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DOE/PC/89776--T5

PROJECT STATUS REPORT

Project Title:

Effects of Calcium Magnesium Acetate on the Combustion of Coal-Water Slurries

DOE/PC/89776--T5

DE92 004499

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Project Period : 1 September 1989 - 30 November 1989

Project Objectives :

The general objective of the project is to investigate the combustion behavior of single Coal-Water Slurry particles burning at high temperature environments. Both uncatalyzed as well as catalyzed CWS drops with Calcium Magnesium Acetate (CMA) catalyst will be investigated. Emphasis will also be given in the effects of CMA on the sulfur capture during combustion. To help achieve these objectives the following project tasks were carried over this three month period.

Project Tasks :

1 **LAMINAR FURNACE CONSTRUCTION** A laminar, drop tube furnace was purchased this past summer by the Mechanical Engineering Department of Northeastern University mainly for the needs of this project. It is manufactured by *ATS* and utilizes *Kanthal Super 33* molybdenum disilicide heating elements, to heat a 25 cm long radiation cavity to temperatures up to 1650 °C. The furnace was mounted on a stand below a ventilation hood, Fig. 1.

A 60 cm long 7 cm i.d. high purity alumina tube, manufactured by *Coors*, was installed along the centerline of the furnace. Two diagonally opposite holes were drilled on the alumina tube at a certain height to match the side observation windows

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of the furnace, which are fitted with quartz glass and a shutter. The two holes were connected to the corresponding quartz windows by 1 cm i.d. alumina tubes. To ensure a leak-tight system the connections between the vertical and the side tubes were made by press fitting (and gluing) medium density alumina washers machined for this purpose, Fig. 2. To support the vertical alumina tube as well as to provide for an air tight system two "O-ring" assemblies were used. These assemblies were water-cooled and made of stainless steel, Figs. 1, 2 and 3. The top enclosed a *Viton* "O-ring" having a 6.3 mm cross section. The bottom "O-ring" presented a considerable problem since is placed down-stream of the hot furnace gases and gets very hot. Both *Viton* and *Teflon* "O-rings" partially melted, thus, to alleviate the problem alumina insulation blanket in the form of a ring was compressed in the assembly. This provides for effective support as well as sealing for the alumina tube.

A stainless steel, water cooled injector was designed, constructed and positioned at the top of the drop tube furnace, Fig. 1. The injector was designed to perform various functions:

- Enable injection of particles or drops at various heights in the furnace radiation cavity. For this purpose the injector should be cooled and well insulated to withstand the high temperatures of the furnace.
- Enable pyrometric observations of burning particles from the top of the furnace. For this purpose the injector should be: on one hand as short and as wide as possible to maximize collection of light emitted from burning particles ($I_{rad} \propto (distance)^{-2}$), and on the other hand should be long and narrow enough to avoid observation of *direct* radiation from the furnace walls.

The injector design was excecuted with the above criteria in mind. Then the injector was passivated black to minimize *reflected* furnace-wall radiation from climbing up to the top where the optics will be situated. The injector is supported by a brass flange through a *Cajon* fitting, Fig. 1 and 2. The flange also provides for the introduction of the main furnace air through a side port and incorporates a thick metallic screen that serves as a flow straightener.

Thermal load and pressure drop considerations were used to determine the dimensions of the water-cooling jacket and the water flow rate in the injector. The bottom part of the injector was insulated with specially machined low density alumina-zirconia insulation. Finally a second air flow straightener was machined out of the same low density alumina material, and placed in the annular space between the injector and the tubular furnace wall to break any large eddie vorticity, Fig. 2.

Water and air flow metering devices have been mounted on wall-attached panels next to the furnace, Fig. 1. Tap water is filtered and then channeled to the injector and the "O-ring" assemblies. Air is also filtered and regulated to 1 bar gage pressure. The furnace main air flow is regulated by a *Matheson* electronic mass flow meter (1-20 lpm), meanwhile the injector air flow is controlled by a needle-valve *Matheson* rotameter (0.01-1.0 lpm). To control the composition of the oxidizing gas in experiments where oxygen concentrations other than 21%(air) are required two additional *Gelman* rotameters have been mounted in parallel to each other, (in series to the previous two flowmeters) for controlling the nitrogen and oxygen flows. Lastly a fifth rotameter has been installed to control the particle quenching nitrogen that will be introduced to the particle collecting probe which is under construction.

2 FLUID FLOW MODELLING Combustion experiments will be carried out in the experimental apparatus described above, the laminar flow, drop tube furnace. Despite the fact that the environment of this furnace is much more well characterized than any real life turbulent coal burner it still presents considerable challenge to account for it. Even if the temperature of the furnace walls in the radiation cavity has been shown elsewhere for a similar furnace to be relatively uniform (Y.A. Levendis Ph.D. Thesis, 1988) the burning particle will also see the injector opening and walls, the second flow straightener, the furnace walls above and below the radiation cavity, and the exit opening or the collection probe at the bottom of the furnace. The view factor to all of these furnace parts will depend on the vertical position (and the radial position) in the furnace where the particle ignites as well as the velocity profiles in the furnace. The gas temperature that the particle burns at is also varying during burntime and is a function of the injector and furnace gas flowrates. To model the velocity and temperature environment in our apparatus the "FLUENT" software package, developed by *Creare* (1989) was utilized for this purpose. Thus, we can obtain numerical solutions for the gas phase by simultaneously solving the continuity, momentum and energy equations. In particular we are interested in the gas phase environment near the tip of the particle injector where steep velocity and gas temperature gradients are expected. The program can be used to study the effects of the injector and furnace flow rates, as well as the importance of the vertical position of the injector and the flow straightener. Furthermore an other feature of this program can handle the introduction of a second phase i.e. a liquid drop or a solid particle. Thence, the trajectory of the drop can be studied, and the time for vaporization and remaining solid heat-up can be estimated. Moreover, crude estimates may be obtained for devolatilization and solid residue combustion.

A brief description of the calculation with FLUENT is given in the following: *A finite difference grid is set up which divides the domain of the problem into a number of computational cells. Boundary conditions are specified at the inlet and walls of the domain. The partial differential equations are reduced to a set of simultaneous algebraic equations and an iterative scheme is used to converge to a stable solution. A power law variation of the dependent variable is used to interpolate between grid points and to calculate the derivatives of the flow variables in order to calculate the finite difference coefficients. The iterative scheme is as follows: (i) The momentum equations are solved using input values from the previous iteration. (ii) The velocities* *are then adjusted to attempt to satisfy the continuity equation for the cell. (iii) The energy equation is solved using the updated values of velocity and pressure, and new values of temperature are obtained. After completion of this procedure for all cells, the program reports the error for each conservation equation, summed over all cells in the domain and the procedure is repeated until this error has decreased to a specified value. Physical property values are updated at each iteration if pressure or temperature variations are significant.*

Results obtained with Fluent for one case are shown in Fig. 4a-c for an injector flow rate of 0.5 lpm, main furnace flow rate of 2 lpm and a furnace wall temperature, T_w, of 1500 K in the radiation cavity. T_w at the regions were the top and bottom insulation sections exist was assumed to decrease according to a linear ramp profile. The entering temperature of air at the second flow straightener was set to 800 K in this case according to measurements made elsewhere (Levendis, Y.A., Ph.D. Thesis, 1988). In all of these plots the scale in the radial direction has been expanded by 2.5 times. Fig. 4a and b depict the velocity profiles in the axial and radial direction, respectively. In Fig. 4c temperature profiles are depicted. It can be seen that the effects of the injector air stream are greatly influencing the flow conditions inside the furnace. Under these conditions it takes a length of over 20 injector inner diameters for the momentum of the jet to dissipate. The highest velocities are observed to take place directly after the exit of the injector. It can also be observed that it takes ca. 5 injector diameters for the entering gas temperature to climb to the wall temperature of 1500 K.

Other cases are under investigation.

3 SINGLE DROP PRODUCTION Techniques to produce single droplets of coal-water slurries are been developed in order to study the combustion behavior of the slurries. All stages of slurry combustion are of interest to the present study, however, emphasis will be given to the combustion of the solid agglomerate char which remains upon the termination of the water evaporation and the devolatilization periods.

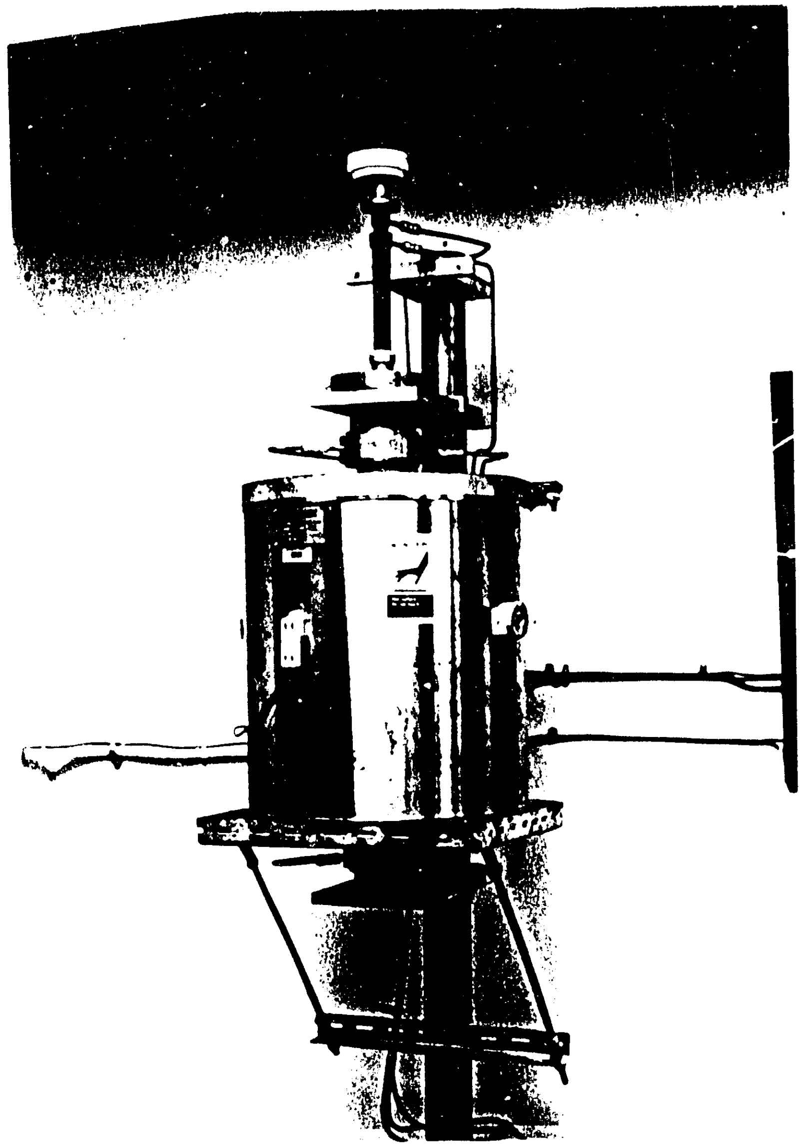
Under investigation are two different types of droplet generators: **(i)** one that utilizes mechanical means i.e. the action of a plunger to push a small quantity of slurry out of an orifice, and **(ii)** a generator that utilizes electrically driven piezoelectric transducers to generate a pressure wave and create a drop. Various configurations of the latter design are shown in Fig. 4a-c, they all use the principle of the uniform break-up of a liquid jet when a periodic disturbance is imposed. To drive these generators a single pulse electrical signal generator has been constructed. This device is capable of creating pulses having durations in the range of 1 ms to 1 sec, and amplitudes up to 30 V.

The approach we will take in this selection is to evaluate each design qualitatively with respect to certain design criteria then calculate the dimensions of the piezoelectric elements required in each case to obtain a prescribed volume displacement. A rough cost estimate will then be made for each configuration. The design criteria are:

- Ease of construction - making electrical connections and connecting the transducer to the reservoir and capillary tube.
- Ease of use - filling with coal water slurries without air bubbles in the system, emptying and cleaning.
- Effectiveness of transmission of the motion of the transducer to the fluid. This is important in order to maximize the amplitude of the pressure wave and volume displacement.
- Effectiveness with which the primary pressure wave is transmitted to the orifice - in other words eliminate as far as possible restrictions and obstructions which could dissipate the energy in the wave, and provide a smooth flow path from the transducer to the orifice.

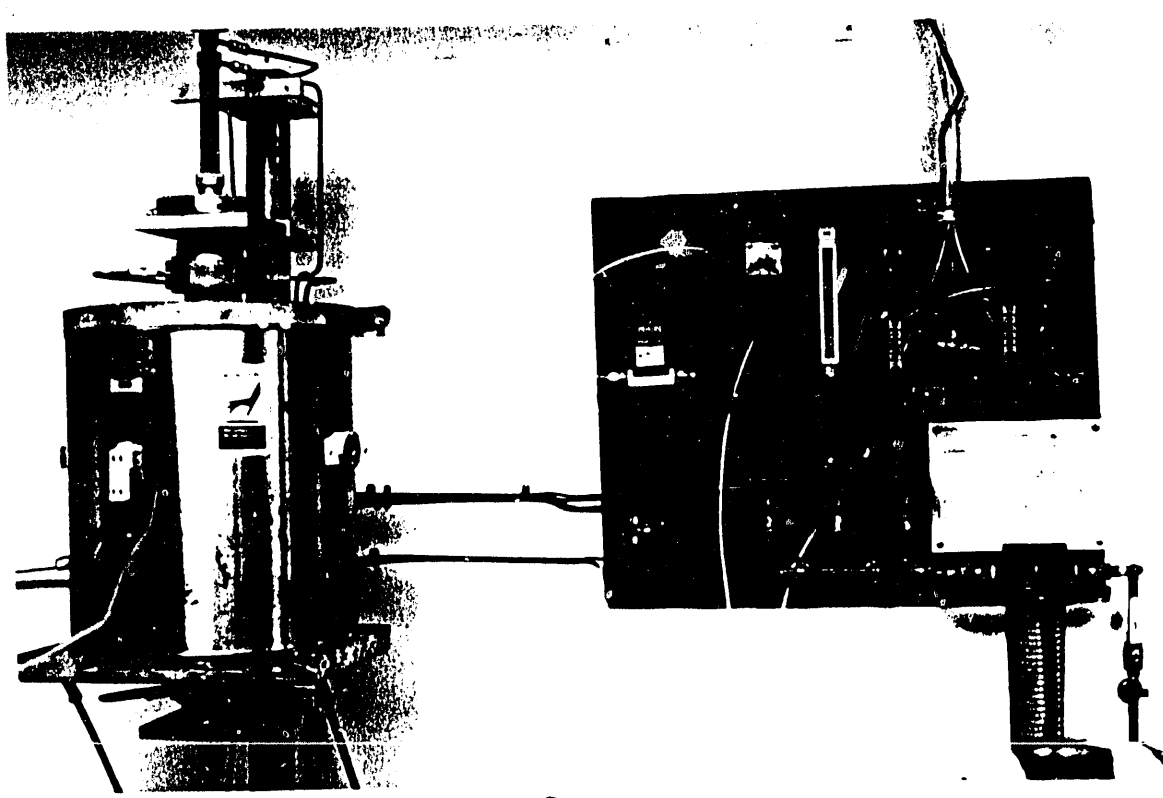
Preliminary tests with the design of Fig. 4a were not successful but work in this area continues.

Finally, to gain understanding of the physical transformations that take place during combustion of char agglomerates, partially burned agglomerates will be removed from the furnace by means of a water-cooled collector probe. Such a probe will be constructed and will utilize nitrogen to facilitate "freezing" the combustion reactions.



a

FIGURE 1. Photographs of the laminar flow, drop tube furnace and the control unit.



b

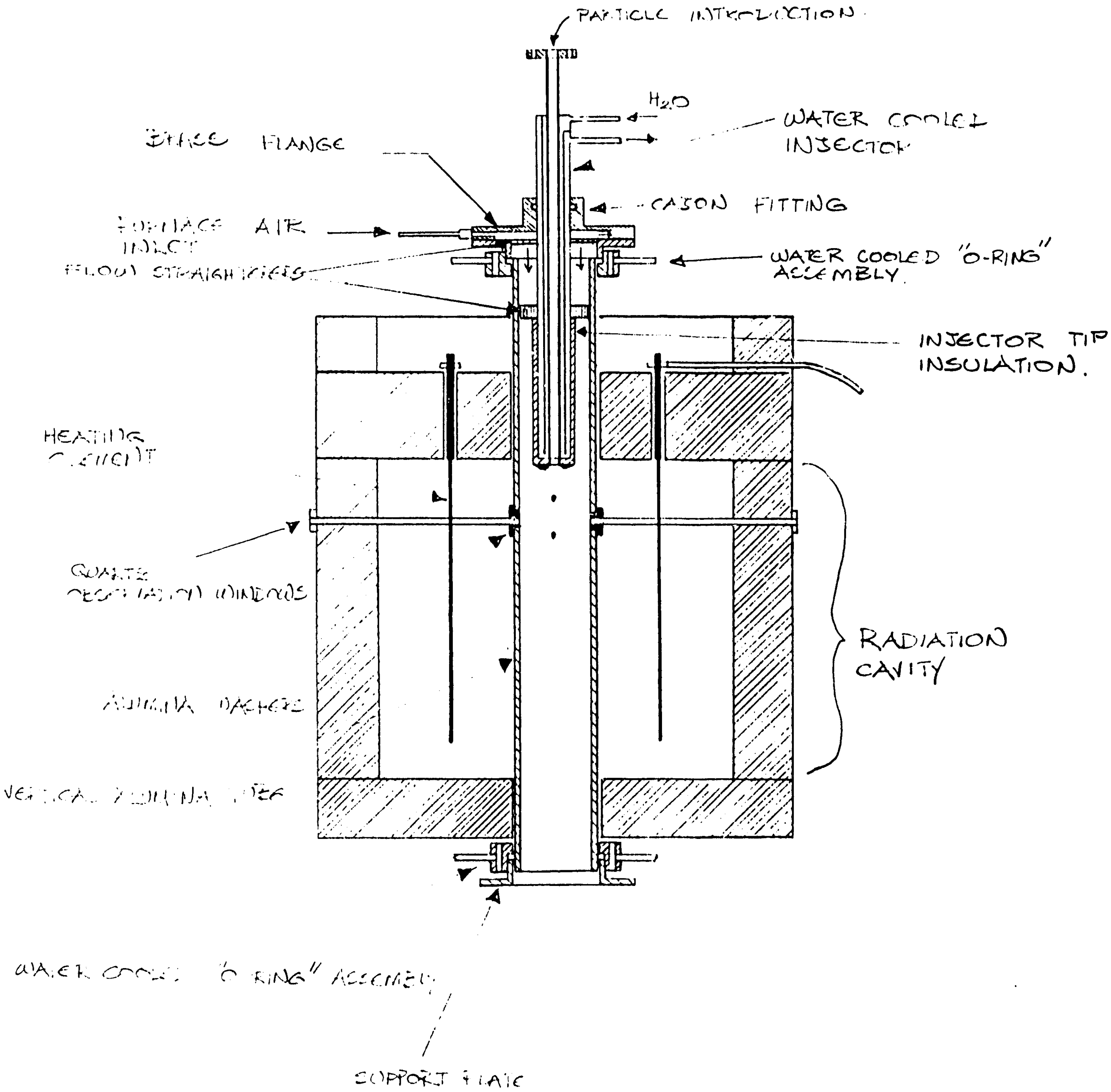


FIGURE 2. Schematic of the furnace and injector assembly.

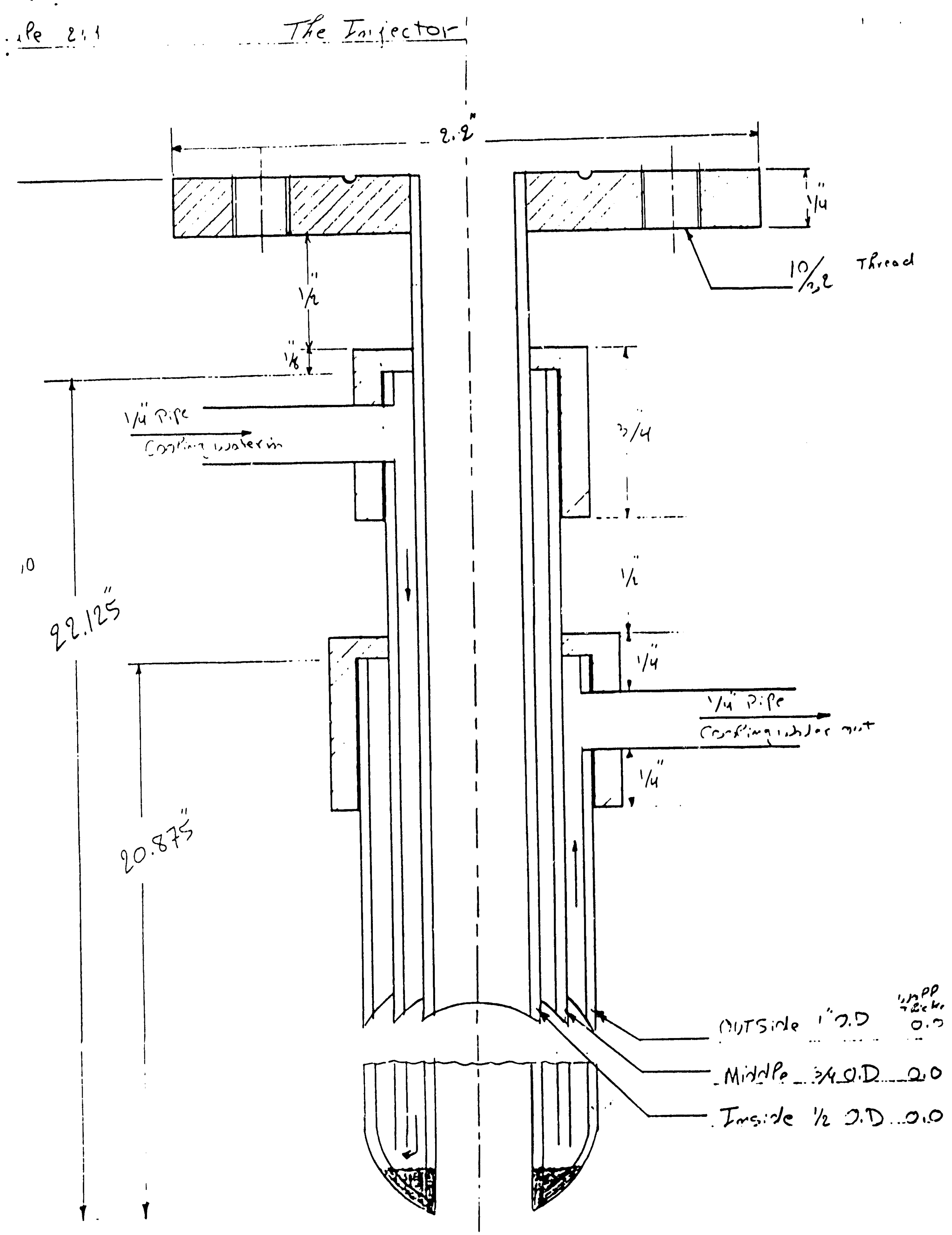
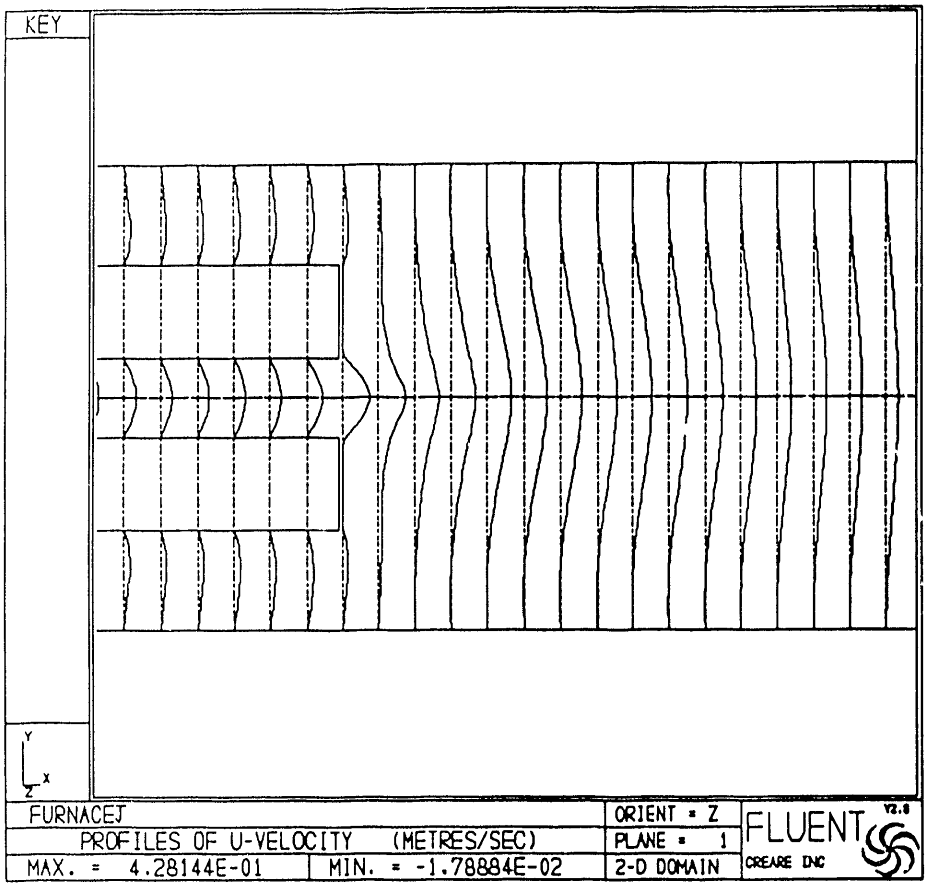


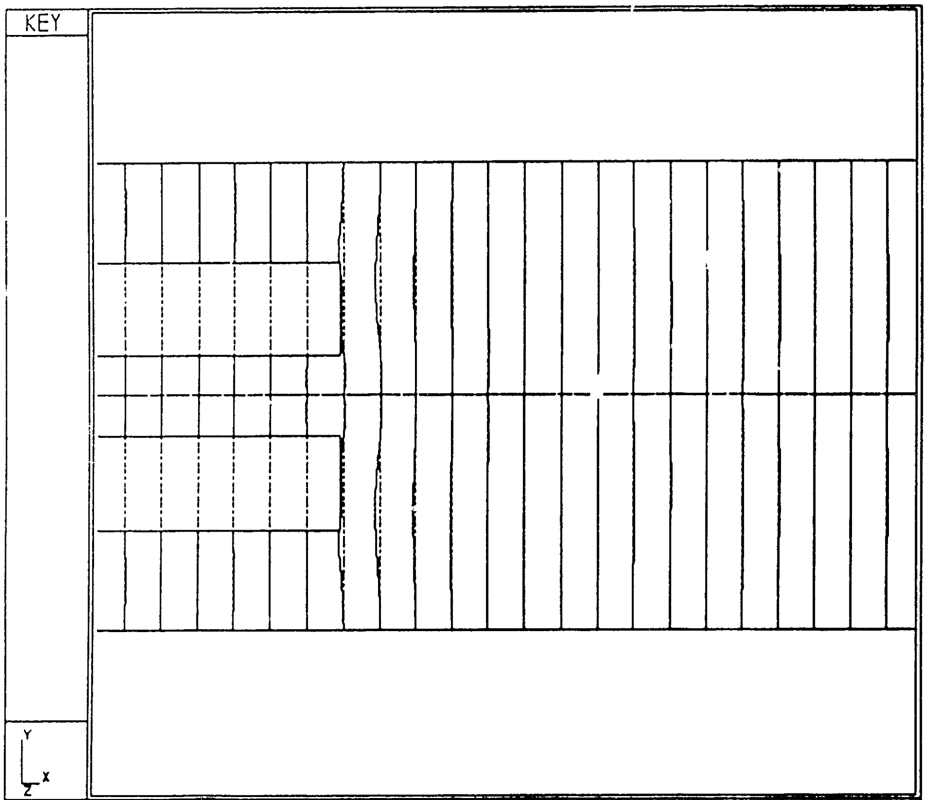
FIGURE 3. Drawing of the injector



(i)

FIGURE 4: Numerical calculations for modelling the air flow inside the drop tube furnace, (i) vertical velocity profiles, (ii) radial velocity profiles, and (iii) temperature profiles. Conditions: furnace air flow-rate 2.0 lpm, injector flow-rate 0.5 lpm and T_w = 1500 K.

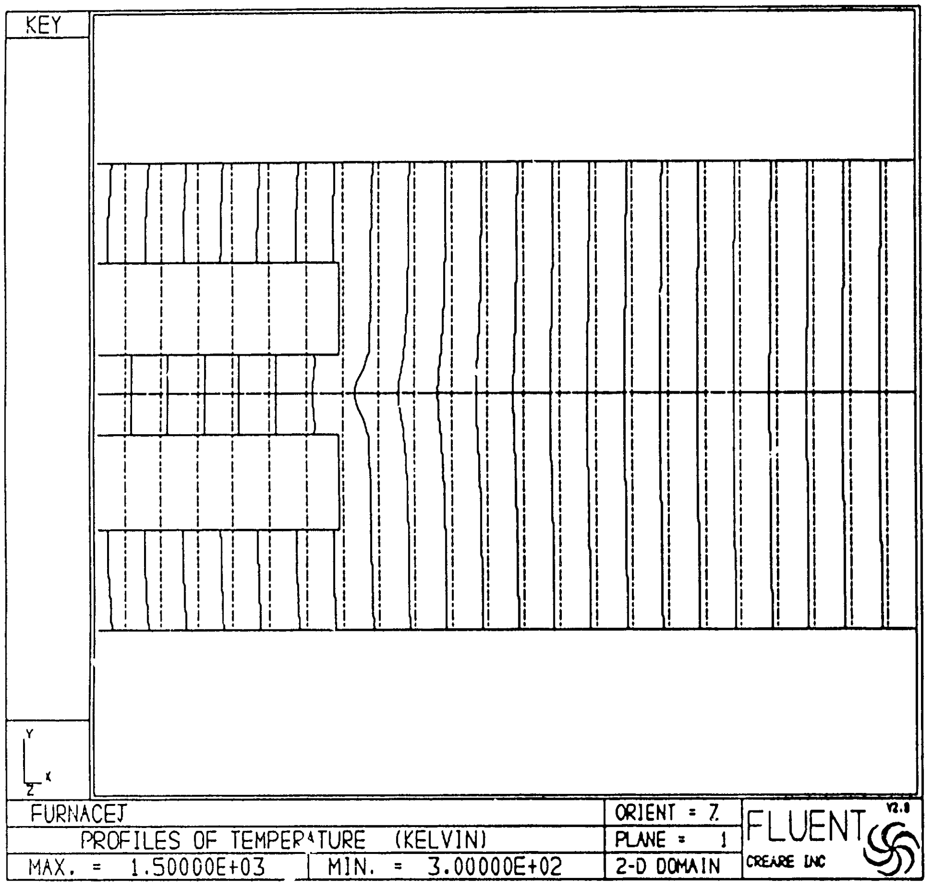
5 days, 2 days, 3 weeks, 4 1/2



FURNACEJ		ORIENT = Z
PROFILES OF V-VELOCITY (METRES/SEC)		PLANE = 1
MAX. = 2.11189E-02	MIN. = -2.21558E-01	2-D DOMAIN

FLUENT V2.8 CREARE INC

(ii)


KEY
Y
X
Z
FURNACEJ
PROFILES OF TEMPERATURE (KELVIN)
MAX. = 1.50000E+03
MIN. = 3.00000E+02
ORIENT = Z
PLANE = 1
2-D DOMAIN
FLUENT
V2.8
CREARE INC

(iii)

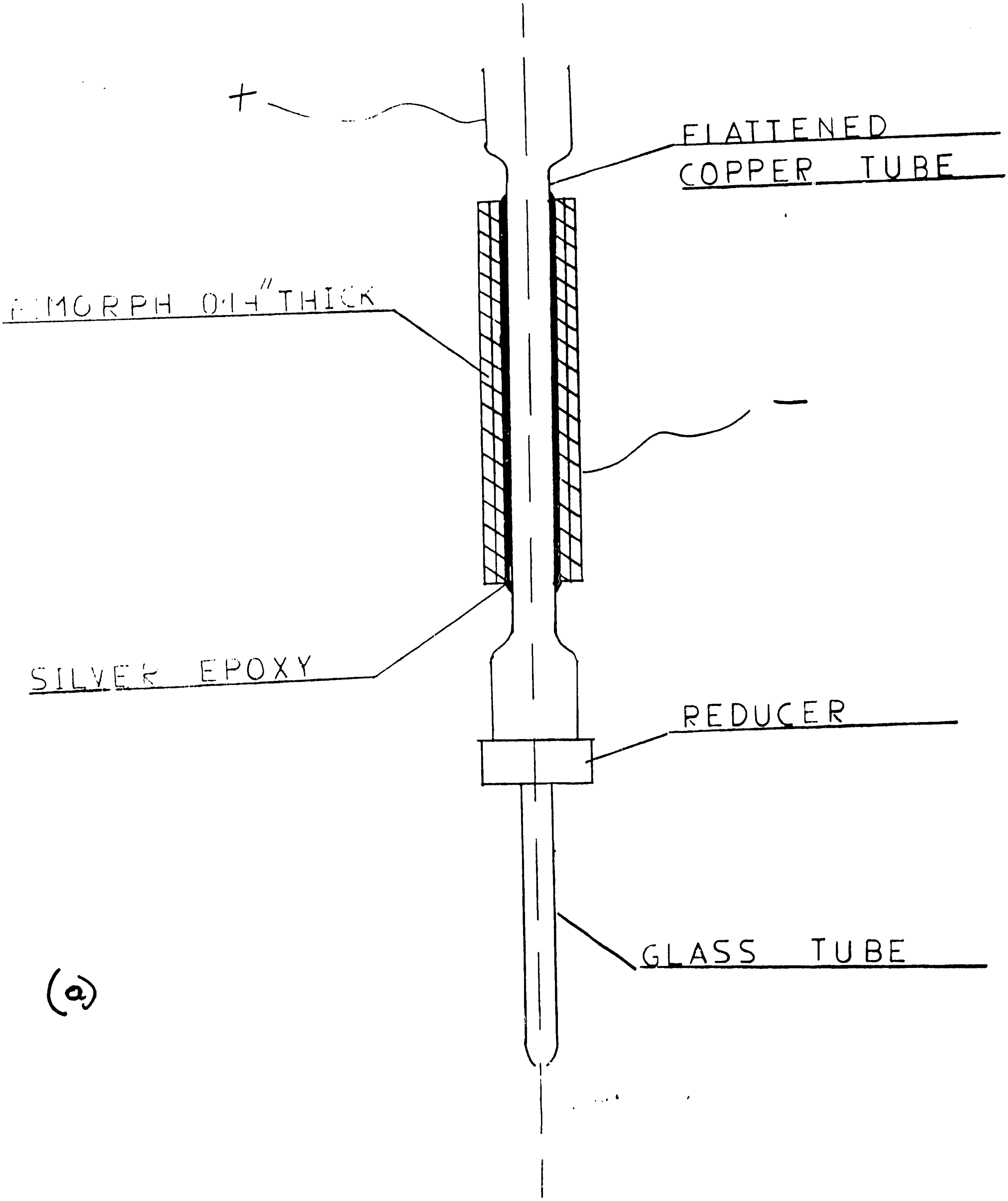
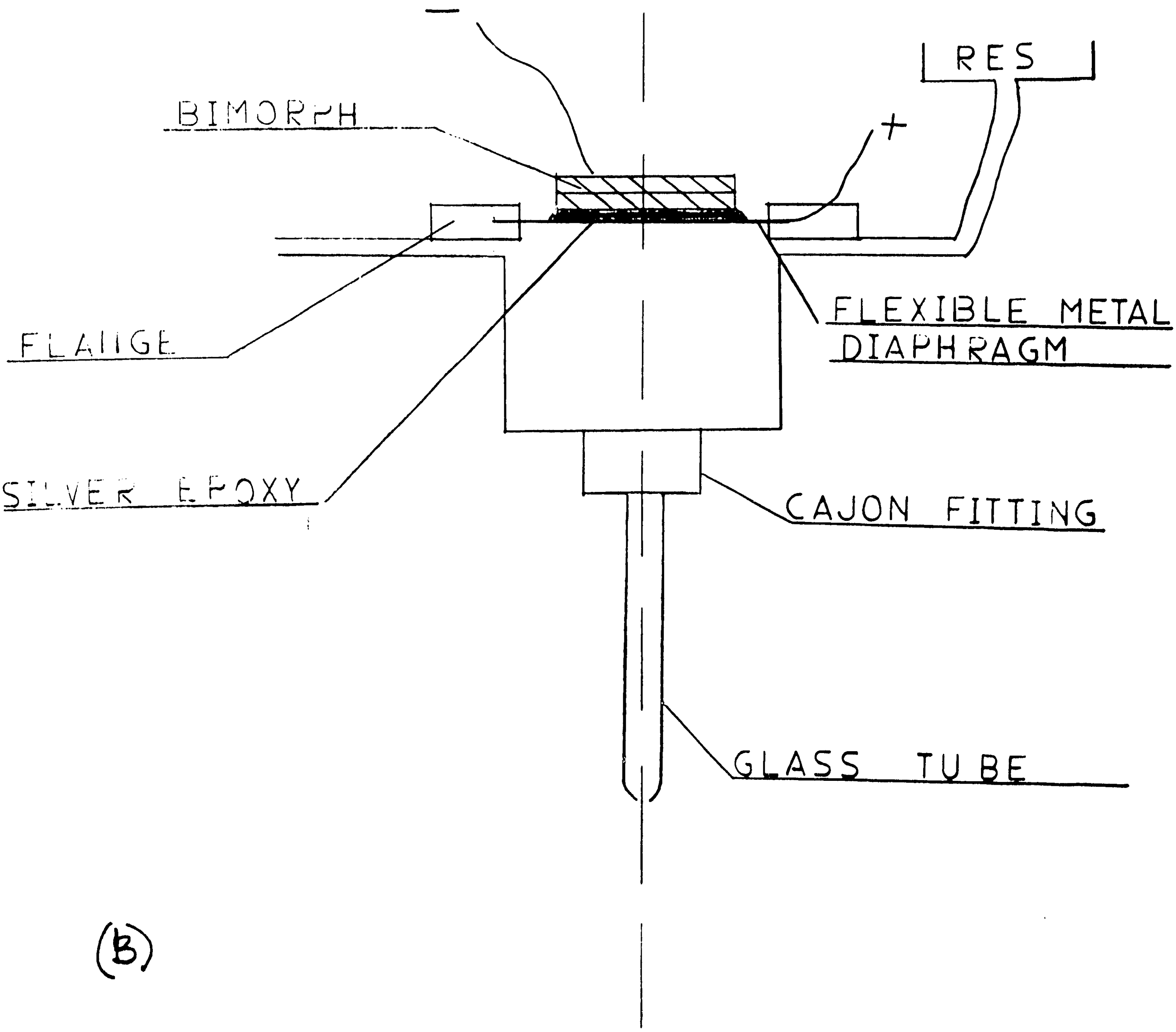
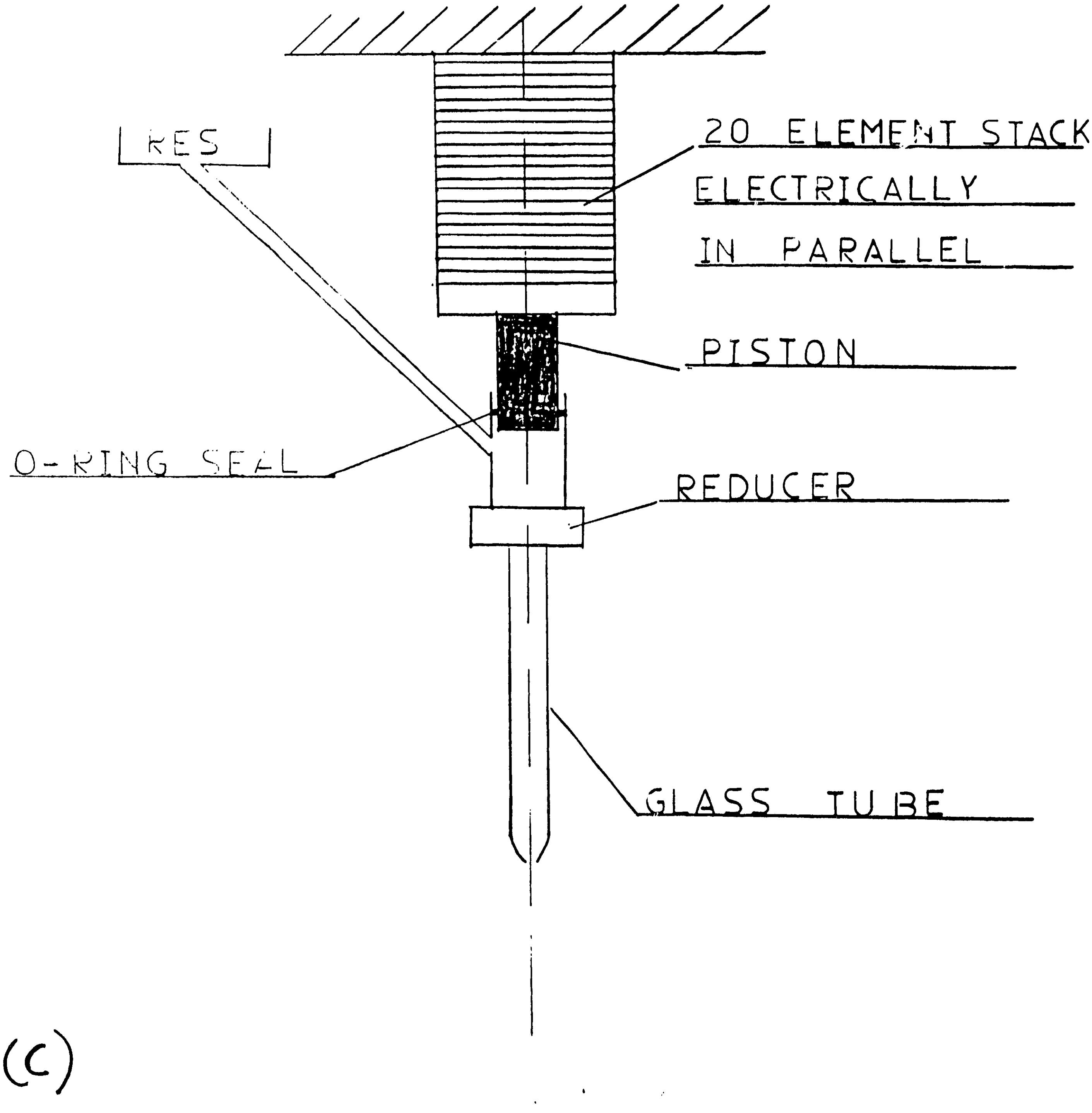


FIGURE 5: Three configurations of electrically driven droplet generators.



−
+
RES
BIMORPH
FLANGE
FLEXIBLE METAL DIAPHRAGM
SILVER EPOXY
CAJON FITTING
GLASS TUBE

(B)



RES
20 ELEMENT STACK
ELECTRICALLY
IN PARALLEL
PISTON
O-RING SEAL
REDUCER
GLASS TUBE

(C)

END

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