

# The Chevron STB Oil Shale Retort

EXHIBIT B-3

A semiworks unit is being located adjacent to Chevron's Salt Lake City refinery and will be commissioned in early 1983.

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Interest in developing the oil shales of the Green River Formation as another source of domestic oil has followed a cyclic pattern since the early part of this century. With the energy shortages of the early 1970's and the Mideast Oil Embargo in 1973-74, oil-shale processing once again began to appear attractive. Therefore, Chevron Research Company began reevaluating existing retorting technologies [1-7], determining where improvements might be made, and developing an improved "second-generation" retorting process for the future.

In evaluating retorting technologies, a checklist of the desirable characteristics for an aboveground retorting process was assembled. The ideal aboveground retorting process would incorporate all of these characteristics.

- **Ability to Handle All the Mined Shale**—Many retorting processes have feed-particle size limitations. Because the acceptable particle size range is usually narrower than that which can be achieved by crushing and grinding, particles less than a certain size (usually called "fines") have to be discarded. A process which can handle all the mined shale avoids wasteful "overmining."

- **Ability to Handle a Wide Range of Shale Grades**—The grade of Green River oil shale ranges widely with depth. Many retorting processes have limitations on the grade of shale they can process. These limits may be dictated either by process or by economic considerations. Some have a limit on the maximum grade that they can accommodate; however, usually this can be surmounted by shale blending. More troublesome is a limit on the minimum grade, because it restricts the extent of the total resource which can be developed.

- **High Thermal Efficiency**—The thermal efficiency of a retorting process is defined as the percent of the hydrocarbon resource which is recovered as saleable products. Different retorting processes vary widely in this respect. Thermally efficient processes can economically process leaner shale grades.

- **High Liquid Yield**—The liquid yield from different retorting processes varies with the process's ability to control the product distribution (liquid-gas-carbonaceous residue) and with its thermal efficiency. For the foreseeable future, liquid products will be the premium products and, therefore, the retort which maximizes liquid yield will usually be the most economically attractive.

- **High Quality Product Gas**—Different retorting processes vary widely in the quality of their gaseous product. Those processes which produce a product gas uncontaminated with the products of combustion can claim a second saleable product. However, for the claim to be valid, the thermal efficiency of the process must be high enough so that the gas is available as a net product.

- **High Shale Throughput**—The throughput of a retorting process, or the volume of equipment required to process a given mass rate of shale, strongly affects the capital cost for the process. The throughputs of various retorting processes differ greatly. Since the capital cost for an oil-shale process is an order-of-magnitude higher than for

conventional refinery processes, the economics of shale-oil production are very sensitive to process throughput.

- **Ability to Operate on a Large Scale**—The scale on which a retorting process is able to operate, that is, the mass rate that a single processing module can handle, affects both capital and operating costs. Some retorting processes have mechanical constraints which limit the scale on which they can be operated. If the economics of scale cannot be realized, project economics suffer.

- **Minimal Disposal Problems for the Spent Shale**—The properties of the spent shale from different retorting processes can be quite different. Common variables are particle size, mineral composition, and hydrocarbon content. All of these variables can affect the physical and chemical stability of the disposal pile. Since strict control requirements will be placed on spent-shale disposal, the cost of disposal may well have a significant effect on the production economics for the different retorting processes.

During the same time period in which Chevron Research was evaluating existing retorting technologies, work was also begun to gather basic data on oil-shale retorting which was not otherwise available in the literature. An example of one such study was the work recently presented on retorting kinetics [8, 9]. In this study fine shale particles were retorted in a fluidized-bed reactor, thereby virtually eliminating heat-transfer effects and allowing direct measurement of the pyrolysis kinetics under isothermal conditions. A range of shale particle sizes was used and the results were correlated with a simple empirical model. Figure 1 shows the measured cumulative oil generation versus time for 0.4-mm and 3-mm particles and the predicted result for a 6.4-mm (1/4-in.) particle. It is obvious from these results that, under heat-transfer conditions equivalent to those in a fluid bed, even gravel-size particles can be completely retorted in a matter of minutes. Or, in other words, a process which can handle small particles is capable of achieving an extremely high throughput. This promise was a key consideration in the Chevron Research development.

A number of oil-shale retorting processes which possessed many of the desirable characteristics listed above

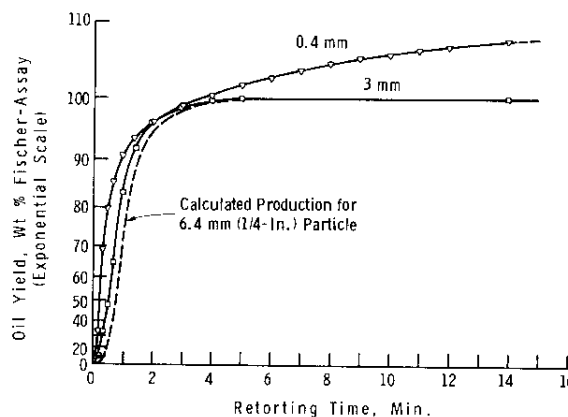


Figure 1. Oil production kinetics for fine shale particles at 500°C.

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were conceived and evaluated. Most of them were fine-particle retorting processes in which retorted shale was burned in a separate combustor and recycled to the retort to supply the process-heat requirement. The factors which proved most important in choosing between these process concepts were mechanical complexity and amenability to scale-up studies. The culmination of this work was a process concept which came to be known as the Staged Turbulent Bed Retorting Process, or for brevity, the STB Retort [10].

## PROCESS DESCRIPTION

The STB Retort is a small-particle retorting process in which retorted shale is burned in a separate combustor and recycled to the retort to supply the process-heat requirement. The flow scheme for the core of the process is shown schematically in Figure 2. Fresh-shale preheat facilities and heat-recovery facilities for the flue gas and spent shale are not shown.

The environment in the retort section can best be described as a staged, moving bed of particles, in which a portion of the particles are "fluidized." Solids move downward through the retort with an average velocity of 0.6-1.5 m/min (2-5 ft/min). Proprietary internals within the retort restrict mixing in the vertical dimension and thereby produce "staging" of the solids flow. The "staging" gives an approach to plug flow for the solids and thereby improves the stripping action of the countercurrent gas flow and minimizes the residence time required to assure complete retorting. Locally, conditions within the bed have all the appearances of a fluidized state, although the superficial gas velocity is far below the minimum fluidization velocity of many of the particles. Rapid local mixing and a high rate of heat transfer keep the temperature profile in the retort very nearly isothermal. Being well agitated, isothermal, and oxygen-free, this retort avoids the solids flow, oil burning, and oil coking problems found in some other retorts. Fine particles in the crushed shale need not be discarded because the turbulent conditions in the retort easily accommodates them.

The retort can be operated with a stripping gas consisting of either recycled product gas, steam, or an inert gas. The superficial gas velocity at the bottom of the retort is within the range of 0.3-1.5 m/sec (1-5 ft/sec). The volumetric flow of gas in the retort increases significantly in going from the bottom to the top because of the vapor traffic added by the pyrolysis products.

The combination of thermal shock experienced by the fresh shale on entering the retort, removal of the binding kerogen, and the turbulent conditions within the retort causes some breakup of the shale. The finest particles [ $<200$  mesh (0.074 mm)] are swept overhead from the retort with the product vapors. Most of the elutriated particles are recovered from the vapor stream before condensa-

tion of the oil. The recovered particles, collected by primary and secondary devices, contain carbonaceous residue, and they are therefore sent to the combustor section for recovery of their fuel value.

In the product-recovery section the product vapors are condensed in stages, producing several oil fractions and foul water. The initial condensation stage has to be capable for handling some solids, as the fines-removal equipment is never 100% efficient. The noncondensable gases are either produced directly or a portion is recycled to the retort for stripping. With very lean shales, some or all of the product gas can be used as a supplemental fuel in the combustor.

The combustion section receives coarse retorted shale withdrawn from the bottom of the retort and retorted shale fines removed from the product vapors. Air injected at the bottom of the combustor both transports the shale pneumatically and combusts the carbonaceous residue. The temperature of the solids rises rapidly. At the outlet of the combustor, a solids separator splits the stream once again into fine and coarse fractions. Most of the hot, coarse fraction is recycled to the retort to provide the necessary process heat. The excess coarse shale is sent on to the heat-recovery section, from which it eventually discharges as net coarse spent shale. The fine fraction exits the separator with the flue gas. This stream is also sent to the heat-recovery section where it is cooled and then separated into a net fine spent shale stream and a flue gas stream.

Nominal operating conditions for the process are summarized in Table 1. The fresh-shale throughput for this process is 5-10 times that of most other retorting processes. The use of small shale particles, the excellent heat-transfer conditions in the retort, and the "staging" effect in the retort make the residence time required for complete retorting quite low. The extremely low residence time required in the combustor is a consequence of the high reactivity of the carbonaceous residue.

## CHARACTERISTICS OF THE STB RETORT

The STB Retorting Process has been tested by Chevron Research in several pilot units. The latest and most sophisticated of these is a one-ton/day integrated pilot plant. The retort and combustor are closely coupled. While not adiabatic, the pilot plant is sufficiently large so that it supplies, internally, a majority of the necessary process heat. Heat losses are counteracted by means of about 60 individually temperature-controlled, electrically heated zones. The pilot plant models the process sufficiently closely to allow the study of the effects of process variables, to generate representative products, and to allow the evaluation of process effluents. However, it is too small to allow detailed study of certain process features and equipment which will be employed in commercial operations. These aspects will be studied in a larger-scale plant, as will be discussed later.

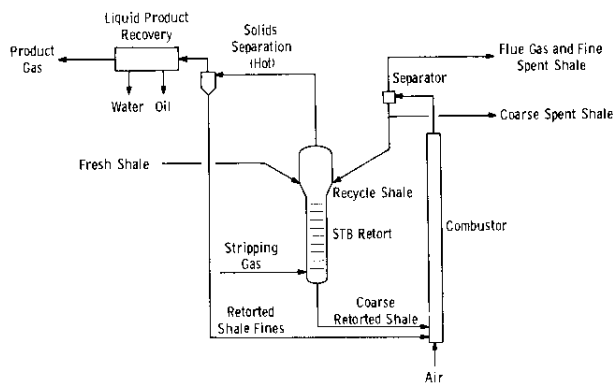


Figure 2. Process flow scheme for the STB retort.

TABLE 1. NOMINAL PROCESS OPERATING CONDITIONS FOR THE STB RETORT

Fresh Shale Throughput	10-25 Tonnes/Hr/m <sup>2</sup> Retort (2000-5000 Lb/Hr/Ft <sup>2</sup> )
Retort Temperature	477-510°C (890-950°F)
Retort Residence Time	2-8 Min.
Stripping Gas Velocity	0.3-1.5 m/Sec. (1-5 Ft/Sec.)
Combustor Residence Time	1-5 Sec.
Combustor Outlet Temperature	594-816°C (1100-1500°F)
Recycle Shale Ratio	2:1 to 5:1

### Particle Size

When oil shale is crushed, a relatively broad distribution of particle sizes is produced. The range of particle sizes in the crushed shale can be changed only modestly by different crushing equipment because the properties of the material itself control the breakup. For this reason, certain retorting processes with particle-size limitations are forced to discard a portion of the crushed shale [1-3].

The top size of the fresh shale used in the pilot plant had to be limited because of the small scale of the equipment. However, the suitability of the 6.4-mm (1/4-in) top size, proposed for the commercial plant, was investigated in a separate study, as will be discussed later. The cost of grinding shale to a 6.4-mm top size is greater than the crushing costs for the lump-shale retorting processes. This is more than offset by other advantages offered by the STB Process. Also, the grinding cost for the STB Process is significantly less than the cost of producing the still finer distributions required by most fluidized processes.

### Retorting Temperature

The optimum temperature for oil-shale retorting, based on oil production, is broadly placed in the range of 455-540°C (850-1000°F). Different retorting processes report slightly different optima [3, 5, 11]. Fischer Assay, the batch-retorting operation widely used as an assay tool, is carried out to 500°C (930°F).

Retorting temperature was one of the first process variables studied in the STB pilot plant. Retort residence time was maintained constant by keeping the feed rate and recycle ratio constant. Retort temperature was varied primarily by changing the temperature of the recycle shale. This was accomplished by adjusting the carbon burn in the combustor. With a retort residence time of four minutes, a broad optimum was observed between 480°C and 500°C (895-930°F). Yields of C<sub>5</sub>+ oil in this temperature range averaged 100 ± 3 wt. % of the Fischer Assay oil yield. The uncertainty in the oil yield is due to a host of factors, including imperfect sampling, analytical variation, small differences in process conditions, and small deviations from material-balance closure. Similar problems are encountered in all retorting processes. The falloff in oil yield observed at higher temperatures in the result of cracking of vaporized liquid products, and the falloff observed at lower temperatures is the result of incomplete retorting. Use of a different retort residence time will both shift the position of the maximum and change the maximum oil yield.

### Product Properties

Typical properties of Colorado shale oil produced in the one-ton/day pilot plant are shown in Table 2. The feed shale had a grade of 93 liters/tonne (27 gal/ton) and was obtained from the Anvil Points mine. These properties were measured on the collected oil and do not reflect any contribution of C<sub>5</sub>+ hydrocarbons contained in the product gas. The unrecovered C<sub>5</sub>+ hydrocarbons amount to about 2 wt. % of total C<sub>5</sub>+ oil. The raw shale oil properties are not greatly different from those for oils produced in other aboveground retorting processes [7]. The oil contains substantial quantities of nitrogen and oxygen and a significant quantity of arsenic, all of which must be dealt with when the oil is upgraded to premium products. It also has a relatively high pour point, a fact of importance if the raw oil is to be pipelined. Oil properties remain essentially the same over the grade range of 48-130 liter/tonne (14-38 gal/ton) tested in the STB pilot plant.

The yield of gaseous product in the pilot plant, at operating conditions optimized for oil production, was essentially the same as that produced in a Fischer Assay. The gaseous product advantageously contains less than one-fourth as much hydrogen sulfide as the gas from some of

TABLE 2. TYPICAL OIL PROPERTIES STB RETORT PILOT PLANT  
93 liter/Tonne (27 GPT) Shale from Anvil Points Mine

Specific Gravity	0.934
Carbon, Wt. %	85
Hydrogen, Wt. %	11
Nitrogen, Wt. %	2.1
Oxygen, Wt. %	1.2
Sulfur, Wt. %	0.6
Arsenic, ppm	20
Viscosity at 100°F, cS	22
Viscosity at 130°F, cS	12
Pour Point, °C	19
Ramsbottom Carbon, Wt. %	3.5
Distillation, ASTM D 1160	
Vol. % Distilled	°C
St/5	146/196
10/20	220/273
30/40	322/371
50	411
60/70	452/489
80/90	529/—
95/EP	—/534

the other retorting processes. The yields of carbon oxides produced in the retorting section could not be accurately measured in the pilot plant because the plant's design allows some of the carbon oxides produced by mineral carbonate decomposition in the combustor to enter the retort. This would not be the case in a commercial retorting facility, and the carbon-oxide content of the product gas should then equal that produced by an isothermal retort operating near 500°C (e.g., a Fischer Assay retort).

The combustor used in the one-ton/day pilot plant is a single-stage, entrained-bed combustor. The residence time of the finest particles is approximately one second. The residence time of the coarse particles is somewhat longer. Interestingly, the combustor residence time is actually dictated by the fine particles rather than by the coarse particles because the fine particles get but a single pass through the combustor. The combustor is usually run with excess air, although other conditions have been tested. The overall conversion of carbonaceous residue in the pilot plant approaches 90%. Higher conversions are anticipated in the commercial process using a refined combustor design. The SO<sub>2</sub> content of the flue gas is unusually low (<20 ppm) because of the scrubbing action of the shale itself.

The spent shale from the STB Retorting Process has specific properties which ease the problems associated with its disposal considerably. With the addition of only 10-12 wt. % water and a modest compactive effort, a compressive strength (unconfined) of about 1379 kPa (200 psi) can be generated in the spent shale within 14 days. This is quite adequate for surface disposal and is a significantly better strength than is obtained with the spent shales from most other retorting processes [12, 13]. Another particularly advantageous property of this spent shale is its relatively low concentration of carbonaceous residue (0.3-0.7 wt. % in the pilot plant and even lower in a commercial plant), making it much less susceptible to leaching of organic residues. The spent shales from many other retorting processes can have up to 10 times as much carbonaceous residue [1, 2, 5].

### PHYSICAL MODELING FOR RETORT DESIGN AND SCALE-UP

The STB Retorting Process makes use of a proprietary reactor design unlike anything currently in use. This reactor has the unique property of achieving fluidlike behavior in a bed of particles at gas velocities well below the minimum fluidization velocity of many of the particles. It also produces staging within the moving bed, thereby creating an approach to plug flow for both the solids and the gas. Because of its uniqueness, the scale-up of the retort reactor received particular attention.

Simultaneous with the piloting of the process on a small scale, physical modeling studies were initiated. These studies were carried out in translucent equipment at ambient temperature. Visual observations, pressure measurements, solids sampling, and tracer tests with radioactive tagged particles were all used to study the flow mechanics within the process reactors. Models were built on several different scales.

A schematic of one of the models is shown in Figure 3. This particular unit models a retort capable of processing 320 tonne/day (350 ton/day) of fresh shale. Solids with a size distribution appropriate to a particular study are charged to the model and recycled repeatedly. Fresh shale is usually used as the circulating solid during testing to minimize solids breakup. Elutriated fines are collected and returned to the retort section. Both the stripping gas for the retort section and the lift gas for the combustor section are supplied by a single compressor. The gas is recycled so that any of a variety of inert atmospheres can be easily studied. The locations of radiation detectors, used in the tracer tests, are indicated in Figure 3.

An empirical approach is often applied to the scale-up of fluidized systems. A series of experiments is conducted on progressively larger scales until a set of measurable parameters, characteristic of the system, no longer changes with the scale. When this point is reached, the results are assumed to be applicable to all larger scales. This type of approach was applied to the physical modeling of the STB reactor. The relative bed-pressure drop, for example, was significantly greater in small-diameter reactors, although small variations were observed at each diameter for different gas or solids flow rates, particle-size distributions, and internals designs. Based on results like these, it was concluded that a reactor diameter of about one meter would be adequate for obtaining data for application on a much larger scale.

The physical models were used extensively to determine the internals design and operating conditions which give the optimum solids-flow characteristics in the reactor. Several different oil shale grinds were evaluated, including a 6.4-mm (1/4-in) minus feed appropriate for commercial operation.

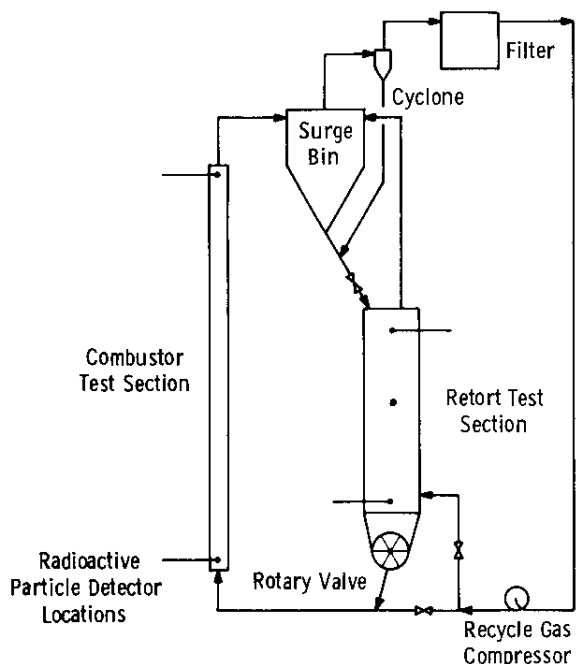


Figure 3. Flow scheme for the physical model.

## INCENTIVES FOR DEVELOPMENT OF THE STB RETORT

An economic comparison of the STB Retorting Process and all the other retorting processes in an advanced stage of development (Paraho, Tosco II, Union B, and Lurgi-Ruhrgas) was made by Chevron Research. In developing the comparative cost estimates, it was assumed that the competitive processes would perform as their developers claimed. Until these processes are well demonstrated, it would be highly speculative and would bias the results to make any other assumption. The processes were compared on the basis of a fixed production rate of raw shale oil, while meeting all of the energy requirements of the retorting complex internally. The advantage of this approach is that the alternative processes are compared on a consistent basis. Consequently, the differential costs between the processes reflect real differences, even though the absolute costs may be somewhat uncertain.

Based on these comparative economic studies, it is estimated that the STB Retorting Process has an economic advantage of \$1.50-\$7.00, per barrel of oil produced, over the other retorting processes. The incremental cost advantage is a function of shale grade in each comparison because of the differences in thermal efficiency of the various processes. The advantage of the Chevron STB Retort results from its higher throughput, larger module size, utilization of the carbonaceous residue, and acceptance of all the mined shale. Improvements now under investigation are expected to further decrease the relative cost of retorting with the STB Process.

In addition to the economic incentives, there are also strategic incentives for the Chevron STB technology. The main strategic incentives are:

Ability to Process Lower Grade Shales Economically—The recoverable reserves of lean shale [65-69 liters/tonne (~19-20 gal/ton)] are approximately 10 times greater than the reserves of richer shale (100 liters/tonne or ~30 gal/ton) obtainable by underground mining on Chevron's shale properties in Colorado. The ability to efficiently retort leaner shales would permit the use of surface mining. This could be highly desirable since surface mining is safer and less labor-intensive than underground mining.

Ability to Rapidly Scale up to Large Module Sizes—Because the Chevron STB Retort is in many ways similar to "fluidized" solids handling, it should be possible to build very large modules with a high degree of confidence. A parallel can be drawn to the development of the fluidized catalytic cracking process where very large scale-ups were accomplished in an orderly fashion. Experience gained in this area of technology has been utilized in the development of the STB Retorting Process and will be helpful in scale-up to commercial-size units.

Ability to Dispose of Spent Shale in an Acceptable Manner—The relatively good strength which can be developed in the spent shale makes it well suited for surface disposal, particularly as a solid backfill as surface mining proceeds.

## FURTHER DEVELOPMENT OF THE STB RETORT

The laboratory program and engineering evaluations carried out at Chevron Research have established that the STB Process provides an excellent prospect for the responsible development of the company's oil-shale resources on a commercial scale.

It has been concluded that a 320-tonne/day semiworks unit is the next logical and technically sound step in the development of this technology. This size selection resulted from a careful balancing of the problems of conducting developmental work in large-scale equipment with the need to obtain data at a sufficient scale of operation to be applicable to commercial modules. A 320-tonne/day unit is sufficiently large to provide the necessary scale-up data for

design of large commercial modules and to demonstrate the entire process. On the other hand, this size allows one to make some process changes, produces minimal environmental impact, expedites permitting, and reduces the investment and operating costs.

The design approach used for the semiworks facility emphasizes flexibility of operation so that the operating program will generate the data needed to optimize, design, and construct commercial oil-shale facilities. The semiworks is not simply a miniature model of a commercial facility. Those areas where in-house petroleum processing background is applicable—for example, upgrading and environmental controls—will be greatly simplified in the semiworks compared to what will be incorporated in the commercial facility. Figure 4 is a simplified block flow diagram for the semiworks facility.

The semiworks unit is being located adjacent to Chevron U.S.A.'s Salt Lake City Refinery and will be commissioned in early 1983. The oil shale feed for the semiworks unit will be obtained from Chevron Shale Oil Company property in the Piceance Basin. It is expected that most of the retorted shale will be disposed of in the Salt Lake City Area. However, some of it will be returned to the company's property in Colorado for disposal and revegetation studies. Current plans call for a two-year operating program for the semiworks unit to gather all the data necessary to construct commercial size modules.

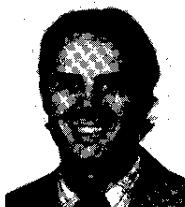
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**Corey A. Bertelsen** attended Gustavus Adolphus College and the University of Minnesota, receiving a B.S. degree in Chemical Engineering from the latter institution in 1978. He joined the Process Engineering Department of Chevron Research Co. in the same year. He has worked in both research and process design capacities on several synthetic fuels development projects. He is currently involved in new product development and process design engineering in the Chemicals Department.

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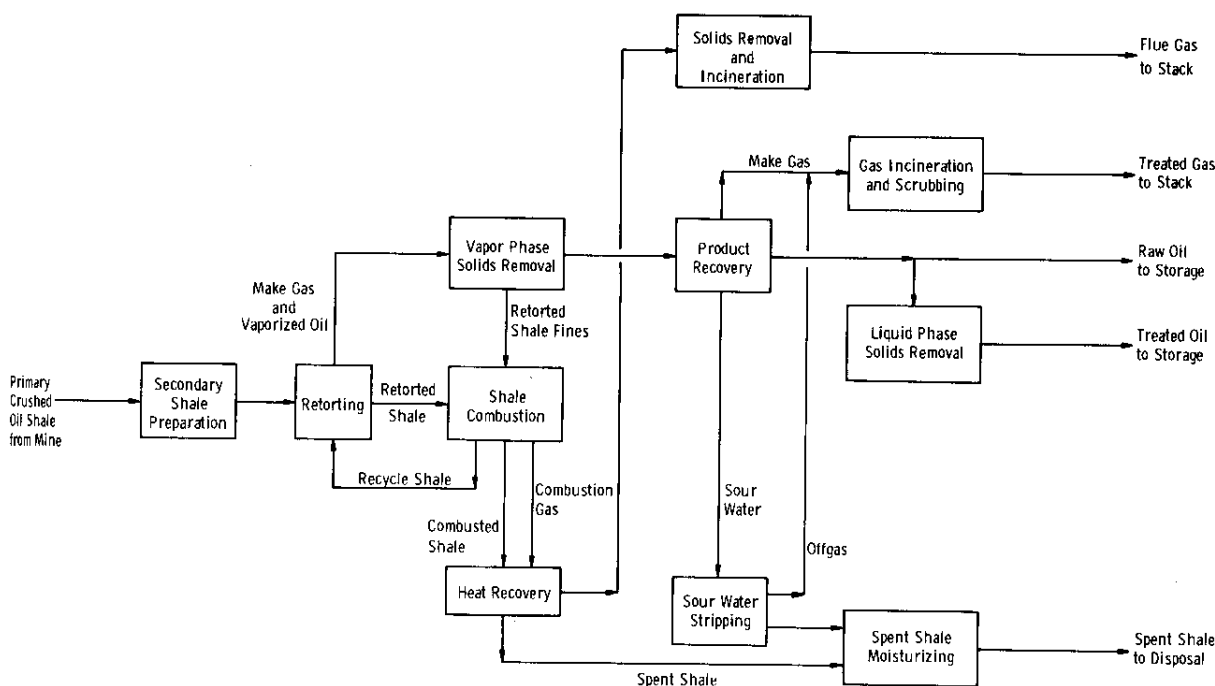
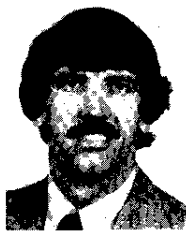


Figure 4. Block flow diagram for the semiworks oil shale plant.



**Gene M. Handel** received his B.S. degree in Chemical Engineering from Northwestern University in 1968. He joined the Process Design Division of Chevron Research Co. the same year. Following an assignment with the Manufacturing Department of Chevron U.S.A., he took over responsibility for the alternate energy group in the Process Engineering Department of Chevron Research. In 1979 he received an MBA degree from the University of California. He is currently with the Comptrollers Department of Standard Oil Co. of California.



**P. Henrik Wallman** received his M.S. degree in Chemical Engineering from Helsinki Institute of Technology in 1972, his Licentiate in Technology (Chemical Engineering and Applied Mathematics) from the same institution in 1975, and his Ph.D. in Chemical Engineering from the University of California—Berkeley in 1977. He joined the Process Research Department of Chevron Research Co. in 1977. He is currently a Senior Research Engineer specializing in oil shale retorting process development.



**Byron G. Spars** received his B.S. degree in Chemical Engineering from the South Dakota School of Mines and Technology in 1957 and an M.S. in Chemical Engineering from the University of Wisconsin in 1960. He joined Chevron Research the same year. He was involved in process development work in the areas of catalytic cracking, hydro-treating, and solvent extraction until 1974. After an assignment with the Chevron U.S.A. Manufacturing Department, he rejoined Chevron Research in 1977 and assumed responsibility for the oil shale project in the Process Research Department.

## Coal Gasification—An Overview

Given the long term need for alternative fuels, now is the time for chemical engineers to become not only "paper smart" but "real-world smart" in the design of efficient coal-gasification equipment.

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Coal gasification is an old technology that is now undergoing modernization. In the early part of this century, a large number of coal gasifiers were commercially operated to produce industrial and residential fuel gas. The availability of abundant and inexpensive natural gas and crude oil led to the abandonment of most coal gasification units by the mid-1950s. However, since 1973, OPEC has dramatically increased oil prices and, in effect, decoupled oil prices from oil supply capacity. Natural gas will likely move toward price parity with crude oil as contracts with Canada and Mexico are negotiated and United States gas is deregulated. Continued intermediate and long-term price escalation for conventional fuels seems certain. This situation significantly increases the attractiveness of coal gasification and reduces its economic risk. This paper presents an objective technical overview of coal gasification.

### THE COAL GASIFICATION PROCESS

Coal gasification is an adaptation of coal combustion whereby the combustion process is limited by insufficient oxygen. The difference between coal combustion and coal gasification is analogous to the difference between a flaming fireplace and one that is only smoldering. A combination of combustion and pyrolysis reactions of the coal, plus gas-phase reactions, produce a combustible raw gas. Depending on process conditions, the raw gas is a complex mixture of steam, hydrogen, carbon monoxide, carbon dioxide, hydrocarbons, hydrogen sulfide and also particulates consisting of ash and unconsumed coal. In addition,

the gas may contain other reduced sulfur compounds, ammonia, other nitrogen compounds, atmospheric nitrogen and inert gases, and trace element compounds. Fortunately, these formidable gaseous mixtures can be treated by low-temperature liquid absorption to remove the bulk of the undesirable compounds and leave a premium gaseous fuel or chemical synthesis feedstock.

Those who choose coal gasification as an alternative to conventional fuels may find coal gasification to be expensive, inefficient, and technically difficult. Direct coal firing is a well established practice and sulfur dioxide emission control *via* flue-gas desulfurization, though more troublesome, has been widely applied commercially. However, there are compelling reasons for the use of coal gasification including:

- almost total control of toxic emissions from combustion
- production of synthesis gas, liquid fuels, or chemicals from coal
- ease of utilization of products in existing natural gas or fuel-oil-fired equipment.

In our judgment, these reasons will lead to an expanded commercial use of coal gasification by the end of the century [1]. Furthermore, increased commercial experience with coal gasification will result in considerable process improvement and in new markets for by-products.

### COMMERCIALLY PROVEN GASIFIERS

There are only four commercially proven coal gasification processes:

- Gas Producers
- Winkler
- Lurgi
- Koppers-Totzek.

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