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# Two-phase electrolytic magnetohydrodynamic generation

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by

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# INTRODUCTION

A magnetohydrodynamic (MHD) generator is a device for direct conversion of heat energy to electrical energy. In the MHD generator, a fluid conductor is forced to flow through a magnetic field, analogous to a copper wire moving through a magnetic field in a conventional generator, thus converting the kinetic energy of the fluid to electrical energy.

One of the first demonstrations of this type of MHD generation was performed by Lord Kelvin when he placed two electrodes across the mouth of a salt-water river. As the water flowed between the two electrodes, in effect an electrical conductor was cutting the magnetic field of the earth. This cutting of the flux induced an e.m.f. between the electrodes and hence caused a current to flow in an interconnecting cable.

This thesis is concerned with the evaluation of an electrolyte as a working fluid for a magnetohydrodynamic generator. The electrolyte used in this project was a salt-water solution. The salt used was sodium chloride.

Most of the research work currently being done in the field of magnetohydrodynamics is concerned with the plasma or gas MHD generator [3]. This device uses a thermally ionized gas as the conducting fluid. Suitable conductivities for this device can be obtained by thermal ionization, but this requires temperatures of the order of 10,000°C. Such

temperatures are still outside the capabilities of present building materials. It is generally believed that there must be a technological breakthrough in the area of gas ionization before the gas or plasma MHD generator is to become a major component in electrical power generation [3]. This breakthrough will have to be some method of producing significant ionization of the gas at lower temperatures. The ionization is necessary to produce high conductivities of the gas so that a current can be induced in the fluid by the magnetic field without too much electrical resistance. High conductivities are necessary to obtain a high power output.

A possible solution to the ionization at lower temperatures problem is a process called seeding the gas. By injecting a seed material into the hot gas it has been possible to obtain higher fluid conductivities at lower temperatures. The seeding process to be used in a MHD generator simply involves injecting the cooler seed material into the hot gas where it is heated above its ionization temperature thus giving a higher fluid conductivity. A seed material, such as cesium, is thermally ionized at a lower temperature than combustion gasses, a fluid thought to be ideal for a plasma MHD generator.

There are, however, problems that must be solved if the gas MHD generator is to become a practical reality. For one, it is currently believed that the best approach to gas MHD is

the open cycle system [3]. Here the used gas will be exhausted to the atmosphere and this will result in a large amount of pollutants, such as nitrogen oxides, being discharged to the atmosphere. Also, available seed materials, like cesium, are expensive and must be recovered and reused to make the device practical. Another problem facing all types of MHD generators is the high intensity magnetic fields necessary to obtain significant power output. These magnetic fields are currently within technological feasibility with the advent of the superconducting magnets but are expensive and not readily available.

A very promising use for a MHD generator is as a "topper" unit in addition to an ordinary steam cycle for the production of electrical power on a large scale as illustrated in Figure 1. In this design the MHD unit would be operated at high temperatures and the exhaust from the MHD generator would still be hot enough to operate an ordinary steam cycle. It is within reach to operate a MHD generator at a temperature where plant efficiency is as much as 60 to 80% as shown in Figure 2. An overall increase in plant efficiency is gained when an MHD generator is used as a topper mechanism in conjunction with a steam cycle. For example a system employing a fluid metal MHD device along with a steam cycle operating at 870°C maximum temperature gains about 14% in overall plant efficiency over the steam cycle alone [10]. A system such as

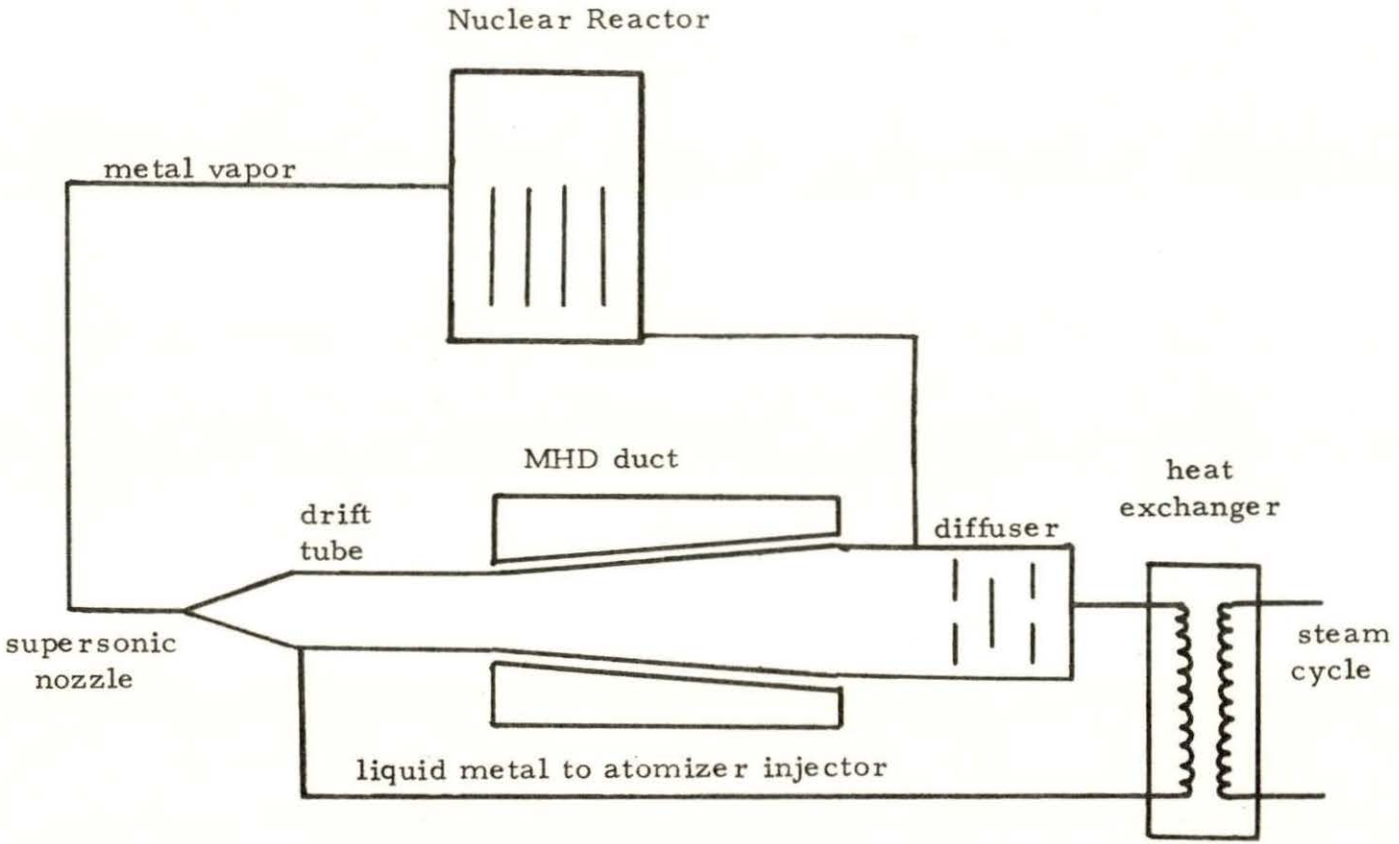


Figure 1. Typical two-loop liquid metal MHD system

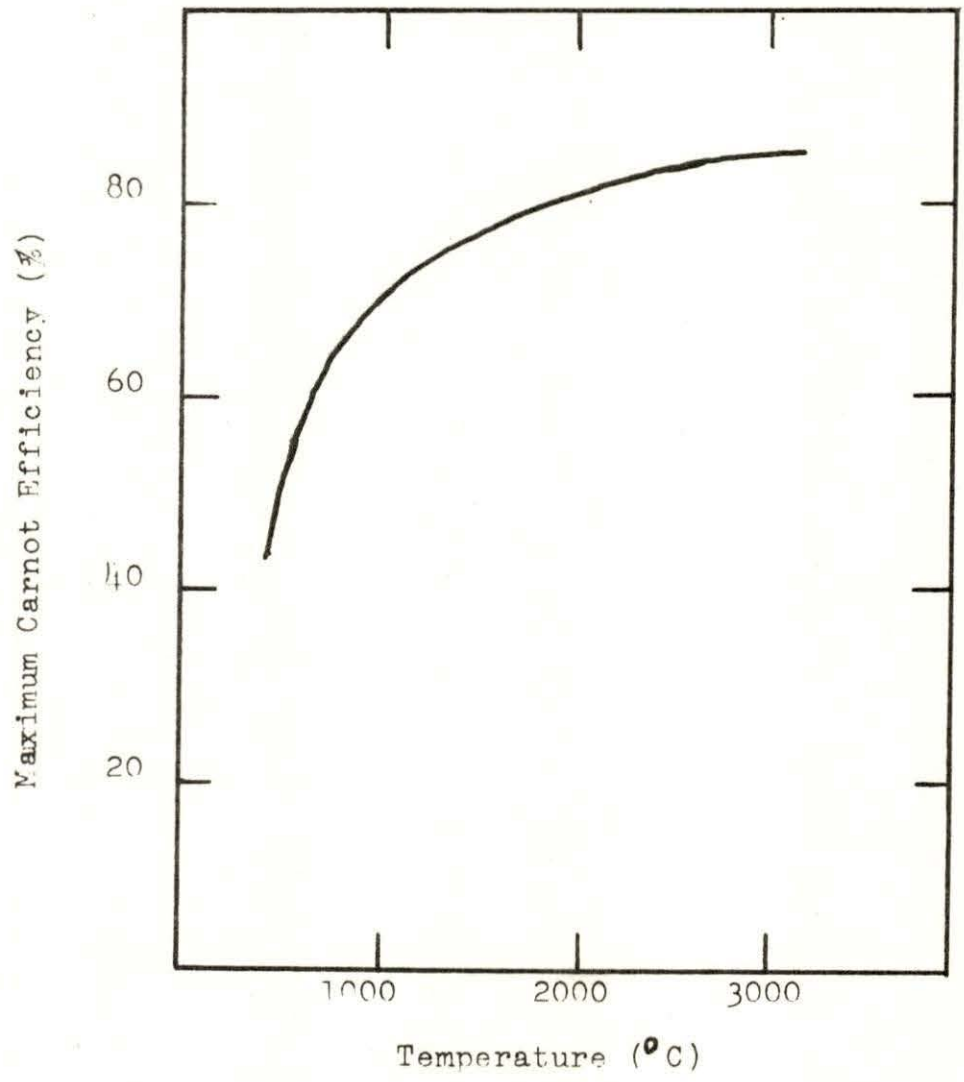


Figure 2. MHD generator carnot efficiency

this operating at 1000 MWe receives about 125 MWe from the MHD topping unit. This increase in plant efficiency results in a fuel cost savings and a decrease in the thermal pollution discharged to the environment.

In recent years the liquid metal MHD generator has emerged as a possible solution to some of the problems associated with the plasma generator. The liquid metal generator can be operated at lower temperatures and the fluid conductivities are higher than the gas generator. The electrolytic MHD generator proposed in this thesis is expected to have the same advantages. A typical liquid metal MHD generator cycle is illustrated in Figure 1. Fluid metal flows in a continuous stream through a closed bicyclic system. In the first loop the liquid metal is partially vaporized by a heat source. A nuclear reactor is an ideal heat source because of the high operating temperature possibilities available and the easy adaptability to liquid metal cooling. The resulting two-phase fluid is then expanded by passing it through a supersonic nozzle and thus part of its thermal energy is converted to kinetic energy. Downstream of the nozzle, atomized liquid metal at considerably lower temperature is injected from the second loop into the two-phase, high velocity vapor stream from the first loop. Due to a momentum exchange, the injected stream of atomized particles is accelerated while at the same time, due to mass heat transfer

between the two streams, the vapor component of the two-phase fluid is condensed. As a result, the fluid entering the generator is predominantly in a liquid phase traveling with a high velocity and with high electrical conductivity. A large part of the kinetic energy of the fluid is converted to electrical energy within the generator. The effluent enters a diffuser where its remaining kinetic energy is converted to pressure. The second loop then carries part of the metal through the heat disposal unit which cools the liquid to the required injection temperature after which it is then returned to the injection point downstream of the expansion nozzle. Metal flowing in the first loop is returned to the heat source and the cycle is repeated.

This thesis is concerned with the evaluation of an electrolytic solution as a working fluid analogous to the ionized gas or the liquid metal fluids used in the generators mentioned above. It is the author's opinion that an electrolytic MHD generator would offer several advantages over either the plasma or the liquid metal MHD generators discussed earlier. One advantage over the liquid metal cycle shown in Figure 1 is that the heat transfer from the reactor to a liquid like water would be much better than the heat transfer to the metal vapor proposed in Figure 1. Also the operating temperature of the electrolytic generator would be less than that required to vaporize the metal necessary for the liquid

metal generator. Another advantage is the simple but very effective mechanism used for conversion of thermal energy into kinetic energy, i.e. boiling. Whereas the liquid metal MHD generator used something similar to this it remained difficult to accelerate the relatively heavy liquid metal to high velocities with the atomized liquid method used. A fourth advantage would be the adaptability of an electrolytic system such as this to already existing steam systems. For example, a nuclear reactor using boric acid as a control mechanism in the coolant water has a ready-made electrolytic solution that could be used as the working fluid for this kind of generator. There also exists the possibility that the vapor given off by the electrolytic MHD generator could be used directly to drive a turbine since it is in the form of steam. The great range of possible operating temperatures available gives much flexibility of application. The generator could be incorporated at several places in a steam cycle, the efficiency of operation being the determining factor.

# THEORY

The conductivity $\sigma$ of the two-phase electrolytic fluid used in this experiment is

$$\sigma = L/RA \tag{1}$$

where A is the area of one electrode, R is the resistance measured between the electrodes, and L is the electrode spacing.

In this type of MHD generator the fluid is forced to flow at a velocity $\underline{U}$ normal to a magnetic field of flux density $\underline{B}$. As a result, a potential gradient $\underline{E}$ given by

$$\underline{E} = \underline{U} \times \underline{B} \tag{2}$$

is induced across the fluid. Since the velocity and magnetic flux density vectors are mutually perpendicular the vector notation will be discontinued and

$$E = UB \tag{3}$$

A voltage

$$V = UBL \tag{4}$$

is induced across the channel of width L.

The voltage drop across an external load $V_{ex}$ is

$$V_{ex} = V - JAL/\sigma A \tag{5}$$

$$V_{ex} = UBL - JL/\sigma \tag{6}$$

where J is the current density.

A loading factor K can be defined by

$$K = \frac{V_{ex}}{V} \tag{7}$$

$$K = V_{ex}/UBL \tag{8}$$

The current density J is given by

$$J = UB\sigma(1-K) \tag{9}$$

The specific power output, power per unit volume, $P_o$ of a device like this is

$$P_o = \frac{V_{ex}\ i}{AL} \tag{10}$$

$$P_o = \frac{KUBLJA}{AL} \tag{11}$$

$$P_o = KUBJ \tag{12}$$

$$P_o = \sigma U^2 B^2 K(1-K) \tag{13}$$

where i is the internal current flowing through the fluid.

The total power output P is

$$P = ALP_o \tag{14}$$

$$P = AL\sigma U^2 B^2 K(1-K) \tag{15}$$

Differentiating (13) with respect to K and setting it equal to zero, we find that the maximum power output $P_{om}$ occurs when the internal voltage V is equal to the external voltage $V_{ex}$, that is

$$P_{om} = 1/4\ \sigma U^2 B^2 \tag{16}$$

The Joule heating $P_j$ of the fluid in this device is

$$P_j = \frac{i^2 r}{AL} \tag{17}$$

$$P_j = \frac{J^2 A^2 L}{AL\sigma A} \tag{18}$$

$$P_j = J^2/\sigma \tag{19}$$

where r is the internal resistance of the fluid.

The fractional efficiency of this type of MHD generator is

$$\eta = \frac{P_o}{P_o + P_j} \tag{20}$$

$$\eta = \frac{1}{1+P_j/P_o} \tag{21}$$

$$\eta = \frac{1}{1+\frac{1-K}{K}} \tag{22}$$

$$\eta = K \tag{23}$$

i.e. the loading factor.

## DESCRIPTION OF EXPERIMENT

The experiment was designed as a preliminary evaluation of an electrolytic solution as a possible working fluid in a magnetohydrodynamic generator. The experiment was patterned after some experiments previously performed with a liquid metal as the working fluid [10]. Since the conductivity of the fluid used in a MHD generator is of critical importance to its successful operation as indicated by (15), conductivity measurements of the two-phase electrolytic working fluid are the primary objective of this experiment. The electrolytic solution used in this experiment consisted of sodium chloride dissolved in water. Sodium chloride was chosen because of its availability and well known properties in solution with water. Any other electrolytic solution could have been used but it was assumed that the sodium chloride system was a typical one and would be representative of the electrolytic class of fluids.

The sodium chloride solution was heated to various temperatures between 212 and 300°F. Pressures up to 80 psig were required to maintain this solution in the liquid phase at these temperatures. Next the solution was allowed to flow to the expansion chamber of the MHD duct where it was allowed to boil. The boiling supplied the impetus to the resulting two-phase fluid forcing it at high velocities through the electrode region of the duct. The two-phase fluid now flowing

through the duct consists of a carrier vapor (steam) and small droplets of electrolyte solution. These droplets are analogous to the liquid metal in the liquid metal MHD generator.

The conductivity of this two-phase fluid is dependent upon several variables such as void fractions of the fluid, conductivity of the small droplets, velocity of flow, ion mobility of the electrolyte solution, and quality of the fluid. All of these variables could not be evaluated because of the limited time available and the scope of the experiment undertaken. Two of the factors affecting conductivity were experimentally observed in this project. Variation of conductivity across the MHD duct with concentration of electrolyte solution and variation of conductivity with fluid velocity. A concentration range from 2 to 25 grams of sodium chloride per liter of solution was examined and a fluid velocity range of 0 to 110 feet per second.

The electrical resistance of the fluid flowing in the MHD duct was measured between the two duct electrodes at various fluid velocities. These measurements were taken using the same electrolyte concentration throughout the entire velocity range. The concentration of the solution was then changed and another series of measurements were taken for this particular electrolyte. From this data the variation of the two-phase fluid's conductivity with solution concentration and with fluid velocity could be calculated.

Velocity of the two-phase fluid was measured by a water-wheel technique. A finned wheel was put in the exhaust stream of the duct and by measuring the rotational velocity of the wheel and knowing the radius of the wheel the fluid velocity could be approximated. The fluid velocity at various tank pressures was determined. The actual fluid velocity would probably be slightly different from what was measured since some of the energy of the stream was used to maintain the velocity of the wheel and the effect of the spreading stream of exhaust fluid could not be measured. Also the velocity slip ratio between the gas and the liquid portions of the fluid could not be determined by this method. It was assumed that the measured velocity was the velocity of the liquid.

A mass flow measurement was made as a function of tank pressure. Also fluid velocity was measured as a function of tank pressure so that a mass flow rate could be determined.

Open circuit voltages produced by the generator were measured. This was accomplished by placing a magnet across the duct and measuring the voltages produced at the various fluid velocities and with the various solution concentrations. Also using this same arrangement short circuit current measurements were taken as a function of fluid velocity and solution concentration.

## DESCRIPTION OF EXPERIMENTAL APPARATUS

The electrolytic working solution was heated and stored under pressure in a tank made of a 30 in. length of 6 in. diameter steel pipe with 1/4 in. wall thickness. Two endplates of 1/2 in. thick steel were welded to each end of the pipe. Two 650 watt headbolt heaters were used as internal heaters to heat the electrolyte solution. The heaters were placed in the tank through penetrations in the end plates. One heater was placed into the tank through each endplate for even heating of the solution. On one end of the tank a pressure gauge was installed through a second tank penetration. On the other end two additional penetrations were made, one for the exhaust plumbing necessary to provide a flow path to the MHD duct and the other was a plugged hole used to fill the tank with solution. The tank was designed to maintain pressures over 100 psig although the highest pressures encountered in the experiment did not exceed 80 psig. An additional external heater was used during the experiment to hasten the heating process since it was found that the internal heaters required too much time to heat the solution. The external heater was a common two burner hotplate.

The exhaust plumbing used to route the solution from the tank to the MHD duct consisted of an 8 in. length of pipe tapped into the tank and attached to a valve. On the duct side of the valve was a short pipe extension to which was

attached a 24 in. length of high pressure rubber hose. The rubber hose was used to provide flexibility in positioning the duct.

The duct illustrated in Figure 3 was made of plexiglass with copper electrodes. The rubber hose carrying the fluid from the tank fits over the cylindrical section of the duct. The fluid enters the duct and travels through a 1/8 in. diameter hole drilled in the cylindrical section. The fluid next enters an expansion chamber where violent boiling occurs. The resulting two-phase solution is accelerated by the steam pressure through the electrode area of the duct. The fluid is then exhausted to the atmosphere. A total electrode area of 19.3 square contimeters was used in this duct. An electrode spacing of 0.6 centimeters was maintained by the spacers which also served as the sides of the duct.

An electromagnet with its accompanying power supply was used to produce a 8500 gauss magnetic field. The duct was placed in this field during the voltage and amperage measurements.

Other equipment used included a Simpson multi-purpose meter used to measure voltage, resistance, and amperage. A scale was used to determine the mass flow rate of the system. A water-wheel type device was used in the fluid velocity measurement.

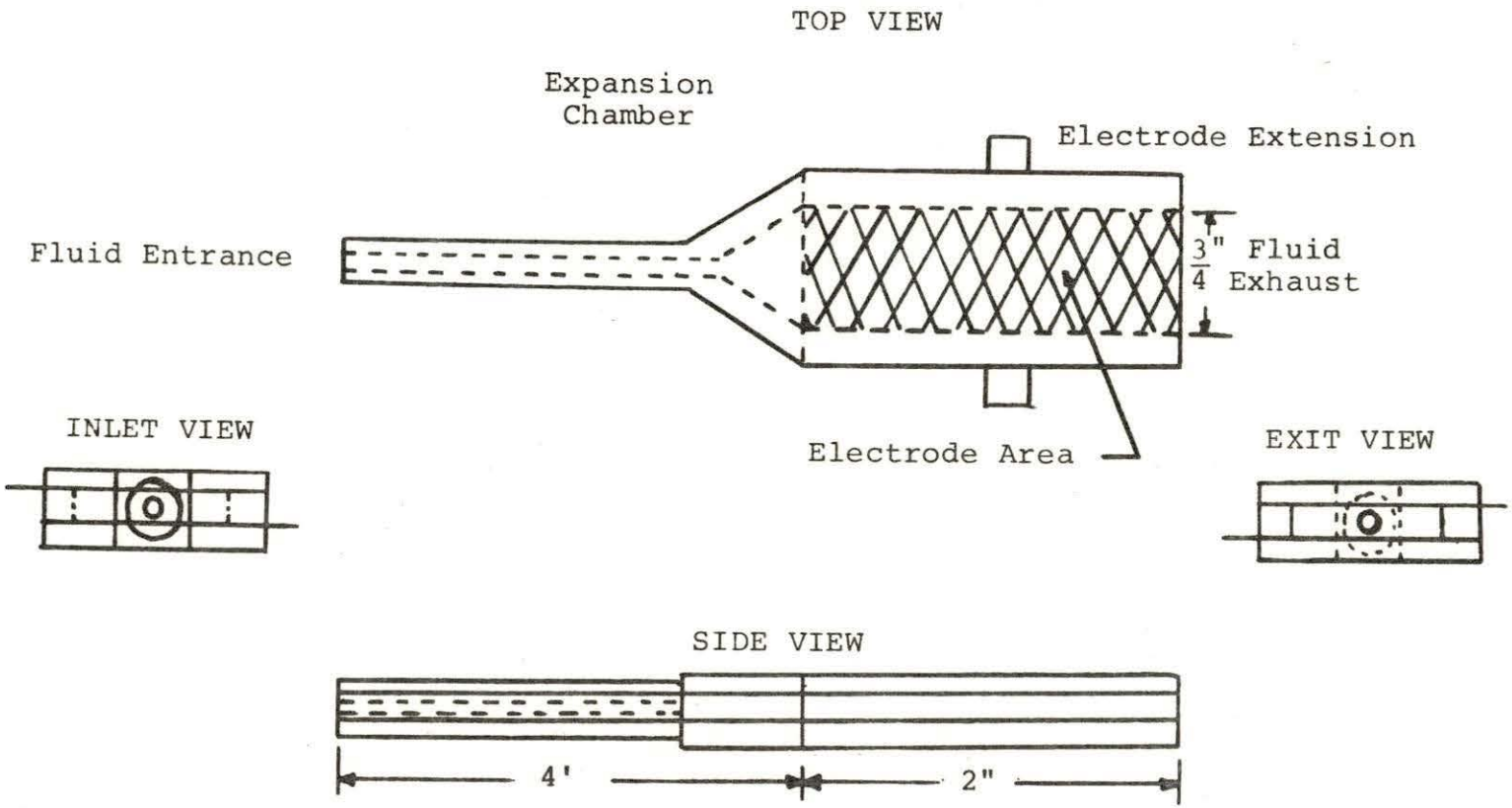


Figure 3. Experimental MHD duct

# EXPERIMENTAL RESULTS

Some of the results obtained from this research are presented in Figures 4, 5, 6 and 7. These Figures show the variation of resistance across the MHD duct versus concentration of the electrolytic solution. These curves, measured at constant pressures of 10, 30, 50, and 70 psig. respectively, all exhibit the same general shape. As concentration increases the resistance across the duct drops off rapidly at first and then levels off to an approximate linear decrease as concentration is increased further. Also shown for comparison is the pure liquid resistance variation with concentration. The general shape of these curves is very significant from a design standpoint since not much is gained as far as conductivity is concerned by increasing the solution concentration from about 8 grams per liter to 25 grams per liter. This phenomena could be very important as far as deposits on the electrodes and corrosion of the electrodes are concerned since it was observed that at higher concentrations more deposits were formed on the electrodes and in the duct in general. This could be very significant if an acid or basic electrolytic solution were used from corrosion, safety, and material design standpoints. The deposits were a result of the boiling of part of the liquid thus separating the vapor from the dissolved sodium chloride. Also there was possibly some reaction between the hot electrolytic solution and the copper electrodes.

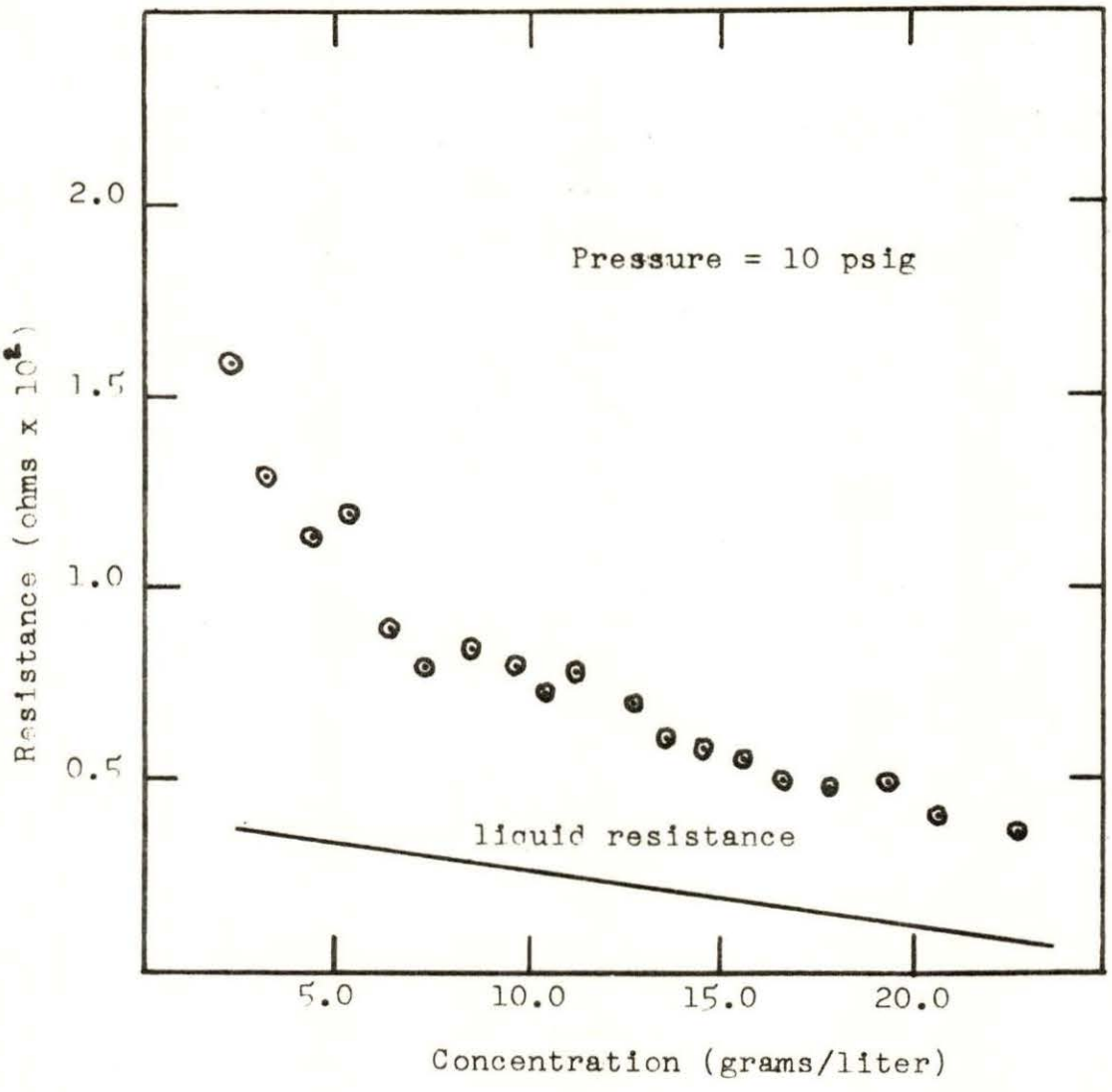


Figure 4. Resistance versus concentration

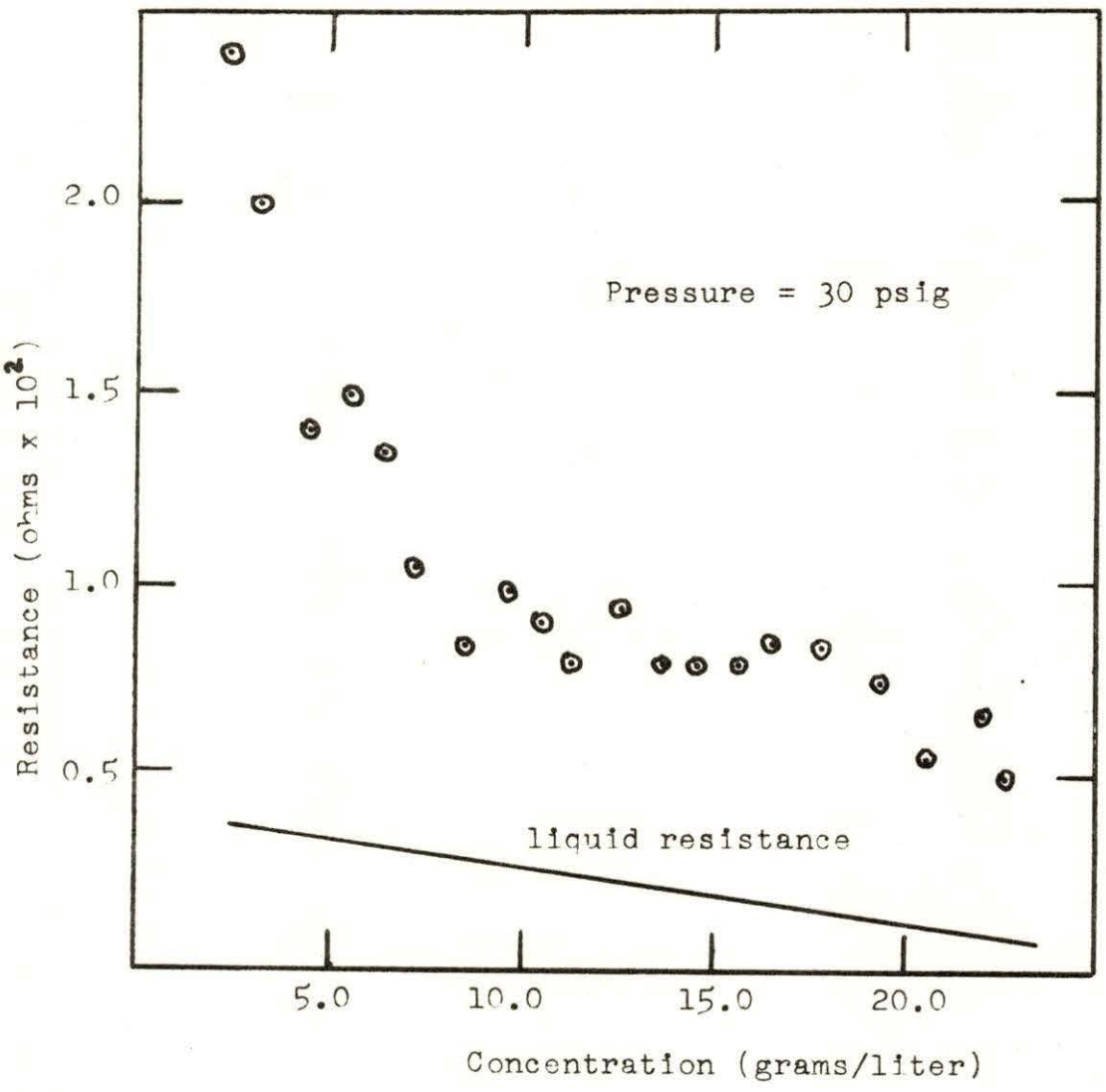


Figure 5. Resistance versus concentration

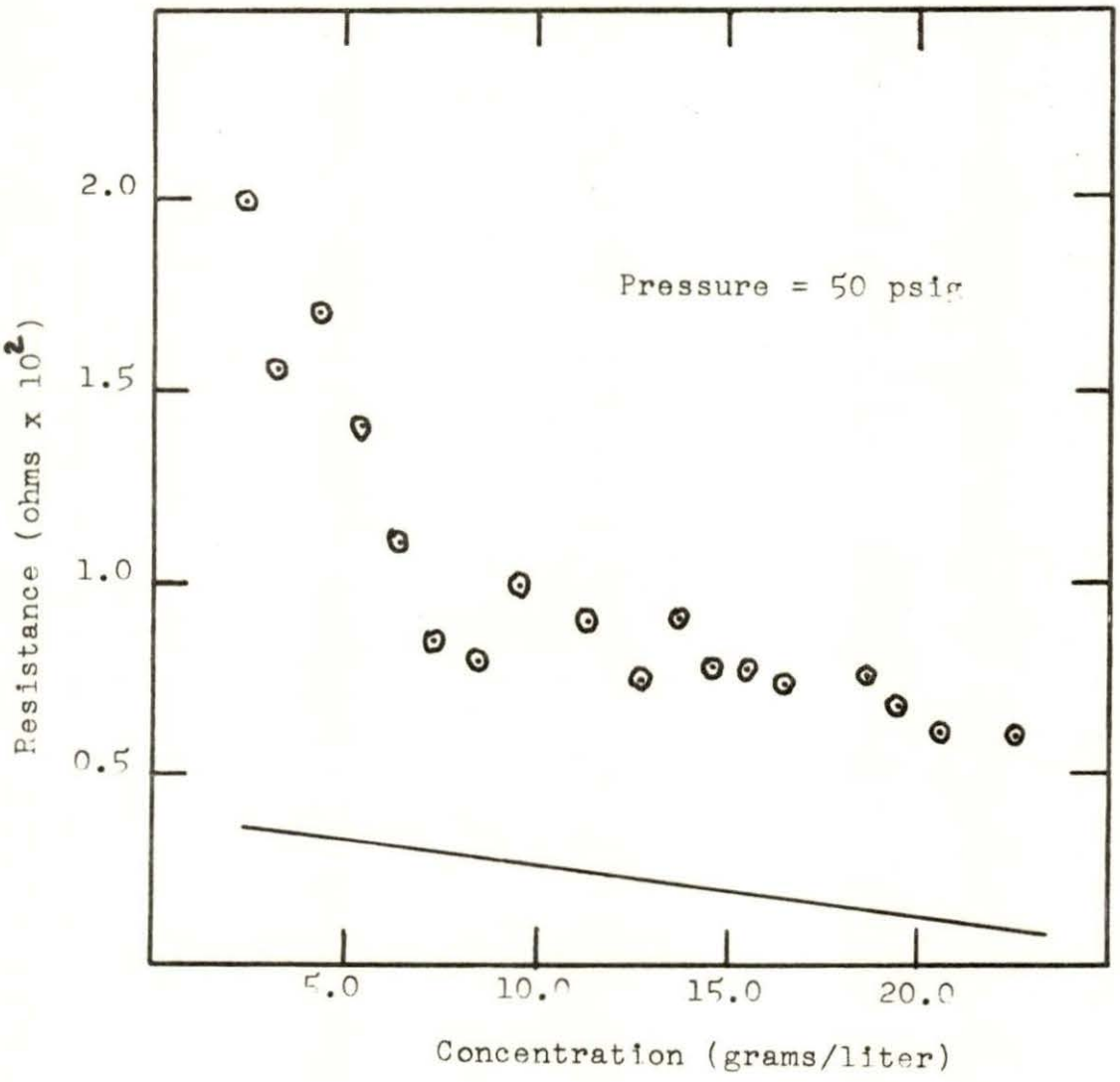


Figure 6. Resistance versus concentration

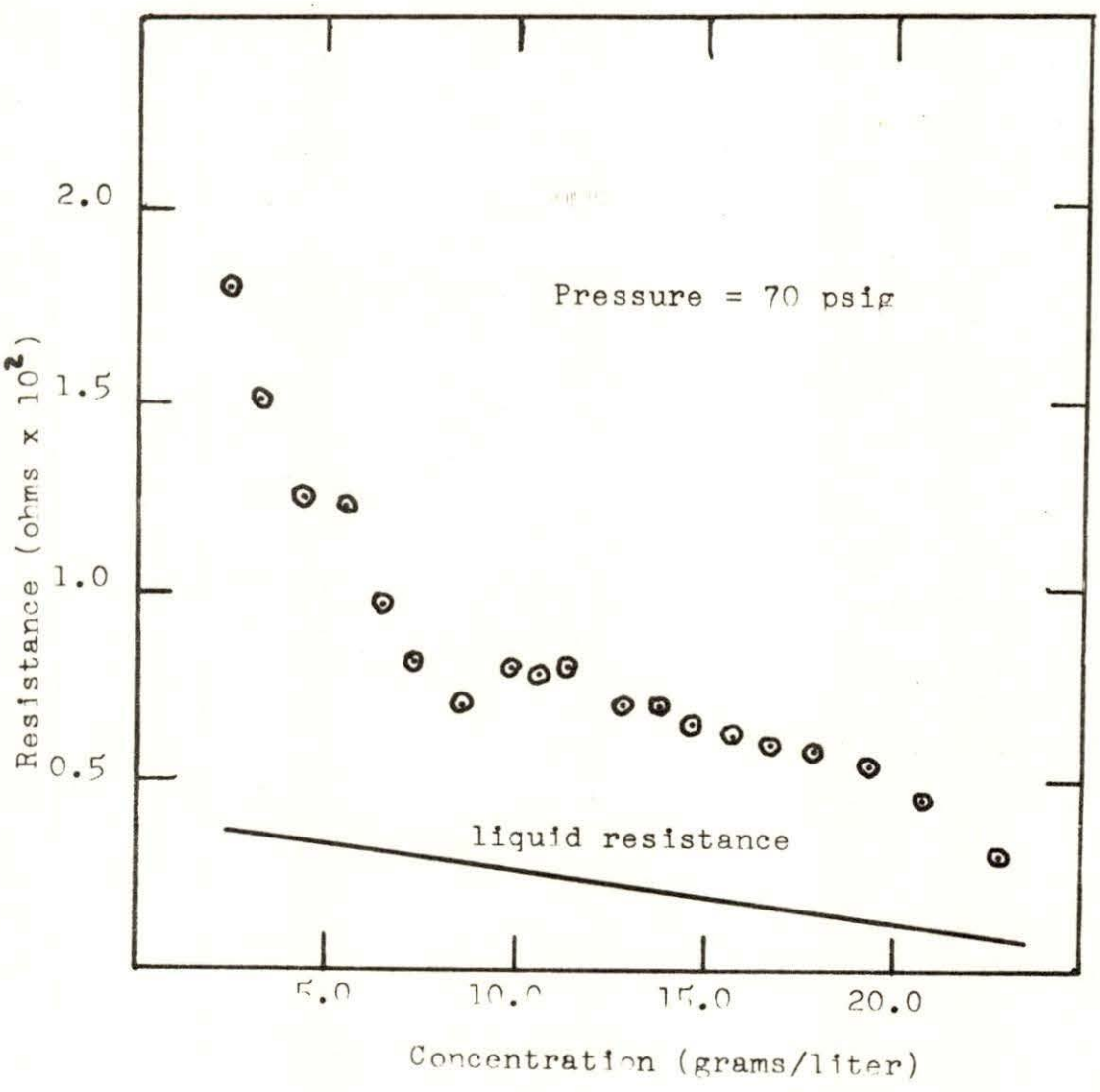


Figure 7. Resistance versus concentration

The only variation between the data at the different pressures is that the transition between the lower concentration end and the linear higher concentration regions is a little more pronounced at the higher pressures. Figures 6 and 7 represent the higher velocity data while Figures 4 and 5 present the lower velocity data.

Figure 8 shows the variation of resistance as a function of tank pressure. Concentration of the solution was held constant during these measurements. The curves shown in Figure 8 are representative of other data taken at different concentrations. In all cases it was found that the value of resistance measured at the lower pressures was approximately three times the resistance of the liquid itself. That is a resistance measurement of pure liquid solution at the same sodium chloride concentration as the fluids used in obtaining the data for Figure 8 yielded a value that was approximately 1/3 of the two-phase resistance at low pressure. Therefore, it is believed that at the lower pressures a "water jet" effect is occurring such that only part of the total electrode area is being covered by the two-phase fluid. As pressure is increased the expansion of the jet of fluid in the expansion chamber occurs faster and thus as pressure is increased more and more of the electrode area is being used [8]. This phenomena would indicate that resistance should decrease as pressure increases. There is however, an opposing phenomena

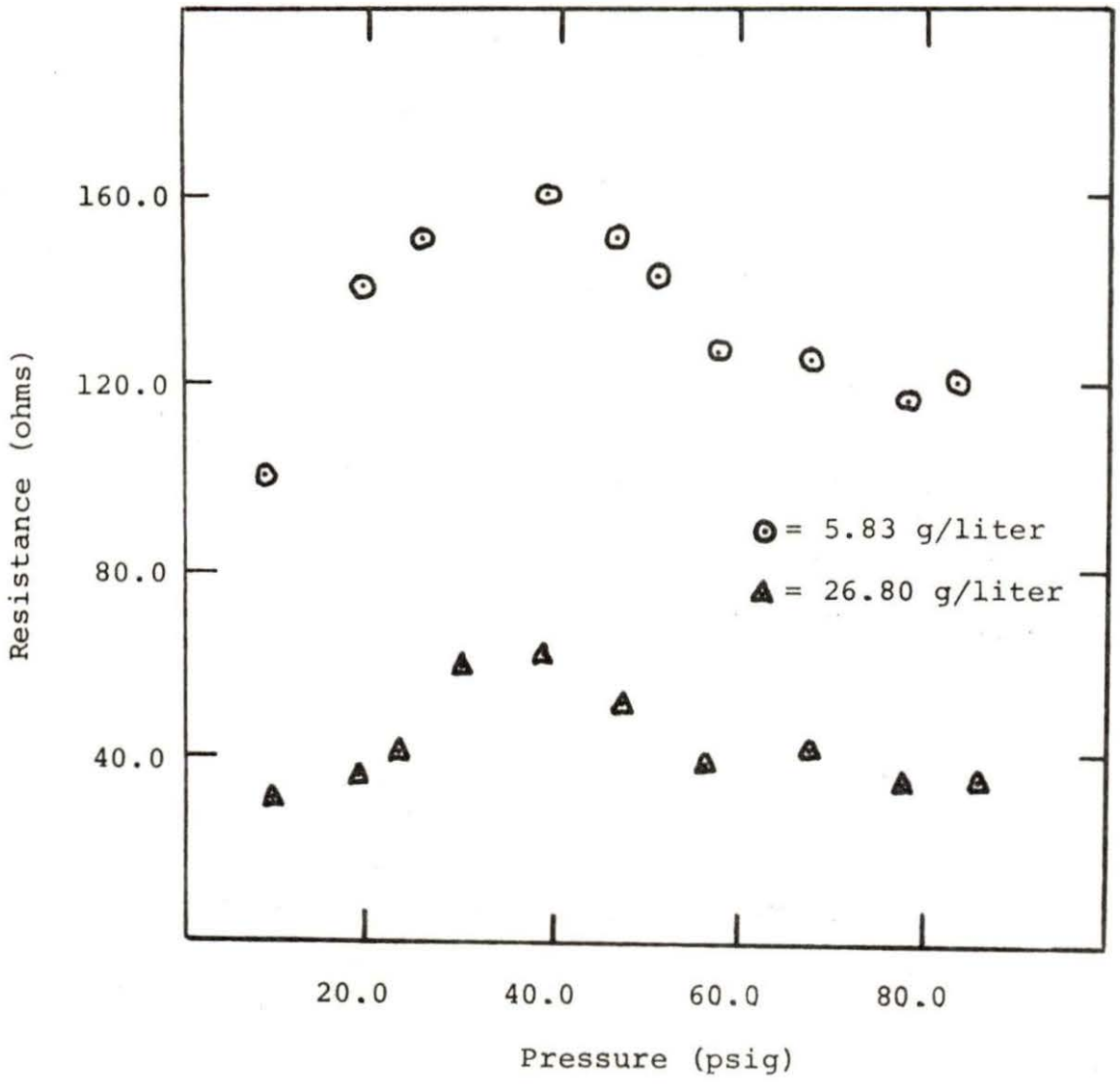


Figure 8. Resistance versus tank pressure

occurring simultaneously. As tank pressure and temperature are increased the quality of the fluid flowing into the duct increases. This means a larger fraction of vapor and a smaller fraction of liquid in the two-phase fluid entering the duct, leading to increased resistance as a function of increasing tank pressure. The opposing nature of these phenomena leads to the shape of the curves shown in Figure 8. Initially as tank pressures are increased from zero the rise in resistance is caused by the higher fluid quality phenomena. Eventually the curve is caused to turn over and decrease by the increased electrode area utilized as increasing pressures cause faster expansion of the fluid. The author believes these curves will again turn up at higher pressures than those measured in this experiment because eventually either choked flow will occur or the entire electrode will be used nullifying this phenomena and the increasing quality-higher resistance phenomena will dominate.

Figure 9 shows the variation of the potential difference developed between the two electrodes as a function of tank pressure for the various solution concentrations. These measurements were made using a constant magnetic field of 8500 gauss. It can be seen that the voltage is approximately a linear function of pressure. The solid line is a theoretical calculation of the expected voltage using Equation (4). The voltages measured are well within experimental error of the

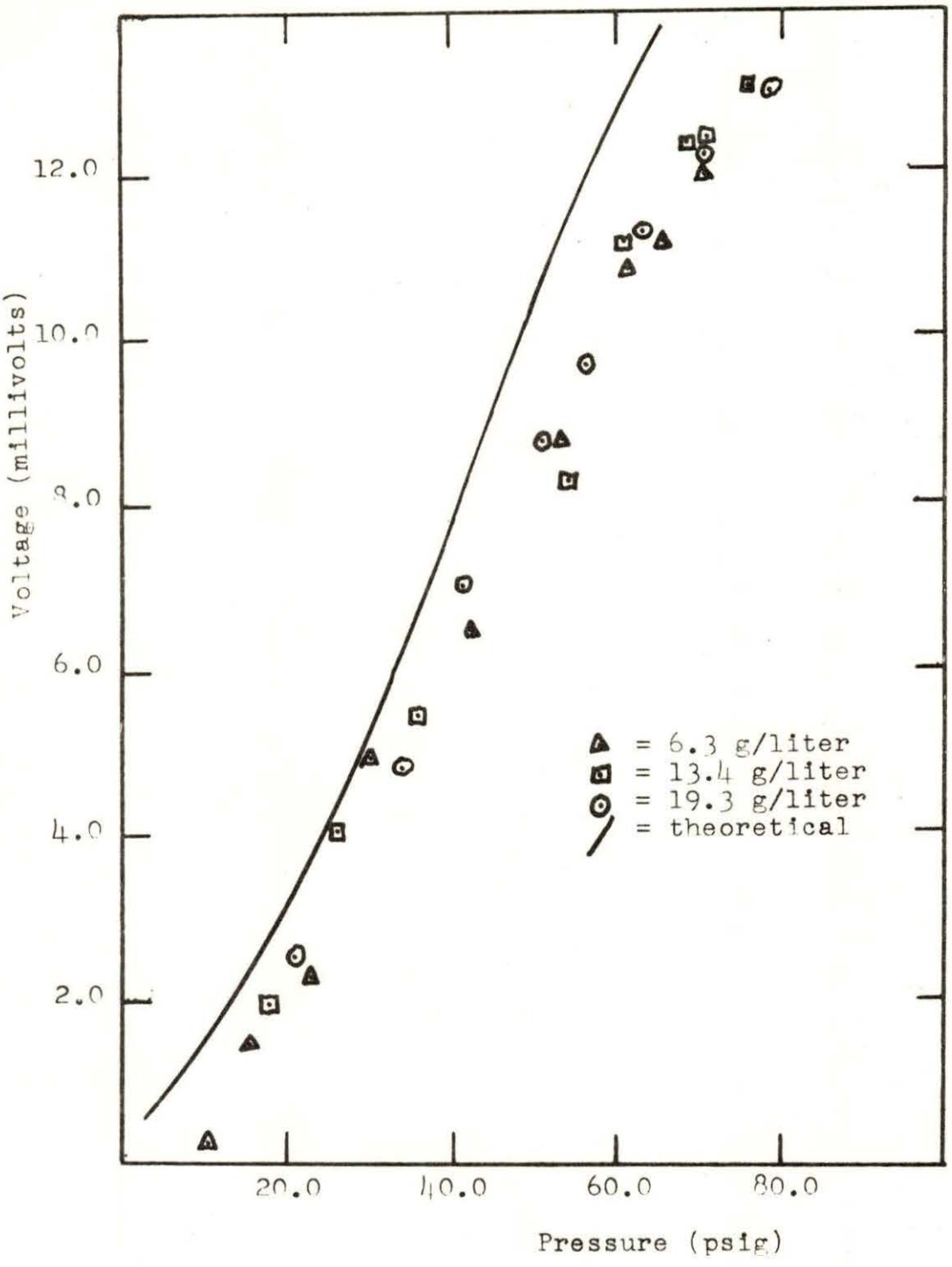


Figure 9. Open circuit voltage vs. tank pressure

theoretical value presented in Figure 9.

It can be seen that the open circuit voltage across the duct is independent of the sodium chloride concentration of the two-phase working fluid. This is reasonable and expected from electromagnetic theory since the open circuit voltage between two ends of a conductor moving in a magnetic field is only a function of the magnetic field strength, the velocity of the conductor and the length of the conductor, not the conductivity of the conductor as shown by Equation (4).

The values of the voltages encountered here are too low if a MHD generator of this design is to be used on a macroscopic level. Techniques to increase the voltage include increasing the velocity of the fluid to the supersonic level as in the liquid metal MHD devices, which some sources say is necessary for the efficient operation of an MHD generator [10]. Another way is to increase the magnetic field by using superconducting magnets as suggested by Bueche [3]. Also since voltage is a function of electrode spacing in this type of system, one could widen the duct (perhaps a better way to do this would be to use an induction type generator such as the one used by Dudzinsky and Wang [5]).

Typical current as a function of velocity data is shown in Figure 10. This data was taken with a constant magnetic field of 8500 gauss. The current appears to be a linear function of velocity as would be expected from Equation (4).

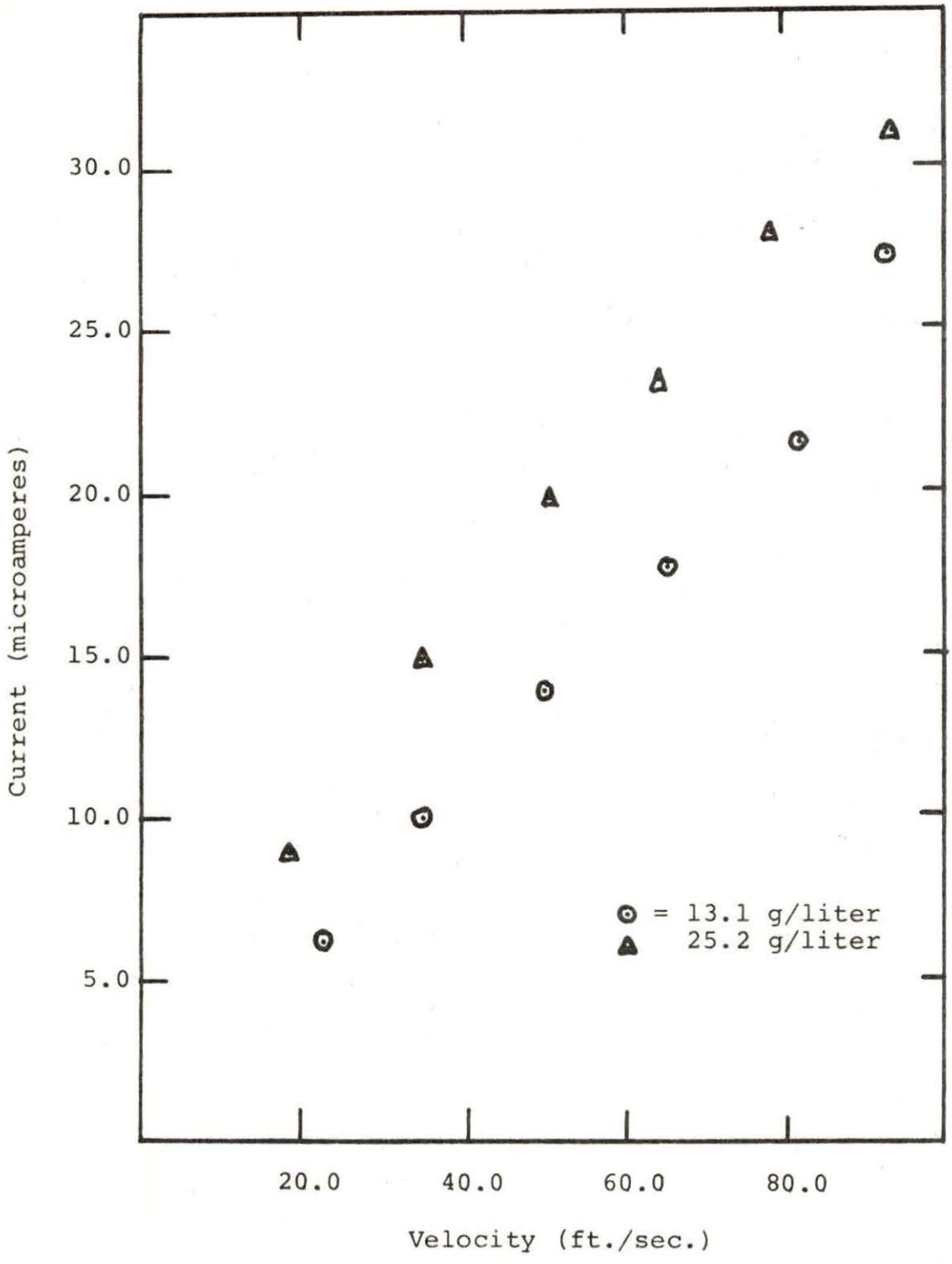


Figure 10. Short circuit current vs. fluid velocity

It can be seen from Figure 10 that the current produced by the generator increases with increasing concentration at any given velocity. This is to be expected on the basis of the results given in Figures 4, 5, 6, and 7, that is the conductivity of the two-phase fluid increases with increasing sodium chloride concentration.

It must be pointed out that the current produced by this device is in the microampere range, much too small for practical application. One way to increase amperage output is again to increase the magnetic field strength. It has been estimated that for a practical liquid metal MHD generator a magnetic field in the range of 35 to 50 kilogauss is necessary [3]. It is reasonable to say that this kind of field will also be necessary for the electrolytic MHD generator. Another significant way to increase output amperage would be to increase the velocity of the fluid flowing through the generator. This velocity can be increased by operating the generator at higher temperatures and higher pressures or by using better expansion nozzles. Data on steam water expansion nozzles has been tabulated and is given in reference [2]. From this data reasonable estimates can be made as to the possible performance of this generator. Another way to increase flow velocity would be to optimize the duct design, a process that will require additional experimental work.

Figure 11 shows amperage data versus solution concentration at a constant pressure. The output current, which was measured by the short circuit method, increases with increasing concentration. This phenomena was also observed in the data presented in Figure 10. It can also be noted that there is a leveling off of the curves at higher concentrations. This leveling off can be explained by noting the data presented in Figures 4, 5, 6, and 7. In these figures it was observed that the resistance decreased rapidly at lower concentrations. This corresponds to the sharp rise in output current observed in Figure 11 at low concentrations. The latter portion of the curves in Figure 11 would correspond to the linear portion of Figures 4, 5, 6, and 7 which shows that the resistance of the duct does not decrease rapidly in the latter portion, therefore we would not expect to see a rapid increase in output current in this concentration range.

Another feature of the data in Figure 11 is that current increases as pressure increases. This is expected since as pressure increases velocity of the two-phase fluid also increases as shown in Figure 12. This data again points to the fact that much higher operating fluid velocities are necessary for significant power generation.

Figure 12 gives the variation of fluid velocity with respect to tank pressure. As can be seen the fluid velocity is approximately a linear function of tank pressure. This

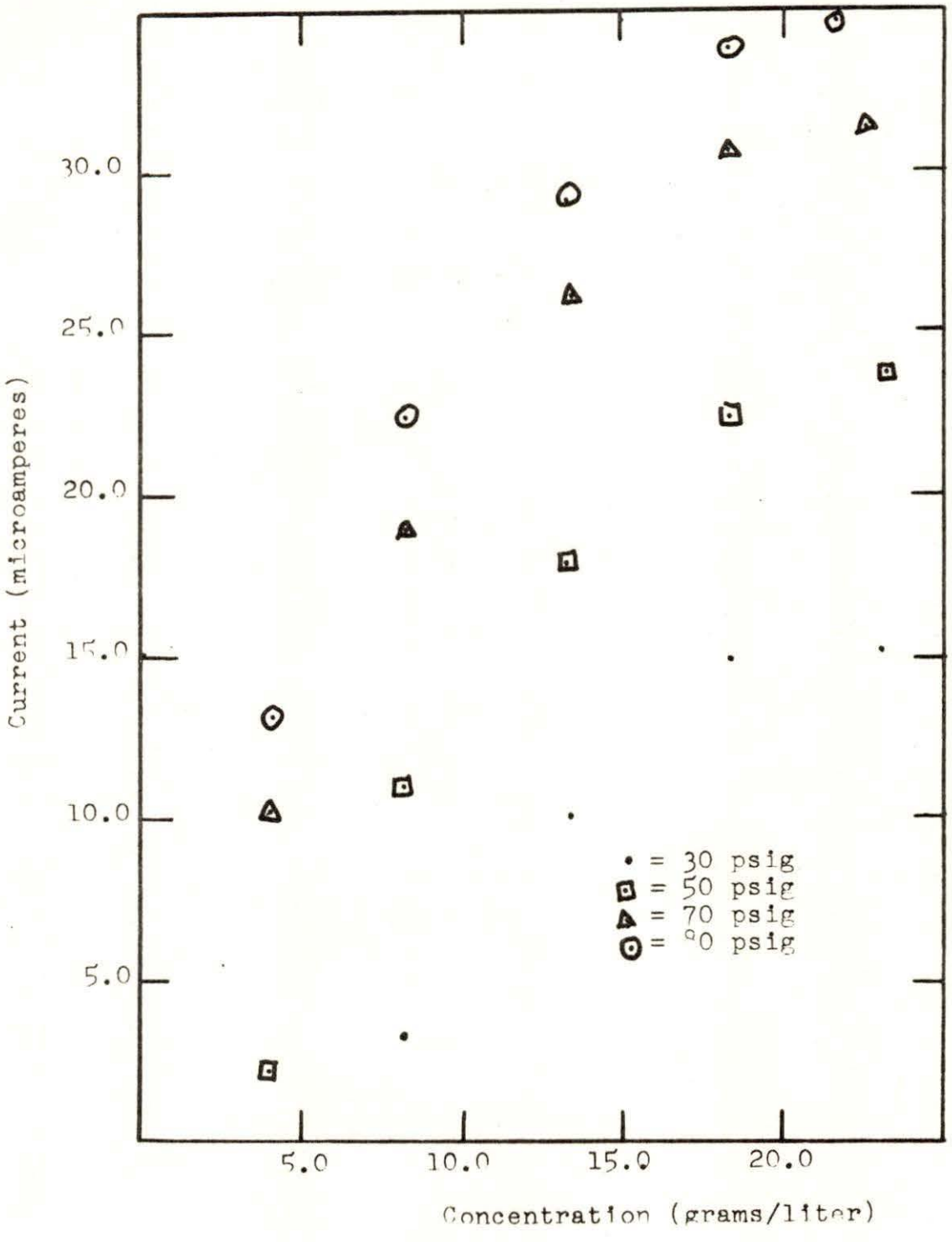


Figure 11. Short circuit amperage vs. concentration

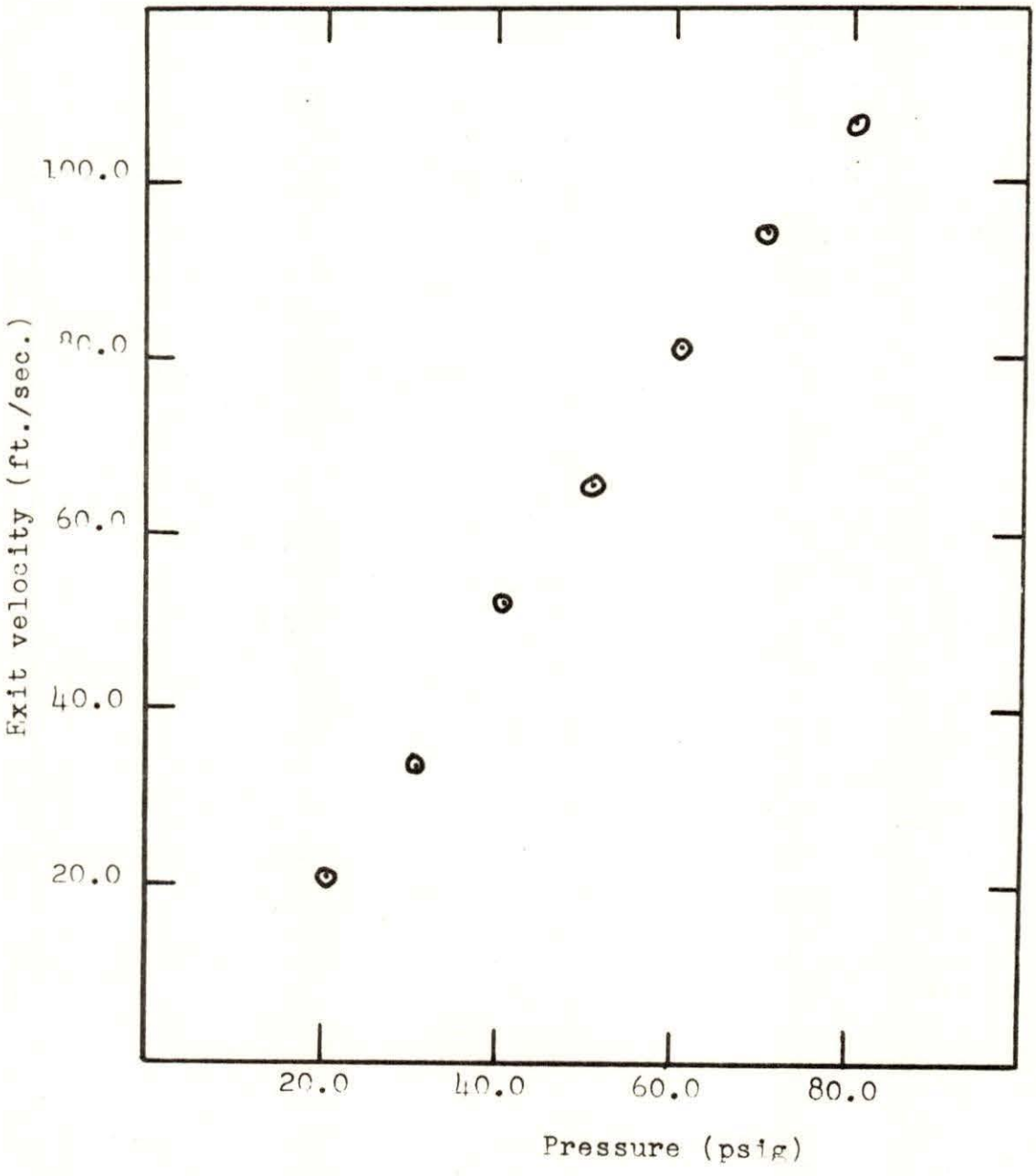


Figure 12. Exhaust velocity vs. tank pressure

data was obtained using a water-wheel device which consisted of a finned wheel that was placed in the exhaust stream of the MHD duct. The rotational velocity of the wheel was determined and the exhaust velocity was calculated. It must be remembered that this velocity does not account for any possible "slip" of the liquid part of the two-phase fluid. There is evidence that slip ratios are near unity for this type of system [8]. An indication that there is a difference in velocity between the vapor and liquid portions of the fluid is given in Figure 9 where it should be noted that all the experimental data is less than what was calculated using the velocities measured by this technique.

Figure 13 is a plot of mass flow rate versus tank pressure. There is an indication that choked flow is being approached as the pressure is increased. The data also exhibits an increase in mass flow rate with increasing tank pressure as expected.

Because the area of the electrode utilized by the two-phase fluids varied with tank pressure, it was impossible to calculate the conductivities of these fluids. However, the conductance could be calculated. Conductances for various tank pressures and different solution concentrations are listed in Table 1.

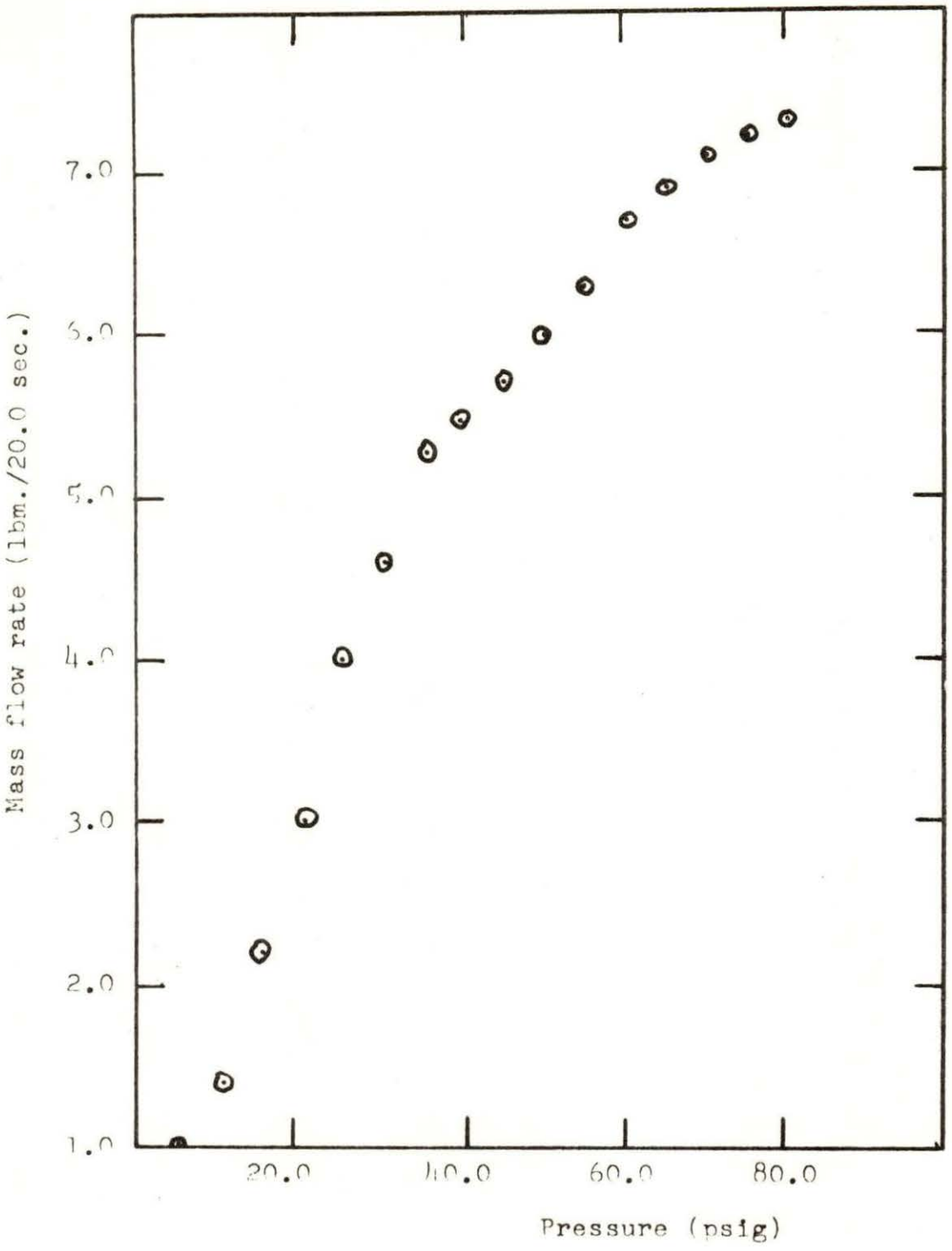


Figure 13. Mass flow rate vs. tank pressure

Table 1. Fluid conductances ($ohm^{-1}$) x $10^{-3}$

| | 2.0 g/ℓ | 5.0 g/ℓ | 10.0 g/ℓ | 15.0 g/ℓ | 20.0 g/ℓ | 25.0 g/ℓ |
|---|---|---|---|---|---|---|
| Pressure = 10 | 6.27 | 9.12 | 13.30 | 16.80 | 24.90 | 40.00 |
| Pressure = 30 | 4.34 | 6.67 | 11.00 | 14.30 | 16.67 | 25.00 |
| Pressure = 50 | 4.77 | 7.15 | 11.10 | 12.75 | 15.35 | 18.18 |
| Pressure = 70 | 5.56 | 8.15 | 12.50 | 16.67 | 22.80 | 37.00 |

Figures 14 and 15 are graphical representations of the data presented in Table 1. In Figure 14 we notice an initial decrease in conductance with increasing pressure to a minimum and then an increase above 50 psig. Since conductance is reciprocal resistance as can be derived from Equation (1), we would expect this curve to be the inverse of Figure 8 as it is. The shape of the curve is caused by the same opposing phenomena which were discussed in connection with Figure 8. Figure 15 shows the variation of conductance with solution concentration.

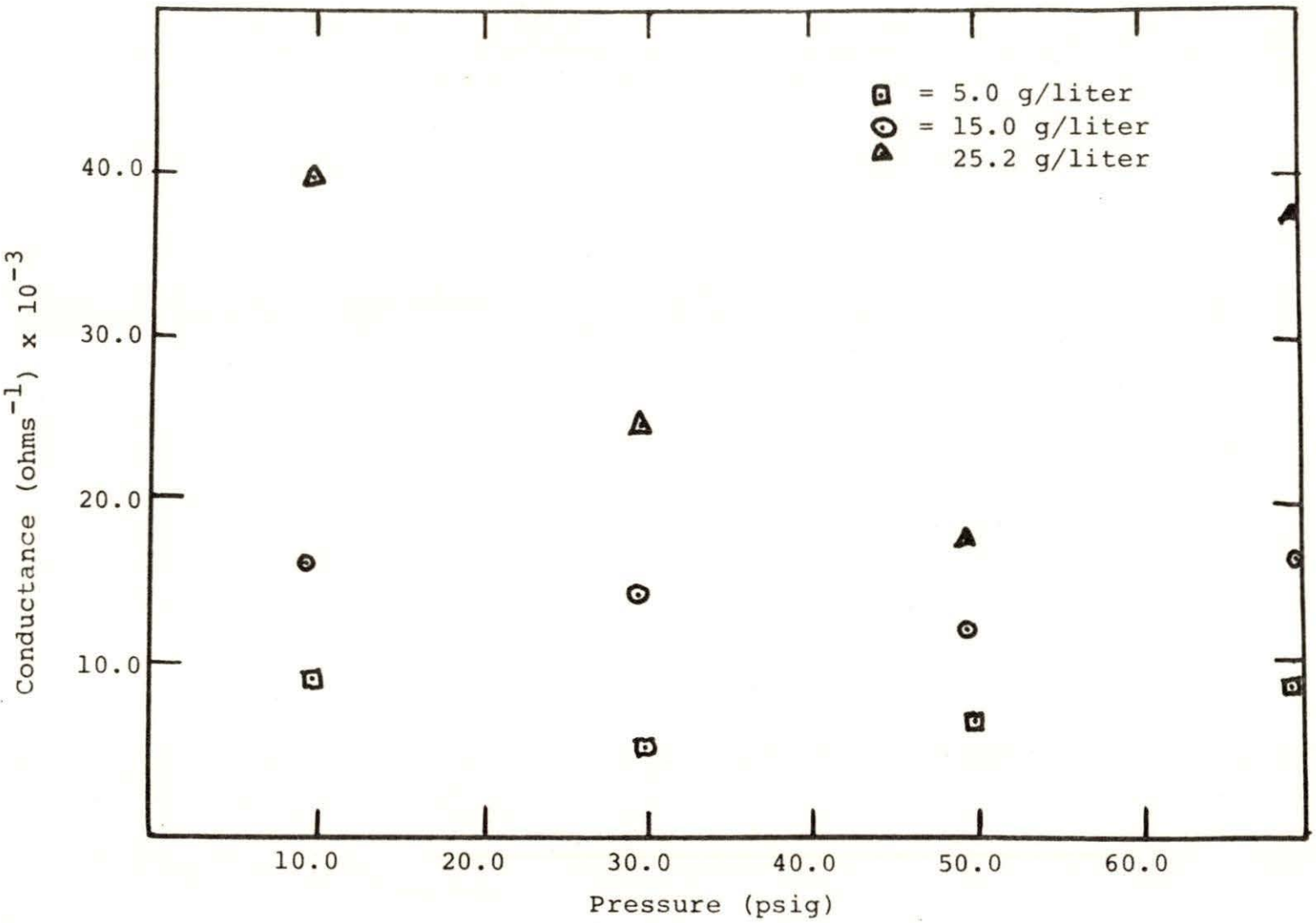


Figure 14. Conductance vs. tank pressure

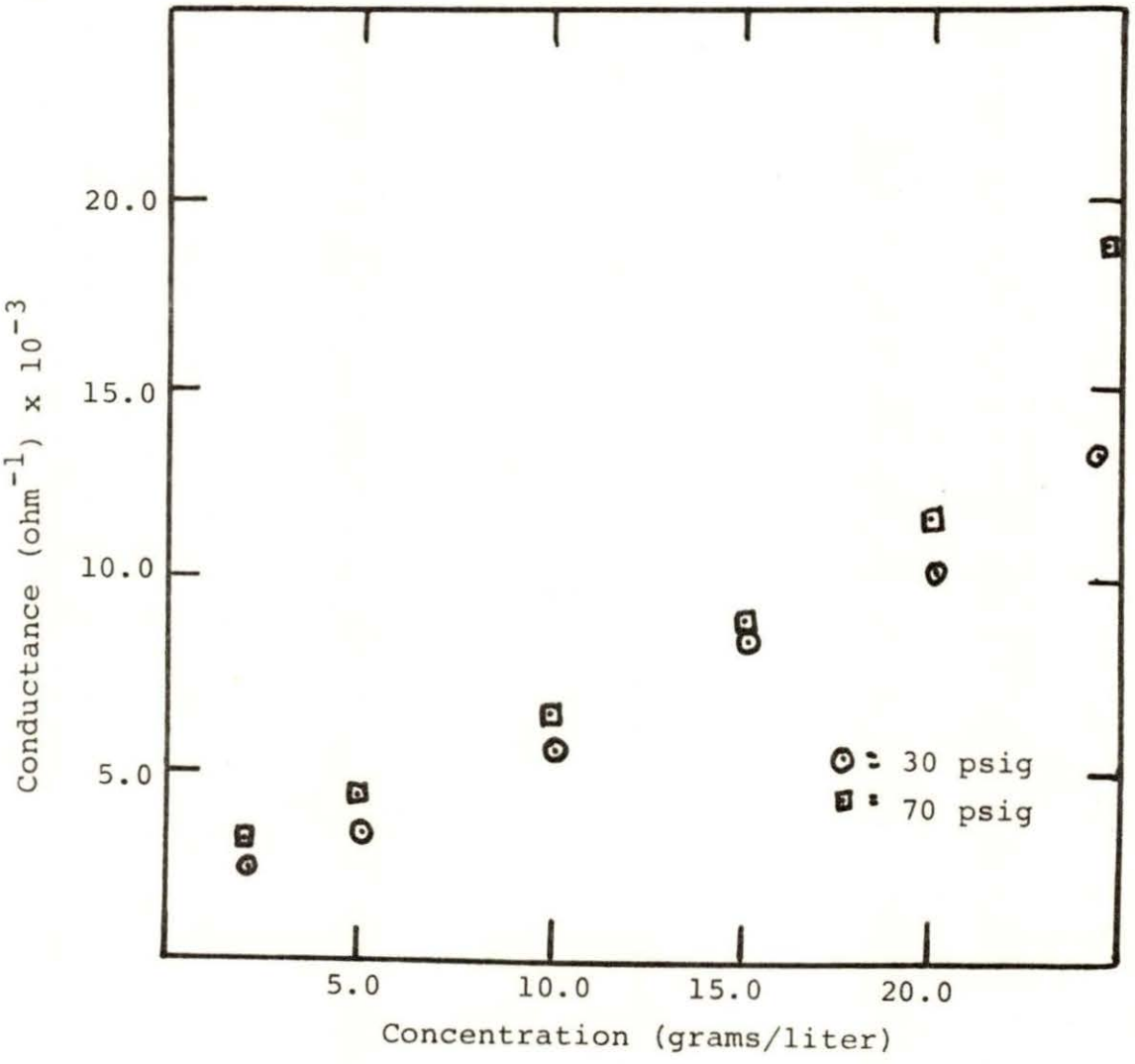


Figure 15. Conductance vs. solution concentration

# SUMMARY AND CONCLUSIONS

No definite yes or no answer can be given to the question of the electrolytic MHD generator's feasibility of the basis of the work done in this thesis. The small voltages and the small output amperages produced by the experimental apparatus indicate that much higher fluid velocities or much higher fluid conductivities are necessary to produce the necessary voltages and amperages. The relatively high two-phase fluid resistances measured indicate that perhaps some other mechanism such as that used to obtain good conductivities with the liquid metal MHD devices should be investigated with the electrolytic fluid. The problems encountered in this project with varying electrode area utilization will have to be taken into account in future investigations.

The electrolytic MHD generator is a device with some significant advantages over other MHD generators and warrants further study. Future study, however, should take into account the experience gained in this project in designing the duct and in selecting the proper operating conditions.

# TOPICS FOR FURTHER STUDY

It is the opinion of the author that the next step in the investigation of the electrolytic MHD generator should be to explore the two-phase fluid conductivities at higher velocities. These higher velocities should probably be in the supersonic range if possible. In the author's opinion it would be a waste of time to explore two phase fluid conductivities at velocities intermediate between those reported in this thesis and supersonic velocities. The reason for this being that it is advantageous to operate a MHD generator at the highest possible fluid velocities from a power output standpoint. From these investigations at supersonic velocities a more reasonable estimate of the electrolytic MHD generator's potential value for central station power production can be made. These high velocity conductivity measurements should be made as a function of fluid quality and fluid void fraction. They should be made as a function of solution concentration and ion mobilities in the solution. Also they should be made as a function of initial temperature and pressure of the superheated electrolytic working fluid. All of these variables and their interdependence will have to be determined before an initial prototype generator can be built.

An optimum duct shape and nozzle arrangement will have to be determined. There is much information on nozzle design for steam systems as shown in reference [2]. Also much work

has been done on supersonic nozzles for liquid metal MHD generators much of which would be applicable to the electrolytic MHD generator [1, 10]. A supersonic nozzle or nozzles will have to be adapted to allow large mass flow rates in order to achieve a high power density which is desirable for efficient operation of a generating unit.

The electrode corrosion and electrode deposit problem observed in this experiment will have to be investigated further to facilitate the design of the nozzles, the electrodes, and the duct itself. These problems will have to be reviewed for each of the different classes of electrolytes such as acids, bases, and salt solutions. Also a materials problem should be considered if the device were intended to be used with a nuclear reactor and its accompanying radiation and heat properties.

It is probable that the type of MHD duct used in this system is not as well suited to high power outputs as an induction type device as used in references [1, 5, and 12]. Also an analysis of loss mechanisms such as end losses (done for the fluid metal MHD generator by Fouad and Weiss [6] will have to be made for the electrolytic system.

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