THE HEATING OF SOLIDS IN HIGH TEMPERATURE PLASMA

by

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INTRODUCTION

Until recently, processing of solid particulate matter in plasma systems has been thermally inefficient, with systems capable of handling only small feed rates. The economic implications of this were overwhelming, and retarded the development of commercial scale plasma heating processes. The actual direct cost of energy was only a small part of the total cost. The major detriment lay in the high capital costs of energy conversion equipment which would be required for a thermally inefficient process.

Within the past two years we have culminated a 10 year effort and achieved a major upgrading of plasma generator solids heating capability. A pilot plant has been in operation for over two years, producing commercial quantities of materials, with processing capabilities over 1000 lbs/hr. and powder sizes up to 1000 microns. Power requirements have been dramatically reduced.

SYSTEM PERFORMANCE

The TAFA/Ionarc plasma furnace, in operation since 1968, has achieved efficient heat affectation of solid particles on a large scale. We have found the most logical measure of particle heating performance to be the spheroidizing capability of the system. Performance measurement works as follows. The plasma system is turned on and adjusted to the desired power level, say 1000 kW. A 300 pound sample is then fed through the plasma column at a fixed rate. A series of tests are performed in this manner with all parameters except feed rate held constant. The particles are allowed to cool and solidify while still in flight. The product is then collected, screened, and the various fractions run over the sphere separation table shown in Figure 1. These measurements give a complete picture relative to the heat affectation capability of the device operating under the test conditions. The spheroidization process is an automatic one; if the particles become molten, surface tension pulls them into a spherical shape. Melted particles below 150 microns are almost all spherical upon passing through a device. As the particle size increases above 150 microns, careful product analysis reveals a gradual increase in the number of egg shaped particles and non-perfect spheres in the product. This is undoubtedly caused by the large mass of the particle and the associated distortion forces as compared with the surface tension forces. If a feed stock below 150 microns is utilized, essentially 100 percent spheres are achieved under conditions adequate to melt all particles. Therefore, feed stocks in this size range are used when evaluating the spheroidizing capability. The performance measurement then is one of continually increasing the feed rate through the device in a series of tests and measuring the decreasing number of spheres formed. With such data it is easy to determine the minimum kWh/lb. of feed stock which achieves complete melting of all the particles. It has been observed that this is a reproducible number which can be compared with similar data generated with different feed injection techniques, power levels, apparatus geometries, feed stock size, feed stock composition, etc. Figure 2 shows zircon sand (zirconium silicate) which has been spheroidized. The illustration shows particles below 150 microns which have been processed at 1 kWh/lb. Note that they are all spherical. In Figure 3, the polished cross sections show that the spherical particles have been melted throughout. On the other hand, larger particles, such as the 300 micron particle shown in Figure 4, are not completely spherical. The center core has not been heated to 1775°C, which is the dissociation temperature of zircon.[1] This is clearly seen in Figure 4, where clear, glassy zircon can be seen in the center surrounded by a completely dissociated mixture of zirconium oxide and silica.

We feel that by this performance measurement technique we can accurately compare various plasma systems and their particle heating capability. We have been intensively active in this field since 1956 and have compared a variety of plasma torches using this technique. Typically, a conventional dc spray torch, shown in Figure 5, exemplifies the dc plasma torches used for particle heating. Powder is injected downstream of the arc foot point to prevent contamination of these areas. Much of the thermal impact of such a device is lost because the particles cannot be passed through the arc and thereby take advantage of the temperatures in this region, which are often twice that of the tailflame where particles are injected. It is recalled that the thermal radiation from hot gas is a function of the fourth power of the temperature; therefore, much

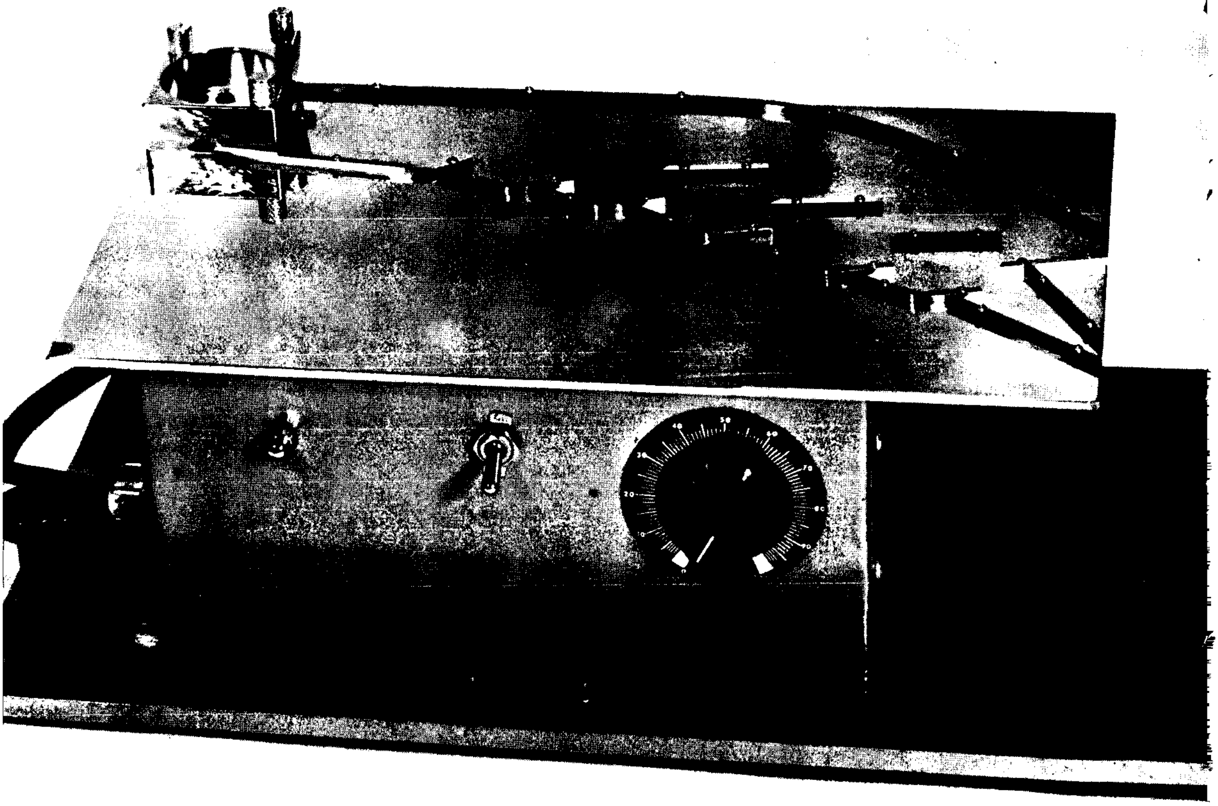


Figure 1. Table for Separating Spherical Powders

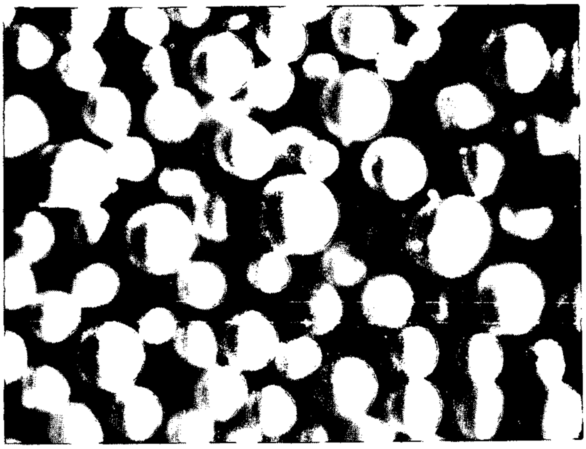


Figure 2. Typical Zircon Product As Removed from Furnace Without Upgrading.

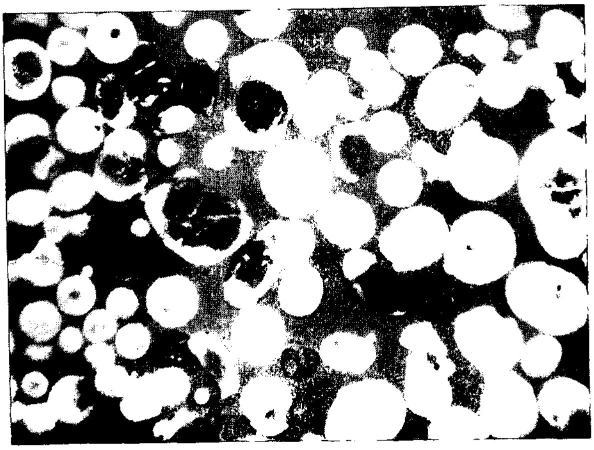
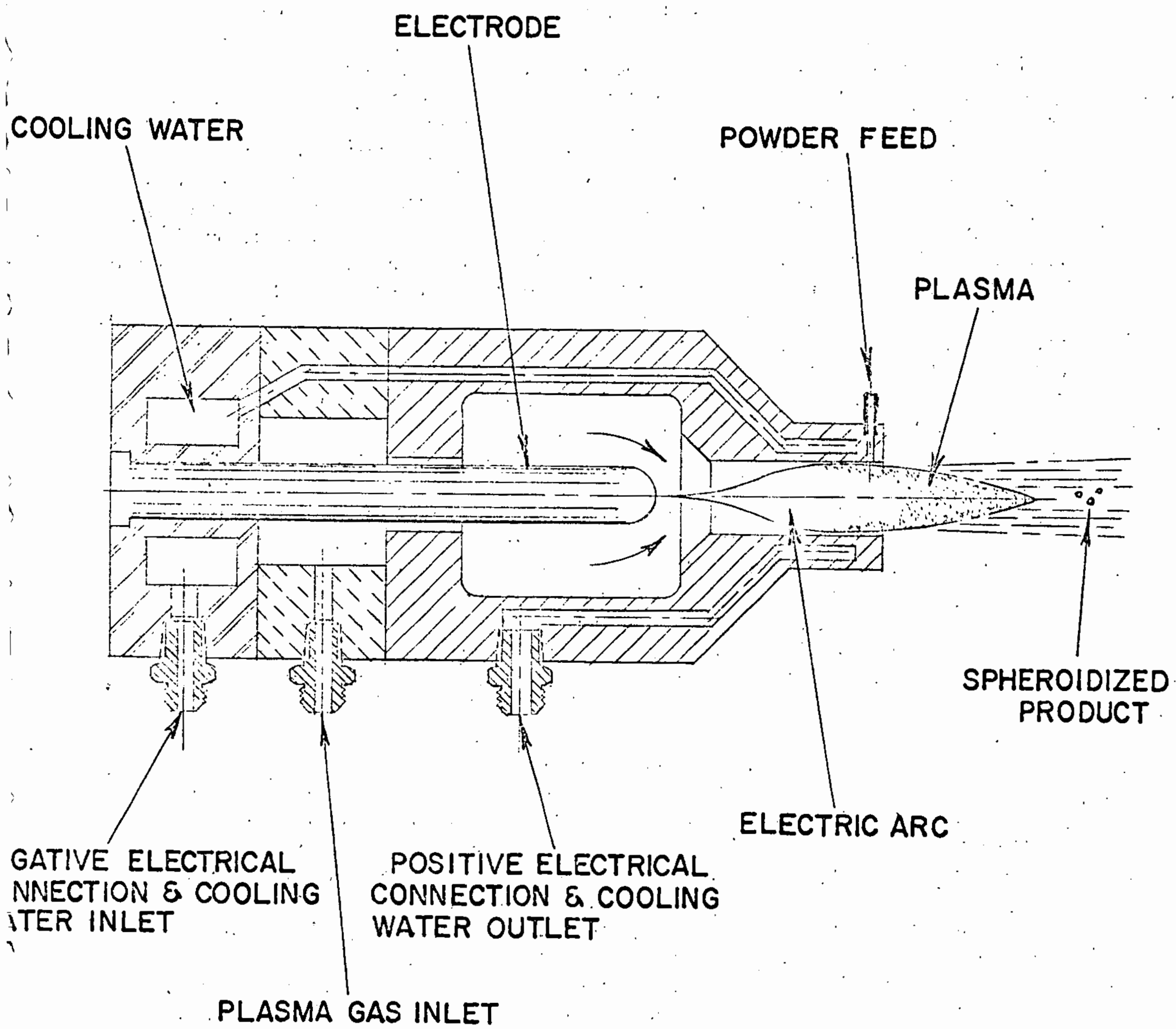


Figure 3. Typical Zircon Product Showing Degrees of Heat Affectation

Section in oblique, reflected light shows dissociated mixture (white) with cores of residual $ZsiO_4$ (gray, translucent).

Figure 4. Partially Dissociated 300 Micron Zircon Furnace Product

This particle, in partially polarized transmitted light, shows a core of residual $ZrSiO_4$, with rim of monoclinic ZrO_2 (fibrous) and cubic ZrO_2 (black). The reason for the black color of the cubic ZrO_2 phase is explained by the exceedingly fine grained nature and the high index of refraction of cubic ZrO_2 resulting in total reflection of the light. In reflected light this phase would be perfectly white. Note the sequence $ZrSiO_4$, monoclinic ZrO_2, cubic ZrO_2, indicating formation of monoclinic ZrO_2 ahead of cubic ZrO_2.



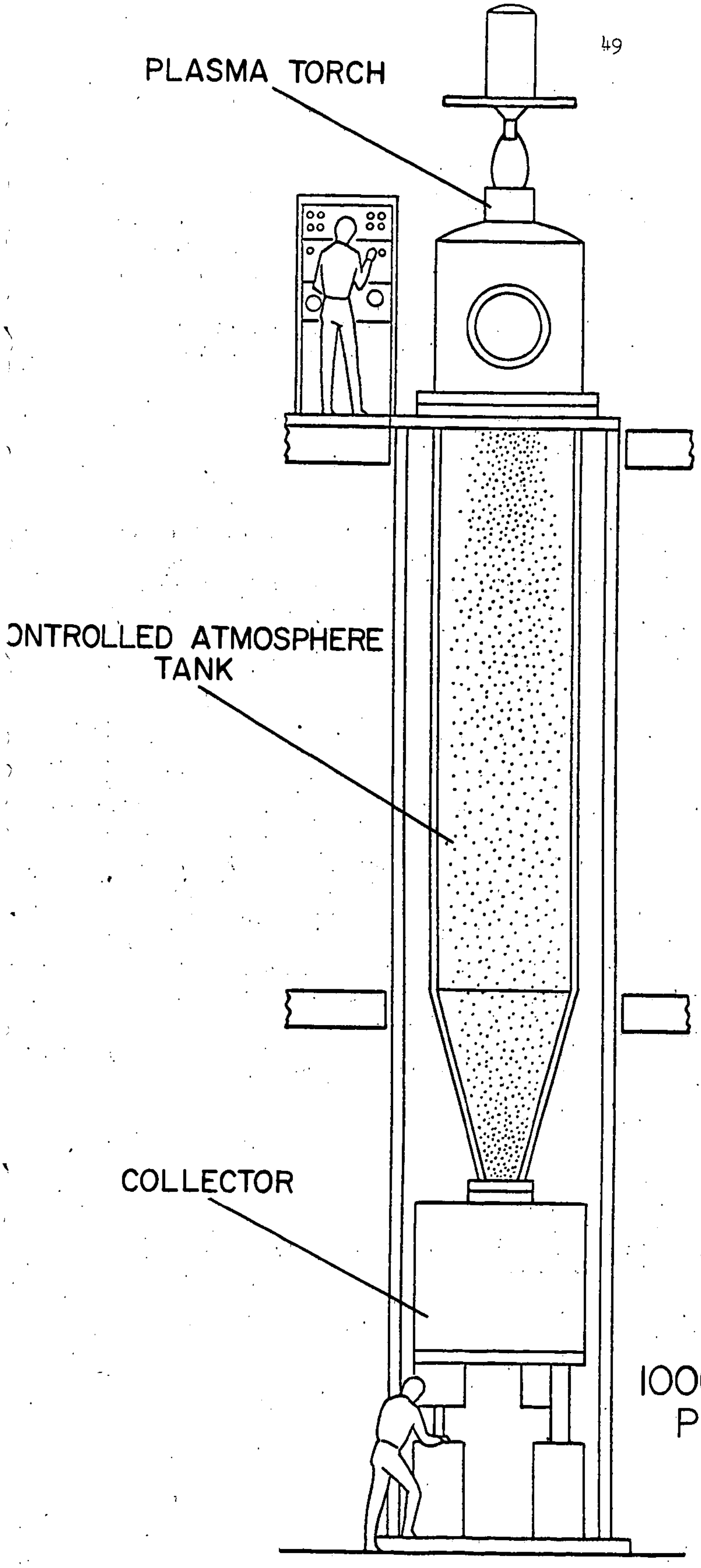
CONVENTIONAL DC SPRAY TORCH

FIG. 5

more particle heating capability is lost than is apparent from conductive heat transfer calculations. Our measurements would indicate radiant energy is the dominant factor in heating particles.

We therefore feel, on the basis of comparing the performance of a variety of devices, that we have achieved a dramatic improvement in solids handling capability with the plasma heater. This manifests itself in two ways; first, a much higher themal efficiency (0.5 - 1.5 kWh/lb.) for such materials as zircon, ilmenite, aluminum oxide, and most metals. This is to be compared with energy requirements of 5 - 10 kWh/lb. which were typical of previously available devices. Secondly, we have achieved reliable scale up, which has permitted the design and operation of a reliable 1000 kW-1000 lb/hr. system, illustrated in Figure 6. This is to be compared with previous systems which operated in the 1-10 lb/hr. range and with which most investigators have worked. Units can be easily duplexed, and it would appear that further scale up will not be difficult. In fact, thermal efficiency seems to improve, as might be expected, as the scale of the apparatus is increased. Powder melting costs with such a device, including all operating costs, plant amortization, and labor are in the range of $0.06/lb. at the 1000 kW level. Projected costs are as low as $0.01-0.02/lb. in the range of 10,000 kW. A third advantage of our present system is its ability to operate with almost any gas environment, including hydrogen, oxygen and chlorine. This has permitted us to subject molten particles to an almost unlimited number of reducing, oxidizing and reactive environments. Conventional gas-solid reaction kinetics[2] continue to govern. However, with the molten particles it appears that liquid turbulence may be considerable and complete particle reaction can be achieved in many systems with particles below 100 microns. Iron ore is a good example of this. We have achieved nearly complete reduction in one pass through the device at power levels below 2 kWh/lb, even though the reaction is endothermic.

One can vaporize a considerable portion of the feed stock by increasing the kWh/lb. This gives the obvious advantage in some chemical reactions of creating a vapor for reaction with the environment. Under such circumstances the solid feed could be recycled until consumed. The power consumption for vaporization, however, would be in the range of two to seven times the power consumption required for spheroidizing, thus limiting such an application to relatively high priced materials. We have estimated the cost of producing fumed silica by such a technique, passing beach sand through the plasma and vaporizing 10-20 percent of it. Operating and amortization costs are in the range of $0.15/lb. An interesting by-product is produced in this case; clear, amorphous silica spheres, which can be used as reflective beads in the sign and pavement lining industry. The advantage of silica over glass, which is used at present, lies in the superior reflectivity of silica.



1000 KW - 1000 LB./HR.
PLASMA POWDER
FURNACE

FIG. 6

The hybrid particle heater, in which commercial scale activities are carried out, might be applicable or adaptable to the treatment of coal particles. The already promising economic picture derived from the work of Krukonis and co-workers[3] for the Office of Coal Research might be made even more favorable.

The specific geometry of our hybrid particle heater is company confidential, however, we have made this system available to industry on a variety of business arrangement bases.

CONTINUOUS MONITORING

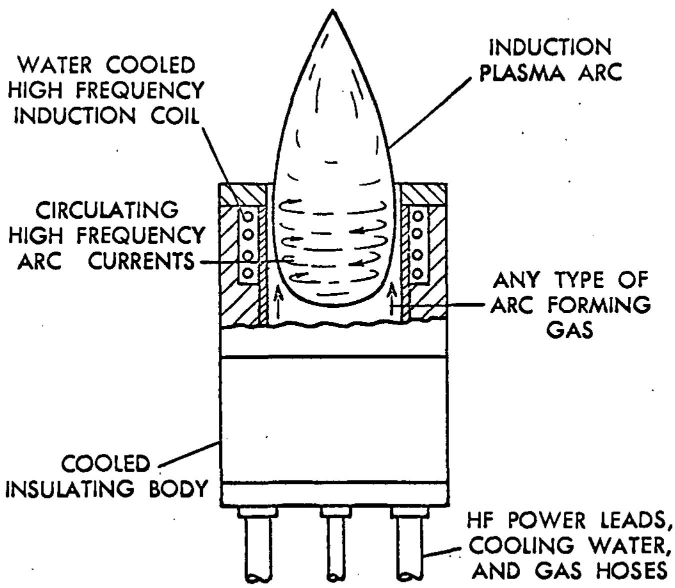
One application of solids heating which is quite interesting and timely is the determination of sulfur in coal and various ores. This can be either a pollution oriented or process control application and operates on the principle of instantaneous and complete oxidation of the test material, which is fed continuously into an oxygen plasma. Spectrographic or chromatographic techniques may be used to assay the resulting oxides.

ORE PROCESSING

The spheroidization-dissociation phenomena described previously for zircon, which is the starting material for the zirconium oxide industry, typifies one of the applications of the plasma generator to ore processing. We have developed a complete flow sheet for the economic production of zirconium dioxide via the plasma route. This involves the dissociation of zircon ore (zirconium silicate) to zirconium dioxide and silica, followed by conventional hydrometallurgical processing of the dissociated product to various purities of zirconium dioxide. A variety of purities have been produced, ranging from 70 percent to ultrapure, hafnium-free nuclear grade material. It appears that the process has some economic advantages. Large samples of some of the grades have been produced and are in the hands of end users for evaluation.

INDUCTION PLASMA HARDWARE

We have been active in the development of induction plasma heating systems for approximately 10 years. It is recalled that the induction plasma generator, shown in Figure 7, uses an intense electromagnetic field to heat



SCHEMATIC INDUCTION HEATER

FIG. 7

gases without hot electrodes. The basic advantages of the system, from the standpoint of heating solids and gases, include absolute freedom from contamination, since no electrodes are used and all containing materials can remain at water cooled temperatures. Second, the containing walls can be constructed of almost any material, ranging from quartz to nickel, hence, reactive gases can be handled with ease. Third, the device produces relatively large arc diameters (6-12 inches at 1000 kW). These large diameters result in velocities as low as 1-2 ft/sec and concomitantly long residence time. The simple gas mixing system of the induction plasma holds many advantages for performing chemical reactions. Moreover, performance has been improved in several areas recently to make the system even more attractive. A description of some of these improvements follows.

1. Power Density

Initially, plasma generators were constructed with quartz walls. Water cooling of the quartz was then added. This wall construction, however, was limited to power densities corresponding to the containment of diatomic gases at a maximum enthalpy of 7000 Btu/lb. Recently, segmented water cooled metal walls of the type shown in Figure 8 have been developed and operated at power levels up to 1000 kW. Diatomic gases at enthalpies of 40,000 Btu/lb. are successfully contained within these structures.

More recently, permeable walls have been utilized. This technique involves transpiration of a gas through the containing wall of the induction arc. This appears to have two advantages; first, essentially eliminating the wall heat loss to the device, which normally removes 20-30 percent of the input power; and second, preventing build-up of reactants and reaction products on the wall.

2. Pressure

Recently, torches have been operated at pressures in the range of 1000 psi. Previous to this only 1-2 atm. operation had been demonstrated reliably. This development should widen applications in the chemical industry. Reactions in which yields improve with increasing pressure, such as nitrogen fixation[4], may become economically attractive.

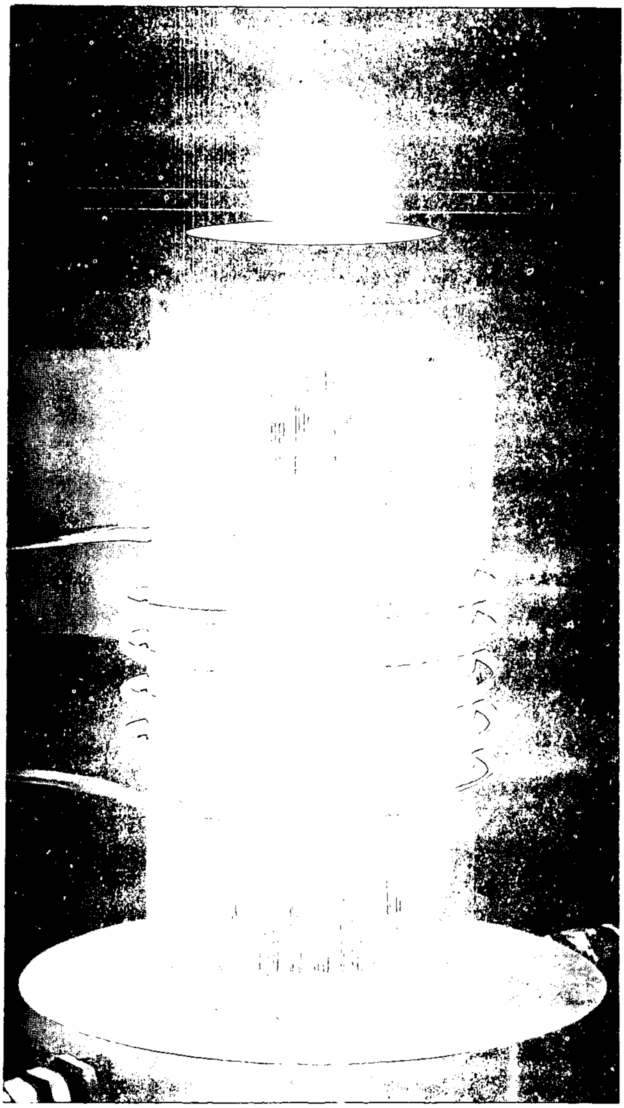


Figure 8. 6" Diameter Metal Wall Induction Torch in Operation at Low Power

3. Frequency

From the standpoint of power conversion economy, the ultimate in an induction chemical plant heater would be direct 60 cycle heating of gas. This now appears to be a possibility. During the past year, frequencies have been reduced from the 4 MHz-400 KHz range to 10 KHz. This has changed the power supply from an electron tube device to a motor generator, with consequent reduction in capital cost and simplified maintenance. Tests are presently underway at 960 Hz and a development program is underway to demonstrate 60 Hz heating during 1971.

CONCLUSION

In summary, advances made during the past two years have taken processes to treat solids in plasma out of the laboratory and into the pilot plant. Economically justified large scale commercial processes have been designed and could be placed in operation with today's technology. In addition, recent improvements in plasma generating equipment and technology promise to speed the advent of large scale industrial plasma chemistry.

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