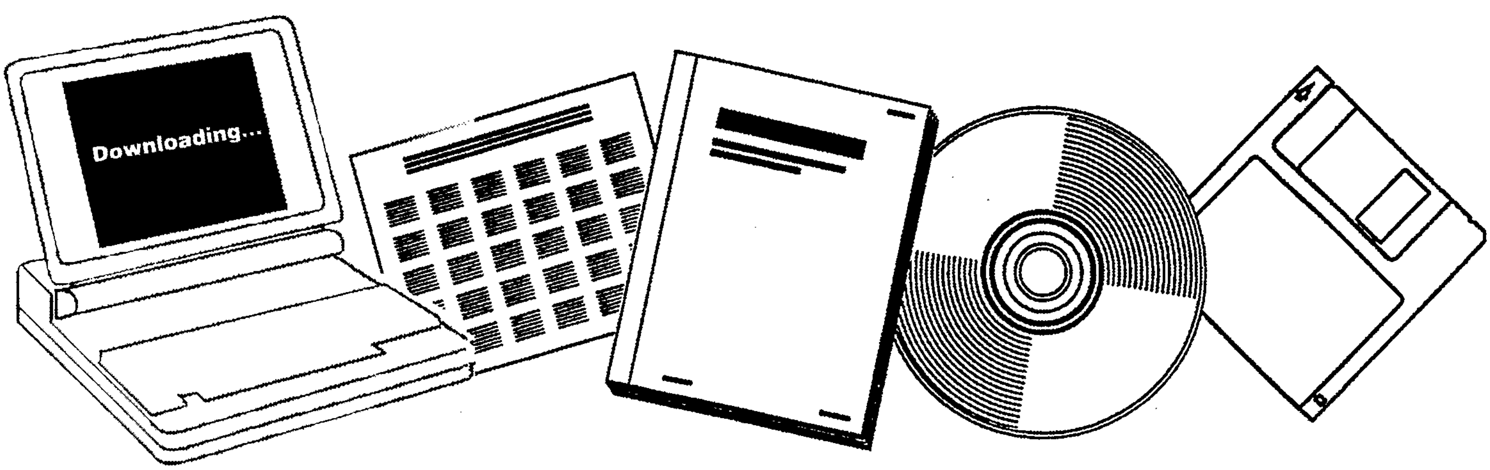
OPTIMIZATION OF COAL GASIFICATION PROCESSES. MONTHLY PROGRESS REPORT FOR PERIODS, JANUARY--AUGUST AND OCTOBER--DECEMBER 1973

WEST VIRGINIA UNIV., MORGANTOWN

JAN 1973



FE--497-T-7

OPTIMIZATION OF COAL GASIFICATION PROCESSES

Monthly Progress Reports for the periods
January - August and October - December 1973

C. Y. Wen

West Virginia University
College of Engineering
Morgantown, West Virginia 26506

Prepared for

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CONTENTS

OPTIMIZATION OF COAL CONVERSION PROCESSES
PROGRESS REPORT NO. 64
JANUARY 1973

to

The U. S. Office of Coal Research
Contract No. 14-01-0001-497

Conversion of Coal to Low-Btu Gas

The mass balance calculation models for the (coal)-to-(low-Btu gas)-to-(electrical Power) conversion process have been completed, both for a single-stage coal gasification reactor system and for a two-stage pyrolysis-gasification system. The two-stage system has the higher thermal efficiency; however, because this process arrangement requires two reactors in-series, the capital equipment cost will likely be higher than the single-stage arrangement. To determine if this probable higher equipment cost will be offset by the better process thermal efficiency, the individual subsystems in the overall process must be size-designed in determining the capital cost of the plant. A major portion of the capital expenditure will be that of the coal-gasification reactors. The emphasis of the work in this next month will be directed at utilizing the kinetics-reactor design model to design and determine the estimated construction costs for these reactors. After these cost relationships have been obtained, the entire coal-to-electricity system will be optimized using the lowest electrical power generation cost as the objective function.

Conversion of Coal Into Liquids and Subsequent Coal-Char Utilization

The emphasis of this project is directed at the profitable utilization of the char produced in a coal-to-liquid fuel conversion plant similar to the COED Process" (F.M.C. Corporation). This last month was devoted to reviewing the previous work in char utilization and in formulating the constraints and alternatives to be used in this project study.

Initially studied will be a plant processing 500 billion Btu per day of raw coal. This coal-feed rate roughly corresponds to 6.3 million tons per year (90% stream factor) of a bituminous coal averaging 13,000 Btu/pound and represents the maximum production limit of a single large coal mine in the Appalachian region. This conceptual plant is also in the coal utilization size-range of the "standardized" high Btu plant producing 250 million cubic feet per day. It was also decided that the initial study should concentrate on the processing of the medium or high sulfur coals since the chars from these coals will present the most troublesome disposal and/or utilization problems.

The plant must be self-sustaining with regard to electrical power and steam generation. Several alternatives for the profitable utilization of the large amounts of produced char (representing 55–60% of the raw coal fed to the process) are;

(a) Conversion to low-Btu gas for electrical power generation,

(b) Conversion to high-Btu pipeline quality gas,

(c) A combination of (a) and (b)

During the next month, these three potential product-distribution alternatives will be more thoroughly evaluated. Also, the alternative processes for gasifying the char will be examined in greater detail.

C. Y. Wen

C. Y. Wen, Project Director

OPTIMIZATION OF COAL CONVERSION PROCESSES

PROGRESS REPORT NO. 65

FEBRUARY 1973

to

The U. S. Office of Coal Research

Contract No. 14-01-0001-497

Conversion of Coal to Low-Btu Gas

Efforts during this past month in the study of electrical power generation via the coal conversion to low-Btu gas have been directed at reviewing and correcting the heat and mass balance relationships in each subsystem of the process, in preparation for the cost estimation and mathematical optimization evaluations which will be conducted next. Several design and operating parameters have been found to affect the overall thermal efficiency of the process significantly, and the sensitivity of these parameter values will be studied in greater detail after the optimization has been completed. The study comparing the efficiency of the two-stage pyrolyzer-gasifier process with that of the single-stage coal gasification operation is being updated.

During this next month, we will concentrate on initiating the reaction design and cost estimation portion of the study. Also, the gas purification and sulfur-recovery subsystems must be examined in greater detail.

Conversion of Coal Into Liquids and Subsequent Coal-Char Utilization

This study is directed at evaluating the several alternatives for efficiently utilizing the large amounts of char produced in a coal-pyrolysis operation such as the "COED Process" (F.M.C. Corporation). It was decided that, initially, the study would concentrate on the processing of char from high-sulfur coals since this sulfur-containing char would present many problems in conversion to useable products, or even in its pollution-free disposal if not utilized.

In the past month, the various techniques to gasify the char, either with air to form a low-Btu gas for subsequent conversion to electrical power or with oxygen to form a synthesis fuel gas to be upgraded to pipeline gas quality, have been studied and reviewed. As the low-Btu gas generation-combined cycle electrical power plant study is nearly completed, the "COED Process" will now be integrated with this low-Btu gas generation scheme. The several char-utilization alternatives will also be studied and ranked, and the systems appearing potentially the most attractive will be evaluated in greater detail.

C. Y. Wen /og

C. Y. Wen, Project Director

OPTIMIZATION OF COAL CONVERSION PROCESSES

PROGRESS REPORT NO. 66

MARCH 1973

to

The U. S. Office of Coal Research

Contract No. 14-01-0001-497

In the past month the study of the processes converting coal into electrical power via the production of a low-Btu gas has been devoted to the revision of the paper "Production of Low Btu Gas Involving Coal Pyrolysis and Gasification", which is being presented at the A.C.S. National Meeting in Dallas, Texas, on April 9th. A copy of the original paper was sent to O.C.R. in December 1972 and permission to present the paper was granted at that time. Later developments in our study necessitated a revision and up-dating of certain portions of the manuscript, specifically to include consideration of the gas purification step.

The study of processes converting coal to low-Btu gas to electricity and the study into ways to utilize pyrolysis char (unreacted solids from the "Project COED") will be combined with the objective of preparing a report summarizing our study results and conclusions with regard to the air-blown gasification of coal and char. Certainly, one alternative useage of the vast amounts of char from the "COED Process" is the on-site generation of electricity. A significant problem in using the pyrolysis char is associated with its high sulfur content, the char having almost the same sulfur content value as in the original coal. Thus, the processes converting char into electricity will be hampered by the same problem as the coal-to-electricity schemes, that of removing the sulfureous compounds either from the synthesis fuel gas before the final combustion step or from the combustion gases in a tail-end scrubbing stage. Since the gasification of the char to low-Btu gas will utilize almost the same flowscheme as that of coal gasification and is composed of the same process subsystems, a coordinated study for the processing of both feedstock types is warranted.

The proposed report will include consideration of all steps from the feeding of the coal or char into the gasification subsystem to the ultimate power generation by combined cycle turbine arrangement, and including the purification of the gas to remove sulfur and solid particulates. The objective of the study report will be directed at recognizing the best process paths leading to maximum energy-utilization efficiency, prior to considering equipment costs and operating expenses. The economic evaluations of the most efficient process schemes will be undertaken after completing the efficiency optimization study.

April will be devoted to the preparation of this proposed report.

C. Y. Wen

C. Y. Wen, Project Director

OPTIMIZATION OF COAL CONVERSION PROCESSES

PROGRESS REPORT NO. 67

APRIL - JUNE 1973

to

The U. S. Office of Coal Research

Contract No. 14-01-0001-497

In the last three months the study of the processes to convert coal to electrical energy via low-Btu gas generation was involved in writing a major report titled "Production of Electricity Via Coal and Coal-Char Gasification". This 81-page report was sent to the Office of Coal Research on June 15, 1973. The results and conclusions of the study, as summarized in the report, are attached to this progress report.

In addition to the gasification of raw coal, a medium-sulfur pyrolysis char was considered in the reported study as an alternative feed-fuel for an air-blown gasification reactor, followed by a gas purification stage and conversion of the low-Btu gas into electricity by an advanced combined gas and steam turbine power cycle. This feed char was assumed to have the properties of a typical solid residure from the "Project COED" laboratory studies (F.M.C. Corporation). In this next month, we intend to study alternative ways of combining this char-to-electricity conversion process with the capabilities of the "Project COED" flowscheme, to produce electricity as well as a synthetic crude oil and light hydrocarbon liquids.

Because this overall process scheme ("Project COED" plus electrical power generation) will yield several major products, a study will also be undertaken dealing with the development of methods to economically evaluate a process scheme which produces several major products and to determine, in a manner hopefully free of bias and prior prejudice, the cost of producing the individual products. Such a cost computation technique is necessary in evaluating a multi-product process to select its most optimal apportionment of product quantity distribution with regard to maximum energy-utilization efficiency or minimum production cost.

C. Y. Wen /ots

C. Y. Wen, Project Director

PRODUCTION OF ELECTRICITY VIA COAL AND COAL-CHAR GASIFICATION

Report Submitted to the Office of Coal Research, June 15, 1973

Pertinent Results and Conclusions

This report concerns the first phase of the study of potential process alternatives converting coal or coal-char into electricity, via the production of low-Btu gas for combustion in an advanced combined gas-and-steam turbine power cycle. This study has concentrated on recognizing the optimum equipment arrangement and operating conditions with regard to maximizing the energy-conservation efficiency of the overall coal-to-electricity process. Cost values presented here apply to these processes operating at their maximum energy-conservation efficiency and may or may not represent the lowest capital investment or cheapest power production cost. For convenience, the conclusions of this study are itemized.

(a) The choice of removing the sulfur by either a tail-end SO_2 removal system or by coal gasification to low-Btu gas offers slight difference in cost if both process alternatives use a conventional steam-turbine cycle to generate the electricity. The low-Btu gas generation path might offer some savings in capital investment, but the electrical power production cost will likely be higher because of the lower energy-conversion efficiency of the coal-gasification process.

(b) If the low-Btu gas generation and purification can be integrated with an optimal-designed combination of gas-and-steam turbine power cycles, the coal can be converted to electricity and the obnoxious sulfur compounds removed from the system with little loss in overall energy-conversion efficiency from that occuring in today's conventional steam-turbine power generation plants having no sulfur-pollution emission controls.

(c) There is a decided advantage in a multi-stage coal pyrolysis-gasification scheme in which as much as possible of the synthetic fuel gas compounds are evolved from the coal-structure matrix at a rapid heating rate and under operating conditions favoring the formation and stabilization of the low molecular weight aliphatic hydrocarbons; CH_4, C_2H_6, C_2H_4, etc. This leads to the generation of a synthetic fuel gas product having a higher Btu-content, meaning that a significantly smaller gas mass volume is needed to deliver a designated amount of combustion-heat energy to the power generation cycles. A smaller gas mass flowrate per power generation capacity leads to lower capital investment and utility demands in those systems significantly affected by the total volume of gas processed rather than by the gas quality. A "Two-Stage" pyrolysis-gasification scheme can offer a 10.9% savings in capital investment and a 5.5% lower per-kilowatthour electrical power production cost compared to the "Single-Stage" high-temperature coal gasification alternate.

(d) The conversion of already pyrolyzed coal-char into electrical power certainly cannot be achieved as efficiently or as cheaply as the conversion of raw coal; however, the generation of electrical power from this high-sulfur potential solid-waste material, not useable in its present form, is still quite feasible and potentially profitable. A power plant utilizing this char as fuel would cost only about 9% more in capital investment than a power plant using a raw-coal feed, and the electrical production cost would be only 7% higher. This char-to-electricity process can be integrated into the "Project COED" multi-stage pyrolysis flowscheme to realize a very profitable multi-product coal-conversion complex.

(e) In the breakdown of the estimated cost of the proposed "advanced" coal-to-electricity plant, the power-generation subsystems (gas and steam turbines, plus powerplant accessories) comprise 49% of the total capital investment. The coal preparation, gasification and gas purification subsystems form about 15% of the capital outlay.

(f) Raw material (coal or char) compose 27% of the production cost of the product electricity. Capital charges (including depreciation, profits, taxes, etc.) are responsible for 41% of this final product cost.

(g) On the average, the final cost of the electricity will increase about 1.01 mills/kilowatthour for each 10¢ increase in the per-million Btu price of the raw coal.

(h) The reliability of the process to remain on-stream without costly downtimes for unscheduled maintenance is significant in maintaining a low final production cost for the electrical power product. The cost of the produced power will increase about 0.3 mills per kilowatt-hour for each ten days the plant remains inactive.

(i) The complete conversion of all the carbon in the feed fuel is highly desirable in realizing the greatest overall energy conversion efficiency for the entire coal-to-electricity process. However, most coal-gasification reactors of a practical size with reasonable solids residence time cannot realize a 100% utilization of the carbon, particularly in the fluidized-bed design which approaches a completely-mixed stage in its reaction characteristics. Better utilization of the carbon is a commendable goal because the total plant energy-conversion efficiency will increase about 1.5% for each 5% improvement in the carbon utilization.

(j) The overall energy efficiency of the process will significantly improve with an increase in the temperatures of the gases entering the gas turbine. A 1% to 2% increase in overall efficiency can be realized for each 200°F increase in the inlet gas temperature tolerance. Thus, the goals of the turbine designers to increase the temperature limitations by developing better cooling cycles, better construction materials and more oxidation-resistant coatings are well directed for their contribution to improvements in the coal-to-electricity conversion process.

(k) As turbine design is improved to tolerate higher and higher temperatures, the differential between the efficiency of the "Two-Stage" coal pyrolysis-gasification system and the efficiency of the "Single-Stage" high-temperature coal gasification process tends to become larger. Therefore, as higher-temperature gas turbines are developed and enter into commercial use, the advantages of the multi-stage coal pyrolysis-gasification sub-system to generate a synthesis fuel gas with a higher Btu content will become more and more favorable.

(l) An important factor not explicitly considered in this study is the effect on the overall plant cost of potentially large concentrations of undesirable trace compounds in the waste streams, either as gaseous wastes or liquid wastes. Of considerable concern will be water contaminants such as ammonia, phenol and thiocyanates, air pollutants such as COS, mercaptans, CS_2, thiophenes, NO_x compounds, aromatics and others, and finally the sulfur, mercury and arsenic contents of the discarded solid char, ash and tars. Because of the large size of these proposed plant ventures and the havoc that an improperly designed facility can impose on a locality, all aspects of the technical design must be studied with regard to maximum control over all air, water and waste disposal pollution treatment methods.

OPTIMIZATION OF COAL CONVERSION PROCESSES

PROGRESS REPORT NO. 68

JULY 1973

to

The U. S. Office of Coal Research

Contract No. 14-01-0001-497

This last month was spent in correlating the "Project COED" Process for producing a synthetic crude oil by the multi-stage pyrolysis of coal (now being developed by the F.M.C. Corporation) with the conversion of the pyrolysis char into electricity via the gasification of the char to form a low-Btu gas and the subsequent combustion of that gas in an advanced combined steam-and-gas turbine power generation cycle. A preliminary flowscheme of a combined oil-and-electricity producing process indicates that such a venture is certainly feasible. The next month will be devoted to selecting the most optimum of several alternative subsystem flow paths encountered in the overall combining of these two coal conversion schemes.

One general problem area, encountered now in combining the "Project COED" Process with the char-to-electricity process, is the selection of the most optimum methods to form the hydrogen needed to hydrotreat the coal-derived crude oil stock. Since the coal-to-hydrogen conversion will likely be quite important in several of the coal-liquefaction processes other than the "Project COED" - char gasification study, it has been decided to consider this coal conversion system as a major study area for process optimization and evaluation. The results of this study will be later utilized in the studies of the specific coal to liquid fuel processes.

Work is continuing in the evaluation of cost accounting methods to attempt to determine the unbiased production costs of the individual specific products from a multi-product coal-conversion process. A review of several accounting textbooks indicate that there is no single accounting technique for allocating the cost of a process between the several major products, and each method described has several major disadvantages. Thus, we will need to develop or modify the known and published accounting techniques into a new method which offers the best combination of advantages to fulfill our needs in evaluating the coal conversion systems.

C. Y. Wen

C. Y. Wen, Project Director

OPTIMIZATION OF COAL CONVERSION PROCESSES

PROGRESS REPORT NO. 69
AUGUST 1973

to

The U. S. Office of Coal Research
Contract No. 14-01-001-497

Several key personnel changes among the engineers working on this project have necessitated a reorganization of the project staff. Accordingly, this past month as well as a portion of September will be spent in acquainting the new project staff members with the project history, procedure details and a general understanding of the theory and applications of the optimization methods and systems methodology used to evaluate the numerous coal-to-gas conversion schemes studied during the past several years. The overall project will now consist of three major study directions.

One study will concentrate on evaluating those processes which convert coal into a liquid fuel (coal-oil) as the single product from the coal-conversion plant. This study will simulate the proposed coal-to-liquid flowschemes (Hydrocarbon Research's "Project H-Coal", Consolidation Coal's "CSF Project", Pittsburgh & Midway's "S.R.C. Process", University of Utah's "Western Coal Hydrogen-Liquefaction Process", the U. S. Bureau of Mines Coal Liquefaction Process, etc.), as well as other coal-to-liquid reaction schemes which, to date, have not been formally proposed but which may be found to offer attractive advantages. After simulation and preliminary study, these processes will be optimized and critically examined, following the previously developed techniques and methods used, in the past, to study the coal gasification processes and those process schemes converting coal to low-Btu gas, which is then purified and burned to generate electricity.

Because the raw coal is relatively hydrogen-deficient and a substantial quanitty of hydrogen is needed to convert the coal to either the liquid or the gaseous form, the second portion of the project will evaluate the many methods of efficiently and economically generating hydrogen from air, water and coal. This may involve the direct gasification of the coal to a synthesis gas followed by a shift in the gas composition, by reaction with steam, to form a hydrogen-rich mixture, or the production method may involve the generation of methane and other lower molecular weight hydrocarbons, followed by their reforming reaction to form CO_2 and H_2. After simulation of the various coal-to-hydrogen flowschemes, each of these schemes will be critically evaluated by the use of mathematical optimization techniques and sensitivity analysis mehtods.

The third study area deals with the optimal coordination of several single-product processes to form a multi-product coal-conversion complex, in the pattern of Pittsburgh & Midway's "C-O-G Refinery" or Dr. Arthur Squires' "Coalplex Plant". The initial efforts in this study have been directed at developing a cost-accounting technique which can be used to determine, hopefully without bias, the individual production costs of the several major products being formed in such a process. Such a cost-determining method is needed if alternative flow paths, located internally within the overall process scheme, are to be optimized with respect to lowest production cost and compared. This general approach to evaluating multi-product processes is being initially tested by combining the oil-and-gas producing coal-pyrolysis step of the F.M.C. Corporation's "Project COED" with the utilization of the pyrolysis char to generate electricity, via the combination of an air-blown gasification step, a gas purification-desulfurization subsystem and finally an advanced design gas-and-steam turbine power cycle.

C. Y. Wen, Project Director

OPTIMIZATION OF COAL CONVERSION PROCESSES

PROGRESS REPORT NO. 70
OCTOBER - DECEMBER 1973

to

The U. S. Office of Coal Research
Contract No. 14-01-0001-497

KINETICS OF COAL LIQUEFACTION

Efforts are being made to study the recycle operation in the dissolution of coal in Solvent Refined Coal process. The recycle stream may consist either of unfiltered coal solution, or of a mixture of unfiltered coal solution and distilled liquid product, or of entirely distilled liquid product. Data are extracted from previous Pittsburgh and Midway monthly reports. Material balance is made and the rate of dissolution is calculated in terms of grams of organics dissolved per hour per cubic centimeter of reactor volume. The preliminary kinetic model is then formulated as follows: Rate of dissolution = (rate constant) x (fraction of organics in feed slurry) x (coal/solvent). Thus with the above equation, a reactor design may be made once the feed information and the performance criteria are specified.

The following points are noted from the analyses and screening of the experimental data.

(1) The substitution of synthesis gas for hydrogen is feasible with only very slight sacrifice in dissolution performance.

(2) The partial pressure of hydrogen has little effect on the rate of dissolution above 1400 psia partial pressure.

(3) Different ash levels in coal feed have little effect on overall rate. This suggests that the process can be used to treat a wide variety of high volatile bituminous coal.

(4) The observed rate is higher for a large coal to solvent ratio. The rate seems to tapper off at the coal-to-solvent ratio of around 0.55 as shown in Figure 1.

(5) For coal-to-solvent ratio of less than 0.55, the calculated rate constant is fairly constant and has the value of 0.56 gram/hr-cc.

(6) Arrhenius plot shown in Figure 2 reveals that at temperature around 400°C, the activation energy for the reaction is about 3 to 6 Kcal/g-mole. This suggests that that rate is probably controlled by diffusion mechanism.

(7) Figure 3, indicates that the amount of organic material dissolved increases rather sharply when hydrogen consumption is increased.

Since the SRC process is in many ways similar to the Synthoil Process developed by the Bureau of Mines, further work will be directed in comparing these two processes in an attempt to provide a general model useful for design and optimization of coal dissolution processes.

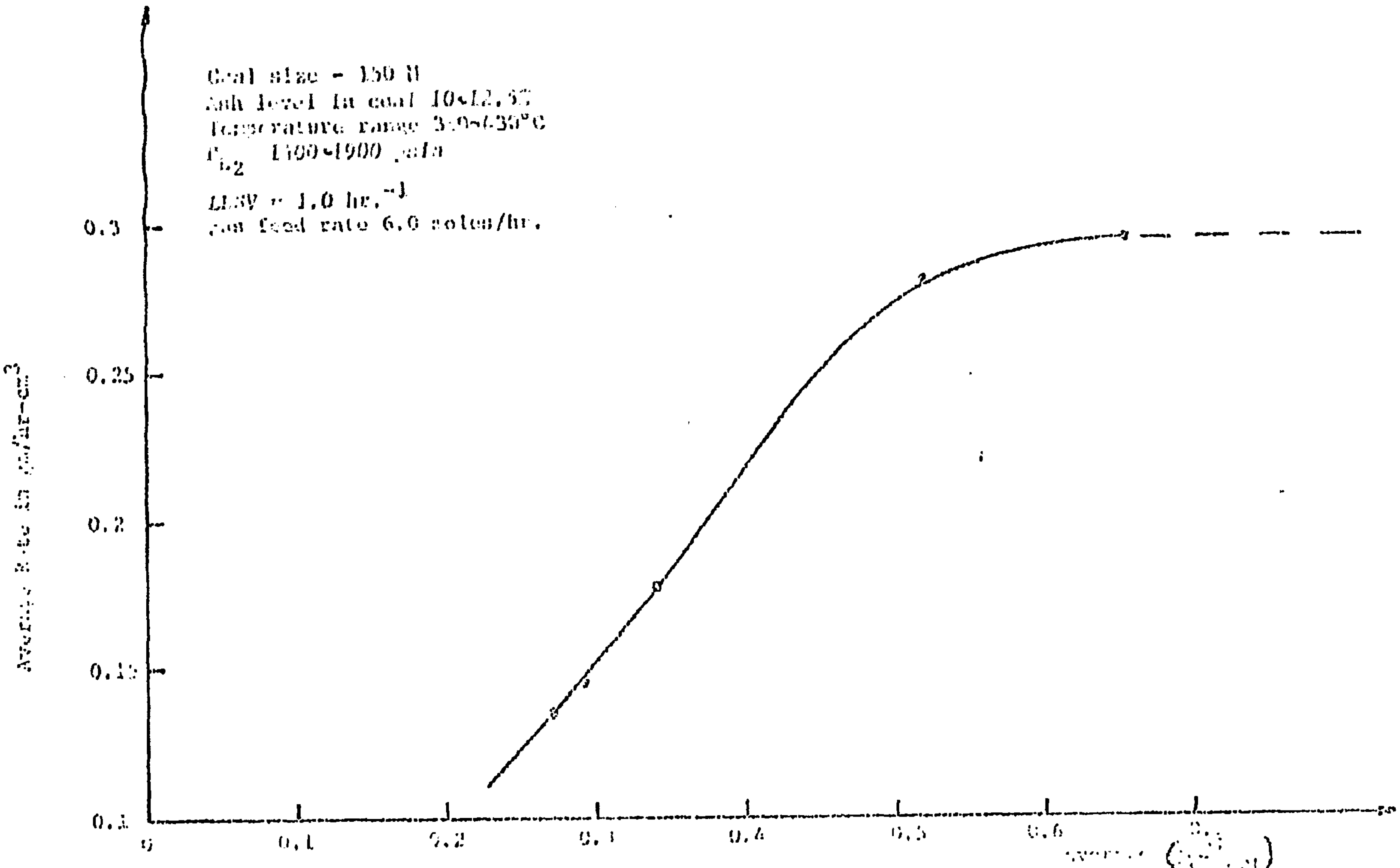
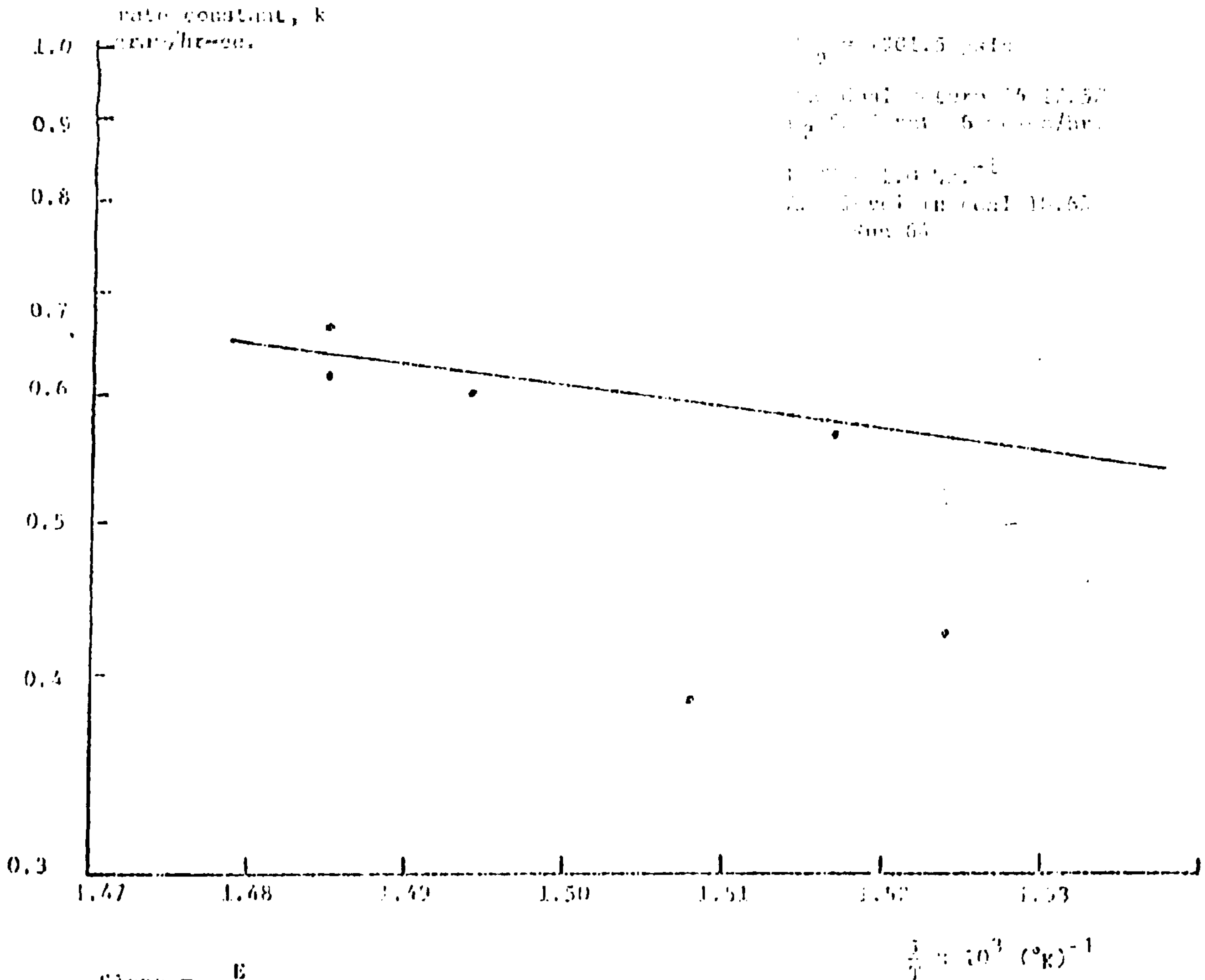


Figure [illegible]. Relationship between Coal to Solvent [illegible]



Slope = $-\frac{E}{R}$

E = $\frac{0.08\ R}{0.42 \times 10^{-[illegible]}}$ = 3.7[illegible]4 Kcal

Figure 2. [illegible]

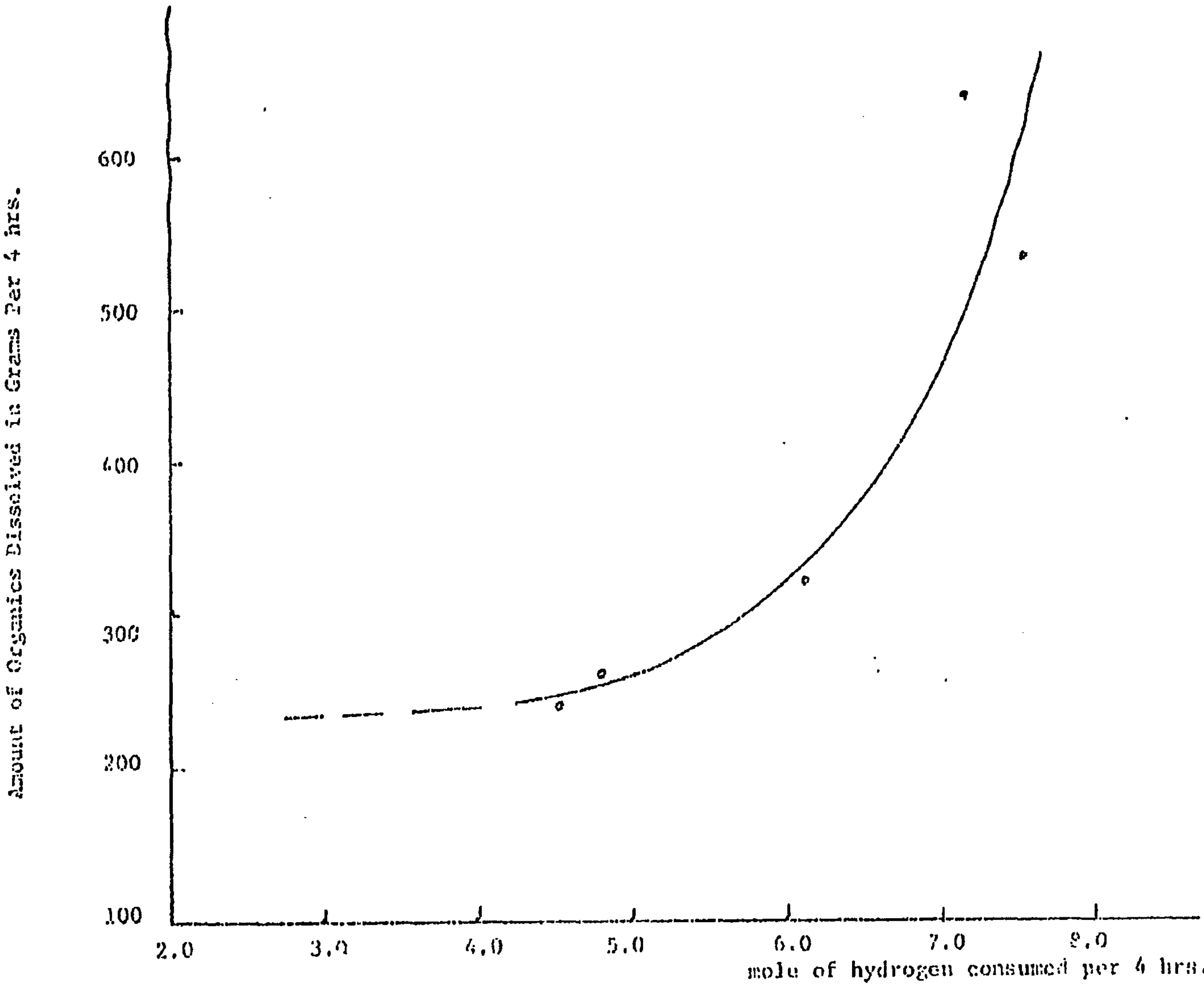


Figure 3. Relation of Organic Dissolved With Respect To Hydrogen Consumed

PRODUCTION OF CRUDE OIL AND ELECTRICITY VIA COED PROCESS

Development of a conceptual commercial design and economic evaluation of the COED coal pyrolysis to produce crude oil have been undertaken in an effort to integrate the gasification of the COED char to produce electricity via Low-Btu gas power generation system.

The integrated plant considered is designed to use a variety of coals including Illinois No. 6 coal to produce the required crude oil and the electricity. Since the COED pilot plant data based on Illinois coal is available (FMC, 1970), a commercial plant design and economic evaluation of the crude oil product based on the same coal has been made by AMOCO (1972). A cost estimation on combined gas-and-steam turbine power generation using coal and COED char was reported by Wen (1973). An integration of this study with the cost estimation of the COED plant designed to produce oil, gas and electricity is now being considered. Some of the process consideration and selections are briefly discussed below.

There are a few ways heat may be supplied to the pyrolysis stages. FMC (1970, 1971) suggested that heat may be supplied by burning the pyrolysis char either with oxygen or with air and steam in the final few stages. Since COED plant is based on the design of the pyrolysis stage in which oxygen is burned, this scheme is considered first.

In the COED pilot plant, the hydrogen gas supplied to the hydrotreating process is of very high purity (above 95%). Experimental results (FMC, 1971) seems to indicate that an increase in hydrogen partial pressure increases the hydrogeneration to cracking ratio slightly. If a small temperature difference is neglected, these experimental results indicate that an increase in partial pressure of hydrogen four folds at constant total pressure increases the yield of gas product by a factor of two but decreases the yield of oil by approximately 10%.

Generally in a commercial plant design, about 90% of the exit gas from the hydrotreating reactor is recycled, the other is vented to the incinerator. The partial pressure of recycled hydrogen may be increased by using make up hydrogen of high purity. If larger quantity of hydrogen gas of low purity, which can be produced by the shift reaction of the COED gas, is used in the make up hydrogen stream, it can be shown that the hydrogen partial pressure differs very little from that by mixing the lower purity hydrogen gas with the recycled gas. This indicates the resulting gas and oil yield from the hydrotreating process does not depend singificantly upon the purity of make up hydrogen gas. Since hydrogen gas can be generated by steam reforming; by partial oxidation of COED gas; or by shifting the synthetic gas produced from COED char reaction with oxygen and steam, hydrogen gas of different purity is available for use in hydrogen make up stream. The gas and oil product yield may be assumed to be proportional to the hydrogen partial pressure in the design if the change in hydrogen concentration is significant.

The steam and gas ratio for the shift reaction in the hydrogen production process has been studied and the data available from previous OCR reports by Wen (1971) can be directly applied. Also, hot potash process for removal of CO_2 and Amine Process for removal of H_2S studied and the material presented in these reports will be used in the process calculation.

In the Low-Btu gas-power generation process, exhaust gas from gas turbine is available at high temperature and can be used to supply heat for coal drying process. A large amount of steam required in the gas shift reaction will also be supplied from the Low-Btu gas steam generated from heat exchangers.

Different alternatives of producing hydrogen gas for the hydrotreating process use will be considered in this plant design program. Further economic evaluation of some of the alternatives will be carried out in the future.

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C. Y. Wen

C. Y. Wen, Project Director

TABLE 1. KINETICS OF COAL LIQUEFACTION EVALUATION OF RATE CONSTANT (RUN 62)

	Rate In gm/hr-c.c.	Conversion = amt. organics dissolved / amt. solid organic feed in	C_s=fraction of organics in feed slurry	Coal/Solvent	Rate Constant $k = \frac{Rate}{C_s'(coal/solvent)}$	$\frac{1}{T}$ (°k)$^{-1}$	Mole of H_2 Used per 4 hr.
1	0.3136	0.6622	0.945	0.6313	0.5256	0.001432	8.03
2	0.3114	0.6542	0.9367	0.6934	0.4794	0.001422	7.63
3	0.2940	0.6949	0.9221	0.6459	0.4936	0.001443	7.72
4	0.2798	0.6629	0.9319	0.7377	0.4070	0.001443	7.18
5	0.2775	0.6222	0.9303	0.6215	0.4799	0.001453	6.95
6	0.2843	0.6367	0.9289	0.5896	0.5190	0.001453	7.69

Ash level in coal = 12.5%
LHSV = 1.0 hr^{-1}
H_2 feed rate = 6.07 moles/hr.
Hydrogen partial pressure = 1430.5 psia
Raw coal in return = 33%
Coal size = -150 M.

TABLE 2. KINETICS OF COAL LIQUEFACTION EVALUATION OF RATE CONSTANT (RUN 63)

	Rate in gm/hr-c.c.	Conversion = amt. organics dissolved / amt. solid organics feed in	C_s=fraction of organics in feed slurry	Coal/Solvent	Rate Constant $k=\frac{Rate}{C_s \cdot (coal/solvent)}$	$\frac{1}{T}$ (°k)$^{-1}$	Mole of H_2 Used per 4 hr.
1	0.1854	0.5948	0.9375	0.3005	0.6581	.00146	5.76
2	0.1796	0.4983	0.9269	0.3248	0.5965	.001464	4.97
3	0.1764	0.5242	0.9169	0.3231	0.5954	.001485	4.65
4	0.1818	0.5424	0.9097	0.3232	0.6183	.001485	4.79
5'	0.1770	0.5005	0.9005	0.3381	0.5813	.001485	5.93
6	0.1664	0.4047	0.8889	0.3795	0.4952	.001485	5.19
7	0.1718	0.4556	0.8960	0.3547	0.5405	.001485	7.80
8	0.1761	0.485	0.8875	0.3506	0.5659	.001485	8.0
9	0.1748	0.4836	0.8778	0.3570	0.5577	.001485	7.38
10	0.1809	0.5144	0.8716	0.3529	0.5881	.0015	6.64

Ash level in coal = 12.5%
LHSV = 1.0 hr^{-1}
H_2 feed rate = 6.07 mole/hr for 1-6
6.3 mole/hr for 7-10

Hydrogen partial pressure = 1430.5 psia for 1-6
= 1906.6 psia for 7-16
Raw coal in return = 20%

TABLE 3. KINETICS OF COAL LIQUEFACTION EVALUATION OF RATE CONSTANT (RUN 64)

Rate in gm/hr-c.c.	Conversion = amt. organics dissolved / amt. solid organics feed in	C_s=fraction of organics in feed slurry	coal/solvent	Rate Constant $k = \frac{Rate}{C_s \cdot (coal/solvent)}$	$\frac{1}{T}$ $(°k)^{-1}$	Moles of H_2 Used per 4 hr.
0.1530	0.4609	0.9623	0.2562	0.6205	.001485	5.40
0.1617	0.5236	0.9484	0.2557	0.6667	.001485	4.20
0.1542	0.4520	0.9330	0.2744	0.6023	.001494	4.06
0.1319	0.2568	0.9097	0.3754	0.3862	.001508	4.76
0.1328	0.2722	0.8896	0.3513	0.4249	.001524	4.15
0.1408	0.3974	0.8766	0.2591	0.6199	.001531	5.36
0.1372	0.3306	0.8727	0.2770	0.5675	.001517	5.76

Ash level in coal = 10.6%
LHSV = 1.0 hr^{-1}
H_2 feed rate = 6.0 moles/hr.
Hydrogen partial pressure = 1901.5 psia
Raw coal in return = 15-17.5%
Coal size = -150 M.

TABLE 4. KINETICS OF COAL LIQUEFACTION EVALUATION OF RATE CONSTANT (RUN 65)

Rate In gm/hr-cc.	Conversion = amt. organics dissolved / amt. solid organic feed in	C_s=fraction of organics in feed slurry	Coal/Solvent	Rate Constant $k = \frac{Rate}{C_s \cdot (coal/solvent)}$	$\frac{1}{T}$ $(°k)^{-1}$	Mole of H_2 Used per 4 hr.
0.1341	0.373	0.8741	0.2638	0.5815	.001531	4.44
0.1308	0.344	0.8711	0.2777	0.5407	.001508	4.48
0.1351	0.388	0.8662	0.2691	0.5795	.001485	4.64

Ash level in coal = 10.6%
LHSV = 1.0 hr^{-1}
Gas feed rate = 6 moles/hr. (H_2+CO)
Hydrogen partial pressure = 1426.1 psia
Raw coal in return = 15%
Coal size = ±150 M.

TABLE 5. KINETICS OF COAL LIQUEFACTION OF RATE CONSTANT (RUN 66)

Rate In gm/hr-c.c.	Conversion = amt. organics dissolved / amt. solid organic feed in	C_s=fraction of organics in feed slurry	Coal/Solvent	Rate Constant $k = \frac{Rate}{C_s \cdot (coal/solvent)}$	Mole of H_2 Used per 4 hr.
0.2790	0.7991	0.9650	0.5163	0.5599	6.82
0.2925	0.8092	0.9644	0.5157	0.5881	7.11
0.2845	0.8161	0.9645	0.5184	0.5290	7.34
0.2814	0.8186	0.9644	0.5173	0.5640	7.53
0.2863	0.8212	0.9655	0.5171	0.5734	5.92
0.2839	0.8189	0.9647	0.5164	0.5698	6.92
0.2796	0.8191	0.9643	0.5175	0.5602	7.38
0.2785	0.8160	0.9642	0.5175	0.5581	6.95
0.2785	0.8159	0.9645	0.5175	0.5579	( ) not available
0.2762	0.8210	0.9663	0.5177	0.5521	8.18
0.2889	0.8287	0.9665	0.5171	0.5780	8.26
0.2801	0.8255	0.9674	0.5168	0.5602	6.27
0.2784	0.8145	0.9664	0.5167	0.5575	7.10

Ash level in coal = 10.6%
LHSV = 1.0 $hr.^{-1}$
H_2 feed rate = 6 moles/hr
Hydrogen partial pressure = 1429.6 psia
Raw coal in return = 33%

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Technical Information Service
Springfield, VA 22161 (703) 605-6000