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STEAM GASIFICATION OF A LIGNITE CHAR

by

Sachchida Nand

A thesis submitted to the School of Graduate Studies in partial fulfilment of the requirements for the degree of Ph.D. in Chemical Engineering.

University of Ottawa
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ABSTRACT

Steam gasification of lignite char has been studied in a fixed bed reactor at 640-800°C and atmospheric pressure with and without the presence of an added catalyst. The effect of experimental parameters, such as char particle size, char bed height, steam flow rate, steam partial pressure and gasification temperature on carbon conversion were investigated.

A modified shrinking core model which represented the kinetics of char gasification adequately is given as follows:

$$\frac{dx}{dt} = \frac{3(1-X)^{2/3}}{\rho_B R_p} [k_1 p_{H_2O} + k_2 p_{CO_2}]$$

The kinetic model shows that in addition to the primary C-H_2O reaction, the secondary C-CO_2 reaction was also responsible for carbon conversion. The same kinetic model was found to fit the results of catalyzed gasification showing thereby that the addition of catalyst did not change the mechanism of gasification reactions.

Activation energies for k_1 and k_2 were substantially lower than those for pure carbon-steam and carbon-carbon dioxide reactions. It showed that gasification reactions even without an added catalyst were catalyzed by inorganic impurities of the ash content of char.

Addition of a catalyst (K_2CO_3 or Na_2CO_3) did not catalyze the gasification reactions by lowering their activation energies but perhaps by increasing the active site density on the carbon surface.

Alkali metal salts, nickel and ferric oxide were tested for their catalytic activity under a wide range of experimental conditions. While carbonates of potassium and sodium showed comparable catalytic activity, alkali metal chlorides, nickel and ferric oxide were not equally effective. The presence of a dual catalyst (1% N_i + 10% K_2CO_3) in the char bed showed an additive catalytic effect of the two individual catalysis.

Catalyst not only increased the gasification rates by as much as 5-6 times, it also shifted the product gas composition towards favoured hydrogen and carbon monoxide at the expense of undesirable carbon dioxide. Carbon monoxide to hydrogen ratio (H_2/CO) could be varied from 1.3 to 51.1 by changing the experimental conditions.

ESR spectra of the char and char-catalyst mixtures showed that increase in the reactivity of char was accompanied by higher free radical concentration on the carbon surface.

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NOMENCLATURE

A	Frequency factor, g $cm^{-2}min^{-1}atm^{-1}$
A, B	Subscripts for reactants
b	Molar stoichiometry of the reaction
C	Reactant concentration mol lit^{-1} or g cm^{-3}
D_{AB}	Binary diffusivity of steam in nitrogen, cm^2s^{-1}
De	Effective diffusivity of gaseous reactant in ash layer, cm^2s^{-1}
d	Char particle diameter, cm
E	Energy of activation, k cal $(g\ mol)^{-1}$
K	Equilibrium constant of carbon-steam reaction
k	Reaction rate constant g $cm^{-3}min^{-1}atm^{-1}$ or g $cm^{-2}s^{-1}atm^{-1}$
M	Mass rate of carbon gasification, g min^{-1}
M_c	Molecular weight of carbon
M_g	Molecular weight of steam
N_A	Number of moles of gaseous reactant
N_B	Number of moles of solid reactant
P	Pressure at the reactor inlet, atm
P_{H_2O}	Partial pressure of steam in the reactor, atm
P_{CO_2}	Partial pressure of CO_2 in the reactor, atm
P_{CO}	Partial pressure of CO in the reactor, atm
P_{H_2}	Partial pressure of H_2 in the reactor, atm
P_{CH_4}	Partial pressure of CH_4 in the reactor, atm
$P^o_{H_2O}$	Partial pressure of steam at the reactor inlet, atm

Q_A	Flux of gaseous reactant through ash layer, gs^{-1}
R	Gas constant, cal (g mol K)$^{-1}$
R_p	Radius of char particle at time, t=0, cm
r	Radius of char particle at any time t, cm
r_c	Radius of unreacted core of char particle, cm
r_m	Experimental specific gasification rate, s^{-1}
$r_{m,D}$	Diffusion limited specific gasification rate, s^{-1}
S	Surface area of char, cm^2g^{-1}
T	Reaction temperature, ^oC or K
t	Reaction time, min.
V	Volume of the char particle, cm^3
X	Fractional carbon conversion
ρ_B	Molar density of solid reactant (char) mol cm^{-3}
σ	Particle density of char, g cm^{-3}
Δ	Gravimetric stoichiometric coefficient
η	Effectiveness factor for char gasification reactions

CHAPTER 1

INTRODUCTION

Recent energy demand has focussed attention on the utilization of vast resources of coal. Coal may be utilized in four major ways, namely, gasification, combustion, liquifaction and pyrolysis. Selection of one or two of these processes depends on the end-use and environmental considerations. Gasification plays an important role in coal conversion processes in providing gaseous and liquid fuels. Coal behaviour in gasification process can be considered in two stages: rapid pyrolysis followed by slow heterogeneous char-gas reaction.

Efficiency of a gasification process depends considerably on the heterogeneous kinetics controlling char gasification with steam, carbon dioxide and hydrogen. The efficiency of certain liquifaction processes and in situ gasification also hinges on effective utilization of coal char left after liquifaction or pyrolysis.

Pyrolysis of coal produces solid char plus liquid and gaseous volatile matter. Char accounts for 30-70% by weight of original coal and consists mainly of carbon and ash. The exact amount and composition of char depends on the conditions of coal devolatilization.

The char-steam reaction has a unique importance in utilization of coal. The major products of the reaction

are carbon monoxide and hydrogen. The mixture of these gases can be used directly as a medium heating value fuel or indirectly as building blocks for the catalytic synthesis of wide range of products such as SNG,methanol,ammonia and through Fischer-Tropsch synthesis LPG, gasoline, fuel oil, etc. Hydrogen can also be used for coal liquifaction and upgrading of heavy oil.

The char-steam reaction is endothermic. This places a considerable burden on the gasification process. In most cases, the heat requirement is provided by oxidation of a part of coal. This often amounts to one-third of the energy in coal (1). Operation at lower temperature is, therefore, desirable and provides an incentive for the development of catalytic gasification processes. The function of the catalyst will be to achieve high gasification rates at relatively low temperatures. Also, catalysts have potential to favourably alter the product distribution.

Literature on coal gasification is numerous. Nevertheless, the uncertainty of kinetics of coal reactions and its physical and chemical behaviour still presents a major problem to the designer of a coal gasification unit. One of the objectives of the present study was to find a simple kinetic model for the char-steam reaction applicable over an entire range of carbon and steam conversion.

Most kinetic models reported in

based on initial rates of carbon gasification or rates at

fixed carbon conversion. While gasification rate varies with the extent of carbon gasified, it has not been accounted for in reaction rate equations. The carbon-steam reaction may be accompanied by secondary reactions such as carbon-carbon dioxide reaction. Concentrations of reactant and product gases in the reactor vary as the reaction proceeds towards higher carbon conversion. Therefore, effect of carbon conversion, secondary reactions and varying gas composition in the reactor should be taken into account in formulating a kinetic model for the complex carbon-steam system.

Second objective of the study was to investigate the effect of various potential catalytic agents on gasification rate and product gas composition and also the kinetics of catalytic gasification. Though, it is established that alkali metal salts catalyze the carbon-steam reaction, the effect of parameters such as catalyst concentration, reaction temperature and partial pressure of steam on gasification rate and product gas composition have often been overlooked. Comparison of kinetics of gasification with and without added catalyst should reveal some facts of mechanism of catalysis. Kayembe and Pulsifier (2) recently investigated the kinetics of bituminous coal char gasification in the presence of potassium carbonate. The reaction was carried out in excess steam,

thus neglecting the effect of steam partial pressure. They found that the activation energy of the first order rate equation with respect to carbon in char is lowered by the addition of potassium carbonate.

The mechanism by which alkali metal salts catalyze the carbon steam reaction is not well understood. Though an enormous experimental effort is required to clarify certain aspects of catalytic gasification, the aim of this project was to shed some light on this aspect of the reaction. Efforts in this direction were limited by the lack of experimental facilities.

A simple experimental apparatus consisting of a laboratory-scale fixed bed reactor with the facilities for steam generation, reactor furnace and analysis of the product gas mixture was installed to study the char-steam reaction. An isothermal plug-flow reactor is amenable to easy kinetic analysis. While the height and weight of char bed were kept small, flow rate of steam was kept relatively high to approximate these conditions. A bench scale reactor a definite advantage over a thermal gravimetric analysis (TGA) balance which has often been employed for gasification and pyrolysis studies. While a TGA balance can produce more experimental data in relatively shorter time, product analysis is extremely difficult due to small amounts of product gases involved.

A high temperature lignite char from Saskatchewan lignite, provided by Energy Mines and Resources (EMR) Research

Laboratory was used in this work. Lignite is a low rank coal and has higher intrinsic reactivity than higher rank coals. Saskatchewan has large deposits of lignite coal which, at present, are mainly used for thermal power generation. Various EMR sponsored research projects are underway for the efficient utilization of Saskatchewan lignite coal.

This thesis is comprised of nine chapters, first being the Introduction itself. The second chapter gives a comprehensive survey of the literature on the carbon-steam reaction in general and the char-steam reaction in particular. The details of experimental setup, reactor assembly and experimental techniques involved are included in Chapter 3. The kinetic analysis is described in Chapter 4. Chapter 5 includes the experimental results. Discussion on the results of this study and conclusions drawn therefrom are given in Chapters 6 and 7 respectively. Chapter 8 outlines the significant contributions made as a result of this study. Recommendations for further research in this field are included in Chapter 9.

CHAPTER 2

LITERATURE REVIEW

The literature on the kinetics and catalysis of carbon gasification has been reviewed extensively several times (3, 4, 5, 6, 7, 8, 9, 10, 11, 12). In these reviews, the carbon-steam reaction has been considered either as one step in the carbon gasification reaction or as a reaction system by itself. In either case, it has been shown that some aspects of the reaction mechanism of the gas-carbon reaction are analogous. The thermodynamics of the carbon-steam reaction has also been extensively investigated (9, 10, 13). Laurendeau (7) has specifically reviewed only gasification of char with oxygen, carbon dioxide and steam. All aspects except catalysis of the gasification reactions have been described.

2.1 Carbon-Steam System

The carbon-steam reaction is represented by a set of reactions where secondary reactions are also prominent. Depending on the experimental conditions, the products of the primary carbon-steam reaction may in turn react with steam or the carbon surface. Neglecting reactions involving the formation of higher hydrocarbons, dissociation of methane and reactions involving molecular oxygen, the system can be represented by the following reactions:

$$C + H_2O = CO + H_2 \quad (1)$$

$$CO + H_2O = CO_2 + H_2 \quad (2)$$

$$C + 2H_2O = CO_2 + 2H_2 \quad (3)$$

$$C + CO_2 = 2CO \quad (4)$$

$$C + 2H_2 = CH_4 \quad (5)$$

Reactions 1, 3 and 4 are highly endothermic, whereas reaction 2 and 5 are moderately exothermic. Reaction 2 is known as the water-gas shift reaction.

There seems to be a general agreement that reaction 1 is the primary mode of steam decomposition (6, 9, 12, 14). Taylor and Neville (8) explained that the carbon dioxide is formed not by reaction 3, but through reaction 2 by establishment of the water-gas shift equilibrium. They also showed that approach to equilibrium is speeded by the ash in the fuel, by lowering the reaction temperature and by using the excess steam. Gadsby et al. (15) report that under similar conditions of temperature and reactant partial pressure, reaction 4 is three times slower than reaction 1.

Reaction 5 is not favoured at atmospheric pressure. Walker and co-workers (10) estimate reaction 5 to be 1000 times slower than reaction 1 at 800°C and 0.1 atm partial pressure of reactant gas. Jolley and Poll (6) showed that methane formed, accounts only for 1-2 percent of total gas produced from steam reaction with Baddesley Coke at 800°C.

These observations suggest that between 600°C and 1000°C and in the absence of any catalytic agents, reaction 1 occurs with no significant interference by the other four reactions. The effect of ash in the fuel will be to increase the contribution of the water-gas shift reaction to the overall process (8). Reaction 1 will be referred to as the carbon-steam reaction.

2.2 Heterogeneous Nature of the Reaction

The reaction between carbon and steam is heterogeneous and may therefore be affected by the diffusional phenomenon that occur during the interaction of the steam and the carbon surface. Since most carbonaceous materials are porous, the sequence of steps involved may include some or all of the following:

1. diffusion of reacting gas from the bulk gas stream to the solid surface;
2. diffusion of reacting gas from the exterior surface of the solid to an active site within the pore structure;
3. adsorption of reactant, in whole or in part, on the solid surface;
4. chemical reaction of the adsorbed reactant to adsorbed products;

5. desorption of adsorbed products;
6. diffusion of products from the pore structure to the exterior surface of the solid;
7. diffusion products from the solid surface to the bulk gas stream.

The rate of carbon-steam reaction may be controlled by any of these steps. It is essential that the effects of boundary film diffusion (steps 1 and 7) and pore diffusion (steps 2 and 6) be minimized if a better understanding of the true kinetics is required. If not properly accounted for, diffusion effects will lead to erroneous reaction rates, order of reaction and activation energies (16, 17). It has been pointed out that the importance of these transport effects generally increases with the reactivity of the carbon surface and the particle size.

There appears to be a general agreement that the rate of the carbon steam reaction is controlled by chemical reactions at the carbon surface (steps 3-5) at low temperatures, and by external diffusion at high temperatures. Transition from kinetic control to pore diffusion control presumably occurs between 1100°C and 1150°C (6, 9, 18). The transition temperatures vary with fuel reactivity.

Walker et al. (11) point out that in the absence of diffusional effects, the rate controlling step in gas-carbon

reactions depends on the partial pressure of reacting gas and on the reaction temperature. Thus, the reaction rate is controlled by the adsorption step at very low partial pressures and by the desorption at very high partial pressures. Their relative effects change at intermediate pressures. Their relative effects change in such a way that control may pass from one step to another under certain conditions. Batchelder (3) shows that desorption step is rate controlling below 980°C, whereas adsorption step controls above 1090°C at atmospheric pressure. As the pressure is increased at high temperatures, the desorption step may again be controlling the rate of the reaction.

2.3 Reaction Rate Models

Formulation of a precise mathematical model which would satisfactorily correlate experimental data may require considerable experimentation. The rate of the carbon-steam reaction has been represented either by power law models or by a rate equation developed from Langmuir-Hinshelwood mechanism. Differences in proposed models can be, in part, attributed to differences in experimental conditions. Mechanistic model forms are to be preferred to power law models. They offer some insight into the mechanism of reaction and as such can be used for extrapolation purposes with more confidence than the empirical power models.

The problem is to identify the best model for the reaction. Mezaki and Happel (19) have reviewed the work in this area. Kittrel (20) offers a set of criterion which must be satisfied to ensure the physical justification of rate models. The estimated rate constants must be positive with positive activation energies, whereas the estimated adsorption constants must be positive with negative heat of adsorption. In the case of dissociative (endothermic) adsorption, positive heat of adsorption will be expected. Kittrel (20) also recommends that confidence intervals for all the parameters estimates be examined before rejecting a given model.

A general rate model based on Langmuir-Hinshelwood kinetics and a power law model are presented here.

2.3.1 General Rate Model

Experimental rate data on steam gasification of carbon are in general accord with a Langmuir-Hinshelwood kinetics of the form:

$$r = \frac{k_1 p_{H_2O}}{1+k_2 p_{H_2}+k_3 p_{H_2O}} \qquad (2.1)$$

where r is the specific rate of carbon gasification and p_{H_2O} and p_{H_2} are the partial pressures of steam and hydrogen respectively. The constants k_1, k_2 and k_3 are related to

specific rate constants of certain elementary kinetic steps of a postulated reaction mechanism. According to equation 2.1 the rate process is slowed down by hydrogen and steam. It also reveals that the order of reaction with respect to steam varies from zero to unity depending on the conditions of pressure and temperature. Since the constants k_2 and k_3 decrease exponentially with temperature, the reaction is expected to become first order at high temperatures and low pressures of steam. At high steam pressures and normal gasification temperatures, the reaction is zero order. A fractional order is expected at other conditions.

It should be noted that the rate model of equation 1 is subjected to the limitations of Langmuir-Hinshelwood mechanism from which it was derived. Smith (15) has discussed these limitations. Results of investigators whose data has been adequately described by this model will be presented here.

Johnstone et al. (21) fitted their differential rate data on the gasification of graphite tubes with the three parameter model but showed that constants k_1, k_2 and k_3 depend not only on the reaction temperature but also on the extent of carbon conversion. Activation energies for k_1, k_2 and k_3 were 32.7, -60.8 and -79.3 k cal/mol at zero carbon conversion and 13.1, -69.2 and -82.9 k cal/mol at 7.5% conversion. The negative values can be considered as heats

of adsorption.

Long and Sykes (22) report activation energies of 62.3 and 20.1 k cal/mol for k_1 and k_2 respectively for their experiments with coconut char at 680°C to 770°C and steam pressures of 10 to 760 mm Hg. The constant k_2 was found to be independent of temperature.

From the rate data of May et al. (23) on the gasification of Disco coke at 870°C to 980°C, respective activation energies of 42.0 and 4.0 k cal/mol for k_1 and k_2 have been presented. Activation energy for k_3 was assumed to be the same as that of k_2. Von Fredstroff and Elliott (9) reported an activation energy of 59.1 k cal/mol for k_1 and heat of adsorption of -20.5 k cal/mol for k_2.

Recently Katta and Keairns (24) have explained their results of C-H_2O and C-CO_2 reactions with the help of a simplified Langmuir-Hinshelwood rate expression. They found the activation energies of 69 k cal/mol for C-CO_2 reaction and 48.2 k cal/mol for C-H_2O reaction.

There have been examples (25) where investigations have not been able to fit their data properly with rate model of equation 2.1 and they resorted to a power law model.

2.3.2 Power Law Model

Reaction rate models with rate being proportional to steam pressure raised to a power, have often been used to explain the experimental data of steam gasification. The

power could be zero, a fraction, one or even more than one.

Batchelder (3) used the three parameter model, with kinetic data of Johnstone et al. (21) on the gasification of graphite tubes to show that carbon-steam reaction is zero order with respect to steam below 980°C at atmospheric pressure. They also predicted that zero order reaction will prevail above 1090°C at high pressures. Strickland-Constable (26) has also predicted zero order reaction for the gasification of carbon filaments at 700°C and steam pressures lower than 1 mm of mercury.

Results of several investigations with their experimental conditions are summarised in Table 2.1. Overall activation energies of the order of 30-60 k cal/mol have been reported in the atmospheric pressure studies at temperatures from 850°C to 1150°C.

Jensen (27) studied the C-H_2O reaction in a fluidized bed in the temperature range of 1040°C to 1430°C at atmospheric pressure. He applied the unreacted shrinking core model for the kinetics of a Kentucky Coal gasification and reported an activation energy of 20 k cal/mol.

Linares et al. (28) studied the reactivities of several chars in air, H_2O and CO_2. They correlated their results with carbon conversion as a function of $t/t_{0.5}$, where t is the reaction time and $t_{0.5}$ is the time for 50% carbon conversion.

Table 2.1

INVESTIGATIONS OF CARBON-STEAM REACTION

	Investigators	Sample	T, °C	P, atm	m	E, k cal/mol
1.	Jolley & Poll (6)	Coke	850- 950	1	0.7-0.8	40
2.	Pilcher et al. (57)	Carbon	1000-1100	0.04-0.47	0.7	41
3.	Binford & Erying (38)	Graphite	900-1100	$\sim 10^{-3}$	0	60
4.	Van Heek et al. (33)	Coals & Chars	600-1100	10	0	30-50
5.	Scott (58)	Lignite Char	700-1000	?	2	26
6.	Riede & Hanesian (59)	Graphite	500- 900	$\sim$ 0.1	1	16
7.	Kayembe & Pulsifier (2)	Bituminous Char	600- 852	1	0	61
8.	Linares et al. (60)	Lignite Char	752- 932	10^{-3}	0.6	42
9.	Zielke & Gorin (32)	Disco Char	890- 927	1-30	0.1-1.5	40-75
10.	Jensen (27)	Kentucky Coal	1040-1430	1	1	20

Gasification reactions were closely described by a first order rate equation over a carbon conversion range up to 70% and by cubic equation over the entire range. Effect of temperature was not investigated.

Reaction rate of carbon gasification depends on other factors other than reaction temperature, namely carbon conversion, particle size etc. Effect of these factors are also being reviewed here.

2.4- Effect of Carbon Conversion

The effect of carbon conversion on the specific gasification rate has not yet been completely established. Some investigators (21, 23, 29, 30, 31) report an increase in the specific rate with carbon conversion while others (4, 25, 29, 30, 32) find the rate to decrease with increasing conversion. Still others (32) find the gasification rate independent of conversion. These conclusions have been drawn by experimental studies both in fixed bed and fluidized bed reactors.

Jolley and Poll (6) found a linear increase in specific gasification rate with carbon conversion up to 75 percent for various cokes at 800°C and 1 atm in a fixed bed reactor. Relation between two parameters is parabolic at temperatures above 850°C. Lewis et al. (25) on the other hand found decrease in specific rates with increase in conversion at

constant steam rate and pressure up to 28 atm at 650°C. The specific gasification rate tended to decrease at a falling rate.

May and Mueller (23) studied the carbon-steam reaction at 870°C to 980°C using low temperature Disco coke with 13.4 percent ash. They found an increase in specific gasification rate with carbon conversion in all cases. They also noted that the rate may either increase or decrease with carbon conversion, depending on the initial reactivity of carbon fuel. Gasification rates for initially reactive fuel will decrease, whereas those for refractory carbons will increase with conversion.

Goring and co-workers (29, 30) investigated the gasification in fluidized bed of disco char with steam-hydrogen mixtures. They maintained a constant superficial fluidizing velocity of 13.4 cm/sec in the temperature range of 815°C to 927°C and pressures up to 30 atmospheres. They showed (29) that rate may increase or decrease with carbon conversion depending on the time allowed for char pretreatment with nitrogen at reaction temperature. In general, chars without prior treatment exhibit a decrease in rate with carbon conversion, whereas pretreated chars would show an increase in rate. Increasing the hydrogen content of fluidizing gas mixtures resulted in a decrease in the gasification rate (30). However, Zielke and Gorin (32) reported a general

decrease in rate with carbon conversion for all inlet gas mixtures at all temperatures investigated. The later works also found that the rate of decrease of the specific gasification rate diminished with increase in temperature.

2.5 Effect of Particle Size

Several investigators (2, 4, 6, 18, 33) have found the specific gasification rate of carbon is generally not affected by particle size in the size range of 0.2 to 2.0 mm between 600°C and 1200°C at atmospheric or higher pressures. Jolley and Poll (6) showed the independence of rate by comparing initial rates obtained at content steam rate and initial bed depth of coke for various particle sizes in the range 0.211 to 1.20 mm. Gasification rate data of Van Heek et al. (31) where plotted as a function of particle size showed minima and maxima as the particle size increased from about 0.5 to 1.6 mm. The effect of particle size can be considered insignificant for sub-bituminous coal at temperatures up to 950°C and for lignite up to 750°C only. Particle size seems to have considerable influence at higher temperatures (33).

Kayembe and Pulsifier (2) in their study of gasification of a bituminous coal char at 815°C and 1 atm found the rate of gasification is unaffected by the particle size in the range of 1.25 mm to 1.49 mm.

From the literature reviewed here, it is obvious that there is no general rule to predict the effect of various experimental variables on the gasification rate. This is more so in case of coals and coal chars. Therefore, each coal and coal char or any other carbon fuel should be characterized individually under a set of operating conditions.

The literature review also shows that most kinetic models are based either on initial rate or rate at fixed carbon conversion. The change in the rate of gasification with carbon conversion has been studied to a very limited extent. These considerations point out the need for developing a more meaningful rate model which can apply over a wide range of carbon and steam conversion and other experimental conditions, still exists.

2.6 Mechanism of the Reaction

There are several mechanisms which have been proposed for the carbon-steam reaction. But a general feature of gas-carbon reaction is that the first step involves chemisorption of reacting gas molecules on the solid surface, forming either adsorbed molecules or surface-oxygen complexes (9). Some of the reaction products may also be adsorbed on the carbon surface and retarded the progress of the reaction.

The fraction of the surface covered by adsorbed reactant and product molecules has been found to be relatively small and appears to depend on the concentration of active sites in the carbon structure. Adsorbed products may be removed from the surface by desorption into the gas phase, or by reaction with gaseous reaction products. The rate of formation of surface complexes, the rate of their disappearance and the extent of surface coverage determine the rate of carbon gasification. The theory of chemisorption has been described by Smith (17) and reviewed by Van Fredstroff and Elliott (9).

2.6.1 Formation of Surface-Oxygen Complexes

Numerous investigators studied the formation of surface-oxygen complexes in gas-carbon reactions (15, 22, 26, 34, 35, 36). Puri (36) has recently reviewed the role played by carbon oxygen complexes in influencing surface reactions. Surface behaviour and electrical and catalytic properties of carbons.

Many workers have demonstrated the ability of carbon to dissociate oxygen atoms from oxygen and oxygen containing gas molecules and to adsorb them strongly (4, 22, 34, 37, 38). In carbon steam reaction, it is believed that decomposition of steam at the carbon surface results in rapid

chemisorption on adjacent sites of an oxygen atom and molecular hydrogen (9). Chemisorption of steam in molecular form has been suggested by Strickland-Constable (26). Johnstone et al. (21), on the other hand, support a mechanism of adsorption involving dissociation of steam into a hydrogen atom and hydroxyl group adsorbed on neighbouring sites.

2.6.2 The Concept of Active Sites

According to active site theory, the reaction occurs at favoured sites on the surface. Such sites are thought to consist of carbon atoms attached to the carbon lattice by less than four bonds (22). The resulting valance force induce electron transfer causing gas-solid bonding or chemisorption. In a recently published review on char gasification (7), the active sites for char have been attributed to carbon edges and dislocations; inorganic impurities and oxygen and hydrogen functional groups. According to the author, following phenomenon may occur on each site: (1) reaction adsorption, (2) migration of intermediate, and (3) product desorption. Both adsorption and desorption can occur via a single site or dual site mechanism (7). Migration account for changes in the mobility and stability of surface intermediates (39).

Difference in reactivity of carbonaceous fuels has been attributed to the difference in the number and density of active free sites (9).

2.6.3 Rate Hindrance by Products

It is an established fact now that hydrogen retards the rate of carbon-steam reaction. There is some disagreement however as to the mechanism by which rate hindrance occurs (9). Some investigators (15, 21, 22, 26) hold that hydrogen inhibits the reaction by adsorption on the carbon surface. Others favour (40) the reaction of hydrogen with surface oxygen complex as the primary mode of retardation. The difference between the two mechanisms is the reversibility of the surface-oxygen complex formation step, which the first group of investigators reject. Keeping in view the observed (22, 26) rapid and strong adsorption of hydrogen at sub-atmospheric pressures and gasification temperatures, the first mode of rate hindrance has been more widely accepted (9, 10). But later advances (5, 41) appear to support the second mechanism.

Majority of workers (9) reject the rate hindrance by carbon monoxide. Strickland-Constable (26) observed that carbon monoxide is adsorbed on the carbon surface slowly and to a small extent. In order to explain the formation of carbon dioxide in the carbon-steam reaction, Rief (40) suggests that carbon monoxide may react with surface-oxygen complex. This explanation of rate hindrance by carbon monoxide has not been accepted by other authors.

Gadsby et al. (15) found no decrease in reaction rate upon addition of small amounts of carbon dioxide to the system. These observations have led to the conclusion that desorption of surface-oxygen complex into the gas phase as carbon monoxide may be the rate controlling step at atmospheric pressure and normal gasification temperatures.

Rate equation of the same form is obtained regardless of the postulated mechanism of rate hindrance by reaction products (9, 10). In the absence of diffusional effects, therefore, the inhibiting effects of one or more of the reaction products, and the removal of surface complexes will give the correct form of the rate equation.

2.7 Catalysis of Carbon-Steam Reaction

Early studies of the carbon-steam reaction were generally concerned with process for enriching hydrogen content of water-gas produced by interaction of steam and charcoal or coke. Taylor and Neville (8) have reviewed the literature over a period of fifty years since the late 1800s.

Metal oxides and salts of alkaline earth metals were among the suggested catalysts. Oxides of iron, chromium and manganese were used to promote the water-gas shift reaction. No information, however, was given with regard to effectiveness of the suggested catalysts toward the gasification process or to the effect of temperature changes or reaction rates. A

more recent review by Walker et al. (11) reveals that only few investigators have examined these factors in the study of the catalysis of the carbon steam reaction.

2.7.1 Relative Effectiveness of Catalysts

The effectiveness of a catalyst in accelerating the carbon-steam reaction depends on the experimental conditions (11). Therefore such factors as the chemical state of the catalyst, the intimacy of the contact between the catalyst and the carbon surface, relative amount of catalyst and fuel in the bed, and the carbon fuel type should be taken into account while comparing the performance of catalyst from different experimental studies.

Taylor and Neville (8) studied the catalyzed gasification of coconut-shell charcoal with steam at atmospheric pressure and temperatures of 490°C to 570°C. Carbonates of potassium, sodium, lithium, barium and calcium and ferric oxide were used as catalysts by wet impregnation. Potassium and sodium carbonate were by far the most effective catalysts, former being two to three times more effective than sodium salt. The other salts were only slightly effective and in order of reactivity were the carbonates of lithium, barium and calcium. They also observed that the same catalysts were effective toward the carbon-carbon dioxide reaction in exactly the same order as they accelerate the carbon-steam reaction. Ferric

oxide had no detectable effect on the gasification of char coal either by steam or carbon dioxide.

Tuddenham and Hill (42) reported that the gasification rate of graphitized carbon rods was increased by 19, 27 and 32 times at 1100°C when catalyzed by nitrates of nickel, cobalt and iron respectively. Carbon rods were soaked in 0.1 molar solutions of the nitrates for two or more days, followed by heating at 200°C to 400°C in vacuum by brief graphitization at 1100°C. The ash content of treated rods was 0.14 percent by weight.

Haynes et al. (43) investigated the relative catalytic activity of various inorganic additives in the gasification of a high volatile bituminous coal at 850°C and 20 atm. Catalyst and coal were mixed dry in a catalyst to coal ratio of 5 percent by weight. Catalyst effectiveness were examined with respect to the rates of production of H_2, CO and CH_4. The most effective catalysts in increasing the gasification rate were KCl, K_2CO_3, Li_2CO_3 and NaCl with respective increases of 66, 62, 40 and 31 percent. KCl and K_2CO_3 were also most effective in increasing the hydrogen production and carbon monoxide production, but the least effective toward methane production. Lithium carbonate with a 21 percent increase in methane production was only second to Raney nickel catalyst with 24 percent increase.

Rewick et al. (44) reported an increase in specific gasification rates one to two orders of magnitude higher than those reported by Haynes et al. (43). They investigated highly dispursed transition metal catalysts and relatively pure carbons at temperatures of 700°C to 900°C at 1 atm pressure. The effectiveness decreased from potassium to nickel and cobalt. The order of decrease in activity correspond to that of Tuddenham and Hill (42) mentioned above.

Kayembe and Pulsifier (2) investigated several catalysis with respect to a bituminous coal char-steam reaction at 650°C and 1 atm in a fixed bed reactor. In order of increasing catalytic effectiveness, the active catalysis were CuO, NaCl, KCl, Li_2CO_3, Na_2CO_3 and K_2CO_3. Calcium oxide, calcium carbonate and iron (III) oxide were totally ineffective.

Recently Verra and Bell (45) conducted a study of the effect of LiCl , NaCl, RbCl, CsCl, KOH and K_2CO_3 on the steam gasification of char produced from a subbituminous coal. Each of these materials were added by aqueous impregnation. The experiments were performed with the help of the thermogravimetric balance at an isothermal temperature of 900°C. The highest gasification rates were achieved with K_2CO_3 and KOH. All of the alkal metal chlorides behaved in identical fashion. These catalysts act as inhibitors in the early stage of gasification but improve the rate in later stages.

Overall, metal chlorides cause a net reduction in the total time for complete gasification over that required for an uncatalysed sample.

Hippo et al. (46), in their study of lignite char gasification introduced the catalyst in the dimineralized parent coal (lignite) by ion exchange before charification. Activities of catalysts were tested in a fluidized bed reactor at 650°C and 1 atm. At comparable loadings of metal cation on the acid treated lignite, the char subsequently produced, had reactivities in steam in the order: K > Na ≈ Ca > Fe > Mg.

Effects of calcium, strontium and barium on the gasification of two coal chars, one of low and one of high intrinsic activity, were evaluated by Otto et al. (47). The chars were derived from coal powders which had been impregnated with Ca, Sr or Ba, pelletized and pyrolyzed in nitrogen. The additives increased the rates in the order Ca < Sr < Ba.

From these investigations, one fact is obvious that a wide range of chemicals have been listed for their catalytic activity towards carbon gasification. But the experimental conditions were widely different in each case, also different carbon fuels were used in all these studies. There is a need that all the promising materials be tested under a wide range of identical experimental conditions and with same carbon fuel.

2.7.2 Effect of Catalyst Concentration

Literature is not plenty on the studies involving the effect of catalyst concentration. It is reported, in general, that the gasification rate increases with catalyst concentration, but this may not hold good over an extended range of concentrations.

Taylor and Neville (8) varied the concentration of catalyst between 0.5 mg to 1 g of catalyst per gram of charcoal for a charcoal charge of 8 g. They observed that, other factors being same, the rate of gas formation generally increased with the concentration of K_2CO_3 or Na_2CO_3, but became insensitive to further increases in concentration above 0.25 g/g charcoal. It was observed that at 570°C the rate actually decreased at higher concentration. It was also found that at 525°C and 575°C, a charcoal system containing 20 percent Na_2CO_3 by weight was nearly as reactive as one containing 5 percent K_2CO_3. However, charcoal-catalyst system containing 10 and 20 percent K_2CO_3 was two and three times more reactive than one containing 5 percent K_2CO_3.

Fox and White (48) and Weiss and White (41) have shown that small amounts of Na_2CO_3 can increase the gasification rate of graphite. Later, investigators reported that catalytic effect was maximum when the graphite contains 0.1 percent Na_2CO_3 by weight. They showed that above 800°C, soaking

graphite in a saturated solution of Na_2CO_3 and drying was more effective than mixing the dry carbonate with graphite. The later procedure was more effective at lower temperatures. Na_2CO_3 was not decomposed below 850°C, the coating of Na_2CO_3 on the graphite surface would hinder the reaction.

Gasification of a Wyoming subbituminous coal in the presence of a commercial nickel catalyst and potassium carbonate was studied by Wilson and co-workers (68). Varying amounts of K_2CO_3 up to 60 g were mixed with a charge of 100 g of core and 110 g of nickel catalyst. The yield of methane first increased with loadings of K_2CO_3, reached maximum between 20 to 25 g of K_2CO_3 per 100 g of coal and decreased to a constant value with further addition of carbonate. A similar relation was found between total gas production and the ratio of K_2CO_3 to coal.

Kayembe and Pulsifier (2) found that as the concentration of K_2CO_3 and Na_2CO_3 in the initial bed was decreased below 10% level, so was the value of specific rate constant of first order reaction rate of carbon gasification in a bituminous coal char at 650°C. In the case of K_2CO_3, rate constant decreased from 0.539 to 0.0385 hr^{-1} as the catalyst concentration was lowered from 10 to 5%. A further decrease from 5 to 1% level resulted in sixfold decrease in the value of

specific rate constant. Although 10% K_2CO_3 was more effective than 10% Na_2CO_3. Na_2CO_3 was better at 5% level.

Gasification rate of subbituminous coal char with steam increased as the catalyst loading increased from 2.5% to 10% potassium as carbonate in a char pellet. These were the findings of Verra and Bell (45) in their experiments conducted with the help of TGA balance at 900°C and atmospheric pressure. Hippo et al. (46) found a linear increase in the reactivity of lignite char when the calcium loadings in the original coal increased from 1.1 to 12.9%.

2.7.3 Effect of Reaction Temperature

The effect of temperature on the rate of carbon gasification in the presence of a catalyst is dictated by two conflicting factors. On the one hand, rate of reaction increases with increase in temperature, on the other hand, the activity of catalyst decreases. Therefore, it is important to find an optimum for a catalyst before it could be used in industrial reactor.

The data of Taylor and Neville (8) show that for a char catalyst system, the effectiveness of K_2CO_3 is reduced by 52% and that of Na_2CO_3 by 34% as the temperature increased from 525°C to 570°C, Haynes et al. (43) report that when Raney nickel catalyst was used, the specific gasification rate was increased by 33% at 750°C and was unaffected at 950°C.

The investigations of Rewick et al. (44) show that the increase in rate due to catalysts goes through a maximum in the temperature range of 750°C to 900°C. For a carbon black containing 0.8 percent platinum, ruthenium or nickel by weight, the maximum occurs at 800°C.

Few investigators have reported the activation energy for the catalyzed gasification of carbon by steam. Fleer and White (49) were the earliest workers to study the reaction between coke and steam-oxygen mixtures in the pressure of 5 percent Na_2CO_3 by weight. An activation energy of 26.8 k cal/mol was obtained for a first order reaction with respect to steam at atmospheric pressure and temperatures between 900°C and 1000°C.

Long and Sykes (50) found that gasification rate of charcoal reduced to about half after the ash content of the char was reduced from 3.5 to 0.04% by acid wash. The catalytic effect of impurities in the original charcoal was apparent from the activation energy which was required for desorption of the surface-oxygen complex into the gas phase as carbon monoxide. Catalysis decreased this activation energy from 83 ± 5 k cal/mol for the extracted charcoal to 53 ± 7 k cal/mol for the original charcoal. These results were obtained in the temperature range of 700°C to 900°C and steam pressures between 0.1 to 1 atm.

An addition of 10% K_2CO_3 to the coal char lowered the apparent activation energy of the char steam reaction from 60.8 to 34.5 k cal/mol and the frequency factor from 2.41 x 10^8 to 1.32 x 10^4 s^{-1}. These results were obtained by Kayembe and Pulsifier (2) for a first order reaction with respect to carbon in the temperature range of 650°C to 800°C near 1 atm pressure.

Verra and Bell (45) have reported the activation energies of 49, 45 and 39 k cal/mol for catalyst loadings of 0, 5 and 10 percent potassium by weight respectively. A sub-bituminous coal char and steam-helium mixture were used as reactant in the temperature range of 600°C to 700°C. But the reaction might not have been entirely free from diffusion effects.

Otto et al. (47) from their study of steam-char reaction in the presence of alkaline earth catalysts (calcium, strontium and barium) concluded that increase in gasification rate is not caused by the lowering of activation energy of gasification reaction but due to an increase in the reaction site density. They further stated that sometimes, especially in case of North Dakota lignite char, the apparent activation energies of the catalyzed rates were significantly larger than those for untreated char. A value of 80 k cal/mol was obtained for uncatalyzed gasification.

2.8 Mechanism of Catalyzed Gasification

Wen (51) has recently published a review covering all aspects of alkali metal catalysis in the gasification of coal, char or graphite. Taylor and Neville (8) in 1921 gave the earliest explanation of catalysis. It was based on the physico-complex theory of carbon gasification developed by Rhead and Wheeler. It shows no direct interaction between catalyst and carbon or steam. An alternate oxidation reduction mechanism for metal oxide catalysts has been postulated by Fox and White (48). A modern theory of catalysis advanced by Long and Sykes (50, 52) involves the transfer of electrons between the carbon and the metal oxide catalyst.

2.8.1 Surface-Cleaning Mechanism

Taylor and Neville (8) observed that both carbon-steam and carbon-carbon dioxide reaction were accelerated by the same catalyst. They ascribed the catalysis of both the reactions to the increase in adsorption characteristics of the charcoal surface toward carbon dioxide in presence of alkali metal salts. For the carbon-steam reaction the catalytic effect was viewed as the result of the catalysis of the reaction between carbon and carbon dioxide formed by the water-gas shift reaction at equilibrium. The catalytic effect in the carbon-carbon dioxide reaction on the other

hand, was attributed to an increasingly clean carbon surface resulting from surface complex removal. The clean surface was more reactive toward the carbon dioxide.

Lambert (53) postulated a similar mechanism for catalysis of the oxidation of carbon by iron and magnese. He also assumed that the function of the catalyst was to catalyze the decomposition of the surface-oxygen complex, which otherwise is stable at low temperatures and retards the reaction.

2.8.2 Oxidation-Reduction Mechanism

Fox and White (48) in 1931 showed that above 800°C, sodium carbonate reacts with carbon to give sodium vapor and carbon monoxide. The sodium vapor reacts with carbon dioxide giving sodium oxide and carbon monoxide, and sodium oxide further reacts with another molecule of carbon dioxide to generate sodium carbonate. Thus, catalysis of graphite-steam reaction by sodium carbonate was explained by an alternate reduction and regeneration of carbonate. Taylor and Neville did not accept this sodium cycle as a possible mechanism of catalysis (8).

Fox and White (48) considered sodium vapor as the primary catalytic agent. Its influence was thought to be one of rupturing the stagnant gas film surrounding each graphite particle, thus allowing a more ready reaction between the carbon and gas.

Lewis et al. (25) observed a decrease in reaction rate with increasing partial pressure of carbon dioxide in a catalytic study at 650°C and pressures up to 50 atm. They explained that the active agent of catalyst pressumably migrates through gas phase to active free sites on the carbon surface and that the concentration of active catalyst may be controlled by the concentration of carbon-dioxide. The nature of the active agent of the catalyst was not specified.

McKee and Chatterji (54) suggested the following sequence of reaction steps for the sodium and potassium catalysts:

$$K_2CO_3 + 2C = 2K + 3CO \quad (1)$$

$$2K + 2H_2O = 2KOH + H_2 \quad (2)$$

$$2KOH + CO = K_2CO_3 + H_2 \quad (3)$$

One to one mixtures by weight, of carbonate and spectroscopic graphite was used. They conclude that reaction 1 is the rate determining step in the cycle and that the overall gasification rate will depend on the salt-carbon interfacial contact area, which will be rapidly increased as the carbonate phase melts and wets the carbon surface. Hippo et al. (46) have noted that this should show a discontinuous increase in the gasification rate as the temperature passes from below to above the melting point of carbonate. But McKee and Chatterji (54) reported a smooth Arrhenius plot for the graphite-steam reaction in the presence of K_2CO_3 over the

temperature range of 850°C to 1035°C. The melting point of K_2CO_3 is 891°C. Verra and Bell (45) also reported a smooth curve of coal char-steam reaction in the presence of K_2CO_3 in the temperature range of 700°C to 900°C.

Ferriks et al. (55) have recently investigated some aspects of carbon-steam reaction catalyzed by decomposition products of potassium carbonate using temperature programmed desorption and in-situ Fourier transform infrared spectroscopy. Their results show that with potassium carbonate impregnated carbon, the carbonate is unstable above 700°C and decomposes into CO_2 and a surface potassium compound. According to them, this explains the absence of a discontinuous increase in reaction rate at the melting point of the alkali metal carbonate.

Milner et al. (56) presented another version of the oxidation reduction mechanism. The metal oxide catalyst was assumed to react with steam first, forming an unstable complex. The complex is then decomposed by carbon to give hydrogen, carbon monoxide and the metal oxide.

Hippo et al. (46) have suggested that the dissociation of steam into adsorbed oxygen and hydrogen atoms is an important step in the catalyzed gasification. The oxygen then produced migrates from the catalyst onto the char surface, where its interaction with active sites leads to gasification.

2.8.3 Electron Transfer Mechanisms

Long and Sykes (50) observed that the reaction mechanism was generally not changed by the presence of a catalyst but only the rates of certain stages were enhanced. In particular, the rate of formation of the surface-oxygen complex was slightly increased, whereas the increase in the rate of its desorption was proportionately larger. They postulated that the action of catalyst must be one of lowering the activation energy required for both the adsorption and desorption steps of the reaction mechanism. To accomplish this, the catalyst must exert its influence at certain active sites at the edges of the carbon lattice.

An oxygen atom adsorbed at such a site is attached firmly to the carbon structure by a single bond. Desorption of the carbon-oxygen complex (carbon monoxide) should be facilitated if the carbon-carbon bond is weakened. It was shown that the required change in bond order, from a double bond to a single carbon-carbon bond and from a single to a double carbon-oxygen bond, could be made by electron transfer between catalyst and carbon. Catalysis was then explained as being due to this interaction, at the electronic level, between catalyst and carbon.

Long and Sykes (50) demonstrated that a transition metal oxide catalyzes the reaction by accepting an electron from

the carbon. The oxide need only be in contact with the place of the carbon lattice from which the electron is removed for catalysis to occur. In a later development (52), it was shown that an alkali metal atom catalyzes the reaction by sharing its unpaired electron with the carbon, that is by forming a covalent bond with a carbon atom.

Walker et al. (11) discuss some of the modifications of this general electronic theory of catalysis to explain the experimental results which cannot be rationalized by the concepts of Long and Sykes (50).

CHAPTER 3

EXPERIMENTAL DETAILS

3.1 Apparatus

The flow diagram of the experimental set up is shown in Figure 1. It consists of a fixed bed reactor, a furnace, a system for generating steam, equipment for removal of unreacted steam and facilities for sampling, metering and analyzing the product gases. Nitrogen alone dried over a calcium sulfate dessicant could also be circulated through the reactor.

Distilled water, stored in a 3 cm ID glass container was supplied at a constant flow rate to an electrically heated vaporizer where steam was generated. The steam or steam-nitrogen mixture was allowed to pass through a pre-heating section at reaction temperature in a bench scale reactor mounted in a vertical furnace. Hot gases from the reactor, consisting of steam, nitrogen, hydrogen, carbon monoxide, carbon dioxide and methane passed through a water cooled heat exchanger where steam was condensed. The condensate was collected in a cylindrical glass container. The product gases were further dried and metered through a calibrated wet-test meter before being vented to the atmosphere.

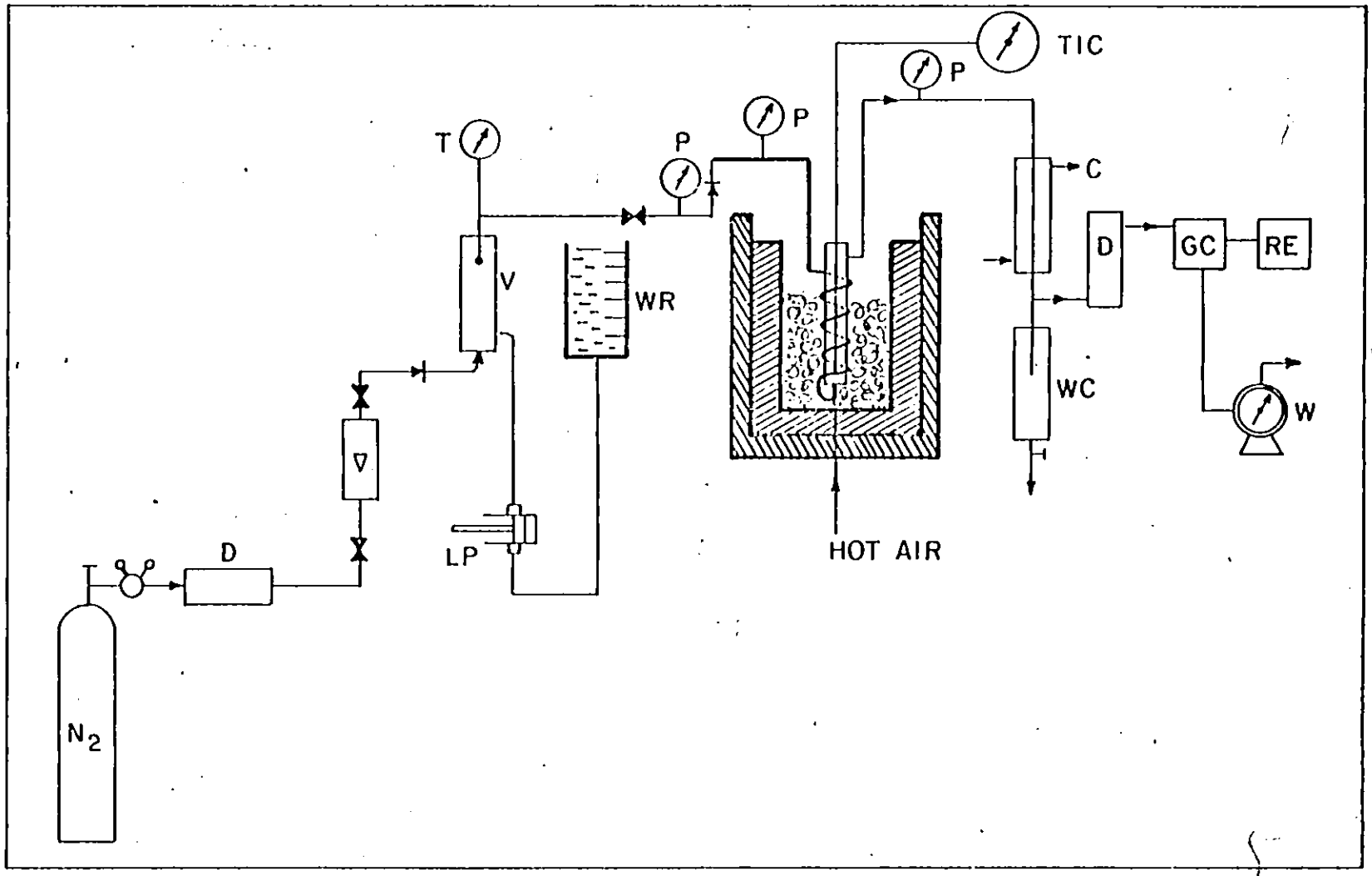

Figure 1. Experimental Set Up

C-Condenser; D-Drying Tube; GC-Gas Chromatograph; LP-Liquid Pump; P-Pressure Gauge; R-Reactor; RE-Recorder-Integrator; T-Temperature Gauge; TIC-Temperature Controller-Indicator; V-Vaporizer; W-Wet-Test Meter; WC-Water Collector; WR-Water Reservoir.

3.1.1 Vaporizer

The vaporizer was a vertical 20 cm x 3 cm ID stainless steel (ss) tube. Water was fed near the bottom through a 0.63 cm ID ss tubing. Nitrogen was bubbled from the bottom of the vaporizer tube. The vaporizer tube was filled with steel balls and turnings to improve the heat transfer rate. A heating wire was wound around the vaporizer tube and covered with asbestos insulation.

A micro-pump (Milton Roy Company, River Beach, Florida) was used to feed water at a constant rate. The water was vaporized quickly upon contact with the vaporizer wall and the ss balls and turnings inside, thus assuring a continuous generation of steam. The steam content of the total gas flow rate could be controlled by manipulating the temperature and pressure of the vaporizer and flow rate of nitrogen. The process line connecting the vaporizer to the reactor inlet was wound with insulating-heating tape. The temperature and pressure of steam-gas mixture at the outlet of the vaporizer were continuously monitored.

3.1.2 Reactor Design

The layout of the reactor is shown in Figure 2. It consisted of 20.5 cm length x 12.5 mm OD ss 316 tube with wall thickness of 1.1 mm. The char bed was supported on a

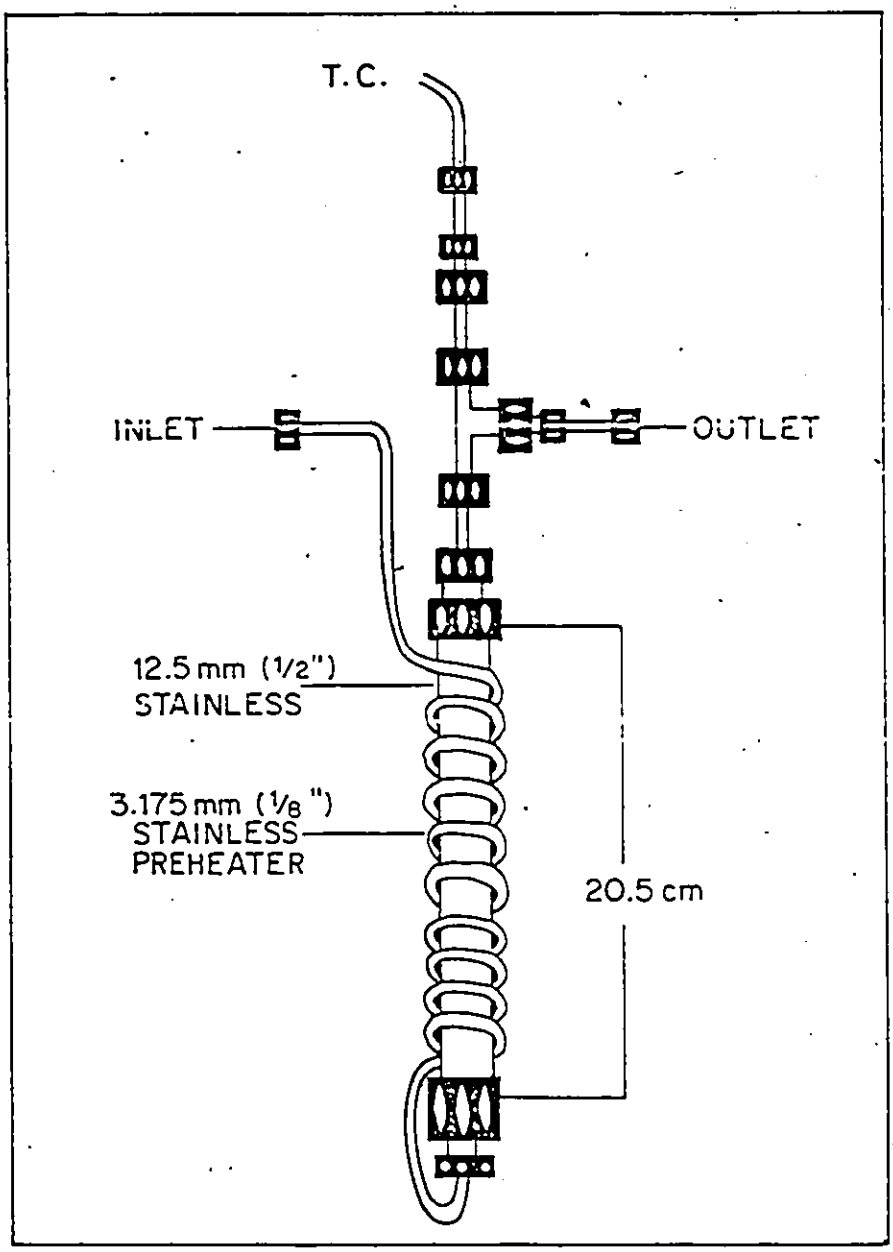

Figure 2. Reactor Layout

porous ss plate (grade D with a mean pore size of 65 micron). A thermocouple (type K, sheathed and sealed in 1.6 mm OD, ss casing) was inserted into the char bed. A desired amount of char was packed in the reactor. The amount was varied from 2 to 5 g to give a bed height of 4 to 10 cm.

The steam/nitrogen entered a preheating zone comprising of a 3.175 OD tube wound loosely around the reactor tube. The purpose of the preheater was to bring the temperature of the gas to reactor temperature. The steam entered from the bottom of the reactor, passed through the char bed and the products were drawn from the top of the reactor.

3.1.3 Furnace Assembly

The reactor was placed in a furnace comprising of a stainless steel cylinder of dimensions 40 cm length x 9 cm OD x 0.5 cm wall thickness, filled with sand. The sand bed was supported on a porous ss plate which also served as distributor for the hot air used to fluidize the bed. The air was preheated by wrapping the air inlet tube with electrical heating tape.

The ss cylinder was enclosed in a cylindrical furnace. The furnace consisted of five heaters. Three of these were in parallel and were kept in 'ON' position at all times. The other two heaters were powered by a temperature controller

(Honeywell, type K, 0-1300°C). The power input into the two blocks of heaters was varied depending on the reaction temperature required. The electric current flowing through these heaters was also monitored. The feed back to the controller was from the thermocouple inserted in the char bed. The controller was a cyclic on-off type, thereby performing as a proportional controller.

The heater assembly was placed in a larger aluminium container and the annular space was filled with insulating material. The top of the furnace was covered with two halves of asbestos sheet.

3.1.4 Gas Analysis

A sample was drawn from the product stream by means of a gas sampling valve and analyzed by a gas chromatograph (HP5730A). The sampling valve was equipped with a dual loop. The dual loop configuration had the advantage of allowing one loop to be purged and filled while the other loop was being used.

The chromatograph was equipped with two identical columns (ss 3.175 mm OD x 2.1 m length) packed with carbo-sieve S. The columns were provided by Supelco, Inc., Bell-tonte, Pa., U.S.A. One of these columns served as an analytical column, the other one was used as reference column. Helium was used as carrier gas at a flow rate of 40 cm^3/min.

Column temperature was programmed from 35°C to 180°C at the rate of 16°C/min with an initial time of 5 min at 35°C.

Thermal conductivity detector response was calibrated with standard samples of all the components, namely hydrogen, carbon monoxide, carbon dioxide, methane and nitrogen. The response for these components except hydrogen was linear in the concentration range used and the response factors matched with those of Pietz (61). A calibration curve for hydrogen and response factors for other product gases are listed in in Appendix I. The gases of research purity were provided by Matheson, Canada Limited.

3.2 Char Sample

A Saskatchewan lignite char sample was obtained from Energy, Mines and Resources, Research Lab, Ottawa. It was produced by the pyrolysis of the lignite at 927°C in a helium atmosphere. Char/bed characteristics are given in Table 3.1 and 3.1a.

Table 3.1

CHAR CHARACTERISTICS

Proximate, weight %		Ultimate, weight %	
Moisture	0.3	Carbon	78.8
Ash	17.9	Hydrogen	0.9
Volatile Matter	4.4	Nitrogen	0.9
Fixed Carbon	77.4	Sulfur	0.3
		Oxygen	1.0
	100.0	Ash	18.1
			100.0

Cumulative pore vol = 0.044 cm^3/g

Apparent density = 1.5284 cm^3/g

Calorific value = 11,858 BTU/lb.

B.E.T. surface area (N_2) = 216 m^2/g

Figure 3 shows a curve of circulative surface area vs. pore diameter. It shows that 60% of pore surface area lies within the pores of smaller than 0.0049 μm in diameter and 80% of the pore surface area was due to pores smaller than 0.013 μm in diameter. Surface area and pore distribution of the char was provided by Micromeritics, Norcross, Ga., U.S.A.

3.3 Addition of Catalyst

Alkali metal salts K_2CO_3, Na_2CO_3, KCl, and NaCl were added to the char by wet impregnation. Catalyst and char were mixed dry and moistened with water. Water was evaporated over a water bath with continuous stirring of the mixture. Finally, the moisture was removed by heating at 110°C for two hours. In the past, this method was proved more effective than just physical mixing of catalyst with char.

Ferric oxide (Fe_2O_3) was admixed with dry coal char. Nickel nitrate was also added by wet impregnation, and later reduced to nickel at 650°C in an atmosphere of hydrogen.

3.4 Temperature Profile in the Reactor

Temperature readings were taken at different bed depths of the reactor bed by adjusting the height of the thermocouple.

Table 3.1a

CHAR BED CHARACTERISTICS

Bed volume	= 6.22 cm^3
Average particle diameter	= 214 μm
Bed porosity	= 0.546
Residence time	= 2 to 4 sec.
Particle Reynolds number	< 1

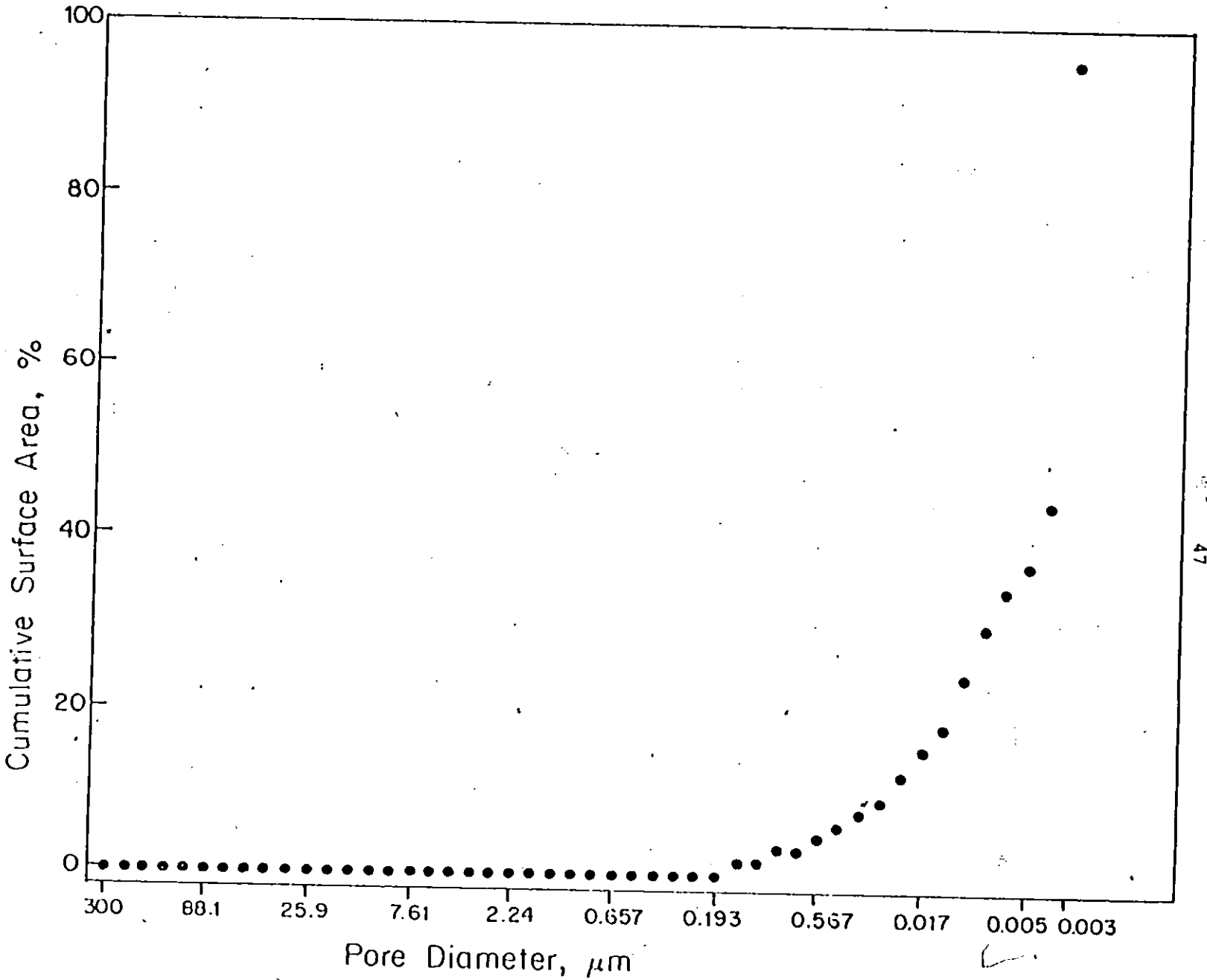

Figure 3. Surface Area Distribution Within Pores of Lignite Char

By proper positioning of the reactor tube in the sand bed it was found that there was an isothermal zone of 11 cm from the bottom of the reactor. The char bed was always confined to the isothermal zone of the reactor. Temperature readings inside and outside the reactor tube agreed with each other within 2-3°C. It showed that there were no significant radial temperature gradient in the char bed.

3.5 Start-up and Operation

The reactor was charged with a weighed sample of char with or without the added catalyst. The empty space above the char bed was packed with glass wool to prevent the char particles from being carried away by the gas-stream. A drying tube filled with fresh anhydrous calcium sulfate and a condensate collector were connected to the process line. The steam feed valve was closed and only nitrogen flow was started through the reactor. The system was then checked for leaks. Power to the furnace was turned on and increased slowly to obtain the desired reaction temperature inside the char bed. It took 5-6 hours to reach a temperature of 600°C.

The water feed pump was set to get a desired flow rate to the vaporizer. Nitrogen was bubbled from the bottom of the vaporizer. The variable transformer was set at a value to give a predetermined power input to the vaporizer heater. Temperature of the outcoming steam-N_2 mixture was monitored

continuously. Steam content of the gas mixture was condensed to determine the fraction of steam in the gas mixtures. By adjusting the flow rate and power input to the vaporizer heater, a desired steam fraction was obtained. Steam content of the gas mixture was monitored for at least two hours before the start of the reaction.

Helium flow to the gas chromatograph was started and the temperature controllers for the heating system of the gas chromatograph were set at optimum operating conditions. The gas chromatograph was ready for use within two hours. A sample of gas coming out of the reactor before start of the reaction was analyzed for its content. It contained mainly nitrogen with trace amounts of carbon monoxide and carbon dioxide at higher reaction temperatures (>700^{o}C).

Once the char bed temperature reached the desired value and was steady for at least 30 minutes, nitrogen flow was discontinued. The steam feed valve was opened and the vent valve of the vaporizer was closed, thus marking the start of the run.

The reactor pressure increased to its final value (1-2 atm) within 15-20 minutes and remained essentially constant during the time period of the run. During the course of the run, process gas samples were taken at regular intervals of 20 minutes and analyzed. Total gas volume was measured with the help of a wet-test meter during each 20 minute

period. The reaction was stopped after 2-5 hours of operation by closing the steam feed valve and shutting the power supply off to the furnace and the vaporizer. When the reactor cooled to the ambient temperature, it was disconnected from process line, removed from the furnace and opened. The residue char was weighed and analyzed for its carbon and hydrogen content.

3.6 Data Reduction

Experiments were performed to evaluate the kinetics and product gas composition of char gasification, to test the performance of various catalytic agents and to evaluate the kinetics of char gasification in the presence of an added catalyst. The experimental parameters varied were, particle size of char, bed height, reaction temperature and partial pressure of steam. Various experimental results were arrived at as follows.

3.6.1 Gas Yield and Composition

The total gas volume and the gas temperature and pressure were obtained using a calibrated wet-test meter. For analytical purposes, the gas volume was reduced to standard temperature and pressure. Gas yield was obtained by dividing the total gas volume on a moisture and nitrogen free basis by the product of initial carbon in the char bed and total reaction time.

During the course of a run, gas samples were taken every 20 minutes and analyzed for hydrogen, carbon monoxide, carbon dioxide, methane and nitrogen. Oxygen was also detected in some cases, but it was present in extremely small amounts. The area under the peak of each component on the chromatogram was first corrected by an appropriate calibration factor. Thereafter, volume of each component was calculated which gave the composition of the product gas on molar basis.

3.6.2 Carbon Conversion

The procedure used to calculate the carbon conversion consisted of making material balance over a period of 20 minutes. The volume of gas produced within this time interval and the product gas composition were used to calculate carbon conversion. The volume of the gas produced was the difference between the two volume measurements taken 20 minutes apart. The composition of this volume of the gas was taken on the average of the two composition readings, at the beginning and at the end of a 20 minute period. The amount of carbon gasified was taken as the sum of molar amounts of carbon monoxide, carbon dioxide and methane produced. Carbon conversion was defined as the ratio of total mass of carbon gasified to the initial mass of carbon present in the char bed.

To obtain a complete mass balance for carbon, residue left after the reaction was analyzed for its carbon content. In most experimental runs, carbon balance of better than 90 percent was obtained.

3.6.3 Steam Decomposition

The amount of steam decomposed was calculated from the gas appearing as hydrogen and methane as dictated by the hydrogen balance in the gas phase. The fraction of steam decomposed was obtained by dividing the molar amount of steam decomposed by the molar amount of steam fed to the reactor during a 20 minute period. The fraction of the total steam reacted was defined as the ratio of the total amount of steam converted to the total amount of steam fed.

3.6.4 Specific Gasification Rate

The specific gasification rate is defined as the ratio of instantaneous mass rate of carbon gasification to the mass of carbon char remaining in the reactor at that time. In this study, it has been expressed in grammes of carbon gasified per minute per gramme of carbon present in the reactor, g/(min.g). It was calculated by differentiating conversion-time data and dividing the derivative by the fraction of carbon remaining in the reactor.

CHAPTER 4

KINETIC ANALYSIS

Based on the information obtained from pore volume and pore size distribution it could be safely assumed that the char under investigation was essentially non-porous. In that case, the char particle will not react as a whole, and the reaction would proceed from the outer surface of the particle to the inside of the particle. Consequently, an attempt has been made to apply the unreacted shrinking core model described by Levenspiel (62) and recently used by Jensen (27) to the results of present investigation.

The reaction is visualized here as taking place at the outer skin of the particle. The reaction zone then moves into the solid and leaves behind a layer of inert solid "ash". Thus, at any time there exists an unreacted shrinking core of material during reaction as shown in Figure 4. Following five steps will occur in succession during the reaction.

Step 1 - Diffusion of gaseous reactant A through the film surrounding the particle to the surface of solid.

Step 2 - Penetration and diffusion of A through the blanket of ash to the surface of unreacted core.

Step 3 - Reaction of reactant A with solid at this reaction surface.

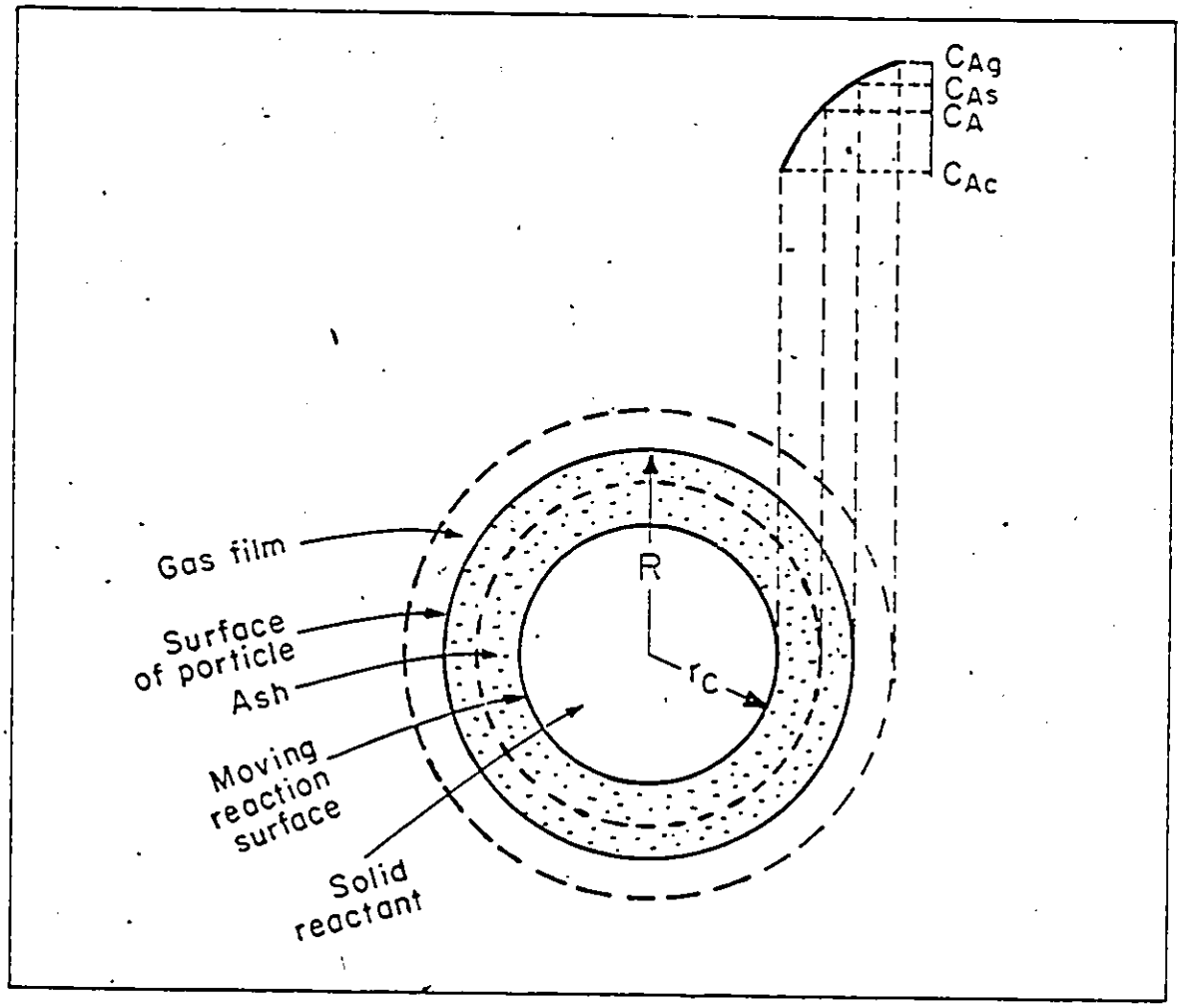

Figure 4. Schematic Diagram of Concentration Profile for the Unreacted Shrinking Core Model

Step 4 - Diffusion of gaseous products through the ash back to the exterior surface of the solid.

Step 5 - Diffusion of gaseous products through the gas film back into the bulk of fluid.

Mathematical model for the following reaction has been developed, by Levenspiel (62) and is reproduced here.

A (fluid) + bB (solid) → fluid and solid products

Assuming this reaction to be irreversible, steps 4 and 5 will not apply and steps 1, 2 or 3 could be rate controlling. They will be considered one by one for spherical particles.

i) Diffusion Through Gas Film Controls

Rate equation based on the surface of the particle could be written as

$$-\frac{1}{S}\frac{dN_B}{dt} = \frac{1}{4\pi R_p^2}\frac{dN_B}{dt} = -\frac{b}{4\pi R_p^2}\frac{dN_A}{dt} = b_{kg}(C_{Ag}-C_{As}) \quad (4.1)$$

$$= b_{kg} = \text{constant}$$

Here $(C_{Ag}-C_{As})$ is the concentration driving force and is constant at all times during the reaction. C_{As} could be neglected if diffusion through the fluid film is slow. Let ρ_B be the molar density of B in the solid and V the volume of a particle, then

$$N_B = \rho_B V \quad (4.2)$$

$$\text{and } -dN_B = -bdN_A = -\rho_B dV = -\rho_B\left(\frac{4}{3}\pi r_c^3\right) \qquad (4.3)$$

$$= -4\pi\rho_B r_c^2 dc$$

Substituting Equation 4.3 and 4.1 gives:

$$-\frac{1}{S}\frac{dN_B}{dt} = -\rho_B r_c^2\frac{dr_c}{dt} = bk_g C_{Ag} \qquad (4.4)$$

where kg is the mass transfer coefficient between fluid and particle. Rearranging and integrating 4.4, one can get

$$t = \frac{\rho_B R_p}{3bk_g C_{Ag}} \qquad (4.5)$$

Fractional conversion of B could be defined:

$$X = 1 - \left(\frac{\text{Volume of unreacted core}}{\text{Total volume of particle}}\right) = I - \left(\frac{r_c}{R}\right)^3 \qquad (4.6)$$

Therefore

$$t = \frac{\rho_B R_p X}{3bk_g C_{Ag}} \qquad (4.7)$$

Thus a relationship between time, radius of particle and conversion B in solid is obtained.

ii). Diffusion Through Ash Layer Controls

In a partially reacted particle, both reactant A and the boundary of the unreacted core move inward toward the centre of the particle. But the shrinkage of the unreacted core is slower than the flow rate of A toward unreacted core by a factor of about 1000, which is roughly the ratio of

densities of solid to gas (62). Therefore, it will be a reasonable assumption that the unreacted core is stationary while considering the concentration gradient of A in the ash layer at any time. Consequently, rate of reaction of A at any time is given by its rate of diffusion to the reaction surface, or

$$-\frac{d_{NA}}{dt} = 4\pi r^2 Q_A = 4\pi R_p^2 Q_{As} = 4\pi r_c^2 Q_{Ac} = \text{constant} \qquad (4.8)$$

Applying Fick's law for equi-molar counter diffusion, one could write:

$$Q_A = De \frac{dC_A}{dr} \qquad (4.9)$$

where De is the effective diffusion coefficient of gaseous reactant in the ash layer. Combining equation 4.8 and 4.9 for any r,

$$-\frac{dN_A}{dt} = 4\pi r^2 De \frac{dC_A}{dr} = \text{constant} \qquad (4.10)$$

Integrating across the ash layer and with the initial conditions $R_p = r_c$, $C_{AC} = 0$, $R_p = R$, $C_{Ag} = C_{As}$, one can get

$$-\frac{dN_A}{dt}\left(\frac{1}{r_c} - \frac{1}{R_p}\right) = 4\pi De C_{Ag} \qquad (4.11)$$

Equation 4.11 could be further treated as in the case of film diffusion. The final result will be:

$$t = \frac{\rho_B R_p^2}{6bDeC_{Ag}} \left[1 - 3\left(\frac{r_c}{R_p}\right)^2 + 2\left(\frac{r_c}{R_p}\right)^3\right] \qquad (4.12)$$

or in terms of conversion of B

$$t = \frac{\rho_B R_p^2}{6bDeC_{Ag}} \left[1 - 3(1-X)^{2/3} + 2(1-X)\right] \qquad (4.13)$$

Wen (63) has shown that effective diffusivity through ash layer (De) may be defined based on the surface area of the unreacted core. In such a case the ash diffusion controlling Equation 4.13 will become:

$$t = \frac{\rho_B R_p^2}{6bDeC_{Ag}} \left[1 - (1-X)^{1/3}\right]^2 \qquad (4.14)$$

iii) Chemical Reaction Controls

The quantity of material reacting is proportional to the available surface area of unreacted core. Thus, based on unit surface of unreacted core, the rate of reaction can be written as:

$$-\frac{1}{4\pi r_c^2}\frac{dN_B}{dt} = \frac{b}{4\pi r_c^2}\frac{dN_A}{dt} = bk_s C_{Ag} \qquad (4.15)$$

where ks is the first order rate constant. Writing N_B in terms of shrinking radius from Equation 4.3 and integrating:

$$-\rho_B \int_R^{r_c} dr_c = bk_s C_{Ag} \int_0^t$$

or

$$t = \frac{\rho_B}{bk_s C_{Ag}} (R_p - r_c) \qquad (4.16)$$

In terms of conversion of B, the following can be obtained:

$$t = \frac{\rho_B R_p}{bk_s C_{Ag}} [1 - (1-X)^{1/3}] \qquad (4.17)$$

From Equations 4.14 and 4.17 it can be seen that a log-log plot of $1-(1-X)^{1/3}$ vs. t will give a straight line of slope of unity if chemical reaction is controlling and straight line of slope 2 if ash diffusion is controlling.

Three resistances to the reaction rate can also be combined in one equation.

4.1 Char-Steam Reaction

Equation 4.17 in its differential form can be represented as:

$$\frac{dx}{dt} = \frac{3(1-X)^{2/3}}{\rho_B R} (k_s C_{Ag}) \qquad (4.18)$$

For carbon-steam system secondary reactions and products inhibition may also be prominent in addition to primary C-H_2O reaction. Therefore, reaction rate may not be a simple first order with respect to steam concentration. In that case the term within the parenthesis in Equation 4.18 can be given a general form as follows:

$$\frac{dx}{dt} = \frac{3(1-X)^{2/3}}{\rho_B R_p} (f(c)) \qquad (4.19)$$

Here f(c) is function involving the reaction rate and concentration of reactive species in gas phase surrounding the

the particle. Several forms which function f(c) can be assigned are given in Table 4.1. The reaction rate data for char-steam reaction should be tested for best fit with respect to all these function forms.

Table 4.1

MECHANISTIC MODEL FORMS

Mechanistic Function	Comments
$F(c) = \frac{k_1 P_{H_2O}}{1+k_2 P_{H_2}+k_3 P_{H_2O}}$	Langmuir-Hinshelwood mechanism hindrance by H_2 and H_2O
$= \frac{k_1 P_{H_2O}}{1+k_2 P_{H_2}}$	Hindrance by H_2 only
$= \frac{k_1 P_{H_2O}}{1+k_2 P_{H_2O}}$	Hindrance by H_2O only
$= k_1 P_{H_2O} + k_2 P_{CO_2}$	Two parallel reactions $C-H_2O$, $C-CO_2$
$= \frac{k_1 P_{H_2O}}{1+k_2 P_{H_2}} + \frac{k_3 P_{CO_2}}{1+k_4 P_{CO}}$	Two parallel reactions $C-H_2O$ hindered by H_2 $C-CO_2$ hindered by CO
$= \frac{k_1 P_{H_2O}}{1+k_2 P_{H_2}} + k_3 P_{CO_2}$	$C-H_2O$ hindered by H_2 $C-CO_2$ not hindered
$= k_1 P_{H_2O} + \frac{k_2 P_{CO_2}}{1+k_3 P_{CO}}$	$C-CO_2$ hindered by CO $C-H_2O$ not hindered
$= k(P_{H_2O} - \frac{P_{CO} P_{H_2}}{K})$	Empirical model by Wen (64) K = equil. const. for $C-H_2O$ reaction

CHAPTER 5

EXPERIMENTAL RESULTS

Experiments conducted are divided into three series of runs:

1. uncatalyzed gasification of char
2. screening of various materials for their catalytic activity
3. catalyzed gasification of char

Summary of experimental runs is given in Table 5.1

Table 5.1

SUMMARY OF EXPERIMENTAL RUNS

Run No.	Description	Parameter Studied
26-36, 39-42, 66-70	uncatalyzed	temperature, steam partial pressure
37, 38, 63	uncatalyzed	particle size
12, 14, 16	uncatalyzed	bed height
103, 104	uncatalyzed	steam flow rate
44-61, 81, 82	catalysis	catalyst type, catalyst concentration
99-102, 107, 108	screening	temperature, steam partial pressure
71-80, 83-93, 97	catalyzed (10% K_2CO_3 or Na_2CO_3)	temperature, steam partial pressure
95, 96, 98	catalyzed (10% K_2CO_3)	particle size

5.1 Uncatalyzed Gasification

In the first series of runs, char was gasified in the temperature range of 650-800°C and steam partial pressures of 0.20 to 0.83 atm. Total pressure at the inlet of the reactor was near atmospheric pressure. Balance of the reactant gas was made up by nitrogen. Char particle size of 177-250 μm was used in all the experiments except when the effect of particle size was studied. The char bed consisted of about 3 g of char with a bed height of approximately 6.1 cm.

Reaction temperature and steam partial pressure were varied to evaluate the kinetics of reaction. Effect of such as particle size of char, bed height, steam flow rate on gasification rate were also studied to clarify the kinetics. Plots of carbon conversion vs. reaction time are shown in Figures 5, 6, 7 and 8, temperature and partial pressure being the parameters. Results of all these runs are summarised in Table 5.2.

Total carbon conversion obtained over the entire run period varied from 12.2% to 88% and steam conversion ranged from 8.1% to 93.5%. While carbon conversion depended on reaction time, reaction temperature and steam partial pressure, steam conversion was function of reaction temperature and steam partial pressure. Apparent stoichiometry (H_2O/C varied

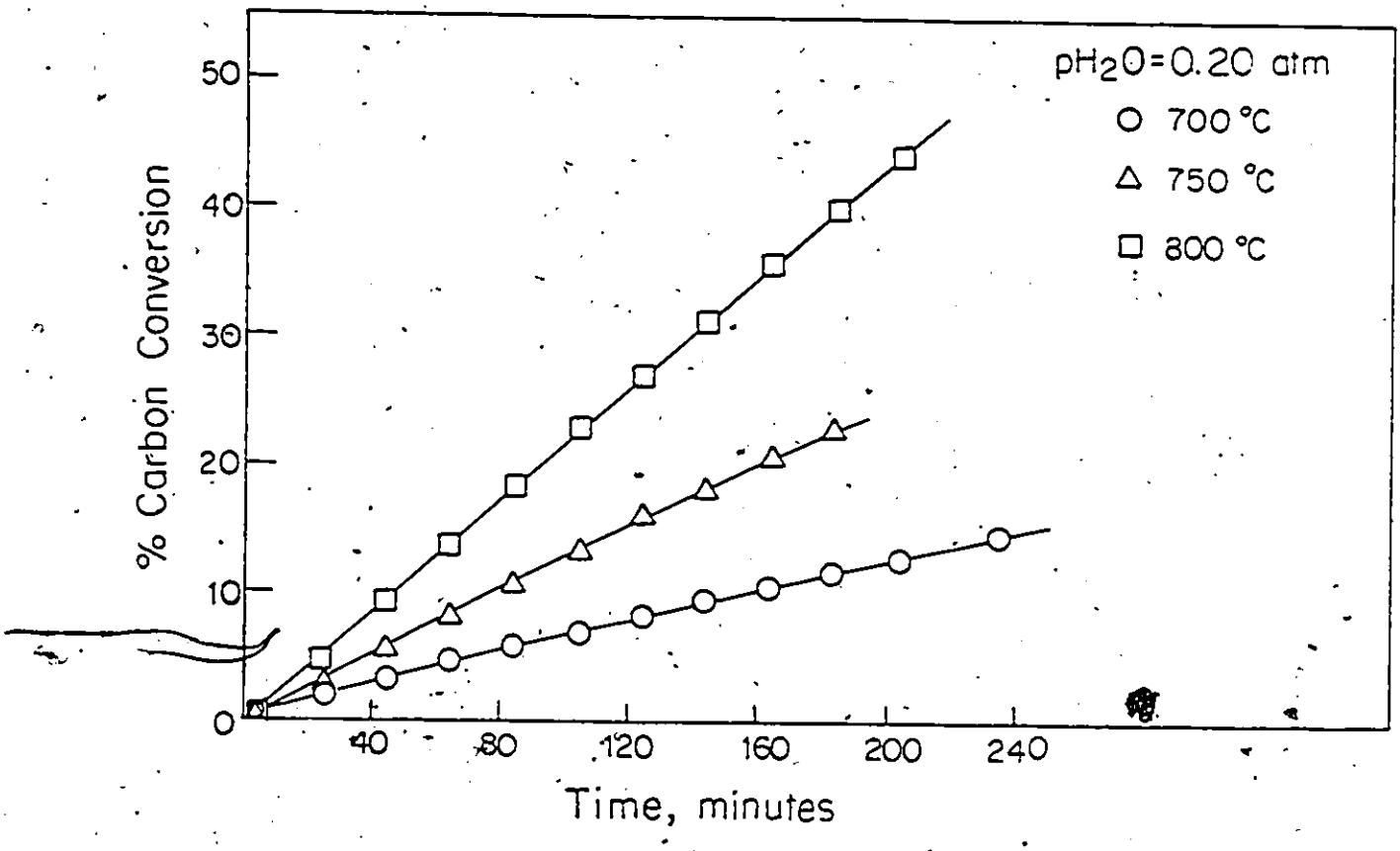

Figure 5. Carbon Conversion vs Reaction Time

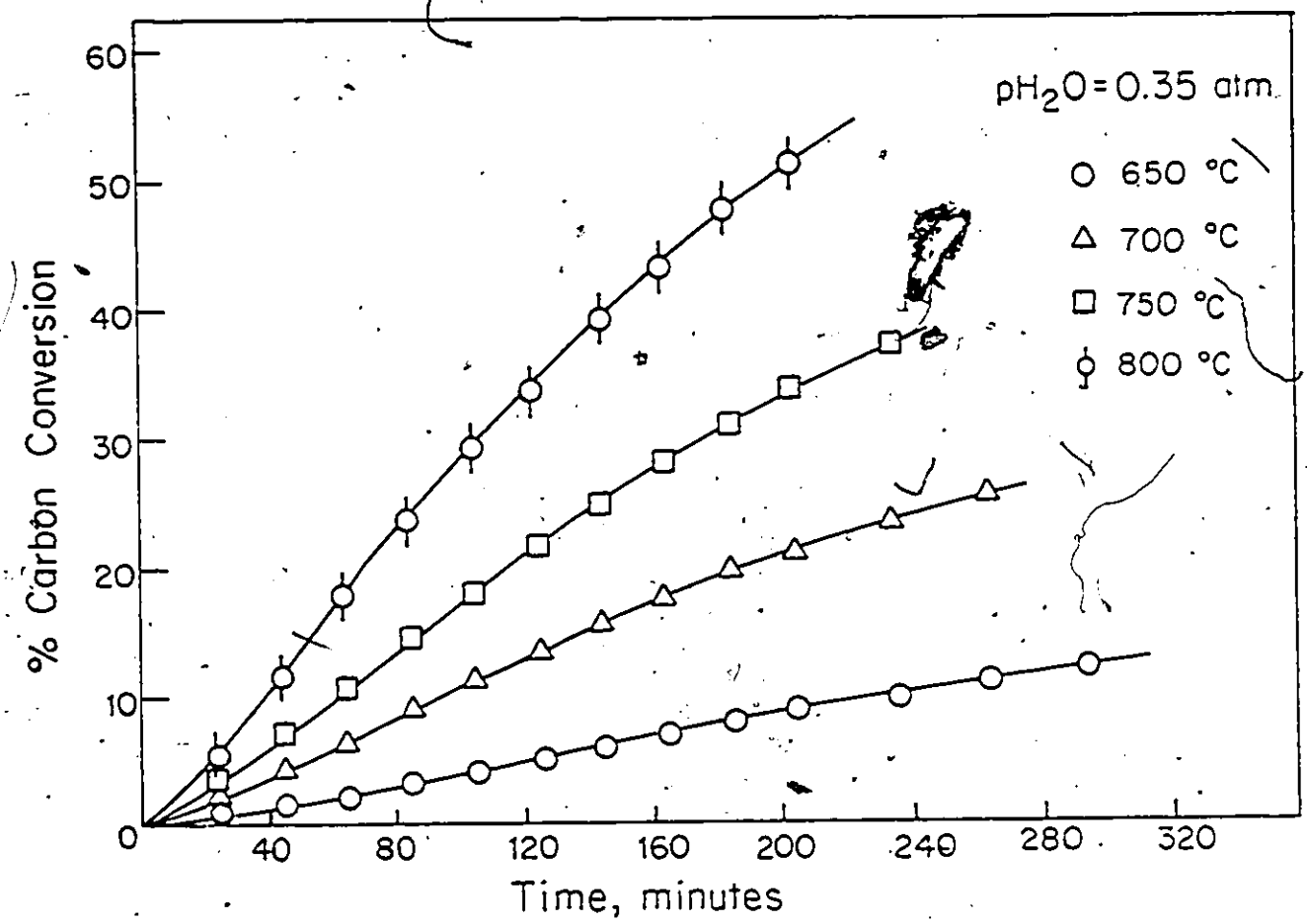

Figure 6. Carbon Conversion vs Reaction Time

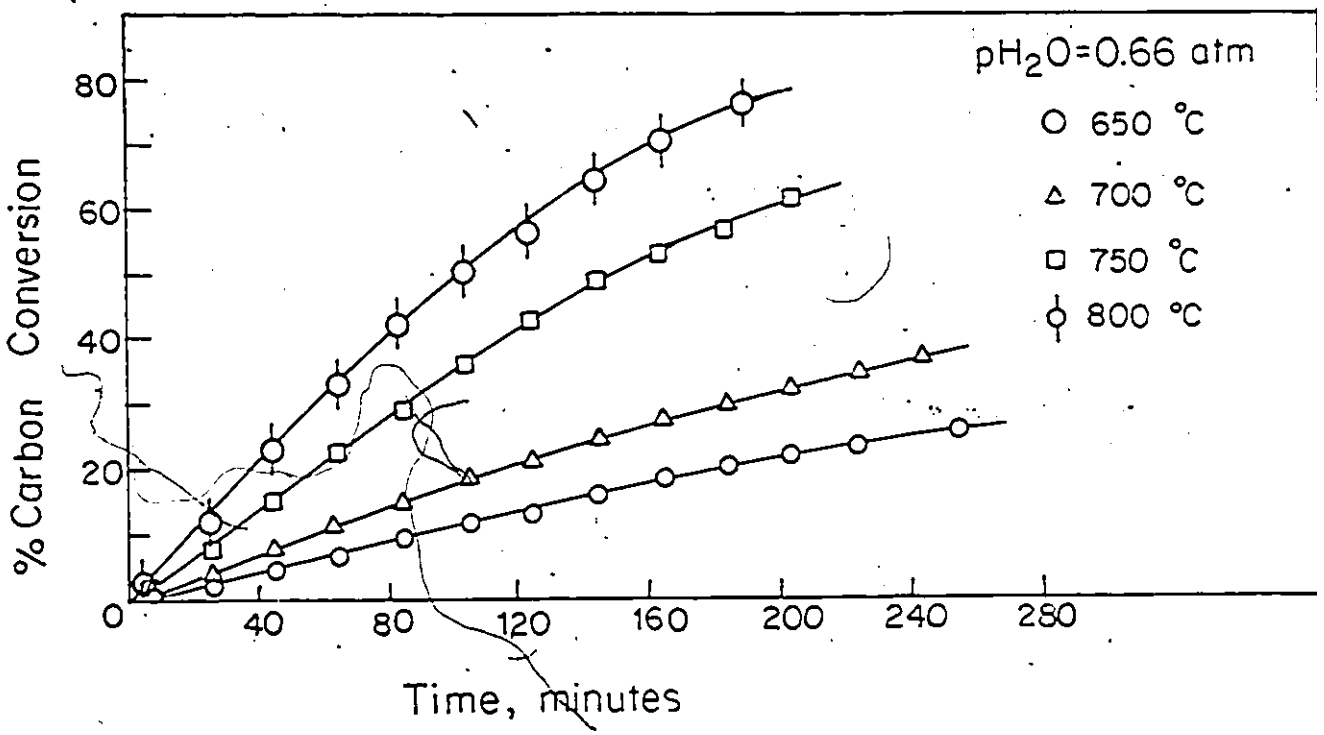

Figure 7. Carbon Conversion vs Reaction Time

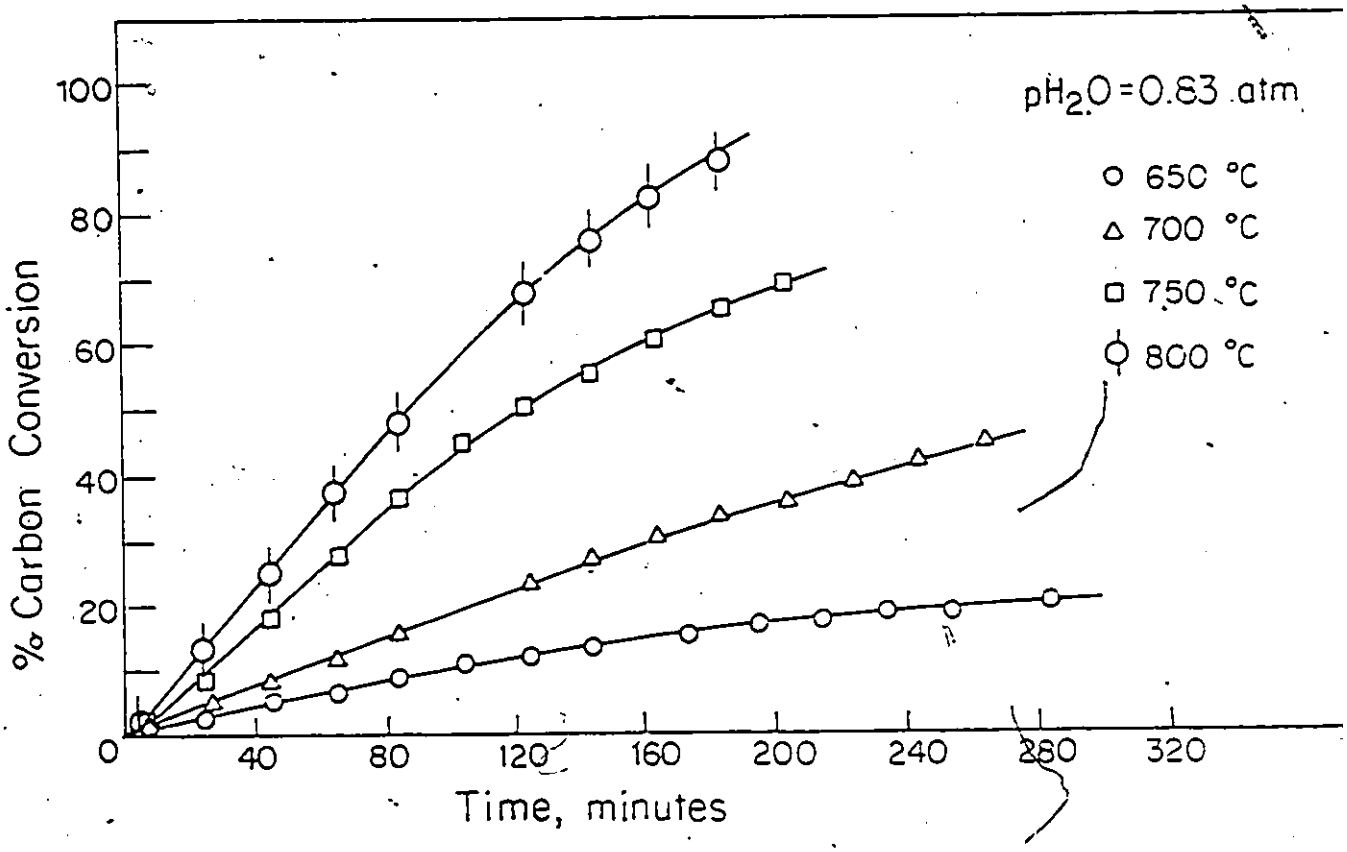

Figure 8. Carbon Conversion vs Reaction Time

Table 5.2

RESULTS OF GASIFICATION OF LIGNITE CHAR

Run No.	T, °C	P_{H_2O} atm.	Reaction time min.	Total carbon conv., %	Total steam conv., %	Apparent stoichiometry H_2O/C	Gas yield ml/hr-g	Gas composition mole percent H_2	CO	CO_2	CH_4	H_2/CO ratio
30	700	0.20	234	14.7	32.9	1.66	186.0	62.5	14.1	23.5	0.0	4.4
31	750	0.20	184	22.8	56.9	1.47	337.9	59.5	23.3	17.3	0.0	2.6
32	800	0.20	204	44.2	93.5	1.37	560.9	57.2	31.9	10.3	0.7	1.8
39	650	0.35	294	12.2	16.4	1.93	134.9	65.9	3.6	30.5	0.0	18.3
40	700	0.35	264	25.4	36.0	1.82	302.2	64.6	10.3	25.1	0.0	6.5
41	750	0.35	234	37.3	59.2	1.86	501.0	64.7	15.6	19.3	0.5	4.2
42	800	0.35	204	51.1	67.1	1.34	640.4	56.6	30.8	11.9	0.7	1.8
66	650	0.55	294	23.6	19.5	1.94	238.7	66.0	4.3	29.7	0.0	15.3
67	700	0.55	194	36.3	37.1	1.56	489.5	60.9	7.5	31.6	0.0	8.1
68	750	0.48	234	45.6	36.8	1.64	549.8	61.8	19.2	18.5	0.5	3.2
70	800	0.42	204	66.3	81.4	1.41	857.0	57.9	27.4	14.0	0.7	2.1
29	650	0.66	254	26.9	11.0	1.95	320.4	66.1	2.1	31.8	0.0	31.5
27	700	0.66	244	37.0	16.4	1.87	482.3	65.1	5.7	29.2	0.0	11.4
26	750	0.66	204	60.9	26.5	1.51	823.6	59.9	16.4	23.3	0.4	3.7
28	800	0.66	189	76.5	35.5	1.49	1103.3	59.3	24.3	15.8	0.6	2.4
33	650	0.83	284	20.7	8.1	2.19	259.5	68.7	1.6	29.7	0.0	43.3
34	700	0.83	224	38.7	18.8	2.10	589.8	67.5	6.5	25.7	0.4	10.4
35	750	0.83	204	69.2	30.0	1.73	1017.3	63.0	13.0	23.4	0.5	4.8
36	800	0.83	184	87.9	39.4	1.59	1387.0	61.3	17.4	20.9	0.4	3.5

from 1.37 to 2.19. It increased with increase in steam partial pressure and decrease in reaction temperature.

Gas yield reported is based on the total amount of hydrogen, carbon monoxide, carbon dioxide and methane produced, divided by the product of reaction time and amount of carbon initially present in the reactor. As expected, gas yield increased with increase in reaction temperature and steam partial pressure. This quantity was useful in comparing the performance of various catalytic agents.

The composition of the product gas was calculated on moisture and nitrogen free basis. Gas mixtures consisted of 57-69% H_2, 2-32% CO, 10-30% CO_2 and 0-0.7% CH_4. While the amounts of hydrogen and carbon dioxide decreased and those of carbon monoxide increased with increase in reaction temperature and decrease in steam partial pressure. This change in product gas composition was also reflected in H_2/CO ratio which varied between 1.8 at 800°C and 0.20 atm of steam partial pressure to 43.3 at 650°C and 0.83 atm of steam partial pressure.

5.1.1 Effect of Particle Size

Four particle sizes of char 88-105, 125-150, 170-250 and 500-595 μm were gasified at 800°C and 0.83 atm pressure of steam. The plots of carbon conversion vs. time are shown in Figure 9 and results of these runs are summarized in

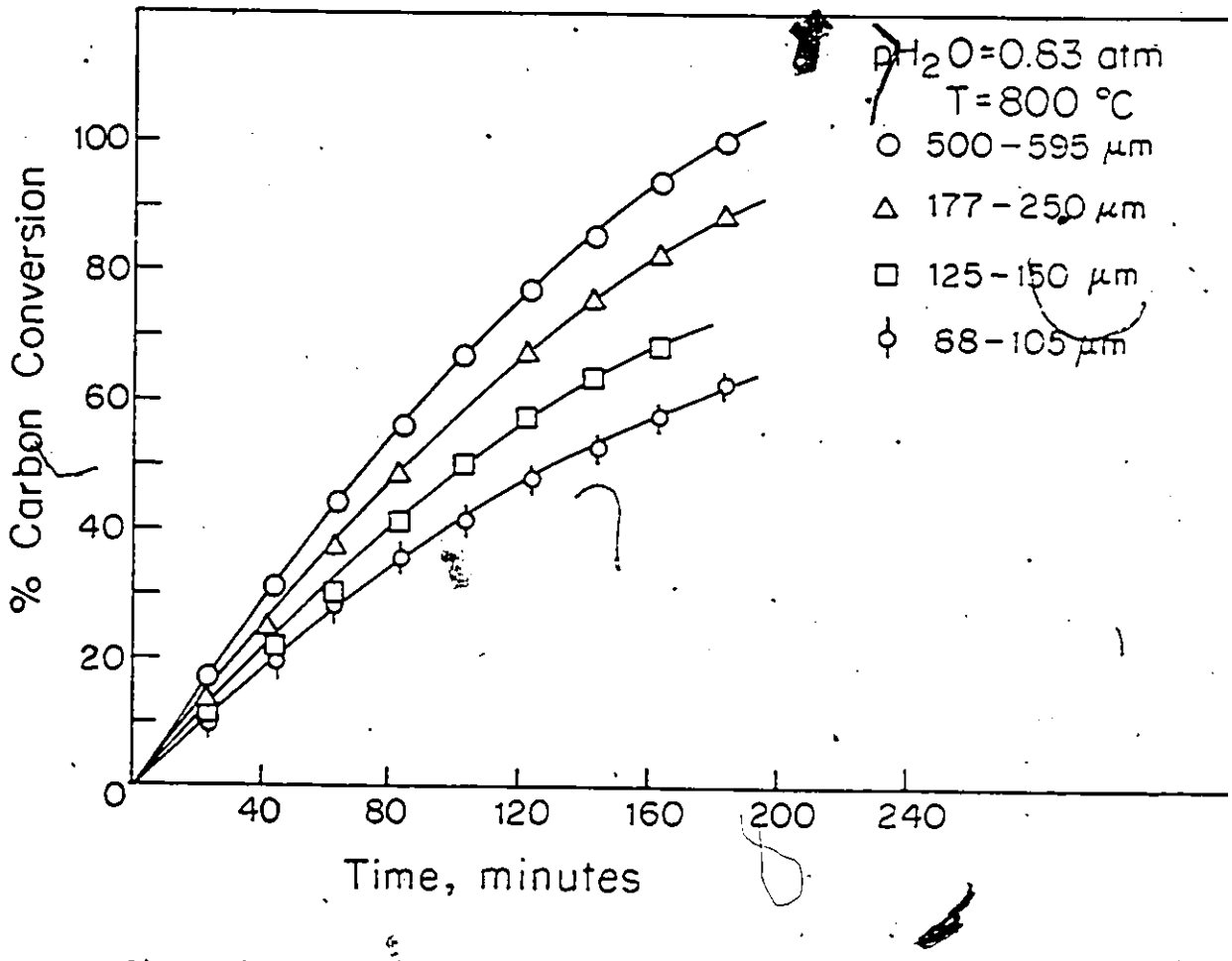

Figure 9. Effect of Particle Size on Carbon Conversion

Table 5.3. Carbon and steam conversion increased with increase in particle size showing thereby that rate of gasification of carbon was increasing with increase in particle size. H_2/CO ratio also tended to increase with particle size, that is, more hydrogen and carbon dioxide and less carbon monoxide were produced as the particle size increased.

5.1.2 Effect of Steam Flow Rate

Char gasification was carried out at 800°C with steam flow rates of 62.1, 85.6 and 144.0 ml/min while keeping partial pressure of steam around 0.83 atm during all the three experiments. Conversion time plots in Figure 18 show that there was no significant change in the extent of carbon gasification even when steam flow rate was more than doubled. It could be inferred from these results that diffusion through the gas film surrounding the char particle had insignificant effect on the rate of carbon gasification.

5.1.3 Effect of Bed Height

The effect of char bed height was investigated by varying the initial amount of char in the reactor bed. The amount of char were 4.6 g for a bed height of 9.2 cm, 3.1 g for a bed height of 6.1 cm and 2.3 g for a bed height of 4.6 cm.

Table 5.3

EFFECT OF PARTICLE SIZE ON CHAR GASIFICATION

Run No.	Particle size μm	Reaction time min.	Carbon conversion %	Steam conversion %	Apparent stoichiometry H_2O/C	Gas yield $\frac{ml}{hr\text{-}g}$	Gas composition mole percent				H_2/CO ratio
							H_2	CO	CO_2	CH_4	
38	500-595	184	100.0	45.8	1.84	1572.0	64.6	10.1	25.2	0.3	6.4
36	177-250	184	89.0	39.4	1.62	1387.0	61.3	17.4	20.9	0.4	3.5
37	125-150	164	68.3	32.2	1.52	1143.6	59.2	22.5	17.5	0.8	2.6
63	88-105	184	61.0	27.9	1.63	953.2	61.0	20.3	18.0	0.8	3.0

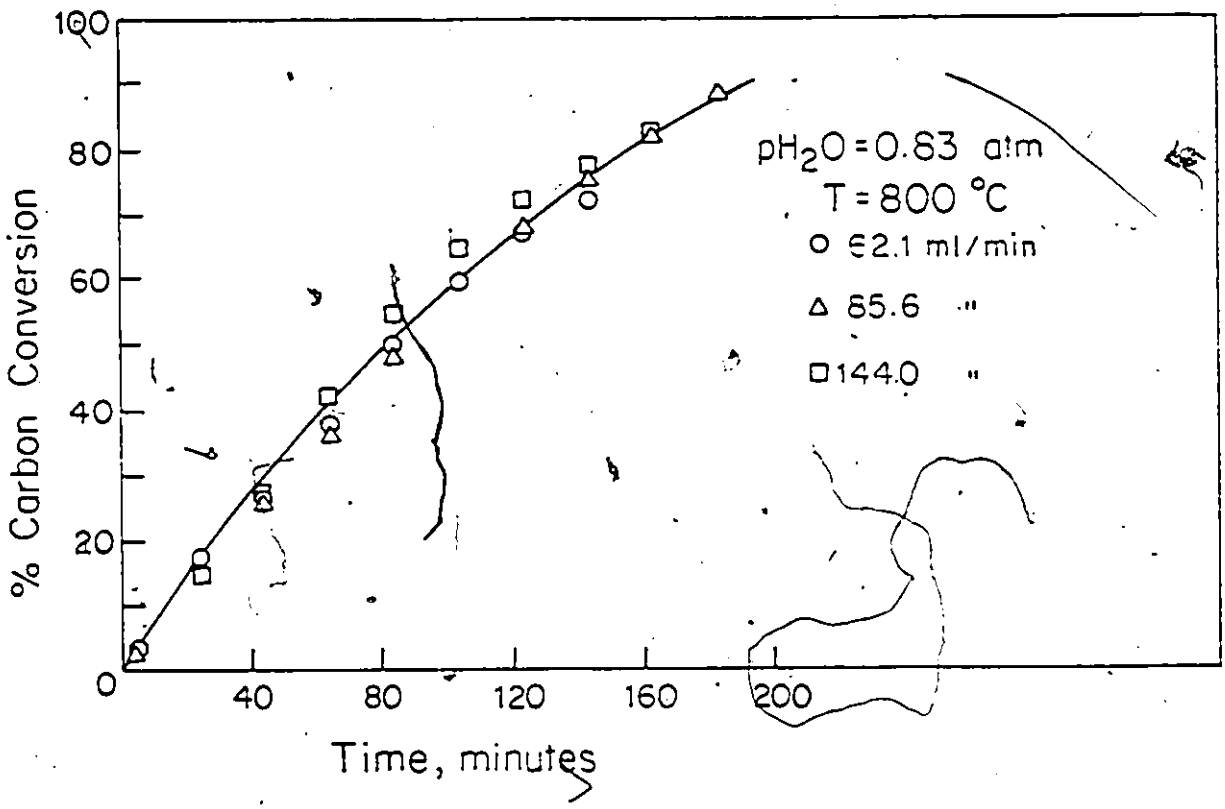

Figure 10. Effect of Steam Flow Rate on Carbon Conversion

Reaction temperature (750°C) and steam flow rate were kept unchanged in all the three experimental runs. These runs produced conversion data over a range of inverse specific steam rate (W/F). The conversion-time curves for the runs were overlapping (Figure 11) showing that the variation of bed height in this range did not affect carbon gasification rate.

5.1.4 Kinetics of Gasification

The observations that gasification rate increases with increase in particle size and char particles were essentially non-porous led to the attempt to use the unreacted shrinking core model for kinetics of gasification. The following assumptions were involved:

i) reaction proceeds at the outer surface of the particle with unreacted shrinking core;

ii) each particle reacts independently without being affected by neighbouring particles in the bed implying that the conversion of all the particles of the same size is the same at any time during the reaction.

Mathematical expressions based on these assumptions have been derived in Chapter 4 and the equations obtained are as follows:

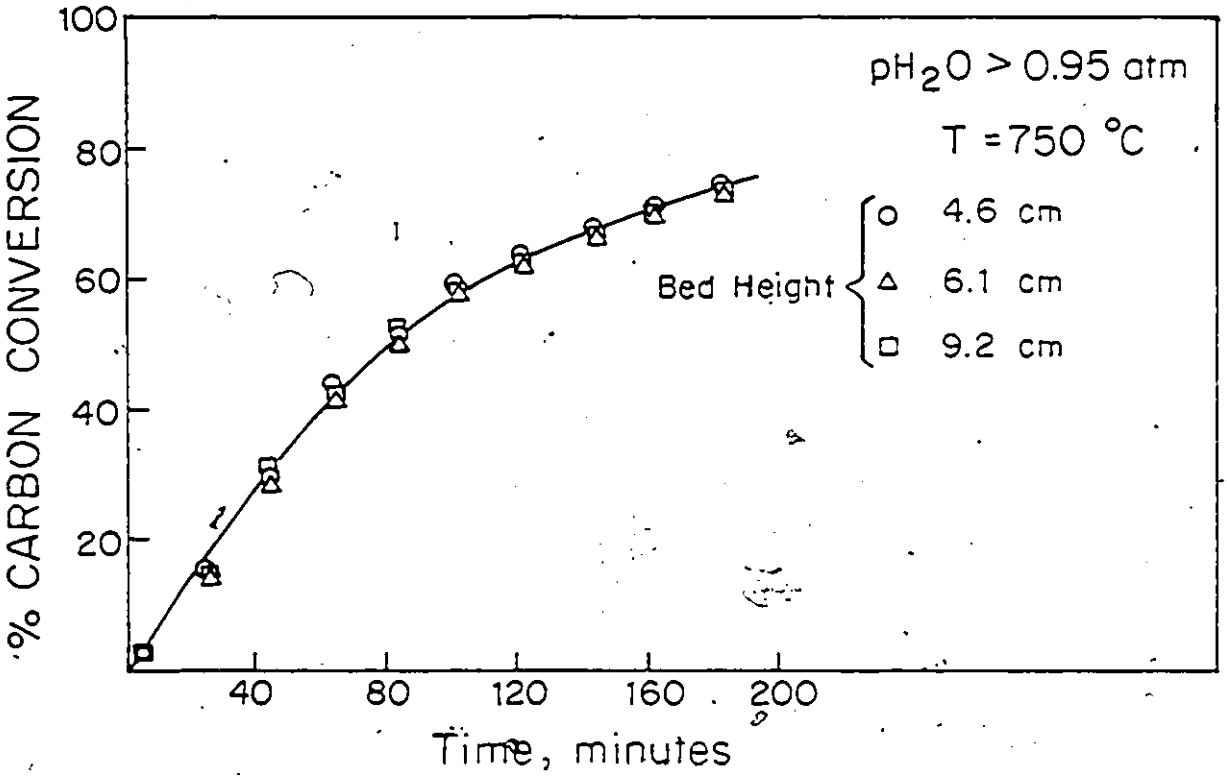

Figure 11. Effect of Bed Height on Carbon Conversion

$$t = \frac{\rho_B R_p X}{3kg\ C_{Ag}} \qquad (5.1)$$

when film diffusion is controlling.

$$t = \frac{\rho_B R_p^2}{6De\ C_{Ag}} [1 - (1-X)^{1/3}]^2 \qquad (5.2)$$

when ash diffusion is controlling.

and $$t = \frac{\rho_B R_p}{k_s C_{Ag}} [1 - (1-X)^{1/3}] \qquad (5.3)$$

when chemical reaction is controlling.

Theoretical calculations (Appendix B) and results of the experiments with varying steam flow rate showed that diffusion through gas film was not controlling the reaction. Therefore, either of the equations 5.2 or 5.3 should be applicable to the kinetic data.

Plots of $[1-(1-X)^{1/3}]$ vs t were made on a log-log graph for the experimental results. These plots are shown in Figures 12, 13 and 14 for various temperatures and steam partial pressures. Figure 15 shows the same plots for different particle sizes of char at 800°C and 0.83 atm of steam pressure. Experimental point at any temperature and partial pressure could be represented by reasonably good straight line. Slopes of these straight lines were in the range of 0.9 to 1.1. This shows the applicability of Equation 5.3 and thereby the conclusion that ash diffusion

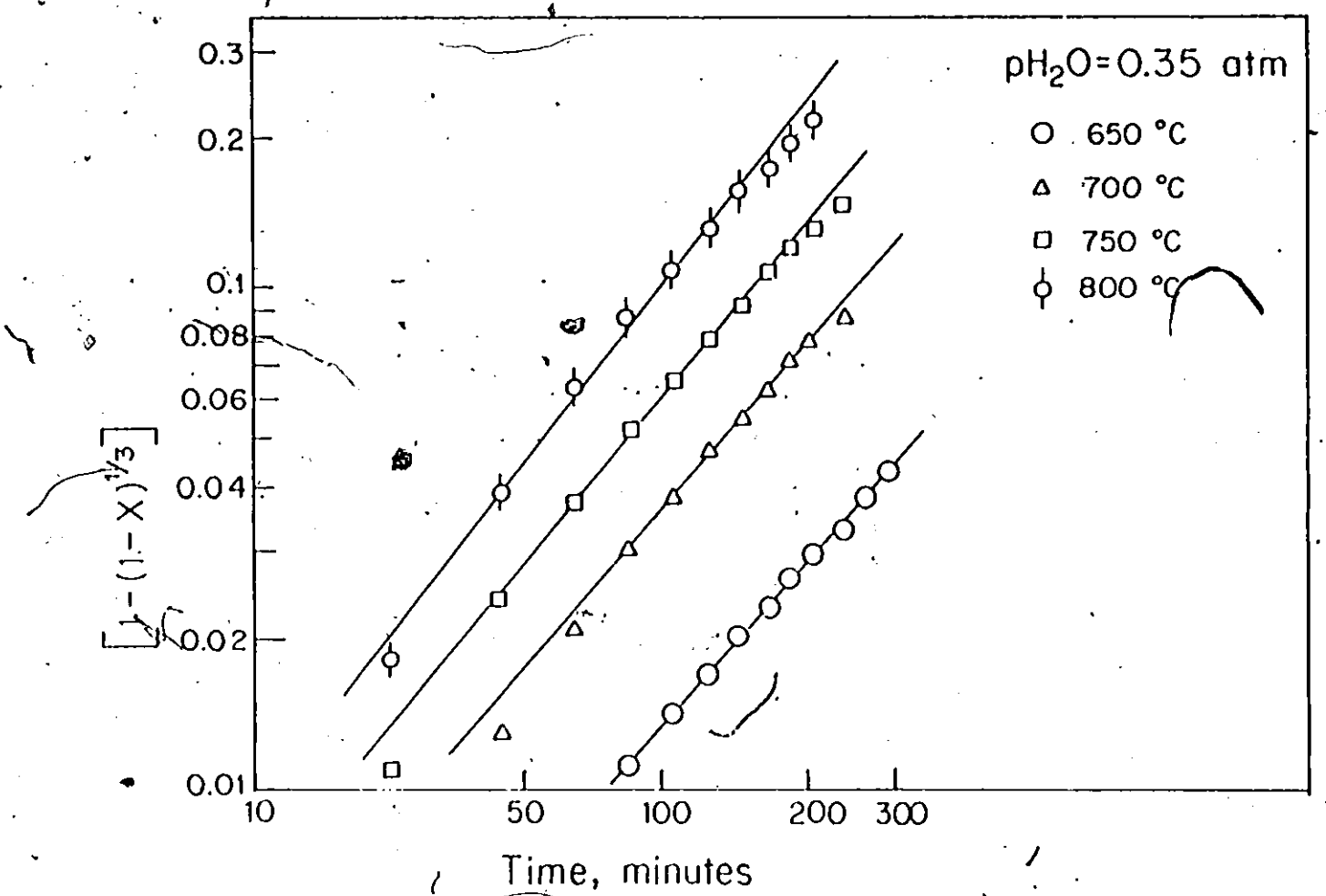

Figure 12. Plots for Unreacted Shrinking Core Model

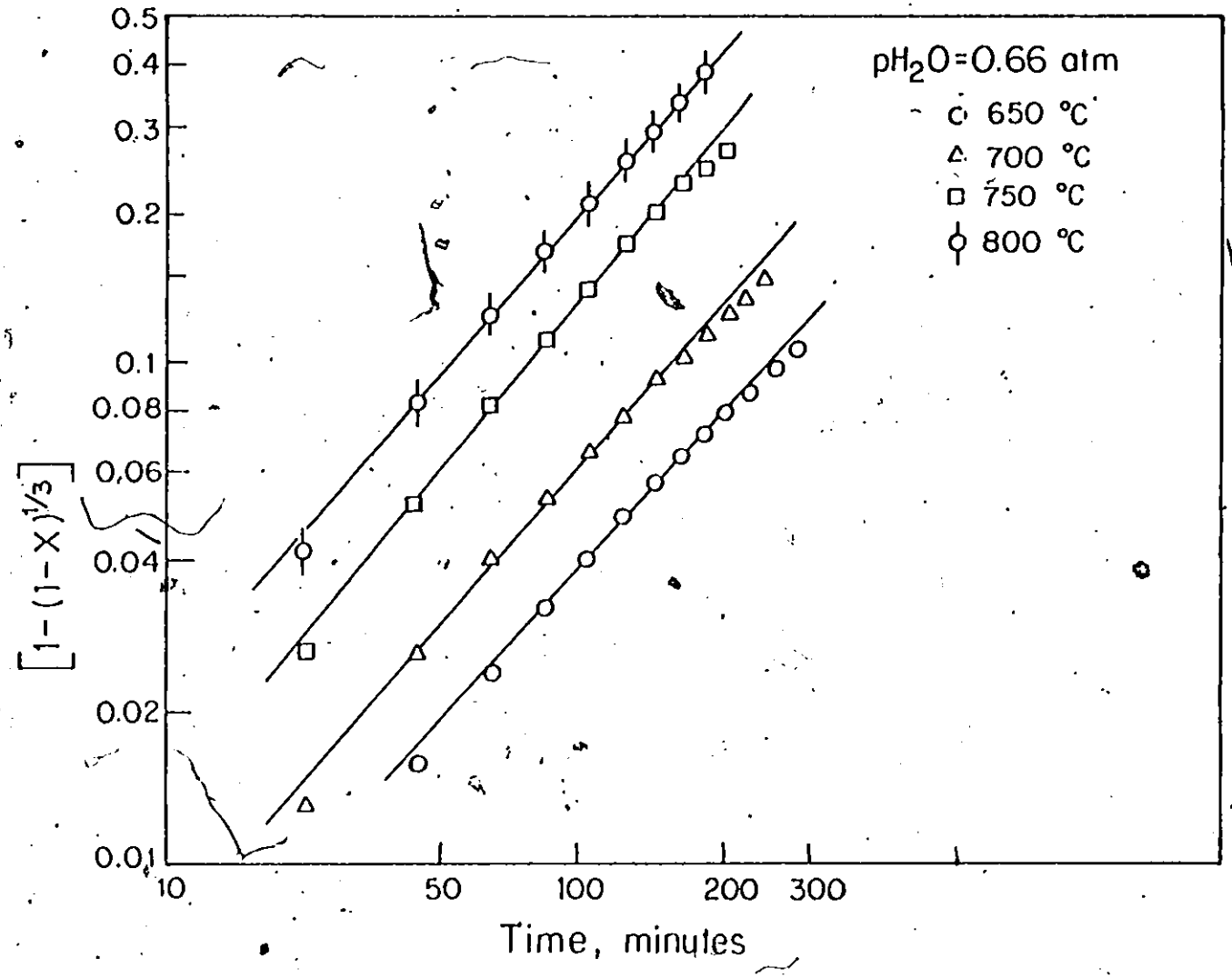

Figure 13. Plots for Unreacted Shrinking Core Model

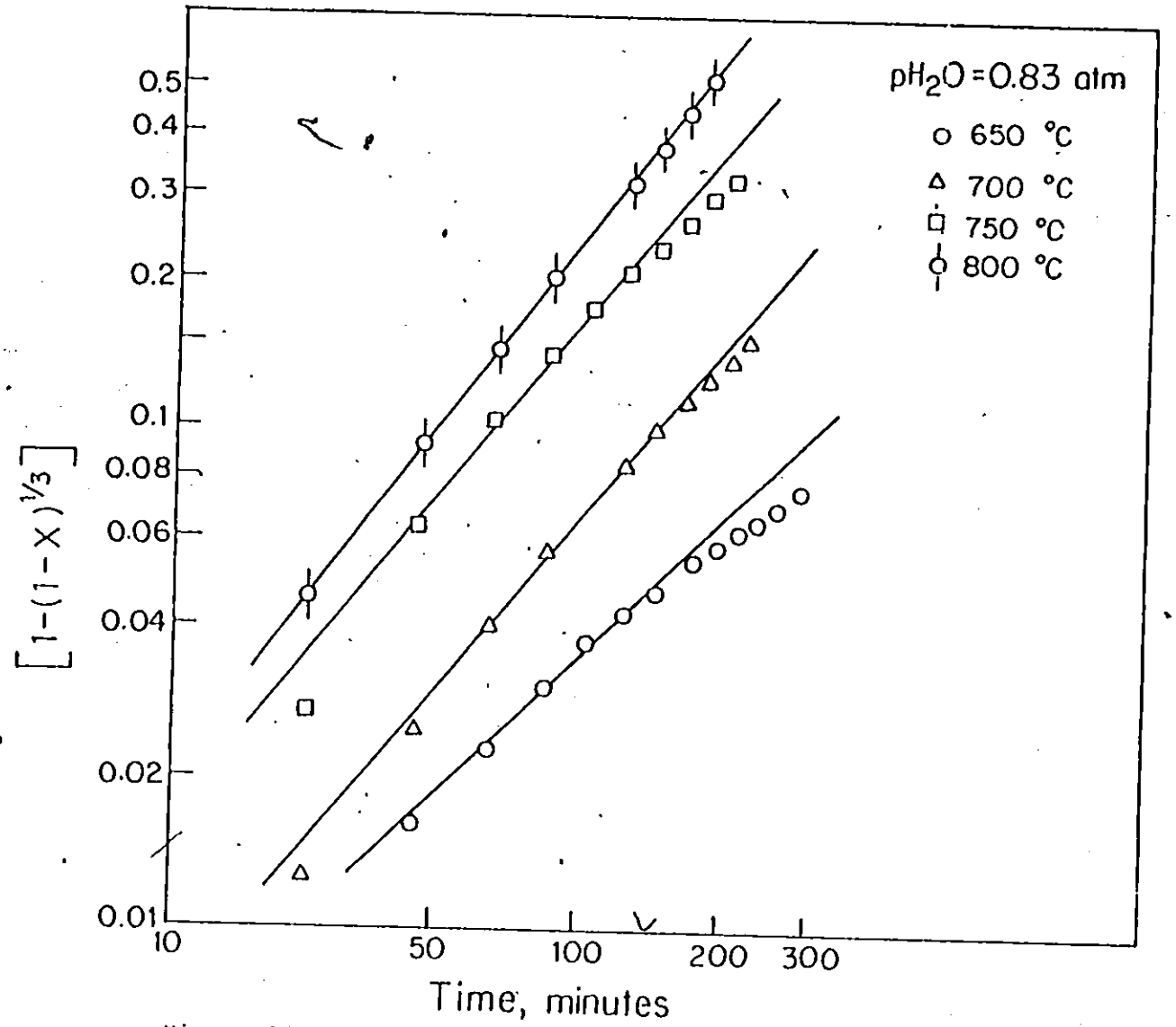

Figure 14. Plots for Unreacted Shrinking Core Model

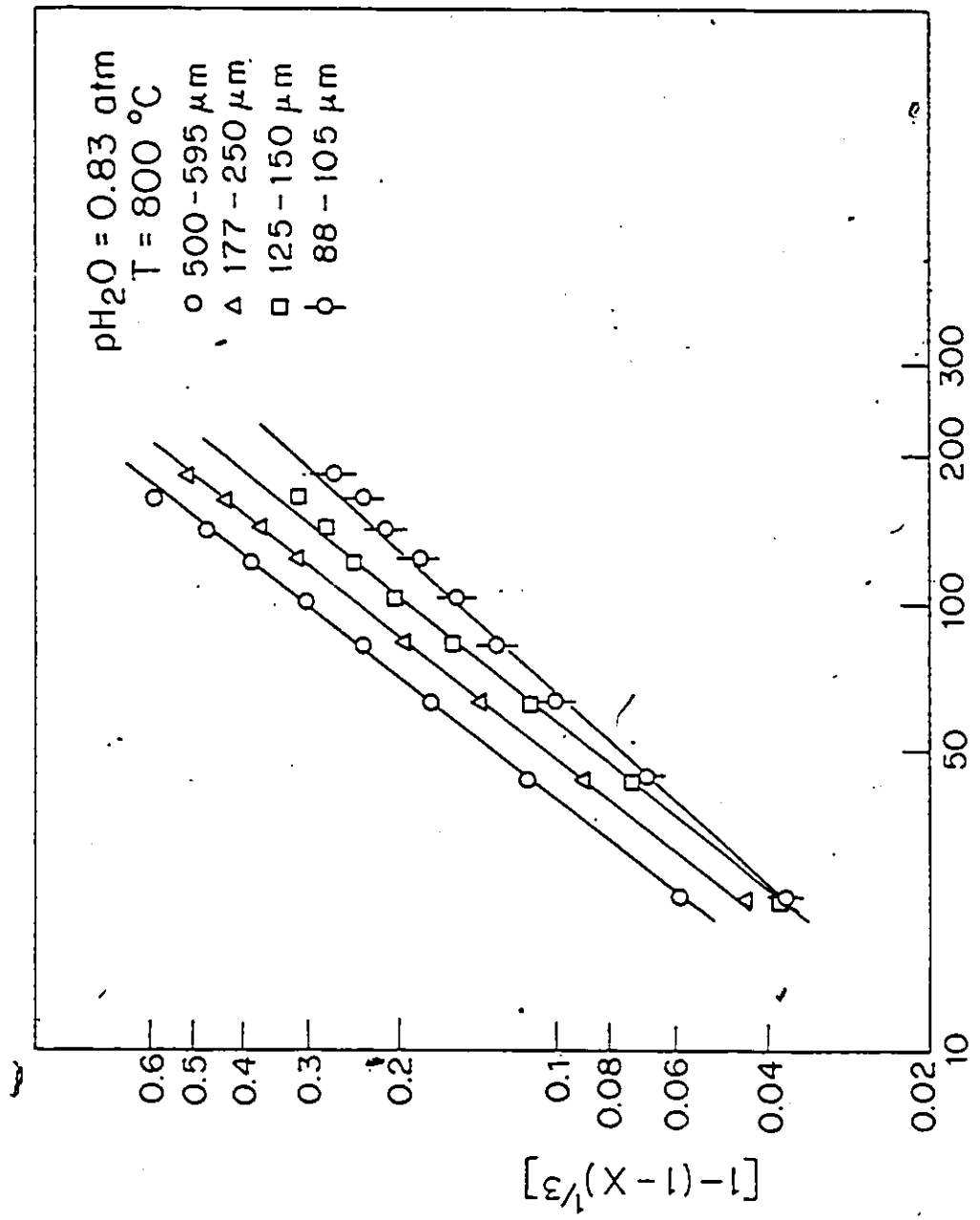

Figure 15. Plots for Unreacted Shrinking Core Model with Different Particle Sizes

was not limiting the rate and it was chemical reaction controlled.

Equations 5.1, 5.2 and 5.3 were derived with the assumption that steam partial pressure remained constant with reaction time and that product gases were not affecting the reaction rate. To improve upon this, varying partial pressures of steam and product gases and also the secondary reactions were incorporated in Equation 5.3. Consequently, Equation 5.3 in its differential form is written as follows:

$$\frac{dx}{dt} = \frac{3(1-X)^{2/3}}{\rho_B R_p} \cdot F(c) \qquad (5.4)$$

Various expressions for F(c) are listed in Table 4.1. Differential rate data was obtained by differentiating the conversion time data. Partial pressure of each gaseous component at any time during the reaction was obtained by taking the average of partial pressures at inlet and outlet of the reactor. A non-linear least square computer programme was used to test the different forms of function F(c) for the best fit. The package for this programme was available in the Computer Centre Library.

For selection of the best model, the first condition was that rate constants k_1, k_2, k_3 etc. should be positive. Therefore, those kinetic models which gave negative reaction rate constants were rejected. The following three equations gave

positive reaction rate constants:

$$\frac{dx}{dt} = \frac{3(1-X)^{2/3}}{\rho_B R_p} (kp^o_{H_2O}) \qquad (5.5)$$

$$\frac{dx}{dt} = \frac{3(1-X)^{2/3}}{\rho_B R_p} (kp_{H_2O}) \qquad (5.6)$$

and

$$\frac{dx}{dt} = \frac{3(1-X)^{2/3}}{\rho_B R_p} (k_1 p_{H_2O} + k_2 p_{CO_2}) \qquad (5.7)$$

Here $p^o_{H_2O}$ is the steam partial pressure at the inlet of reactor, p_{H_2O} and p_{CO_2} are the partial pressures of steam and carbon dioxide respectively inside the reactor and are changing with time.

These models were discriminated by comparison of residuals obtained from predicted and experimental values of reaction rates. It was found that Equation 5.7 not only gave the lowest values of residuals but they were also most randomly distributed. Therefore, Equation 5.7 was considered to represent the kinetic data of char gasification best. Values of k_1 and k_2 were obtained at various temperatures. Mean values of k_1 and k_2 with their intervals at 95 percent confidence level are listed in Table 5.4. Confidence intervals were calculated from four or five different values of k_1 and k_2 obtained at different partial pressures of steam.

Table 5.4

REACTION RATE CONSTANTS FOR UNCATALYZED GASIFICATION

T, °C	650	700	750	800
$k_1 x 10^6$	0.257±0.191	0.587±0.315	1.364±0.328	2.555±0.862
$k_2 x 10^5$	0.665	1.712±0.917	3.239±0.709	5.625±0.800

Variation of k_1 and k_2 with temperature is shown by Arrhenius plots of Figure 16. From the least square fit of the plots the following equations for k_1 and k_2 were obtained:

$$k_1 = 4.270 \exp(-\frac{30,500}{RT}) \quad (5.8)$$

$$k_2 = 28.140 \exp(-\frac{27,900}{RT}) \quad (5.9)$$

Here R is in cal/mol-K.

Figure 17 shows the experimental and calculated values of gasification rates for a set of experimental conditions. By visual inspection it could be seen that agreement between experimental and calculated values is very good.

5.1.5 Effectiveness Factor

Wen (63) suggested the use of an effectiveness factor for gas-solid reaction which is given as:

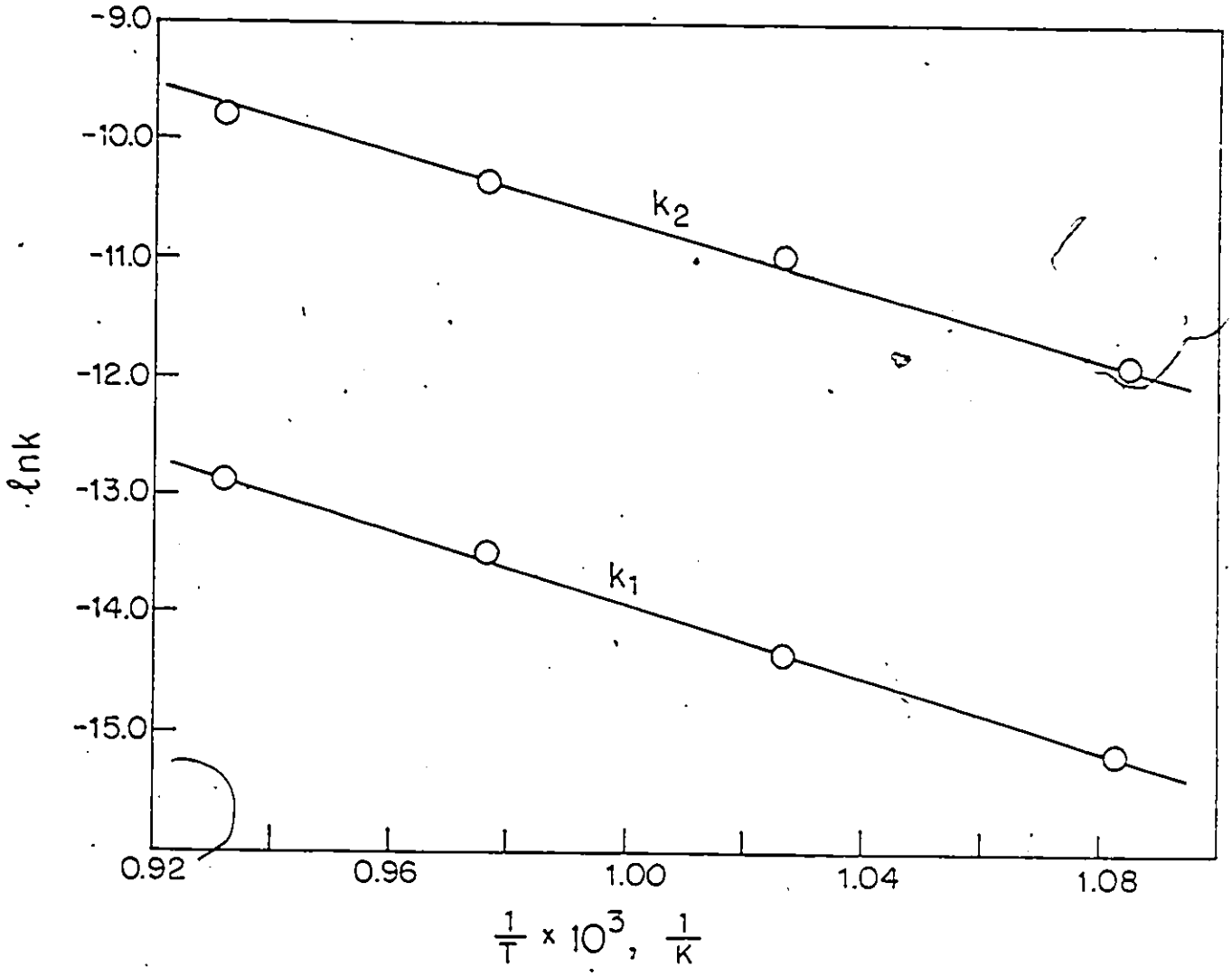

Figure 16. Arrhenius Plots for Reaction Rate Constants

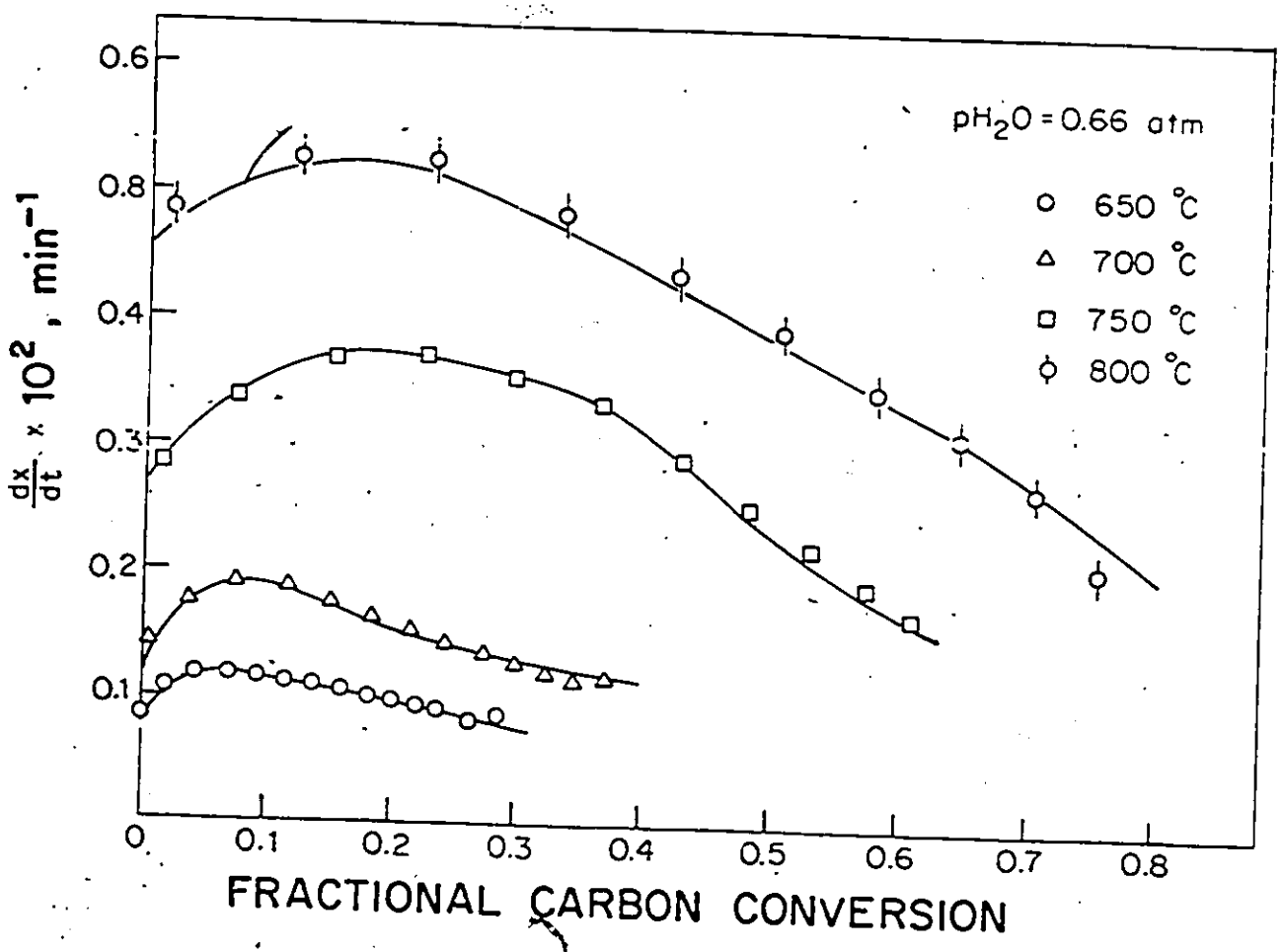

Figure 17. Predicted (Solid Line) and Experimental (Points) Rates

$$\eta = \frac{\text{actual reaction rate}}{\text{reaction rate obtainable at the concentration and temperature of the bulk phase}} \qquad (5.10)$$

This effectiveness factor relates the reaction rate at any time to the initial rate and permits the examination of effect of diffusion. The effectiveness factor for an unreacted shrinking core model is proportional to the reaction rate per unit reaction surface area. Reaction rate per unit surface area is defined as

$$(\eta_s) r_c \propto \frac{M}{4r_c^2} \qquad (5.11)$$

where r_c is defined as

$$4\pi r_c^2 = 4\pi R_p^2 (r_{c/R_p})^2 = 4\pi R_p^2 (1-X)^{2/3} \qquad (.11)$$

and M is the total reaction rate of carbon gasification.

Normalizing by dividing the reaction rate per unit reaction surface area at X=0, unit reaction rates were calculated and plotted in Figure 18 vs carbon conversion to clarify the mathematical model.

It could be seen from Figure 18 that reaction rate per unit surface area increased with carbon conversion for the three coarser particle sizes and remained virtually constant for smallest size. Therefore, it could be concluded that reaction rate was not limited by diffusion. Increase in reaction rates

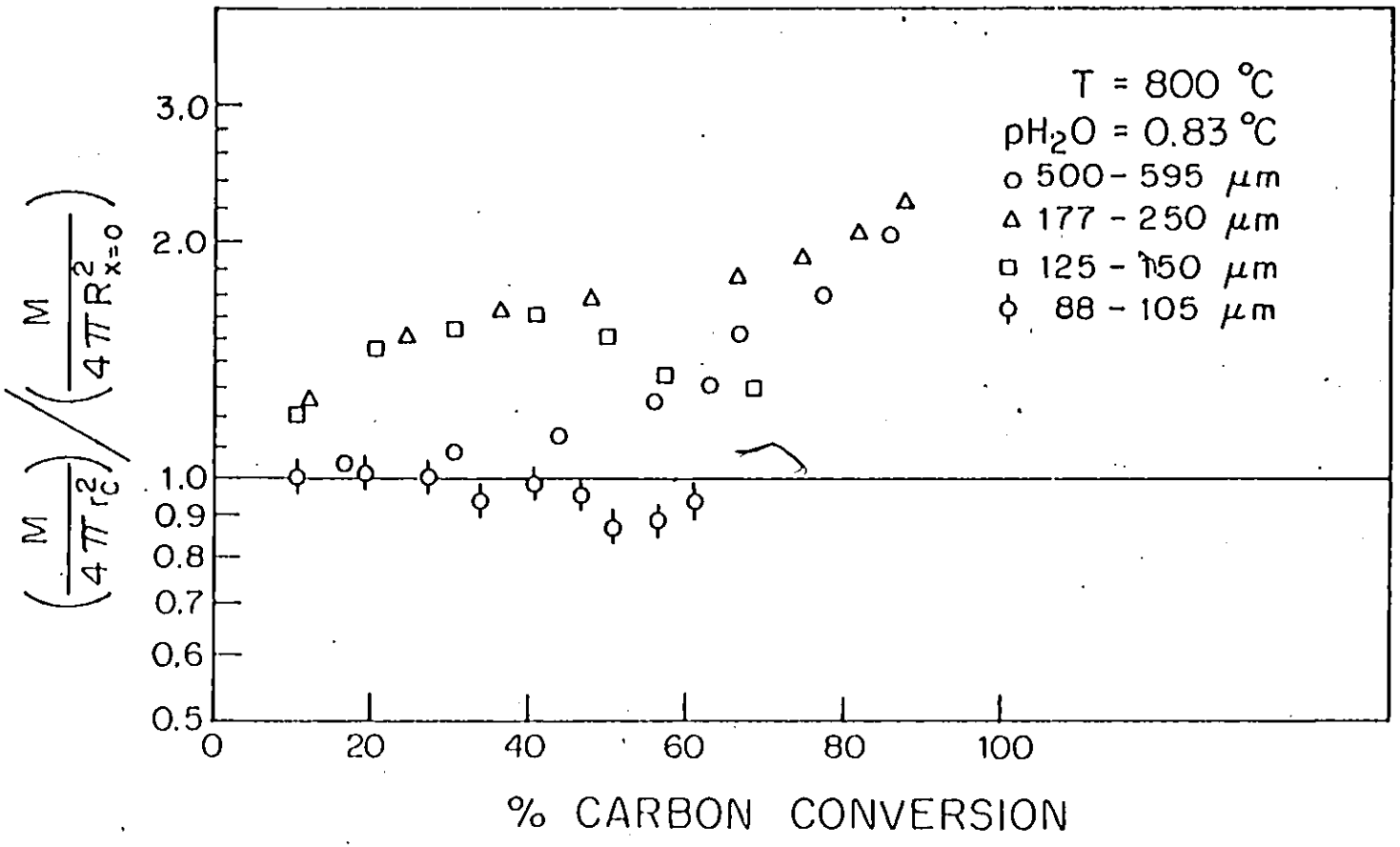

Figure 18. Normalized Reaction Rate Per Unit Surface Area vs Carbon Conversion

per unit surface area with carbon conversion could be explained with the help of the concept of geometrical instability of an unreacted shrinking core particle (63). As the carbon conversion increases, unevenness of reaction surface increases. This results in greater penetration of the char particle by reactant gas and the reaction was not limited only to the outer surface of the particle. Hence, higher reaction rates per unit surface area are obtained with increase in carbon conversion.

5.2 Catalysis Screening

In this series of runs variations in gasification rate and product gas composition were investigated:

1. by gasifying char at 650°C and 0.86 atm of steam partial pressure in the presence of different catalysis each at 20 percent concentration level except Ni and Fe_2O_3 which were added at 1 and 10 percent level respectively, and also by varying concentration of sodium and potassium carbonates between 1 and 20 percent;
2. by gasifying char at 800°C and 0.86 atm of steam in the presence of different catalysis each at 20 percent concentration level and varying the concentration of sodium and potassium carbonates;

3. by gasifying char at 650°C and 0.35 atm of steam in the presence of sodium or potassium carbonate, each at 10 percent concentration level; and
4. by gasifying char at 760°C and 0.35 atm of steam in the presence of sodium or potassium carbonate, each at 10 percent concentration level.

Description of all the experimental parameters studied, is given in Table 5.5. Results of this series of runs are summarized in Table 5.6, 5.7 and 5.9. The effect of parameters namely: catalyst type, catalyst concentration, gasification temperature and steam partial pressure on gasification rate and product gas composition are described here.

5.2.1 Catalyst Type

Figure 19 shows the carbon conversion vs. time curves for K_2CO_3, Na_2CO_3, KCl and NaCl, each at 20% by weight. While K_2CO_3 and Na_2CO_3 were comparable in increasing the carbon conversion, KCl and NaCl were not equally effective. Conversion vs. time curves for 1% nickel, 10% K_2CO_3 and 1% nickel + 10% K_2CO_3 are shown in Figure 20. Carbon gasification rate at 10% carbon conversion level and gas yield for each of the catalysis are reported in Table 5.6.

Table 5.5

EXPERIMENTAL SCHEME FOR CATALYSTS SCREENING

		K_2CO_3	1, 5, 10, 20%
		KCl	20%
	650°C	NaCl	20%
		Ni	1%
		Ni + K_2CO_3	1 + 10%
	0.86 atm	Fe_2O_3	10%
		K_2CO_3	5, 10, 20%
	800°C	Na_2CO_3	5, 20%
CHAR		KCl	20%
		NaCl	20%
	650°C	K_2CO_3	10%
		Na_2CO_3	10%
	0.35 atm		
	760°C	K_2CO_3	10%
		Na_2CO_3	10%

Table 5.6

COMPARISON OF CATALYSTS
P_{H_2O}=0.86 atm

Run No.	T, °C	Catalyst	Concn. %	Reaction time min.	Total carbon conv.%	Stoichiometry H_2O/C	Specific Gasification rate* $\frac{g}{min\text{-}g} \times 10^2$	Gas yield $\frac{ml}{hr\text{-}g}$	Gas composition mole percent H_2	CO	CO_2	CH_4	H_2/CO ratio
47	650	none	-	206	14.9	1.97	0.060	241.0	66.4	1.3	32.4	0.0	51.1
100	650	K_2CO_3	1	206	31.3	1.96	0.185	503.0	66.2	2.5	31.3	0.0	26.5
46	650	K_2CO_3	5	206	37.0	1.92	0.210	589.0	65.8	3.0	31.2	0.0	21.9
99	650	K_2CO_3	10	206	52.9	1.98	0.285	861.8	66.6	3.6	29.8	0.0	18.5
45	650	K_2CO_3	20	206	59.5	1.49	0.340	801.8	59.6	11.5	28.6	0.3	5.2
49	650	Na_2CO_3	5	206	37.5	2.02	0.215	614.5	66.9	3.3	29.8	0.0	20.3
59	650	Na_2CO_3	10	206	40.6	1.95	0.240	646.2	65.9	4.8	29.3	0.0	13.7
48	650	Na_2CO_3	20	196	47.2	1.88	0.325	777.5	65.3	4.3	30.4	0.0	15.2
50	650	KCl	20	206	30.6	1.97	0.180	493.8	66.3	2.5	31.2	0.0	26.5
51	650	NaCl	20	206	18.8	1.99	0.105	306.5	66.6	2.1	31.3	0.0	31.7
107	650	Ni	1	206	23.4	2.39	0.156	522.3	70.5	1.5	28.0	0.0	47.0
108	650	Ni+K_2CO_3	1+10	206	67.5	2.00	0.373	1096.3	66.5	5.3	28.0	0.2	12.5
18	650	Fe_2O_3	10	206	18.1	2.53	0.108	347.6	71.5	1.8	26.4	0.4	39.7

* Gasification rate at 10% carbon conversion.

Table 5.7

COMPARISON OF CATALYSTS

P_{H_2O}=0.86 atm

Run No.	T, °C	Catalyst	Concn. %	Reaction time min.	Total carbon conv.%	Stoichiometry H_2O/C	Specific Gasification rate* $\frac{g}{min\text{-}g} \times 10^2$	Gas yield $\frac{ml}{hr\text{-}g}$	Gas composition mole percent H_2	CO	CO_2	CH_4	H_2/CO ratio
61	800	none	-	188	76.7	1.50	0.80	1126.4	59.4	21.2	18.7	0.6	2.8
57	800	K_2CO_3	5	124	91.4	1.32	1.45	1887.7	56.3	30.0	13.1	0.6	1.9
101	800	K_2CO_3	10	68	96.3	1.13	2.40	3340.8	52.5	39.3	7.6	0.6	1.3
56	800	K_2CO_3	20	78	94.1	1.23	2.85	2931.1	54.7	36.1	8.7	0.4	1.5
58	800	Na_2CO_3	5	146	93.8	1.39	1.45	1705.5	57.8	27.9	13.9	0.5	2.1
102	800	Na_2CO_3	20	68	94.4	1.13	3.35	3340.2	52.5	39.3	7.6	0.6	1.3
53	800	KCl	20	148	96.4	1.44	1.45	1748.4	58.5	24.9	16.1	0.6	2.3
52	800	NaCl	20	178	94.1	1.58	1.25	1510.6	60.8	18.0	20.7	0.4	3.4

Table 5.9

COMPARISON OF CATALYSTS

P_{H_2O}=0.35 atm

39	650	none	-	294	12.2	1.93	0.045	134.9	65.9	3.6	30.5	0.0	18.3
80	650	K_2CO_3	10	264	37.9	1.74	0.186	440.0	63.5	13.2	23.3	0.0	4.8
81	650	Na_2CO_3	10	294	35.2	1.85	0.155	378.9	64.9	9.7	25.4	0.0	6.7
-	760	none	-	264	37.3	1.88	0.210	501.0	64.7	15.6	19.3	0.5	4.2
79	760	K_2CO_3	10	204	78.3	1.24	0.470	948.1	54.4	37.5	7.4	0.7	1.5
82	760	Na_2CO_3	10	204	59.9	1.16	0.360	692.9	53.0	39.3	6.9	0.7	1.3

* Gasification rate at 50% carbon conversion.

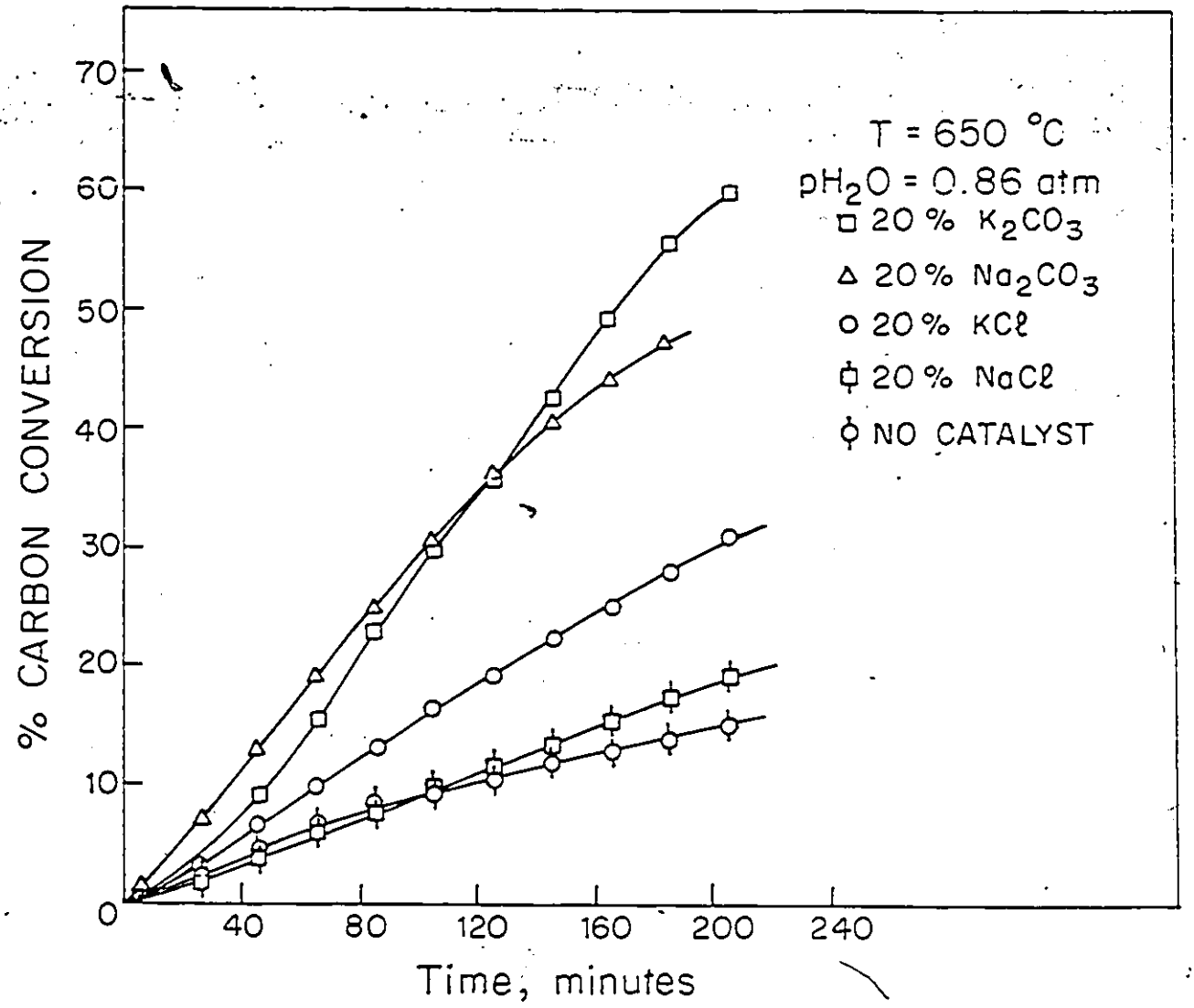

Figure 19. Effect of Catalyst Type on Carbon Conversion

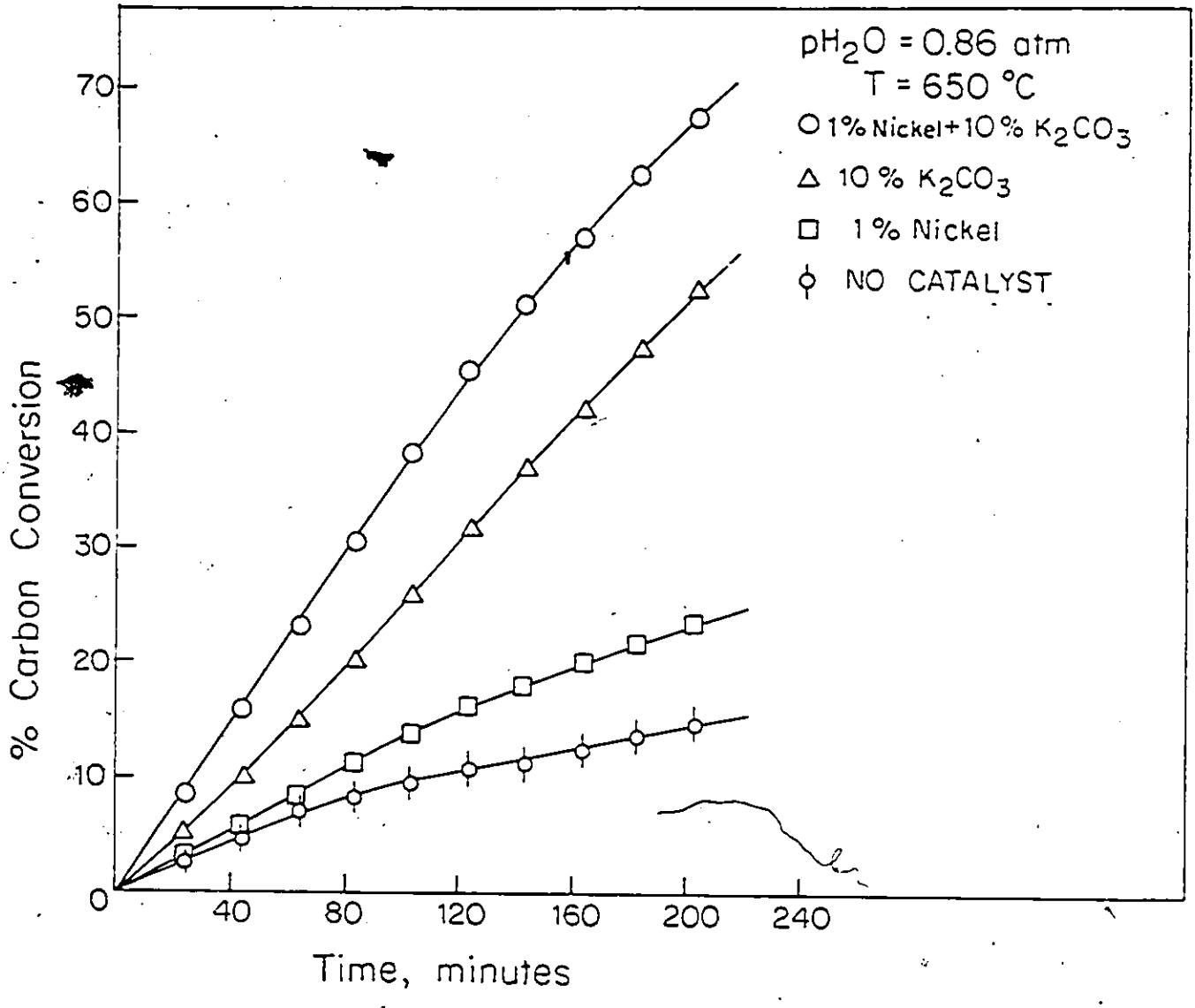

Figure 20. Effect of Nickel, Potassium Carbonate and Mixed Catalyst on Carbon Conversion

Comparison of gasification rates show that 1% nickel was a more effective catalyst than 20% KCl or NaCl. Also, the combined catalytic activity of 1% nickel and 10% K_2CO_3 was better than 20% K_2CO_3 or Na_2CO_3. Ferric (III) oxide was found to have very little catalytic activity towards carbon gasification.

Product gas composition shifted towards more carbon monoxide and less carbon dioxide in the presence of any of the catalysts. The amount of hydrogen either decreased or remained unchanged in the presence of K_2CO_3, Na_2CO_3, KCl or NaCl. However, hydrogen content of the product gas increased on the addition of nickel. The H_2/CO ratio was calculated (Table 5.5) to indicate the shift in product gas composition. The resence of 20% K_2CO_3 in the char bed, gave the lowest value of 5.2 for H_2/CO ratio corresponding to highest amount of carbon monoxide (11.5%) at 650°C and 0.86 atm of steam. Fe_2O_3 was least effective in changing the H_2/CO ratio.

Methane was usually absent except in the presence of 20% K_2CO_3, 10% FeO_3 the dual catalyst ($Ni+K_2CO_3$). When present, the amount of methane was less than 0.5 percent.

Stoichiometry of the reaction reported in Table 5.6 was calculated by dividing total hydrogen content by total carbon content of product gas. It was assumed that all the hydrogen

present in the product gas was obtained from steam decomposition. Stoichiometry decreased in the presence of K_2CO_3 or Na_2CO_3 remained nearly the same in the presence of KCl or NaCl and increased in the presence of nickel or Fe_2O_3.

5.2.2 Catalyst Concentration

Figure 21 shows the conversion time curves for 1, 5, 10 and 20% K_2CO_3 present in the char bed. Carbon conversion and gasification rate increased with increase in catalyst concentration. Increase in gasification rate was three-fold for 1% K_2CO_3 and more than five-fold for 20% K_2CO_3. Rate also increased in the presence of Na_2CO_3 when its concentration was raised from 5 to 20%. Na_2CO_3 proved to be a better catalyst than K_2CO_3 at the 5% concentration level. However, K_2CO_3 was more effective at the 10 and 20% levels. Concentration of KCl and NaCl were not varied because of their very poor activity even at 20% concentration level.

Increase in concentration of K_2CO_3 shifted the gas composition further towards less hydrogen and carbon dioxide and more carbon monoxide. The H_2/CO ratio went down from 26.2 to 5.2 as the concentration of K_2CO_3 was increased from 1 to 20 percent. In the presence of Na_2CO_3, the H_2/CO ratio decreased from 30.3 at the 5% level to 13.7 at the 10% level and then increased slightly to 15.2 at the 20% level.

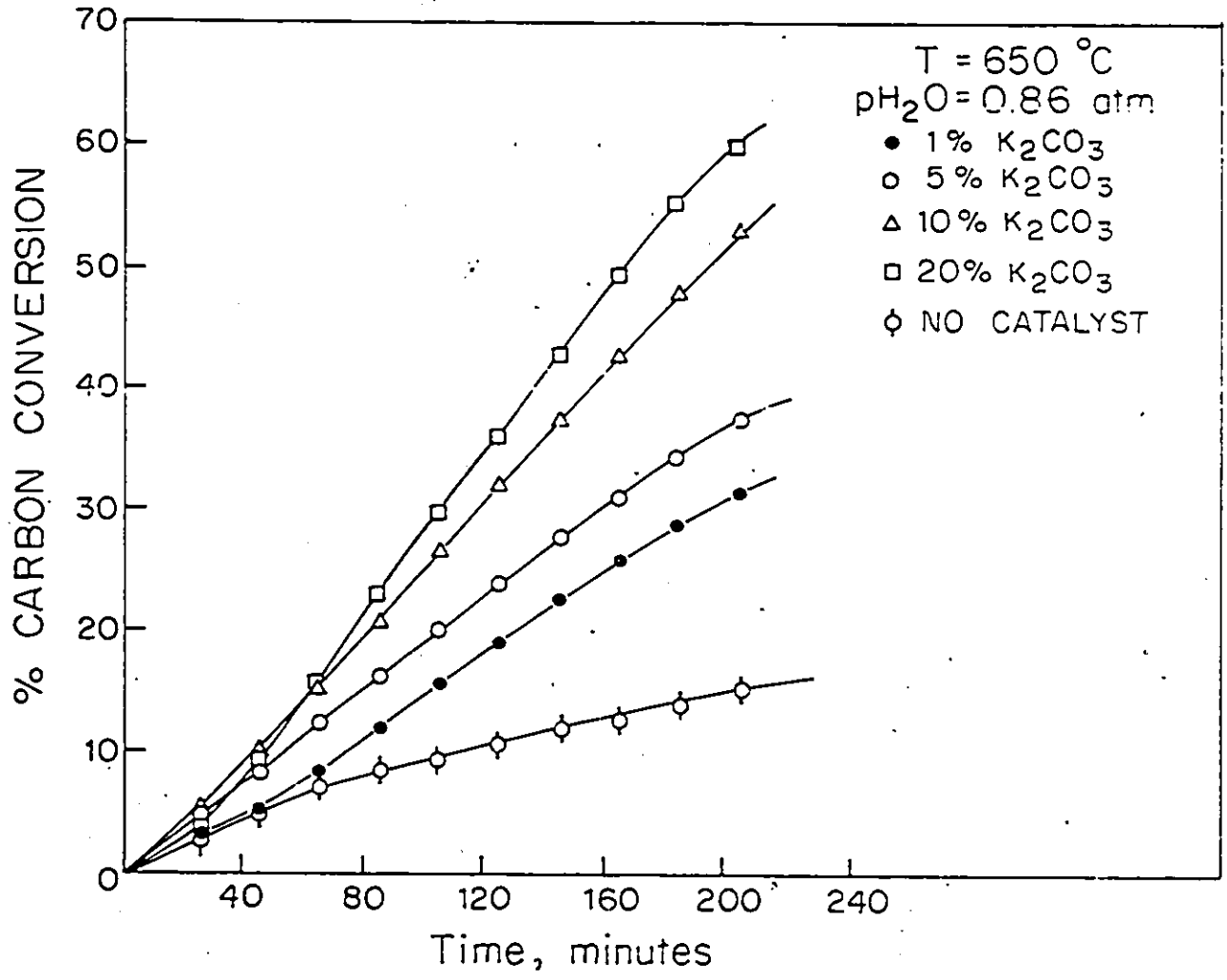

Figure 21. Effect of Potassium Carbonate Concentration on Carbon Conversion

5.2.3 Gasification Temperature

Experiments were conducted to study the effect of temperature on the catalytic activity of K_2CO_3, Na_2CO_3, KCl and NaCl at 800°C keeping the partial pressure of steam constant (0.86 atm). The concentration of each of these catalysts was kept at 20% by weight. Results of this set of experiments are compiled in Table 5.7. The catalytic effect of 20% K_2CO_3 on carbon conversion at two temperature levels of 650°C and 800°C are shown in Figure 22. The Relative effectiveness of K_2CO_3 was lower at higher temperature.

Carbon conversions of more than 90% were obtained within a relatively short time in the presence of any of the catalysis. Reaction time taken to achieve this conversion is indicative of the effectiveness of each of catalysts at 800°C Gasification rates at 50% carbon conversion are compared in Table 5.6.

At 800°C, K_2CO_3 and Na_2CO_3 were almost equally effective at 5% concentration level. Na_2CO_3 gave a higher gasification rate than K_2CO_3 at 20% concentration level. This was the reverse for K_2CO_3 and Na_2CO_3 when the gasification temperature was 650°C. The relative effectiveness of KCl and NaCl remained unaffected with an increase in temperature.

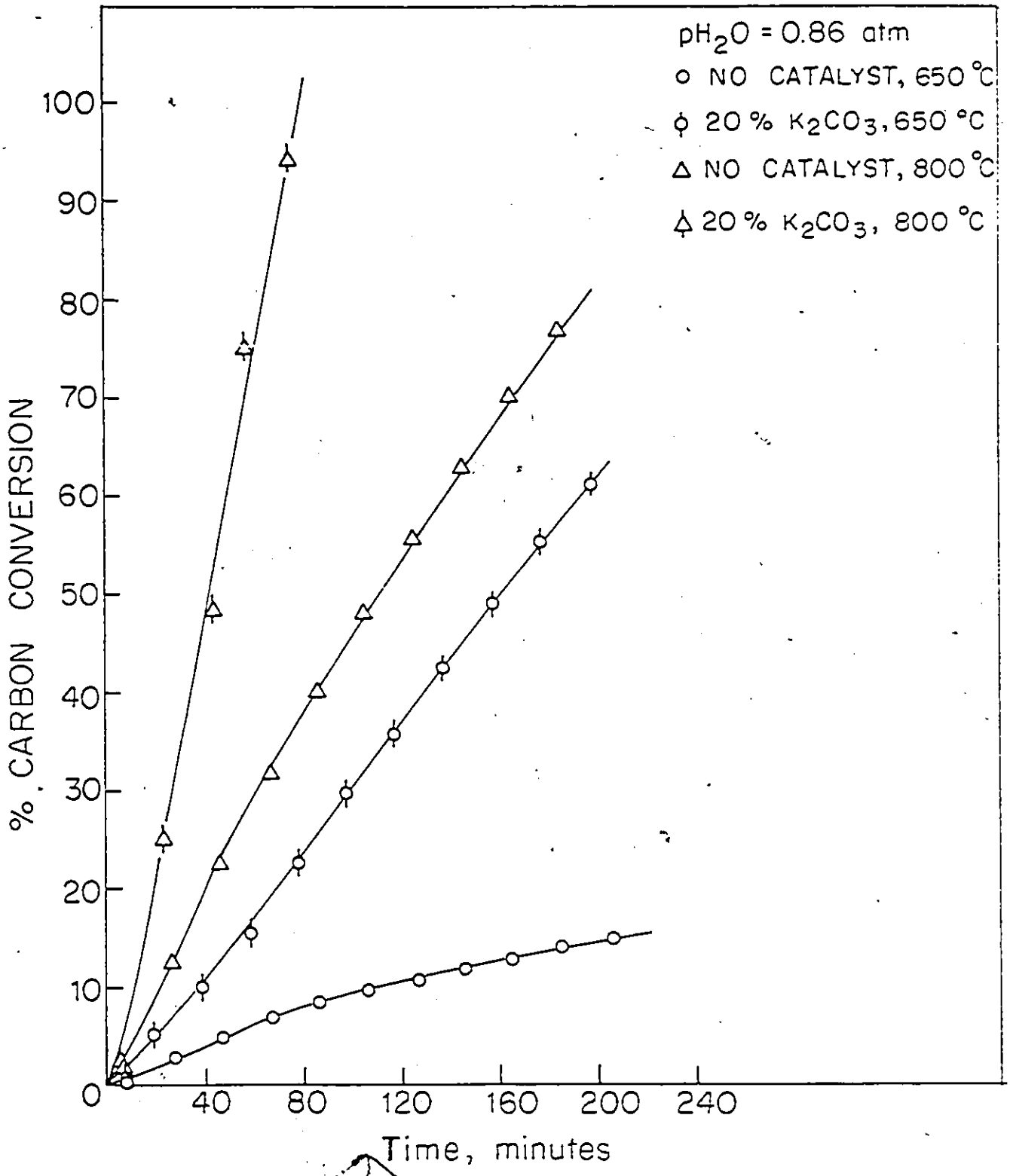

Figure 22. Effect of Catalyst and Temperature on Carbon Conversion

A shift in product gas composition in the presence of a catalytic agent at 800°C was similar to that obtained at 650°C. Figure 23 shows the change in the mole percent of each component at 800°C when 20% K_2CO_3 was added. H_2/CO ratio was lowered from 2.8 to 1.5 by addition of K_2CO_3 under the experimental conditions.

Figure 24 shows the effect of temperature on the product gas composition in the presence of 20% K_2CO_3. An increase in temperature from 650°C to 800°C further lowered the H_2/CO ratio. Therefore the addition of catalyst at both temperatures (650°C and 800°C) and an increase in temperature with or without catalyst had similar effect on the gas composition. The value of the H_2/CO ratio under various conditions is given below to clarify the changes in product gas composition.

Table 5.8

EFFECT OF CATALYST AND TEMPERATURE ON THE PRODUCT GAS COMPOSITION
P_{H_2O}=0.86 atm.

T, °C, catalyst → ↓	H_2/CO Ratio None	20% K_2CO_3
650	51.1	5.2
800	2.8	1.5

It should be noted that values of the H_2/CO ratio between 1.5 and 51.1 could be obtained under intermediate conditions of temperature and catalyst concentration.

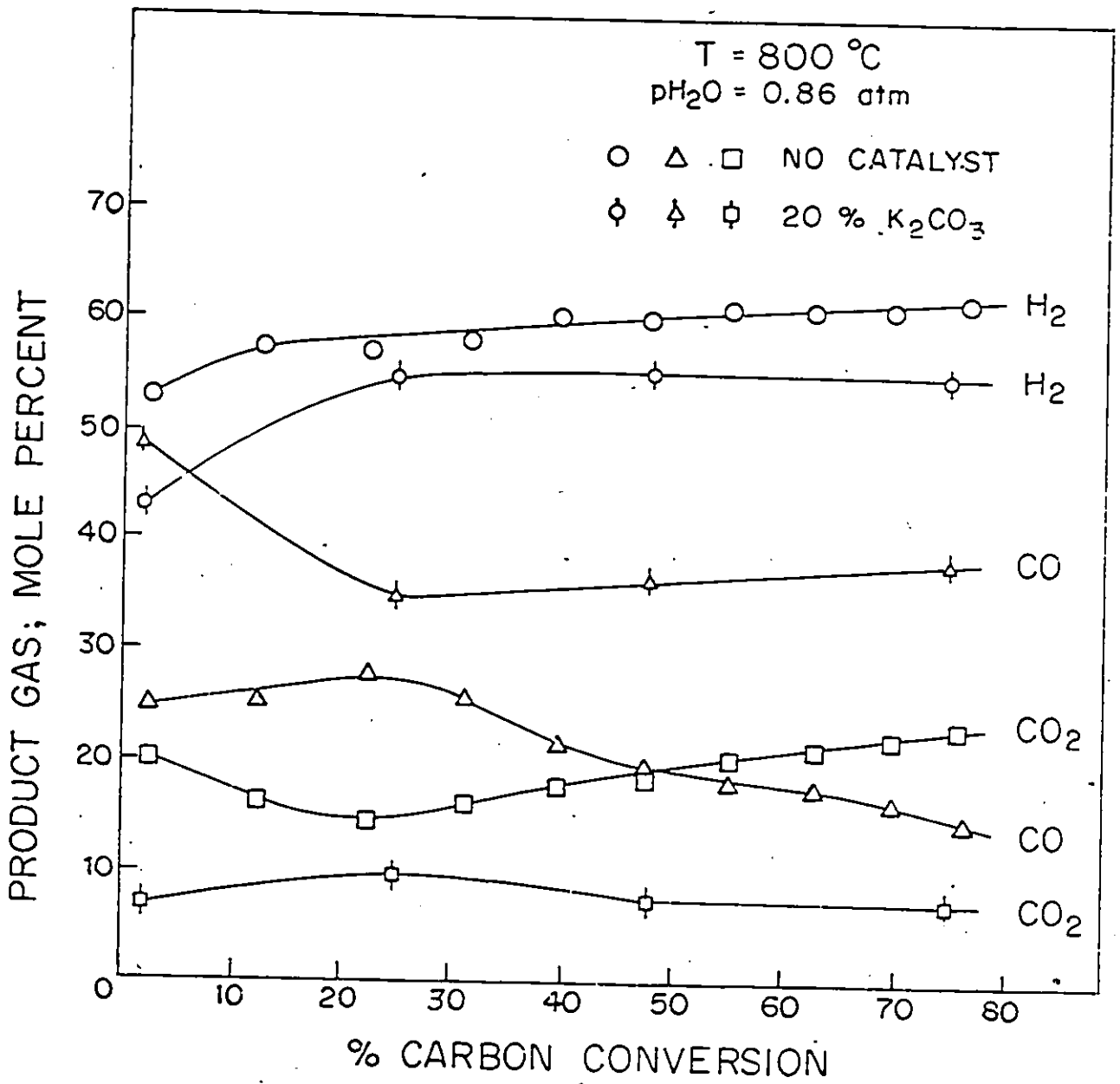

Figure 23. Effect of Catalyst on Product Gas Composition

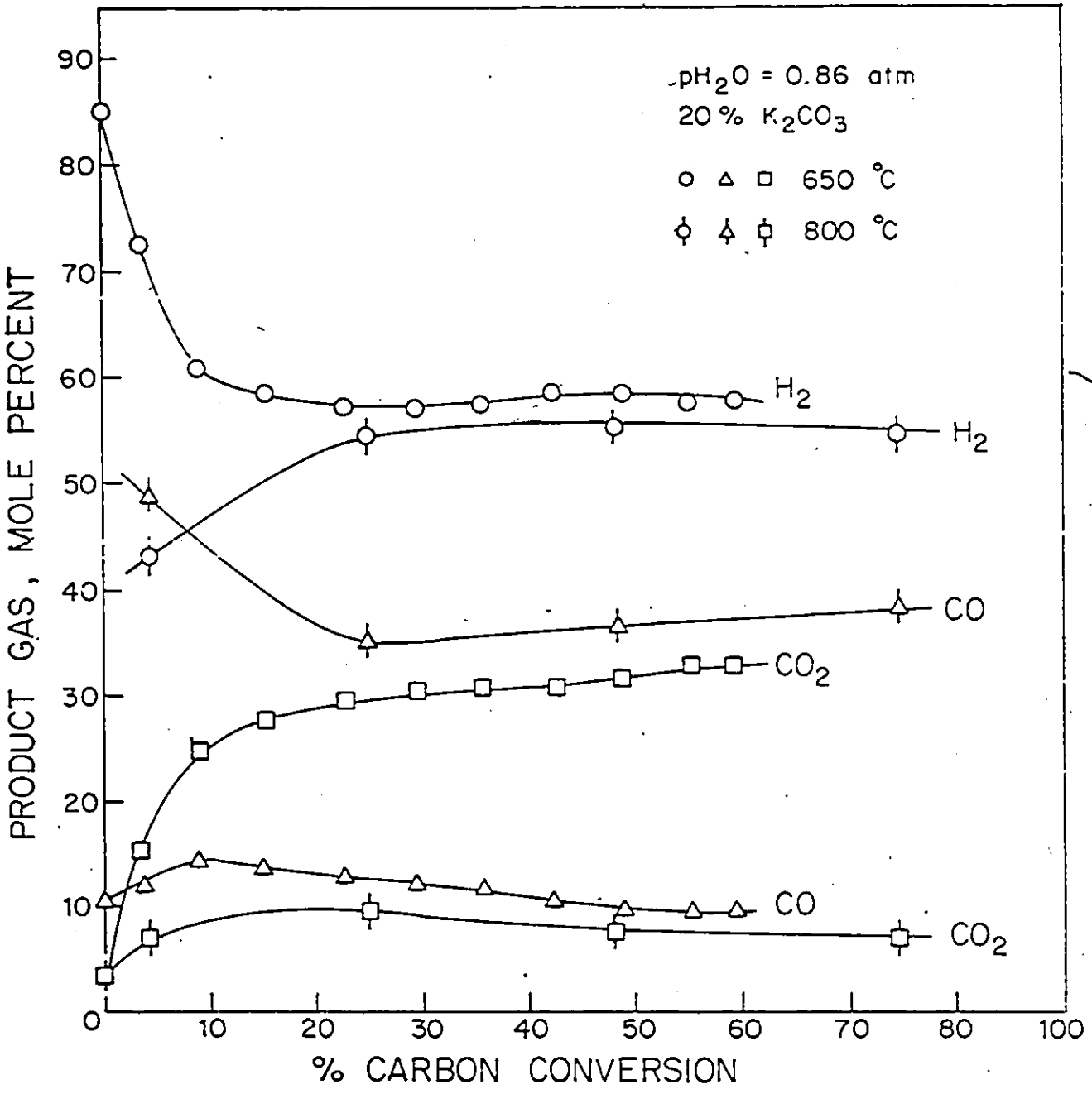

Figure 24. Effect of Temperature on Product Gas Composition during Catalyzed Gasification

5.2.4 Steam Partial Pressure

The results described so far were from the experiments conducted at 0.86 atm steam partial pressure. Experiments were conducted at 0.35 atm of steam to study the effect of steam partial pressure on carbon conversion and product gas composition in the presence of catalyst. Gasification of char was carried out at 650°C and 760°C in the presence of 10% K_2CO_3 and 10% Na_2CO_3. Results of the six experiments thus completed are given in Table 5.9.

Conversion time curves for uncatalyzed and catalyzed gasification at 650°C for two steam partial pressures are shown in Figure 25. The Catalytic effect of K_2CO_3 was of the same order of magnitude at both steam partial pressures.

Figure 26 shows the comparison of K_2CO_3 and Na_2CO_3 at 650°C and 0.35 atm of steam. While the two catalytic agents had comparable performance at 0.86 atm, K_2CO_3 was distinctly better than Na_2CO_3 at 0.35 atm of steam.

Lower steam partial pressures favoured lower values of H_2/CO ratio with or without an added catalyst. The values ranged from 18.5 at 650°C for uncatalyzed gasification to 1.3 at 760°C in the presence of 10% Na_2CO_3. This ratio at 650°C and in the presence of 10% K_2CO_3 was 18.5 at 0.86 atm and 4.8 at 0.35 atm of steam. Again, the shift in product gas composition could be understood from the values tabulated below:

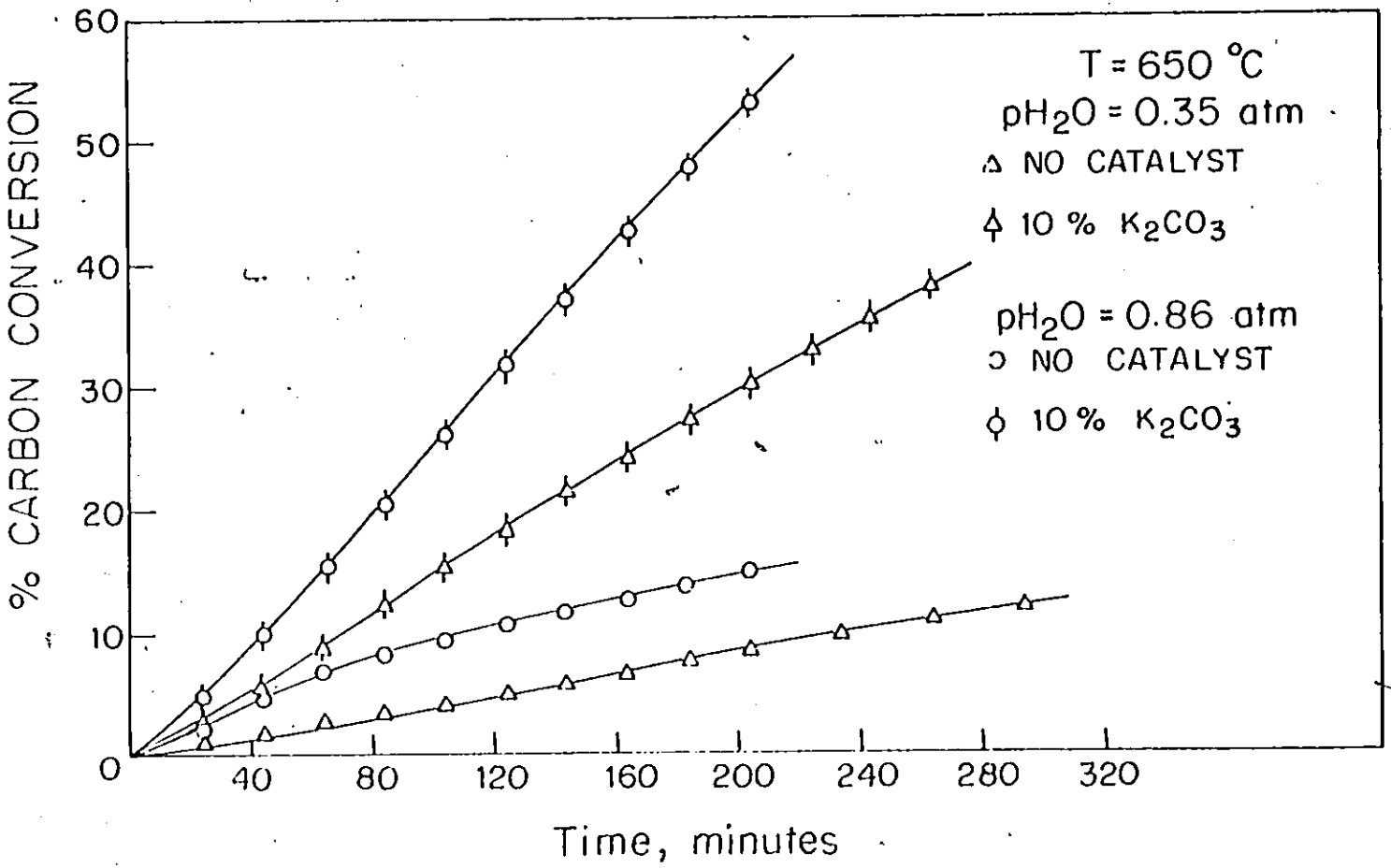

Figure 25. Effect of Steam Partial Pressure and Catalyst on Carbon Conversion

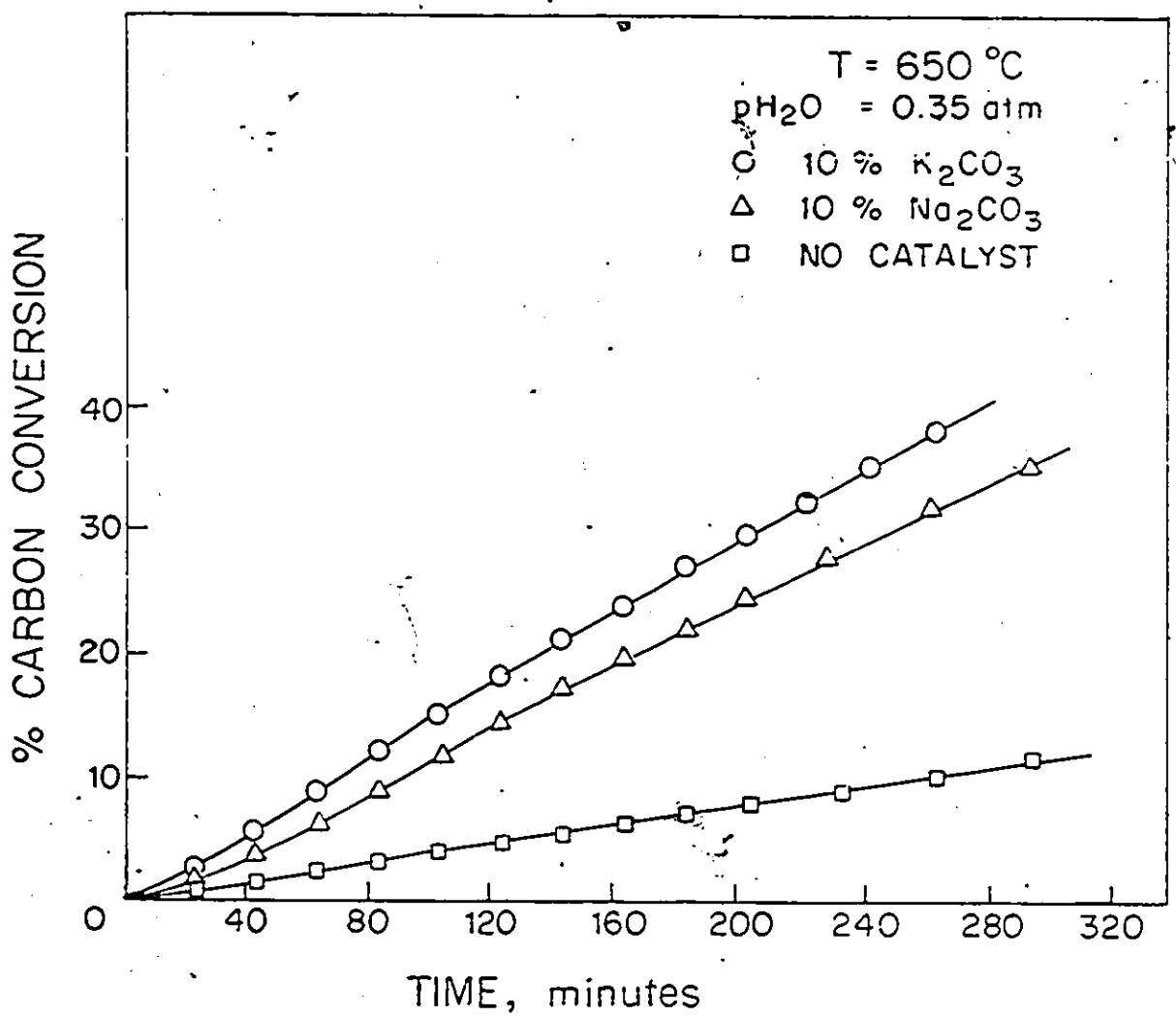

Figure 26. Effect of Potassium and Sodium Carbonate on Carbon Conversion

Table 5.10

EFFECT OF STEAM PARTIAL PRESSURE AND CATALYST ON PRODUCT GAS COMPOSITION
Temperature = 650°C

P_{H_2O} (atm), catalyst → ↓	H_2/CO Ratio None	10% K_2CO_3
0.86	51.1	18.5
0.35	18.3	4.8

It should be noted that either addition of 10% K_2CO_3 or lowering of steam partial pressure from 0.86 to 0.35 atm had almost the same effect on the H_2/CO ratio.

5.3 Kinetics of Catalytic Gasification

10% potassium carbonate catalyst was selected for kinetics experiments from the results of catalysts screening. In the presence of 10% K_2CO_3, there was not only manifold increase in the gasification, but also an appreciable shift in the product gas composition under all the experimental conditions tested. 10 percent carbonate carbonate was also equally effective at 0.86 atm of steam but was inferior to K_2CO_3 at the lower partial pressure (0.35 atm) of steam. Some kinetics experiments were also conducted in the presence of 10% Na_2CO_3.

Gasification of char was carried out in the presence of 10% K_2CO_3 in the temperature range of 640°C to 760°C. Partial pressure of steam at the inlet of the reactor was varied from 0.33 to 0.74 atm. Results of this series of experiments are summarized in Table 5.11. Carbon conversion from 36.2 to 94.6 percent and steam conversion of 20.1 to 81.3 percent were obtained under varying conditions of temperature and steam partial pressure. The apparent stoichiometry was lower than that observed under identical conditions of uncatalyzed gasification. The value of stoichiometry ranged from 1.22 at 760°C and 0.33 atm to 1.92 at 640°C and 0.74 atm of steam.

The product gas composition shifted towards larger amounts of carbon monoxide and smaller amount of hydrogen and carbon dioxide with an increase in gasification temperature and decrease in steam partial pressure. The effect was similar to that for uncatalyzed gasification. This shift in the gas composition was indicated by H_2/CO ratio values given in Table 5.11. This ratio changed from 1.5 at 760°C and 0.33 atm of steam to 12.6 at 640°C and 0.74 atm of steam. The ratio between 1.5 and 12.6 were obtained under intermediate conditions of temperature and steam partial pressure. Methane was also present in small amounts during most of the runs. The maximum amount of methane produced during a run was 0.8 percent.

The particle size of the char was also varied in a similar manner to that during uncatalyzed gasification. Potassium carbonate

Table 5.11

RESULTS OF CATALYTIC GASIFICATION
(10% K_2CO_3)

Run No.	T, °C	P_{H_2O}	Reaction time min	Total carbon conv, %	Total steam conv, %	Apparent stoichiometry H_2O/C	gas yield ml/hr-g	Gas Composition mole percent H_2	CO	CO_2	CH_4	H_2/CO ratio
80	650	0.33	264	37.9	42.4	1.74	439.9	63.5	13.2	23.3	0.0	4.8
77	700	0.33	244	55.2	52.4	1.32	588.5	57.0	28.6	14.5	0.0	2.0
78	730	0.33	234	76.9	77.7	1.34	857.4	57.0	31.3	11.3	0.0	1.8
79	760	0.33	204	78.3	81.3	1.22	948.1	54.0	37.5	7.4	0.7	1.5
75	640	0.49	284	44.5	32.1	1.76	483.7	63.8	7.3	28.9	0.0	8.8
71	670	0.48	270	53.9	39.2	1.70	603.5	63.0	12.4	24.6	0.0	5.1
72	700	0.49	234	72.1	54.6	1.57	883.0	60.9	17.8	21.0	0.3	3.4
73	730	0.43	224	71.7	60.5	1.37	842.6	57.5	28.2	14.0	0.3	2.0
74	760	0.50	214	93.8	66.3	1.30	1181.1	56.1	32.4	11.0	0.5	1.7
84	640	0.61	284	36.2	20.1	1.80	400.1	64.4	7.5	28.2	0.0	8.6
83	670	0.61	244	49.3	29.8	1.69	605.0	62.6	13.9	23.2	0.3	4.5
85	700	0.61	224	62.5	37.5	1.51	773.8	59.6	20.9	18.8	0.8	2.9
86	730	0.61	204	78.8	49.7	1.43	1025.9	58.4	25.2	15.8	0.7	2.3
87	760	0.61	184	82.9	50.8	1.28	1132.0	55.4	34.3	9.5	0.8	1.6
93	640	0.74	284	60.1	28.6	1.92	691.9	65.7	5.2	29.1	0.0	12.6
92	670	0.74	244	71.7	35.7	1.74	899.0	63.4	11.7	24.8	0.2	5.4
90	700	0.74	204	84.5	46.1	1.60	1197.9	61.3	18.5	20.0	0.3	3.3
91	730	0.74	164	91.8	59.1	1.32	1567.9	56.6	30.3	12.8	0.4	1.9
97	760	0.74	124	94.6	80.0	1.42	2111.5	59.5	23.5	16.6	0.4	2.5

was added to four different sizes of char particles and gasified at 760°C and 0.74 atm of steam inlet pressure. Results for the four experimental runs are given in Table 5.12. Carbon conversions of the same order (>90%) were obtained within 124 minutes of reaction time for three of the four particle sizes. The finest particle size gave 83.2 percent carbon conversion within 164 minutes. Gasification rates for the three coarser size particles were of the same order of magnitude and were significantly lower than that of the finest particle size.

Carbon conversion vs. time curves for different temperatures and steam partial pressures are shown in Figures 27, 28, 29 and 30. The approach used to find a suitable kinetic model for the experimental data was similar to that used for uncatalyzed gasification. The unreacted shrinking core model of Equation 5.3 was applied to these results. Plots of $[1-(1-X)^{1/3}]$ vs t on a log-log graph are shown in Figures 31, 32, 33 and 34 for four different steam partial pressures. Figure 35 shows a similar plot for the four different particle sizes of char at 760°C and 0.74 atm of steam.

Experimental data for each temperature and partial pressure could be represented well by a straight line. Slope of these straight lines ranged from 0.9 to 1.1 showing thereby that the unreacted shrinking core model was applicable to the results of catalyzed gasification and also that the rate was

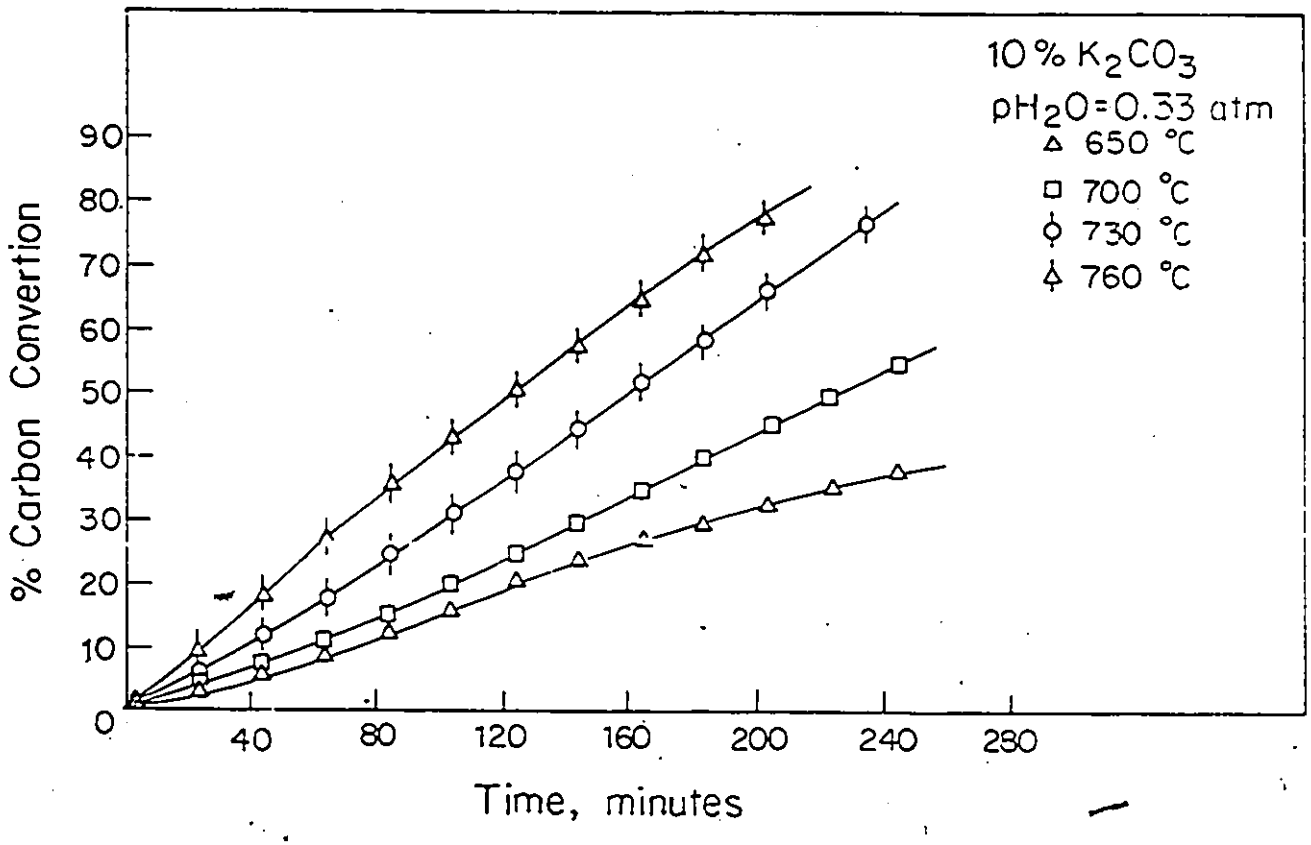

Figure 27. Carbon Conversion vs Reaction Time During Catalyzed Gasification

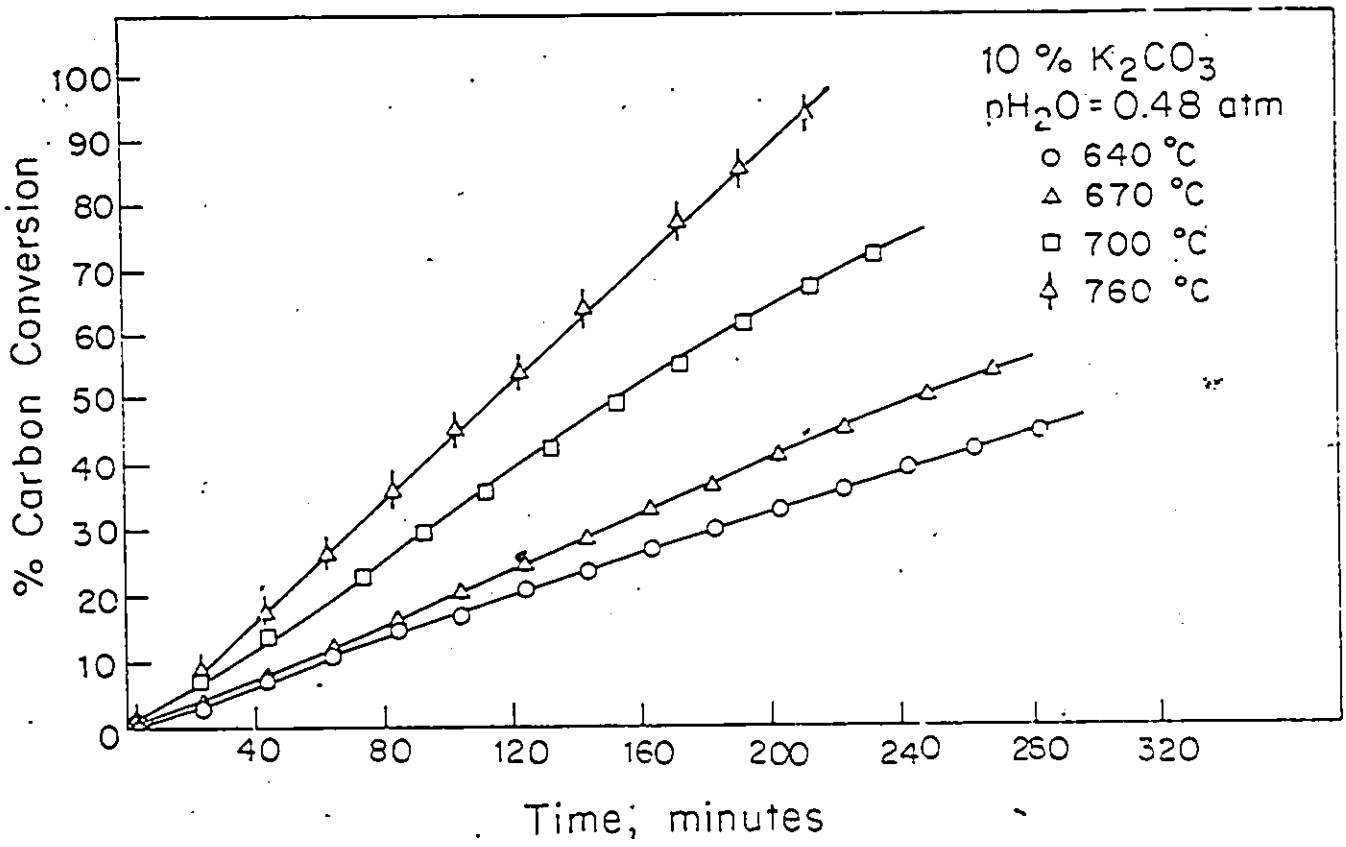

Figure 28. Carbon Conversion vs Reaction Time During Catalyzed Gasification

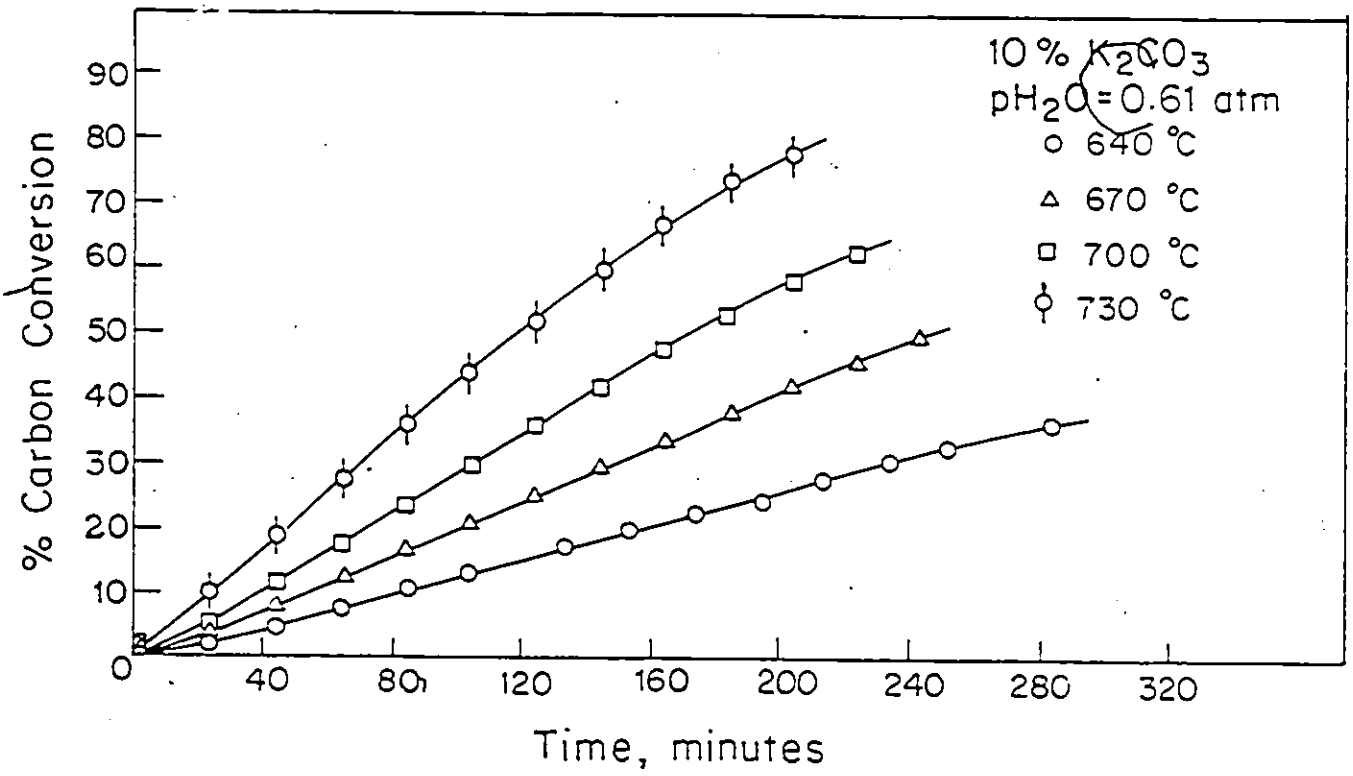

Figure 29. Carbon Conversion vs Reaction Time During Catalyzed Gasification

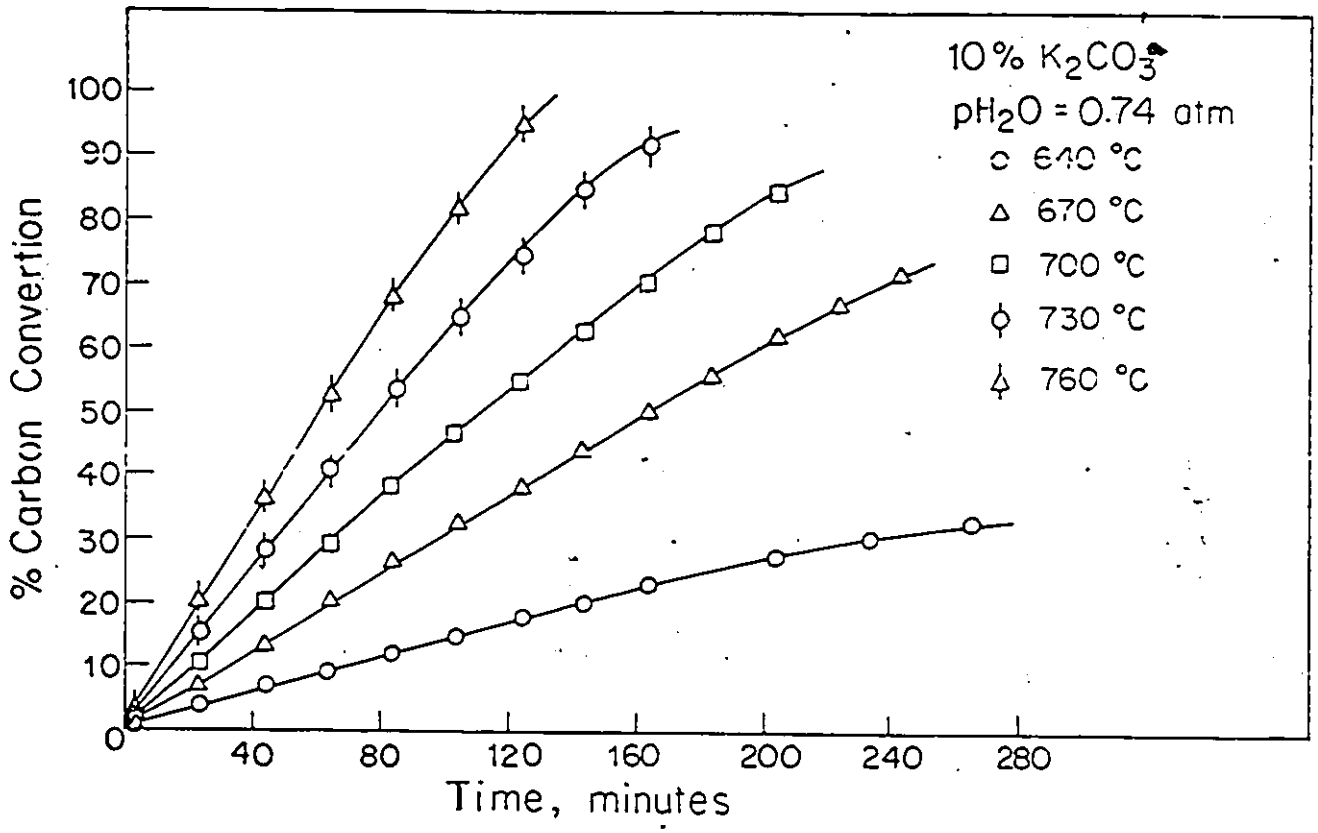

Figure 30. Carbon Conversion vs Reaction Time During Catalyzed Gasification

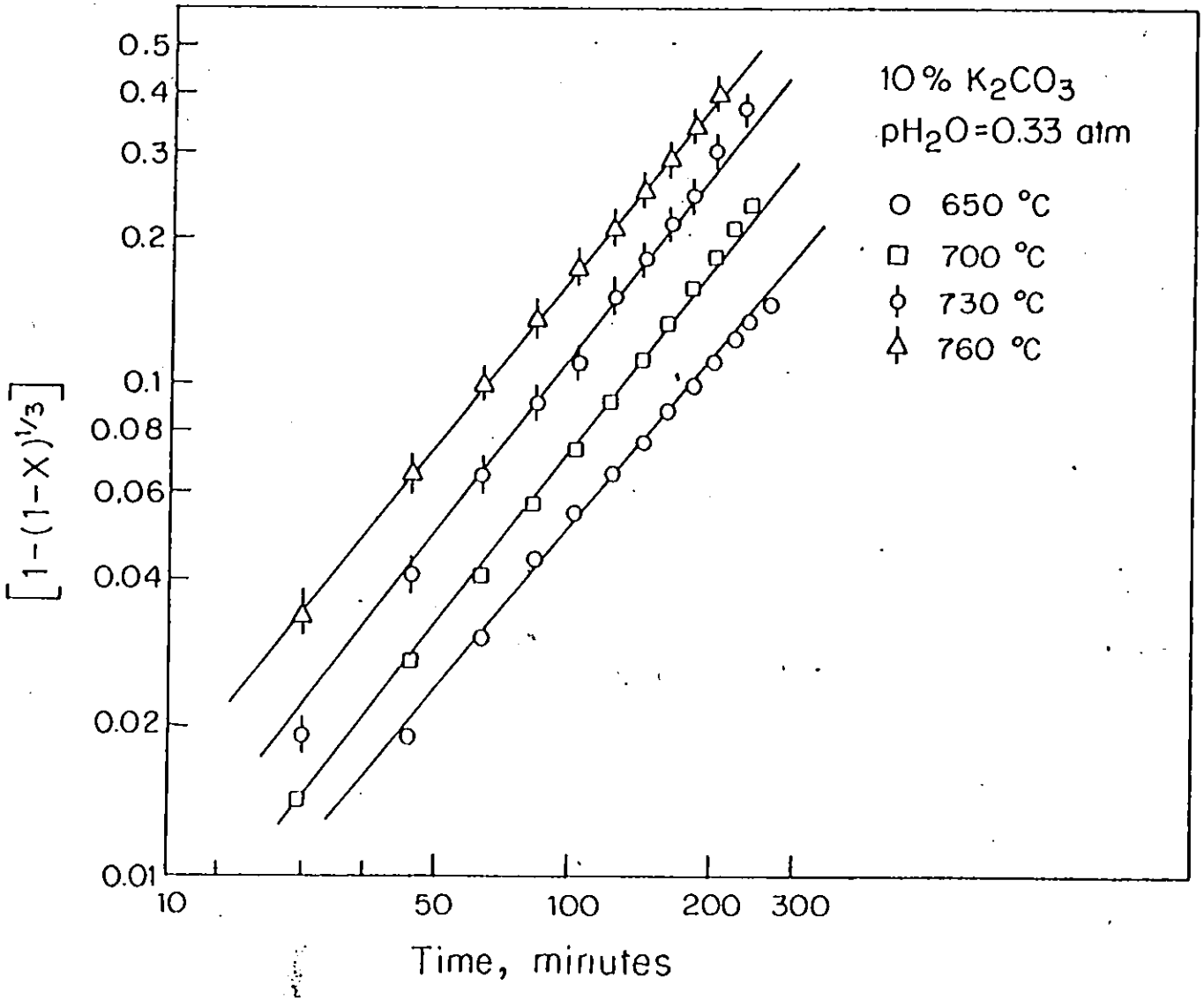

Figure 31. Plots for Unreacted Shrinking Core Model for Catalyzed Gasification

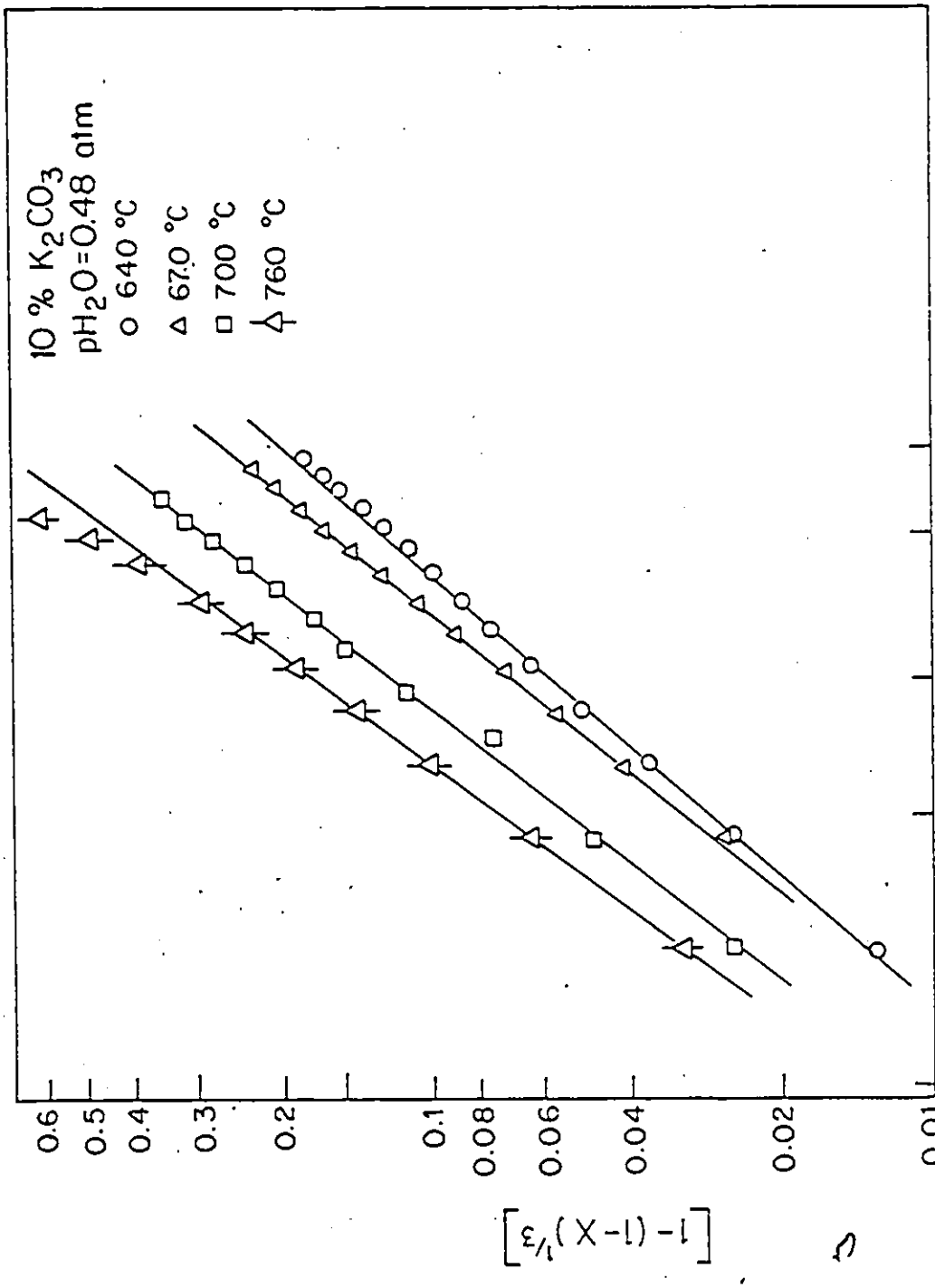

Figure 32. Plots for Unreacted Shrinking Core Model for Catalyzed Gasification

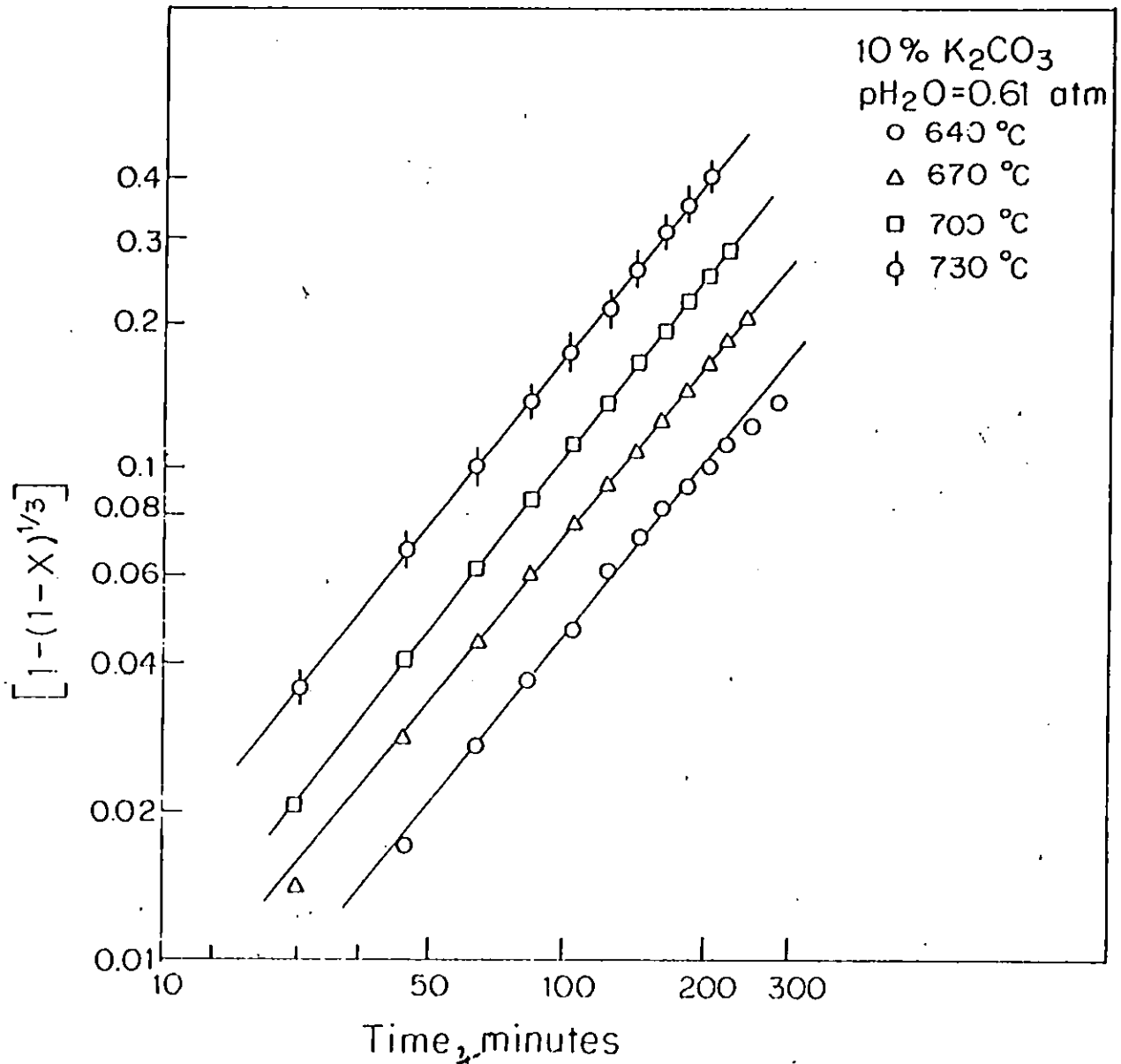

Figure 33. Plots for Unreacted Shrinking Core Model for

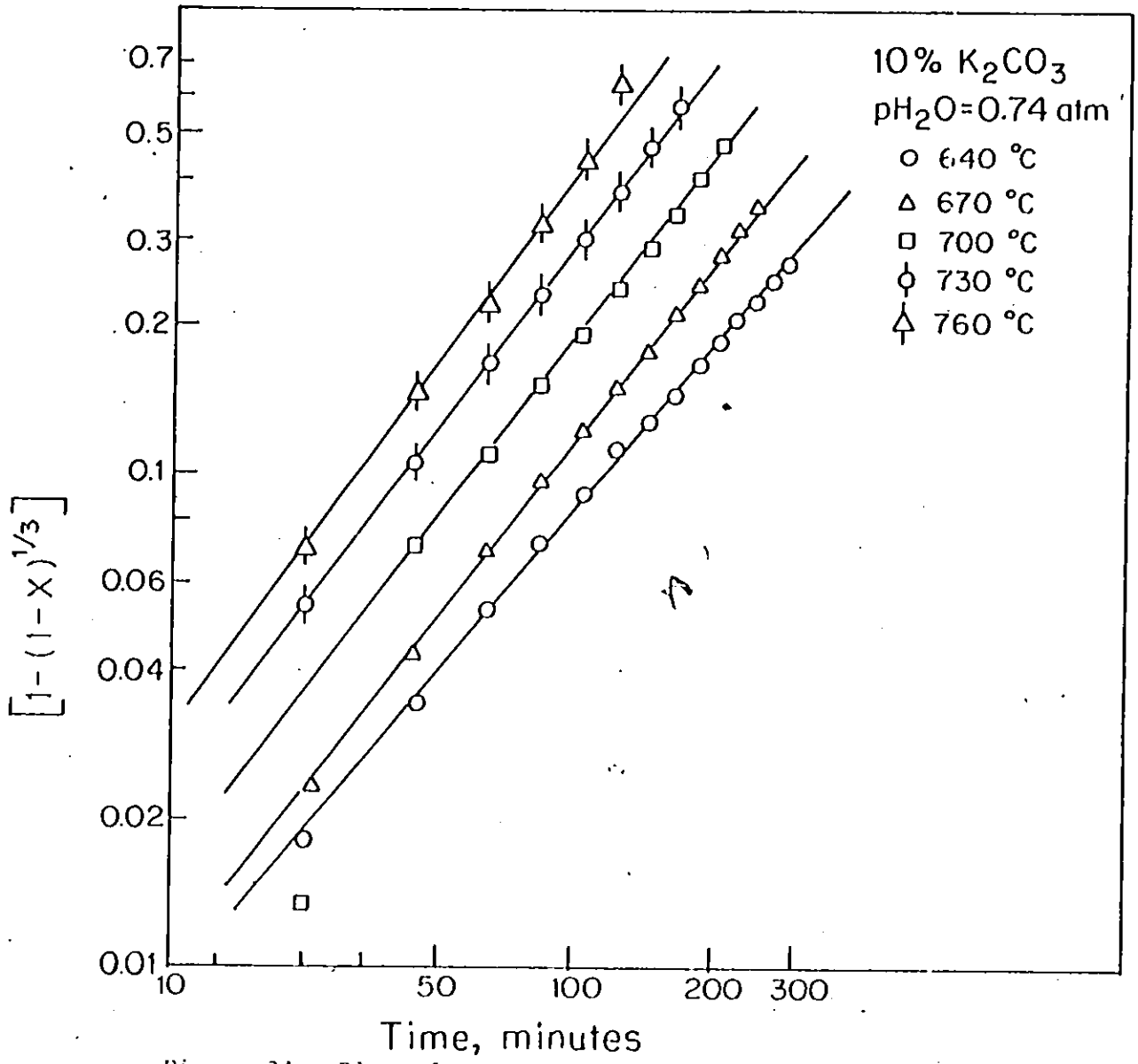

Figure 34. Plots for Unreacted Shrinking Core Model for Catalyzed

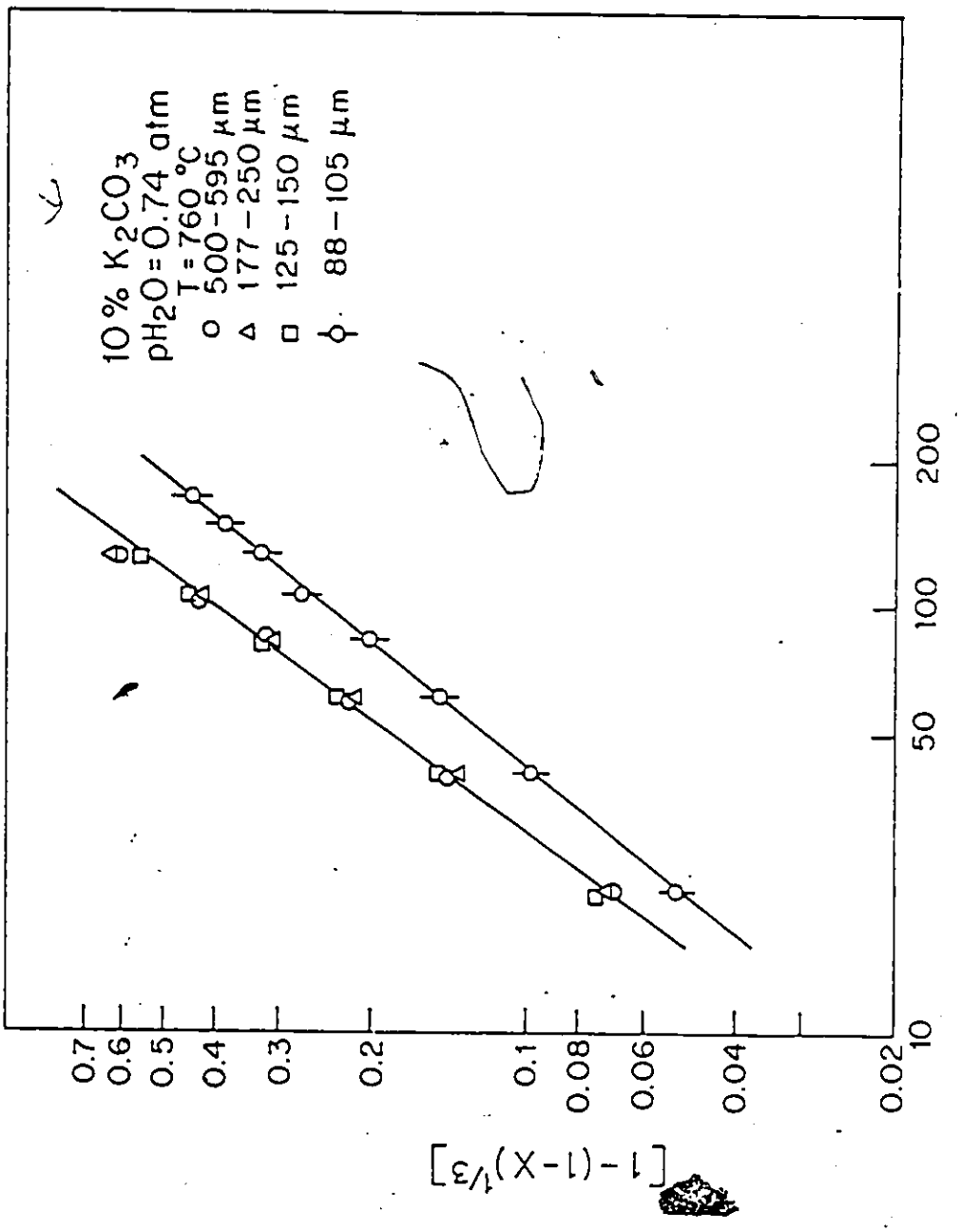

Figure 35. Plots for Uncreated Shrinking Core Model for Catalyzed Gasification for Different Particle Sizes

Table 5.12

EFFECT OF PARTICLE SIZE ON CATALYTIC GASIFICATION

P_{H_2O} = 0.74 atm

T = 760°C

Catalyst 10% K_2CO_3

Run No.	Particle size μm	Reaction time min.	Carbon conversion %	Steam conversion %	Apparent stoichiometry H_2O/C	Gas yield $\frac{ml}{hr-g}$	Gas composition mole percent				H_2/CO ratio
							H_2	CO	CO_2	CH_4	
95	500-595	124	94.1	65.2	1.33	1922.7	56.6	30.3	12.8	0.4	1.9
97	177-250	124	94.6	78.7	1.55	2111.5	60.2	22.1	17.3	0.4	2.7
96	125-150	124	92.3	67.7	1.27	1908.2	55.2	31.0	13.3	0.5	1.8
98	88-105	164	83.2	43.7	1.22	1243.0	54.3	34.4	10.8	0.5	1.6

chemical reaction controlled under the experimental conditions.

To seek a best fit kinetic model, again various forms of function of F(c) given in Table 4.1 were tested with the help of non-linear least square computer programme. The kinetic model represented by Equation 5.7 expressed the experimental results best as it did in the case of uncatalyzed gasification. Equation 5.7 is being reproduced here for the sake of convenience:

$$\frac{dx}{dt} = \frac{3(1-X)^{2/3}}{\rho_B R_p} (k_1 p_{H_2O} + k_2 p_{CO_2}) \qquad (5.7)$$

Therefore catalyzed gasification of char was also represented by parallel C-H_2O and C-CO_2 reactions. Mean values of k_1 and k_2 found from different sets of results are given in Table 5.13.

Table 5.13

REACTION RATE CONSTANTS FOR CATALYZED GASIFICATION (10% K_2CO_3)

T, °C	640	670	700	730	760
$k_1 \times 10^6$	0.672	1.174±0.212	1.724±0.204	3.249±1.290	4.573±1.137
$k_2 \times 10^5$	1.237±0.644	2.418±1.362	4.294±1.652	7.067±3.078	12.539±1.960

Here the range for k_1 and k_2 values is reported at 95% confidence level. Some of the values of k_1 and k_2 were rejected because of obvious larger error. The range for k_1 at

640°C was not calculated since only two values of k_1 at 640°C were available. The confidence interval has little significance if the number of data points are small.

Arrhenius plots for k_1 and k_2 are drawn in Figure 36. Best lines obtained by least squares fit gave the following equations for k_1 and k_2:

$$k_1 = 12.491 \exp(-\frac{30,380}{RT}) \quad (5.12)$$

$$k_2 = 4.920 \times 10^3 \exp(-\frac{35,900}{RT}) \quad (5.13)$$

Here R is in cal/mol-K.

Normalized gasification rates based on the unit surface area of char particle were calculated for different particle sizes of char at 760°C and 0.74 atm of steam. Figure 37 shows the plots of these rates against carbon conversion. It could be seen that the normalized rate in each case was increasing with the extent of gasification. The trend was similar to that obtained for uncatalyzed gasification rates. It shows that the gasification rate is not limited by the diffusion of reactant gas through the ash as the reaction proceeded with time. An increase in the rate with the extent of carbon conversion indicates that the reaction was not limited to the surface of the particle. The reactant gas was penetrating the char particle

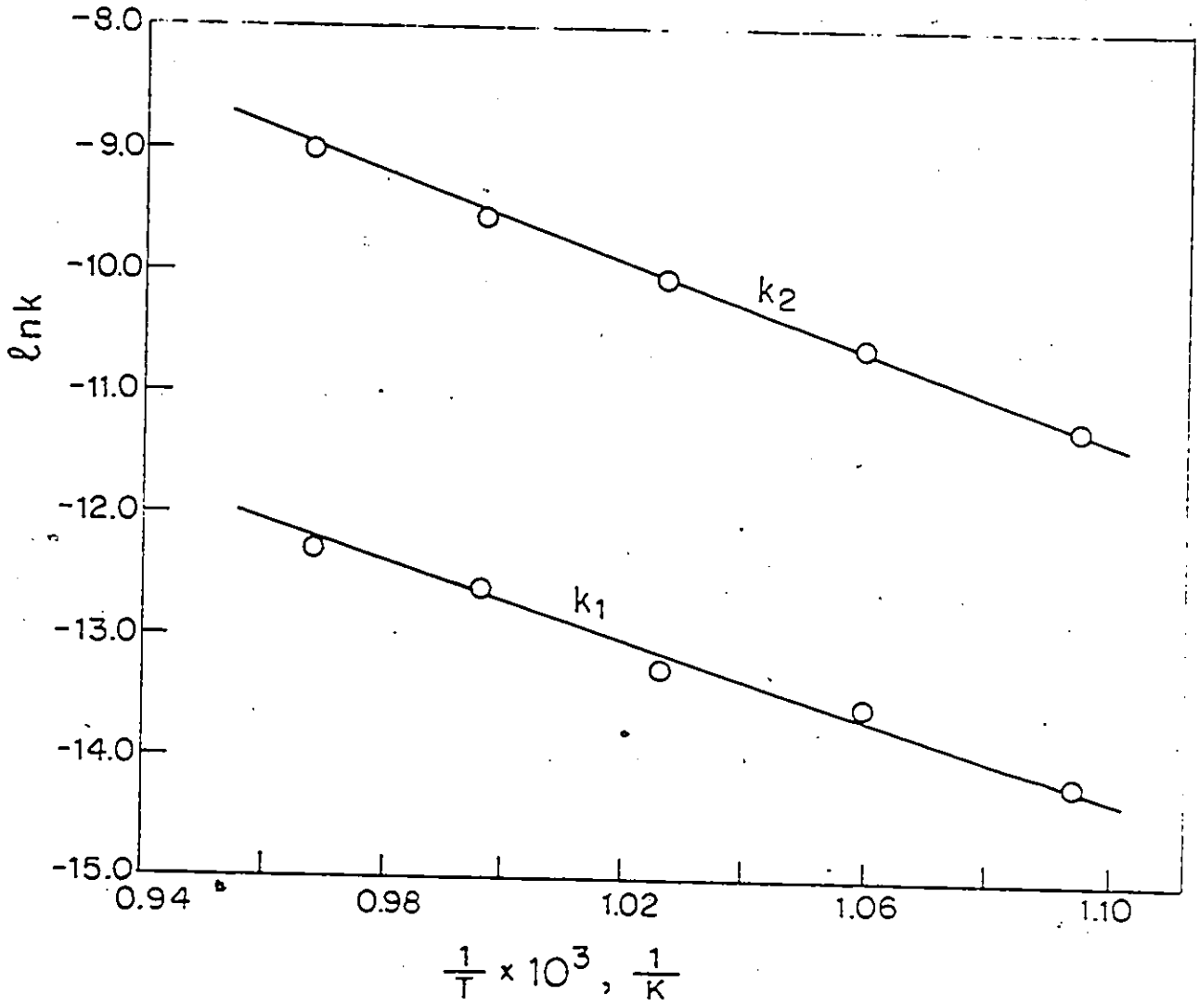

Figure 36. Arrhenius Plots for Reaction Rate Constants

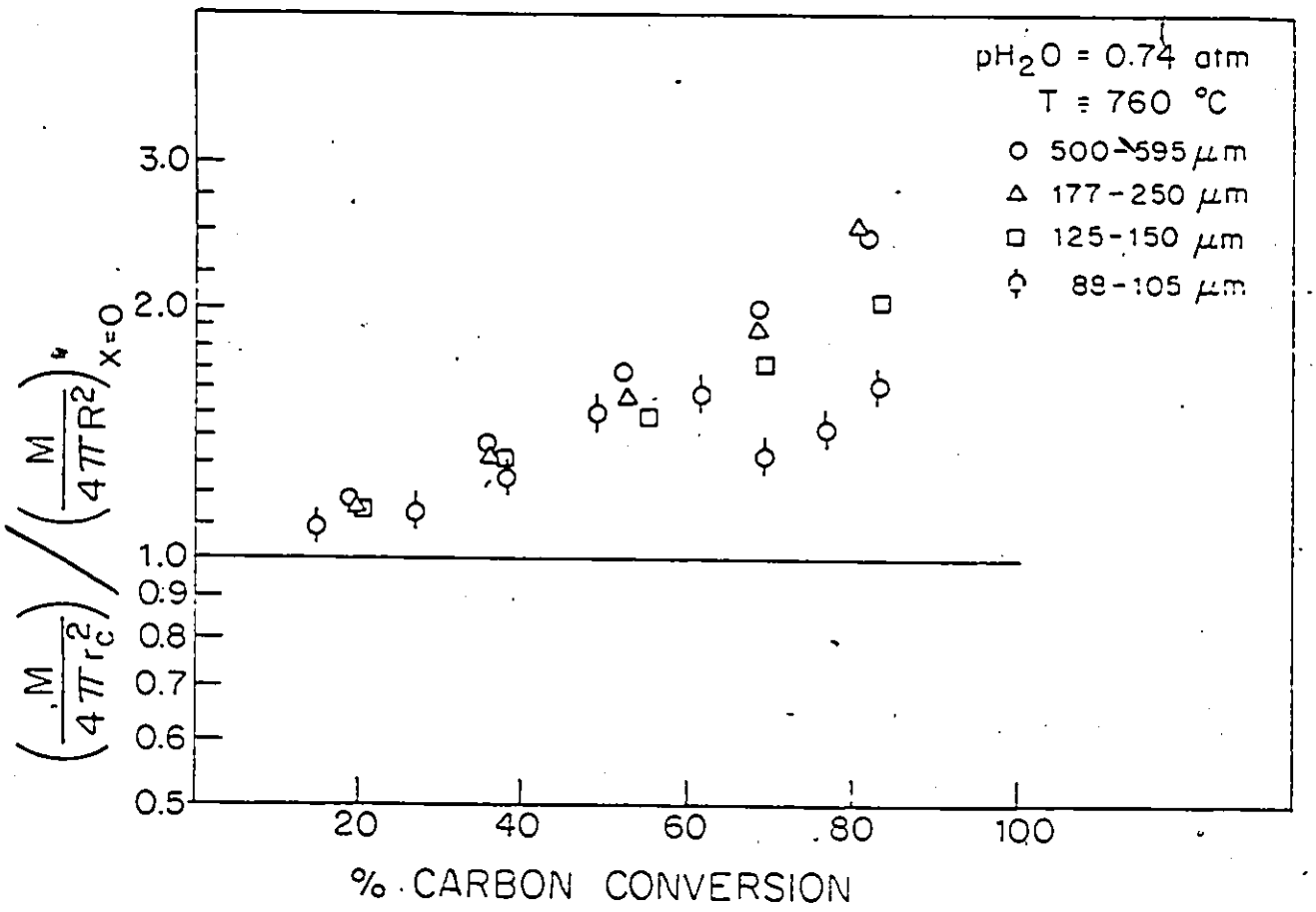

Figure 37. Normalized Reaction Rate Per Unit Surface Area vs Carbon Conversion

to a greater extent as the carbon conversion increased. This observation is similar to the results of uncatalyzed gasification.

During the screening process of various catalysts, gasification of char was carried out in the presence of 10% Na_2CO_3 at 0.35 atm of steam and at 650°C and 760°C. An exercise in fitting the kinetic model to the results of Na_2CO_3 catalyzed gasification also resulted in the same kinetic model of Equation 5.7. The activation energies of k_1 and k_2 were estimated from the additional experiments carried out at 700°C and 730°C in the presence of 10% Na_2CO_3. Following values of k_1 and k_2 at various temperatures were obtained:

Table 5.14

REACTION RATE CONSTANTS FOR CATALYZED GASIFICATION (10% Na_2CO_3)

T, °C	650	700	730	760
$k_1 x 10^6$	0.355	0.681	1.240	2.810
$k_2 x 10^5$	2.560	3.536	5.017	11.000

The temperature dependency of k_1 and k_2 was determined from Arrhenius plots and are given as follows:

$$k_1 = 1.040 \times 10^{2} \exp\left(-\frac{35,800}{RT}\right) \qquad (5.14)$$

$$k_2 = 1.297 \exp\left(-\frac{20,000}{RT}\right) \qquad (5.15)$$

The significance of activation energies obtained for uncatalyzed and K_2CO_3 and Na_2CO_3 catalyzed gasification is discussed in Chapter 6.

CHAPTER 6

DISCUSSION

The results of lignite char gasification with steam are discussed in two parts, firstly, the kinetics of catalyzed and uncatalyzed gasification and secondly, the performance of various materials as catalysts towards gasification. While kinetic modelling is an important aspect of the study, results of catalysts screening are no less significant.

6.1 Kinetics of Gasification

It has been established from the results of the kinetic experiments that gasification is a slow chemical reaction controlled process under the experimental conditions studied. A modified unreacted shrinking core model was found to represent the experimental data best. The rate equation thus obtained is as follows:

$$\frac{dx}{dt} = \frac{3(1-X)^{2/3}}{\rho_B R_p} (k_1 P_{H_2O} + k_2 P_{CO_2}) \qquad (6.1)$$

The equation is applicable to uncatalyzed as well as potassium and sodium catalyzed gasification over the entire range of carbon and steam conversions.

It shows that the following two reactions are responsible for carbon conversion:

$$C + H_2O \rightarrow CO + H_2 \qquad (1)$$

$$C + CO_2 \rightarrow 2CO \qquad (2)$$

The carbon-steam reaction is the primary reaction and the carbon-carbon dioxide reaction is the secondary. The reaction rate is first order with respect to both steam and carbon dioxide partial pressures.

According to the rate Equation 6.1 neither of the reactions is hindered by their products. However, there is ample evidence in the literature that the carbon-steam and carbon-carbon dioxide reactions are hindered by the presence of hydrogen and carbon monoxide respectively. Therefore, the present kinetic model can be considered a semi-empirical one. It has some physical significance, but does not describe the complete mechanism of the complex gasification process.

In addition to reaction 1 and 2, the shift reaction is present in the carbon-steam system:

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad (3)$$

Carbon dioxide formed by the shift reaction reacts with the carbon in char. The shift reaction approaches equilibrium at lower temperatures (~650^{o}) but is far from equilibrium at higher temperatures. The addition of an alkali metal salt removes the reaction further from equilibrium. The addition of nickel or ferric oxide helps it approach

equilibrium.

The fact that the same rate equation can fit the uncatalyzed and catalyzed gasification of char indicates that the addition of a catalyst does not change the mechanism of the reaction. It only enhances the rates of certain preliminary steps in the reaction mechanism.

The values of reaction rate constants k_1 and k_2 obtained for uncatalyzed and catalyzed gasification are compared in Table 6.1. Comparison of these values shows that potassium carbonate catalyzes both the carbon-steam and carbon-carbon dioxide reactions whereas sodium carbonate seems to have only a small effect on the carbon-steam reaction but strongly catalyzes the carbon-carbon dioxide reaction.

Table 6.1

COMPARISON OF RATE CONSTANTS
($g\ cm^{-2} min^{-1} atm^{-1}$)
Temperature = $700^{\circ}C$

Catalyst	None	10% K_2CO_3	10% Na_2CO_3
$K_1 x 10^6$	0.587	1.174	0.681
$k_2 x 10^5$	1.712	2.418	3.536

For gasification of coconut shell charcoal, Taylor and Neville (8) have reported that alakli metal salts; namely

K_2CO_3, Na_2CO_3 and Li_2CO_3 are effective for both the carbon-steam as well as the carbon-carbon dioxide reactions.

Lignite char, used in the present investigation, was also gasified in an atmosphere of carbon dioxide at 780°C using thermogravimetric balance. It was found that addition of 10% K_2CO_3 to the char increases the carbon conversion from 58 to 92 percent during 42 minutes reaction time. This confirms that carbon-carbon dioxide reaction is catalyzed by potassium carbonate.

Activation energies of k_1 and k_2 obtained for uncatalyzed and catalyzed gasification are listed in Table 6.2.

Table 6.2

COMPARISON OF ACTIVATION ENERGIES
(kcal/mol)

Catalyst → / Rate Constant ↓	None	10% K_2CO_3	10% Na_2CO_3
k_1	30.5	30.4	35.8
k_2	27.9	35.9	20.0

The values of activation energies are much lower than those obtained for pure carbon-steam and carbon-carbon dioxide reactions. However, they compare well with values recently reported in the literature for gasification of various coals and chars.

Linares et al. (60) reported a value of 42 kcal/mol for gasification of a lignite char with steam in the temperature range of 750°C to 900°C. Van Heek et al. (33) gasified a lignite coal with steam at 10 atm and 700-850°C in a fixed bed reactor. They reported an activation energy of 30 kcal/mol. Jensen (27) studied the gasification of a Kentucky coal with steam in a fluidized bed reactor at atmospheric pressure and 1040-1430°C. He interpreted his experimental data with the help of the unreacted shrinking core model and obtained an activation energy of 20 kcal/mol.

Wen and Dutta (64) have reviewed the kinetics of various coal-gas reactions. They reported the activation energy for the slow char-steam reaction of the order of 35 kcal/mol. They also determined an activation energy of 59 kcal/mol for carbon-carbon dioxide reaction for various coals and chars.

Results of investigations on carbon-steam and carbon-carbon dioxide reactions published prior to 1960 are usually unreliable because of ill-defined experimental conditions and kinetics limited by mass transfer effects. It is almost impossible to make a comparison with earlier investigations.

Lowry (65) in 1963, reviewed the kinetics of gasification of different types of carbon fuels including coal, char, coke and graphite. The values of activation energy for carbon-steam reaction ranged from 13 kcal/mol to 62 kcal/mol and that for carbon-carbon dioxide reaction was between 24 and 62

k cal/mol. The wide range of values is due to reactivity of fuel used, different experimental conditions and interference of mass transfer effects.

The activation energy for the carbon-steam reaction during uncatalyzed gasification in this work falls within the range reported in the literature for similar fuel. The value for the carbon-carbon dioxide reaction is lower than those reported. But values for both the reactions of gasification indicate that gasification is catalyzed by inorganic impurities of lignite char ash. Evidence of this has been reported in the literature (50, 66).

There is a lack of kinetic data on catalyzed gasification. Few investigators have reported the activation energy of the catalyzed carbon-steam reaction. Kayembe and Pulsifier (2) found that an addition of 10% K_2CO_3 to bituminous coal char lowered the apparent activation energy of the carbon-steam reaction from 61 to 35 k cal/mol.

Verra and Bell (45) gasified a sub-bituminous coal char with a steam-helium mixture. They reported activation energies of 49, 45 and 39 k cal/mol for potassium loadings of 0, 5 and 10 percent by weight respectively.

In the present work, the values of 30.4 and 35.8 k cal/mol were obtained for the carbon-steam reaction in the presence of 10% K_2CO_3 and 10% Na_2CO_3 respectively. These values compare well

with those reported for the catalyzed char-steam reaction.

It can be seen from Table 6.2 that the activation energy for the carbon-steam reaction is not lowered with the addition of potassium carbonate and is in fact higher in the presence of sodium carbonate. It is possible that the catalyst does not lower the activation energy of the reaction, but the catalytic effect is due to an increase in reaction site density.

The theory has been confirmed by Otto et al. (47) during the steam gasification of coal chars in the presence of alkaline earth metals. They contended that catalysts which are solely effective by producing additional reaction sites, and not by lowering of the activation energy, have to be added in rather larger amounts. In most of the studies in catalyzed gasification, alkali metal salts have been added in large (>1%) amounts. Otto et al. (47) have reported that activation energy increased in some cases, though the rate of gasification was enhanced.

For the carbon-carbon dioxide reaction, potassium carbonate increased the activation energy from 28 to 36 k cal/mol and Sodium carbonate lowered the same value to 20 k cal/mol. Both the alkali metal salts increased the reaction rate, but sodium carbonate proved to be better catalytic agent for the carbon-carbon dioxide reaction.

6.2 Catalysts Screening

Various alkali metal salts, nickel and ferric (III) oxide were tested for their ability to increase the carbon gasification rate and change the product gas composition. The significance of results of these experiments are discussed here in two parts: firstly, the effect of catalysts on the gasification rate and secondly, the change in the gas composition in the presence of different catalysts.

6.2.1 Gasification Rate

Alkali metal salts, nickel and ferric (III) oxide were added at different concentration levels. Their effect on the gasification rate are given in Table 6.3 and 6.4. The numbers listed in Table 6.3 were obtained by dividing the rate in the presence of a catalyst by the rate in the absence of any catalyst. The catalysts are listed in decreasing order of their effectiveness. Certain salient features of Table 6.3 are:

i) potassium carbonate and sodium carbonate are almost equally effective at all concentration levels and at both temperatures;

ii) sodium chloride is the least effective alkali metal salt and potassium chloride is intermediate between the carbonates and sodium chloride;

Table 6.3

RELATIVE EFFECTIVENESS OF CATALYSTS
p_{H_2O} = 0.86 atm.

	Increase in rate	
	650°C*	800°C**
1% Ni + 10% K_2CO_3	6.22	-
20% K_2CO_3	5.67	3.56
20% Na_2CO_3	5.45	4.04
10% K_2CO_3	4.10	3.00
10% Na_2CO_3	4.00	-
5% Na_2CO_3	3.58	1.81
5% K_2CO_3	3.50	1.81
1% K_2CO_3	3.08	-
20% KCl	3.00	1.81
1% Ni	2.67	-
10% Fe_2O_3	1.80	-
20% NaCl	1.75	1.56

* rates compared at 10% carbon conversion
** rates compared at 50% carbon conversion

Table 6.4

RELATIVE EFFECTIVENESS OF CATALYSTS
p_{H_2O} = 0.35 atm.

	Increase in rate	
	650°C*	760°C*
10% K_2CO_3	4.80	2.24
10% Na_2CO_3	3.44	1.71

* rates compared at 10% carbon conversion

iii) a combination of 1% nickel and 10% K_2CO_3 (dual catalyst) gave the largest increase in the gasification rate;

iv) the relative effectiveness of alkali metal salts was lower at higher temperature.

The observation that the relative effectiveness of potassium and sodium carbonates decreased with an increase in temperature is in agreement with the results reported in the literature (67). Potassium carbonate is more effective than sodium carbonate at both steam partial pressure (Table 6.5).

The dual catalyst (Ni + K_2CO_3) gives an additive catalytic effect of the two catalysis. This observation is in agreement with the results of an earlier study (68) carried out using a dual catalyst.

The effect of steam partial pressure on the gasification rate with or without a catalyst is shown in Table 6.5. It can be seen that the gasification rate increases due to an increase in steam partial pressure is larger for catalyzed gasification. The advantage of the catalyst is that much higher rates (0.186×10^{-2} and 0.155×10^{-2} $\frac{g}{min-g}$) are obtained at 0.35 atm than at 0.86 atm without a catalyst (0.060×10^{-2} $\frac{g}{min-g}$).

Thus the results of present study indicate the following order of effectiveness of various catalysis:

$$K_2CO_3 > Na_2CO_3 > KCl > Ni > Fe_2O_3 > NaCl$$

Table 6.5

EFFECT OF STEAM PARTIAL PRESSURE ON RATE
Temperature = 650°C

Catalyst → / P_{H_2O} ↓	None	Gasification Rate ($\frac{g}{min\text{-}g} \times 10^2$) 10% K_2CO_3	10% Na_2CO_3
0.35	0.045	0.186	0.155
0.86	0.060	0.285	0.240

* at 10% carbon conversion level

This observation is in agreement with the results of other recent studies. Veera and Bell (45) tested several alkali metal salts for their catalytic activity towards the gasification of a sub-bituminous coal char with steam. They found that KOH and K_2CO_3 were much more effective than KCl, NaCl, LiCl, RbCl and CsCl.

Hippo et al. (46) established the order K > Na ≈ Ca > Fe > Mg, when dimineralized char was impregnated with these metal ions. Similarly Kayembe and Pulsifier (2) have reported that K_2CO_3, Na_2CO_3, Li_2CO_3, KCl, NaCl and CuO increased the activity of a sub-bituminous coal char in that order.

6.2.2 Product Gas Composition

The H_2/CO ratio has been used as an indicator to judge the ability of a catalyst to affect a change in the product

gas composition. An increase in this ratio is accompanied by an increase in the amounts of hydrogen and carbon dioxide and a decrease in the amount of carbon monoxide and vice versa.

The desired value of the H_2/CO ratio is dictated by the end use of the product. For example, if the product gas is to be used as fuel gas, its calorific value should be maximized. Calorific value of the product gas increases as the H_2/CO ratio decreases. The addition of an alkali salt lowers the H_2/CO ratio, hence increases the calorific value of the gas.

When the product gas mixture is to be used as synthesis gas, the H_2/CO ratio should be between 2 and 4 depending on the product to be synthesized. The proper H_2/CO ratio can be achieved by judicious selection of catalyst, catalyst concentration, gasification temperature and steam partial pressure.

Table 6.6 shows the values of H_2/CO ratio at 0.86 atm of steam. The values at 650°C have been arranged in the decreasing order. Therefore, the effectiveness of the catalysis in changing the gas composition increases from the top to the bottom of the table. The maximum value of 51.1 is obtained at 650°C in the absence of any catalyst and minimum value of 1.3 is obtained at 800°C in the presence of 10% K_2CO_3. The addition of a catalyst can achieve a particular value of H_2/CO ratio at much lower temperature.

Table 6.6

COMPARISON OF H_2/CO RATIO

P_{H_2O} = 0.86 atm

Catalyst (wt.%)	H_2/CO Ratio	
	650°C	800°C
None	51.1	2.8
1% Ni	47.0	-
10% Fe_2O_3	39.7	-
20% NaCl	31.7	3.4
20% KCl	26.5	2.3
1% K_2CO_3	26.5	-
5% K_2CO_3	21.9	1.9
5% Na_2CO_3	20.3	2.1
10% K_2CO_3	18.5	1.3
20% Na_2CO_3	15.2	1.3
10% Na_2CO_3	13.7	-
1% Ni + 10% K_2CO_3	12.5	-
20% K_2CO_3	5.2	1.5

The effect of steam partial pressure is shown in Table 6.7. Lower steam partial pressure gives a lower H_2/CO ratio and a lower gasification rate. Addition of 10% K_2CO_3 at 0.86 atm gives the same H_2/CO ratio as obtained at 0.35 atm without a catalyst. Hence the lower H_2/CO ratio can be achieved without reducing the gasification rate. The addition of a catalyst and lowering the steam partial pressure has an additive effect in lowering the H_2/CO ratio.

Table 6.7

COMPARISON OF H_2/CO RATIO

Temperature = 650°C

Catalyst → P_{H_2O} ↓ atm	None	10% K_2CO_3	10% Na_2CO_3
0.86	51.1	18.5	13.7
0.35	18.3	4.8	6.7

Veera and Bell (45) have reported that the H_2/CO ratio decreased with the addition of a catalyst and that the effect of temperature on the product gas composition was similar with or without the addition of a catalyst. This is in conformity with the results of this work.

However, Kayembe and Pulsifier (2) found that the H_2/CO ratio increased with addition of a catalyst and also that there was no effect of temperature on the gas composition in the presence of K_2CO_3. One of the possible explanations for these results is that they used pure steam in excess as the gasifying agent and large amounts of carbon monoxide and steam were available during the catalyzed gasification. This pushed the water-gas shift reaction in the forward direction and producing larger amounts of carbon dioxide and hydrogen.

In the present study, a steam-nitrogen mixture was used for gasifying lignite char and the steam quantity was only slightly in excess of the stoichiometry of the reaction. This is obvious from the high level of steam conversions obtained during uncatalyzed and catalyzed gasification (Table 5.2 and 5.8). Veera and Bell (45) used steam diluted with helium for gasification of char.

6.3 Mechanism of Catalysis

The mechanism by which alkali metal carbonates catalyse the carbon-steam reaction is not well understood. The sequence of steps suggested by McKee and Chatterji (54) is the most plausible explanation to date. According to this, the reaction takes place as follows:

$$M_2CO_3 + 2C = 2K + 3CO \quad (1)$$

$$2M + 2H_2O = 2MOH + H_2 \quad (2)$$

$$2MOH + 3CO = M_2CO_3 + H_2 \quad (3)$$

where M stands for an alkali metal (Na, K, Li, etc.). Veera and Bell (45) have also suggested a similar sequence of reactions. According to this mechanism, reaction 1 is the rate controlling step and that the overall gasification rate depends on the salt-carbon interfacial contact area which is rapidly increased as the carbonate phase melts and wets the carbon surface.

The main objection to this theory is that the catalytic effect of K_2CO_3 observed at 650°C is much lower than its melting point of 891°C. Therefore, the explanation seems to be incomplete. The alkali metal formation may certainly be taking place, but it may also involve some solid phase complexes of alkali metal and carbon (51).

In a recent review, Wen (51) has shown that graphite formed intercalates with potassium of the type:

$$C_8K \quad C_{24}K \quad C_{36}K \quad C_{46}K \quad C_{60}K$$

Potassium atoms per carbon atom decreased with increase in temperature from 250°C to above 500°C. Similar compounds in the case of coals and chars would be much more complex in the potassium atom attached to a complex aromatic molecule.

These potassium compounds have been called electron-donor-acceptor (EDA) complexes. They are specially strong electron donors. Alkali metals can form many EDA complexes with aromatic hydrocarbons (51).

Wen (51) has suggested an alternate mechanism involving these alkali metal complexes (C_nM):

Initiation:

$$M_2CO_3(\ell) + 2C(s) = 2M(g) + 3CO(g) \qquad (1)$$

Formation of EDA complexes:

$$2M(g) + 2nC(s) = 2C_nM(s) \qquad (4)$$

Formation of an intermediate:

$$2C_nM(s) + 2H_2O(g) = 2nC(s) + 2MOH(\ell) + H_2(g) \qquad (5)$$

Recovery of the starting material:

$$2MOH(\ell) + CO(g) = M_2CO_3(\ell) + H_2(g) \qquad (6)$$

Overall Reaction:

$$C(s) + H_2O(g) = CO(g) + H_2(g) \qquad (7)$$

More recently, Freriks et al. (55) have investigated the carbon-steam reaction catalyzed by K_2CO_3 using a temperature programmed desorption and in-situ infrared spectroscopic techniques. They have shown that when carbon is impregnated

with potassium carbonate, the carbonate is unstable above 700°C and it decomposes into CO_2 and a surface potassium compound. This surface potassium compound could be similar to EDA complexes described by Wen (51).

From the discussion so far, it can be concluded that surface potassium compound or alkal metal-carbon complexes facilitate certain preliminary steps of the carbon-steam reaction by accepting or donating electrons. If so, there should be more unpaired electrons on the carbon surface in alkali metal-char mixture in the carbon alone. Keeping this view in mind, an electron spin resonance (ESR) study was performed of char and various char-alkali metal mixtures. The free radical intensity of char and these mixtures are given in Table 6.8.

Table 6.8

RESULTS OF ESR STUDIES

		Free Radical Relative Intensity
1.	Char	799
2.	5% K_2CO_3	889
3.	5% Na_2CO_3	958
4.	20% Na_2CO_3	1200
5.	20% K_2CO_3	1569
6.	20% KCl	1553
7.	20% NaCl	1084

It was observed that free radical concentration was proportional to the reactivity of the char-catalyst mixture with the exception of KCl which gave a high free radical concentration but a low activity towards gasification. This observation indicates the role of unpaired electrons in the catalytic gasification.

Further research in this direction and related aspects of the mechenism of catalysis were limited by the available experimental facilities.

CHAPTER 7

CONCLUSIONS

Gasification of lignite char has been studied with steam in a fixed bed reactor at atmospheric pressure and 640-800^{o}C. Effect of experimental parameters such as char particle size, char bed height, steam flow rate, steam partial pressure and gasification temperature on carbon conversion were investigated. Kinetic data was collected with and without an added catalyst over a wide range of carbon (up to 90%) and steam (15-95%) conversion.

A kinetic model based on the assumption of an unreacted, shrinking core char particle was found to represent the results of both uncatalyzed and catalyzed gasification most adequately. The model is represented as follows:

$$\frac{dX}{dt} = \frac{3(1-X)^{2/3}}{\rho_B R_p} [k_1 p_{H_2O} + k_2 p_{CO_2}]$$

Salient features of the kinetic model are:

i) The rate was a function of the extent of carbon conversion.

ii) The rate was also a function of steam and carbon dioxide partial pressures.

iii) In addition to the primary carbon-steam reaction (C-H_2O), the secondary carbon-carbon dioxide (C-CO_2) reaction was also contributing to the carbon gasification.

The fact that the same kinetic models applied to both uncatalyzed and catalyzed gasification showed that the mechanism of gasification reactions were similar in both cases.

Activation energy values of 30.5 and 27.9 k cal/mol were obtained for C-H_2O and C-CO_2 reactions respectively. The values showed that both reactions were catalyzed by the inorganic impurities of ash in the char.

Addition of potassium or sodium carbonate did not lower the activation energies of the two reactions, showing thereby that catalytic effect was probably due to increased active site density by the addition of a catalyst.

Several catalysts were tested over a wide range of concentration (1-20 wt%), gasification temperature (650-800^{o}C) and steam partial pressure (0.35-0.86 atm). Alkali metal salts demonstrated the following order of activity.

$$K_2CO_3 > Na_2CO_3 > KCl > NaCl$$

The effect of 1% Ni and 10% Fe_2O_3 was smaller than K_2CO_3, Na_2CO_3 and KCl each at 20wt%. But they were more effective than 20% NaCl. A dual catalyst (1% Ni + 10% K_2CO_3) increased the rate as much as six times the rate without catalyst. It was an additive effect of the two individual catalysis.

The addition of alkali metal salts increased the amount of carbon monoxide at the expense of carbon dioxide in the product gas mixture while amount of hydrogen either remained the same or was somewhat lower. Ni and Fe_2O_3 increased the amount of hydrogen and to a small extent, that of carbon monoxide. Gas composition varied from 66.4% H_2, 1.3% CO, 32.4% CO_2 and no methane at 650°C and 0.86 atm of steam in the absence of any catalyst to 53.0% H_2, 39.3% CO, 6.9% CO_2 and 0.6% CH_4 at 760°C and 0.35 atm of steam in the presence of 10% Na_2CO_3.

Results of the ESR study showed that an increase in the reactivity of char-catalyst mixture was accompanied by an increase in the free radical concentration. The increase in free radical concentration could be due to more unpaired electrons available on the char surface impregnated with catalyst. The observation seems to support the theory that alkali metals formed complex compounds with aromatic hydrocarbon molecules in the char. These compounds presumably facilitate the formation of carbon monoxide by their electron donating ability. Much more experimental research is needed to further clarify the mechanism of catalysis.

CHAPTER 8

SIGNIFICANT CONTRIBUTIONS

It has been recognized in a recent review on char gasification (7) that there is a lack of data on the char-steam reaction. Therefore, the large amount of data collected in this study 'steam gasification of lignite char' should be helpful to the workers engaged in coal gasification research.

The present investigation has been of great importance in the understanding of the kinetics of reaction and the catalytic activity of various catalysts. In summary, the following significant contributions are made:

i) for the first time, steam gasification of a char has been studied in detail with and without the presence of an added catalyst.

ii) a kinetic model which accounts for the change in the gasification rate with carbon conversion and includes the contribution due to secondary reactions, has been proposed. The kinetic model explains the results of both uncatalyzed and catalyzed gasification over the entire range of carbon and steam conversion.

iii) the following sequence was determined for the catalytic activity of alkali metal salts towards char gasification:

$$K_2CO_3 > Na_2CO_3 > KCl > NaCl$$

This order also represents their ability to change the product gas composition. Activity of Ni and Fe_2CO_3 falls between carbonates and chlorides of alkali metals.

iv) selection of a proper catalyst and other experimental conditions can give desired composition of the product gas mixture.

v) the catalytic activity of alkali metal salts can be related to the free radical concentration of their mixtures with char.

CHAPTER 9

RECOMMENDATIONS

Though a detailed study of char gasification has been carried out and kinetics of the gasification has been evaluated, some fundamental aspects of gasification need clarification. It is suggested that the following studies be made:

i) reactivity of char towards O_2, CO_2 and H_2O should be related to the physical and chemical properties of the char. Modern spectroscopic methods used in catalysis research should be applied to coal char to study the details of specific site adsorption, desorption and chemical transformation.

ii) change in surface area, pore size distribution and pore volume should be measured with carbon conversion.

iii) char reactivity should also be related to charification conditions and rank of coal.

iv) effect of ash components on the char reactivity should be isolated.

v) more work is needed on the catalytic activity of various materials towards char gasification. The degree of contact between catalyst and the carbon surface and change in the carbon surface properties with the addition of catalyst are some of the important factors which should be carefully looked into.

vi) effect of a dual catalyst (e.g., Ni + K_2CO_3) on the rate of gasification and product gas composition should be studied in more detail. Presence of a dual catalyst may provide a high calorific product gas at only moderately high gasification pressures (<10 atm).

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APPENDIX A

SAMPLE CALCULATIONS

A-1 Calibration Factors

Response of thermal conductivity detector (TCD) for N_2, CO, CO_2 and CH_4 is linear in the concentration range obtained in the present work. Calibration factors for these components are:

Nitrogen	1 ml/1.750 x 10^6 area units
Carbon monoxide	1 ml/1.785 x 10^6 area units
Carbon dioxide	1 ml/2.140 x 10^6 area units
Methane	1 ml/1.667 x 10^6 area units

TCD response for H_2 is not linear and calibration curve obtained is shown in Figure A-1.

A-2 Preliminary Calculations

All the calculations given here are for RUN 97. First sample of product gas was withdrawn after 4 minutes of starting the reaction and subsequently after every 20 minutes. The gas sample was analyzed by a gas chromatograph. Table A-1 gives the reaction time, total volume of gas collected during each time period and peak areas for all the gas components in the mixture.

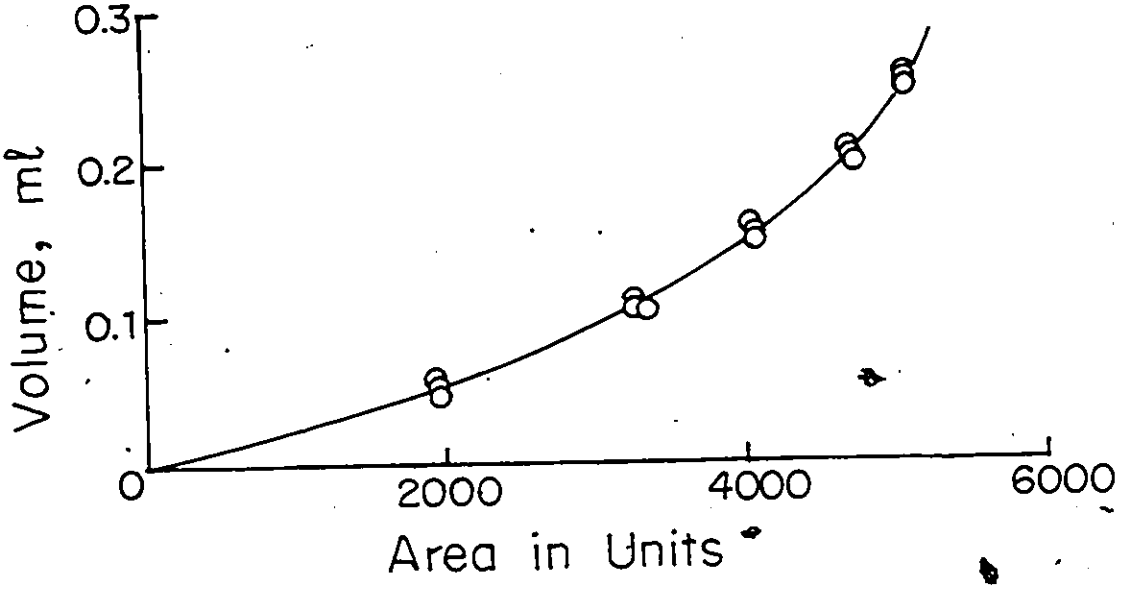

Figure A-1. Calibration Curve for Hydrogen

Table A-1

EXPERIMENTAL DATA

S.N.	Reaction Time Min	Total Vol ml	N_2		H_2		CO		CO_2		CH_4	
			Area	ml	Area	ml	Area	ml	Area	ml	Area	ml
Blank	-	-	778,631	0.445	-	-	3463	0.002	14,119	0.007	-	-
1	4	860	219,698	0.126	4622	0.186	183,779	0.103	71,193	0.033	3176	0.003
2	24	2180	195,589	0.112	4802	0.207	190,266	0.107	108,746	.051	2508	6.002
3	44	2180	162,382	0.093	4844	0.210	175,362	0.098	98,739	.046	2260	0.002
4	64	2150	187,564	0.107	4864	0.210	173,124	0.097	110,433	.052	1887	0.002
5	84	2120	142,975	0.082	4978	0.228	141,015	0.079	145,011	.068	1343	0.001
6	104	2080	203,894	0.117	4895	0.220	80,380	0.045	160,455	.075	1041	0.001
7	124	2110	226,932	0.130	5046	0.238	58,882	0.033	231,935	.108	1000	0.000

Volumes from the peak areas are calculated using calibration factors for N_2, CO, CO_2 and CH_4 and calibration curve for H_2. These volumes readings are also listed in Table A-1.

To calculate the gas composition for any time period, average of two volume readings (at beginning and end of the period) is taken. For example, to obtain the composition of gas evolved during first 4 minute period, average of blank and first readings in Table A-1 is taken. These average values for each time period are listed in Table A-2.

Table A-2

COMPOSITION OF GAS SAMPLE INJECTED

S.N.	N_2 ml	H_2 ml	CO ml	CO_2 ml	CH_4 ml	Total volume ml
1	0.286	0.093	0.055	0.020	0.002	0.456
2	0.119	0.195	0.105	0.043	0.002	0.464
3	0.103	0.208	0.103	0.048	0.002	0.464
4	0.100	0.210	0.098	0.049	0.002	0.449
5	0.098	0.219	0.088	0.060	0.001	0.466
6	0.100	0.224	0.062	0.071	0.001	0.458
7	0.124	0.229	0.039	0.091	0.000	0.483

Volume readings in each row of Table A-2 represent the volume of each gas component present in the volume of gas sample analyzed. Total of each row represents the volume of the gas sample.

Now, the total volume of each gas component evolved during first 4 minute period is calculated as:

$$N_2 = \frac{0.286}{0.456} \times 860 = 539.4 \text{ ml}$$

$$H_2 = \frac{0.093}{0.456} \times 860 = 175.4 \text{ ml}$$

$$CO = \frac{0.055}{0.456} \times 860 = 103.7 \text{ ml}$$

$$CO_2 = \frac{0.020}{0.456} \times 860 = 37.7 \text{ ml}$$

$$CH_1 = \frac{0.002}{0.456} \times 860 = 3.8 \text{ ml}$$

Total gas volume = 860.0 ml

Similarly the volumes for each time period are calculated and are listed in Table A-3. Total volume of each gas produced over the entire run are given at the bottom of Table A-3. Gas composition on the nitrogen free basis is also listed.

From the data of Table A-3, product gas composition can be calculated at any time during the run.

A-3 Carbon Conversion

Carbon gasified during any time period is calculated by multiplying total number of moles of CO, CO_2 and CH_4 by the atomic weight of carbon. For example, for the first 4 minute

Table A-3

PRODUCT GAS COMPOSITION AND CARBON CONVERSION
Initial weight of carbon = 2.3345 g

S.N.	N_2 ml	H_2 ml	CO ml	CO_2 ml	CH_4 ml	Carbon gasified g	Cumulative carbon gasified g	Fractional carbon conversion X
1	539.4	175.4	103.7	37.7	3.8	0.0777	0.0777	0.033
2	559.0	916.2	493.3	202.0	9.4	0.3775	0.4332	0.195
3	483.9	977.2	493.9	225.5	9.4	0.3904	0.8456	0.362
4	468.4	983.7	459.0	229.5	9.4	0.3739	1.2195	0.522
5	445.8	996.3	400.3	273.0	4.5	0.3631	1.5821	0.677
6	454.1	1017.3	281.5	322.4	4.5	0.3259	1.9085	0.817
7	541.7	1000.4	170.4	397.5	0.0	0.3042	2.2127	0.947
Total vol, ml								
	3492.5	6066.3	2392.3	1687.5	41.0			
% (N_2 free)								
	-	59.5	23.5	16.6	0.4			

period, the calculations are made as follows:

Total volume of CO, CO_2 and CH_4 = 103.7 + 37.7 + 3.8

= 145.2 ml (from Table A-3)

Total number of moles of CO, CO_2 and CH_4 = $\frac{145.2}{22,400}$ = 0.00648

Carbon gasified = 0.00648 x 12 = 0.0777 g

Fractional carbon conversion X is defined as:

$$X = \frac{\text{carbon gasified}}{\text{carbon initially present}}$$

$$= \frac{0.0777}{2.3345} = 0.033$$

Likewise, amount of carbon gasified is calculated for each time period and listed in Table A-3. To obtain the carbon conversion at any time during the run, the total carbon gasified before that time is divided by the initial amount of carbon. The conversion values are also listed in Table A-3.

A-4 Carbon Balance

To make the carbon balance, the residue left after the reaction is analyzed for carbon. Carbon balance for run 97 is checked as follows:

Initial weight of carbon = 2.3345 g

Total carbon conversion = 94.6%

Total carbon gasified = 2.3345 x 0.947 = 2.2108 g

Weight of residue left = 0.7820 g

Carbon present in the residue = 12.2%

Amount of carbon left in the residue = 0.782 x 0.122 = 0.0954 g

Total carbon out of the reactor = 2.2108 + 0.0954 = 2.3062 g

$$\text{Carbon balance} = \frac{\text{carbon out}}{\text{carbon in}} \times 100$$

$$\simeq \frac{2.3062}{2.3345} \simeq 98.8\%$$

A-5 Steam Conversion

Steam conversion over the entire run period is calculated as follows:

Volume of steam converted = volume of H_2 + 2 (volume of CH_4)

= 6066.3 + 2(41)

= 6148.3 ml

Total steam fed = steam flow rate x reaction time

= (62.0) (124),

= 7688.0 ml

$$\text{Fractional steam conversion} = \frac{\text{volume of steam converted}}{\text{volume of steam fed}}$$

$$= \frac{6148.3}{7688.0} = 0.80$$

A-6 Partial Pressures

Volume of each product gas in the exit gas stream is already calculated. Volume of steam in the exit gas stream is calculated by subtracting the steam converted from the steam fed during any time period. Thus the volume of N_2, H_2, CO, CO_2, CH_4 and H_2O in the exit gas stream are known. Partial pressure of each component is calculated by taking total pressure as 1 atm. The partial pressures are listed in the tables given for each experimental run in Appendix C.

APPENDIX B

GAS FILM DIFFUSION

Laurendeau (7) has derived an expression for the highest possible reactiyity allowed by the gas film diffusion during a char-gas reaction. The expression is given as follows:

$$r_{m,D} = \frac{12\Lambda\, D_{AB} C_A}{\sigma d^2} \qquad \text{(A-1)}$$

if $r_m < r_{m,D}$, chemical reaction controls the rate. Here

$r_{m,D}$ = specific gasification rate limited by film diffusion, s^{-1}

rm = specific gasification rate obtained experimentally, s^{-1}

Λ = gravimetric stoichiometric coefficient

$$= \frac{M_c}{bM_g}$$

b = molar stoichiometry

M_c = molecular weight of carbon

M_g = molecular weight of steam

D_{AB} = binar diffusivity of steam in nitrogen, cm^2/s

C_A = steam concentration, g/cm^3

σ = particle density of char, g/cm^3

d = char particle diameter, cm

B-1 Uncatalyzed Gasification

During the uncatalyzed kinetics runs, the maximum gasification rates were obtained in run 36. Following experimental

conditions are applicable:

Steam partial pressure = 0.83 atm

Reaction temperature = 800°C or 1073 K

Particle diameter, d_p = 0.0213 cm

$$\Lambda = \frac{M_C}{bM_g} = \frac{12}{18} \times \frac{1}{1.62} = 0.412$$

$$\sigma = 1.6386 \text{ g/cm}^3$$

$$C_A = \frac{P}{RT} = \frac{0.83}{82(1073)} \times 18 = 1.700 \times 10^{-4} \text{g/cm}^3$$

Diffusivity of steam in nitrogen is calculated from Gilliland equation.

$$D_{AB} = 0.0043 \frac{T^{3/2}}{P(V_A^{1/3} + V_B^{1/3})^2} \left(\frac{1}{MA} + \frac{1}{MB}\right)^{1/2}$$

Here P = 1 atm

T = 1073 K

molar volume of steam, V_A = 18.9 cm^3/g mol

molar volume of nitrogen, V_B = 31.2 cm^3/g mol

molecular weight of steam, M_A = 18

molecular weight of nitrogen, M_B = 14

Then D_{AB} = 1.629 cm^2/s

Substituting all the values in Equation A-1:

$$r_{m,D} = \frac{(12)\ (0.412)\ (1.629)\ (1.70 \times 10^{-4})}{(1.6386)\ (0.0213)^2}$$

$$= 1.842\ s^{-1}$$

The highest reactivity achieved during run 36 is

$$r_m = 4.08 \times 10^{-4} s^{-1}$$

Therefore $r_m << r_{m,D}$

Hence char-steam reaction is not limited by gas film diffusion.

B-2 Catalyzed Gasification

During the kinetic runs of catalyzed gasification, maximum gasification rates were obtained in run 97. Following experimental conditions prevailed:

Steam partial pressure = 0.74 atm

Reaction temperature = 760°C or 1033 K

$\Lambda = \frac{12}{18} \times \frac{1}{1.53} = 0.436$ $\quad \sigma = 1.6386\ g/cm^3$

$\quad d = 0.0213\ cm$

$D_{AB} = 1.539\ cm^2/s$

$$C_A = \frac{(0.74)\ (18)}{(82)\ (1033)} = 1.572 \times 10^{-4}\ g/cm^3$$

$$r_{m,D} = \frac{(12)\ (0.436)\ (1.538)\ (1.572 \times 10^{-4})}{(1.6386)\ (0.0213)^2}$$

$$= 1.703\ s^{-1}$$

Maximum reactivity obtained during run 97 is

$$r_m = 1.443 \times 10^{-3}\ s^{-1}$$

Again, $r_m << r_{m,D}$ showing that reaction even during catalyzed gasification is very slow and is not film diffusion limited.

APPENDIX C

EXPERIMENTAL AND CALCULATED DATA

Experimental and calculated data for all the successful runs are listed here. Experimental parameters such as initial weight of carbon in char bed, steam flow rate, steam partial pressure, reaction temperature and catalyst type are given at the top of each page.

First table gives the reaction time at which gas sample were withdrawn from the exit stream, volume of gas collected during each time period, and volumes of each gas component in the representative sample analyzed by gas chromatograph. The total volume of each gas evolved over the entire reaction time of the run also listed at the bottom of the first table.

Second table for each run gives the partial pressure of the gas components in the reactor during each time period. These partial pressures are the average of partial pressures of these gases in entering and exit stream. This table also includes the fractional carbon conversion, X, and differential rate $\frac{dx}{dt}$ with reaction time.

RUN NUM= 12 10 POINTS

WEIGHT OF CARBON 3.6467 G FLOW RATE 1200.0 ML/MIN

NO CATALYST

TEMP= 750.00 C PH2O= 0.95 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4100	0.1650	0.0220	0.0650	0.0010	850.0	4.0
0.0970	0.3600	0.0440	0.1540	0.0020	2950.0	24.0
0.0270	0.3800	0.0570	0.1740	0.0020	3200.0	44.0
0.0560	0.3700	0.0420	0.1700	0.0010	2430.0	64.0
0.1090	0.3550	0.0240	0.1620	0.0010	2170.0	84.0
0.1980	0.3100	0.0120	0.1350	0.0	1900.0	104.0
0.3050	0.2400	0.0060	0.1050	0.0	1850.0	124.0
0.3620	0.1950	0.0040	0.0900	0.0	1790.0	144.0
0.3630	0.1950	0.0040	0.0890	0.0	1580.0	164.0
0.4090	0.1700	0.0030	0.0730	0.0	1430.0	184.0

TOTAL VOL						
5876.3	9275.0	829.5	4141.8	27.4	ML	

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1293	.5929	.1694	.0455	.0610	.0018	.0166	0.5616E-02
.0967	.8436	.0389	.0052	.0153	.0002	.1485	0.7577E-02
.0172	.8835	.0639	.0078	.0273	.0004	.3196	0.7253E-02
.0053	.8734	.0752	.0113	.0344	.0004	.4386	0.5264E-02
.0085	.9029	.0562	.0064	.0258	.0002	.5302	0.3855E-02
.0145	.9131	.0474	.0032	.0216	.0001	.5929	0.2716E-02
.0230	.9240	.0360	.0014	.0157	.0	.6388	0.2099E-02
.0342	.9265	.0269	.0007	.0116	.0	.6766	0.1778E-02
.0394	.9291	.0212	.0004	.0098	.0	.7100	0.1438E-02
.0351	.9371	.0189	.0004	.0086	.0	.7343	0.3992E-03

RUN NUM= 14 10 POINTS

WEIGHT OF CARBON 2.4696 G FLOW RATE 1200.0 ML/MIN

NO CATALYST

TEMP= 750.00 C PH2O= 0.99 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.1500	0.1020	0.0650	0.0140	0.0020	470.0	4.0
0.0090	0.2520	0.1040	0.0630	0.0020	1430.0	24.0
0.0	0.2940	0.0780	0.1000	0.0020	1650.0	44.0
0.0	0.2900	0.0710	0.1040	0.0020	1570.0	64.0
0.0	0.2900	0.0570	0.1090	0.0020	1180.0	84.0
0.0	0.2920	0.0560	0.1100	0.0020	850.0	104.0
0.0	0.2920	0.0550	0.1110	0.0020	650.0	124.0
0.0	0.2900	0.0440	0.1160	0.0010	580.0	144.0
0.0	0.2900	0.0420	0.1170	0.0010	480.0	164.0
0.0	0.2900	0.0340	0.1200	0.0010	370.0	184.0

TOTAL VOL					
241.6	5603.1	1405.5	1941.7	38.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.0356	.9429	.0148	.0003	.0064	.0	.0248	0.5746E-02
.0413	.9082	.0281	.0179	.0039	.0006	.1867	0.6446E-02
.0012	.9418	.0341	.0141	.0085	.0003	.2826	0.6625E-02
.0	.9330	.0416	.0110	.0141	.0003	.4117	0.5574E-02
.0	.9361	.0397	.0097	.0142	.0003	.5056	0.4031E-02
.0	.9517	.0306	.0060	.0115	.0002	.5730	0.2971E-02
.0	.9650	.0222	.0043	.0084	.0002	.6244	0.2410E-02
.0	.9732	.0170	.0032	.0065	.0001	.6694	0.2046E-02
.0	.9760	.0154	.0023	.0062	.0001	.7064	0.1624E-02
.0	.9801	.0128	.0019	.0052	.0000	.7343	0.1171E-02

RUN NUM= 16 10 POINTS

WEIGHT OF CARBON 1.8261 G FLOW RATE 1200.0 ML/MIN

NO CATALYST

TEMP= 750.00 C PH2O= 0.98 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3630	0.1450	0.0290	0.0310	0.0020	620.0	4.0
0.1240	0.3000	0.0530	0.0980	0.0020	1680.0	24.0
0.0460	0.3000	0.0500	0.1320	0.0020	1450.0	44.0
0.0030	0.3000	0.0450	0.1330	0.0020	1250.0	64.0
0.0030	0.3100	0.0400	0.1340	0.0020	820.0	84.0
0.0030	0.3100	0.0350	0.1360	0.0020	650.0	104.0
0.0050	0.3100	0.0260	0.1400	0.0020	530.0	124.0
0.0080	0.3100	0.0200	0.1420	0.0020	410.0	144.0
0.0130	0.3100	0.0170	0.1430	0.0020	340.0	164.0
0.0130	0.3150	0.0150	0.1450	0.0010	350.0	184.0

TOTAL VOL					
929.2	4609.4	621.2	1909.4	30.7	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.0	.9847	.0100	.0012	.0041	.0000	.0109	0.6110E-02
.0751	.8821	.0300	.0060	.0064	.0004	.1505	0.6953E-02
.0146	.9322	.0352	.0062	.0115	.0002	.2982	0.7108E-02
.0051	.9411	.0333	.0056	.0147	.0002	.4348	0.5581E-02
.0003	.9489	.0317	.0048	.0141	.0002	.5214	0.3961E-02
.0002	.9662	.0214	.0028	.0092	.0001	.5849	0.3049E-02
.0002	.9732	.0171	.0019	.0075	.0001	.6434	0.2375E-02
.0002	.9781	.0141	.0012	.0064	.0001	.6943	0.1856E-02
.0003	.9830	.0109	.0007	.0050	.0001	.7176	0.1678E-02
.0004	.9859	.0090	.0005	.0042	.0001	.7514	0.1703E-02

RUN NUM= 26 11 POINTS

WEIGHT OF CARBON 2.4278 G FLOW RATE 76.2 ML/MIN

NO CATALYST

TEMP= 750.00 C PH2O= 0.66 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3630	0.0660	0.0190	0.0260	0.0010	680.0	4.0
0.2790	0.1260	0.0400	0.0430	0.0010	1640.0	24.0
0.2770	0.1250	0.0420	0.0510	0.0010	1740.0	44.0
0.2590	0.1240	0.0400	0.0540	0.0010	1700.0	64.0
0.2440	0.1250	0.0370	0.0530	0.0010	1650.0	84.0
0.2310	0.1250	0.0350	0.0510	0.0010	1620.0	104.0
0.2380	0.1250	0.0320	0.0490	0.0010	1560.0	124.0
0.2790	0.1200	0.0290	0.0460	0.0	1550.0	144.0
0.3000	0.1100	0.0260	0.0420	0.0010	1500.0	164.0
0.3090	0.1030	0.0220	0.0380	0.0	1470.0	184.0
0.3050	0.1000	0.0190	0.0340	0.0010	1400.0	204.0

TOTAL VOL					
9644.8	4105.4	1126.4	1604.6	28.8	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1246	.6665	.1378	.0095	.0616	.0	.0145	0.2843E-02
.5847	.2316	.1095	.0306	.0419	.0016	.0766	0.3373E-02
.8422	.4003	.1545	.0491	.0527	.0012	.1494	0.3683E-02
.3448	.3826	.1556	.0523	.0635	.0012	.2239	0.3664E-02
.3318	.3876	.1589	.0512	.0692	.0013	.2960	0.3656E-02
.3220	.3930	.1649	.0488	.0699	.0013	.3662	0.3341E-02
.3153	.3954	.1706	.0478	.0696	.0014	.4296	0.2939E-02
.3162	.4088	.1661	.0425	.0651	.0013	.4837	0.2545E-02
.3402	.4220	.1463	.0354	.0561	.0	.5314	0.2223E-02
.3514	.4389	.1289	.0305	.0492	.0012	.5726	0.1939E-02
.3600	.4501	.1200	.0256	.0443	.0	.6080	0.1698E-02

RUN NUM= 27 13 POINTS

WEIGHT OF CARBON 2.3822 G FLOW RATE 76.2 ML/MIN

NO CATALYST

TEMP= 700.00 C PH2O= 0.66 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4290	0.0350	0.0030	0.0170	0.0	570.0	4.0
0.3490	0.0850	0.0080	0.0450	0.0	1320.0	24.0
0.3170	0.1080	0.0100	0.0510	0.0	1360.0	44.0
0.3180	0.1160	0.0120	0.0490	0.0	1370.0	64.0
0.3240	0.1130	0.0110	0.0470	0.0	1360.0	84.0
0.3290	0.1080	0.0100	0.0450	0.0	1350.0	104.0
0.3370	0.0990	0.0090	0.0430	0.0	1310.0	124.0
0.3420	0.0930	0.0080	0.0420	0.0	1290.0	144.0
0.3500	0.0900	0.0070	0.0400	0.0	1260.0	164.0
0.3570	0.0820	0.0070	0.0390	0.0	1240.0	184.0
0.3570	0.0810	0.0060	0.0370	0.0	1220.0	204.0
0.3650	0.0820	0.0060	0.0360	0.0	1220.0	224.0
0.3700	0.0810	0.0060	0.0360	0.0	1210.0	244.0

TOTAL VOL					
11368.1	3066.1	270.4	1375.3	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.3560	.4642	.1167	.0222	.0397	.0012	.0053	0.1463E-02
.6061	.3162	.0494	.0042	.0240	.0	.0376	0.1267E-02
.3619	.4950	.0882	.0083	.0467	.0	.0760	0.1909E-02
.3436	.4732	.1171	.0108	.0553	.0	.1140	0.1845E-02
.3421	.4675	.1248	.0129	.0527	.0	.1498	0.1744E-02
.3459	.4715	.1206	.0117	.0502	.0	.1837	0.1633E-02
.3502	.4763	.1150	.0106	.0479	.0	.2151	0.1532E-02
.3522	.4899	.1035	.0094	.0449	.0	.2450	0.1431E-02
.3544	.4974	.0964	.0083	.0435	.0	.2724	0.1345E-02
.3550	.5061	.0913	.0071	.0406	.0	.2998	0.1274E-02
.3573	.5146	.0821	.0070	.0390	.0	.3233	0.1202E-02
.3567	.5194	.0809	.0060	.0370	.0	.3469	0.1169E-02
.3586	.5196	.0806	.0059	.0354	.0	.3701	0.1150E-02

RUN NUM= 28 10 POINTS

WEIGHT OF CARBON 2.4310 G FLOW RATE 76.2 ML/MIN

NO CATALYST

TEMP= 800.00 C PH2O= 0.66 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3480	0.0650	0.0370	0.0150	0.0020	750.0	4.0
0.2180	0.1600	0.0710	0.0430	0.0020	1950.0	24.0
0.1970	0.1780	0.0730	0.0440	0.0020	2050.0	44.0
0.2050	0.1700	0.0710	0.0420	0.0020	1960.0	64.0
0.2150	0.1600	0.0670	0.0410	0.0010	1800.0	84.0
0.2250	0.1500	0.0610	0.0400	0.0010	1780.0	104.0
0.2400	0.1420	0.0550	0.0390	0.0010	1660.0	124.0
0.2550	0.1300	0.0500	0.0370	0.0010	1600.0	144.0
0.2650	0.1200	0.0460	0.0360	0.0010	1520.0	164.0
0.2900	0.1100	0.0400	0.0330	0.0010	1750.0	189.0

TOTAL VOL					
8362.0	5065.0	2071.7	1352.5	48.8	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.3582	.5227	.0784	.0058	.0349	.0	.0191	0.4847E-02
.5920	.2055	.1106	.0629	.0255	.0034	.1200	0.6243E-02
.3044	.3101	.2234	.0992	.0600	.0028	.2288	0.5255E-02
.2900	.2727	.2621	.1075	.0648	.0029	.3302	0.4842E-02
.2941	.2970	.2439	.1019	.0603	.0029	.4225	0.4405E-02
.2992	.3264	.2227	.0932	.0571	.0014	.5064	0.3940E-02
.3068	.3496	.2045	.0832	.0545	.0014	.5801	0.3483E-02
.3134	.3770	.1854	.0718	.0509	.0013	.6457	0.3129E-02
.3222	.4024	.1642	.0632	.0467	.0013	.7051	0.2720E-02
.3251	.4259	.1472	.0564	.0442	.0012	.7553	0.2096E-02

RUN NUM= 29 13 POINTS

WEIGHT OF CARBON 2.4176 G FLOW RATE 76.2 ML/MIN

NO CATALYST

TEMP= 650.00 C PH2O= 0.66 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4020	0.0300	0.0020	0.0130	0.0	450.0	4.0
0.3590	0.0650	0.0030	0.0320	0.0	1130.0	24.0
0.3390	0.0770	0.0030	0.0400	0.0	1430.0	44.0
0.3270	0.0840	0.0030	0.0400	0.0	1120.0	64.0
0.3320	0.0830	0.0030	0.0400	0.0	1120.0	84.0
0.3360	0.0820	0.0030	0.0390	0.0	1120.0	104.0
0.3380	0.0790	0.0030	0.0390	0.0	1110.0	124.0
0.3370	0.0770	0.0030	0.0380	0.0	1090.0	144.0
0.3430	0.0740	0.0020	0.0370	0.0	1070.0	164.0
0.3460	0.0720	0.0020	0.0360	0.0	1060.0	184.0
0.3480	0.0690	0.0020	0.0350	0.0	1060.0	204.0
0.3550	0.0650	0.0020	0.0340	0.0	1060.0	224.0
0.3620	0.0590	0.0010	0.0320	0.0	1600.0	-254.0

TOTAL VOL					
10928.6	2276.6	77.4	1137.3	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.3303	.4601	.1253	.0456	.0376	.0011	.0033	0.6898E-03
.5585	.3790	.0417	.0028	.0181	.0	.0224	0.1219E-02
.3544	.5469	.0642	.0030	.0316	.0	.0521	0.1533E-02
.3891	.4731	.0884	.0034	.0459	.0	.0756	0.1[illegible]E-02
.3311	.5404	.0850	.0030	.0405	.0	.0989	0.1142E-02
.3326	.5412	.0831	.0030	.0401	.0	.1216	0.1129E-02
.3347	.5418	.0817	.0030	.0388	.0	.1441	0.1107E-02
.3346	.5456	.0782	.0030	.0386	.0	.1659	0.1051E-02
.3323	.5514	.0759	.0030	.0375	.0	.1861	0.9[illegible]E-03
.3325	.5579	.0717	.0019	.0359	.0	.2057	0.9[illegible]E-03
.3328	.5614	.0693	.0019	.0346	.0	.2249	0.9422E-03
.3353	.5625	.0665	.0019	.0337	.0	.2434	0.8[illegible]E-03
.3392	.5643	.0621	.0019	.0325	.0	.2602	0.8[illegible]E-03

RUN NUM= 30 12 POINTS

WEIGHT OF CARBON 2.3814 G FLOW RATE 14.0 ML/MIN

NO CATALYST

TEMP= 700.0C C PH2O= 0.20 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4170	0.0180	0.0060	0.0060	0.0	700.0	4.0
0.3860	0.0380	0.0080	0.0130	0.0	1300.0	24.0
0.3940	0.0370	0.0100	0.0130	0.0	1320.0	44.0
0.3950	0.0350	0.0090	0.0120	0.0	1310.0	64.0
0.3960	0.0320	0.0070	0.0120	0.0	1300.0	84.0
0.3960	0.0300	0.0070	0.0120	0.0	1290.0	104.0
0.3960	0.0300	0.0070	0.0120	0.0	1280.0	124.0
0.3970	0.0310	0.0070	0.0120	0.0	1280.0	144.0
0.3980	0.0310	0.0060	0.0120	0.0	1280.0	164.0
0.4010	0.0300	0.0060	0.0120	0.0	1275.0	184.0
0.4030	0.0300	0.0060	0.0110	0.0	1270.0	204.0
0.4050	0.0300	0.0060	0.0120	0.0	1900.0	234.0

TOTAL VOL

13772.4	1088.7	245.3	408.7	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.5631	.2843	.0967	.0187	.0373	.0	.0042	0.65[illegible]E-03
.8972	.0382	.0387	.0129	.0129	.0	.0180	0.72[illegible]E-03
.7676	.1150	.0756	.0159	.0259	.0	.0331	0.71[illegible]E-03
.7676	.1155	.0721	.0195	.0253	.0	.0468	0.[illegible]E-03
.7709	.1198	.0683	.0176	.0234	.0	.0592	0.[illegible]E-03
.7745	.1257	.0626	.0137	.0235	.0	.0716	0.[illegible]E-03
.7741	.1302	.0586	.0137	.0235	.0	.0840	0.[illegible]E-03
.7741	.1302	.0586	.0137	.0235	.0	.0962	0.[illegible]E-03
.7727	.1300	.0603	.0136	.0234	.0	.1078	0.[illegible]E-03
.7746	.1300	.0603	.0117	.0234	.0	.1193	0.[illegible]E-03
.7747	.1325	.0580	.0116	.0232	.0	.1301	0.[illegible]E-03
.7762	.1333	.0578	.0116	.0212	.0	.1471	0.58[illegible]E-03

RUN NUM= 31 10 POINTS

WEIGHT OF CARBON 2.3783 G FLOW RATE 14.0 ML/MIN

NO CATALYST

TEMP= 750.00 C PH2O= 0.20 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4190	0.0150	0.0090	0.0080	0.0	590.0	4.0
0.3750	0.0430	0.0190	0.0130	0.0	1440.0	24.0
0.3520	0.0540	0.0220	0.0160	0.0	1460.0	44.0
0.3620	0.0540	0.0210	0.0150	0.0	1450.0	64.0
0.3640	0.0540	0.0200	0.0150	0.0	1450.0	84.0
0.3640	0.0540	0.0200	0.0150	0.0	1450.0	104.0
0.3640	0.0540	0.0200	0.0150	0.0	1450.0	124.0
0.3640	0.0530	0.0200	0.0150	0.0	1400.0	144.0
0.3650	0.0520	0.0200	0.0150	0.0	1360.0	164.0
0.3660	0.0450	0.0180	0.0140	0.0	1320.0	184.0

TOTAL VOL					
10878.5	1481.3	580.1	430.1	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.7742	.1341	.0573	.0115	.0229	.0	.0050	0.1026E-02
.8751	.0581	.0313	.0188	.0167	.0	.0281	0.1288E-02
.7583	.0900	.0870	.0384	.0263	.0	.0562	0.1354E-02
.7408	.0656	.1136	.0463	.0337	.0	.0822	0.1241E-02
.7460	.0686	.1113	.0433	.0309	.0	.1075	0.1261E-02
.7482	.0688	.1110.	.0411	.0308	.0	.1327	0.1291E-02
.7482	.0688	.1110	.0411	.0308	.0	.1579	0.1241E-02
.7482	.0688	.1110	.0411	.0308	.0	.1824	0.1203E-02
.7438	.0764	.1083	.0409	.0306	.0	.2061	0.1130E-02
.7403	.0833	.1055	.0406	.0304	.0	.2276	0.1015E-02

RUN NUM= 32 11 POINTS

WEIGHT OF CARBON 2.3948 G FLOW RATE 14.0 ML/MIN

NO CATALYST

TEMP= 800.00 C PH2O= 0.20 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4090	0.0250	0.0190	0.0060	0.0010	640.0	4.0
0.3480	0.0630	0.0420	0.0100	0.0010	1450.0	24.0
0.3270	0.0780	0.0470	0.0130	0.0010	1610.0	44.0
0.3250	0.0800	0.0460	0.0140	0.0010	1580.0	64.0
0.3250	0.0750	0.0450	0.0150	0.0010	1550.0	84.0
0.3250	0.0790	0.0440	0.0150	0.0010	1530.0	104.0
0.3250	0.0890	0.0440	0.0150	0.0010	1520.0	124.0
0.3250	0.0870	0.0440	0.0150	0.0010	1510.0	144.0
0.3260	0.0770	0.0440	0.0150	0.0010	1510.0	164.0
0.3270	0.0800	0.0430	0.0150	0.0010	1500.0	184.0
0.3280	0.0880	0.0430	0.0150	0.0	1500.0	204.0

TOTAL VOL					
11288.3	2635.9	1472.3	472.6	30.9	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.7439	.0995	.0915	.0366	.0285	.0	.0081	0.160[illegible]E-02
.8642	.0280	.0528	.0401	.0127	.0021	.0451	0.24[illegible]E-02
.7122	.0503	.1289	.0860	.0205	.0020	.0929	0.23[illegible]E-02
.7001	.0022	.1670	.1006	.0278	.0021	.1396	0.23[illegible]E-02
.6966	.0012	.1715	.0986	.0300	.0021	.1844	0.22[illegible]E-02
.6955	.0134	.1605	.0963	.0321	.0021	.2287	0.21[illegible]E-02
.6946	.0084	.1688	.0940	.0321	.0021	.2717	0.21[illegible]E-02
.6910	*****	.1892	.0936	.0319	.0021	.3147	0.21[illegible]E-02
.6907	*****	.1849	.0935	.0319	.0021	.3584	0.21[illegible]E-02
.6938	.0146	.1639	.0936	.0319	.0021	.4009	0.20[illegible]E-02
.6943	.0106	.1699	.0913	.0318	.0021	.4420	0.20[illegible]E-02

RUN NUM= 33 14 POINTS

WEIGHT OF CARBON 2.3239 G FLOW RATE 85. ML/MIN

NO CATALYST

TEMP= 650.00 C PH2O= 0.83 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3720	0.0470	0.0030	0.0200	0.0	350.0	4.0
0.2910	0.1070	0.0040	0.0430	0.0	660.0	24.0
0.2790	0.1100	0.0040	0.0470	0.0	810.0	44.0
0.2780	0.1070	0.0030	0.0480	0.0	730.0	64.0
0.2790	0.1120	0.0030	0.0480	0.0	760.0	84.0
0.2920	0.1010	0.0030	0.0470	0.0	730.0	104.0
0.3070	0.1000	0.0020	0.0430	0.0	690.0	124.0
0.3320	0.0980	0.0010	0.0390	0.0	640.0	144.0
0.3350	0.0950	0.0010	0.0370	0.0	620.0	164.0
0.3370	0.0900	0.0010	0.0370	0.0	580.0	184.0
0.3400	0.0880	0.0010	0.0360	0.0	540.0	204.0
0.3420	0.0830	0.0010	0.0370	0.0	530.0	224.0
0.3450	0.0770	0.0010	0.0370	0.0	490.0	244.0
0.3470	0.0700	0.0010	0.0370	0.0	440.0	264.0

TOTAL VOL					
6546.0	1975.4	45.6	853.0	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.4627	.1861	.2061	.0966	.0446	.0019	.0242	0.11[illegible]E-02
.4496	.4658	.0568	.0036	.0242	.0	.0281	0.[illegible]E-02
.2378	.6304	.0874	.0033	.0351	.0	.0406	0.[illegible]E-02
.2214	.6508	.0873	.0032	.0373	.0	.0441	0.[illegible]E-02
.2182	.6577	.0840	.0024	.0377	.0	.0465	0.[illegible]E-02
.2105	.6666	.0845	.0023	.0362	.0	.0479	0.[illegible]E-02
.2115	.6792	.0731	.0022	.0340	.0	.0491	0.[illegible]E-02
.2093	.6932	.0679	.0014	.0292	.0	.0497	0.[illegible]E-02
.2038	.7115	.0602	.0006	.0239	.0	.0507	0.[illegible]E-02
.1995	.7213	.0566	.0006	.0220	.0	.0513	0.[illegible]E-02
.1876	.7412	.0501	.0006	.0206	.0	.0538	0.[illegible]E-02
.1837	.7488	.0475	.0005	.0194	.0	.0548	0.[illegible]E-02
.1823	.7531	.0443	.0005	.0197	.0	.0554	0.[illegible]E-02
.1762	.7651	.0393	.0005	.0189	.0	.0572	0.[illegible]E-03

RUN NUM= 34 11 POINTS

WEIGHT OF CARBON 2.3964 G FLOW RATE 65.6 ML/MIN

NO CATALYST

TEMP= 700.00 C PH2O= 0.83 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3450	0.0720	0.0090	0.0310	0.0010	370.0	4.0
0.2700	0.1590	0.0170	0.0570	0.0010	860.0	24.0
0.2150	0.1850	0.0200	0.0680	0.0010	920.0	44.0
0.1800	0.1950	0.0190	0.0770	0.0	920.0	64.0
0.1760	0.2000	0.0180	0.0810	0.0010	920.0	84.0
0.1960	0.1900	0.0170	0.0720	0.0010	1810.0	124.0
0.1950	0.1850	0.0170	0.0700	0.0010	860.0	144.0
0.2130	0.1720	0.0160	0.0650	0.0010	810.0	164.0
0.2230	0.1640	0.0160	0.0620	0.0010	770.0	184.0
0.2380	0.1540	0.0150	0.0580	0.0010	790.0	204.0
0.2450	0.1500	0.0140	0.0560	0.0010	770.0	224.0
TOTAL VOL						
4496.3	3592.0	345.1	1367.9	18.7	ML	

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1767	.7683	.0356	.0005	.0188	.0	.0074	0.12603E-02
.4271	.4331	.0891	.0111	.0334	.0012	.0367	0.16683E-02
.2040	.6192	.1201	.0128	.0431	.0009	.0741	0.19845E-02
.1774	.5965	.1526	.0165	.0561	.0008	.1160	0.21495E-02
.1562	.5913	.1692	.0165	.0668	.0	.1542	0.20788E-02
.1518	.5896	.1724	.0155	.0698	.0009	.1957	0.18437E-02
.1655	.5981	.1604	.0144	.0608	.0008	.2319	0.16998E-02
.1608	.6141	.1526	.0140	.0577	.0008	.2697	0.15248E-02
.1664	.6352	.1344	.0125	.0508	.0008	.3029	0.14312E-02
.1669	.6512	.1227	.0120	.0464	.0007	.3309	0.13357E-02
.1803	.6469	.1167	.0114	.0439	.0009	.3571	0.12065E-02

RUN NUM= 35 11 POINTS

WEIGHT OF CARBON 2.3704 G FLOW RATE 85.6 ML/MIN

NO CATALYST

TEMP= 750.00 C PH2O= 0.83 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3430	0.0750	0.0190	0.0430	0.0010	370.0	[illegible]
0.2010	0.1700	0.0440	0.0560	0.0020	1410.0	[illegible]
0.1320	0.2010	0.0600	0.0700	0.0020	1510.0	[illegible]
0.0750	0.2410	0.0550	0.0890	0.0020	1380.0	[illegible]
0.0550	0.2620	0.0500	0.1000	0.0020	1230.0	[illegible]
0.0410	0.2520	0.0450	0.0920	0.0020	1110.0	[illegible]
0.1180	0.2220	0.0410	0.0820	0.0010	980.0	[illegible]
0.1410	0.2100	0.0380	0.0810	0.0010	920.0	[illegible]
0.1500	0.2050	0.0340	0.0800	0.0010	860.0	[illegible]
0.1550	0.2000	0.0320	0.0800	0.0010	950.0	[illegible]
0.1550	0.2050	0.0320	0.0780	0.0010	850.0	204.0

TOTAL VOL					
3190.9	5217.0	1083.1	1940.3	38.8	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1815	.6548	.1111	.0104	.0415	.0007	.0110	[illegible]
.4039	.4335	.0883	.0224	.0506	.0012	.0797	[illegible]
.2302	.4584	.1947	.0504	.0641	.0023	.1769	[illegible]
.1677	.4093	.2553	.0762	.0889	.0025	.2751	[illegible]
.0949	.4153	.3050	.0696	.1126	.0025	.3650	[illegible]
.0643	.4520	.3062	.0584	.1169	.0023	.4407	[illegible]
.0773	.4970	.2743	.0490	.1002	.0022	.4959	[illegible]
.1123	.5583	.2113	.0390	.0781	[illegible]	.5520	[illegible]
.1242	.5852	.1849	.0335	.0713	.0009	.6004	[illegible]
.1251	.6079	.1710	.0284	.0667	.0008	.6468	[illegible]
.1282	.6128	.1655	.0265	.0662	.0008	.6920	[illegible]

RUN NUM= 36 9 POINTS

WEIGHT OF CARBON 2.3688 G FLOW RATE 85.6 ML/MIN

NO CATALYST

TEMP= 800.00 C PH2O= 0.93 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2770	0.1100	0.0350	0.0350	0.0020	620.0	4.0
0.0990	0.2250	0.0720	0.0680	0.0020	1510.0	24.0
0.0860	0.2200	0.0810	0.0690	0.0020	1500.0	44.0
0.0780	0.2200	0.0820	0.0700	0.0020	1500.0	64.0
0.0780	0.2200	0.0770	0.0700	0.0020	1510.0	84.0
0.0880	0.2150	0.0580	0.0750	0.0010	2740.0	124.0
0.0900	0.2250	0.0480	0.0820	0.0010	1180.0	144.0
0.0900	0.2360	0.0350	0.0920	0.0010	1090.0	164.0
0.0940	0.2360	0.0300	0.0890	0.0010	990.0	184.0

TOTAL VOL					
2744.1	6187.6	1751.0	2093.7	43.4	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1278	.6116	.1691	.0264	.0643	.0008	.0200	0.480[illegible]E-02
.4628	.2331	.1838	.0585	.0585	.0043	.1261	0.55[illegible]
.1294	.3911	.2940	.0941	.0889	.0020	.2484	0.60[illegible]
.1183	.3701	.3026	.1114	.0940	.0024	.3670	0.590[illegible]
.1091	.3676	.3078	.1147	.0979	.0024	.4917	0.53[illegible]
.1069	.3875	.3015	.1055	.0959	.0027	.6717	0.41[illegible]
.1149	.4296	.2806	.0757	.0979	.0013	.7561	0.36[illegible]
.1039	.4850	.2598	.0554	.0947	.0012	.8196	0.32[illegible]
.0969	.5113	.2540	.0377	.0990	.0011	.8793	0.27[illegible]

RUN NUM= 37 9 POINTS

WEIGHT OF CARBON 2.4082 G FLOW RATE 85.6 ML/MIN

NONE

TEMP= 800.00 C PH2O= 0.83 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2530	0.1000	0.0370	0.0260	0.0030	550.0	4.0
0.1200	0.2040	0.0800	0.0530	0.0030	1330.0	24.0
0.1040	0.2060	0.0800	0.0530	0.0030	1430.0	44.0
0.1000	0.2070	0.0910	0.0530	0.0030	1430.0	64.0
0.0980	0.2070	0.0800	0.0000	0.0030	1380.0	84.0
0.1040	0.2020	0.0770	0.0640	0.0020	1280.0	104.0
0.1260	0.1860	0.0650	0.0630	0.0020	1060.0	124.0
0.1370	0.1810	0.0570	0.0650	0.0020	970.0	144.0
0.1420	0.1860	0.0500	0.0670	0.0020	910.0	164.0

TOTAL VOL

2812.5	4457.8	1691.6	1318.4	59.7	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1873	.6728	.0933	.0095	.0372	.0	.0193	0.4135E-02
.4409	.2698	.1743	.0645	.0453	.0052	.1087	0.4[illegible]
.1425	.4538	.2422	.0950	.0629	.0036	.2037	0.5[illegible]
.1354	.4192	.2682	.1042	.0690	.0039	.3047	0.5[illegible]
.1275	.4213	.2639	.1160	.0676	.0038	.4084	0.4[illegible]
.1212	.4361	.2560	.1088	.0742	.0037	.4941	0.4[illegible]
.1233	.4677	.2395	.0913	.0759	.0024	.5884	0.3[illegible]
.1305	.5424	.1926	.0673	.0652	.0021	.6890	0.2[illegible]
.1321	.5738	.1745	.0550	.0627	.0019	.6829	0.2[illegible]

RUN NUM= 38 10 POINTS

WEIGHT OF CARBON 2.3822 G FLOW RATE 85.6 ML/MIN

NO CATALYST

TEMP= 800.00 C PH2O= 0.83 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2820	0.1070	0.0540	0.0230	0.0030	700.0	8.0
0.1020	0.2320	0.1000	0.0520	0.0060	1970.0	24.0
0.0890	0.2450	0.0950	0.0590	0.0060	1920.0	44.0
0.0950	0.2400	0.0880	0.0600	0.0060	1920.0	64.0
0.0900	0.2380	0.0820	0.0660	0.0060	1780.0	84.0
0.0830	0.2360	0.0790	0.0670	0.0040	1570.0	104.0
0.0840	0.2380	0.0680	0.0730	0.0020	1440.0	124.0
0.1010	0.2310	0.0600	0.0770	0.0020	1300.0	144.0
0.1020	0.2340	0.0510	0.0830	0.0020	1200.0	164.0
0.1130	0.2340	0.0420	0.0890	0.0020	1030.0	184.0

TOTAL VOL					
3164.8	7035.2	2327.4	1992.8	129.8	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.2450	.4906	.1729	.0229	.0675	.0011	.0269	0.71[illegible]E-02
.4817	.1988	.1828	.0922	.0393	.0051	.1691	0.[illegible]E-01
.1510	.2717	.3434	.1480	.0770	.0089	.3090	0.[illegible]E-02
.1314	.2708	.3616	.1402	.0871	.0089	.4379	0.62[illegible]E-02
.1363	.2984	.3443	.1263	.0861	.0086	.5609	0.5[illegible]E-02
.1255	.3281	.3318	.1143	.0920	.0084	.6729	0.[illegible]E-02
.1127	.3631	.3205	.1073	.0910	.0084	.7725	0.[illegible]E-02
.1083	.4006	.3068	.0876	.0941	.0026	.8568	0.[illegible]E-02
.1180	.4499	.2698	.0701	.0899	.0023	.9365	0.[illegible]E-02
.1124	.4798	.2579	.0562	.0915	.0022	*****	0.[illegible]E-02

RUN NUM= 39 14 POINTS

WEIGHT OF CARBON 2.4381 G FLOW RATE 22.0 ML/MIN

NO CATALYST

TEMP= 650.00 C PH2O= 0.35 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4120	0.0150	0.0020	0.0140	0.0	370.0	4.0
0.4240	0.0300	0.0020	0.0140	0.0	840.0	24.0
0.4240	0.0340	0.0020	0.0170	0.0	870.0	44.0
0.3940	0.0370	0.0020	0.0170	0.0	870.0	64.0
0.3720	0.0370	0.0020	0.0170	0.0	870.0	84.0
0.3760	0.0370	0.0020	0.0170	0.0	860.0	104.0
0.3760	0.0380	0.0020	0.0170	0.0	870.0	124.0
0.3760	0.0370	0.0020	0.0170	0.0	870.0	144.0
0.3730	0.0370	0.0020	0.0170	0.0	870.0	164.0
0.3720	0.0380	0.0020	0.0170	0.0	870.0	184.0
0.3740	0.0380	0.0020	0.0170	0.0	870.0	204.0
0.3750	0.0370	0.0020	0.0170	0.0	1290.0	234.0
0.3720	0.0380	0.0020	0.0170	0.0	1300.0	264.0
0.3730	0.0380	0.0020	0.0170	0.0	1310.0	294.0

TOTAL VOL

11306.4	1069.7	59.1	494.8	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.3469	.5650	.0565	.0010	.0307	.0	.0029	0.2809E-03
.7725	.1694	.0281	.0037	.0262	.0	.0092	0.3474E-03
.6179	.3151	.0437	.0029	.0204	.0	.0168	0.3921E-03
.6197	.3029	.0497	.0029	.0248	.0	.0249	0.4134E-03
.6151	.2975	.0578	.0031	.0265	.0	.0334	0.4194E-03
.6125	.2955	.0608	.0033	.0279	.0	.0417	0.4175E-03
.6104	.2987	.0601	.0032	.0276	.0	.0501	0.4199E-03
.6124	.2948	.0619	.0033	.0277	.0	.0585	0.4218E-03
.6129	.2958	.0603	.0033	.0277	.0	.0669	0.4233E-03
.6125	.2955	.0608	.0033	.0279	.0	.0754	0.4223E-03
.6119	.2944	.0625	.0033	.0280	.0	.0838	0.4194E-03
.6121	.2946	.0622	.0033	.0278	.0	.0963	0.4191E-03
.6102	.2986	.0602	.0033	.0277	.0	.1090	0.4229E-03
.6110	.2953	.0624	.0033	.0279	.0	.1217	0.4251E-03

RUN NUM= 40 13 POINTS

WEIGHT OF CARBON 2.4381 G FLOW RATE 22.0 ML/MIN

NO CATALYST

TEMP= 700.00 C PH2O= 0.35 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3920	0.0230	0.0060	0.0080	0.0010	370.0	4.0
0.3280	0.0670	0.0120	0.0220	0.0	870.0	24.0
0.2920	0.0910	0.0140	0.0350	0.0	860.0	44.0
0.2780	0.1010	0.0140	0.0410	0.0	860.0	64.0
0.2750	0.0990	0.0140	0.0400	0.0	860.0	84.0
0.2750	0.0970	0.0140	0.0380	0.0	860.0	104.0
0.2800	0.0930	0.0140	0.0370	0.0	850.0	124.0
0.2850	0.0890	0.0140	0.0350	0.0	830.0	144.0
0.2900	0.0870	0.0140	0.0340	0.0	830.0	164.0
0.3030	0.0810	0.0140	0.0320	0.0	830.0	184.0
0.3170	0.0700	0.0120	0.0280	0.0	830.0	204.0
0.3250	0.0630	0.0100	0.0240	0.0	1240.0	234.0
0.3320	0.0570	0.0110	0.0220	0.0	1240.0	264.0

TOTAL VOL					
8063.4	2108.6	336.6	820.5	0.9	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1087	.5384	.2250	.0404	.0856	.0019	.0028	0.6004E-03
.7728	.1523	.0453	.0118	.0158	.0020	.0120	0.9146E-03
.5665	.2590	.1157	.0207	.0380	.0	.0394	0.1135E-02
.5196	.2313	.1619	.0249	.0623	.0	.0634	0.1195E-02
.5009	.2181	.1820	.0252	.0739	.0	.0872	0.1175E-02
.5018	.2189	.1807	.0255	.0730	.0	.1104	0.1141E-02
.5056	.2205	.1783	.0257	.0699	.0	.1328	0.1090E-02
.5086	.2298	.1689	.0254	.0672	.0	.1540	0.1043E-02
.5105	.2423	.1594	.0251	.0627	.0	.1746	0.1003E-02
.5148	.2455	.1544	.0249	.0604	.0	.1941	0.9148E-03
.5252	.2547	.1404	.0243	.0555	.0	.2112	0.8052E-03
.5434	.2680	.1200	.0206	.0480	.0	.2331	0.7210E-03
.5569	.2769	.1079	.0171	.0411	.0	.2544	0.6994E-03

RUN NUM= 41 12 POINTS

WEIGHT OF CARBON 2.3790 G FLOW RATE 22.0 ML/MIN

NO CATALYST

TEMP= 750.00 C PH2O= 0.35 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3940	0.0380	0.0200	0.0120	0.0010	410.0	4.0
0.3180	0.0940	0.0230	0.0280	0.0010	1100.0	24.0
0.2870	0.1180	0.0280	0.0340	0.0010	1180.0	44.0
0.2750	0.1270	0.0300	0.0360	0.0010	1140.0	64.0
0.2720	0.1270	0.0310	0.0360	0.0010	1130.0	84.0
0.2780	0.1220	0.0310	0.0360	0.0010	1110.0	104.0
0.2820	0.1180	0.0300	0.0360	0.0010	1090.0	124.0
0.2860	0.1180	0.0290	0.0360	0.0010	1080.0	144.0
0.2950	0.1120	0.0270	0.0350	0.0010	1060.0	164.0
0.3040	0.1040	0.0250	0.0340	0.0010	1050.0	184.0
0.3150	0.1040	0.0240	0.0320	0.0	1020.0	204.0
0.3350	0.1050	0.0200	0.0300	0.0	1480.0	234.0

TOTAL VOL					
8161.9	3032.2	729.8	904.0	22.1	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DY/DT
.6128	.2935	.0624	.0033	.0279	.0	.0066	0.1168E-02
.7508	.1140	.0724	.0391	.0229	.0019	.0343	0.1588E-02
.5744	.1618	.1698	.0415	.0506	.0018	.0701	0.1611E-02
.5493	.1043	.2258	.0536	.0651	.0019	.1068	0.1[illegible]E-02
.5278	.0998	.2438	.0576	.0691	.0019	.1439	0.1634E-02
.5232	.1016	.2443	.0596	.0693	.0019	.1801	0.1788E-02
.5250	.1162	.2304	.0585	.0680	.0019	.2153	0.1734E-02
.5266	.1279	.2203	.0560	.0672	.0019	.2495	0.1654E-02
.5282	.1320	.2179	.0536	.0665	.0018	.2815	0.1588E-02
.5353	.1472	.2032	.0490	.0635	.0018	.3119	0.1430E-02
.5447	.1615	.1863	.0448	.0609	.0018	.3389	0.1281E-02
.5470	.1752	.1806	.0417	.0556	.0	.3729	0.1001E-02

RUN NUM= 42 11 POINTS

WEIGHT OF CARBON 2.3847 G FLOW RATE 22.0 ML/MIN

NO CATALYST

TEMP= 800.00 C PH2O= 0.35 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3360	0.0250	0.0260	0.0110	0.0010	360.0	4.0
0.2790	0.0850	0.0570	0.0240	0.0020	1000.0	24.0
0.2060	0.1390	0.0730	0.0310	0.0020	1150.0	44.0
0.2050	0.1400	0.0750	0.0300	0.0020	1190.0	64.0
0.2180	0.1290	0.0740	0.0270	0.0020	1160.0	84.0
0.2150	0.1320	0.0730	0.0250	0.0020	1130.0	104.0
0.2260	0.1280	0.0700	0.0230	0.0010	1090.0	124.0
0.2340	0.1240	0.0660	0.0230	0.0010	1050.0	144.0
0.2370	0.1180	0.0620	0.0230	0.0010	1010.0	164.0
0.2420	0.1150	0.0570	0.0240	0.0010	960.0	184.0
0.2490	0.1120	0.0520	0.0240	0.0010	900.0	204.0

TOTAL VOL					
5817.2	2967.3	1616.0	622.0	37.5	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.5551	.1881	.1740	.0331	.0497	.0	.0077	0.1796E-02
.7156	.1502	.0532	.0554	.0234	.0021	.0519	0.2623E-02
.5133	.1776	.1564	.1049	.0442	.0037	.1126	0.3103E-02
.4287	.0615	.2892	.1519	.0645	.0042	.1759	0.3073E-02
.4315	.0487	.2947	.1579	.0631	.0042	.2356	0.2911E-02
.4470	.0773	.2645	.1517	.0554	.0041	.2924	0.2704E-02
.4433	.0785	.2721	.1505	.0515	.0041	.3437	0.2469E-02
.4530	.1019	.2566	.1403	.0461	.0020	.3911	0.2231E-02
.4591	.1211	.2433	.1295	.0451	.0020	.4354	0.2113E-02
.4619	.1406	.2300	.1208	.0448	.0019	.4756	0.1940E-02
.4625	.1609	.2198	.1089	.0459	.0019	.5112	0.1659E-02

RUN NUM= 44. 11 POINTS

WEIGHT OF CARBON 2.4105 G FLOW RATE 144.0 ML/MIN

10% FERRIC OXIDE

TEMP= 650.00 C PH2O= 0.80 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3360	0.1350	0.0050	0.0310	0.0020	270.0	4.0
0.1420	0.3450	0.0090	0.0840	0.0020	300.0	24.0
0.0540	0.3450	0.0080	0.1200	0.0020	310.0	44.0
0.0310	0.3550	0.0080	0.1290	0.0020	320.0	64.0
0.0160	0.3400	0.0080	0.1320	0.0020	310.0	84.0
0.0080	0.3450	0.0090	0.1360	0.0020	300.0	104.0
0.0050	0.3500	0.0090	0.1370	0.0010	300.0	124.0
0.0040	0.3500	0.0100	0.1410	0.0010	290.0	144.0
0.0040	0.3450	0.0090	0.1400	0.0010	270.0	164.0
0.0060	0.3500	0.0090	0.1400	0.0010	260.0	184.0
0.0060	0.3500	0.0080	0.1410	0.0010	250.0	204.0

TOTAL VOL

330.3	2036.3	51.8	752.0	9.6	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.0004	.9855	.0093	.0004	.0043	.0000	.0045	0.39302E-03
.2308	.6504	.0927	.0034	.0213	.0014	.0154	0.76493E-03
.0244	.9000	.0593	.0015	.0144	.0003	.0323	0.89182E-03
.0106	.8962	.0677	.0016	.0236	.0004	.0510	0.39633E-03
.0064	.8926	.0727	.0016	.0262	.0004	.0707	0.39812E-03
.0033	.8958	.0711	.0017	.0276	.0004	.0903	0.97219E-03
.0016	.8990	.0697	.0018	.0275	.0004	.1098	0.97215E-03
.0010	.8990	.0704	.0018	.0276	.0002	.1292	0.93807E-03
.0008	.9023	.0676	.0019	.0272	.0002	.1482	0.97412E-03
.0007	.9089	.0630	.0016	.0256	.0002	.1643	0.88302E-03
.0010	.9121	.0608	.0016	.0243	.0002	.1808	0.90717E-03

RUN NUM= 45 11 POINTS

WEIGHT OF CARBON 2.3400 G FLOW RATE 135.0 ML/MIN

K2CO3 20 %

TEMP= 650.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2870	0.0900	0.0110	0.0040	0.0010	270.0	6.0
0.1560	0.1790	0.0290	-0.0380	0.0010	860.0	26.0
0.0960	0.1830	0.0430	0.0740	0.0010	790.0	46.0
0.0970	0.1930	0.0450	0.0910	0.0010	860.0	66.0
0.0620	0.1990	0.0440	0.1030	0.0010	900.0	86.0
0.0410	0.1980	0.0420	0.1050	0.0010	790.0	106.0
0.0450	0.1980	0.0400	0.1060	0.0010	710.0	126.0
0.0100	0.2010	0.0360	0.1060	0.0010	730.0	146.0
0.0050	0.2010	0.0330	0.1090	0.0010	700.0	166.0
0.0030	0.1950	0.0330	0.1110	0.0010	640.0	186.0
0.1030	0.1750	0.0250	0.1000	0.0	600.0	206.0

TOTAL VOL					
1408.1	3841.3	740.2	1841.5	18.8	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.4673	.2897	.1449	.0670	.0312	.0	.0025	0.1148E-02
.1939	.7345	.0608	.0074	.0027	.0007	.0357	0.2174E-02
.1049	.7290	.1204	.0195	.0256	.0007	.0895	0.2923E-02
.0612	.7469	.1166	.0274	.0472	.0006	.1527	0.3443E-02
.0617	.7285	.1227	.0286	.0579	.0006	.2272	0.3593E-02
.0432	.7150	.1387	.0307	.0718	.0007	.2964	0.3261E-02
.0272	.7437	.1312	.0278	.0696	.0007	.3577	0.3219E-02
.0269	.7669	.1183	.0239	.0634	.0006	.4252	0.3329E-02
.0068	.7576	.1376	.0247	.0726	.0007	.4906	0.3190E-02
.0034	.7661	.1347	.0221	.0730	.0007	.5528	0.2614E-02
.0019	.7847	.1224	.0207	.0697	.0006	.5954	0.1647E-02

RUN NUM= 46 11 POINTS

WEIGHT OF CARBON 2.4285 G FLOW RATE 135.0 ML/MIN

K2CO3 5 %

TEMP= 650.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2290	0.0660	0.0050	0.0370	0.0	450.0	6.0
0.2210	0.1320	0.0060	0.0620	0.0	940.0	26.0
0.2140	0.1350	0.0060	0.0650	0.0	970.0	46.0
0.2080	0.1380	0.0060	0.0670	0.0	990.0	66.0
0.2040	0.1400	0.0060	0.0670	0.0	1000.0	86.0
0.2020	0.1410	0.0070	0.0660	0.0	1000.0	106.0
0.2030	0.1420	0.0070	0.0670	0.0	990.0	126.0
0.2080	0.1400	0.0070	0.0650	0.0	950.0	146.0
0.2130	0.1360	0.0060	0.0630	0.0	930.0	166.0
0.2120	0.1310	0.0050	0.0610	0.0	920.0	186.0
0.2150	0.1280	0.0040	0.0600	0.0	920.0	206.0

TOTAL VOL					
5146.6	3234.1	145.3	1533.9	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.0505	.8026	.0857	.0122	.0490	.0	.0124	0.16095E-02
.2609	.6160	.0752	.0057	.0422	.0	.0459	0.17428E-02
.1475	.7190	.0881	.0040	.0414	.0	.0820	0.16856E-02
.1472	.7112	.0928	.0041	.0447	.0	.1201	0.19178E-02
.1461	.7057	.0969	.0042	.0471	.0	.1587	0.19838E-02
.1454	.7028	.0998	.0043	.0478	.0	.1974	0.19925E-02
.1445	.7025	.1008	.0050	.0472	.0	.2360	0.18628E-02
.1430	.7049	.1000	.0049	.0472	.0	.2719	0.17465E-02
.1411	.7150	.0950	.0047	.0441	.0	.3058	0.16503E-02
.1424	.7205	.0909	.0040	.0421	.0	.3385	0.16178E-02
.1434	.7233	.0886	.0034	.0413	.0	.3704	0.19758E-02

RUN NUM= 47 11 POINTS

WEIGHT OF CARBON 2.3798 G FLOW RATE 135.0 ML/MIN

CATALYST NIL

TEMP= 650.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3490	0.0450	0.0020	0.0230	0.0	300.0	2.2
0.3070	0.1020	0.0030	0.0490	0.0	810.0	6.0
0.3020	0.1030	0.0020	0.0490	0.0	810.0	6.0
0.3110	0.0980	0.0020	0.0470	0.0	780.0	5.8
0.3320	0.0860	0.0010	0.0390	0.0	720.0	5.3
0.3640	0.0630	0.0010	0.0320	0.0	660.0	4.9
0.3620	0.0650	0.0010	0.0330	0.0	660.0	4.9
0.3620	0.0660	0.0010	0.0330	0.0	660.0	4.9
0.3640	0.0670	0.0010	0.0330	0.0	660.0	4.9
0.3590	0.0680	0.0010	0.0330	0.0	660.0	4.9
0.3520	0.0700	0.0020	0.0340	0.0	660.0	4.9

TOTAL VOL					
5620.5	1308.9	26.4	634.2	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1459	.7238	.0869	.0027	.0407	.0	.3048	0.109[illegible]E-02
.2650	.6818	.0342	.0015	.0175	.0	.0267	0.[illegible]E-[illegible]
.1700	.7448	.0565	.0017	.0271	.0	.0492	0.[illegible]E-02
.1692	.7445	.0577	.0011	.0275	.0	.0688	0.[illegible]E-02
.1714	.7476	.0540	.0011	.0259	.0	.0831	0.[illegible]E-02
.1607	.7783	.0416	.0005	.0189	.0	.0938	0.[illegible]E-02
.1597	.7981	.0276	.0004	.0140	.0	.1046	0.[illegible]E-03
.1566	.8005	.0281	.0004	.0143	.0	.1154	0.[illegible]E-03
.1564	.8004	.0285	.0004	.0143	.0	.1261	0.[illegible]E-03
.1563	.8004	.0288	.0004	.0142	.0	.1370	0.[illegible]E-03
.1575	.7977	.0298	.0004	.0145	.0	.1487	0.[illegible]E-03

RUN NUM= 48 10 POINTS

WEIGHT OF CARBON 2.0115 G FLOW RATE 135.0 ML/MIN

NA2CO3 20%

TEMP= 650.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2410	0.0700	0.0060	0.0350	0.0	490.0	6.0
0.2260	0.1350	0.0110	0.0630	0.0	1220.0	26.0
0.2190	0.1450	0.0120	0.0700	0.0	1210.0	46.0
0.2150	0.1550	0.0120	0.0720	0.0	1200.0	66.0
0.2120	0.1550	0.0090	0.0740	0.0	1100.0	86.0
0.2090	0.1550	0.0090	0.0740	0.0	1140.0	106.0
0.2050	0.1530	0.0080	0.0720	0.0	1100.0	126.0
0.2250	0.1500	0.0080	0.0630	0.0	1040.0	146.0
0.2490	0.1300	0.0070	0.0580	0.0	970.0	166.0
0.2650	0.1140	0.0070	0.0520	0.0	920.0	196.0

TOTAL VOL					
5360.8	3338.4	218.8	1552.1	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1556	.7975	.0310	.0009	.0150	.0	.0152	0.2664E-02
.2790	.5925	.0810	.0069	.0405	.0	.0705	0.2863E-02
.1790	.6555	.1069	.0087	.0499	.0	.1297	0.2959E-02
.1690	.6559	.1119	.0093	.0540	.0	.1889	0.2927E-02
.1628	.6562	.1174	.0091	.0545	.0	.2468	0.2859E-02
.1600	.6603	.1170	.0068	.0559	.0	.3032	0.2747E-02
.1547	.6691	.1148	.0067	.0548	.0	.3567	0.2440E-02
.1507	.6780	.1125	.0059	.0529	.0	.4008	0.2048E-02
.1548	.6932	.1032	.0055	.0433	.0	.4386	0.1575E-02
.1607	.7135	.0839	.0045	.0374	.0	.4716	0.6257E-03

RUN NUM= 49 11 POINTS

WEIGHT OF CARBON 2.4243 G FLOW RATE 135.0 ML/MIN

NA2CO3 5%

TEMP= 650.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3030	0.0700	0.0070	0.0300	0.0	430.0	6.0
0.2260	0.1620	0.0100	0.0620	0.0	1020.0	26.0
0.2120	0.1640	0.0100	0.0680	0.0	1060.0	46.0
0.2010	0.1660	0.0080	0.0720	0.0	940.0	66.0
0.1900	0.1670	0.0080	0.0760	0.0	950.0	86.0
0.1830	0.1670	0.0080	0.0780	0.0	950.0	106.0
0.1790	0.1650	0.0070	0.0780	0.0	950.0	126.0
0.1940	0.1580	0.0070	0.0760	0.0	950.0	146.0
0.2120	0.1490	0.0070	0.0690	0.0	920.0	166.0
0.2320	0.1390	0.0050	0.0620	0.0	850.0	186.0
0.2520	0.1290	0.0050	0.0590	0.0	820.0	206.0

TOTAL VOL					
4725.6	3419.8	168.8	1525.8	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1177	.8055	.0506	.0031	.0231	.0	.0036	0.164[illegible]E-02
.2724	.6314	.0629	.0063	.0270	.0	.0439	0.1[illegible]E-02
.1491	.6965	.1069	.0066	.0409	.0	.0841	0.193[illegible]E-02
.1466	.6861	.1134	.0069	.0470	.0	.1219	0.152[illegible]E-02
.1284	.7144	.1061	.0051	.0460	.0	.1613	0.203[illegible]E-02
.1244	.7113	.1093	.0052	.0498	.0	.2027	0.207[illegible]E-02
.1213	.7109	.1107	.0053	.0517	.0	.2443	0.204[illegible]E-02
.1207	.7108	.1112	.0047	.0526	.0	.2843	0.1[illegible]E-02
.1282	.7126	.1044	.0046	.0502	.0	.3197	0.160[illegible]E-02
.1350	.7217	.0949	.0045	.0439	.0	.3484	0.137[illegible]E-02
.1373	.7409	.0822	.0030	.0367	.0	.3746	0.123[illegible]E-02

RUN NUM= 50 11 POINTS

WEIGHT OF CARBON 2.0211 G FLOW RATE 135.0 ML/MIN

KCL 20 %

TEMP= 650.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3220	0.0500	0.0030	0.0250	0.0	400.0	6.0
0.2660	0.1240	0.0050	0.0520	0.0	840.0	26.0
0.2520	0.1290	0.0050	0.0600	0.0	800.0	46.0
0.2490	0.1280	0.0050	0.0610	0.0	800.0	66.0
0.2510	0.1260	0.0050	0.0610	0.0	830.0	86.0
0.2540	0.1230	0.0050	0.0590	0.0	810.0	106.0
0.2610	0.1190	0.0050	0.0560	0.0	780.0	126.0
0.2690	0.1130	0.0040	0.0540	0.0	800.0	146.0
0.2680	0.1140	0.0040	0.0540	0.0	800.0	166.0
0.2620	0.1200	0.0040	0.0570	0.0	810.0	186.0
0.2510	0.1260	0.0040	0.0590	0.0	780.0	206.0

TOTAL VOL					
5023.4	2272.3	86.8	1067.6	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1415	.7502	.0724	.0028	.0331	.0	.0074	0.1355E-02
.2776	.6552	.0431	.0026	.0216	.0	.0358	0.1484E-02
.1512	.7460	.0705	.0028	.0295	.0	.0668	0.1564E-02
.1385	.7553	.0704	.0027	.0330	.0	.0984	0.1609E-02
.1376	.7553	.0707	.0028	.0337	.0	.1312	0.1598E-02
.1428	.7480	.0717	.0028	.0347	.0	.1623	0.1494E-02
.1421	.7534	.0688	.0028	.0330	.0	.1909	0.1414E-02
.1412	.7614	.0644	.0027	.0303	.0	.2189	0.1398E-02
.1485	.7572	.0624	.0022	.0298	.0	.2468	0.1438E-02
.1480	.7570	.0629	.0022	.0298	.0	.2764	0.1479E-02
.1456	.7538	.0667	.0022	.0317	.0	.3060	0.1481E-02

RUN NUM= 51 11 POINTS

WEIGHT OF CARBON 2.0173 G FLOW RATE 135.0 ML/MIN

NACL 20 %

TEMP= 650.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3660	0.0370	0.0030	0.0170	0.0	310.0	6.0
0.3450	0.0800	0.0030	0.0380	0.0	720.0	26.0
0.3250	0.0940	0.0030	0.0450	0.0	720.0	46.0
0.3240	0.0930	0.0030	0.0440	0.0	700.0	66.0
0.3210	0.0900	0.0030	0.0420	0.0	680.0	86.0
0.3330	0.0900	0.0030	0.0410	0.0	700.0	106.0
0.3270	0.0950	0.0030	0.0430	0.0	730.0	126.0
0.3200	0.0970	0.0030	0.0460	0.0	690.0	146.0
0.3260	0.0920	0.0020	0.0440	0.0	660.0	166.0
0.3350	0.0900	0.0020	0.0420	0.0	690.0	186.0
0.3170	0.1010	0.0030	0.0480	0.0	730.0	206.0

TOTAL VOL

5207.1 1414.5 44.4 663.9 0.0 ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1366	.7605	.0686	.0022	.0321	.0	.0039	0.77048E-03
.2454	.7163	.0248	.0020	.0114	.0	.0207	0.91119E-03
.1617	.7816	.0375	.0014	.0178	.0	.0404	0.86211E-03
.1530	.7802	.0443	.0014	.0212	.0	.0592	0.90678E-03
.1500	.7853	.0430	.0014	.0204	.0	.0766	0.87388E-03
.1487	.7907	.0404	.0013	.0189	.0	.0941	0.91422E-03
.1529	.7856	.0413	.0014	.0188	.0	.1132	0.95822E-03
.1554	.7776	.0452	.0014	.0204	.0	.1325	0.91617E-03
.1460	.7875	.0442	.0014	.0210	.0	.1498	0.89407E-03
.1436	.7956	.0405	.0009	.0194	.0	.1670	0.95687E-03
.1513	.7882	.0406	.0009	.0190	.0	.1861	0.11517E-02

RUN NUM= 52 10 POINTS

WEIGHT OF CARBON 2.0286 G FLOW RATE 135.0 ML/MIN

NACL 20 %

TEMP= 800.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2830	0.0830	0.0270	0.0230	0.0020	420.0	4.0
0.1750	0.1780	0.0600	0.0490	0.0020	1520.0	22.0
0.1440	0.1920	0.0690	0.0560	0.0020	1520.0	40.0
0.1110	0.2030	0.0750	0.0640	0.0020	1500.0	58.0
0.0900	0.2130	0.0710	0.0700	0.0020	1500.0	78.0
0.0830	0.2160	0.0670	0.0740	0.0010	1500.0	98.0
0.1140	0.2090	0.0610	0.0770	0.0010	1490.0	118.0
0.1420	0.1980	0.0500	0.0770	0.0010	1480.0	138.0
0.1660	0.1860	0.0330	0.0740	0.0	1170.0	158.0
0.1920	0.1670	0.0180	0.0690	0.0	900.0	178.0

TOTAL VOL					
3908.6	5528.4	1639.4	1885.3	38.2	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1508	.7769	.0480	.0014	.0228	.0	.0138	0.4944E-02
.3259	.5187	.0956	.0311	.0265	.0023	.1098	0.5728E-02
.1709	.5468	.1739	.0586	.0479	.0020	.2199	0.6[illegible]E-02
.1430	.5403	.1906	.0685	.0556	.0020	.3427	0.6593E-02
.1127	.5381	.2061	.0761	.0650	.0020	.4697	0.6384E-02
.0872	.5677	.2064	.0688	.0678	.0019	.5972	0.6140E-02
.0816	.5663	.2124	.0659	.0728	.0010	.7156	0.5832E-02
.1048	.5754	.1921	.0561	.0708	.0009	.8225	0.4473E-02
.1266	.5828	.1765	.0446	.0686	.0009	.8945	0.2960E-02
.1246	.6555	.1396	.0248	.0555	.0	.9409	0.1677E-02

RUN NUM= 53 8 POINTS

WEIGHT OF CARBON 2.0142 G FLOW RATE 135.0 ML/MIN

KCL 20 %

TEMP= 800.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2660	0.0980	0.0460	0.0260	0.0020	580.0	8.0
0.1240	0.2010	0.0680	0.0510	0.0020	1330.0	28.0
0.1080	0.1950	0.0790	0.0540	0.0020	1600.0	46.0
0.1110	0.1920	0.0870	0.0550	0.0020	1670.0	68.0
0.1140	0.2000	0.0860	0.0550	0.0020	1700.0	88.0
0.1220	0.1980	0.0880	0.0550	0.0020	1700.0	108.0
0.1110	0.2000	0.0860	0.0550	0.0020	1700.0	128.0
0.1030	0.2010	0.0870	0.0550	0.0010	1650.0	148.0

TOTAL VOL					
3193.5	5111.0	2174.2	1402.1	49.3	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1187	.7242	.1033	.0111	.0427	.0	.0261	0.3919E-02
.2310	.6197	.0851	.0399	.0226	.0017	.1220	0.5678E-02
.1082	.6110	.1753	.0593	.0445	.0017	.2532	0.6856E-02
.1104	.5522	.1994	.0806	.0552	.0020	.3963	0.7143E-02
.1140	.5409	.1972	.0894	.0565	.0021	.5391	0.7098E-02
.1159	.5335	.2033	.0894	.0559	.0020	.6801	0.7113E-02
.1218	.5357	.1977	.0879	.0549	.0020	.8239	0.7104E-02
.1137	.5329	.2049	.0901	.0563	.0020	.9643	0.6435E-02

RUN NUM= 56 5 POINTS

WEIGHT OF CARBON 2.0380 G FLOW RATE 135.0 ML/MIN

K2CO3 20 %

TEMP= 800.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2520	0.0900	0.1010	0.0150	0.0020	680.0	6.0
0.0950	0.1950	0.1250	0.0340	0.0020	2180.0	24.0
0.0580	0.2050	0.1360	0.0280	0.0020	2290.0	42.0
0.0510	0.2040	0.1430	0.0260	0.0020	2510.0	60.0
0.0480	0.2040	0.1140	0.0430	0.0	1910.0	78.0

TOTAL VOL					
1666.0	4324.5	2854.4	690.0	35.1	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1056	.5418	.2061	.0892	.0564	.0010	.0459	0.1058E-01
.2757	.4967	.0985	.1105	.0164	.0022	.2504	0.1215E-01
.1259	.4024	.2584	.1656	.0450	.0026	.4823	0.1382E-01
.0859	.3647	.3036	.2014	.0415	.0030	.7482	0.1271E-01
.0809	.3243	.3236	.2268	.0412	.0032	.9409	0.8704E-02

RUN NUM= 57 7 POINTS

WEIGHT OF CARBON 2.3486 G FLOW RATE 135.0 ML/MIN

K2CO3 5%

TEMP= 900.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2230	0.1050	0.0490	0.0270	0.0020	890.0	6.0
0.1150	0.2000	0.0990	0.0480	0.0020	1790.0	24.0
0.1100	0.1990	0.1100	0.0480	0.0020	2030.0	44.0
0.1060	0.2010	0.1110	0.0480	0.0020	1820.0	64.0
0.1000	0.2020	0.1110	0.0480	0.0020	1760.0	84.0
0.0890	0.2070	0.1110	0.0460	0.0020	1880.0	104.0
0.0780	0.2080	0.1100	0.0450	0.0020	1900.0	124.0

TOTAL VOL					
2897.7	5157.4	2748.3	1203.7	52.9	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	IX/B
.0662	.4361	.2812	.1572	.0593	.0	.0386	-0.6993E-02
.3325	.3947	.1566	.0731	.0403	.0030	.1697	0.7975E-02
.1292	.4786	.2247	.1112	.0539	.0022	.3276	0.[illegible]
.1236	.4729	.2236	.1236	.0539	.0022	.4705	0.[illegible]
.1107	.5111	.2100	.1160	.0501	.0021	.6104	0.7230E-02
.1034	.5213	.2088	.1148	.0496	.0021	.7500	0.7[illegible]
.0992	.4930	.2307	.1237	.0513	.0022	.9135	0.7773E-02

RUN NUM= 58 8 POINTS

WEIGHT OF CARBON 2.3350 G FLOW RATE 135.0 ML/MIN

NA2CO3 5 %

TEMP= 800.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2650	0.0920	0.0460	0.0230	0.0020	910.0	8.0
0.1200	0.1889	0.0940	0.0460	0.0020	1960.0	26.0
0.1140	0.1940	0.1040	0.0460	0.0020	2100.0	46.0
0.1080	0.1990	0.1060	0.0460	0.0020	2020.0	66.0
0.1040	0.2020	0.1030	0.0450	0.0020	1810.0	86.0
0.1050	0.2020	0.0950	0.0450	0.0010	1720.0	106.0
0.1150	0.2000	0.0830	0.0490	0.0010	1650.0	126.0
0.1310	0.1820	0.0640	0.0540	0.0	1310.0	146.0

TOTAL VOL					
3689.8	5599.6	2698.6	1346.2	45.9	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.0906	.4852	.2417	.1278	.0523	.0023	.0346	0.7232E-02
.3155	.4904	.1095	.0548	.0274	.0024	.1690	0.7703E-02
.1417	.4677	.2230	.1110	.0543	.0024	.3282	0.7650E-02
.1336	.4610	.2273	.1219	.0539	.0023	.4830	0.7295E-02
.1235	.4727	.2276	.1213	.0526	.0023	.6196	0.6520E-02
.1118	.5098	.2172	.1107	.0484	.0022	.7428	0.5915E-02
.1108	.5271	.2132	.1003	.0475	.0011	.8562	0.4987E-02
.1175	.5424	.2043	.0848	.0500	.0010	.9385	0.3829E-02

RUN NUM= 59 13 POINTS

WEIGHT OF CARBON 2.2362 G FLOW RATE 135.0 ML/MIN

NA2CO3 10%

TEMP= 650.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3130	0.0650	0.0120	0.0320	0.0	390.0	5.0
0.2330	0.1300	0.0110	0.0550	0.0	920.0	25.0
0.2060	0.1440	0.0110	0.0670	0.0	950.0	45.0
0.1980	0.1560	0.0110	0.0720	0.0	950.0	65.0
0.1920	0.1620	0.0110	0.0760	0.0	940.0	85.0
0.1920	0.1640	0.0110	0.0770	0.0	940.0	105.0
0.1960	0.1580	0.0110	0.0680	0.0	920.0	125.0
0.2120	0.1500	0.0100	0.0640	0.0	910.0	145.0
0.2150	0.1460	0.0100	0.0640	0.0	900.0	165.0
0.2050	0.1540	0.0100	0.0660	0.0	870.0	185.0
0.1860	0.1680	0.0120	0.0720	0.0	830.0	205.0

TOTAL VOL					
4558.6	3267.3	237.4	1456.7	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1152	.6210	.1600	.0563	.0475	.0	.0097	0.1506E-02
.2878	.6119	.0598	.0110	.0294	.0	.0436	0.1995E-02
.1495	.7247	.0834	.0071	.0353	.0	.0851	0.2119E-02
.1373	.7147	.0960	.0073	.0447	.0	.1294	0.2191E-02
.1300	.7131	.1024	.0072	.0473	.0	.1728	0.2226E-02
.1242	.7147	.1048	.0071	.0492	.0	.2174	0.2121E-02
.1234	.7145	.1054	.0071	.0495	.0	.2576	0.1930E-02
.1268	.7199	.1022	.0071	.0440	.0	.2946	0.1842E-02
.1342	.7240	.0950	.0063	.0405	.0	.3313	0.1827E-02
.1349	.7271	.0916	.0063	.0402	.0	.3677	0.1864E-02
.1257	.7333	.0944	.0061	.0405	.0	.4058	0.1950E-02

RUN NUM= 61 10 POINTS

WEIGHT OF CARBON 2.3759 G FLOW RATE 135.0 ML/MIN

CATALYST NONE

TEMP= 800.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2660	0.0800	0.0380	0.0300	0.0020	730.0	8.0
0.1290	0.1640	0.0730	0.0460	0.0030	1480.0	28.0
0.1140	0.1720	0.0840	0.0440	0.0030	1400.0	48.0
0.1090	0.1760	0.0770	0.0460	0.0020	1310.0	68.0
0.1070	0.1780	0.0640	0.0530	0.0020	1250.0	88.0
0.1140	0.1780	0.0580	0.0570	0.0020	1240.0	108.0
0.1230	0.1780	0.0530	0.0590	0.0010	1240.0	128.0
0.1300	0.1740	0.0500	0.0600	0.0010	1220.0	148.0
0.1310	0.1720	0.0460	0.0620	0.0010	1190.0	168.0
0.1310	0.1720	0.0400	0.0640	0.0010	1160.0	188.0

TOTAL VOL					
3834.2	4983.2	1780.0	1568.0	54.6	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1097	.7416	.0991	.0071	.0425	.0	.0277	0.48788-02
.2808	.5609	.0844	.0401	.0317	.0021	.1258	0.49328-02
.1287	.5859	.1637	.0728	.0459	.0030	.2250	0.47558-02
.1093	.6003	.1649	.0805	.0422	.0029	.3160	0.43528-02
.1008	.6189	.1628	.0712	.0444	.0018	.3990	0.40758-02
.0977	.6309	.1626	.0585	.0484	.0018	.4790	0.38078-02
.1020	.6340	.1593	.0519	.0510	.0019	.5559	0.37478-02
.1083	.6354	.1568	.0467	.0520	.0009	.6299	0.36148-02
.1123	.6415	.1503	.0432	.0518	.0009	.6999	0.34578-02
.1117	.6487	.1467	.0392	.0529	.0009	.7672	0.32748-02

RUN NUM= 63 10 POINTS

WEIGHT OF CARBON 2.4326 G FLOW RATE 85.6 ML/MIN

NO CATALYST

TEMP= 800.00 C PH2O= 0.83 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2560	0.0960	0.0330	0.0290	0.0020	600.0	4.0
0.1280	0.1990	0.0740	0.0550	0.0030	1300.0	24.0
0.1170	0.2030	0.0870	0.0500	0.0030	1200.0	44.0
0.1140	0.2040	0.0900	0.0540	0.0030	1240.0	64.0
0.1390	0.1930	0.0660	0.0530	0.0020	1120.0	84.0
0.1280	0.2030	0.0580	0.0640	0.0020	1080.0	104.0
0.1310	0.1980	0.0550	0.0660	0.0020	960.0	124.0
0.1550	0.1860	0.0530	0.0590	0.0020	920.0	144.0
0.1640	0.1830	0.0470	0.0580	0.0020	920.0	164.0
0.1690	0.1780	0.0440	0.0610	0.0020	900.0	184.0

TOTAL VOL					
3328.4	4339.7	1440.4	1277.0	54.5	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DR/DT
.6913	.0010	.1855	.0906	.0316	.0	.0224	0.459[illegible]E-02
.4814	.2178	.1805	.0621	.0545	.0038	.1104	0.4[illegible]E-02
.1562	.4398	.2429	.0903	.0671	.0037	.1282	0.4[illegible]E-02
.1305	.4809	.2264	.0970	.0558	.0033	.2748	0.372[illegible]E-02
.1306	.4789	.2336	.0916	.0618	.0034	.3411	0.32[illegible]E-02
.1458	.5228	.2024	.0713	.0556	.0021	.4059	0.3[illegible]E-02
.1321	.5306	.2094	.0599	.0660	.0021	.4452	0.2[illegible]E-02
.1270	.5619	.1919	.0533	.0640	.0019	.5160	0.24[illegible]E-02
.1394	.5907	.1673	.0477	.0531	.0018	.5687	0.1[illegible]E-02
.1475	.5917	.1646	.0423	.0522	.0018	.6104	0.[illegible]E-02

RUN NUM= 66 14 POINTS

WEIGHT OF CARBON 2.3783 G FLOW RATE 32.0 ML/MIN

NO CATALYST

TEMP= 650.00 C PH2O= 0.56 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4730	0.0340	0.0020	0.0200	0.0	560.0	4.0
0.4670	0.0570	0.0040	0.0280	0.0	1440.0	24.0
0.4610	0.0570	0.0040	0.0270	0.0	1390.0	44.0
0.4540	0.0570	0.0040	0.0260	0.0	1380.0	64.0
0.4500	0.0560	0.0040	0.0260	0.0	1370.0	84.0
0.4500	0.0540	0.0040	0.0240	0.0	1370.0	104.0
0.4500	0.0540	0.0040	0.0240	0.0	1360.0	124.0
0.4510	0.0540	0.0040	0.0240	0.0	1370.0	144.0
0.4520	0.0550	0.0040	0.0240	0.0	1370.0	164.0
0.4550	0.0550	0.0030	0.0240	0.0	1360.0	184.0
0.4560	0.0550	0.0030	0.0230	0.0	1370.0	204.0
0.4590	0.0550	0.0030	0.0240	0.0	2010.0	234.0
0.4610	0.0540	0.0030	0.0230	0.0	2000.0	264.0
0.4650	0.0460	0.0030	0.0210	0.0	2000.0	294.0

TOTAL VOL					
17275.1	2028.8	132.8	913.3	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1488	.6002	.1567	.0387	.0537	.0018	.0052	0.9581E-03
.7680	.1411	.0552	.0032	.0325	.0	.0239	0.9087E-03
.6259	.2548	.0764	.0054	.0375	.0	.0416	0.8729E-03
.6190	.2629	.0765	.0054	.0363	.0	.0588	0.8627E-03
.6178	.2638	.0776	.0054	.0354	.0	.0761	0.8379E-03
.6161	.2661	.0767	.0055	.0356	.0	.0929	0.8091E-03
.6194	.2677	.0743	.0055	.0330	.0	.1095	0.8084E-03
.6178	.2696	.0741	.0055	.0330	.0	.1247	0.8000E-03
.6195	.2678	.0742	.0055	.0330	.0	.1408	0.7999E-03
.6192	.2670	.0753	.0055	.0329	.0	.1562	0.7596E-03
.6193	.2691	.0749	.0041	.0327	.0	.1712	0.7495E-03
.6222	.2673	.0750	.0041	.0314	.0	.1938	0.7374E-03
.6166	.2732	.0739	.0040	.0322	.0	.2154	0.6977E-03
.6174	.2755	.0723	.0040	.0308	.0	.2356	0.6496E-03

RUN NUM= 67 9 POINTS

WEIGHT OF CARBON 2.3845 G FLOW RATE 32.0 ML/MIN

NO CATALYST

TEMP= 700.00 C PH2O= 0.55 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4500	0.0490	0.0100	0.0350	0.0	660.0	0.0
0.4410	0.0960	0.0120	0.0580	0.0	2030.0	32.0
0.4290	0.1100	0.0120	0.0540	0.0	1890.0	54.0
0.4360	0.0980	0.0120	0.0490	0.0	1940.0	74.0
0.4480	0.0860	0.0130	0.0420	0.0	1960.0	91.0
0.4560	0.0720	0.0120	0.0390	0.0	1970.0	114.0
0.4600	0.0700	0.0090	0.0330	0.0	2000.0	134.0
0.4580	0.0690	0.0080	0.0340	0.0	2980.0	164.0
0.4570	0.0680	0.0060	0.0340	0.0	2960.0	194.0

TOTAL VOL					
14147.8	2525.6	313.4	1303.1	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.6235	.2826	.0617	.0040	.0282	.0	.0123	0.17513E-02
.7494	.0941	.0816	.0167	.0563	.0	.0649	0.20063E-02
.5662	.2207	.1232	.0154	.0745	.0	.1112	0.21732E-02
.5955	.1601	.1527	.0167	.0750	.0	.1559	0.21295E-02
.6289	.1418	.1414	.0173	.0707	.0	.1963	0.19867E-02
.6455	.1527	.1239	.0173	.0605	.0	.2353	0.17995E-02
.6560	.1670	.1036	.0173	.0561	.0	.2683	0.16497E-02
.6715	.1650	.1022	.0131	.0482	.0	.3177	0.15023E-02
.6703	.1673	.1010	.0117	.0498	.0	.3632	0.14517E-02

RUN NUM= 68 12 POINTS

WEIGHT OF CARBON 2.3932 G FLOW RATE 37.3 ML/MIN

NO CATALYST

TEMP= 750.00 C PH2O= 0.48 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4660	0.0390	0.0150	0.0180	0.0010	630.0	4.0
0.3960	0.0840	0.0280	0.0260	0.0010	1660.0	24.0
0.3660	0.1080	0.0310	0.0310	0.0010	1680.0	44.0
0.3860	0.1080	0.0330	0.0290	0.0010	1770.0	64.0
0.3900	0.1000	0.0320	0.0280	0.0010	1740.0	84.0
0.3940	0.0980	0.0300	0.0280	0.0010	1720.0	104.0
0.4020	0.0910	0.0290	0.0280	0.0010	1690.0	124.0
0.4110	0.0840	0.0280	0.0270	0.0010	1660.0	144.0
0.4160	0.0760	0.0260	0.0270	0.0010	1630.0	164.0
0.4160	0.0750	0.0260	0.0270	0.0	1630.0	184.0
0.4050	0.0890	0.0250	0.0250	0.0	1660.0	204.0
0.4110	0.0850	0.0240	0.0240	0.0	2500.0	234.0

TOTAL VOL					
14772.5	3279.4	1043.2	988.8	20.7	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.6655	.1772	.0990	.0037	.0495	.0	.0083	0.16835-02
.7448	.1385	.0623	.0240	.0368	.0016	.0471	0.21372-02
.5744	.2240	.1218	.0406	.0377	.0015	.0944	0.23088-02
.5635	.1733	.1663	.0477	.0477	.0015	.1382	0.21448-02
.5662	.1830	.1584	.0484	.0425	.0015	.1829	0.21082-02
.5091	.1959	.1459	.0467	.0409	.0015	.2285	0.20008-02
.5710	.2014	.1420	.0435	.0406	.0014	.2731	0.19348-02
.5721	.2158	.1295	.0413	.0396	.0014	.3169	0.18418-02
.5767	.2268	.1179	.0393	.0379	.0014	.3597	0.17558-02
.5782	.2411	.1056	.0361	.0376	.0014	.3992	0.17538-02
.5794	.2423	.1045	.0362	.0377	.0	.4078	0.16958-02
.5818	.2190	.1278	.0359	.0359	.0	.4561	0.15978-02

RUN NUM= 70 11 POINTS

WEIGHT OF CARBON 2.3977 G FLOW RATE 25.0 ML/MIN

NO CATALYST

TEMP= 800.00 C PH2O= 0.42 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4870	0.0020	0.0150	0.0020	0.0020	370.0	4.0
0.3850	0.0820	0.0500	0.0140	0.0020	1470.0	24.0
0.2850	0.1460	0.0800	0.0240	0.0020	1540.0	44.0
0.2750	0.1460	0.0800	0.0310	0.0020	1620.0	64.0
0.2600	0.1500	0.0790	0.0350	0.0020	1680.0	84.0
0.2630	0.1530	0.0710	0.0380	0.0020	1660.0	104.0
0.2790	0.1530	0.0670	0.0380	0.0020	1630.0	124.0
0.2860	0.1490	0.0630	0.0380	0.0020	1570.0	144.0
0.2910	0.1380	0.0600	0.0370	0.0010	1510.0	164.0
0.3030	0.1340	0.0540	0.0370	0.0010	1460.0	184.0
0.3000	0.1360	0.0470	0.0420	0.0010	1440.0	204.0

TOTAL VOL					
8898.2	4086.2	1930.3	983.6	51.7	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.5851	.2256	.1210	.0342	.0342	.0	.0031	0.13528-02
.7618	.2054	.0031	.0235	.0031	.0031	.0438	0.27158-02
.6128	.1517	.1305	.0796	.0223	.0032	.1117	0.36138-02
.5077	.0434	.2601	.1425	.0428	.0036	.1883	0.39708-02
.5011	.0270	.2660	.1458	.0565	.0036	.2705	0.40088-02
.4931	.0043	.2845	.1479	.0664	.0038	.3486	0.37608-02
.4974	.0033	.2894	.1343	.0719	.0038	.4209	0.34968-02
.5097	.0152	.2795	.1224	.0694	.0037	.4891	0.32478-02
.5141	.0330	.2678	.1132	.0693	.0036	.5536	0.29478-02
.5183	.0614	.2458	.1069	.0659	.0018	.6075	0.27868-02
.5277	.0787	.2334	.0940	.0644	.0017	.6626	0.27108-02

RUN NUM= 71 14 POINTS

WEIGHT OF CARBON 2.3557 G FLOW RATE 37.2 ML/MIN

10%K2CO3

TEMP= 670.00 C PH2O= 0.48 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4240	0.0570	0.0140	0.0150	0.0	520.0	4.0
0.3480	0.1080	0.0260	0.0310	0.0	1230.0	24.0
0.3310	0.1160	0.0260	0.0420	0.0	1250.0	44.0
0.3250	0.1250	0.0250	0.0500	0.0	1270.0	64.0
0.3200	0.1270	0.0250	0.0520	0.0	1270.0	84.0
0.3180	0.1270	0.0250	0.0510	0.0	1260.0	104.0
0.3160	0.1290	0.0240	0.0530	0.0	1260.0	124.0
0.3160	0.1300	0.0240	0.0530	0.0	1260.0	144.0
0.3170	0.1310	0.0240	0.0530	0.0	1260.0	164.0
0.3180	0.1290	0.0240	0.0510	0.0	1250.0	184.0
0.3280	0.1280	0.0240	0.0510	0.0	1250.0	204.0
0.3240	0.1270	0.0240	0.0520	0.0	1250.0	224.0
0.3310	0.1240	0.0240	0.0500	0.0	1610.0	250.0
0.3380	0.1220	0.0240	0.0490	0.0	1240.0	270.0

TOTAL VOL					
10781.6	4027.6	794.4	1576.4	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.0	.0	.0	.0	.0	.0	.0067	0.1393E-02
.7079	.1485	.0952	.0234	.0250	.0	.0378	0.1715E-02
.4865	.2828	.1510	.0363	.0433	.0	.0753	0.1970E-02
.4692	.2701	.1644	.0369	.0595	.0	.1166	0.2092E-02
.4593	.2580	.1767	.0353	.0707	.0	.1590	0.2106E-02
.4546	.2557	.1804	.0355	.0739	.0	.2008	0.2102E-02
.4532	.2575	.1810	.0356	.0727	.0	.2431	0.2111E-02
.4506	.2556	.1840	.0342	.0756	.0	.2853	0.2105E-02
.4503	.2548	.1852	.0342	.0755	.0	.3273	0.2072E-02
.4503	.2543	.1861	.0341	.0753	.0	.3682	0.2025E-02
.4519	.2582	.1833	.0341	.0725	.0	.4083	0.2029E-02
.4562	.2615	.1760	.0334	.0709	.0	.4493	0.2015E-02
.4540	.2616	.1780	.0336	.0729	.0	.5005	0.1946E-02
.4579	.2681	.1716	.0332	.0692	.0	.5391	0.1914E-02

RUN NUM= 72 12 POINTS

WEIGHT OF CARBON 2.3444 G FLOW RATE 38.5 ML/MIN

10%K2CO3

TEMP= 700.00 C PH2O= 0.49 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3890	0.0460	0.0280	0.0190	0.0010	610.0	4.0
0.3070	0.1210	0.0520	0.0330	0.0010	1510.0	24.0
0.2890	0.1550	0.0500	0.0430	0.0010	1540.0	44.0
0.2720	0.1560	0.0490	0.0490	0.0010	2250.0	74.0
0.2650	0.1520	0.0480	0.0500	0.0010	1490.0	94.0
0.2650	0.1510	0.0470	0.0520	0.0010	1490.0	114.0
0.2650	0.1510	0.0440	0.0530	0.0010	1490.0	134.0
0.2680	0.1490	0.0420	0.0540	0.0010	1490.0	154.0
0.2730	0.1480	0.0380	0.0560	0.0	1480.0	174.0
0.2790	0.1470	0.0360	0.0570	0.0	1480.0	194.0
0.2860	0.1480	0.0320	0.0570	0.0	1460.0	214.0
0.2950	0.1480	0.0270	0.0590	0.0	1400.0	234.0

TOTAL VOL					
9615.5	4917.2	1436.7	1696.7	22.9	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.4625	.2707	.1669	.0328	.0670	.0	.0139	0.2793E-03
.6985	.1328	.0826	.0503	.0341	.0018	.0716	0.2980E-02
.4701	.2130	.1853	.0796	.0505	.0015	.1331	0.3182E-02
.4446	.1723	.2385	.0769	.0662	.0015	.2297	0.3248E-02
.4253	.1760	.2439	.0766	.0766	.0016	.2950	0.3283E-02
.4215	.1792	.2418	.0764	.0795	.0016	.3610	0.3272E-02
.4209	.1805	.2398	.0746	.0826	.0016	.4259	0.3229E-02
.4229	.1797	.2410	.0702	.0846	.0016	.4901	0.3150E-02
.4263	.1823	.2370	.0668	.0859	.0016	.5519	0.3056E-02
.4300	.1889	.2331	.0598	.0982	.0	.6125	0.2934E-02
.4346	.1916	.2290	.0561	.0888	.0	.6692	0.2720E-02
.4394	.1964	.2274	.0492	.0876	.0	.7212	0.2481E-02

RUN NUM= 73 12 POINTS

WEIGHT OF CARBON 2.3465 G FLOW RATE 31.0 ML/MIN

10%K2CO3

TEMP= 730.00 C PH2O= 0.43 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4070	0.0400	0.0320	0.0030	0.0010	610.0	4.0
0.3340	0.1080	0.0650	0.0120	0.0010	1010.0	24.0
0.3210	0.1320	0.0680	0.0270	0.0010	1590.0	44.0
0.3100	0.1420	0.0710	0.0370	0.0010	1590.0	64.0
0.3000	0.1500	0.0730	0.0410	0.0010	1600.0	84.0
0.2920	0.1480	0.0710	0.0410	0.0010	1590.0	104.0
0.2930	0.1460	0.0710	0.0390	0.0010	1590.0	124.0
0.2930	0.1440	0.0690	0.0380	0.0010	1610.0	144.0
0.3030	0.1390	0.0660	0.0340	0.0010	1540.0	164.0
0.3100	0.1350	0.0640	0.0290	0.0	1500.0	184.0
0.3220	0.1300	0.0600	0.0320	0.0	1450.0	204.0
0.3210	0.1240	0.0530	0.0360	0.0	1400.0	224.0

TOTAL VOL					
9977.5	4242.4	2084.3	1031.9	23.9	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.4390	.2127	.2203	.0402	.0878	.0	.0104	0.1704E-02
.7548	.1042	.0742	.0593	.0056	.0019	.0552	0.2694E-01
.5091	.2074	.1646	.0991	.0193	.0015	.1183	0.3329E-02
.5092	.1292	.2094	.1079	.0428	.0016	.1984	0.3611E-01
.4865	.1195	.2229	.1114	.0581	.0016	.2628	0.3713E-02
.4747	.1059	.2374	.1155	.0649	.0016	.3369	0.3686E-02
.4720	.1061	.2392	.1148	.0663	.0016	.4102	0.3652E-02
.4753	.1078	.2368	.1152	.0633	.0016	.4830	0.3456E-02
.4812	.1049	.2365	.1133	.0624	.0016	.5484	0.3115E-02
.4882	.1251	.2240	.1063	.0548	.0016	.6076	0.2840E-02
.4957	.1397	.2159	.1023	.0464	.0	.6636	0.2731E-02
.4980	.1587	.2010	.0928	.0495	.0	.7169	0.2596E-02

RUN NUM= 74 11 POINTS

WEIGHT OF CARBON 2.3451 G FLOW RATE 37.3 ML/MIN

10%K2CO3

TEMP= 760.00 C PH2O= 0.50 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3810	0.0610	0.0510	0.0110	0.0020	590.0	4.0
0.2830	0.1380	0.0860	0.0150	0.0020	1610.0	24.0
0.2650	0.1480	0.0960	0.0200	0.0020	1700.0	44.0
0.2510	0.1560	0.1010	0.0240	0.0020	1690.0	64.0
0.2400	0.1590	0.1050	0.0250	0.0020	1650.0	84.0
0.2330	0.1620	0.1030	0.0300	0.0020	1610.0	104.0
0.2320	0.1640	0.0990	0.0340	0.0010	1610.0	124.0
0.2320	0.1650	0.0920	0.0380	0.0010	1610.0	144.0
0.2350	0.1680	0.0850	0.0400	0.0010	2420.0	174.0
0.2360	0.1680	0.0810	0.0420	0.0010	1620.0	194.0
0.2390	0.1680	0.0740	0.0420	0.0	1590.0	214.0

TOTAL VOL					
8348.0	5244.9	3033.5	1026.4	47.2	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.4965	.1740	.1918	.0820	.0557	.0	.0170	0.32695E-02
.6696	.1107	.1072	.0896	.0193	.0035	.0893	0.39655E-02
.4529	.1613	.2209	.1376	.0240	.0032	.1756	0.44532E-02
.4330	.1324	.2418	.1569	.0327	.0033	.2675	0.46380E-02
.4117	.1242	.2559	.1657	.0394	.0033	.3612	0.46895E-02
.3947	.1268	.2615	.1727	.0411	.0033	.4549	0.46677E-02
.3822	.1305	.2658	.1690	.0492	.0033	.5478	0.46068E-02
.3806	.1305	.2690	.1624	.0558	.0016	.6391	0.44935E-02
.3831	.1282	.2724	.1519	.0627	.0017	.7298	0.43635E-02
.3893	.1236	.2783	.1408	.0693	.0017	.8577	0.41975E-02
.3926	.1217	.2795	.1347	.0699	.0017	.9382	0.38602E-02

RUN NUM= 75 15 POINTS

WEIGHT OF CARBON . 2.3409 G FLOW RATE 37.3 ML/MIN

10%K2CO3

TEMP= 640.00 C PH2O= 0.49 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4230	0.0360	0.0080	0.0230	0.0	490.0	4.0
0.3480	0.1050	0.0160	0.0450	0.0	1130.0	24.0
0.3320	0.1200	0.0150	0.0510	0.0	1180.0	44.0
0.3240	0.1270	0.0120	0.0540	0.0	1210.0	64.0
0.3220	0.1280	0.0120	0.0540	0.0	1190.0	84.0
0.3290	0.1200	0.0120	0.0530	0.0	1170.0	104.0
0.3360	0.1170	0.0120	0.0500	0.0010	1150.0	124.0
0.3440	0.1120	0.0120	0.0460	0.0	1140.0	144.0
0.3490	0.1080	0.0120	0.0470	0.0	1130.0	164.0
0.3590	0.1030	0.0120	0.0470	0.0	1130.0	184.0
0.3560	0.1000	0.0120	0.0470	0.0	1120.0	204.0
0.3580	0.0980	0.0120	0.0490	0.0	1120.0	224.0
0.3600	0.0940	0.0120	0.0490	0.0	1110.0	244.0
0.3570	0.0940	0.0110	0.0480	0.0	1100.0	264.0
0.3480	0.0940	0.0100	0.0480	0.0	1100.0	284.0

TOTAL VOL

11110.1	3416.8	389.8	1551.1	2.2	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.3981	.1289	.2798	.1233	.0700	.0	.0071	0.1442E-02
.7013	.1877	.0597	.0133	.0381	.0	.0378	0.1627E-02
.4650	.3131	.1403	.0214	.0601	.0	.0722	0.1744E-02
.4576	.2860	.1654	.0207	.0703	.0	.1078	0.1798E-02
.4571	.2705	.1792	.0169	.0762	.0	.1424	0.1717E-02
.4526	.2747	.1799	.0169	.0759	.0	.1762	0.1650E-02
.4558	.2878	.1663	.0166	.0734	.0	.2094	0.1534E-02
.4592	.2948	.1599	.0164	.0683	.0014	.2378	0.1479E-02
.4659	.3039	.1517	.0163	.0623	.0	.2674	0.1471E-02
.4662	.3108	.1443	.0160	.0628	.0	.2967	0.1466E-02
.4712	.3162	.1352	.0157	.0617	.0	.3260	0.1493E-02
.4696	.3206	.1319	.0158	.0620	.0	.3563	0.1504E-02
.4690	.3227	.1284	.0157	.0642	.0	.3864	0.1480E-02
.4693	.3287	.1225	.0156	.0639	.0	.4155	0.1454E-02
.4686	.3306	.1234	.0144	.0630	.0	.4447	0.1462E-02

RUN NUM= 77 13 POINTS

WEIGHT OF CARBON 2.3458 G FLOW RATE 24.8 ML/MIN

10%K2CO3

TEMP= 700.00 C PH2O= 0.33 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4390	0.0390	0.0200	0.0070	0.0	690.0	4.0
0.4100	0.0690	0.0420	0.0130	0.0	1440.0	24.0
0.4010	0.0730	0.0430	0.0140	0.0	1460.0	44.0
0.3900	0.0770	0.0460	0.0160	0.0	1440.0	64.0
0.3800	0.0810	0.0460	0.0180	0.0	1470.0	84.0
0.3700	0.0860	0.0480	0.0190	0.0	1520.0	104.0
0.3600	0.0920	0.0470	0.0240	0.0	1550.0	124.0
0.3630	0.0960	0.0480	0.0280	0.0	1550.0	144.0
0.3590	0.1020	0.0480	0.0290	0.0	1550.0	164.0
0.3580	0.1060	0.0490	0.0310	0.0	1550.0	184.0
0.3570	0.1110	0.0480	0.0320	0.0	1530.0	204.0
0.3550	0.1120	0.0480	0.0320	0.0	1540.0	224.0
0.3550	0.1120	0.0470	0.0290	0.0	1450.0	244.0

TOTAL VOL					
13126.0	3197.4	1603.3	813.3	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.4671	.3289	.1262	.0134	.0644	.0	.0094	0.1646E-02
.8151	.0624	.0724	.0371	.0130	.0	.0423	0.1742E-02
.6318	.1771	.1063	.0647	.0200	.0	.0701	0.1651E-02
.6281	.1682	.1143	.0674	.0219	.0	.1166	0.1967E-02
.6149	.1659	.1214	.0725	.0252	.0	.1576	0.2139E-02
.6118	.1548	.1304	.0741	.0290	.0	.2020	0.2313E-02
.6089	.1393	.1415	.0790	.0313	.0	.2501	0.2482E-02
.6016	.1259	.1538	.0785	.0401	.0	.3004	0.2624E-02
.5949	.1232	.1573	.0787	.0459	.0	.3510	0.2[illegible]E-02
.5903	.1154	.1677	.0789	.0477	.0	.4031	0.2577E-02
.5849	.1112	.1732	.0801	.0506	.0	.4541	0.2561E-02
.5808	.1084	.1806	.0781	.0521	.0	.5055	0.2445E-02
.5808	.1050	.1833	.0785	.0524	.0	.5519	0.2190E-02

RUN NUM= 78 12 POINTS

WEIGHT OF CARBON 2.3522 G FLOW RATE 24.8 ML/MIN

10%K2CO3

TEMP= 730.00 C PH2O= 0.33 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4420	0.0360	0.0260	0.0040	0.0020	640.0	4.0
0.3760	0.0890	0.0630	0.0040	0.0020	1620.0	24.0
0.3380	0.1110	0.0730	0.0080	0.0010	1630.0	44.0
0.3370	0.1210	0.0730	0.0190	0.0010	1700.0	64.0
0.3340	0.1210	0.0710	0.0220	0.0010	1740.0	84.0
0.3320	0.1210	0.0710	0.0230	0.0010	1750.0	104.0
0.3280	0.1210	0.0700	0.0220	0.0010	1740.0	124.0
0.3220	0.1230	0.0660	0.0230	0.0010	1750.0	144.0
0.3120	0.1260	0.0640	0.0200	0.0010	1740.0	164.0
0.3040	0.1300	0.0620	0.0340	0.0	1750.0	184.0
0.3190	0.1330	0.0630	0.0360	0.0	1760.0	204.0
0.3210	0.1330	0.0590	0.0390	0.0	2610.0	234.0

TOTAL VOL					
12564.4	4487.3	2460.9	886.5	30.9	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.5756	.1196	.1816	.0762	.0470	.0	.0091	0.2142E-02
.8050	.0711	.0656	.0474	.0073	.0036	.0568	0.2629E-02
.6220	.1166	.1472	.1042	.0066	.0033	.1141	0.3067E-02
.5832	.0838	.1815	.1260	.0138	.0017	.1795	0.3338E-02
.5724	.0641	.2055	.1240	.0323	.0017	.2473	0.3424E-02
.5734	.0575	.2077	.1219	.0378	.0017	.3164	0.3407E-02
.5721	.0557	.2085	.1223	.0396	.0017	.3844	0.3376E-02
.5719	.0549	.2110	.1221	.0384	.0017	.4515	0.3317E-02
.5733	.0474	.2190	.1175	.0410	.0018	.5197	0.3569E-02
.5654	.0413	.2263	.1160	.0471	.0018	.5919	0.3601E-02
.5525	.0367	.2363	.1127	.0618	.0	.6639	0.3584E-02
.5564	.0389	.2320	.1099	.0628	.0	.7694	0.3463E-02

RUN NUM= 79 11 POINTS

WEIGHT OF CARBON 2.3380 G FLOW RATE 25.0 ML/MIN

10%K2CO3

TEMP= 760.00 C PH2O= 0.33 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4290	0.0530	0.0420	0.0080	0.0020	700.0	4.0
0.3400	0.1150	0.0860	0.0110	0.0020	1980.0	24.0
0.3220	0.1320	0.0940	0.0170	0.0020	1950.0	44.0
0.3120	0.1340	0.0940	0.0180	0.0020	1900.0	64.0
0.3100	0.1340	0.0910	0.0160	0.0020	1650.0	84.0
0.3120	0.1330	0.0900	0.0150	0.0020	1770.0	104.0
0.3160	0.1290	0.0860	0.0150	0.0010	1740.0	124.0
0.3240	0.1150	0.0800	0.0150	0.0010	1690.0	144.0
0.3280	0.1080	0.0750	0.0180	0.0010	1700.0	164.0
0.3310	0.1120	0.0740	0.0210	0.0010	1700.0	184.0
0.3370	0.1180	0.0730	0.0220	0.0010	1710.0	204.0

TOTAL VOL					
11153.4	4100.9	2824.9	558.4	52.3	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.5570	.0423	.2308	.1024	.0677	.0	.0156	0.3854E-02
.7754	.0349	.0958	.0759	.0145	.0036	.0967	0.4253E-02
.5914	.0364	.2000	.1496	.0191	.0035	.1857	0.4442E-02
.5587	.0163	.2290	.1631	.0295	.0035	.2744	0.4304E-02
.5480	.0165	.2353	.1651	.0316	.0035	.3579	0.4054E-02
.5492	.0203	.2374	.1612	.0283	.0035	.4365	0.3827E-02
.5465	.0332	.2330	.1576	.0263	.0035	.5110	0.3599E-02
.5516	.0469	.2234	.1501	.0262	.0017	.5805	0.3464E-02
.5622	.0710	.1996	.1388	.0260	.0017	.6496	0.3462E-02
.5696	.0797	.1875	.1302	.0313	.0017	.7190	0.3441E-02
.5672	.0763	.1919	.1268	.0360	.0017	.7872	0.3385E-02

RUN NUM= 80 14 POINTS

WEIGHT OF CARBON 2.3423 G FLOW RATE 25.5 ML/MIN

10%K2CO3

TEMP= 650.00 C PH2O= 0.34 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4520	0.0170	0.0120	0.0020	0.0	660.0	4.0
0.4110	0.0520	0.0180	0.0160	0.0	1380.0	24.0
0.3990	0.0820	0.0180	0.0300	0.0	1420.0	44.0
0.3840	0.0920	0.0180	0.0350	0.0	1420.0	64.0
0.3770	0.0940	0.0170	0.0390	0.0	1440.0	84.0
0.3810	0.0890	0.0170	0.0310	0.0	1440.0	104.0
0.3940	0.0930	0.0170	0.0300	0.0	1440.0	124.0
0.3960	0.0800	0.0170	0.0290	0.0	1440.0	144.0
0.3980	0.0810	0.0170	0.0290	0.0	1420.0	164.0
0.3990	0.0810	0.0160	0.0310	0.0	1410.0	184.0
0.4000	0.0820	0.0150	0.0310	0.0	1410.0	204.0
0.3980	0.0820	0.0150	0.0290	0.0	1400.0	224.0
0.3940	0.0810	0.0150	0.0310	0.0	1400.0	244.0
0.4020	0.0750	0.0150	0.0290	0.0	1370.0	264.0

TOTAL VOL					
14516.5	2876.5	599.0	1058.0	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.5691	.0694	.1993	.1233	.0372	.0017	.0044	0.8827E-03
.8360	.1066	.0314	.0222	.0037	.0	.0260	0.1277E-02
.6538	.2094	.0927	.0286	.0255	.0	.0554	0.1550E-02
.6264	.1695	.1287	.0263	.0471	.0	.0880	0.1688E-02
.6124	.1563	.1467	.0267	.0558	.0	.1230	0.1636E-02
.6084	.1495	.1517	.0274	.0629	.0	.1535	0.1501E-02
.6221	.1542	.1453	.0278	.0506	.0	.1830	0.1464E-02
.6288	.1637	.1325	.0271	.0479	.0	.2121	0.1437E-02
.6317	.1673	.1276	.0271	.0463	.0	.2405	0.1430E-02
.6292	.1700	.1281	.0269	.0458	.0	.2693	0.1421E-02
.6268	.1722	.1272	.0251	.0487	.0	.2974	0.1375E-02
.6280	.1711	.1287	.0235	.0487	.0	.3243	0.1379E-02
.6289	.1720	.1296	.0237	.0458	.0	.3525	0.1368E-02
.6256	.1727	.1286	.0238	.0492	.0	.3790	0.1278E-02

RUN NUM= 81 14 POINTS

WEIGHT OF CARBON 2.3587 G FLOW RATE 25.5 ML/MIN

10%NA2CO3

TEMP= 650.00 C PH2O= 0.34 ATM

N2	H2	CO	CO2	CH4	VOL, ML	TIME, MIN
0.4700	0.0330	0.0050	0.0070	0.0	590.0	4.0
0.4360	0.0550	0.0070	0.0150	0.0	1270.0	24.0
0.4170	0.0630	0.0110	0.0220	0.0	1320.0	44.0
0.4010	0.0760	0.0130	0.0290	0.0	1410.0	64.0
0.3910	0.0790	0.0140	0.0320	0.0	1400.0	84.0
0.3910	0.0800	0.0140	0.0320	0.0	1400.0	104.0
0.3970	0.0790	0.0130	0.0320	0.0	1380.0	124.0
0.4040	0.0730	0.0110	0.0300	0.0	1390.0	144.0
0.4040	0.0740	0.0110	0.0300	0.0	1370.0	164.0
0.4040	0.0750	0.0120	0.0290	0.0	1370.0	184.0
0.4010	0.0760	0.0120	0.0300	0.0	1410.0	204.0
0.3920	0.0760	0.0100	0.0300	0.0	1810.0	230.0
0.4000	0.0760	0.0100	0.0330	0.0	2160.0	260.0
0.4180	0.0740	0.0080	0.0290	0.0	2140.0	294.0
TOTAL VOL						
16010.2	2862.2	429.5	1118.1	0.0	ML	

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.2242	.4431	.1880	.1109	.0325	.0012	.0031	0.8656E-03
.8231	.0981	.0578	.0068	.0123	.0	.0156	0.7414E-03
.6566	.2274	.0628	.0105	.0226	.0	.0348	0.1113E-02
.6433	.2086	.0972	.0170	.0339	.0	.0607	0.1350E-02
.6358	.1771	.1205	.0206	.0460	.0	.0891	0.1479E-02
.6260	.1755	.1249	.0224	.0512	.0	.1174	0.1388E-02
.6253	.1732	.1279	.0224	.0512	.0	.1456	0.1331E-02
.6256	.1789	.1245	.0205	.0504	.0	.1734	0.1330E-02
.6362	.1843	.1150	.0173	.0472	.0	.1990	0.1224E-02
.6330	.1868	.1160	.0172	.0470	.0	.2236	0.1178E-02
.6327	.1857	.1174	.0188	.0454	.0	.2485	0.1274E-02
.6358	.1771	.1205	.0190	.0476	.0	.2768	0.1451E-02
.6342	.1781	.1230	.0162	.0485	.0	.3075	0.1568E-02
.6259	.1879	.1189	.0156	.0516	.0	.3515	0.2584E-03

RUN NUM= 82 11 POINTS

WEIGHT OF CARBON 2.3431 G FLOW RATE 25.5 ML/MIN

10%NA2CO3

TEMP= 760.00 C PH2O= 0.34 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.4640	0.0260	0.0330	0.0050	0.0020	710.0	4.0
0.4160	0.0750	0.0690	0.0120	0.0020	1580.0	24.0
0.3480	0.1100	0.0860	0.0140	0.0020	1550.0	44.0
0.3280	0.1120	0.0880	0.0150	0.0020	1520.0	64.0
0.3400	0.1100	0.0810	0.0150	0.0020	1500.0	84.0
0.3460	0.1100	0.0800	0.0140	0.0010	1490.0	104.0
0.3450	0.1090	0.0790	0.0140	0.0010	1490.0	124.0
0.3740	0.1140	0.0780	0.0140	0.0010	1480.0	144.0
0.3930	0.1180	0.0800	0.0150	0.0010	1520.0	164.0
0.3860	0.1220	0.0850	0.0150	0.0010	1530.0	184.0
0.3960	0.1230	0.0830	0.0150	0.0010	1560.0	204.0

TOTAL VOL

10355.2	2955.9	2192.5	386.1	40.3	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.6365	.1945	.1127	.0122	.0442	.0	.0123	0.23045-02
.8054	.0801	.0451	.0573	.0087	.0035	.0645	0.29207-02
.6115	.1562	.1102	.1014	.0176	.0029	.1290	0.32488-02
.5522	.1115	.1745	.1365	.0222	.0032	.1960	0.31071-02
.5361	.1093	.1830	.1438	.0245	.0033	.2573	0.30018-02
.5481	.1166	.1773	.1306	.0242	.0032	.3161	0.29287-02
.5513	.1220	.1753	.1275	.0223	.0016	.3745	0.29158-02
.5524	.1226	.1745	.1265	.0224	.0016	.4287	0.27267-02
.5622	.1266	.1714	.1173	.0210	.0015	.4936	0.28214-02
.5690	.1211	.1708	.1158	.0217	.0014	.5416	0.29704-02
.5610	.1148	.1773	.1235	.0218	.0015	.5988	0.29359-02

RUN NUM=105 13 POINTS

WEIGHT OF CARBON 2.3849 G FLOW RATE 37.0 ML/MIN

10%NA2CO3

TEMP= 700.00 C PH2O= 0.48 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3160	0.0600	0.0250	0.0140	0.0010	540.0	4.0
0.2690	0.1050	0.0460	0.0260	0.0010	1070.0	24.0
0.2660	0.1160	0.0440	0.0310	0.0010	1190.0	44.0
0.2540	0.1190	0.0410	0.0370	0.0010	1200.0	64.0
0.2600	0.1170	0.0390	0.0370	0.0010	1190.0	84.0
0.2770	0.1130	0.0400	0.0340	0.0010	1180.0	104.0
0.2890	0.1080	0.0400	0.0330	0.0010	1160.0	124.0
0.2900	0.1040	0.0400	0.0320	0.0010	1150.0	144.0
0.2860	0.1000	0.0400	0.0310	0.0010	1120.0	164.0
0.2800	0.0990	0.0410	0.0310	0.0010	1100.0	184.0
0.2800	0.0970	0.0410	0.0320	0.0010	1070.0	204.0
0.2860	0.0950	0.0390	0.0280	0.0010	1040.0	224.0
0.2980	0.0920	0.0350	0.0280	0.0010	1440.0	254.0

TOTAL VOL					
8862.6	3289.5	1262.7	983.4	31.8	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.5698	.1108	.1770	.1194	.0216	.0014	.0117	0.1835E-02
.6752	.1111	.1282	.0534	.0299	.0021	.0509	0.2090E-02
.4144	.3114	.1618	.0709	.0401	.0015	.0953	0.2207E-02
.4257	.2670	.1857	.0704	.0496	.0016	.1424	0.2311E-02
.4166	.2587	.1952	.0672	.0607	.0016	.1877	0.2262E-02
.4212	.2646	.1895	.0632	.0599	.0016	.2305	0.2092E-02
.4317	.2753	.1761	.0623	.0530	.0016	.2714	0.2033E-02
.4369	.2879	.1633	.0605	.0499	.0015	.3118	0.1991E-02
.4384	.2940	.1572	.0605	.0484	.0015	.3513	0.1984E-02
.4342	.3046	.1518	.0607	.0471	.0015	.3912	0.1984E-02
.4274	.3100	.1511	.0626	.0473	.0015	.4307	0.1870E-02
.4217	.3207	.1461	.0618	.0482	.0015	.4661	0.1669E-02
.4259	.3313	.1415	.0581	.0417	.0015	.5117	0.1371E-02

RUN NUM= 83 13 POINTS

WEIGHT OF CARBON 2.3430 G FLOW RATE 49.7 ML/MIN

10%K2CO3

TEMP= 670.00 C PH2O= 0.61 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3960	0.0360	0.0230	0.0010	0.0020	530.0	4.0
0.2980	0.0950	0.0260	0.0260	0.0010	1240.0	24.0
0.2870	0.1390	0.0280	0.0490	0.0010	1190.0	44.0
0.2870	0.1360	0.0280	0.0530	0.0010	1190.0	64.0
0.2940	0.1310	0.0290	0.0520	0.0010	1180.0	84.0
0.2940	0.1270	0.0290	0.0470	0.0010	1200.0	104.0
0.2990	0.1230	0.0290	0.0430	0.0	1200.0	124.0
0.3010	0.1200	0.0270	0.0450	0.0	1200.0	144.0
0.3020	0.1180	0.0250	0.0470	0.0	1200.0	164.0
0.3090	0.1170	0.0260	0.0460	0.0	1210.0	184.0
0.3090	0.1180	0.0260	0.0470	0.0	1200.0	204.0
0.3000	0.1240	0.0250	0.0480	0.0	1190.0	224.0
0.2980	0.1310	0.0230	0.0500	0.0	1160.0	244.0

TOTAL VOL
9125.2 3610.0 801.5 1338.7 14.5 ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.6282	.1859	.1172	.0234	.0453	.0	.0000	0.1[illegible]E-02
.6714	.2235	.0610	.0390	.0017	.0034	.0406	0.1[illegible]E-02
.4218	.3687	.1345	.0368	.0368	.0014	.0827	0.2[illegible]E-02
.3661	.3571	.1773	.0357	.0625	.0013	.1269	0.2[illegible]E-02
.3638	.3598	.1724	.0355	.0672	.0013	.1705	0.2151E-02
.3670	.3671	.1635	.0350	.0662	.0012	.2129	0.2[illegible]E-02
.3762	.3628	.1625	.0371	.0601	.0013	.2529	0.2[illegible]E-02
.3832	.3668	.1577	.0372	.0551	.0	.2930	0.2[illegible]E-02
.3852	.3691	.1536	.0346	.0576	.0	.3331	0.2[illegible]E-02
.3864	.3705	.1510	.0320	.0601	.0	.3741	0.2[illegible]E-02
.3893	.3701	.1474	.0328	.0605	.0	.4141	0.2[illegible]E-02
.3881	.3720	.1482	.0327	.0590	.0	.4541	0.1[illegible]E-02
.3806	.3694	.1573	.0317	.0609	.0	.4927	0.1[illegible]E-02

RUN NUM= 84 14 POINTS

WEIGHT OF CARBON 2.3430 G FLOW RATE 49.7 ML/MIN

10%K2CO3

TEMP= 640.00 C PH2O= 0.61 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3040	0.0550	0.0060	0.0010	0.0	400.0	4.0
0.3120	0.0850	0.0130	0.0210	0.0	1070.0	24.0
0.3260	0.0960	0.0140	0.0420	0.0	1050.0	44.0
0.3330	0.0970	0.0140	0.0420	0.0	1080.0	64.0
0.3280	0.0970	0.0140	0.0420	0.0	1060.0	84.0
0.3260	0.0970	0.0140	0.0430	0.0	1040.0	104.0
0.3350	0.0910	0.0130	0.0410	0.0	1590.0	134.0
0.3370	0.0910	0.0120	0.0400	0.0	1020.0	154.0
0.3420	0.0910	0.0120	0.0400	0.0	1010.0	174.0
0.3470	0.0910	0.0120	0.0390	0.0	990.0	194.0
0.3450	0.0930	0.0120	0.0410	0.0	1010.0	214.0
0.3430	0.0940	0.0110	0.0430	0.0	1030.0	234.0
0.3370	0.0930	0.0100	0.0420	0.0	1020.0	254.0
0.3400	0.0920	0.0090	0.0440	0.0	1480.0	284.0
TOTAL VOL						
10412.5	2856.1	376.1	1205.3	0.0	ML	

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.3720	.3734	.1635	.0287	.0624	.0	.0017	0.7443E-03
.6168	.2575	.1116	.0122	.0020	.0	.0210	0.1186E-02
.4180	.4226	.1139	.0174	.0281	.0	.0492	0.1414E-02
.3906	.4272	.1150	.0168	.0503	.0	.0776	0.1417E-02
.3982	.4189	.1160	.0167	.0502	.0	.1058	0.1411E-02
.3928	.4240	.1162	.0168	.0503	.0	.1341	0.1391E-02
.3873	.4298	.1152	.0166	.0511	.0	.1750	0.1303E-02
.3992	.4280	.1084	.0155	.0489	.0	.2002	0.1251E-02
.3933	.4398	.1062	.0140	.0467	.0	.2250	0.1204E-02
.3925	.4434	.1044	.0138	.0459	.0	.2486	0.1213E-02
.3903	.4499	.1024	.0135	.0439	.0	.2735	0.1271E-02
.3915	.4428	.1055	.0136	.0465	.0	.2944	0.1277E-02
.3939	.4362	.1079	.0126	.0494	.0	.3246	0.1248E-02
.3924	.4367	.1083	.0116	.0489	.0	.3616	0.1217E-02

RUN NUM= 85 12 POINTS

WEIGHT OF CARBON 2.3465 G FLOW RATE 49.0 ML/MIN

10%K2CO3

TEMP= 700.00 C PH2O= 0.61 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2690	0.0500	0.0260	0.0030	0.0030	600.0	4.0
0.2640	0.1090	0.0480	0.0220	0.0020	1300.0	24.0
0.2620	0.1190	0.0460	0.0400	0.0020	1320.0	44.0
0.2600	0.1250	0.0460	0.0420	0.0020	1350.0	64.0
0.2570	0.1290	0.0480	0.0430	0.0020	1380.0	84.0
0.2560	0.1300	0.0500	0.0420	0.0020	1400.0	104.0
0.2540	0.1300	0.0490	0.0400	0.0020	1370.0	124.0
0.2550	0.1310	0.0470	0.0390	0.0010	1370.0	144.0
0.2570	0.1320	0.0430	0.0450	0.0010	1320.0	164.0
0.2600	0.1350	0.0390	0.0480	0.0010	1330.0	184.0
0.2630	0.1380	0.0360	0.0490	0.0010	1250.0	204.0
0.2650	0.1400	0.0350	0.0450	0.0010	1210.0	224.0

TOTAL VOL

8431.5	4041.0	1413.1	1271.2	53.2	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.3857	.4499	.1044	.0102	.0499	.0	.0125	0.21[illegible]E-02
.6566	.1432	.1221	.0635	.0079	.0073	.0605	0.20147E-02
.3955	.3333	.1633	.0719	.0330	.0030	.1171	0.26[illegible]E-02
.3774	.3244	.1714	.0663	.0576	.0029	.1755	0.30[illegible]E-02
.3764	.3124	.1809	.0666	.0608	.0029	.2371	0.31[illegible]E-02
.3759	.2994	.1887	.0702	.0629	.0029	.2997	0.30[illegible]E-02
.3754	.2962	.1906	.0733	.0616	.0029	.3596	0.29[illegible]E-02
.3731	.3023	.1910	.0720	.0588	.0029	.4171	0.28[illegible]E-02
.3759	.3027	.1931	.0693	.0575	.0015	.4732	0.27[illegible]E-02
.3677	.3160	.1889	.0615	.0644	.0014	.5285	0.26[illegible]E-02
.3704	.3119	.1923	.0556	.0684	.0014	.5799	0.24[illegible]E-02
.3609	.3318	.1894	.0494	.0672	.0014	.6250	0.21[illegible]E-02

RUN NUM= 86 11 POINTS

WEIGHT OF CARBON 2.3494 G FLOW RATE 49.0 ML/MIN

.10%K2CO3

TEMP= 730.00 C PH2O= 0.61 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2560	0.0800	0.0360	0.0200	0.0020	800.0	4.0
0.2230	0.1850	0.0780	0.0330	0.0020	1560.0	24.0
0.2230	0.1710	0.0830	0.0400	0.0020	1560.0	44.0
0.2230	0.1680	0.0800	0.0430	0.0020	1510.0	64.0
0.2170	0.1660	0.0780	0.0460	0.0020	1480.0	84.0
0.2090	0.1660	0.0740	0.0460	0.0020	1470.0	104.0
0.2070	0.1660	0.0700	0.0460	0.0020	1450.0	124.0
0.2090	0.1660	0.0660	0.0470	0.0020	1420.0	144.0
0.2160	0.1620	0.0620	0.0470	0.0020	1380.0	164.0
0.2320	0.1500	0.0550	0.0460	0.0010	1340.0	184.0
0.2530	0.1350	0.0510	0.0430	0.0010	1290.0	204.0
TOTAL VOL						
6904.1	4900.0	2097.3	1302.2	56.4	ML	

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.3593	.3411	.1898	.0474	.0610	.0014	.0269	0.3644E-02
.6297	.0308	.1968	.0886	.0492	.0049	.1040	0.4071E-02
.3382	.2098	.2806	.1163	.0501	.0030	.1897	0.4227E-02
.3328	.2254	.2552	.1239	.0597	.0030	.2731	0.4174E-02
.3285	.2399	.2475	.1178	.0633	.0029	.3566	0.4145E-02
.3210	.2471	.2455	.1154	.0680	.0030	.4389	0.4043E-02
.3175	.2451	.2522	.1124	.0699	.0030	.5184	0.3886E-02
.3171	.2479	.2543	.1072	.0705	.0031	.5944	0.3685E-02
.3175	.2555	.2522	.1003	.0714	.0030	.6658	0.3398E-02
.3223	.2704	.2417	.0925	.0701	.0030	.7302	0.3056E-02
.3382	.2944	.2187	.0802	.0671	.0015	.7880	0.2729E-02

RUN NUM= 87 10 POINTS

WEIGHT OF CARBON 2.3380 G FLOW RATE 49.0 ML/MIN

10%K2CO3

TEMP= 760.00 C PH2O= 0.61 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2820	0.0620	0.0450	0.0050	0.0030	600.0	8.0
0.2240	0.1480	0.1010	0.0140	0.0030	1340.0	24.0
0.2150	0.1490	0.1100	0.0200	0.0030	1470.0	44.0
0.2060	0.1500	0.1050	0.0240	0.0020	4570.0	64.0
0.1980	0.1510	0.1010	0.0260	0.0020	1640.0	84.0
0.1930	0.1520	0.0960	0.0280	0.0020	1660.0	104.0
0.1910	0.1530	0.0940	0.0300	0.0020	1660.0	124.0
0.1920	0.1560	0.0890	0.0310	0.0020	1590.0	144.0
0.2050	0.1570	0.0800	0.0310	0.0020	1510.0	164.0
0.2260	0.1580	0.0710	0.0310	0.0010	1400.0	184.0

TOTAL VOL					
7592.8	5422.0	3431.3	916.6	77.4	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.3549	.3225	.1894	.0715	.0603	.0014	.0184	0.3292E-02
.6148	.1345	.1352	.0981	.0109	.0005	.0923	0.4102E-02
.3226	.2943	.2131	.1455	.0202	.0043	.1824	0.9295E-02
.3193	.2619	.2213	.1634	.0297	.0045	.4641	0.9577E-02
.4709	*****	.3429	.2400	.0549	.0046	.5655	0.5079E-02
.3253	.2146	.2481	.1659	.0427	.0033	.6673	0.5093E-02
.3254	.2058	.2563	.1619	.0472	.0034	.7692	0.4913E-02
.3235	.2040	.2591	.1592	.0508	.0034	.8638	0.4420E-02
.3202	.2163	.2601	.1484	.0517	.0033	.9461	0.3754E-02
.3294	.2367	.2523	.1286	.0498	.0032	*****	0.3031E-02

RUN NUM= 90 11 POINTS

WEIGHT OF CARBON 2.3409 G FLOW RATE 62.0 ML/MIN

10%K2CO3

TEMP= 700.00 C PH2O= 0.74 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2350	0.0880	0.0260	0.0250	0.0020	680.0	4.0
0.1630	0.1900	0.0540	0.0550	0.0010	1480.0	24.0
0.1410	0.1950	0.0630	0.0600	0.0010	1550.0	44.0
0.1340	0.1970	0.0650	0.0630	0.0010	1450.0	64.0
0.1260	0.1970	0.0620	0.0630	0.0010	1390.0	84.0
0.1250	0.1940	0.0600	0.0630	0.0010	1330.0	104.0
0.1320	0.1900	0.0570	0.0610	0.0010	1320.0	124.0
0.1390	0.1830	0.0550	0.0600	0.0010	1320.0	144.0
0.1460	0.1740	0.0530	0.0610	0.0	1330.0	164.0
0.1540	0.1750	0.0490	0.0640	0.0	1290.0	184.0
0.1610	0.1740	0.0440	0.0650	0.0	1120.0	204.0

TOTAL VOL					
4725.9	5839.9	1761.7	1907.1	25.4	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.3384	.2708	.2366	.1063	.0464	.0015	.0219	0.3645E-02
.5580	.1072	.2090	.0617	.0594	.0047	.1024	0.4402E-02
.2474	.2973	.2884	.0820	.0835	.0015	.1980	0.4717E-02
.2235	.2710	.3090	.0998	.0951	.0016	.2911	0.4558E-02
.2048	.2970	.3010	.0993	.0963	.0015	.3903	0.4362E-02
.1937	.3098	.3028	.0953	.0968	.0015	.4855	0.4166E-02
.1894	.3288	.2939	.0909	.0955	.0015	.5871	0.4038E-02
.1990	.3351	.2865	.0859	.0920	.0015	.6871	0.3999E-02
.2092	.3408	.2754	.0828	.0903	.0015	.7870	0.3886E-02
.2197	.3470	.2618	.0797	.0918	.0.	.7825	0.3460E-02
.2226	.3611	.2529	.0708	.0925	.0	.8454	0.2883E-02

RUN NUM= 91 9 POINTS

WEIGHT OF CARBON 2.3444 G FLOW RATE 62.0 ML/MIN

10%K2CO3

TEMP= 730.00 C PH2O= 0.74 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2090	0.1200	0.0360	0.0200	0.0010	820.0	4.0
0.1310	0.2100	0.0710	0.0600	0.0010	1940.0	24.0
0.1270	0.2100	0.0760	0.0630	0.0010	1910.0	44.0
0.1250	0.2060	0.0760	0.0650	0.0010	1900.0	64.0
0.1220	0.2040	0.0760	0.0660	0.0010	1790.0	84.0
0.1350	0.1970	0.0750	0.0630	0.0010	1690.0	104.0
0.1470	0.1910	0.0710	0.0610	0.0010	1570.0	124.0
0.1510	0.1850	0.0660	0.0580	0.0	1500.0	144.0
0.1710	0.1780	0.0590	0.0550	0.0	1350.0	164.0

TOTAL VOL					
4422.9	6029.0	2160.4	1832.7	25.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.2114	.4170	.2285	.0578	.0853	.0	.0277	0.6076E-02
.5489	*****	.3152	.0946	.0525	.0026	.1514	0.6295E-02
.2325	.1603	.3728	.1260	.1065	.0010	.2795	0.6461E-02
.2210	.1700	.3654	.1322	.1096	.0017	.4099	0.6376E-02
.2179	.1755	.3591	.1325	.1133	.0017	.5345	0.5967E-02
.2075	.2022	.3470	.1293	.1123	.0017	.6485	0.5382E-02
.2186	.2374	.3190	.1214	.1020	.0016	.7498	0.4763E-02
.2262	.2754	.2938	.1092	.0938	.0015	.8422	0.4209E-02
.2304	.2980	.2823	.1007	.0885	.0	.9182	0.3387E-02

RUN NUM= 92 13 POINTS

WEIGHT OF CARBON 2.3380 G FLOW RATE 62.0 ML/MIN

10%K2CO3

TEMP= 670.00 C PH2O= 0.74 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2490	0.0650	0.0120	0.0230	0.0010	550.0	4.0
0.2050	0.1560	0.0260	0.0570	0.0010	1230.0	24.0
0.1890	0.1710	0.0320	0.0680	0.0010	1280.0	44.0
0.1850	0.1750	0.0330	0.0680	0.0010	1270.0	64.0
0.1820	0.1760	0.0350	0.0680	0.0010	1260.0	84.0
0.1860	0.1660	0.0340	0.0650	0.0	1230.0	104.0
0.1880	0.1580	0.0340	0.0590	0.0	1220.0	124.0
0.1880	0.1610	0.0320	0.0610	0.0	1210.0	144.0
0.1870	0.1670	0.0320	0.0670	0.0	1200.0	164.0
0.1830	0.1750	0.0310	0.0720	0.0	1190.0	184.0
0.1850	0.1720	0.0280	0.0690	0.0	1200.0	204.0
0.1970	0.1660	0.0260	0.0670	0.0	1100.0	224.0
0.2070	0.1600	0.0240	0.0640	0.0	1050.0	244.0

TOTAL VOL					
6441.6	5420.2	997.5	2118.1	12.6	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.2408	.3481	.2506	.0831	.0774	.0	.0130	0.2394E-02
.5649	.2060	.1475	.0272	.0522	.0023	.0662	0.2936E-02
.2787	.3951	.2121	.0353	.0775	.0014	.1304	0.3213E-02
.2573	.3724	.2328	.0436	.0926	.0014	.1947	0.3231E-02
.2513	.3724	.2377	.0448	.0924	.0014	.2597	0.3171E-02
.2464	.3745	.2383	.0474	.0921	.0014	.3215	0.3027E-02
.2515	.3903	.2244	.0460	.0879	.0	.3807	0.2839E-02
.2585	.3963	.2173	.0468	.0811	.0	.4391	0.2961E-02
.2561	.3978	.2194	.0436	.0831	.0	.4992	0.3023E-02
.2480	.3993	.2215	.0424	.0888	.0	.5601	0.2992E-02
.2388	.3985	.2283	.0405	.0939	.0	.6188	0.2754E-02
.2463	.3956	.2290	.0373	.0919	.0	.6702	0.2448E-02
.2450	.4329	.2065	.0323	.0833	.0	.7168	0.2205E-02

RUN NUM= 93 15 POINTS

WEIGHT OF CARBON 2.3515 G FLOW RATE- 62.0 ML/MIN

10%K2CO3

TEMP= 640.00 C PH2O= 0.74 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2580	0.0800	0.0060	0.0290	0.0	510.0	4.0
0.2260	0.1680	0.0110	0.0670	0.0	1110.0	24.0
0.2140	0.1710	0.0120	0.0760	0.0	1080.0	44.0
0.2030	0.1730	0.0140	0.0770	0.0	1100.0	64.0
0.1910	0.1750	0.0150	0.0800	0.0	1050.0	84.0
0.1880	0.1750	0.0140	0.0800	0.0	1050.0	104.0
0.2020	0.1670	0.0130	0.0760	0.0	1030.0	124.0
0.2160	0.1610	0.0130	0.0720	0.0	1010.0	144.0
0.2210	0.1580	0.0140	0.0690	0.0	990.0	164.0
0.2260	0.1560	0.0150	0.0670	0.0	970.0	184.0
0.2230	0.1560	0.0140	0.0700	0.0	970.0	204.0
0.2200	0.1590	0.0120	0.0730	0.0	930.0	224.0
0.2190	0.1580	0.0110	0.0720	0.0	930.0	244.0
0.2270	0.1560	0.0110	0.0700	0.0	900.0	264.0
0.2280	0.1570	0.0110	0.0680	0.0	890.0	284.0

TOTAL VOL
6819.0 5064.0 397.8 2239.1 0.0 ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.2487	.4533	.1922	.0288	.0769	.0	.0109	0.1997E-04
.5439	.2137	.1686	.0126	.0611	.0	.0527	0.2[illegible]E-04
.2719	.4322	.2021	.0132	.0806	.0	.0985	0.23[illegible]E-04
.2532	.4403	.2023	.0142	.0899	.0	.1473	0.24[illegible]E-04
.2474	.4308	.2109	.0171	.0939	.0	.1966	0.24[illegible]E-04
.2300	.4449	.2107	.0181	.0963	.0	.2458	0.23[illegible]E-04
.2288	.4438	.2130	.0170	.0974	.0	.2914	0.21[illegible]E-04
.2398	.4563	.1982	.0154	.0902	.0	.3337	0.20[illegible]E-04
.2488	.4679	.1854	.0150	.0829	.0	.3742	0.1[illegible]E-04
.2504	.4766	.1790	.0159	.0782	.0	.4133	0.19[illegible]E-04
.2508	.4851	.1731	.0166	.0743	.0	.4534	0.19[illegible]E-04
.2481	.4849	.1735	.0156	.0779	.0	.4922	0.19[illegible]E-04
.2382	.4977	.1721	.0130	.0790	.0	.5304	0.1[illegible]E-04
.2393	.4975	.1726	.0120	.0787	.0	.5662	0.17[illegible]E-04
.2396	.5102	.1647	.0116	.0739	.0	.6007	0.16[illegible]E-04

RUN NUM= 95 7 POINTS

WEIGHT OF CARBON 2.2635 G FLOW RATE 62.0 ML/MIN

10%K2CO3

TEMP= 760.00 C PH2O= 0.74 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2810	0.0930	0.0570	0.0160	0.0020	800.0	4.0
0.1190	0.1850	0.1140	0.0340	0.0020	2050.0	24.0
0.1080	0.1840	0.1190	0.0340	0.0020	2040.0	44.0
0.1090	0.1830	0.1180	0.0360	0.0010	2030.0	64.0
0.1090	0.1840	0.1100	0.0390	0.0010	2030.0	84.0
0.1100	0.1980	0.0960	0.0440	0.0010	1730.0	104.0
0.1180	0.1930	0.0720	0.0560	0.0	1690.0	124.0
TOTAL VOL 3425.7	5020.3	2865.8	1073.4	34.9	ML	

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.2391	.5134	.1647	.0115	.0713	.0	.0316	0.7837E-02
.5721	.0859	.1893	.1160	.0326	.0041	.1919	0.8193E-02
.2205	.1587	.3428	.2113	.0630	.0037	.3593	0.8350E-02
.2035	.1577	.3467	.2242	.0641	.0038	.5259	0.8232E-02
.2037	.1646	.3420	.2205	.0673	.0019	.6886	0.7450E-02
.2066	.1604	.3487	.2085	.0739	.0019	.8239	0.6298E-02
.1983	.2088	.3388	.1730	.0793	.0018	.9406	0.5364E-02

RUN NUM= 96 7 POINTS

WEIGHT OF CARBON 2.3426 G FLOW RATE 62.0 ML/MIN

10%K2CO3

TEMP= 760.00 C PH2O= 0.74 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2860	0.0880	0.0540	0.0200	0.0020	740.0	4.0
0.1190	0.1830	0.1050	0.0380	0.0020	2390.0	24.0
0.1110	0.1850	0.1120	0.0400	0.0020	2280.0	44.0
0.1070	0.1920	0.1160	0.0410	0.0020	2140.0	64.0
0.1050	0.2150	0.1110	0.0440	0.0010	1910.0	84.0
0.1050	0.2050	0.0990	0.0480	0.0010	1830.0	104.0
0.1180	0.1890	0.0830	0.0480	0.0010	1310.0	124.0

TOTAL VOL					
3361.9	5203.4	2848.3	1141.9	44.5	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.2077	.2273	.3397	.1267	.0986	.0	.0286	0.8836E-02
.5621	.1156	.1730	.1061	.0393	.0039	.2059	0.8893E-02
.2419	.0913	.3720	.2135	.0772	.0041	.3843	0.8700E-02
.2195	.1102	.3658	.2215	.0791	.0040	.5542	0.7826E-02
.2029	.1316	.3641	.2200	.0777	.0028	.6974	0.6960E-02
.1849	.1620	.3785	.1954	.0775	.0018	.8326	0.5633E-02
.1871	.1841	.3652	.1764	.0855	.0018	.9227	0.3375E-02

RUN NUM= 97 7 POINTS

WEIGHT OF CARBON 2.3345 G FLOW RATE 62.0 ML/MIN

K2CO3 10%

TEMP= 760.00 C PH2O= 0.74 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2860	0.0930	0.0550	0.0200	0.0020	860.0	4.0
0.1190	0.1950	0.1050	0.0430	0.0020	2180.0	24.0
0.1030	0.2080	0.1030	0.0480	0.0020	2180.0	44.0
0.1000	0.2100	0.0980	0.0490	0.0020	2150.0	64.0
0.0980	0.2190	0.0880	0.0600	0.0010	2120.0	84.0
0.1000	0.2240	0.0620	0.0710	0.0010	2080.0	104.0
0.1240	0.2290	0.0390	0.0910	0.0	2110.0	124.0

TOTAL VOL

3492.5	6066.4	2392.3	1687.7	41.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1778	.3384	.2848	.1251	.0723	.0015	.0333	0.80055E-02
.5831	.0703	.1896	.1121	.0408	.0041	.1950	0.81677E-02
.2250	.1228	.3687	.1985	.0813	.0038	.3600	0.81288E-02
.1996	.1006	.4032	.1996	.0930	.0039	.5202	0.78938E-02
.1962	.0995	.4120	.1923	.0961	.0039	.6757	0.73800E-02
.1893	.0996	.4231	.1700	.1159	.0019	.8154	0.67448E-02
.1980	.0931	.4435	.1228	.1406	.0020	.9457	0.62883E-02

RUN NUM= 98 9 POINTS

WEIGHT OF CARBON 2.3629 G FLOW RATE 62.0 ML/MIN

10%K2CO3

TEMP= 760.00 C PH2O= 0.74 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2850	0.1000	0.0620	0.0170	0.0020	730.0	4.0
0.1420	0.2000	0.1140	0.0330	0.0020	1750.0	24.0
0.1350	0.1900	0.1100	0.0350	0.0020	1700.0	44.0
0.1330	0.1830	0.1060	0.0360	0.0020	1630.0	64.0
0.1380	0.1900	0.1030	0.0350	0.0020	1570.0	84.0
0.1490	0.1740	0.1000	0.0330	0.0010	1480.0	104.0
0.1590	0.1700	0.0970	0.0300	0.0010	1240.0	124.0
0.1730	0.1620	0.0950	0.0270	0.0010	1140.0	144.0
0.1860	0.1560	0.0920	0.0270	0.0010	1090.0	164.0

TOTAL VOL					
4166.5	4615.3	2668.9	837.0	42.2	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.2305	.1020	.4258	.0725	.1692	.0	.0288	0.6024E-02
.5477	.1044	.1922	.1192	.0327	.0038	.1492	0.6011E-02
.2237	.2267	.3150	.1796	.0520	.0032	.2692	0.5983E-02
.2169	.2415	.3053	.1768	.0562	.0032	.3849	0.5612E-02
.2135	.2616	.2938	.1702	.0578	.0032	.4987	0.5160E-02
.2171	.2796	.2831	.1620	.0551	.0031	.5921	0.4428E-02
.2244	.3116	.2621	.1506	.0497	.0015	.6709	0.3704E-02
.2143	.3841	.2291	.1307	.0404	.0013	.7402	0.3340E-02
.2184	.4218	.2045	.1199	.0341	.0013	.8044	0.3079E-02

RUN NUM= 99 11 POINTS

WEIGHT OF CARBON 2.3507 G FLOW RATE 124.2 ML/MIN

K2CO3 10%

TEMP= 650.00 C PH2O= 0.85 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3380	0.0850	0.0070	0.0290	0.0	450.0	5.0
0.1970	0.1650	0.0120	0.0590	0.0	1150.0	25.0
0.1850	0.1700	0.0130	0.0700	0.0	1120.0	45.0
0.1780	0.1750	0.0140	0.0790	0.0	1120.0	65.0
0.1680	0.1830	0.0120	0.0830	0.0	1120.0	85.0
0.1650	0.1850	0.0090	0.0870	0.0	1120.0	105.0
0.1620	0.1850	0.0090	0.0870	0.0	1120.0	125.0
0.1650	0.1850	0.0080	0.0870	0.0	1120.0	145.0
0.1750	0.1850	0.0080	0.0860	0.0	1120.0	165.0
0.1700	0.1850	0.0060	0.0860	0.0	1120.0	185.0
0.1730	0.1840	0.0050	0.0880	0.0	1120.0	205.0

TOTAL VOL					
4724.7	4631.2	250.0	2074.1	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1107	.6553	.1453	.0338	.0541	.0008	.0078	0.201+E-02
.3363	.5443	.0846	.0070	.0279	.0	.0509	0.22?+E-02
.1637	.6402	.1371	.0100	.0490	.0	.0992	0.25?0E-02
.1493	.6466	.1372	.0105	.0565	.0	.1524	0.2690E-02
.1413	.6461	.1389	.0111	.0627	.0	.2068	0.27?3E-02
.1342	.6438	.1461	.0096	.0663	.0	.2617	0.275?E-02
.1320	.6432	.1480	.0072	.0696	.0	.3170	0.27?5E-02
.1306	.6429	.1491	.0073	.0701	.0	.3715	0.26??E-02
.1323	.6431	.1484	.0064	.0638	.0	.4244	0.2?3?E-02
.1372	.6442	.1450	.0063	.0674	.0	.4769	0.2?3?E-02
.1356	.6434	.1476	.0048	.0686	.0	.5296	0.2?4?E-02

RUN NUM=100 11 POINTS

WEIGHT OF CARBON 2.3891 G FLOW RATE 124.2 ML/MIN

K2CO3 1%

TEMP= 650.00 C PH2O= 0.85 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3650	0.0620	0.0030	0.0270	0.0	300.0	5.0
0.2580	0.1390	0.0060	0.0600	0.0	650.0	25.0
0.2230	0.1570	0.0080	0.0710	0.0	700.0	45.0
0.1960	0.1750	0.0090	0.0800	0.0	750.0	65.0
0.1880	0.1800	0.0080	0.0830	0.0	800.0	85.0
0.1880	0.1800	0.0060	0.0850	0.0	800.0	105.0
0.1940	0.1750	0.0060	0.0870	0.0	800.0	125.0
0.1850	0.1750	0.0050	0.0870	0.0	750.0	145.0
0.1940	0.1690	0.0050	0.0840	0.0	700.0	165.0
0.2020	0.1680	0.0050	0.0820	0.0	670.0	185.0
0.2060	0.1680	0.0050	0.0780	0.0	640.0	205.0

TOTAL VOL

3434.5	2731.5	102.7	1291.4	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1369	.6440	.1456	.0040	.0696	.0	.0048	0.6[illegible]E-03
.2722	.6592	.0462	.0022	.0201	.0	.0252	0.11[illegible]E-02
.1232	.7788	.0664	.0029	.0287	.0	.0522	0.14[illegible]E-02
.1155	.7623	.0813	.0041	.0368	.0	.0847	0.17[illegible]E-02
.1084	.7456	.0968	.0050	.0442	.0	.1203	0.[illegible]E-02
.1103	.7307	.1056	.0047	.0487	.0	.1556	0.[illegible]E-02
.1103	.7307	.1056	.0035	.0499	.0	.1928	0.[illegible]E-02
.1095	.7310	.1041	.0036	.0518	.0	.2270	0.[illegible]E-02
.1043	.7452	.0986	.0028	.0490	.0	.2578	0.[illegible]E-02
.1028	.7605	.0896	.0026	.0445	.0	.2965	0.[illegible]E-02
.1018	.7696	.0847	.0025	.0413	.0	.3126	0.[illegible]E-02

RUN NUM=101 4 POINTS

WEIGHT OF CARBON 2.3460 G FLOW RATE 124.2 ML/MIN

K2CO3 10%

TEMP= 800.00 C PH2O= 0.85 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.1470	0.1410	0.1110	0.0180	0.0030	1480.0	8.0
0.0680	0.1930	0.1530	0.0210	0.0030	3200.0	28.0
0.0750	0.1830	0.1550	0.0210	0.0020	3200.0	48.0
0.0610	0.2050	0.1210	0.0450	0.0010	2930.0	68.0

TOTAL VOL					
1987.3	4663.6	3486.3	678.4	54.3	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.0999	.7784	.0814	.0024	.0378	.0	.1062	0.1510E-01
.2649	.2432	.2541	.2000	.0324	.0054	.4070	0.1498E-01
.1187	.2353	.3370	.2671	.0367	.0052	.7054	0.1391E-01
.1277	.2578	.3115	.2639	.0357	.0034	.9634	0.1190E-01

RUN NUM=102 3 POINTS

WEIGHT OF CARBON 2.3369 G FLOW RATE 124.2 ML/MIN

NACO3 20%

TEMP= 800.00 C PH2O= 0.85 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.1590	0.1440	0.1170	0.0120	0.0020	1500.0	8.0
0.0560	0.2180	0.1180	0.0490	0.0010	5740.0	28.0
0.0410	0.2250	0.0610	0.0900	0.0	4100.0	48.0

TOTAL VOL					
1679.9	5541.0	2536.5	1562.7	19.9	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1029	.2699	.3456	.2040	.0759	.0017	.1038	0.2900E-01
.2773	.2432	.2511	.2040	.0209	.0035	.6039	0.2101E-01
.1355	*****	.5275	.2855	.1186	.0024	.9443	0.1302E-01

RUN NUM=103 9 POINTS

WEIGHT OF CARBON 2.4074 G FLOW RATE 144.0 ML/MIN

NONE

TEMP= 800.00 C PH2O= 0.83 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2680	0.1020	0.0310	0.0360	0.0020	1030.0	8.0
0.1570	0.1940	0.0490	0.0470	0.0020	2240.0	24.0
0.1420	0.1910	0.0590	0.0550	0.0020	2280.0	44.0
0.1390	0.1880	0.0620	0.0580	0.0020	2320.0	64.0
0.1550	0.1830	0.0580	0.0620	0.0010	2210.0	84.0
0.1650	0.1760	0.0400	0.0630	0.0010	1840.0	104.0
0.1840	0.1670	0.0290	0.0650	0.0010	1650.0	124.0
0.2200	0.1500	0.0250	0.0590	0.0010	1360.0	144.0
0.2570	0.1280	0.0130	0.0510	0.0	1230.0	164.0

TOTAL VOL
6322.2 6174.1 1599.4 2013.5 50.8 ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.5257	.0782	.2383	.0824	.0736	.0018	.0360	0.488[illegible]E-02
.4633	.2411	.1763	.0536	.0622	.0035	.1448	0.594[illegible]E-02
.1895	.4579	.2342	.0592	.0567	.0024	.2759	0.676[illegible]E-02
.1729	.4532	.2326	.0718	.0670	.0024	.4162	0.674[illegible]E-02
.1707	.4487	.2309	.0761	.0712	.0025	.5458	0.563[illegible]E-02
.1777	.4737	.2098	.0665	.0711	.0011	.6815	0.434[illegible]E-02
.1712	.5382	.1827	.0415	.0654	.0010	.7197	0.336[illegible]E-02
.1743	.5774	.1582	.0275	.0616	.0009	.7763	0.238[illegible]E-02
.1737	.6408	.1184	.0197	.0466	.0008	.8153	0.151[illegible]E-02

RUN NUM=104 8 POINTS

WEIGHT OF CARBON 2.3641 G FLOW RATE 85.6 ML/MIN

NO CATALYST

TEMP= 800.00 C PH2O= 0.83 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.2740	0.1070	0.0320	0.0320	0.0020	690.0	8.0
0.1110	0.2200	0.0630	0.0730	0.0020	1570.0	24.0
0.0820	0.2300	0.0740	0.0770	0.0020	1720.0	44.0
0.0650	0.2360	0.0790	0.0710	0.0020	1720.0	64.0
0.0840	0.2250	0.0750	0.0660	0.0010	1620.0	84.0
0.1240	0.2020	0.0530	0.0650	0.0010	1530.0	104.0
0.1710	0.1740	0.0350	0.0650	0.0010	1420.0	124.0
0.2140	0.1510	0.0200	0.0590	0.0010	1310.0	144.0

TOTAL VOL					
3247.1	5149.7	1455.9	1689.4	37.9	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.0949	.5455	.2383	.0303	.0899	.0010	.0231	0.46[illegible]E-02
.4912	.1987	.1918	.0574	.0574	.0030	.1278	0.58[illegible]E-02
.1467	.3800	.2908	.0833	.0965	.0026	.2560	0.64[illegible]E-02
.1182	.3298	.3315	.1067	.1110	.0029	.3868	0.61[illegible]E-02
.0979	.3177	.3555	.1190	.1069	.0030	.5024	0.52[illegible]E-02
.1199	.3563	.3211	.1070	.0942	.0014	.5951	0.41[illegible]E-02
.1678	.3978	.2734	.0717	.0880	.0014	.6880	0.31[illegible]E-02
.2117	.4478	.2154	.0433	.0805	.0012	.7213	0.21[illegible]E-02

RUN NUM=106 12 POINTS

WEIGHT OF CARBON 2.3573 G FLOW RATE 31.0 ML/MIN

10%NA2CO3

TEMP= 730.00 C PH2O= 0.43 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.3000	0.0540	0.0280	0.0120	0.0010	620.0	4.0
0.2670	0.1130	0.0520	0.0230	0.0010	1180.0	24.0
0.2620	0.1140	0.0600	0.0220	0.0010	1150.0	44.0
0.2640	0.1140	0.0600	0.0220	0.0010	1110.0	64.0
0.2840	0.1010	0.0500	0.0200	0.0	1090.0	84.0
0.2810	0.0890	0.0570	0.0200	0.0	1070.0	104.0
0.2880	0.0920	0.0540	0.0200	0.0	1050.0	124.0
0.2940	0.0880	0.0500	0.0200	0.0	1030.0	144.0
0.2930	0.0900	0.0460	0.0230	0.0	1020.0	164.0
0.2980	0.0890	0.0430	0.0220	0.0	1000.0	184.0
0.3010	0.0840	0.0430	0.0210	0.0	1000.0	204.0
0.3000	0.0930	0.0430	0.0200	0.0	1520.0	234.0

TOTAL VOL					
8122.0	2698.5	1423.2	587.2	9.1	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.4197	.3605	.1296	.0493	.0394	.0014	.0146	0.2111-02
.7177	.0550	.1292	.0670	.0287	.0024	.0593	0.8[illegible]-02
.4599	.2146	.1946	.0896	.0396	.0017	.1046	0.[illegible]-02
.4437	.2226	.1931	.1016	.0373	.0017	.1533	0.[illegible]-02
.4382	.2348	.1892	.0996	.0365	.0017	.1937	0.[illegible]-02
.4541	.2596	.1615	.0927	.0320	.0	.2356	0.2[illegible]-02
.4554	.2755	.1442	.0924	.0324	.0	.2745	0.[illegible]-02
.4571	.2795	.1460	.0857	.0317	.0	.3100	0.[illegible]-02
.4622	.2894	.1383	.0786	.0314	.0	.3467	0.1[illegible]-02
.4602	.2901	.1413	.0722	.0361	.0	.3788	0.1[illegible]-02
.4633	.2973	.1384	.0668	.0342	.0	.4112	0.1[illegible]-02
.4678	.3021	.1306	.0668	.0326	.0	.4439	0.1[illegible]-02

RUN NUM=107 11 POINTS

WEIGHT OF CARBON 2.4574 G FLOW RATE 124.2 ML/MIN

1% NICKEL

TEMP= 650.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.1890	0.0600	0.0020	0.0210	0.0	550.0	6.0
0.2110	0.1540	0.0030	0.0460	0.0	920.0	26.0
0.2330	0.1540	0.0030	0.0490	0.0	910.0	46.0
0.2330	0.1530	0.0040	0.0640	0.0	900.0	66.0
0.2380	0.1520	0.0040	0.0640	0.0	870.0	86.0
0.2430	0.1470	0.0040	0.0620	0.0	850.0	106.0
0.2690	0.1310	0.0020	0.0560	0.0	800.0	126.0
0.3010	0.1080	0.0020	0.0510	0.0	750.0	146.0
0.3020	0.1030	0.0020	0.0460	0.0	730.0	166.0
0.2960	0.1080	0.0020	0.0480	0.0	720.0	186.0
0.2920	0.1120	0.0020	0.0500	0.0	700.0	206.0

TOTAL VOL

5063.8	2562.2	56.1	1017.9	0.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.0922	.0622	.5060	.1372	.2024	.0	.0101	0.11935E-02
.3256	.5315	.1034	.0034	.0362	.0	.0339	0.11811E-02
.1531	.6995	.1118	.0022	.0334	.0	.0574	0.14018E-02
.1571	.7040	.1038	.0020	.0330	.0	.0868	0.14397E-02
.1499	.7079	.0985	.0026	.0412	.0	.1149	0.13748E-02
.1475	.7162	.0942	.0025	.0397	.0	.1417	0.12238E-02
.1480	.7222	.0895	.0024	.0378	.0	.1638	0.10213E-02
.1538	.7381	.0749	.0011	.0320	.0	.1826	0.83085E-03
.1598	.7548	.0573	.0011	.0271	.0	.1994	0.65377E-03
.1597	.7605	.0545	.0011	.0243	.0	.2167	0.47782E-03
.1548	.7626	.0565	.0010	.0251	.0	.2341	0.37801E-03

RUN NUM=108 11 POINTS

WEIGHT OF CARBON 2.3443 G FLOW RATE 124.2 ML/MIN

1% NI+10% K2CO3

TEMP= 650.00 C PH2O= 0.86 ATM

N2	H2	CO	CO2	CH4	VOL,ML	TIME,MIN
0.1550	0.0820	0.0120	0.0300	0.0010	790.0	6.0
0.1460	0.1880	0.0160	0.0640	0.0010	1320.0	26.0
0.1440	0.2070	0.0160	0.0840	0.0010	1350.0	46.0
0.1350	0.2140	0.0160	0.0890	0.0010	1360.0	66.0
0.1330	0.2150	0.0160	0.0930	0.0010	1380.0	86.0
0.1270	0.2150	0.0160	0.0930	0.0	1380.0	106.0
0.1370	0.2100	0.0160	0.0930	0.0	1360.0	126.0
0.1400	0.2060	0.0160	0.0910	0.0	1090.0	146.0
0.1480	0.2010	0.0160	0.0900	0.0	1060.0	166.0
0.1560	0.1960	0.0140	0.0890	0.0	1070.0	186.0
0.1700	0.1880	0.0130	0.0840	0.0	1030.0	206.0

TOTAL VOL					
4366.6	5869.7	463.4	2475.4	15.0	ML

PPN2	PPH2O	PPH2	PPCO	PPCO2	PPCH4	X	DX/DT
.1488	.7676	.0571	.0010	.0255	.0	.0277	0.2692E-02
.3369	.3915	.1782	.0261	.0652	.0022	.0966	0.3195E-02
.1451	.5875	.1869	.0159	.0636	.0010	.1555	0.3583E-02
.1340	.5794	.1926	.0149	.0782	.0009	.2279	0.3704E-02
.1262	.5748	.2000	.0150	.0832	.0009	.3037	0.3749E-02
.1248	.5701	.2018	.0150	.0873	.0009	.3799	0.3783E-02
.1212	.5696	.2052	.0153	.0868	.0	.4542	0.3828E-02
.1270	.5773	.1946	.0148	.0862	.0	.5130	0.2284E-02
.1094	.6459	.1610	.0125	.0711	.0	.5694	0.2797E-02
.1121	.6554	.1522	.0121	.0682	.0	.6248	0.2636E-02
.1186	.6541	.1490	.0106	.0677	.0	.6750	0.2389E-02