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Abstract

Performance and power costs of H_2-O_2 combustion powered steam-MHD central power systems are estimated. Hydrogen gas is assumed to be transmitted by pipe from a remote coal gasifier into the city and converted to electricity in a steam MHD plant having an integral gaseous oxygen plant. These steam MHD systems appear to offer an attractive alternative to both in-city clean fueled conventional steam power plants and to remote coal fired power plants with underground electric transmission into the city. Status and plans are outlined for an experimental evaluation of H_2-O_2 combustion-driven MHD power generators at NASA Lewis Research Center.

I. Introduction

The NASA Lewis Research Center has undertaken a program to evaluate the potential performance of H_2-O_2 combustion-driven MHD power generators. Hydrogen was chosen because it possesses the highest energy content per unit total mass (fuel and oxidizer) of the hydrocarbon fuels. It is therefore especially attractive for mobile applications where the operating time is sufficiently long that the fuel weight is large compared to the dry weight of the system. Hydrogen is also attractive for stationary power plants since it is a relatively cheap coal derived clean fuel which is easily transported by gas pipe. It also possesses adequate power density when burned with O_2 and of the hydrocarbon fuels requires the least amount of O_2 per unit heat release. Another advantage is that its combustion product, i.e., steam, is condensible and easily mated with existing steam power plants. A further feature of H_2-O_2 combustion is that it is pollution free.

Although hydrogen is an attractive fuel from a systems standpoint, it has some undesirable features for an MHD generator. The main undesirable feature is the lower electrical conductivity of the combustion products as compared to that of the higher C/H ratio hydrocarbon fuels. This is due to lower flame temperature, large electron collision cross section of water vapor, OH reaction with alkali metal seed material, and the formation of $(OH)^-$ ions. However, these limitations are partially offset by the lower molecular weight of the hydrogen combustion products which results in a higher flow velocity for a given Mach number. This higher velocity generates a higher Faraday voltage for a given magnetic field strength. This higher voltage may be particularly important in small mobile power plants where the large electrode and boundary layer voltage drops, 100-400 volts (see reference 1), are a significant fraction of the total voltage generated. Unless these drops can be eliminated through more advanced MHD generator designs, hydrogen-fueled generators may have a significant advantage.

Our initial experimental program is directed toward evaluating the performance of H_2-O_2 generators at high voltage, i.e., high Mach number (2) and high magnetic field (7 tesla). This study will be orientated toward understanding electrode and boundary layer voltage drops and the cause of and remedies for axial voltage breakdown in MHD ducts.

II. Steam MHD System Performance and Cost Study

Steam MHD System Performance

The H_2-O_2 steam MHD generator can be easily integrated into cycles using steam turbines. Fig. 1 shows one such cycle. Four options for this power plant cycle were examined in reference 2. In option 1, the H_2, O_2, and the steam diluent to the combustor are preheated to the steam bottoming plant temperature (839 K), the flow is expanded to a total pressure of 1 atm in the MHD generator. In options 2, 3, and 4, 1500 K preheat is assumed and the expansion is to a total pressure of 1, 0.5, and 0.1 atm respectively. All options except option 4 use a low pressure turbine to expand the flow to a pressure of 1/10 atm before the steam is condensed. In all options the combustor is operated stoichiometric at 30 atm and 3468 K. To maintain this combustion temperature for the two different preheat temperatures the steam diluent flow is varied from 17 to 30 percent of the total MHD hydrogen and oxygen mass flow.

If the hydrogen and oxygen are preheated, the cycle efficiency is increased more by recycling water through the high pressure recuperative-boiler and turbine than by increasing the combustion temperature. The gross efficiency of the high MHD expansion ratio cycle is 70 percent (using the higher heating value) for a preheat temperature of 1500 K. Thus, this steam MHD cycle has the potential for obtaining a net efficiency of over 60 percent after subtraction of the power required for oxygen production. Even without preheat the high expansion ratio steam MHD topped cycles offer the potential of over 50 percent efficiency.

Comparison of Power Systems

Table I shows representative average power cost for conventional steam plants using various fuels and for both coal-air MHD and steam MHD systems. In this table, energy and/or power transportation costs are neglected and only east/midwest surface mined coal is considered. Fuel costs are based on 1985 projections given in reference 3.

Table I shows that the option 3 of reference 2 is the most attractive steam MHD system. This 55 percent efficient system is also more attractive than all alternative clean fuel conventional steam power plants, particularly if they are fueled from domestic shale, coal, or crude.

Table I also shows that the direct coal fired power plants can produce power at the lowest average cost, the lowest cost system being a conventional coal-fired steam plant with no SO_x removal. It is 0.9 mills/kW-hr$_e$ below the coal-air MHD topped steam plant which would remove SO_x. This coal-air MHD topped steam plant was investigated in reference 4. The cost estimates made in the present study were based on reference 4.

The power production cost is only one major factor in determining future power plant choices; additional aspects of the cost of power in a city as well as the environmental impact of the power plant must be considered. In figure 2 the cost of power in a city is evaluated for various power plant concepts. The city is assumed to be either 100 miles from east or midwest surface coal mines and/or 1500 miles from western surface coal, syngas, syncrude (shale or coal), and domestic crude.

The calculated power costs include energy/power transportation costs. Investigated are in-city power plants using coal and clean fuels, coal fired power plants 100 miles from the city with either overhead or underground electric transmission, and western minehead coal fired power plants with overhead transmission. For the hydrogen fueled power plants the hydrogen is assumed to be piped to the city from a gasifier located 100 miles outside the city.

Figure 2 again shows that a 55 percent efficient steam MHD power plant has an attractive potential compared to domestic clean-fuel conventional steam power plants. This type plant is used in many cities in the United States. Oil and gas fired power plants account for approximately 25 percent of the U.S. electric power production.

Figure 2 also shows that the steam MHD power cost will be higher than the in-city coal fired power cost but may have lower cost if the coal fired plant is required to be located 100 miles outside the city (the assumed gasifier location) and if electric power transmission into the city is required to be underground like the hydrogen transmission.

III. NASA Lewis H_2-O_2 Experimental Program

Two facilities are being used in this program. The first is a rocket test facility in which proposed MHD channels will be tested for structural integrity and lifetime. Diagnostic measurements will be made with applied electric fields. While this facility does not provide total MHD channel simulation, it is very useful because of the test time limits of the second facility as will be discussed later. The rocket test facility may also be used to test various MHD system components (e.g., seed recovery systems, fuel and oxygen preheaters) associated with the power generation cycle proposed in reference 2. This facility has been completed and is presently being checked out. Initial MHD duct tests are scheduled for the first quarter of 1974.

The second facility is an MHD power generation facility which is now in the final design stage and is projected to be completed by the fourth quarter of 1974. The physical size of the MHD channel is determined by the use of an existing cryogenic magnet (ref. 5) which will be modified for use in the experiment. As shown in figure 3 this magnet presently consists of a stack of 12 aluminum magnet coils which are cooled with liquid neon. The coil bore diameter is 30 cm. The magnet develops 15 tesla at the magnet center. For the MHD experiment the magnet dewar will be modified to provide a 23 cm bore transverse to the coil center line for inserting the MHD duct. In this configuration, as shown in figure 4, eight coils will be used (4 on either side of the MHD duct bore). These coils will produce approximately 7 tesla across the 30 cm magnet bore diameter. With the use of the lower strength fringing field outside the magnet bore a MHD duct length of about 45 cm can be obtained. Aspect ratio considerations then lead to a mean MHD duct hydraulic diameter of approximately 5 cm.

Run times are dictated by the capacity of the neon refrigeration system which allows one period of operation per day. In the present magnet configuration this period of operation is approximately 1 minute at the highest magnetic field strength although several minutes of operation is possible at lower field strengths. Since only a small number of short duration MHD tests (of the order of 10 seconds) can be run each day, a heat-sink cooled MHD duct will be used.

In the rocket engine modified for this program, the gaseous H_2 is injected uniformally into the combustion chamber through a porous stainless steel injection plate at the rear of the chamber. The gaseous O_2 is injected through 36 injection tubes uniformally inserted into the H_2 injection plate. In this design cesium seed injected into the oxygen supply line as a 75 percent solution of CsOH dissolved in water. While initial tests indicate this method of injection is satisfactory a second injection system consisting of 18 injection tubes for oxygen and seed (each tube is separately fed from O_2 and CsOH solution manifolds) is being fabricated. The second injection system was designed to insure that the CsOH solution is injected uniformally into the combustion chamber.

The combustion chamber and nozzle are water cooled electrodeposited copper. The length of the chamber and nozzle is 22.86 cm and the i.d. of the chamber is 6.35 cm. The nozzle is designed for Mach 2 at the 4.96 cm diameter exit. The chamber and nozzle have been tested for H_2-O_2 stoichiometric combustion at chamber pressures up to 20 atm.

IV. Concluding Remarks

H_2-O_2 combustion powered steam-MHD central power systems offer the potential of producing power without air pollution (except for the emission of CO_2 at a remote gasifier). Low thermal pollution for in-city power plants lower the cost of power from clean fuels and lower the economic penalties associated with possibly requiring coal consumption to be remote from cities. Steam MHD systems should, in addition, be the least difficult MHD technology to develop because of their clean fuel and relatively simple chemistry.

The initial program of the NASA Lewis H_2-O_2 MHD generator program is to investigate the performance of generators at high voltage, i.e., high Mach number (2) and high magnetic field (7 tesla). This has particular application to small mobile power units where electrode and boundary layer voltage drops are of the order of the voltage that is generated. Future plans include the study of other fuels, primarily the products of coal gasification, i.e., H_2, CH_4, and CO, in varying combinations.

References

1. Wu, Y. C. L.; et al.: Investigation of Diagonal Conducting Wall Generators. 13th Symposium on the Engineering Aspects of Magnetohydrodynamics, Stanford Univ., Stanford, Calif., March 1973.

2. Seikel, G. R.; Smith, J. M.; Nichols, L. D.: H_2-O_2 Combustion Powered Steam-MHD Central Power Systems. The Hydrogen Economy Miami Energy Conference of 1974, Univ. of Miami, Coral Gables, Florida, March 1974.

3. Anon.: U. S. Energy Outlook: Report of the National Petroleum Council, Committee on U.S. Energy Outlook, vol. I, Summary. National Petroleum Council Committee on U.S. Energy Outlook, Dec. 1972.

4. Bergman, P. D.; Plants, K. D.; Demeter, J. J.; and Bienstock, D.: An Economic Evaluation of MHD-Steam Powerplants Employing Coal Gasification. BM-RI-7796, Bureau of Mines, U.S. Dept. of Interior, 1973.

5. Laurence, J. C.: High-Field Electromagnets at NASA Lewis Research Center, NASA TN D-4910, Nov. 1968.

TABLE I - REPRESENTATIVE POWER COST
ENERGY/POWER TRANSPORTATION NEGLECTED

TYPE PLANT	EFFICIENCY %	AV. FUEL COST mills/KW-hr_e	AV. POWER COST mills/kW-hr_e
CONVENTIONAL STEAM			
East/Midwest Coal			
No SO_x Removal	40	2.2	8.9
With SO_x Removal	40	2.2	10.9
Oil			
Domestic Crude	40	8.9	15.5
Imported Crude	40	6.2	12.8
Syncrude - Shale	40	8.1	14.7
Syncrude - Coal	40	10.4	17.0
Gas			
Syngas - West Coal	40	8.7	15.4
Imported LNG	40	7.1	13.7
Hydrogen			
East/Midwest Coal	40	8.8	15.5
COAL-AIR MHD TOPPED STEAM			
East/Midwest Coal	50	1.8	9.8
H_2-O_2 STEAM MHD			
East/Midwest Coal			
Option 1	48	7.3	13.0
Option 2	51	6.9	12.2
Option 3	55	6.4	11.9
Option 4	60	5.9	16.9

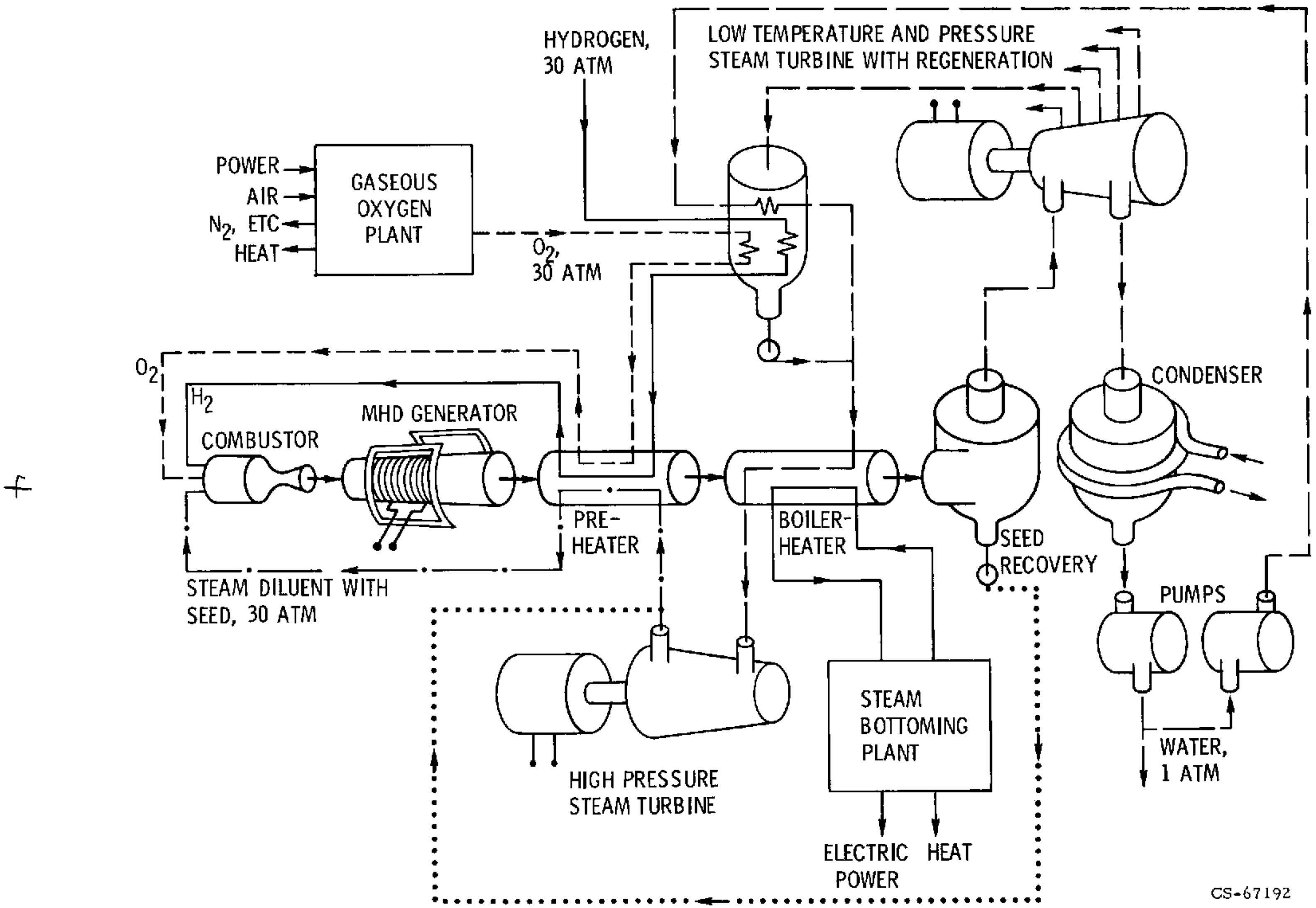

Figure 1. - H_2-O_2 Combustion steam MHD power plant.

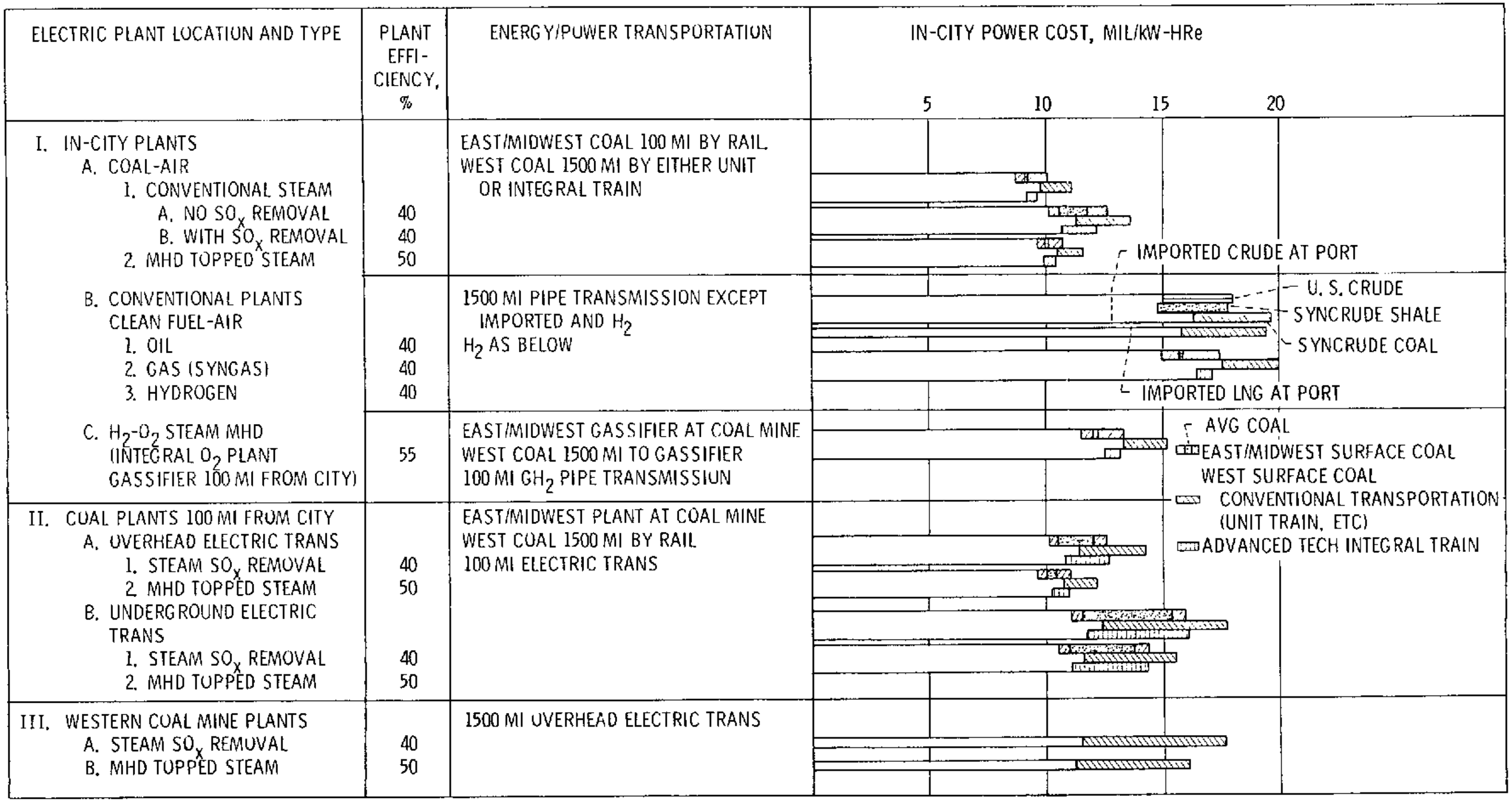

Figure 2. - Comparison of city power costs for various powerplant concepts.

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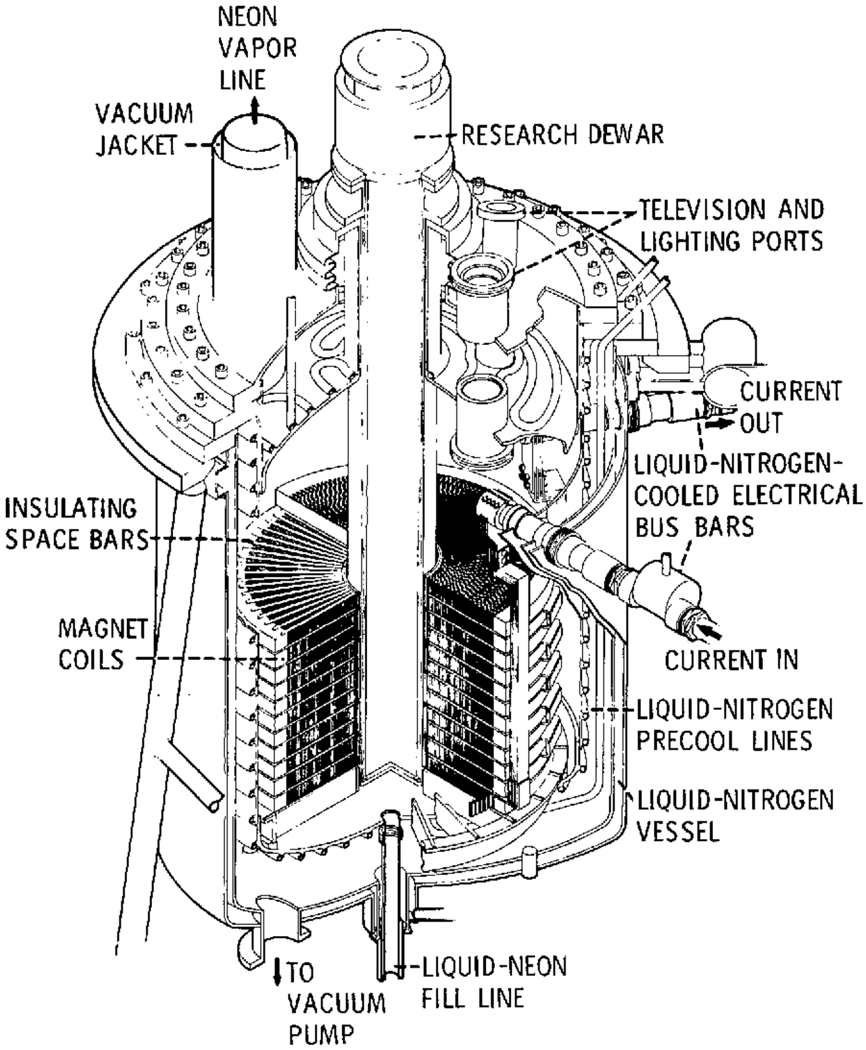

Figure 3. - Liquid-neon-cooled aluminum electromagnet.

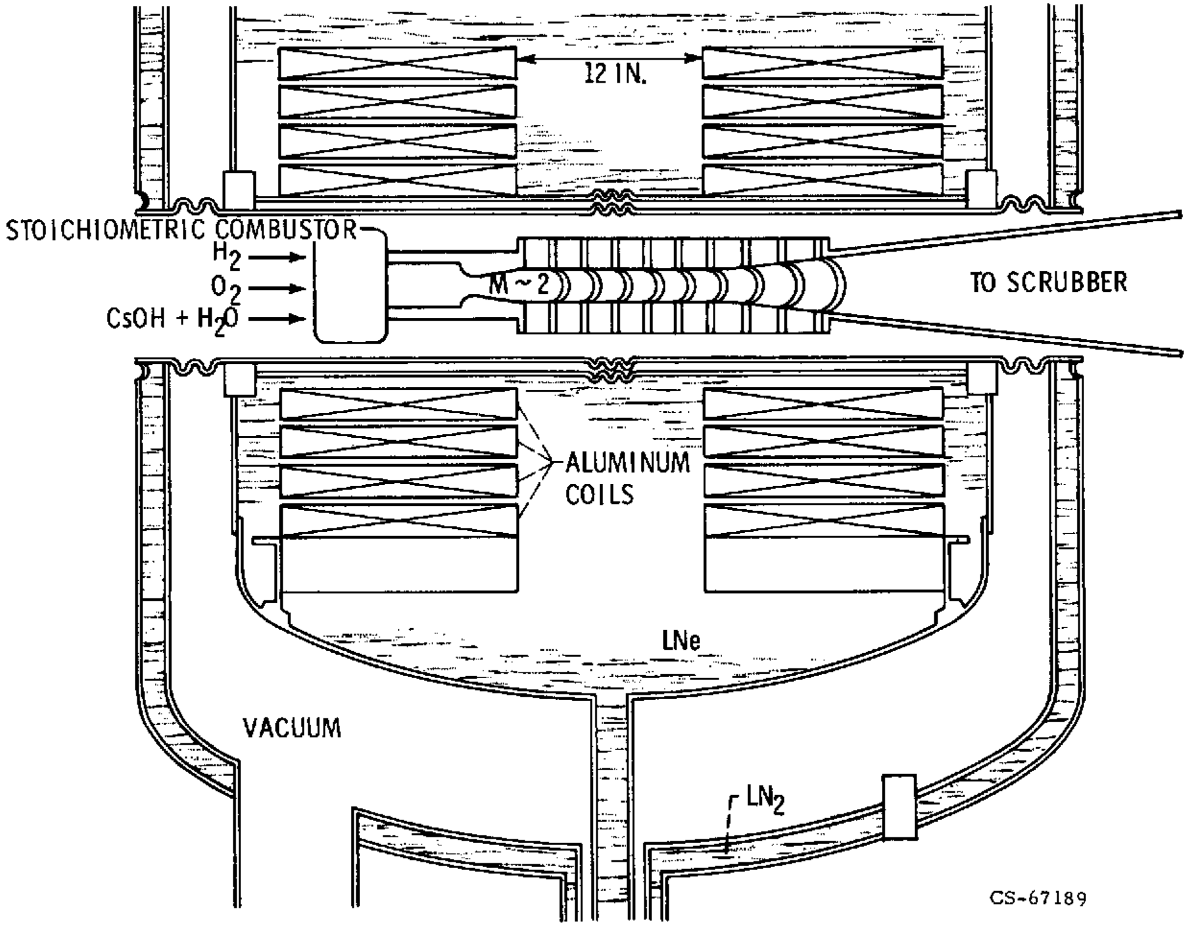

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Figure 4. - H_2-O_2 MHD generator experiment.

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