Section 16

PRESENT STATUS OF THE U-GAS PROCESS

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ABSTRACT

The U-GAS process has been developed by the Institute of Gas Technology to produce a low- to medium-Btu fuel gas from a variety of feedstocks. Tests with different feedstocks have achieved 98% coal utilization with long-term steady-state operation. Reliable techniques have been developed for start-up, shutdown, turndown, and process control. Operation of an IGT pilot plant has firmly established the process feasibility, and has produced a wealth of design data for various coals from three continents.

The process has been selected by Charbonnages de France, the French national coal company, as the design basis for a demonstration plant to be constructed in France. Recently, tests have been conducted in the pilot plant to obtain specific design information for use of the process to generate electrical power. The process has attracted worldwide interest; as a result, several new engineering studies and evaluations are in progress.

PRESENT STATUS OF THE U-GAS PROCESS FOR POWER GENERATION

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INTRODUCTION

The Institute of Gas Technology (IGT) has developed an advanced single-stage, fluidized-bed coal gasification process — The U-GAS process — to produce a low- to medium-Btu gas from a variety of feedstocks including highly caking, high-sulfur, and high-ash coals. The three main goals for developing the new gasification process have been: 1) economical handling of large volumes of gas throughput, 2) high carbon conversion of coal to gas without producing tar or oil by-products, and 3) minimum insult to the environment.

The process represents the fruition of research and development in progress at IGT since 1974. The product gas from the process will be low-Btu gas, usable as a fuel, when operating with air, or medium-Btu (fuel) or synthesis gas when operating with oxygen. The medium-Btu or synthesis gas can be used directly as a fuel, can be converted to substitute natural gas, or can be used for production of chemical products such as ammonia, methanol, hydrogen and oxo-chemicals. It can also be used to produce electricity generated by a combined cycle or by fuel cells.

PROCESS DESCRIPTION

The U-GAS process accomplishes four important functions in a single-stage fluidized-bed gasifier (Figure 1): It decakes coal, devolatilizes coal, gasifies coal, and agglomerates and separates ash from the reacting char. Other process characteristics are listed in Table 1.

In the process, coal (1/4 inch x 0) is dried only to the extent required for handling purposes. It is injected pneumatically into the gasifier through a lockhopper system. Within the fluidized bed, coal reacts with steam and oxygen (air can be substituted for oxygen) at temperatures of 1750° to 2000°F. The temperature of the bed depends on the type of coal feed and is controlled to maintain nonslagging conditions for ash. The operating pressure utilized depends on the ultimate use of product gas and may be varied, as required, between 50 and 450 psig. At the specified conditions, coal is gasified rapidly, producing a gas

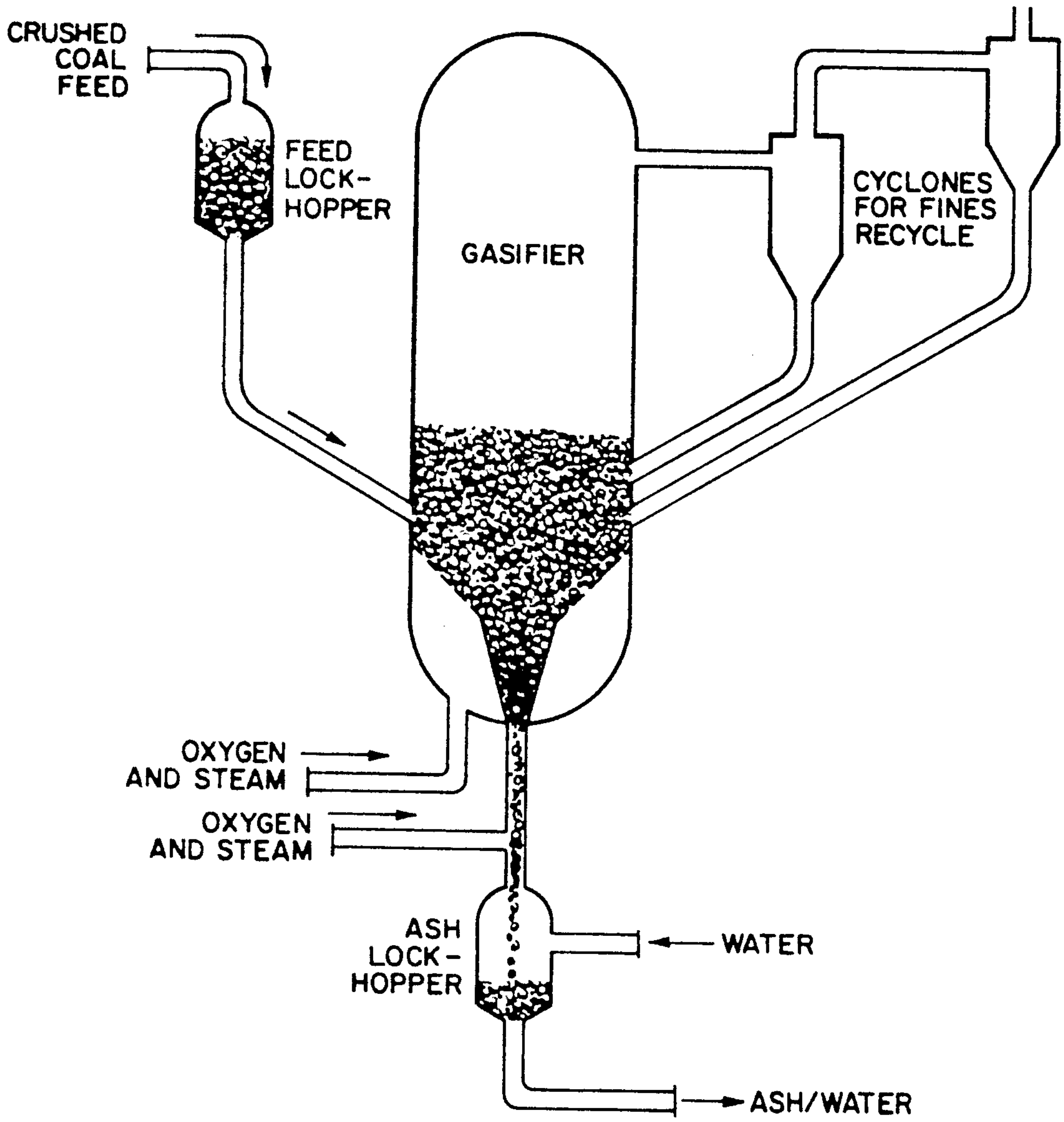

Figure 1. SCHEMATIC DIAGRAM OF THE U-GAS GASIFIER

Table 1

U-GAS PROCESS CHARACTERISTICS

- High Conversion of Coal to Gas Using the Ash-Agglomerating Technique
- Capability to Gasify All Ranks of Coal
- Ability to Accept Fines in Coal Feed
- Simple Design; Safe, Reliable Operation
- Ease of Control; Ability to Withstand Upsets
- Product Gas Virtually Free of Tar and Oils
- No Environmental Problems
- Operation at Lower Temperature Than That Used With Slagging Gasifiers
- Large Turndown Capability
- Large Unit Capacity

mixture of hydrogen, carbon monoxide, carbon dioxide, and a smaller fraction of methane. Because reducing conditions are always maintained in the bed, nearly all of the sulfur present in the coal is converted to hydrogen sulfide.

Simultaneous with coal gasification, the ash is agglomerated into spherical particles and separated from the bed. Part of the fluidizing gas enters the gasifier through a sloping grid. The remaining gas flows upward at a high velocity through a venturi and forms a local hot zone within the fluidized bed. The temperature within the hot zone is higher than at other locations in the bed; therefore, high-ash-content particles agglomerate and grow into larger and denser particles. Agglomerates grow in size until they are selectively separated and discharged from the bed into water-filled ash hoppers where they are withdrawn as slurry. In this manner, the fluidized bed achieves the same low level of carbon losses in the discharge ash generally associated with the ash-slagging type of gasifier.

Coal fines elutriated from the fluidized bed are captured in two external cyclones. Fines from the first cyclone are returned to the bed; fines from the second cyclone are returned to the ash-agglomerating zone, where they are gasified and the ash is agglomerated with bed ash. The raw product gas is virtually free of tar and oils, thus simplifying the ensuing heat recovery and purification steps.

PILOT PLANT DEVELOPMENT

Most of the U-GAS process development work has been accomplished on a pilot plant put into operation in 1974. The development program has been funded by the U.S. Department of Energy (DOE) and the American Gas Association.

The pilot plant is located at IGT's test facilities in southwest Chicago. It consists of a gasifier and all required peripheral equipment with utilities and other support services. Most of the equipment is contained in an enclosed structure about 100 feet high. Figure 2 is an exterior view of the U-GAS plant. Figure 3 is a schematic diagram of the plant. Detailed descriptions of pilot plant test results are included in the literature (1, 2, 3, and 4). Table 2 is a chronological listing of the process development activities in the pilot plant.

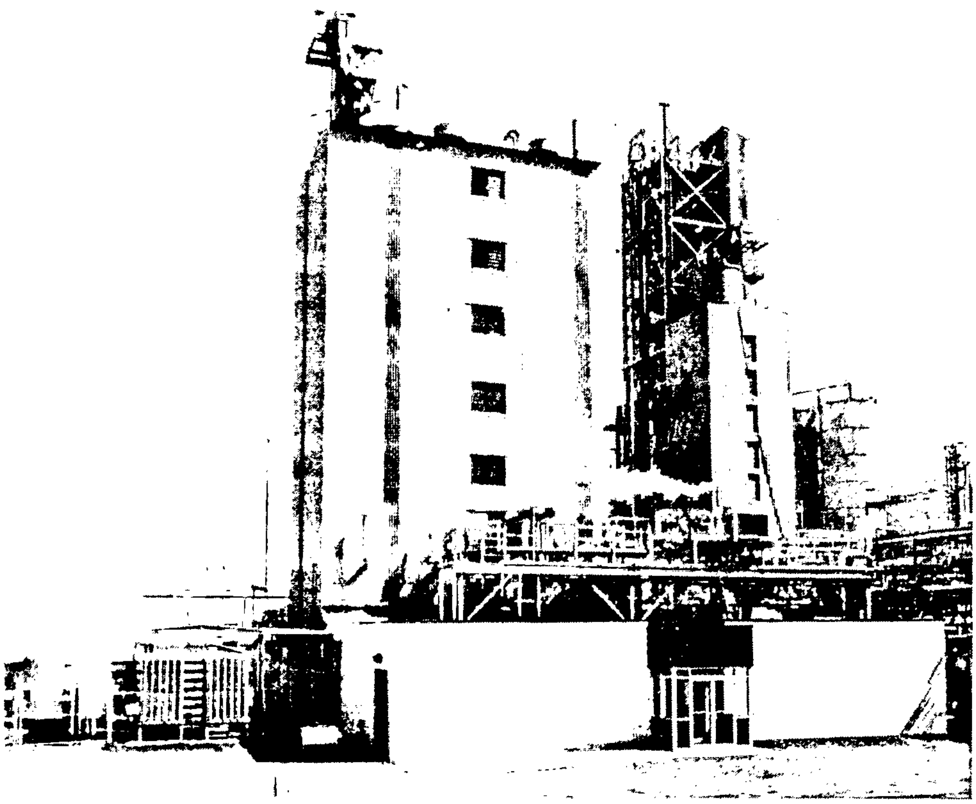

Figure 2. VIEW OF THE U-GAS PILOT PLANT

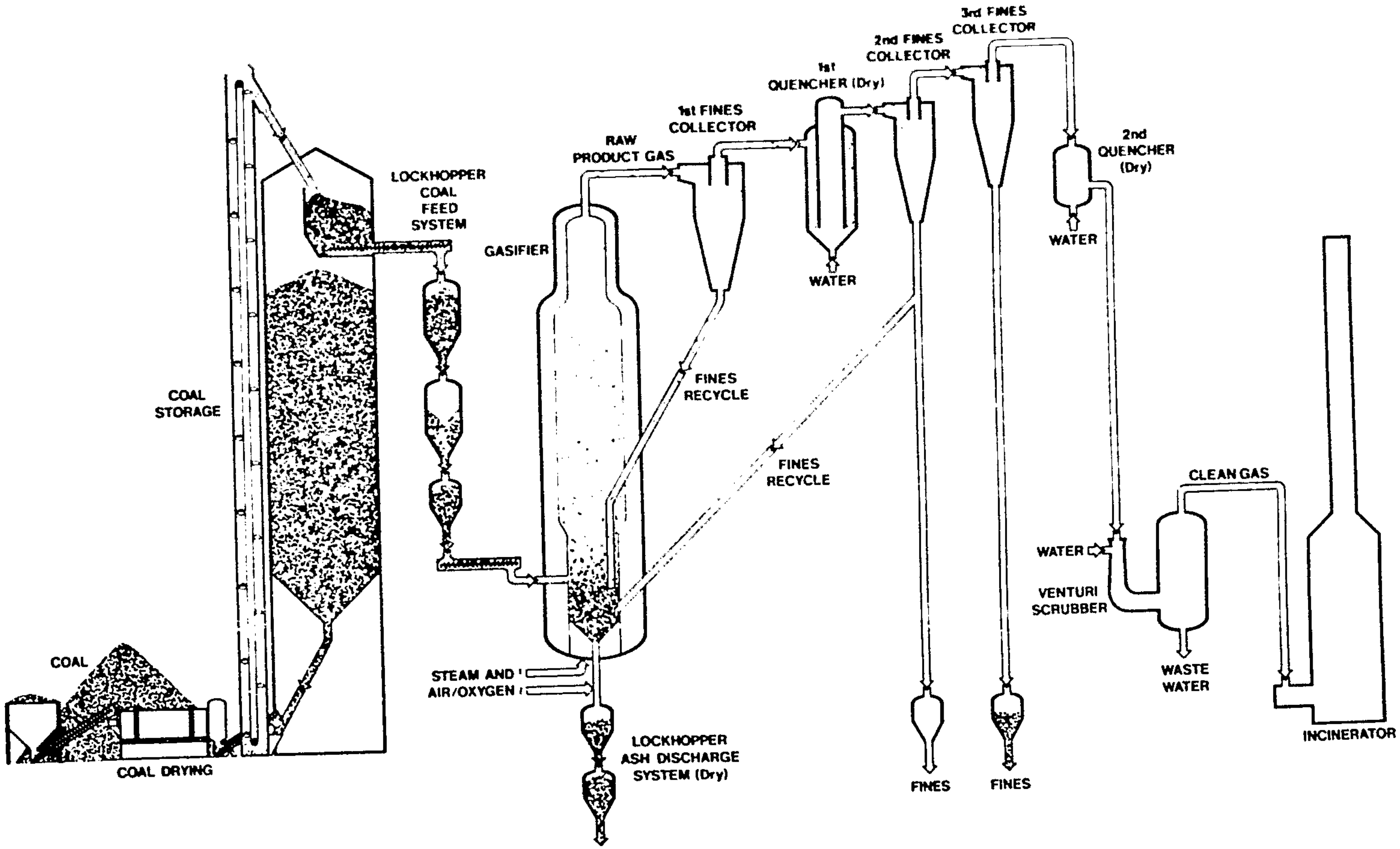

Figure 3. PROCESS FLOW SCHEMATIC OF THE U-GAS PILOT PLANT

Table 2

TESTING HISTORY IN THE U-GAS PILOT PLANT

Period	Number Of Tests	Function
1974	9	Equipment Shakedown
1974-1975	53	Process Feasibility
1975	13	Testing High-Reactive Small Size Feed
1977	4	Shakedown of Modified Pilot Plant
1977	7	Testing High-Reactive Feedstock
1977	6	First Bituminous Coal Trial Tests
1978	8	Testing Unwashed High-Ash Feedstock
1978-1982	25	Demonstration/Commercial Plant Design Data
1980	3	Testing Highly Caking Feedstock
1981	3	Coal Verification Tests With Different Feedstocks for Clients
1983	2	Coal Verification Tests With ROM French Coal
1984	1	Coal Verification Test With ROM Utah Coal (Air and Enriched-Air Gasification)

A total of 10,000 hours of U-GAS process operating time has been logged. The operating time cited represents more than 120 tests conducted with about 3600 tons of various coals from throughout the world. Several tests have been run continuously in excess of 2 weeks, providing long steady-state operating periods with excellent mass and energy balance closures.

PROCESS VERSATILITY

The main attraction of the U-GAS process is its versatility. Pilot plant tests have shown that it can gasify a wide variety of coals with high conversion efficiency; therefore, a U-GAS gasifier can be considered a "universal gasifier".

A wide variety of feedstocks from the United States and other countries has been used to determine process sensitivity to variables including ash content, ash properties, particle size, reactivity, free-swelling index, and nature and percentage of volatile matter. Ten types of coal and three types of char have been tested in the pilot plant; these are listed in Table 3. The feedstocks for testing have been selected to cover a wide range of important coal properties that could have significant effects on gasification and ash agglomeration. The range of the feedstock properties is shown in Table 4.

Table 3

U-GAS GASIFIER FEEDSTOCKS

- Western Kentucky No. 9 Bituminous (both washed and unwashed)
- Western Kentucky No. 11 Bituminous
- Illinois No. 6 Bituminous
- Pittsburgh No. 8 Bituminous
- Australian Bituminous
- Polish Bituminous
- French Bituminous (unwashed)
- Utah Bituminous (unwashed)
- Montana Subbituminous
- Wyoming Subbituminous
- Metallurgical Coke
- Western Kentucky Coal Char
- Illinois No. 6 Coal Char

Table 4

RANGE OF U-GAS GASIFIER FEEDSTOCK PROPERTIES

Moisture, *%	1 to 32
Volatile Matter, **%	3 to 43
Ash, **%	6 to 35
Sulfur, **%	0.5 to 4.6
Free Swelling Index	0 to 8
Ash Softening Temperature, °F	1980 to 2490
°C	1080 to 1370
Gross Heating Value,* Btu/lb	7,580 to 12,650
kJ/kg	17,631 to 29,424

* As received
** Dry basis

All feedstocks are 1/4 inch x 0 in size and are fed to the gasifier without any removal of fines. Coal is fed directly into the fluidized bed of the gasifier without any pretreatment, regardless of caking tendencies (free swelling index). For bituminous coals, both washed and unwashed coals have been successfully tested to determine the effects of the large quantity of clay and shale that is present in the unwashed run-of-mine (ROM) coals.

Recent tests with the French coals have shown that the process can handle both high-ash-content feedstocks and those with a continually changing percentage of ash. This process flexibility is possible because the U-GAS reactor tolerates fluctuation in both the fluidized-bed height and the fluidized-bed carbon/ash ratio. Unlike slagging ash gasifiers, the U-GAS process also can handle coals having very high ash-fusion temperatures. This is possible because the process requires only softening of ash particle surfaces, not melting of the ash. Pilot plant tests have achieved coal conversion efficiency of above 97% with coal that has ash fluid temperatures exceeding 2700°F. Tests with highly reactive coals have also been successful. With these coals, the bulk of the fluidized bed operates at the relatively low temperature needed for gasification; ash agglomeration is achieved by maintaining a higher temperature zone in only a small portion of the fluidized bed.

The process is able to operate with either oxygen/steam or air/steam. The heating value of the product gas is affected by the presence of nitrogen when using air. All other process performance, including the coal conversion efficiency, is unaffected by the choice of the oxidant.

RECENT PILOT PLANT TEST RESULTS

French Coal Test

A French Merlebach coal was successfully gasified in the U-GAS process pilot plant during two tests conducted for Charbonnages de France (CdF). The first test provided useful information on operational characteristics of the coal. The second test yielded a long steady-state operating period during which all of CdF's test objectives were achieved. These objectives were: 1) demonstrate the operability of the U-GAS process with the high-ash French coal, 2) maximize coal conversion efficiency, 3) produce a good-quality product gas, and 4) obtain data for the design of a demonstration plant.

During the second test, the plant was operated continuously for 4 days. In this test period, 48 tons of coal were gasified during 2-1/2 days of steady-state operation. Ash-agglomerating and ash-balanced operations were maintained during three different set-point operating conditions. A coal conversion efficiency higher than 95 percent was maintained continuously during the last two set points. The overall coal conversion results are shown in Figure 4. The test was terminated voluntarily.

Throughout the test, the gasifier was able to handle both the high ash content (ave. 30%) and its variability (20 to 35 wt %). In addition, because the coal was unwashed, it contained a large quantity of shale, which was also handled by the gasifier without any detrimental effect on operations.

Recycle of fines from both cyclones was achieved. Successful recycle demonstrated conclusively: 1) that the fines could be gasified to extinction, 2) and that the resultant fine ash was agglomerated to, and discharged along with the bed ash (through the venturi) without any buildup of fines or ash in the gasifier system.

The pilot plant test showed that the ash of the Merlebach coal can be agglomerated readily in the U-GAS process. This was demonstrated by classification and withdrawal of only high ash content material through the ash-withdrawal device.

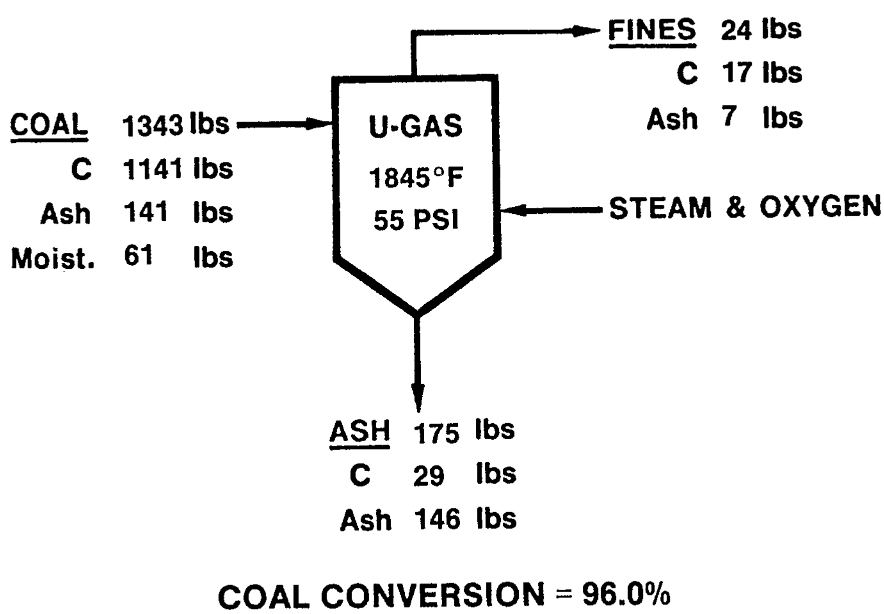

Figure 4. OVERALL RESULTS OF THE TEST CONDUCTED WITH FRENCH COAL

Utah Bituminous Coal Test

A Utah bituminous coal was gasified in a U-GAS pilot-plant test conducted for ANR Technology Co. (ANR). The test confirmed the feasibility of producing low-Btu gas by gasifying the coal with air and steam. ANR was interested in using air instead of oxygen as the gasification medium. Even though — in past testing — different types of bituminous coals were used in the pilot plant, there was no experience with a Western bituminous coal. In addition, during the last four years of pilot plant testing, emphasis had been on oxygen-steam gasification to produce a medium-Btu gas. The recent process developments, therefore, were not evaluated under air-steam gasification. Because of these circumstances, this test for ANR was a severe test of the U-GAS process utilizing both a new coal feedstock and a different gasification agent in the same test.

The test was successful in achieving all of ANR's predetermined test objectives. These objectives were: 1) to prove the feasibility of producing low-Btu gas by gasifying the coal with air and steam, 2) to maximize coal conversion efficiency, 3) to gasify coal with enriched air, 4) to investigate gasifier turndown, 5) to test gas desulfurization using limestone, 6) to evaluate a high-temperature coal-dust filter, 7) to test combustion characteristics of the low-Btu product gas, and 8) to obtain data for design of a commercial plant.

The pilot plant was operated for six days during which 58 tons of the Utah coal were gasified. Steady-state, ash-balanced operations were maintained for six different set-point operating conditions. The fines from the primary cyclone were recycled during all six set points, and the fines from the secondary cyclone were recycled during five of the six set points. The coal conversion efficiency was 93 to 99% during the various set-point operating conditions, as shown in Figure 5. The test was voluntarily terminated when all the test objectives were completed.

Gasification was carried out both with air and steam, and with enriched air (34% oxygen) and steam. The heating value of the low-Btu product gas was varied between 75 and 171 Btu/SCF. The heating value of the low-Btu gas was lower than expected in a commercial plant, due to 1) the high heat losses relative to the reactor coal-feed capacity, and 2) excessive cooling of recycled fines in the primary water-jacketed cyclone.

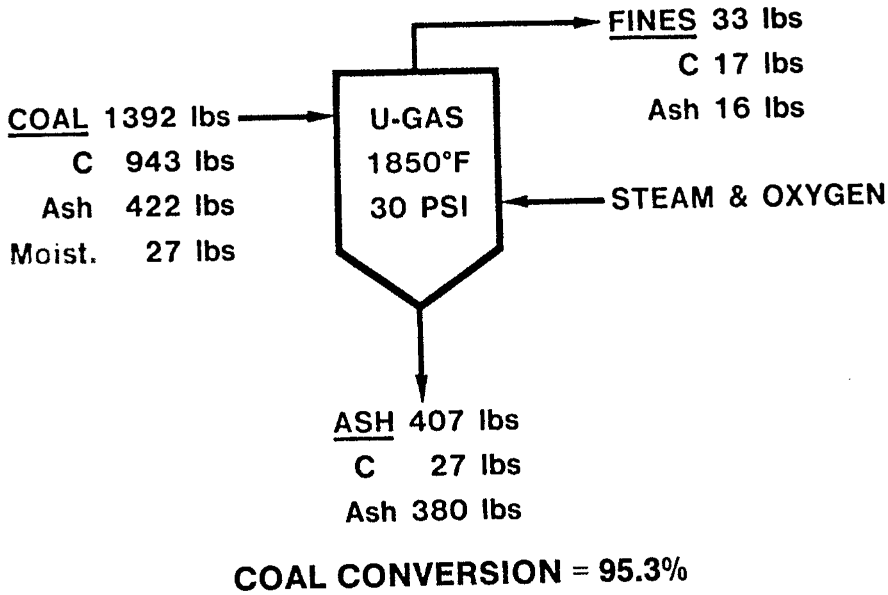

Figure 5. OVERALL RESULTS OF THE TEST CONDUCTED WITH UTAH COAL .

During one of the set points, the ability of the gasifier for turndown was demonstrated by reducing the gas-production rate by half. The capability of the gasifier to be banked was demonstrated also during some mechanical failures encountered during the test. For example, the coal-feed system was shut down for almost ten hours to repair the variable-speed feed mechanism. During this period the gasifier was maintained in a "hot, standby" position, and restarted without any problems after the repairs were completed. During typical plant upsets, the gasifier was able to respond in a controlled and logical fashion without major interruptions in gas production.

As part of the overall program, three special tests were conducted that were aimed to improve the performance and economics of commercial low-Btu gas plants. In one of them, limestone was injected into the fluidized bed along with coal to test the capture of sulfur compounds generated during gasification of coal. The addition of limestone was found to have no adverse effects in the gasifier, ash discharge, or fines recycle. Data indicate that a large portion of the spent limestone exited the gasifier as $CaSO_4$ rather than CaS. The former is the preferred by-product because of its stability in an atmospheric environment. The degree of sulfur reduction in the product gas could not be precisely determined due to difficulty in measuring the relatively low concentration of sulfur compounds because the coal contained only 0.6 wt % sulfur.

Another special test evaluated the high-temperature coal fines filter. If coal fines could be removed from the low-Btu product gas at high temperatures (1000° to 1500°F), then product gas could be utilized directly, thus simplifying the commercial plant design and improving efficiency and economics. A hot ceramic candle filter was installed in the pilot plant on a slipstream after the primary cyclone. The filter operated during the test in a completely automatic mode throughout the six-day test and removed all the dust from the hot product gas. There was no blinding of the filter medium or any continuous increase in pressure drop or cycle time of the filter system.

The combustion characteristics of the low-Btu product gas resulting from operations at three of the set points were evaluated in a specially-installed burner and furnace for this test. Stable combustion was achieved with gases from all set-points. The SO_2 and NO_x emissions were measured during the combustion tests; in addition, both thermal and fuel NO_x formations were determined.

The overall conclusion of the test is that the U-GAS process can produce low-Btu gas from Utah coal at a very high coal conversion efficiency over a wide range of operating conditions. Based on the results of the test, ANR has contracted with an A and E company to prepare a site-specific design and cost estimate for a U-GAS-based plant to provide low-Btu gas.

COMMERCIALIZATION

The process is attracting worldwide interest and the first steps in its commercialization are being taken. A large number of engineering studies and designs are in progress for plants in the United States and other countries. The U-GAS® technology is currently available for licensing from GDC, Inc., a wholly-owned subsidiary of IGT.

MEMPHIS PROJECT

The U-GAS process was selected by Memphis Light, Gas and Water Division (MLGW) of the City of Memphis and the U. S. Department of Energy (DOE) under a competitive procurement known as the Industrial Fuel Gas Demonstration Plant Program. The MLGW coal gasification plant was to be sited on the Mississippi River in southwest Shelby County, Tennessee. The plant was designed to produce 175 million SCF per day of gas with a heating value of about 300 Btu per SCF from about 3160 tons per day of Western Kentucky bituminous coal. Product gas would be distributed by relatively short pipelines to industrial customers in the greater Memphis area for use as industrial fuel and for process heat applications.

Under the joint DOE-MLGW program, the preliminary design of the plant was completed at the end of 1979. In February 1980, DOE signed a contract with MLGW to proceed with the detailed design, construction, and operation of the plant. In June of 1981 the Federal Government decided to withdraw the DOE commitments to participate in all demonstration plant projects, including the Memphis project. Because the detailed engineering work was continued, however, about 45% of it has been completed. The Environmental Impact Statement had been approved by the appropriate government agencies, thus clearing all requirements for starting site work and construction. A consortium of MLGW and others had applied to the Synthetic Fuels Corporation (SFC) for financial assistance in 1982. After 2 years of negotiations, however, a satisfactory agreement could not be reached with SFC. At this time the partners could not bear the burden of carrying the project and decided to cancel it in April 1984.

During the Memphis Project about $65 million were spent to establish a firm design basis and to complete the mechanical design of the plant. Although the project did not move forward, valuable experience was gained in transferring the pilot plant knowledge into mechanical design of a commercial gasifier that should be very useful in any future commercialization efforts.

A flow diagram of the MLGW plant appears in Figure 6. The plant would consist of four gasifiers (three operating plus one spare). Coal is fed to each gasifier through a lockhopper system. Raw product gas, after particulate removal by cyclones, would be cooled by a heat-recovery boiler where process steam would be generated. The cooled gas, containing dust and trace impurities, would be water-scrubbed to remove particulate matter. The saturated raw gas would be dried and compressed before gas treating in a SELEXOL unit to remove sulfur. The clean fuel-gas would then be odorized and metered before entering the pipeline system for distribution. Sulfur would be recovered from the SELEXOL off-gases by the Claus process, and its tail gas would be treated in a Beavon-Stretford unit.

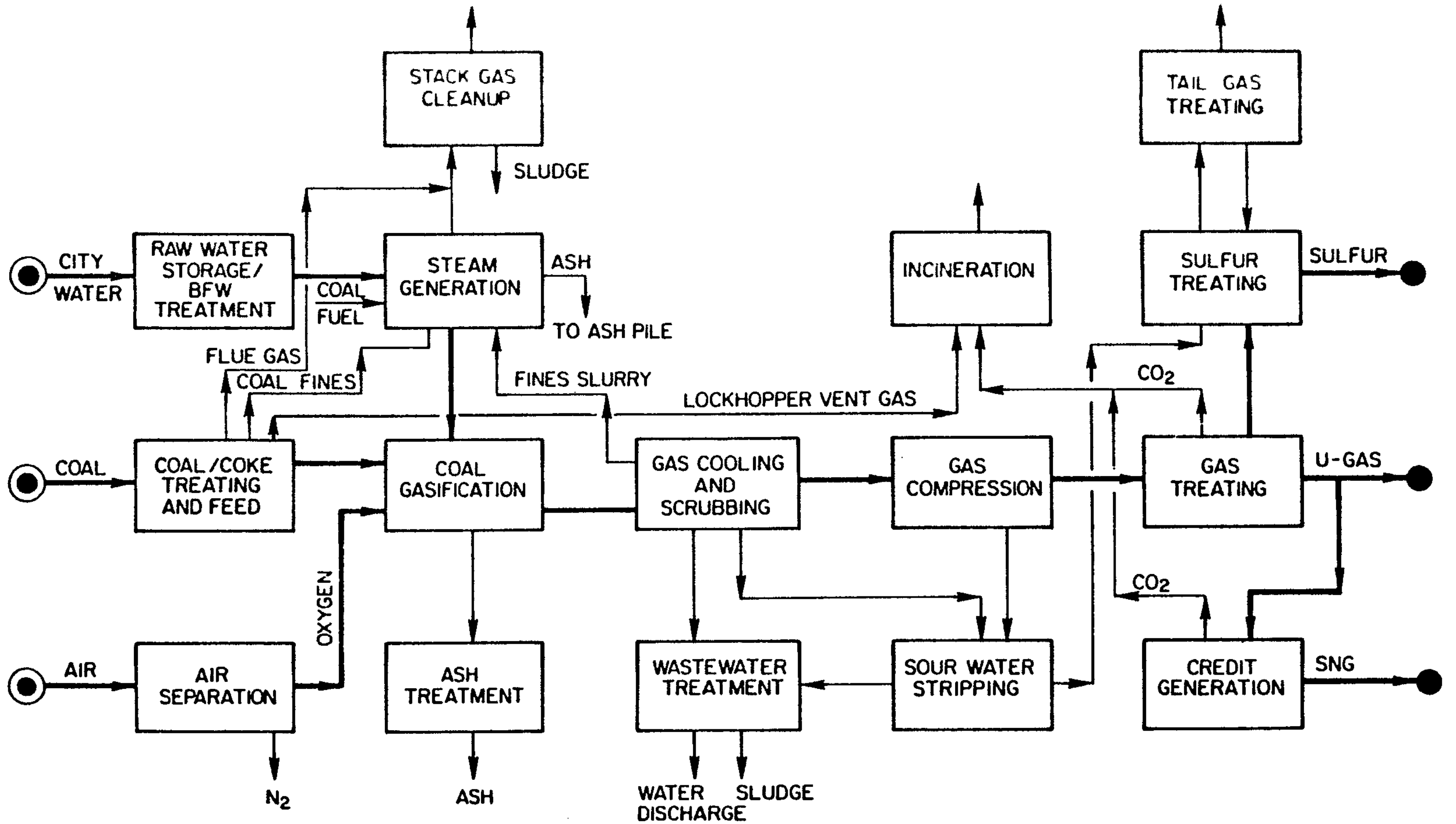

Figure 6. DEMONSTRATION PLANT FLOW DIAGRAM

FRENCH PROJECT

In the early 1980's, Charbonnages de France decided to establish a position in the field of coal gasification. A study on existing coal gasification technology showed that they had some shortcomings in meeting the anticipated future requirements for flexible coal gasification technologies. The study also found that in order to overcome these limitations in all or in part, considerable work had been performed during the past 10 years in the United States, in West Germany, and in Great Britain, on new processes.

An analysis by CdF of the state of progress of this work has shown:

- There is still time, in association with a process licensor, to take part in commercialization of a second-generation process with a true hope of being able to produce profits from such contributions, between now and the end of the 80's.
- It would be a mistake to think that CdF could reach such a target alone, for reasons of time and finance. It is, particularly, a mistake to hope to attain sufficient credibility to market such a gasifier.
- Only circulating beds and fluidized beds allow the reasonable hope of developing gasification processes to produce clean gas under pressure, using various types of coal having different physical-chemical characteristics.
- The fluidized-bed processes available were limited to three: U-GAS, Westinghouse, and Lurgi. U-GAS and Westinghouse, that make use of agglomerated-ash fluidized beds, were both at the 30-tons-per-day pilot stage and their developers were looking for partners who wanted to take an active part in the commercialization phase. Lurgi was considering the development of a circulating fluidized-bed process and was also looking for partners.

In October 1982, Charbonnages de France launched a long-term coal demonstration plant project and negotiations with process licensors. The purposes of this project are:

- To estimate the technical potentialities of each of the processes, and,
- To draw up an appropriate research and development program, depending on the degree of development of each process.

By signing a licensing agreement with IGT/GDC in June 1983, CdF made the decision, among others, to build and operate a 201 tonnes-per-day, 30-bar pilot unit, a stage that was believed to be essential to scaling this gasification process at that pressure to an industrial size without incurring major risks.

MAZINGARBE DEMONSTRATION PLANT

Selection of the Mazingarbe (Figures 7 and 8) site for the pilot gasification plant resulted from a study that showed that the site possesses a number of advantages, that include:

- industry and manpower in the region have long been accustomed to coal mining;
- the unit can be located in a plant of the CdF group (Azote et Produits Chimiques, or "APC");
- utilities are available;
- part of the gas produced can be used within the plant;
- railways are available;
- a coal analytical facility is located nearby;
- other facilities of the group such as laboratories, workshops, and engineering offices, are also located nearby;
- coal can be supplied easily; and
- the plant is easily accessible from Paris, from the Lille Lesquin airport, and from Amsterdam.

The capacity of the plant gasifier will be 8.4 tonnes per hour (201 tonnes per day) of coal and it will operate at pressures up to 30 bar absolute.

The unit will be designed to test a wide variety of coals in order to maintain its function of a demonstration unit. A simplified flow-sheet of the plant is shown in Figure 9.

The various types of coals to be tested will be stored on the coal storage grounds of the Mazingarbe coking works.

The coal will be taken from the stockpile by trucks (10 to 12 truckloads per day) and will be discharged into a hopper feeding two 3000-tonne coal storage silos and one 100-tonne coke breeze storage silo.

The coal will then be screened and crushed to a size of 0-6 mm and dried to a 5 percent surface moisture.

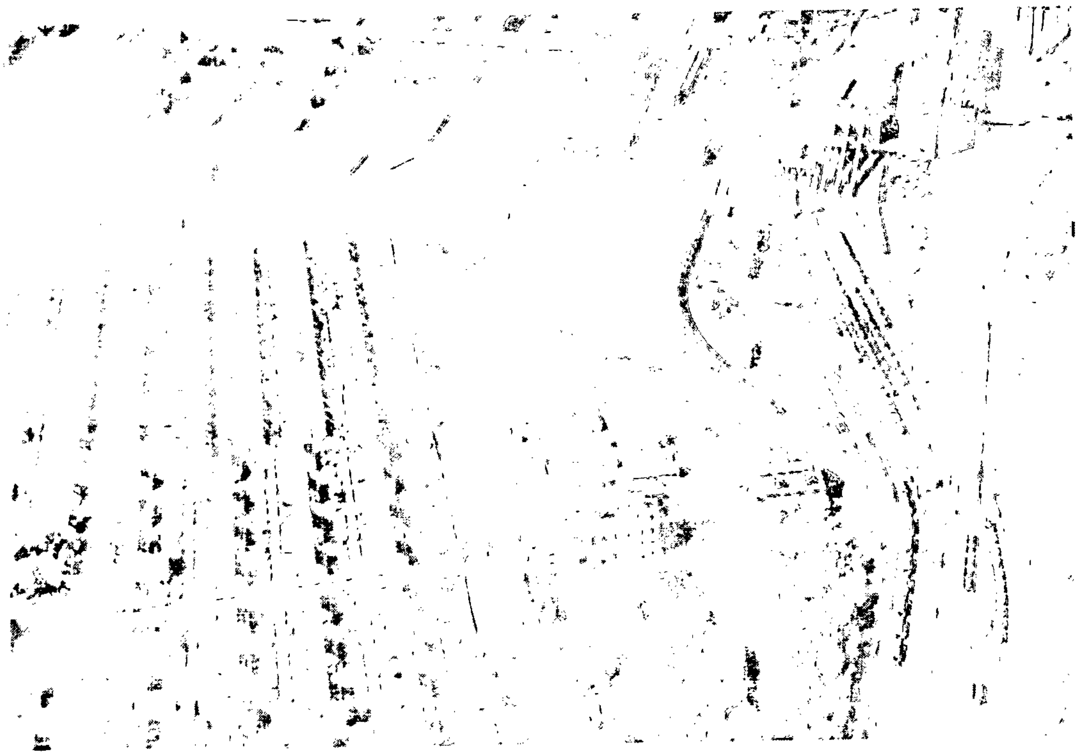

Figure 7. GENERAL VIEW OF THE SITE

Figure 8. SITE FOR IMPLEMENTATION OF THE JOINT DEMONSTRATION

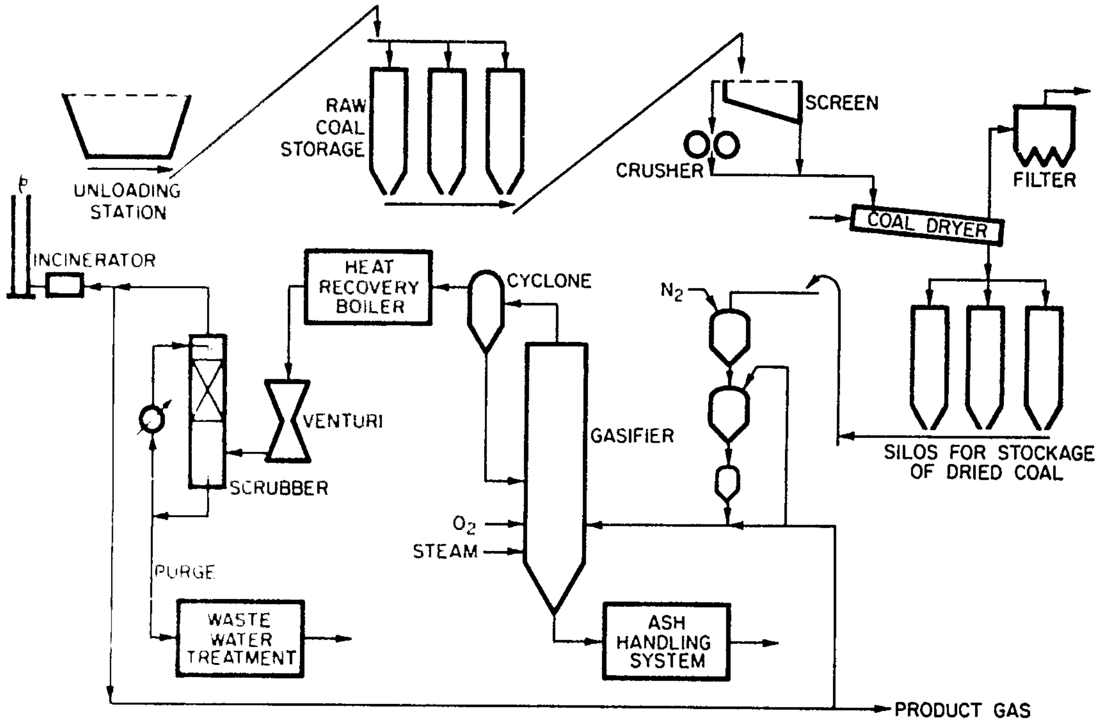

Figure 9. CdF PLANT PROCESS FLOW DIAGRAM

The dried coal will then be stored in silos providing a reserve upstream of the gasifier (two 200-tonne silos for coal and one 200-tonne silo for coke dust).

The system of feeding coal to the gasifier will consist of a set of hoppers pressurized under nitrogen or recirculated gas to the same pressure as the gasifier.

The gasifier will consist of two cylindrical sections. The bottom of the lower cylinder is fitted with a grid and ash-discharging device. The upper cylinder, of greater diameter, forms the gas-release or disengaging zone. The grid allows passage of the bed-fluidization gas and circulation of the char and ash toward the central jet. The venturi acts as an ash-extraction valve and also serves to introduce the oxygen needed for ash agglomeration and gasification.

The gasifier is designed to allow a certain latitude for adjustments of the following parameters — coal feed rate, steam and oxygen flows, and operating pressure.

The plant includes two cyclones that provide separation and recirculation of fines to the gasifier. The ashes removed are cooled, and evacuated by trucks.

Gas cooling and final removal of dust from the gas will take place in a venturi scrubber and in cooling vessels. Part of the gas will be burned in boilers of the APC Company. The remainder will be burned in an incinerator specially provided for the purpose. The gas-cooling circuit drain water will be treated before being discharged.

Operation and control of the whole unit will be carried out from a central control room. The instruments required to provide the analyses needed for control and operation of the gasification unit will be provided in addition to those already existing on site.

Finally, CdF will provide laboratory facilities (hot and cold models) for the kinetic study of the fluidized bed and the tests of agglomeration.

It is noteworthy that areas have also been reserved for the later installation of gas processing units to demonstrate the uses that can be made chemically or energetically (e.g., gas turbine) of the gas produced.

COST AND SCHEDULE

The total cost of the fluidized-bed gasification R&D program amounts to 490 million francs (MF) (≈ $61 million U.S.) as of May 1983, as follows:

ITEM	COST IN MF
Capital outlay	290
Start of tests and measurements	40
Subsidiary research work	160
Total:	490

The European Economic Community, under its program for assistance in operations of research and development in relation to coal gasification and hydrogenation, is providing financial support to the project.

The rest of the capital is being provided by CdF and the Government of France. Recently, additional interest has been expressed by several corporations, both in the U.S.A. and worldwide, to perform tests in the demonstration plant with coal of their interest after the initial testing by CdF is completed.

The present project schedule is shown as Figure 10. The main phases are:

Phase I	:	Basic engineering (completed)	11 months
Phase II	:	Detailed engineering and civil works (underway)	10 months
Phase III	:	Construction	17 months
Phase IV	:	Start-up, tests, measurements	6 months
Phase V	:	Plant operation and development program	28 months

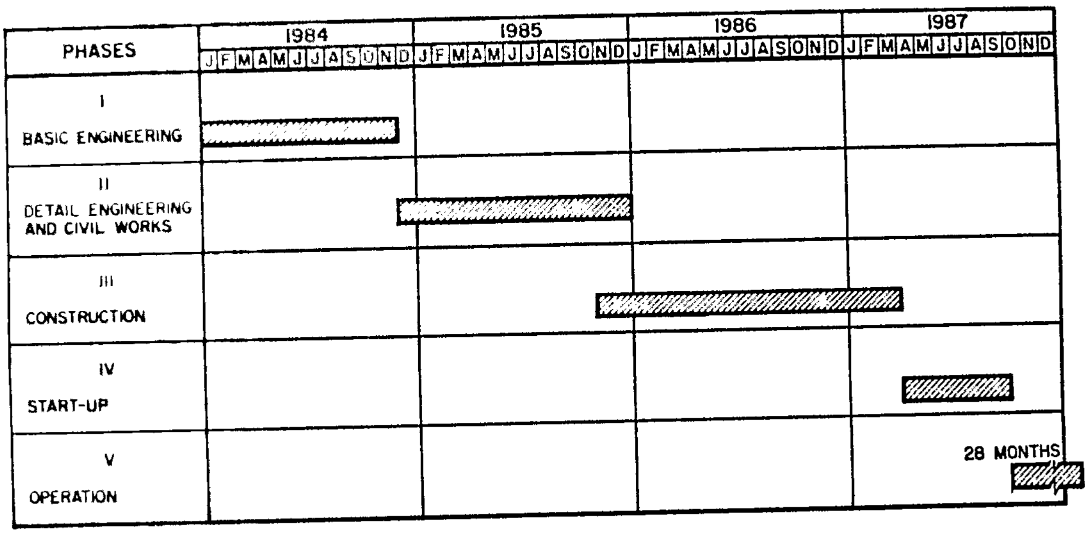

Figure 10. PROVISIONAL PROJECT SCHEDULE

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