gasification rate, due to the addition of nickel and/or potassium salts. Notice for example, that for the char as received, without addition of any catalyst, the rate of steam gasification reported in figure 2 is three times higher than the one shown in figure 1.

2) Catalytic Steam Gasification of Deactivated Char

In order to minimize the catalytic contribution of ash materials to the steam gasification rate, the raw char was treated in steam at 933 K, until no more gas products were evolved. The properties of the potassium and nickel salts, codeposited or by themselves, were then studied for the steam gasification of the remaining solid at 893 K. This way gasification rates observed after addition of the salts must be due to the presence of nickel and/or potassium.

The elemental analysis of the deactivated char is given in table 2. The decrease in the percentage of the organic fraction in the char, from 71.76 wt.% to 50.11 wt.%, agrees with the 48% weight loss determined after the steam gasification process. The composition of the organic and inorganic fractions in the char do not change significantly after the

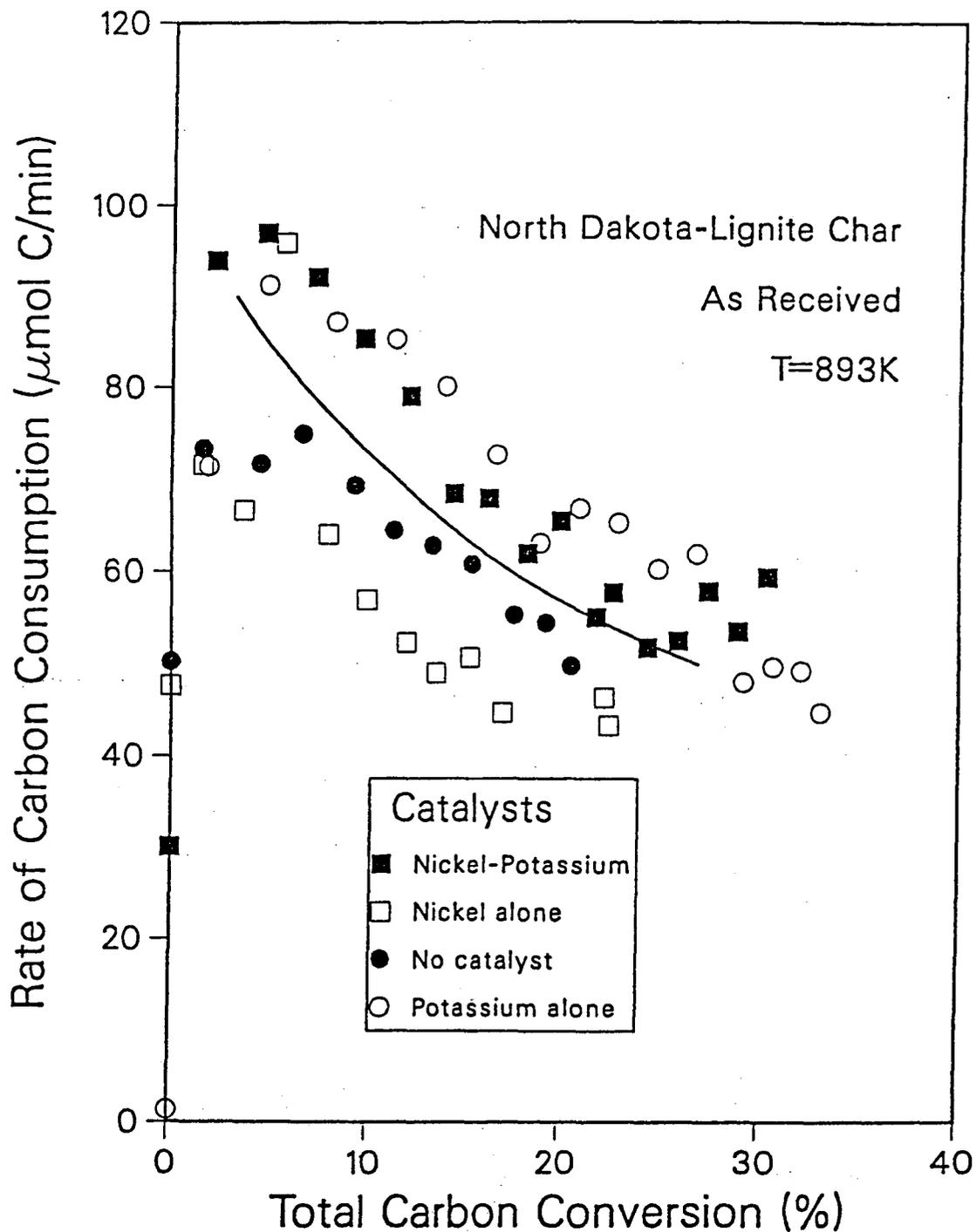


Figure 2: Variation of the rate of carbon gasification by steam at 893 K, with total carbon conversion, for North Dakota-lignite char, as received, after addition of either nickel, potassium, or their mixture. When present, the nickel and potassium loadings were 0.83 mmol cation/g char.

steam treatment, with the notable exception of the amount of sulfur, which decreases from 18.10 wt.% before treatment, to 2.16 wt.% after.

The catalytic activity of the nickel-potassium mixture for steam gasification of the deactivated char at 893 K is shown in figure 3 up to 15% carbon conversion. The rate of gas production remains constant with total carbon consumption, up to 35% conversion; reached after 120 min under reaction conditions. At low carbon conversions, a small increase in the rates of gas production was observed, but this was not always reproducible. The product distribution is very similar to that obtained for the gasification of the char as received. H_2 and CO_2 are the main products. Slightly more CO is produced ($p_{CO}/p_{CO_2}=0.13$), and the amount of CH_4 in the gas collected is within the sensitivity limits of the system.

The rates of gas production are proportional to the amount of nickel and potassium present. For this reason, the reaction rates reported in figure 3 have been normalized with respect to the catalyst loading. In the case of the nickel-potassium mixture, one mole of catalyst is considered to be one mole of nickel plus one mole of potassium. In the particular experiment shown in figure 3, the catalyst loading was equal to 1.04×10^{-3} moles. The absolute rate of carbon consumption is equal, then, to $41 \mu\text{mol C/min}$, which is the same order of magnitude as the initial rates observed for the char as received. This rate, however, is due to the catalytic effect of the nickel-potassium mixture, since in this case the char by itself is inactive.

It has previously been reported that in the case of gasification of graphite a prereduction step enhances the activities of the nickel alone and nickel-potassium mixtures. In the case of the steam gasification of lignite char, however, a pretreatment in H_2 at 933 K had no effect on the activity of these catalysts. Similar rates of gasification are observed with and without the prereduction step.

Table 2: Compositional data for the deactivated North Dakota-lignite char.

Proximate Analysis wt. %	^a Ultimate Analysis wt. %	^b Ash Analysis wt. %
Moisture 1.04		
Loss on ignition ^c 50.11	C 89.55 H 1.05 N 0.41 S 0.0 Cl 0.0 O 8.99	
Ash 49.37		SiO ₂ 29.72 Al ₂ O ₃ 16.48 TiO ₂ 0.75 Fe ₂ O ₃ 7.09 CaO 27.80 MgO 8.14 K ₂ O 0.62 Na ₂ O 2.29 SO ₃ 18.10 P ₂ O ₅ 0.28 SrO 0.68 BaO 0.43 Mn ₃ O ₄ 0.15 total 98.54

^aOxygen by difference.

^bMineral results are reported on an ignited basis.

^cLoss after ignition at 1023 K.

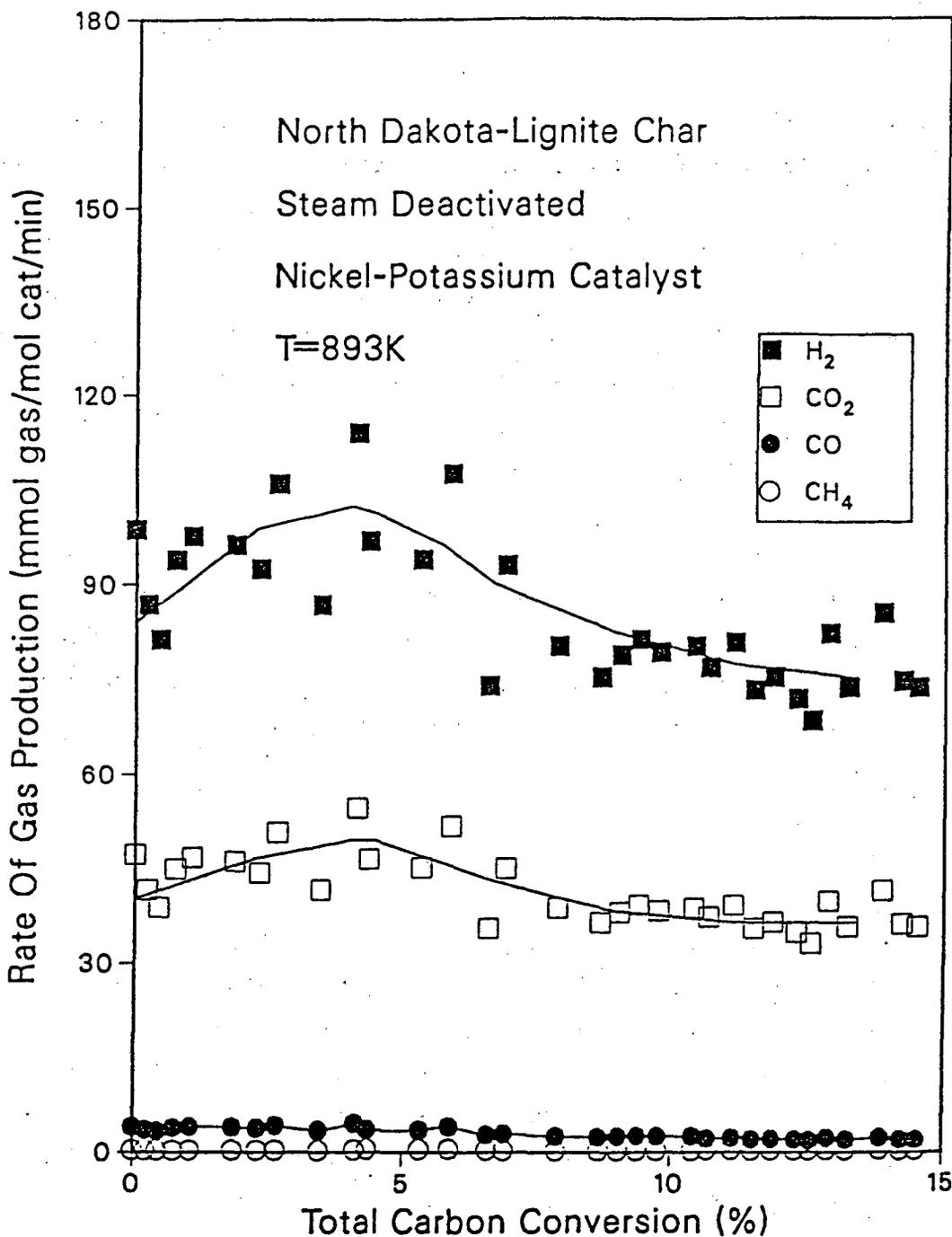


Figure 3: Rate of gas production, as a function of carbon conversion, for all the gases formed on the steam gasification of deactivated char at 893 K, catalyzed by the nickel-potassium mixture. The molar ratio of nickel to potassium was equal to 0.9, and the catalyst loading was equal to 2.0 mmol cat/g char. The initial weight of char was 0.6 g.

The total carbon conversions, determined by weight loss measurements, were 10 to 20% higher than those determined by integration of the gas production curves. These differences are probably caused by the dissolution of a small fraction of the gas products in H₂O during the gas collection step. This implies that the reaction rates presented in this report are slightly lower than the real values. These differences will not change the main conclusions reached in this study.

3) Catalytic Steam Gasification of Demineralized Char

Results of the steam gasification of the deactivated char show that the catalytic properties of nickel and potassium, codeposited or by themselves, vary from those observed for steam gasification of graphite. This is probably due to the interaction between the ash content in the char, and the nickel and/or potassium.

In order to study this possibility, the raw char was demineralized by extractions in HCl and HF.^a Table 3 shows that after these treatments the ash content of the char is reduced from 24.95 wt.% to 3.63 wt.%. The remaining ash is composed mainly of CaO, Al₂O₃ and MgO, with a small amount of iron. In the organic fraction, the oxygen

^aDemineralization procedure: 25 g of char was treated with 30 ml washes of 3 F HCl at 333 K until the calcium, magnesium and iron content of the washes was below 20 ppm, as determined by atomic absorption (about 35 washes were necessary). In the last wash, the calcium concentration was 0.6 ppm, magnesium 0.15 ppm and iron 6.6 ppm. Temperatures above 33 K were avoided to prevent carbon oxidation. After the HCl treatment, the remaining solid was treated with 35 ml of 9 F HF solutions until the silicon concentration in the washes was below 8.0 ppm (7 washes). The solid was then rinsed with distilled H₂O until no more chloride or fluoride ions were detected in the washes (about 60 times).

concentration after demineralization is slightly higher ($O/C_{at.ratio}=0.1$ instead of 0.07), indicating that some oxidation has taken place during the extraction process. Also, a small amount of sulfur and chlorine are now present ($S/C_{at.ratio}=1.3 \times 10^{-5}$ and $Cl/C_{at.ratio}=1.3 \times 10^{-5}$). The char, after demineralization treatment, has no activity toward steam gasification.

The initial rate of steam gasification of the demineralized char at 893 K, promoted by the nickel-potassium mixture, is one order of magnitude higher than that observed for the deactivated char. (Compare figures 4 and 3). The gas product distribution is similar to those reported previously; mainly H_2 and CO_2 with small amounts of CO ($p_{CO}/p_{CO_2}=0.14$), and with CH_4 production rates just above the sensitivity threshold of the system.

Figure 4 also shows that, for the nickel-potassium catalyzed gasification of the demineralized char, the rate of gas production increases with total carbon consumption, up to 50% conversion. Above this value, the rate starts to decrease, but does not stop until all the carbon initially present has reacted. Pore volume analysis of the demineralized char shows that about 25% of the total surface area is accounted for by micropores of less than 20 Å average diameter. This surface area, probably becomes accessible for reaction only after partial gasification, and would explain the increase in reaction rate.

The steam gasification of demineralized char at 893 K, catalyzed by potassium alone, shows qualitatively the same behavior as when the reaction is promoted by the nickel-potassium mixture. The gas products are, again, H_2 and CO_2 plus a small amount of CO ($p_{CO}/p_{CO_2}=0.07$). The rate of gas production increases with the total carbon consumption, up to 50% conversion, and gasification of all the carbon initially present is achieved. The activity of the potassium catalyst, however, is around 50% lower than that of the nickel-potassium mixture. (See table 4).

Table 3: Compositional data for the demineralized North Dakota-lignite char.

Proximate Analysis wt. %	^a Ultimate Analysis wt. %	^b Ash Analysis wt. %
Moisture 4.04		
Loss on ignition ^c 92.33	C 85.85 H 0.91 N 0.68 S 0.4 Cl 0.4 O 11.7	
Ash 3.63		SiO ₂ 2.66 Al ₂ O ₃ 15.25 TiO ₂ 1.94 Fe ₂ O ₃ 3.38 CaO 41.91 MgO 18.27 K ₂ O 0.08 Na ₂ O 0.39 SO ₃ 14.88 P ₂ O ₅ 0.36 SrO 0.44 BaO 0.16 Mn ₃ O ₄ 0.17 total 99.89

^aOxygen by difference.

^bMineral results are reported on an ignited basis.

^cLoss after ignition at 1023 K.

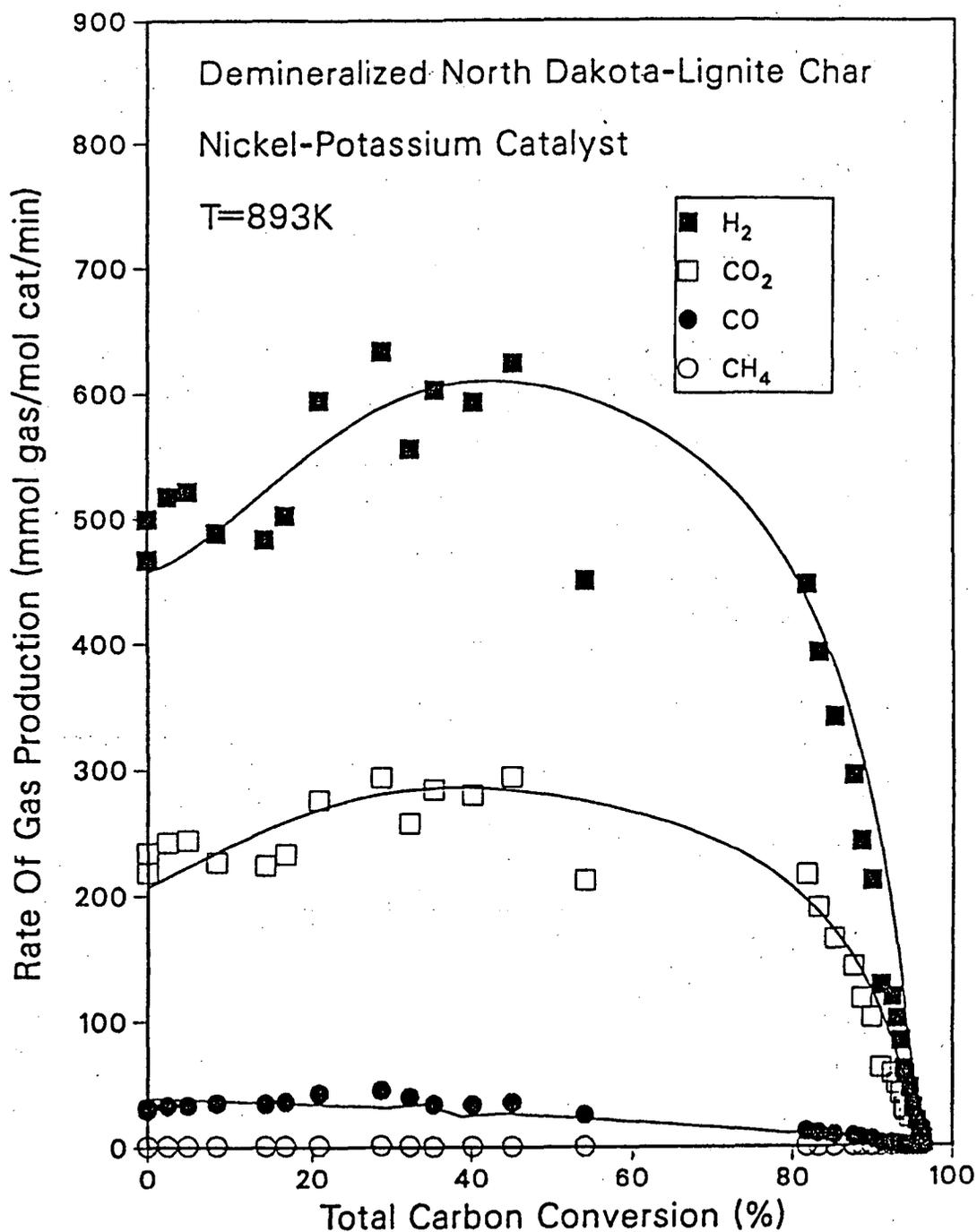


Figure 4: Rate of gas production as a function of carbon conversion, for all the gases formed from the steam gasification of demineralized char at 893 K, catalyzed by the nickel-potassium mixture. The molar ratio of nickel to potassium was equal to 0.9, and the catalyst loading was equal to 2.0, mmol cat/g char. The initial weight of char was 0.5g.

Table 4: Rate of carbon consumption and ratio of CO to CO₂ in the gas products, for the steam gasification at 893 K of demineralized North Dakota-lignite char.

Catalyst	Rate (mmol C/mol cat/min)		P_{CO}/P_{CO_2}	
	32 % conv.	75 % conv	32 % conv.	75 % conv.
No catalyst	No activity			
Nickel-potassium	348±60	224±64	0.14±0.01	0.14±0.01
Nickel alone	14±6	-	0.17±0.01	-
Potassium alone	233±20	133±40	0.09±0.01	0.05±0.01

The activity of the nickel alone catalyst for steam gasification of demineralized char at 893 K is very low. Also, as in the case of the deactivated char, prereduction of the nickel alone did not enhance the catalyst activity.

B) Discussion

The catalytic properties of nickel and potassium for steam gasification of the North Dakota char are in some cases different from those of graphite steam gasification. This is the case for both the mixed catalyst and the two components by themselves. These differences can be explained by the interaction of nickel and potassium with the mineral content of the char.

Comparing the results presented in this report for the steam gasification of the demineralized char with those reported earlier for the steam gasification of graphite, one finds that: the demineralized char contains a relatively low amount of ash (4 wt.%), and the volatile fraction is composed mainly of carbon, hydrogen and oxygen. It has a large surface area ($540 \text{ m}^2/\text{g}$), with an average pore volume of $0.41 \text{ cm}^3/\text{g}$, and a microporosity (pores of diameter less than 20 Å) that accounts for 25 to 30% of the total surface area. The graphite used in the earlier work (UCP-1 from Ultra Carbon) is almost 100% carbon with no ash. Its surface area is relatively low ($5 \text{ m}^2/\text{g}$) and it has no micropores.

The nickel-potassium mixture shows similar catalytic properties for the steam gasification of graphite and demineralized char. In neither case does the catalyst deactivate with time. The product distribution is similar ($p_{\text{CO}}/p_{\text{CO}_2}$ is equal to 0.12 for the demineralized char, and 0.04 for graphite) and in both cases it remains constant with time. For the steam gasification of the demineralized char, the reaction rate at 893 K ($348 \text{ mmol C/mol cat/min}$) is higher than that for graphite gasification ($18 \text{ mmol C/mol cat/min}$) but so is the surface area of the carbon substrate.

Contrary to the nickel-potassium mixture, the nickel-alone catalyst has different properties for steam gasification of graphite and the demineralized char. It has been reported in this work and by other authors [1,2] that nickel alone is a good catalyst for steam gasification of graphite, despite the fact that it deactivates. In the case of the demineralized char, even though the catalyst does not deactivate, its activity for the steam gasification reaction at 893 K (14 mmol C/mol cat/min) is almost 30 times lower than for graphite (400 mmol C/mol cat/min). A prereduction step does not enhance the catalyst activity of the demineralized char, while in the case of graphite gasification it is indispensable.

These differences can be explained by the interaction between nickel and the ash content of the char. Table 3 shows that calcium and sulfur are two major components in the ash content of this carbon substrate. We have previously reported that nickel-calcium mixtures show the same qualitative properties for steam gasification of graphite, as nickel-potassium mixtures, but with much lower activity. Baker and Chludzinski [3] have reported that the activity of the nickel-calcium mixture for steam gasification of graphite is lower than that of nickel and calcium alone. These authors have also shown that despite the low activity, the nickel-calcium catalyst has good mobility. This allows the mixture to remain in contact with the active planes of the substrate and

[1] C.R.F. Lund. J. CATAL. 95 (1985) 71.

[2] T. Wigmans and J.A. Moulijn. In T. Seiyama and K. Tanabe, editors, NEW HORIZONS IN CATALYSIS, page 501, Elsevier Scientific, New York, 1981.

[3] R.T.K. Baker and J.J. Chludzinski Jr. CARBON 23 (1985) 635.

prevents its deactivation. Ohtsuka et al. [4] have also studied the interaction of potassium and calcium with nickel in the steam and hydrogen gasification of brown coal. They concluded, in agreement with our results, that while the activity was increased markedly by potassium, it was decreased by the presence of calcium.

The initial concentration of calcium in the demineralized char (271 $\mu\text{mol Ca/g char}$) is almost eight times lower than the amount of nickel catalyst loaded (2.08 mmol Ni/g char). This, however, does not exclude the possibility of an interaction between nickel and calcium, since for the nickel-potassium case, the cooperative effect between these two components was observed, even at nickel to potassium atomic ratios as high as ten.

Sulfur is another component in the ash that could be responsible for the low activity of nickel. Its concentration in the char is similar to that of calcium (194 $\mu\text{mol S/g char}$) and the sensitivity of nickel catalysts to sulfur content, for a variety of chemical reactions, is very well documented.

The properties of the potassium catalyst for steam gasification of the demineralized char and graphite are also different. Dellanay et al. [5] reported that KOH loaded by itself on UCP-1 graphite is only active for steam gasification at temperatures above 1000 K, whereas it is shown in this report that KOH loaded alone on the demineralized char is active for steam gasification reaction at 893 K. Furthermore, in the latter case, the catalyst does not deactivate, and total carbon conversion is achieved.

[4] Y. Ohtsuka, A. Tomita and Y. Tamai. APP. CATAL. 28 (1986) 105.

[5] F. Dellanay, W.T. Tysoe, H. Heinemann and G.A. Somorjai. CARBON 22 (1984) 1.

The behavior of the potassium catalyst for steam gasification of the demineralized char can also be explained by its interaction with the ash content in the char. McKee et al. [6] have indicated that the degree of promotion of K_2CO_3 for steam gasification of char increases with the rank of the coal char. Wood and Sancier [7] in a review article, suggest that "this dependence on the coal rank is likely a manifestation of the variation of native calcium ion concentration in the coal chars."

Our interpretation for the interaction between potassium and calcium and/or magnesium, is analogous to that described in earlier reports for the nickel-potassium case. It involves the formation of a compound, that improves the mobility of the catalyst, and prevents its deactivation. The advantages of an eutectic mixture of alkali salts or alkali-transition metal salts, as catalysts for steam gasification of carbon solids, has also been suggested by Hüttinger and Minges [8] and by McKee et al. [9]. To the best of our knowledge, however, no work on alkali-alkaline earth mixed catalysts has been reported in the literature.

The catalytic activity of the calcium-potassium or magnesium-potassium mixtures could be due to their ability to extract a hydrogen atom from H_2O vapor and to enhance its dissociation on the carbon surface. A similar mechanism has been proposed for CH_4 activation by alkali/alkaline earth catalysts [10] which is certainly a more demanding reaction.

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- [6] D.W. McKee, C.L. Spiro, P.G. Koguchi and E. Nakamura. FUEL 62 (1983) 217.
- [7] B.J. Wood and K.M. Sancier. CATAL. REV. SCI. ENG. 26 (1984) 233.
- [8] K.J. Hüttinger and R. Minges. FUEL 64 (1985) 491.
- [9] D.W. McKee, C.L. Spiro, P.G. Kosky and E.J. Lamby. FUEL 64 (1985) 805.
- [10] T. Ito, J.X. Wang, C.H. Lin and J.H. Lundsford. J. AM. CHEM. SOC. 107 (1985) 5062.

Further experiments are necessary to support this model. Preliminary results, obtained on graphite, show that the calcium-potassium mixture is active for steam gasification at 893 K, while both potassium and calcium by themselves are inactive. This result, if confirmed, would support the proposed model, and technologically, would be of great importance because of the natural abundance of both potassium and calcium.

A comparison of the catalytic behavior of the nickel-potassium mixtures for steam gasification of the demineralized char, with those of nickel and potassium by themselves, are further evidence for a cooperative effect being responsible for the distinct properties of the mixture. In this case, the increase of the activity of the mixture at 893 K is higher than that expected from the sum of those of nickel and potassium by themselves. (See table 4.) These results indicate that the nickel-potassium interaction is not affected by the presence of micropores and by small amounts of sulfur and ash.

For the gasification of the deactivated char, however, the activity of the nickel-potassium mixture is the same, within experimental error, as that of potassium alone. In this case, the nickel-potassium interaction is probably hindered by interactions between the catalyst components and the ash content, which in this case, is much more abundant than in the demineralized char. A similar conclusion was reached by Suzuki et al. [11] for a sodium-iron mixture. Nickel, as previously discussed, can interact with calcium and/or sulfur, the concentrations of which in the deactivated char (2.5 mmol Ca/g char and 1.0 mmol S/g char) are similar to the nickel loadings (1.0 mmol Ni/g char). This idea is also supported by the fact that the activity of the nickel catalyst for steam gasification of the deactivated char is similar to that observed

[11] T. Suzuki, M. Mishima, T. Takahashi and Y. Watanabe. FUEL 64 (1985) 661.

for the demineralized char. On the other hand, potassium can react with clays and pyrite present in the ash to form catalytically inactive compounds [12]. This could also explain why the activity of potassium alone for gasification of the deactivated char is lower than that of the demineralized char. The ash fraction in the deactivated char, however, is uncommonly high (>50 wt.%) and further work is necessary to determine catalyst tolerance to ash content for both the nickel-potassium and potassium-alone catalyst.

In the case of the char as received, the catalytic activity of the mineral material is probably associated with the presence of calcium. Walker et al. [13] have studied the catalytic properties of calcium for steam gasification of lignite chars and concluded that it is the best in situ catalyst for steam gasification of char. Radovic et al. [14,17] have studied its deactivation and suggest that it is caused by sintering and loss of contact with the active planes of carbon. The same conclusion for deactivation of the nickel catalyst has been demonstrated in our previously reported XPS and electron microscopy work, which also shows that addition of potassium to nickel improves its mobility and prevents its deactivation. As already suggested, a similar interaction between potassium and calcium is feasible, and further studies should be performed to explore this possibility.

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- [12] L. Kühn and H. Plogmann. FUEL 62 (1983) 196.
- [13] P.L. Walker Jr., S. Matsumoto, T. Hanzawa, T. Muira and I.M.K. Ismail. FUEL 62 (1983) 140.
- [14] L.R. Radovic, P.L. Walker Jr. and R.G. Jenkins FUEL 62 (1983) 209.
- [15] L.R. Radovic, P.L. Walker Jr. and R.G. Jenkins J. CATAL. 82 (1983) 382.
- [16] L.R. Radovic, P.L. Walker Jr. and R.G. Jenkins FUEL 62 (1983) 849.
- [17] L.R. Radovic, P.L. Walker Jr. and R.G. Jenkins FUEL 63 (1984) 1030.

V. FUTURE WORK

Work for the immediate future involves essentially two tasks:

- 1) A set of seven chars and their analyses have been received from Illinois Institute of Gas Technology. These chars vary in derivation, ash and sulfur content. The interaction of mineral matter and catalysts will be further studied with these samples.
- 2) Mixtures of earth alkali and alkali salts will be studied as potential gasification catalysts.
- 3) The kinetic gasification unit is being revised and rebuilt to allow greater variation of steam rates than is presently possible.

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