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Coal-Oil Slurries as a Device to Conserve Fuel Oil in Existing Industrial Furnaces

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COAL-OIL SLURRIES AS A DEVICE TO CONSERVE FUEL OIL IN EXISTING INDUSTRIAL FURNACES

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Abstract

Coal-oil slurries constitute a device for extending the supply of heavy fuel oil by admixing up to 40% of ground coal. The resultant slurry can be pumped and burned in standard heavy fuel oil equipment. This paper deals with history, technology and the ERDA program for exploiting the coal-oil slurry idea. It offers a prognosis for program execution and final outcome.

1. DESCRIPTION, TERMINOLOGY AND HISTORY

1.1 DESCRIPTION AND TERMINOLOGY

The subject of this paper, "Coal-Oil Slurries as a Device to Conserve Fuel Oil in Existing Industrial Furnaces," involves an innovative procedure that could decrease fuel oil consumption by about 40% wherever it is applied.

Large public-utility operated boilers in steam electric power plants have for many years burned pulverized coal. The idea of combining pulverized coal with oil will be traced through its historic evolution as this paper progresses. Various terms have been used that relate to coal-oil slurry as presently defined and visualized:

Colloidal fuel - In the 1920s and 1930s when this term originated, there was an underlying belief that if coal could be ground fine enough, coal-oil suspension would be permanent. Colloidal sizes are, as a matter of fact, far smaller than are presently practical for commercial compounding of coal-oil slurries.

Fliesskohle - In the 1930s in Germany concern over foreign oil supplies led to experiments with a mixture of powdered coal and a coal-derived anthracene oil to make a product suitable for applications in which heavy liquid petroleum fuels had been used. In this case, the solid and liquid were particularly compatible, yielding a stable mixture in which the coal was practically dissolved in the anthracene.

Coal-oil ratio - This can be varied over a wide range with pumpability being the governing factor as the percentage of coal is increased. A typical coal-oil slurry contains 40 weight % coal.

Surfactants - By analogy with soap as a suspending agent for solids and oils in water solution, certain soap-like materials seem to help keep coal-oil slurries stable. Their effectiveness could depend upon traces of water also being present.

Where can coal-oil slurries be used? One way to be effective in reducing dependence on petroleum imports would be for at least some current use of heavy fuel oil to be displaced by coal-oil slurry. For this to happen two factors will be involved: (1) conversion is more likely to occur in regions that are particularly short of heavy fuel oil and where that product is especially expensive, and (2) boiler designs that originally contemplated coal as a fuel and subsequently were adapted to oil are more likely to be appropriate for conversion. Conversion to slurry can be effective over a wide range of boiler/furnace sizes, but the most likely include neither the smallest industrial units (where simplicity will overrule other considerations) nor the largest systems in major power generator stations (which are already equipped in many cases for concurrent coal and oil burning, each fuel having its own burners).

In a major power station which has already installed burners for both pulverized coal and heavy fuel oil, mixing the two fuels before firing would show no particular advantage. In other applications nearer the middle of the spectrum of boiler size, there are some real advantages to using the slurry. When compared to the conveyors and air lifts used for coal, substitution of a pumpable fluid offers a much more straightforward way for transporting the fuel both between the producer and the consuming plant and within the consuming plant from receiving tanks to burners. Instrumentation and controls already in place for oil burning are much more adaptable to slurry than they would be to coal, as such.

1.2 HISTORY

The idea of burning coal and oil together in slurry form has been around for a long time. The first proposal for such activity was made in Britain in 1879. During World War I, maritime users of oil for ship propulsion fuel (both merchant and naval) felt considerable concern for possible failures to keep available adequate supplies of oil (sometimes obtained from very distant oil wells). At that time, coal was still widely used for fuel not only in certain older ships but also in industrial, commercial and residential furnaces. Thus, both of the raw materials for slurries were widely available through well-evolved distribution networks. Because equipment for handling and burning liquids is inherently less complex than equipment for burning solids, the slurry idea held out attractions for convenience as well as for spreading out the expected limited supplies of oil.

In spite of the advantages cited, maritime interest waned at the end of World War I. The petroleum industry was expanding everywhere. The demand for gasoline increased, and heavy residual oils came on the market almost faster than consumers were ready to burn them. There was some further British research (where coal held out a little longer), but the whole subject tended to fade away.

It was during the period between the wars when comparatively little work was going on that the term "colloidal fuel" was first introduced to describe a hoped-for effect that would keep slurries from settling. The property contemplated was the ultra-fine subdivision of the coal into particles that are of truly colloidal dimensions. Such fine grinding was never economically accomplished, and the hope for permanence in slurry suspension due to small coal particle size was abandoned.

Other approaches were also made toward the stabilization of coal-oil slurries. It was early discovered that certain soaps or greases (petroleum lubricating grease contains a rosin-based soap) helped a slurry to maintain its homogeneity and not settle out.

The efforts of German researchers in the 1930s to avoid the need for imported petroleum resulted in the product Fliesskohle, which already has been mentioned. This product (ground coal and coal-derived anthracene oil) illustrates a third way for stabilizing coal-oil slurries. That is to have an oil high in aromatic hydrocarbon content which is more compatible with coal than are other oils. Because coal tends to partially dissolve in anthracene, the latter becomes an excellent slurry solvent-vehicle.

American interest in coal-oil slurries, which was fairly high at the end of World War I, hit its second peak early in World War II. This was due to submarine warfare which seriously disrupted the tanker movement of oil from the U.S. Gulf of Mexico ports to the Northeastern states. It was proposed to use coal-oil slurries to overcome the short-fall in fuel oil deliveries. However, successful anti-submarine warfare and new pipelines up the East Coast both quickly ended the need for substitute fuels, and the oil burning installations reverted to business as usual.

After World War II there was a steady low level (in real terms often a declining level) of petroleum prices so that no particular incentives existed for working with coal-oil slurries. This situation changed abruptly with the Arab oil embargo of November 1973 and the subsequent more than trebling of world oil prices. American efforts to overcome these problems quite properly include a reappraisal of coal-oil slurries. This is a current program of the U.S. Energy Research and Development Administration (ERDA).

1.3 THE PRESENT SITUATION

The present state of the art of coal-oil slurry production and burning is influenced by a number of factors. One major difficulty that has to be faced is the elimination of coal as an accessible-on-the-open-market commodity. Today, consumption of coal in the United States has essentially only two user groups. These are (1) the major electric power generating companies and (2) the smelters of metal, particularly the users of metallurgical coke. Both user groups buy in massive quantities and under direct contract from the producing mines. Thus, in contrast to the early 1920s when any major city would have had a whole field of highly competitive coal dealers, today the retail coal dealer is nearly extinct.

A corollary to the near extinction of the role of coal merchant is the present day difficulty of opening a new coal mine. With customers so limited and orders so big, a new mine is an extremely expensive venture. Although the energy crisis of 1973 was already two years behind us, the Bureau of Mines (Weekly Coal Report, December 30, 1975) reported only a 6.5% increase in coal production in 1975; 1976 was running at less than a 5% increase through August. Clearly, extensive adoption of coal-oil slurry fuels will require expansion of coal production. However, compared with reversion to 100% coal, slurries would place less immediate total load on the demand for coal at the mines.

In contrast to the nearly extinct coal dealer, the merchant in coal-oil slurries remains to be born. The evolution of coal-oil slurries has yet to arrive at the point where each user is not obliged to make his own.

Among the more positive factors in the present state of the art, coal grinding (especially in major power stations) is more common and more technically sophisticated than ever before. In general, it is believed that users of slurries will not find serious obstacles in the grinding area.

Knowledge of the chemical make-up of petroleum oils that might be slurry components is also greatly advanced over what prevailed in earlier years. The subject of slurry stabilization, whether by the use of surfactant compounds or by the more careful selection of coal and oil for compatability is now much better understood than it was earlier.

As might logically be expected in the present period of energy shortage and price rises, the ERDA and others are taking renewed interest in coal-oil slurry utilization. Without offering an exhaustive catalog of interested parties, it is noted that General Motors, the Department of Defense, the Department of Commerce, Alberta Research in Canada, and Pennsylvania State University all have current or recent activity in this field.

2. THE CURRENT ERDA PROGRAM

2.1 IDENTIFICATION OF ERDA AND DEFINITION OF ITS ROLE

The Energy Research and Development Administration is a post-energy-crisis (1974) agency of the United States Government. In it are combined former officials and functions of the Atomic Energy Commission and the Office of Coal Research. The latter originally was in the Department of the Interior. As its name implies, ERDA is concerned with energy in all of its forms and aspects, including the subject of the present paper.

The work which presently either is underway or planned by ERDA in the field of coal-oil slurry utilization can be divided into planning, research, industrial demonstration, public utility demonstration, economic evaluation, and (evolving out of all of these activities) the establishment of coal-oil slurries as an article-of-trade which in the future can be ordered from a fuel vendor rather than having to be prepared in each consuming plant.

2.2 CONTINUING PLANNING ACTIVITIES

ERDA/Fossil Energy is the central group that concerns itself with the organization, funding, planning and administration of pertinent coal-oil slurry combustion projects which are ERDA sponsored. As such, its responsibilities continue through the whole range of activities into which the current program is divided. The specific duties involved include, in addition to in-house projects, the selection of participating contractors, the definition of contractor duties, the receipt and examination of contractor reports and the initiation of any adjustments necessary during the course of the in-house or contract work to maximize the useful results from each program component. Because the coal-oil slurry combustion program is a dynamic one, planning is a continuous process.

2.3 RESEARCH-ORIENTED ACTIVITIES

For the purpose of control, many research activities can be logically divided into initial and advanced components. Initial component work should enable all of the interested parties to grasp the idea of whether genuine progress is being made. It also will enable the exact definition of advanced component work to be made in the light of real observations not yet available when activity was first authorized.

Among the research-oriented coal-oil slurry activities that will require attention are:

(1) Optimum coal types - Coals differ widely, and the selection of the coal to go into a slurry is unlikely to be just an arbitrary matter. The range of factors that might influence selection of a particular coal would include its (a) calorific value, (b) sulfur content, (c) ash content, (d) ash melting point, (e) grinding characteristics, (f) density, (g) response to paraffin hydrocarbons, (h) response to aromatic hydrocarbons, as well as (i) price and (j) availability. Some of these factors can be looked up in a book; others will have to be tried in the laboratory. It seldom happens that one coal will be "best" in all categories. Therefore, trade-off judgment involves the balancing of one pattern of good and bad qualities against some other pattern of good and bad qualities. If solvent de-ashed coal were economically available, it is believed that it would be a good choice for slurry combustion.

(2) Optimum fuel oil types - Fuel oils, like coals, also differ widely. In fact, they differ so widely that the term No. 6 Fuel Oil is a rather broad specification. It calls for a definite minimum flash point and a definite maximum viscosity. Within these boundaries, refiners might sell not only non-volatile residuals but (blended with them) other surplus oils as long as the mixture complies with specifications.

(3) Grinding, mixing and stabilization- Some research is required into the best mechanical procedures for making coal-oil slurries. This will include studies of the effect of particle size distribution, advantages and disadvantages of wet versus dry grinding, chemical composition of the coal and the oil, and the specific function of additives in stabilizing slurries.

(4) Handling and storage - It is necessary to identify the types of tanks, pumps and other equipment best suited to efficient transportation, storage and delivery to the point of burning of coal-oil slurries.

(5) Burning experiments - Research is required into the atomization process at the burners, the flame characteristics and the furnace volumetric and other configuration requirements that will get optimum results from coal-oil slurries.

(6) Pollution control - Experimentation is needed to optimize methods of preventing ash, sulfur dioxide and other effluents from exceeding environmental standards and to characterize emissions where additives are employed as a fuel stabilizer.

At this point, it is appropriate to introduce a set of six slides which have been furnished by ERDA to illustrate some of their current research work. These slides were prepared at ERDA's Pittsburgh Energy Research Center.

The first slide is a picture of a 100-horsepower fire-tube package boiler which was surplus from some earlier experiments. It is of Cleaver-Brooks manufacture and originally was intended to fire oil or gas. Comparatively minor modifications, some of which are apparent on succeeding slides, were made in order to conduct coal-oil slurry test burnings. A principal goal of this initial work, which will soon be supplanted by larger and more extensively instrumented equipment, has been to measure and evaluate corrosion and deposits in a small fire-tube boiler.

The second slide is a view of tankage and pumps installed for the coal-oil slurry experiments. There is a total of four tanks, also taken from surplus stocks. Their function will be described when we get to the flow sheet.

The third slide is the manufacturer's cutaway view of the four pass, fire-tube boiler used in the experiments. It is a standardized skid-mounted unit of a widely used type.

The fourth slide is an illustration of thermocouple attachment to selected tubes in the test boiler. Two new tubes of known metallurgical background were installed in each of the last three passes. Each of these six tubes bears three tube-wall thermocouples to permit a continuous examination of temperature gradients during test operation.

The fifth slide is a front view of the air-atomizing No. 6 fuel oil burner installed for the coal-oil slurry tests. Apparently, it worked satisfactorily. Burner manufacturers contacted by the author of the present paper indicated that they would prefer to use steam atomizing equipment.

The sixth slide is a simplified flow diagram of the experimental unit. There are two steam-heated fuel oil storage tanks and two steam-heated slurry tanks. One of the latter is the mixing tank, and the other is the holding tank from which slurry is pumped directly to the burner. The coal for this unit is not ground in the immediate work area but rather at a multi-purpose grinder installation several blocks away in another part of the Pittsburgh Energy Research Center. Ground coal (90% through 200 mesh) is received in steel drums and added to the mixing tank.

2.4 INDUSTRIAL DEMONSTRATION PROGRAMS

ERDA made a public announcement in the official U.S. Commerce Business Daily dated January 21, 1976 that it was seeking sources for the conduct of a complete development program in coal-oil slurry combustion.

One designated aspect of this announcement is the participation of private manufacturing industry. It is an apparent policy position of ERDA that the financial (as well as physical) participation of industrial firms ought to be obtained. A recent article in Science magazine (August 20, 1976) suggests that complications may arise and that voluntary proposals to conduct demonstration projects and to share expenses are rather difficult to come by.

The programs for private industry participation which were announced on January 21, 1976 deal with metallurgical industries separately from general manufacturing industries.

In the case of the metallurgical industries, retrofit equipment and techniques are sought for installation in a commercial blast furnace having a minimum acceptable hot metal capacity of 500 tons per day. The percentage of total fuel requirements to be met by coal-oil slurry cannot possibly be 100 because coke, in a blast furnace, has non-fuel functions. However, the firing of blast furnace stoves is one area in which coal-oil slurries can be directly applied.

In the general manufacturing industries, a 100% substitution of coal-oil slurry for the former fuel is much more likely. Here, three demonstrations are contemplated: (1) on an industrial steam generator originally designed for coal which, at some intermediate date, had been converted to oil or gas, (2) on an industrial steam generator originally designed for oil or gas, and (3) on a direct-fired industrial process heater where direct contact is obtained between the combustion gases and the material being processed. The size of the coal-based steam design (1) installation is stipulated in the range 50,000 to 120,000 pounds of steam per hour. The size of the oil- or gas-based steam design (2) installation is stipulated in the range 30,000 to 120,000 pounds of steam per hour. The size of the direct-fired industrial process (3) installation is stipulated in the range 10 million to 100 million Btu per hour.

2.5 UTILITIES DEMONSTRATION PROGRAMS

As a counterpart of the three industrial projects just described, it is also contemplated in the January 21 announcement that the public utilities will participate (both physically and financially) with ERDA in demonstrating how coal-oil slurries can be adapted to their needs in two different installations.

One utilities demonstration plant is stipulated to involve a steam generator originally designed for coal which, at some intermediate date, had been converted to oil or gas. It is to be associated with a turbine electric generating system demanding at least 500,000 pounds of steam per hour.

The other utilities demonstration plant is required to meet all of the above-described conditions but on a steam generator originally designed for gas or oil as the only fuel.

2.6 ECONOMIC EVALUATION PROGRAMS

Concurrent with the above-described industrial and utility demonstration programs, an initial approach will be made to the economics of coal-oil slurry burning. This work will enjoy the co-sponsorship of the Federal Energy Administration as well as the ERDA and will draw from real-world applications.

Some of the economic evaluation in its final form is recognized as being dependent on the completed work in research and industrial/utility demonstrations. If new understanding and appreciation of the processes involved are in fact generated during research and industrial/utility demonstration, the corresponding economic analysis will recognize the actual findings of that work.

2.7 COAL-OIL SLURRIES AS AN ARTICLE OF TRADE

This is the ultimate test of the total program. Category V in the Commerce Business Daily announcement calls for a slurry mixing and distribution facility for the optimization and marketing of a stable suspension to multiple users under a single general specification.

There are various ways in which this can be established. As an illustrative example, an oil refiner located in a coal producing region might undertake a slurry-burning demonstration on one of his oil refinery furnaces. Having conducted successful experiments leading to satisfactory coal-oil slurry specifications, such an oil refiner might continue to burn the product and begin to offer the same product to nearby industrial plants. As the slurry sales volume increases, the business of slurry vendor would evolve into a permanent activity. At the same time industrialists exploring conversion to slurry would be able to deal with an established slurry supplier. Shipments by tank car, tank truck and barge might become normal, especially in the Northeastern states where the economics of such operations are likely to be most favorable.

3. PROGNOSIS FOR PROGRAM EXECUTION

3.1 DIRECT EXECUTION BY ERDA IN-HOUSE STAFF

Essentially, the areas of interest for direct program execution by ERDA in-house staff are (1) continuing planning activities, (2) research-oriented activities and (3) economic evaluation programs, all of which are described separately in Chapter 2 of this paper.

The execution of continuing planning activities is a most important role for any research and development agency. Any failure to perform that role would tend to negate the whole reason for being a research and development agency. Thus, the in-house staff might really have no more important assignment than to see to the correct and adequate planning of its work, some details of which can be assigned in-house and some details of which can be contracted out to others.

The earlier reference to Science magazine for August 20, 1976 raises the problems which ERDA faces as an arm of government and an arm of scientific research. There are political reasons for starting, stopping and continuing various projects. These political reasons can subvert the scientific reasons and can result in unproductive expense to appease regional or occupational pressure groups. Because ERDA is a young organization, recently composited from the Atomic Energy Commission and the Office of Coal Research, it tends to have to build from scratch whatever position of political strength it wishes. It would be unrealistic to say ERDA doesn't wish a position of political strength because, without such position, it stands to be weak and vacillating.

Similarly, the execution of research-oriented activities partakes of the same general administrative problems when the research is undertaken by in-house staff. In-house in this sense includes the Pittsburgh Research Center of ERDA, which is staffed by federal civil servants.

The one significant difference in the options available to ERDA lies in the ratio which will exist between in-house and contracted research. Unlike planning, where the major share has to remain in-house to justify even having a house, research can occupy a wide range of mixtures. A 10% in-house and 90% contracted program could be justified without damaging the prestige and power of the agency. By contrast, ERDA could undertake a much larger percentage of in-house work without significant criticism.

Finally, the execution of economic evaluation programs is flexible as between in-house, other government agencies and outside contractors. The other government agencies that are expected to take an interest in economic evaluation are the Federal Energy Agency (primarily concerned with pricing and controls) and the Federal Power Commission (primarily concerned with the regulated public utilities). In the economic evaluation area, ERDA will be up against fairly powerful and entrenched bureaucracies who appear to have consumerism on their side. Therefore, ERDA may have to tell them some unpleasant truths.

Overall, the ERDA staff is considered by well qualified observers to be technologically competent although perhaps politically vulnerable. They can be expected to do a satisfactory in-house job on the coal-oil slurry program.

3.2 CONTRACT ADMINISTRATION - GENERAL

In contract administration, in-house work is automatically excluded because it has no outside contractor to be the subject of administration.

As already cited in Chapter 2 of this paper, there are four expected areas of contract administration:

(1) Industrial demonstration
(2) Utilities demonstration
(3) Economic evaluation
(4) Coal-oil slurries as an article of trade

Each of these areas will involve different contractor attitudes toward technological details, financial arrangements, deadlines, reporting, and completion or termination of the relationship under which work was performed.

3.3 CONTRACT ADMINISTRATION - INITIAL COMPONENTS

The term "initial components" is used to describe that portion of an assignment (made by ERDA to an outside contractor) which embraces both the launching of the work and the definition during the early stages of the work of what will eventually become its advanced components.

The launching of the work is an easy concept to grasp. By the time contract negotiations are essentially completed, both ERDA and the contractor will have a fair visualization of what to do first.

The definition during the early stages of the work of what will eventually become its advanced components is more difficult. As an extreme example, consider a program that has been launched but in all logic ought to be abandoned as misconceived or unproductive. Can the contract administrator recognize the truth, and has the contract administrator courage enough to face the truth?

Alternatively, consider a more modest assumption. Suppose a really unimaginative contractor puts forward a set of advanced components that will only prolong the agony without solving the problem. Again, perception and courage are both required from the contract administrator.

3.4 CONTRACT ADMINISTRATION - ADVANCED COMPONENTS

The term "advanced components" describes the later portion of an assignment. To some degree, the work of executing advanced components depends upon detailed definitions that were achieved in the initial stages of the same work.

In administering advanced components work, the ERDA staff will have to face a new set of problems. In particular, there is a need for realism as a project approaches completion. One can explore a problem with theories and hypotheses, but to state a solution can require a more down-to-earth approach.

Although it certainly is not necessary to have separate personnel to administer initial and advanced work, it is desirable that the ERDA project manager change his viewpoint as the work progresses so as to accommodate the above-described ideas.

4. FINAL OUTCOME

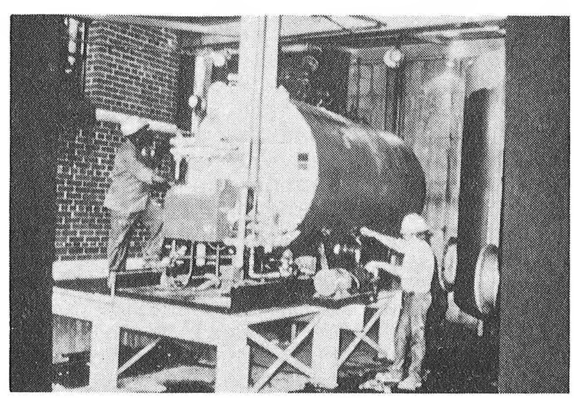
Having introduced the coal-oil slurry concept and having presented some insights into its nature, terminology and history, this paper has turned to the current ERDA program in that field. That program has been reviewed in some detail covering planning, research (illustrated with six slides), demonstration programs, economic evaluation and the establishment of coal-oil slurries as an article of trade.

After a quick review of the prognosis for ERDA program execution, we are now ready to try to answer the final question: What is the logical outcome of the coal-oil slurry program?

This program will probably have only a transient effect in the American energy picture. It is more concerned with conversion of existing furnaces in a way that permits a stretch-out of resources than it is with potential new designs of furnaces adapted to some fuel-of-the-future. Nevertheless, if promptly developed, the interim effect of burning coal-oil slurries will be salutary to the economy and to the concept of energy independence.

Biography

Lee Carter, Registered Professional Engineer, is a sole-proprietorship consultant organization bearing the name of the author of this paper. In the broadest terms, his field of interest is engineering economics (embracing studies and investigations in energy, chemical engineering, industrial development, and the feasibility of river ports and marine terminals). A graduate of Purdue (B.S.Ch.E. '40) and Cornell (M.S. Eng. '45), Mr. Carter has been a naval ordnance officer in World War II, a process engineer and author of proposals and reports for Stone and Webster and the Senior Vice President in charge of studies and investigations for a major St. Louis consulting firm.



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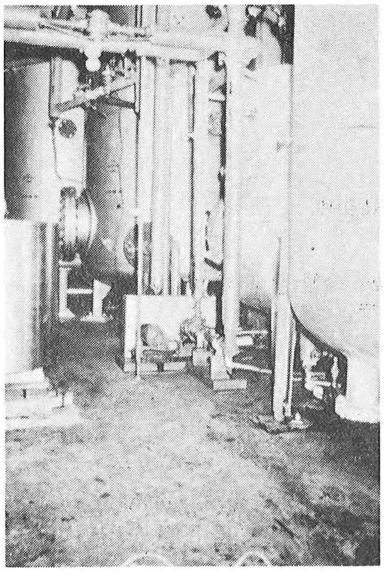

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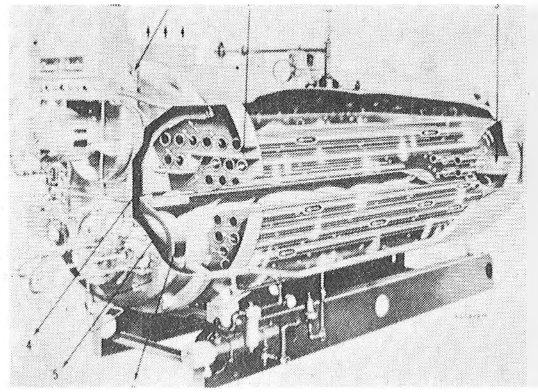

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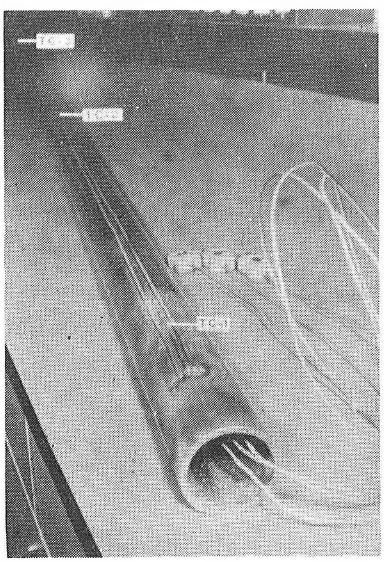

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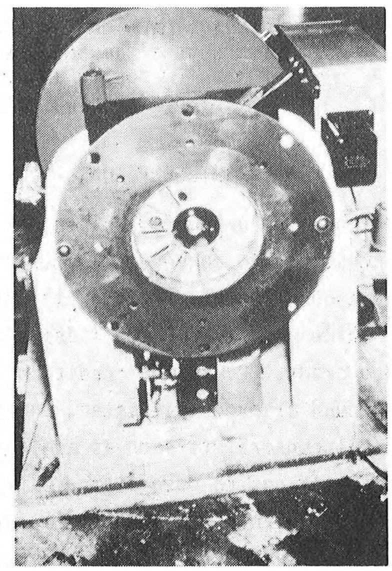

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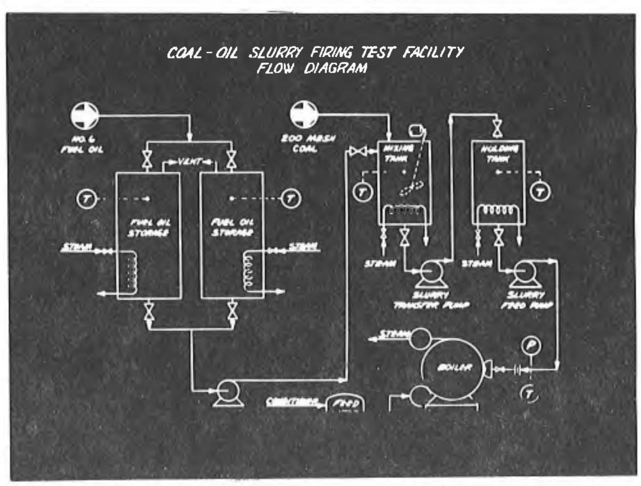

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