APPLICATIONS FOR A HIGH TEMPERATURE GAS COOLED NUCLEAR REACTOR IN OIL SHALE PROCESSING

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ABSTRACT

This paper presents the results of a study concerning possible applications for a high temperature gas cooled reactor as a process heat source in oil shale retorting and upgrading. Both surface and in situ technologies were evaluated with respect to the applicability and potential benefits of introducing an outside heat source. The primary focus of the study was to determine the fossil resource which might be conserved, or freed for higher uses than furnishing process heat.

In addition to evaluating single technologies, a centralized upgrading plant, which would hydrotreat the product from a 400,000 bbl/day regional shale oil industry was also evaluated. The process heat required for hydrogen manufacture via steam reforming, and for whole shale oil hydrotreating would be supplied by an HTGR. Process heat would be supplied where applicable, and electrical power would be generated for the entire industry. This conceptual approach to integration of high temperature gas cooled reactors in the oil shale industry would allow for production of a high quality shale oil without the loss of product in supplying process heat for upgrading operations. The entire industry would also be self-sufficient with respect to both electrical power and process heat.

INTRODUCTION

The purpose of this study was to determine, from a technical standpoint, if existing oil shale processes could be coupled to a nuclear heat source and yield an improvement in overall resource utilization. The basic concept is that the heat supplied from the reactor could replace the combustion of shale oil and retort off-gas in process heat applications and displace other fossil fuels used in steam and electricity generation. Benefits of cogeneration of electricity and process heat are well-documented. Because shale oil is on entirely new industry, it offers a unique opportunity to consider the development of cogeneration on a large scale.

The idea of using a nuclear heat source in synthetic fuels production is not new. West Germany has funded programs for several years to develop the necessary technology for using a reactor in coal gasification and liquefaction. U.S industry has followed those developments and is now evaluating areas in which the HTGR may be used to increase process efficiency in synthetic fuel processes and displace oil and gas in other conventional process applications.

HTGR SYSTEM

The HTGR is considerably different from those systems currently in use at most nuclear powerplants. Rather than a water cooled core, the HTGR uses helium in the primary core cooling loop and either helium or water in the secondary loop. The process heat HTGR is a version of the HTGR developed for electricity production which is currently in operation at the Fort St. Vrain nuclear facility owned by Public Service Company of Colorado.

The HTGR offers a unique heat source for process heat applications because its operating temperature is substantially higher than that of other types of reactors. A secondary cooling loop can provide heat at 900°C.

A system flow diagram for an HTGR process heat plant is illustrated in Figure 1. Thermal energy is removed from the reactor core by two independent primary loops. The primary coolant from the core exchanges heat in two intermediate heat exchangers (IHX) transferring heat to the secondary helium loop.

This secondary loop transports thermal energy from the IHX to the process. The secondary loop may be connected to any number of secondary exchangers to supply heat directly to the process or to generate steam for further process use or electricity generation. The primary cooling loop and the IHX are contained within the reactor vessel and the secondary

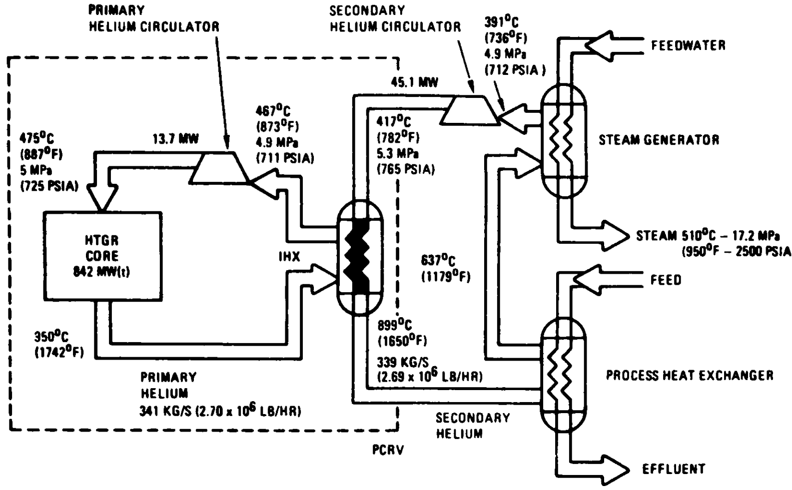

Figure 1. HTGR-PROCESS HEAT FLOW DIAGRAM

loop maintained at a higher pressure than the primary coolant loop to reduce the possibility of contamination outside the reactor containment vessel.

RETORTING APPLICATIONS

An assessment of retorting applications involved evaluating both surface and in situ technology from a general standpoint. That is, a specific class of technology was evaluated rather than individual designs. For surface retorts, indirect heated, vertical kiln retorts were studied; and for in situ retorts, a modified in situ technology was considered. The in situ case included a combination of aboveground and MIS retorts.

A few ground rules were established at the beginning of the study. The major constraint imposed was that no major design changes would be made to the retort system in order to accommodate the reactor. The second constraint was that the combination of process heat and electrical requirements be at least 842 MW(th). This constraint is based on the smallest economical reactor size determined by current technology. As a design basis, commercial plant production was set at 50,000 barrels per day.

The approach used was to break down a commercial facility into three components or modules and determine heat and electrical demand for each section. These modules included: mining, feed pretreatment, retorting and upgrading.

The heat and electrical demand for the surface retort case is shown in Table 1, and for the modified in situ/surface combination in Table 2.

In both cases, the total thermal demand is well below the smallest economical reactor size. In addition, the heat supplied by the reactor must displace the indigenous fuel supplies available, and free those fuels for higher use. Obviously, shale oil product can be used more efficiently, but the major fuel source is retort off-gas. For surface facilities, the high BTU gas could be upgraded to pipeline quality gas. However, no advantage would exist for adding a reactor to make pipeline gas. MIS operations produce tremendous quantities of low BTU gas for which no other real use exists except for supplying process heat and steam.

It appears that for the standard 50,000 barrel per day operation, whether surface or MIS/surface combination, the HTGR provides no real advantage.

The availability of the reactor may however, allow for increasing the quality of the product. This could be accomplished, by suppling heat for steam reforming of off-gas and whole shale oil hydrotreating in order to produce an upgraded shale oil. This product could more easily be used in existing refineries.

TABLE 1

HEAT AND ELECTRICAL DEMAND - SURFACE OIL SHALE FACILITY

	MW (e)	MW (th)
Mining	23.2	—
Crushing	8.4	—
Retorting	41.0	495
Upgrading	5.0	25
TOTAL	77.6	517

TOTAL THERMAL DEMAND 775 MW (th)

TABLE 2

HEAT AND ELECTRICAL DEMAND-MIS/SURFACE RETORTING OPERATION

	MW (e)	MW (th)
Mining	5.0	—
Crushing	2.2	—
Retorting		
Surface	11.0	128.5
In Situ	60.9	284.0
Upgrading	5.0	25.0
TOTAL	84.1	407.5

TOTAL THERMAL DEMAND 659.8 MW(th)

The high BTU gas produced from surface retorting operations can be steam reformed to produce hydrogen. Raw shale oil can be hydrotreated with approximately 2,000 SCF/bbl of hydrogen.

Adding these steps to both the surface and MIS/surface cases results in an overall thermal demand of 1,075 MW (th) and 1,063 MW (th) respectively. These values are more in line with a reasonable reactor size.

While it appears that aboveground retorting combined with hydrogen manufacture and whole shale oil hydrotreating involves a sufficient heat load to justify a small reactor, a major incentive must be provided for extensive on-site upgrading. It may be difficult for a single installation to justify the additional cost of a reactor by the added value of upgraded shale oil.

One of the reasons for integrating a reactor into the processing system would be to accomplish a significant gain in resource utilization over normal operating practice. For indirect heated retorts, it is difficult to determine the amount of resource conserved by use of an HTGR. The net resource saved is derived from the retort off-gas, spent shale, and other fuels used to heat recycle gas. The fuel used for production of purchased power could ultimately be included in a net energy calculation, but the real justification for an HTGR must be the amount of oil shale conserved.

The resource savings potential will include the heating value of the off-gas and shale oil consumed. If the carbon remaining on the spent shale is reacted with steam to produce hydrogen, the energy content of the spent shale can be considered also. The resource savings is shown in Table 3.

The 16.7 percent represents a maximum. In actual operation, a value closer to 10-12 percent might be realized.

Long Term Applications

The introduction of new retorting technology must show a considerable improvement in economics, yield, and operation for those changes to be accepted. We consider this to be a problem with integration of the HTGR into existing surface and in situ operations where considerable engineering work has been completed.

In contrast, there are some developmental technologies currently under study which could effectively utilize an HTGR to integrate a nuclear heat system into the design of commercial plants. The development of the nuclear technology along with the retorting technology should result in a better opportunity to design an optimized system.

There are at least two development projects that appear likely candidates for an HTGR.

The long term potential will of course depend on the technical success of R&D programs:

TABLE 3

OIL SHALE RESOURCE CONSERVED BY UTILIZATION OF AN HTGR

Energy In:		
One Ton Oil Shale	5.48	MMBTU
Energy Out:		
Shale Oil	4.89	MMBTU
Off-Gas	.255	MMBTU
Spent Shale	.340	MMBTU
	5.48	MMBTU
Energy Conserved:		
Off-Gas	.255	MMBTU
Shale Oil	.323	MMBTU
Spent Shale	.340	MMBTU
	0.928	MMBTU

% of Resource Conserved = 16.7

- Illinois Institute of Technology Research Institute radio frequency process (also Texaco and Raytheon).
- Equity In Situ Process

The IITRI process requires a significant amount of electricity which can be provided by an HTGR. Based on preliminary estimates, for a 50,000 barrel per day plant approximately 1,724 MW(th) of energy would be necessary.

The Equity in situ process, which retorts by injection of high temperature, high pressure steam, would appear to be a prime candidate for integration of nuclear reactor for retort steam production. A combination of the IITRI and Equity processes would provide maximum benefits of cogeneration. As these processes become more developed and their heat requirements more defined, the potential advantages for use of an HTGR can also be better defined.

CENTRAL UPGRADING FACILITY

While there does not appear to be a significant advantage for an HTGR in single installations, utilization of a single reactor facility to serve several oil shale operations appears to have considerably more merit. Full scale development in the oil shale region will probably bring a mix of modified in situ and aboveground retorting systems. In the early stages, upgrading of the shale oil product will not be a major problem. Up to a level of 150,000 - 200,000 barrels per day, very little upgrading in the form of hydrotreating is likely to be done. Once production passes this stage, more significant upgrading will be necessary in order to increase the acceptability of shale oil to the refining industry. The capacity of the existing refining industry to process raw shale oil is limited by the availability of hydrogen for severe hydrotreating. Hydrotreating severity required to produce transportation fuels will exceed the design limits of existing units in many refineries. Those refineries which appear capable of processing raw shale oil can handle only small volumes at any one location and are geographically dispersed. Shale oil upgrading in a regional facility would allow the integration of syncrude into the existing refinery and pipeline systems at minimum cost. A nuclear reactor in a regional upgrading facility would appear to provide a significant advantage.

A system which would integrate the reactor into several shale oil plants is illustrated in Figure 2. The off-gas produced from surface operations could be collected and sent to the central facility for reforming operations. The oil produced from all the operations would similarly be collected and sent for hydrotreating.

In addition to supplying heat and power for reforming and hydrotreating, process heat could be returned to the surface operations for retorting and electric power could be generated to supply the entire industry. Process heat could be distributed over a considerable area by means of a chemical heat pipe system. Assuming a production breakdown between aboveground and MIS/aboveground combinations as follows, the overall thermal heat demand would be as listed in Table 4.

Aboveground	270,000 BPD
MIS/aboveground	130,000 BPD
	400,000

The heat balance indicates that for a centralized facility, two or three large reactors would be necessary. This would make it possible for an entire oil shale industry to become fully self-sufficient, requiring no outside power or fuel. Multiple reactors would make it practical to allow for reactor downtime for refueling, etc.

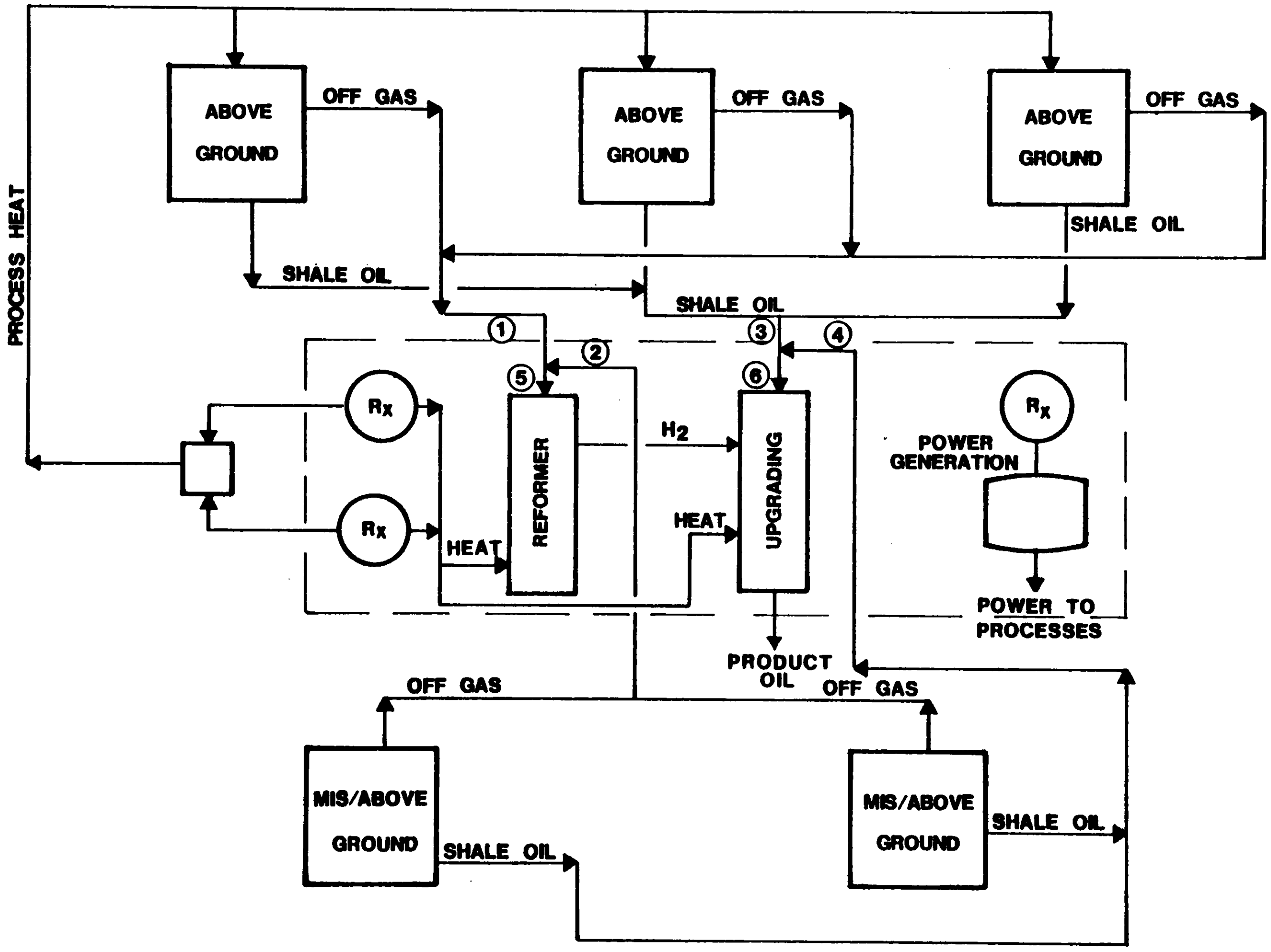

FIGURE 2
CENTRAL UPGRADING FACILITY WITH PROCESS HEAT AND POWER GENERATION

TABLE 4

HEAT AND ELECTRICAL REQUIREMENTS-CENTRALIZED REACTOR PLANT, 400,000 BPCD

Area	MW (e)	MW (th)
Mining	185	—
Crushing	51	—
Retorting		
Aboveground	221	2,995
In Situ	286	-0-
H_2 Manufacturing	51	2,540
Hydrotreating	108	380
TOTAL	902	5,915

TOTAL THERMAL DEMAND 8,621 MW (th)

Both the hot helium cycle and a steam reactor would be applicable. A combination of both, one supplying steam for reforming and hydrotreating operations, and the other providing hot helium for the process heat system would be a logical combination. As more refining studies are conducted, the economics of hydrotreating on site versus building added capacity at the refinery will become more defined for hydrogen deficient refineries. The value of hydrogen is tied to its feedstock cost, rather than its fuel value as in hydrogen surplus installations. We expect that for these situations, a good economic case could be built for the production of hydrogen from retort off-gas and using this hydrogen for upgrading on site by utilizing the HTGR plant.

CONCLUSIONS

It appears that for a single near-term commercial installation, an HTGR does not provide a significant advantage over current planned operation. There maybe merit in a regional upgrading facility integrated with an HTGR. Long-term developments in processing technology may present a better application also.

At this point considerably more technical and economic studies are needed to identify the role of a high temperature nuclear heat source in oil shale processing.