CONCEPTUAL DESIGN OF AN INDUSTRIALLY APPLICABLE PLASMA REACTOR

by

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CONCEPTUAL DESIGN OF AN INDUSTRIALLY

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CHAPTER I

INTRODUCTION

> [Zeus] thundered with a terrible crashing and hurled a dazzling white lightning-bolt. hurled it to earth before Diomedes' team. where it burst in an awesome flare of fuming sulphur.

The above quote was taken from chapter VIII of the Illiad (translated by Rees p. 150). Lightning is an electric discharge (plasma) that is coupled by a chemical reaction mechanism that converts air to ozone. which has a certain stench that without modern scientific knowledge was well described as "fuming sulfur." Homer referenced the smell after lightning in both the Illiad and the Odyssey. "The smell was most likely ozone. and the remarks of Homer are probably the earliest reference to this substance and to reactions initiated by electrical agents" (Glockler, p. 1). The production of ozone is synonymous with plasmas initiated within an air stream. Ozone production is probably the best known phenomena to be studied in the type of plasma reactors used at Oklahoma State University (OSU). and my research utilizes this to study the plasma reactors.

This thesis does not claim to develop the basic theory for plasma reactors. Rather. this thesis consolidates past works with recent research at OSU. It should be realized that past work has been performed in this area. However due to a lack of technology, the potential of the work was not fully realized. resulting in the dissolution of the research. Due to the lack of a consolidated effort among academic disciplines. plasma has been approached from many different perspectives. each employing its own terminology. Thus the end result has been difficulty in researching past work and difficulty in tracking current efforts in plasma technology. The true pioneers in plasma research have been largely overlooked, and some of the work was quite extensive. After looking at the work done, one may ask such questions as, "Why was the research stopped and why was it lost?" One possible answer could be that research was lost due to a lack of analytical equipment paired with the actual motives of the researchers involved. For these pioneers, the technology was being developed in an attempt to understand plasma itself, not in an attempt to apply it industrially.

My research was somewhat limited from a financial standpoint thereby forcing me to work in much the same environment as the pioneers, without product analysis and without the ability to purchase electrical equipment specified for the operating range of the experiments. Without product analysis, the presence of a glowing discharge was the main characteristic used to determine the best state to drive a chemical reaction and this was sufficient for my research. The operation of electrical equipment outside specified ranges was not as easily accepted because it was a source of confusion and uncertainty, but the purchase of electrical equipment could only be justified subsequent to a more finalized reactor design.

The purpose of this thesis is to present my research efforts to further develop the theoretical framework necessary to eventually scale up plasma reactors for industrial applications with an emphasis towards re-designing the reactor for further research at OSU. The basic reactor design previously used at OSU was good, but operational problems persisted. Our research at OSU was not progressing for several reasons including the electrical and physical instabilities of our reactors, which hindered the developing of necessary relationships for scaling-up the reactors. The main purpose of my work was to design a safe and practical reactor, in addition to upgrading the plasma research effort at OSU.

CHAPTER II

OBJECTIVES

The original objective of this thesis was to set up a plasma reactor for removing contaminants from a hazardous environment. This project would have been similar to earlier work with the plasma reactors at OSU, but after a request from Veritech in Dallas, I set out to examine the feasibility of the plasma reactors for the use of destroying polychlorinated biphenyls (PCB).

PCB posed many problems for our reactor. Some problems included: 1) PCB is a toxic chemical compound; 2) PCB it is not gaseous (only able to create a plasma within gases); 3) PCB is very viscous (could plug the reactor); and 4) PCB adheres to glass (our reactors are currently made of fused quartz glass). Possibly the largest problem experienced to date at OSU was burn-through of previous reactors. Burn-through is the phenomena where the reactor is physically pierced by an electrical arc thereby allowing the substance in the reactor annulus to escape to the atmosphere. PCB, having been one of the greatest transformer oils, has a large dielectric constant. It was conceivable that we might break down (burn-through) the reactor walls well before we broke down (created a plasma) the PCB.

Initially I used air to analyze the current setup for its ability to create a plasma. After many attempts to set up a plasma reactor for air, it became apparent that there were electrical problems which had to be addressed before further progress could be made with the plasma research. After considerable discussions with my advisor, we felt that my research would be more beneficial to the entire study of plasma reactors if I could improve upon the electrical connectors and electrodes used in plasma reactors, thus improving plasma reactor design. At this point, I was still unsure what chemical reaction I would attempt with the plasma reactor, but I did know I needed to create a uniform plasma without negative electrical effects (e.g., shorts, arcs, etc.).

Based upon the limitation of our current setup with respect to PCB, we realized the more pressing area was in the design of the plasma reactor. The objective of my research became to conceptually design the plasma reactors for the possibility of industrial scale operations. Previous work had shown that these reactors would remove particular contaminants from air streams. Thus, it was more important to back up and figure out what caused the problems hindering the progress of current research.

At OSU, plasma research had concentrated on near atmospheric pressure plasma reactions produced by electrical discharges because of the potential and versatility believed to exist for industrial application. My work differed from previous research at OSU. Instead of analyzing a chemical reaction based on the formation or destruction of a specific compound, I concentrated on non-destructive tests which do not give information regarding the formation of products of the reaction. My emphasis focused on the apparatus for producing the plasma discharges. A goal of my thesis was to insure future researchers working with this type of plasma reactors would understand the electrical, physical, and chemical operations of these reactors.

CHAPTER III

LITERATURE SURVEY

History

"Indeed, it would seem that the people most actively engaged in developing a given field, are the people least likely to write at length about it." [Davidson, p.ix] Even so, there are numerous examples of "plasma" available in the literature, but most of these are not consistent with the work being done at OSU. The main problem is basically that "plasma" includes a broad range of technology. The problem is increased significantly when one realizes that much of the literature concerning plasmas is hidden under the different terms used by various academic disciplines.

> When engaged in any field of science or technology, it is not a bad idea to pause occasionally and to look backwards a little... The reading of a little history is an excellent backup to the usual literature searches that form part of any projected experimental investigation. An old idea or observation can sometimes trigger a new line of thought. [Stock, p.1]

There appears to be a wealth of information available to the researcher willing to dig through the unconsolidated literature. For this thesis, I had to reach a stopping point well before my personal curiosity was sated. There remains more to be discovered both from past research (literature) and through laboratory work (experiments).

For all practical purposes, plasma is essentially an ionized gas. "The observation of electrically ionized gas is as old as Man. His use of fire unknowingly involved the production of charged gases." [Liao, p.144] An early interest in gas discharges, which is another way of referring to plasma, started primarily as a material consideration. Early studies concentrated on properties of the ionized gases such as: the ability to sustain discharges, the intensity of discharges, and the size of discharges for various gases. A peculiar methodology employed by K. Natterer in 1889 demonstrates the intrigue of the actual discharge to these early pioneers.

> Natterer not only measured the maximum spark distances a gas could support..., but also the distance from the spark at which he could read a book in the darkened room. [Liao, p.145]

It is hard to justify why the interest in the actual discharge was subdued until many years later, but many possibilities exist. The people showing the most signs of active research with discharges were scientists most interested in materials. As arcs and other electric discharges became more common place, the emphasis of the research shifted from the actual discharge to the materials ability to resist forming a discharge (dielectric characteristics).

One of the most interesting topics from my perspective is the actual chemical reaction mechanisms occurring within the discharge (plasma). The nature of plasma corresponds to chemically active species. Transferring energy via the bombardment of electrons is the mechanism for attaining a plasma process. The process of creating a plasma leads to the formation of a host of possible chemically active species: free radicals, positive and negative ions, accelerated electrons with high kinetic energy, metastables, and atoms. Thus, it is not difficult to realize the reactive potential of plasma. A plasma is differentiated from normal (gas, liquid, solid) matter by the presence of free ions. An electric discharge provides an acceptable way of producing and maintaining a plasma state.

> As soon as techniques became available for producing discharges in the laboratory, chemists attempted to use them for chemical synthesis. The first experiments of this kind were reported as early as 1796, when four Dutch chemists subjected ethylene to spark discharges and obtained an oily substance. [Suhr, p.57]

It appears that this technique was not followed up until the emergence of the ozonizer during the turn of the twentieth *century* which used an electric discharge (plasma) to produce ozone from air. We should remember that the early pioneers of "plasma" research identified our reactor as an "ozonizer". The term "ozonizer" was not restricted to ozone producing reactions, but just to similar reactors originally used to produce ozone. With the stimulus of discharge reactions, other reactions were explored. "Particular attention was focused on *high-voltage glow discharges* after the discovery that they could be used to prepare atomic hydrogen, oxygen, and nitrogen." [Suhr, p.58] These types of discharges are similar to the ones that we are focusing on at OSU.

In the early 1930's, Langmuir first used the term *plasma* for what had been referred to as ionized gas. [McTaggart p.7] For classification as plasma, the degree of ionization can range from very little to fully ionized.

> Within this range gases may show a wide variety of physical and chemical properties that are entirely different from their normal properties, thus justifying Crooke's early suggestion that in the *active* condition they represent a fourth state of matter. From the word plasma has been derived the term *plasma chemistry* -- that branch of chemistry concerned with the reactions of the species found

in plasmas, that is atoms, free radicals, ions, and electrons, both between themselves and with other molecules in the gaseous, liquid or solid state. [McTaggart, p.8]

Review of Work at OSU

Work Done at the Naval Research Laboratory in conjunction with OSU

Ronald Sheinson of the Naval Research Laboratory (NRL) headed a research group that investigated using a high voltage discharge for purifying contaminated air. Researchers noted they found parameters dealing with the characteristics of the components, the transformer, the reaction cavity and the AC power source. They decided the understanding of these components is the first step in studying the destruction of hydrocarbons with a glow discharge. At the NRL, the reactor was made of quartz glass. The voltage was fixed, the frequency was varied and the current was measured.

Thesis Reports from OSU

This section is a survey of previous work performed under the guidance of Dr. Johannes and Dr. Veenstra at OSU concerning the use of the plasma reactors. This list does not include every work performed, however it serves to give insight as to the nature of the work to date.

Piatt, M. A., Methane Destruction in an Alternating Current Plasma Reactor, Oklahoma State University, 1988

Being the first to work with these reactors at Oklahoma State, Piatt's work was both exploratory and introductory with the intent to "lay the foundation for future research in this emerging technology." He originally chose methane for his destructive tests because of the high bond energy associated with the C-H bond. He also studied the dependence of input power on different gas types. He noted a weak dependence of power input at optimum frequency on flow rate, claiming less than 5% change when flow rate was increased 41 times, but these flow rates all remained in the laminar region. He was successful for getting the research effort started at OSU, but he lacked the full understanding of plasma. Piatt states a false reaction mechanism: "Organic contaminates in air streams passing through this plasma are broken down by the plasma energy into atoms. These atoms then recombine to form the reaction products."

Tsai, V. Y., Conceptual Design and Performance Analysis of Frequency Tuned Capacitive Discharge Reactors, Oklahoma State University, 1991

Tsai's goal was to uncover broad trends that could "provide a more conceptual approach to the design, scale-up, and operation of frequency-tuned capacitive discharge devices." Tsai ran his destructive tests on Trichloroethylene (TCE) which is a volatile organic compound found in contaminated groundwater.

Tsai's works is largely responsible for the emphasis put on tuning the reactors, but looking at this phenomena is more a factor of the electrical equipment rather than the capacitance of the reactors. Tsai addressed the problem of electrode uniformity in his experiments. His solution was to use evaporated silver for the electrodes. The evaporated silver formed to the walls of the reactor, which was effective, but it eliminated visual observation of the plasma discharge.

Robinowitz, S. B., <u>Production of NO_x in an Alternating Current Plasma Reactor</u>, Oklahoma State University, 1992

Robinowitz's work was directed towards proving the plasma reactor to be an effective method to produce the oxides of nitrogen at atmospheric conditions with respect to electrical and gas flow variables. He noted an optimum frequency at each primary voltage which yielded a maximum power input to the reactor. This corresponded to a maximum production of nitrous oxides. Increased flow rate decreased NO_x production. Maximum NO_x production was noted at a relative humidity of 35%, high power input, and low flow rate.

A weak point of his work were his misunderstand references to plasma as a zone from which energy is stolen to produce reactions.

Desai, V., <u>Decomposition of Hydrogen Sulfide in an Alternating Current, Frequency Tuned Plasma Reactor</u>, Oklahoma State University, 1992

Desai studied the effectiveness of the reactor for decomposition of Hydrogen Sulfide. Desai reached a maximum conversion of 92%. He noted reactors made of Pyrex suffered from thermal stress with heating of reactor walls. He also noted his electrical equipment and measuring devices were not designed for use at frequencies other than 60 Hz although he often operated at frequencies above and below this value. In addition, Desai encountered an unusual phenomenon: the secondary voltage reached a maximum at lower frequencies than where the plasma became visible. This contradicts the trend observed by all other researchers at Oklahoma State, but I also made these observations.

Hurst, M. C., <u>Destruction of Carbon Tetrachloride in an Alternating Current Plasma Reactor</u>, Oklahoma State University, 1993

Hurst's main objectives included determining both the effect of various process parameters upon the destruction efficiency of the plasma reactors on carbon tetrachloride and benzene, and an optimum operational range. This was especially of interest to me since C-Cl bonds in PCB should be easier to break than in carbon tetrachloride. Maximum destruction of benzene was greater than 99.9% and maximum destruction of carbon tetrachloride was greater than 78.9%. Hurst noted humidity had an inverse proportionality to destruction of carbon tetrachloride and residence time had a proportional relationship to destruction efficiency.

Manning, D. K., <u>Hydrocarbon Rearrangements and Synthesis Using an Alternating Current Silent Glow Discharge Reactor</u>, Oklahoma State University, 1993

Manning's first objective was to investigate the effects of changing the plasma zone length and electrode configuration. His second objective was to study the pyrolysis of propane using the plasma reactors. Manning reached three major conclusions: 1)

Prediction of required secondary voltage is a function of reactor capacitance, which I do not accept, 2) Hydrocarbon pyrolysis is possible utilizing a plasma reactor for energy transfer, and, 3) Product distribution was controlled by secondary voltage, residence time, and frequency.

Magunta, S. R., <u>Studies on Destruction of Hydrogen Sulfide Mixed with Carbon Dioxide in an Alternating Current Plasma Arc Reactor</u>, Oklahoma State University, 1995

Magunta's primary effort was an attempt to achieve non-oxidative decomposition of H_2S to hydrogen and sulfur under reasonable process conditions. He mentioned local effects and the affect of changing the transformer had on the electrical behavior of the circuit. Magunta's main recommendations were 1) minimizing electrical losses and "end effects", and 2) performing some type of on-line analysis for a wider range of compositions.

Sidhu, G. S., <u>Production and Destruction of Nitrogen Oxides in Alternating Current Plasma Reactors</u>, Oklahoma State University, 1995

Sidhu's main objective was to continue and expand upon earlier work concerning nitrogen oxides. This included the analysis of several factors concerning nitrogen oxide production: primary voltage, residence time, humidity, and types of alternating current. Sidhu concluded that the plasma reactors are sensitive to changes in the electrical characteristics. He noted that when transformers were changed, the entire circuit characteristics changed. He also noted that a visible plasma is not a definite test for ascertaining the breakdown of the gas.

Falk, M., --Work in Progress--Oklahoma State University, 1995.

Falk attempted destruction of NO_x. He used both square wave and sine wave, but noted no significant differences. He had some situations where the presence of a visible plasma did not necessarily provide energy for the destruction of NO_x. He achieved a maximum destruction efficiency of 94%. He also noted that different transformers of the same type possessed different electrical characteristics.

CHAPTER IV

BACKGROUND

To understand the plasma reactors, an extensive amount of background material should be reviewed. This chapter gives a brief overview of the plasma process. It appears that we sometimes try to decide what is necessary or practical with regard to research and bypass much of the fundamental understanding. I like the approach of Liao and Plump. "We shall not ignore the abstract or theoretical, however, for without them there is no understanding, and understanding is also practical." [Liao, p.143] Of course this idea should not be taken to an extreme or we would accomplish very little. Thus, I have limited background information to include the following areas: defining plasma, explaining the electrical aspects of plasma chemistry, differentiating the types of plasma discharges, and providing some examples which demonstrate the potential of the plasma reactors used at OSU.

Definition of plasma

Plasma is defined by Crookes as the fourth state of matter. To best understand plasma, it is important to look at the energy relationship between the states of matter. Starting with the solid state, an increase in energy will melt the solid and produce a liquid. A further increase in energy vaporizes the molecule to form the gas state. If we further increase the energy of gases we can ionize the gas producing plasma. For most practical purposes, plasma is simply ionized gas.

From our perspective, plasma is not regarded as normal matter because 1) presence of an external field is required to produce plasma on earth and 2) the plasma itself possesses unique qualities. It becomes blatantly apparent with limited investigation of plasma that the properties of plasma are different from normal matter. A simple look at a plasma created with an air stream is enough to suggest the uniqueness of this fourth state. Within a plasma derived from a normal air stream, nitrogen and oxygen no longer coexist as non-reactive species. Common plasmas include such items as neon tubes, fluorescent lighting, and electric arc welding, all of which require an external electric field to maintain the plasma state. Naturally occurring plasmas are the aurora borealis and lightning.

The term plasma is confusing to some for the simple fact that they have no physical association with the word. In most situations, the plasma of interest could simply be referred to as an electric discharge. Plasma is more common than one might assume.

> We stand on the threshold of a space age with the realization that by far the greater part of the universe around us appears to be composed of matter in this state and that the planets of our solar system may be oddities in being formed by what has hitherto been regarded as normal matter. [McTaggart, p.1]

> The plasma state is actually by far the most common form of matter (up to 99 per cent in the universe). It is also the most energetic state; a body will require on average 10^{-2} eV/particle to change its state from solid to liquid or from liquid to gas, whereas a change of state from gas to plasma will require from 1 to 30 eV/particle, depending on the material. [Kettani, p.1]

> A plasma is a partly or wholly ionized state of matter in which a system contains free positive (ions) and negative

> (electrons and, rarely, ions) particles so that their concentrations on average are practically equal. The presence of charged and excited species in a plasma and their interactions bring about some specific physical and chemical features causing the behavior of plasma to differ from that of an ordinary gas, thus giving a reason to consider it as a particular "fourth" state of matter. [Bugaenko et. al. p. 274]

According to A. von Engel, the author of <u>Electric Plasmas: Their Nature and Uses</u>:

> A plasma is electrically energized matter in a gaseous state. In general it consists of three components: electrically neutral gas molecules; charged particles in the form of positive ions, negative ions and electrons; and quanta of electromagnetic radiation (photons) permeating the plasma-filled space.

This definition fits that which is called plasma as it applies to the plasma reactors used at Oklahoma State University. However, this last definition is probably a little too limited to serve as a complete definition for all plasma.

S. Ichimaru, the author of <u>Basic Principles of Plasma Physics</u>, defines a plasma as "...any statistical system containing mobile charged particles." The author notes that this definition is vague, but sufficient for both physics and engineering. This definition does not limit plasma to the gas phase, which the author relates was intended to allow for the inclusion of plasmas also found in the solid phase, including the electrical phenomena associated whit semiconductors and semimetals.

These types of restrictions on plasma prompted me to ask two questions: 1) why can't plasma be in a liquid form?, and 2) if a plasma is a fourth state of matter, how can it be in any other state? The first question is answered in the literature and the second is best left for the truly inquisitive who wish to completely understand and develop theories. Even though theoretical pondering is probably more suited for a physicist, I felt compelled to include some thoughts concerning the question of plasma as a fourth state of matter within this thesis.

There is a little room for confusion concerning the actual definition of "plasma.", so I will attempt to clarify the definitions to answer the questions I originally pondered. "Plasma" is evidence of a fourth state of matter, simply because none of the other states of matter would appropriately describe plasma. Part of the problem stems from defining plasma in reference to the other states. It is much like defining gas as vaporized liquid. I disagree that a partially ionized gas is this fourth state exclusively. Plasma should be regarded as a mixture of a fourth state and gas. One part of the way that plasma is defined that bothers me is that it is referred to as ionized gas. If plasma was its own state of matter, then it shouldn't be referred to as a gas. Although this would be partially true, it would be strange. Gas would not have its own identity. The other part that bothers me is that plasma is only partially ionized, not fully. Does slurry or mud deserve to be called an individual state of matter? The term plasma still fits our work as a mixture of gas and this ionized fourth state of matter. I just do not think that plasma deserves to be called the fourth state, but rather simply a condition where a mixture of the fourth state and any other state exist.

A plasma is a collection of charged particles. The Coulombic force with which the charged particles interacts is well known to be a long-range force. The extremely close proximity of the molecules within a liquid probably does not give enough space to allow free electrons to accelerate and achieve enough kinetic energy to initiate a plasma.

Why isn't an electrolytic solution considered a plasma? According to A. von Engel, the author of Electric Plasmas: Their Nature and Uses:

> Firstly, most of the so-called electrolytes are liquids and only a few are solids. Secondly, in electrolytes free electrons and photons are absent; the only charged particles present are negative and positive ions. Finally, apart from certain exceptions, all the electrolyte particles, whether neutral or charged, are in the ground state because they collide frequently with one another.

Due to the unique nature of plasma, it has been developed into its own branch of chemistry separate from the original association with electrochemistry which is more often concerned with liquids.

Electrical Aspects of the Chemistry

To understand the actual phenomenon associated with our plasma reactors we must achieve a basic understanding of electricity. As engineers, we have only two things to work with, matter and energy. Electricity is simply a combination of the two. Understanding the basic electrical phenomenon is essential for the plasma reactor because of the manner in which electricity is completely intertwined with the chemical aspects of the reactor. For a plasma discharge, electricity is not just the driving force. The electrical phenomenon cannot be overlooked. To understand electricity is to understand the heart of the plasma process. Without a base understanding of the electrical phenomenon, there would be little hope for achieving industrial applications. This theoretical framework is the necessary basis for engineering work with discharge type reactors. Further discussions on the electrical aspects of plasma chemistry can be subdivided into the following: 1) discharge mechanism, 2) driving energy, 3) plasma for reaction medium, and 4) electrical representation.

Discharge Mechanism

To understand the electrical aspects of the chemistry in plasma reactors, one should evaluate each discharge step by step. To initiate a discharge, free electrons within the gas are accelerated in the direction of the applied potential. The electrons gain velocity, thereby increasing their kinetic energy. With enough energy, the impact of an electron with a neutral molecule can cause either ionization or molecular excitation. Ionization strips an electron from the neutral species, thus contributing another electron which gains kinetic energy and perpetuates the discharge mechanism. Excitation moves the outermost electron of the neutral molecule to a higher orbital. Upon relaxation of the excited molecule, a photon is emitted and light is observed.

One of the basic concepts that sometimes slips explanation is where the initial electrons originate from. In reactors with bare electrodes exposed to the gas, the source of initial electrons is irrelevant. However, when the electrodes are separated by a dielectric wall, the question remains. Baring detailed theory involving cosmic rays, it should be sufficient to know all materials contain some amount of free electrons. Electrons are rightly associated with conductivity and "All materials conduct electricity to a greater or lesser extent, and all suffer some form of breakdown in a sufficiently strong electric field." [O'Dwyer p.1]

In response to an electric field, a charged particle (initially just a free electron naturally existing) is accelerated, transferring potential energy from the field to kinetic energy of the charged particle. When one of these accelerated electrons interacts (impacts) with another particle, energy is transferred from the incident electron to the particle. "An atomic electron (of the particle collided with) may receive an energy either lower or higher than its ionization potential, and the molecule will be either excited or ionized, respectively." [Bugaenko p.33] With the random number of collisions occurring simultaneously, both ionization and excitation occurs and is an inseparable part of a plasma.

The electron generated during ionization is a secondary electron having a response to the electric field that duplicates the process. The discharge process' type of breakdown is similar to an avalanche, producing a great number of both ions and electrons. This progressive effect causes extensive breakdown of the gas with the current rising while establishing a discharge. A complete discharge process takes only about one ten-millionth of a second and is repeated each time the electric field reverses. [Coffman, p. 93]

Reversing the voltage potential across the annulus, which happens with every half cycle (AC), produces very rapid succession of discharges that appears continuous. When the voltage potential is removed, the charge gradient is redistributed by diffusion before the voltage can be applied in the opposite direction. The charge redistribution results in an overall neutrality of the plasma. Because the particles are being accelerated from an evenly distributed state, it does not matter if the voltage is reversed or simply decreased and reestablished in the same direction as in a pulse type discharge.

To demonstrate visually how a discharge occurs, I have used an example showing a single discharge producing ozone from air, see Figure 1. The corona discharge mechanism shown is identical to the discharge mechanism used for OSU research processes, even though this process would not technically be considered "corona".

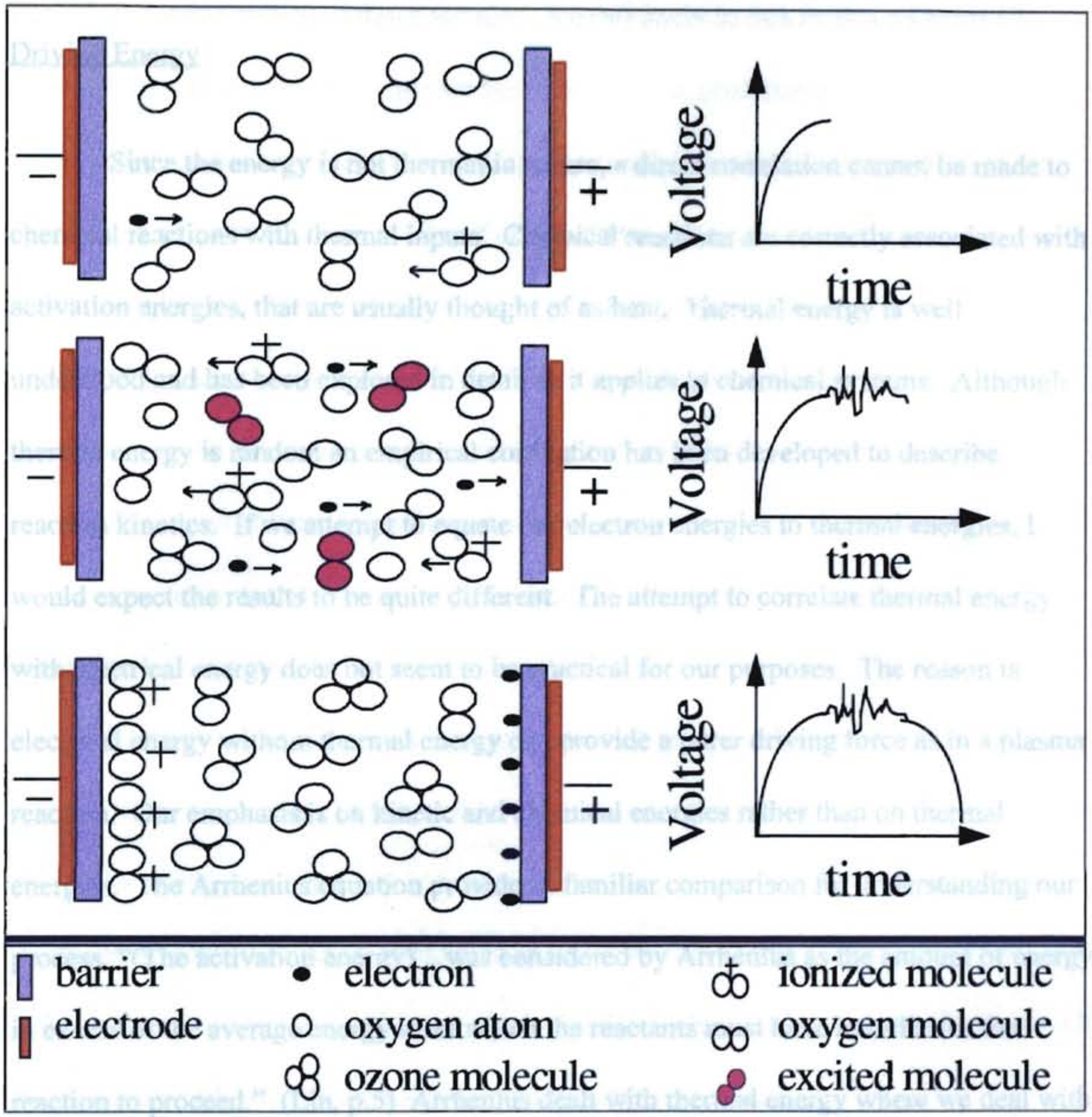

Figure 1. Discharge Cycle -- Ozone synthesis is a simple corona process. In the top drawing, as indicated by the oscilloscope trace (right), a voltage half-cycle is beginning. An electron and ion from the previous corona burst move through the oxygen molecules toward the positive and negative electrodes respectively. In the middle drawing the corona is established. Electrons, ions, and also excited molecules dissociate to form "free radicals" (the oxygen atoms). In the bottom drawing the electrons and ions at the electrodes have damped the corona. Most of the atoms have combined with O_2 molecules to form ozone (O_3). [from Coffman and Browne, p. 92]

Driving Energy

Since the energy is not thermal in nature, a direct correlation cannot be made to chemical reactions with thermal inputs. Chemical reactions are correctly associated with activation energies, that are usually thought of as heat. Thermal energy is well understood and has been explored in detail as it applies to chemical systems. Although thermal energy is random an empirical correlation has been developed to describe reaction kinetics. If we attempt to equate our electron energies to thermal energies, I would expect the results to be quite different. The attempt to correlate thermal energy with electrical energy does not seem to be practical for our purposes. The reason is electrical energy without thermal energy can provide a purer driving force as in a plasma reaction. Our emphasis is on kinetic and chemical energies rather than on thermal energies. The Arrhenius equation provides a familiar comparison for understanding our process. "(The activation energy) ...was considered by Arrhenius as the amount of energy in excess of the average energy level which the reactants must have in order for the reaction to proceed." (Lin, p.5) Arrhenius dealt with thermal energy where we deal with (electrical energy). Actually the energy in a plasma reaction is the result of potential energy from an electric potential being converted to the kinetic energy of charged particles which produces high energy collisions of particles. Our plasma process is very similar to Arrhenius', but our alternate energy transferal process distinguishes our work from his. I would think that, with further study, our plasma systems could be described by an Arrhenius type equation, with temperature substituted by some type of electrical energy, or kinetic energy of the molecules. Further study in this field is addressed by chemists in terms of electron volts for the activation energies associated with excitation levels and ionization levels, but these are not as readily accepted as thermal activation energies. For activation energies based on excitation, one must know the actual energies of the particles within the plasma instead of a well known measure such as temperature.

The ionization process produces the reactive species within a plasma zone, but it would be impractical to attempt to produce ionization without excitation. The electrons within the plasma possess a distribution of energy levels and will collide at random orientations, imparting different levels of energy to the neutral molecule so neither ionization or excitation will be achieved exclusively.

Scientists have known for decades that chemical reactions occur within a plasma zone. These reactions are known to occur because of a reactive species. F.K. McTaggart, the author of Plasma Chemistry in Electrical Discharges, stated that, "Plasma may be produced as a result of the bombardment of molecules by particles of any nature or origin or by quanta of electromagnetic energy, provided sufficient energy is available to provide the required work of ionization and excitation of the neutral species."

The extreme reactivity of a plasma has at times been attributed to ion clustering, but this is probably only a minor factor. Radicals have been shown to exist in plasmas which are most likely the main character playing the role as the reactive species. Whether the formation of radicals is via electron bombardment or via decomposition of an excited molecule is unimportant. The importance issue is that the radicals are a key player in plasma reactions.

One of the greatest aspects of our plasma reactors is the potential to operate near room temperature. Ideally, energy would only be supplied to internal molecular modes without losses to translational energy. "Since the temperatures are low, the reactions are relatively slow and are thus kinetically controlled..." [Safrany, p.99] "The important point is that, even in the low temperature processes, the internal energy that could be used to promote...reactions is converted to undesirable translational energy by secondary processes. [Safrany, p.99]

Plasma for Reaction Medium

Reactions within plasma reactors are often complex in nature.

> Most reactions important in industrial processes are quite complex in nature because their reaction mechanisms are considerably different from the stoichiometric equations. In such cases the reaction mechanisms can frequently be determined by trial and error by postulating that the overall reaction takes place via two or more elementary reaction steps. [Lin p.5]

Three possible ways to use plasma for a chemical reaction are: 1) have the reacting species within the plasma zone, 2) have the reaction occur after one of the species pass through the plasma zone and afterwards combine with a second stream, and 3) have the reaction occur with a species in a different state (maybe liquid) in contact with the plasma, but not within the plasma.

Electrical Representation

It is important to understand how energy is transferred across the dielectric barrier to the gas to create a plasma. It is obvious that energy is being transferred to the gas, but the mechanism may not be so obvious. The first concept to understand is that as long as the dielectric constant is high enough, the wall serves only as an insulator and does not allow any current across the barrier (dielectric breakdown is a destructive process). Thus, it is important that we realize dielectric breakdown of the barriers is not the mode for transferring energy to the plasma. The high voltage actually induces a surface charge across the dielectric as shown in Figure 2 without current crossing the dielectric.

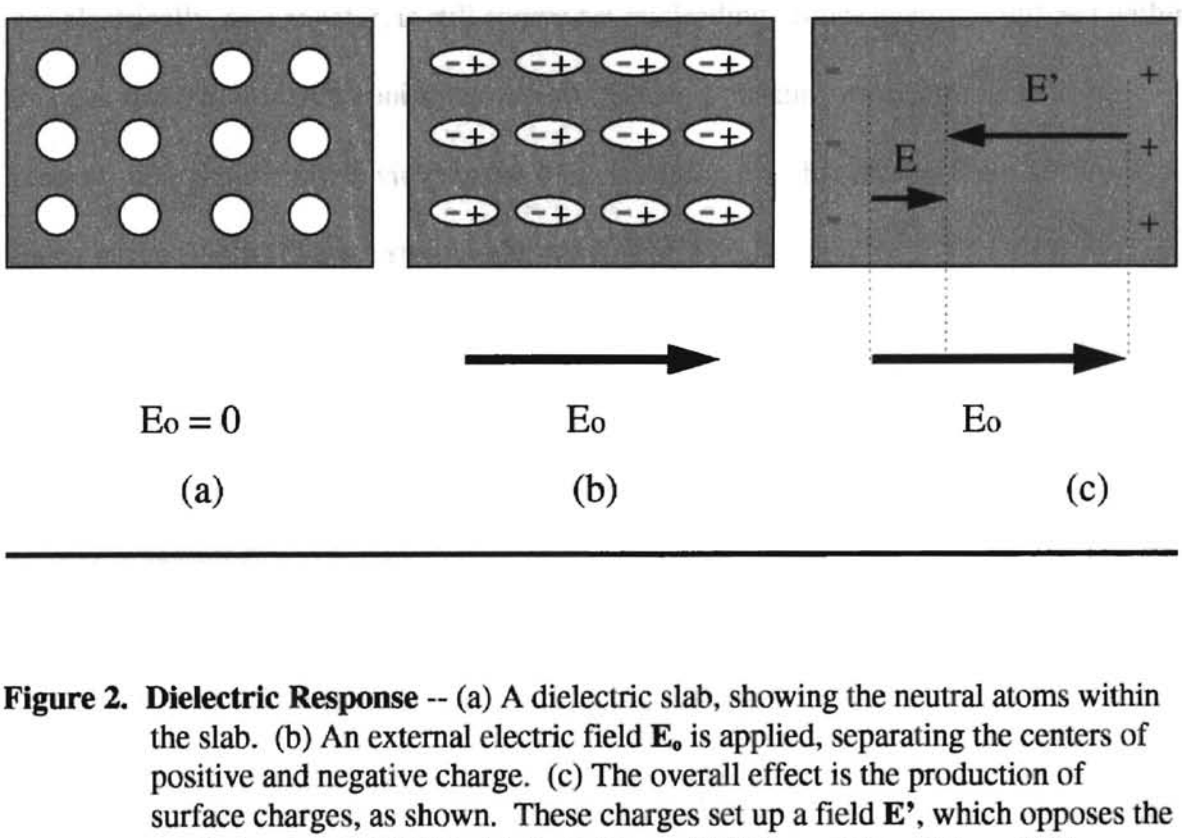

Figure 2. Dielectric Response -- (a) A dielectric slab, showing the neutral atoms within the slab. (b) An external electric field $\mathbf{E_o}$ is applied, separating the centers of positive and negative charge. (c) The overall effect is the production of surface charges, as shown. These charges set up a field **E'**, which opposes the applied external field $\mathbf{E_o}$. [Adapted from Halliday and Resnick, p. 629]

Even though current does not directly cross the reactor walls, this does not mean the discharge does not draw any power, conservation of energy wouldn't allow for that idea. It basically means that there is no direct path for current flow and it thereby eliminates arcing between the electrodes. With an understanding of how the dielectric walls affect the transfer of electricity, we can now consider the function of the reactor in the electrical circuit.

The two dielectric walls of a concentric cylinder plasma reactor each serve as a capacitor. Before the gas is ionized, its dielectric properties provide a third capacitor between the other two capacitors (dielectric walls). As the voltage is increased to a level sufficient to cause a breakdown of the gas, or simply to start ionizing the gas, the gas "capacitor" is now conducting electricity and is no longer a capacitor. To visualize the gas electrically, as a resistor, is still somewhat misleading. Since energy is utilized within this gas space to drive the ionization process (create a plasma), an electronic load is present. The problem with viewing the load as a resistor is that plasma does not follow a linear curve (V=IR) as a resistor would, see Figure 3.

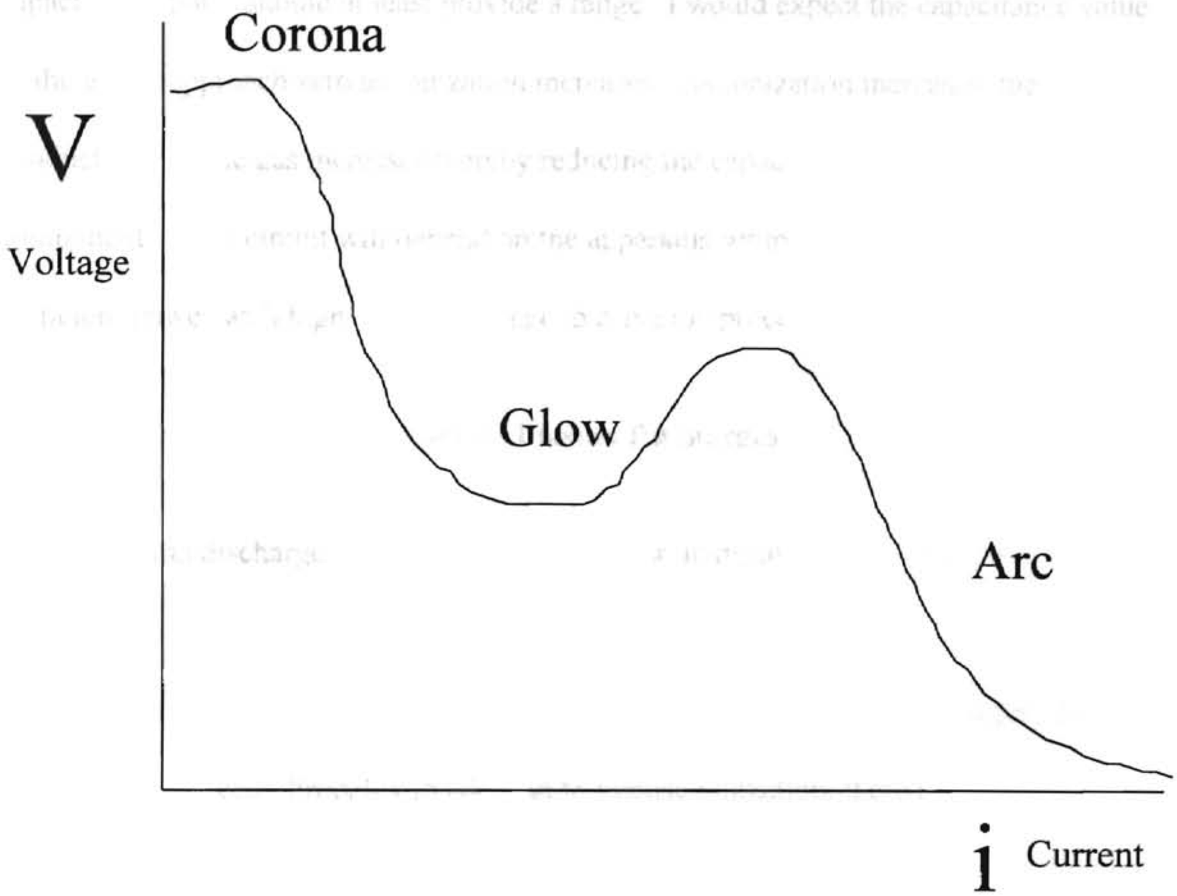

Figure 3. Voltage As A Function Of Current For Electric Discharges -- This is a rough recreation of a sketch by Dr. Jerzy Krasinski (Physicist) which shows that a plasma cannot truly be modeled as a resistor.

Even though the gas can not be measured as a normal resistor, this basic concept relationship serves to show that the gas can be modeled as something with a load between two capacitors. With this idea, one can see that the actual capacitance is going to be near the capacitance of just the two glass walls. This analogy allowed for the approximate capacitance values to be both measured and calculated. By viewing the plasma as a conductor, a resistor with negligible resistance (electrical short), we can just use the capacitance values of the two glass walls in series. This technique may not give the exact capacitance, but it should at least provide a range. I would expect the capacitance value of the gas to approach zero as ionization increases. As ionization increases, the conductivity of the gas increases thereby reducing the capacitance of the gas. The other component, of the circuit will depend on the apparatus setup. Somehow we must have sufficient power with high enough voltage to drive the process.

Various Plasma Discharges

Plasma discharge can be classified as either disruptive or non disruptive.

- Disruptive Discharges -- These comprise the "arc & spark" type discharges. Intense heat is produced. Probably in addition to intense ionization, there is molecular breakdown to almost every type of fragment. Because of this largely uncontrollable behavior, disruptive charges are normally not of great use in the investigation of chemical reactions.
- Non Disruptive Discharges -- These include glow, silent, and electrodeless type discharges.
- Glow Discharges -- A low pressure discharge produced by DC or low frequency AC where the electrodes are in direct contact with the gas. The electrodes can easily become corroded.
- Silent Electrical Discharges -- These discharges include point discharges, corona discharges, and the more uniform discharge associated with ozonizers. These setups also include at least one dielectric barrier to prevent arcing. The first two make use of

the fact that the electric field is much higher near a conductor which has a small radius of curvature. At a point, the electric field may be extremely high, often causing ionization of gases in the vicinity. The term corona is applied when one electrode is a wire, and the other is a metal plate or conducting liquid. Corona is a combination of local intensity as observed in a point discharge and the uniform glow observed in an "ozonizer" type discharge. These types of discharges are often induced at near atmospheric pressures.

- Electrodeless Discharges -- These include radio frequency (rf) discharges and microwave discharges. The rf discharges operate with low pressures, but these discharges have great versatility. Microwave discharges operate with low pressures, and they usually completely destroy substances by pyrolitic decomposition.
- Overview -- The silent electrode discharge (SED) reactor may be the most applicable to industrial scale-up.

> The various kinds of electrical discharges lead to nearly identical results. Therefore, the choice of equipment is not determined by the chemical problem but by questions of flexibility, ease of operation, and cost. High-voltage discharges require the least equipment and may offer the best solution for carrying out reactions on a large scale. For laboratory purposes, radio-frequency equipment is best suited because of its great versatility. [Suhr, page 63]

From a chemical engineering perspective it would appear to be beneficial to work with the same type of system which would be practical for industrial applications. Therefore, although research at OSU is performed in the laboratory setting, I would still recommend using the high voltage-low frequency type of setup. Eventual scale-up should be preceded by research of the same electrical nature as anticipated for industrial applications.

Future Potential of SED Reactors

It would be a little excessive to try and provide a comprehensive list of all of the possibilities for SED reactors, so I will just mention a few. The obvious applications are with the destruction of various contaminates in a gas stream. The unique nature of the chemical reaction mechanism is very well suited for polymerizing reactions which could provide a major future for these reactors. Water treatment is also an extremely promising application. A process could be devised to allow contact of water with a plasma discharge, allowing the transfer of radicals which could effectively purify the water. The application could range from purifying municipal water supplies to substitution for pasteurization. Ozone has already been used for this purpose, but our reactor may improve the process. "Ozone, a potent germicide, is also employed as an oxidizing agent for the destruction of organic compounds producing taste and odor in water." [Taras, et. al., p.271] Regarding the use of plasma, the discharge could be used directly or indirectly by providing an oxidizing agent.

CHAPTER V

PROCEDURE AND DEVELOPMENT

Safety

The first step concerning any experimental investigations should be safety. The dangers associated with our plasma reactors warrant special care. We were located in the Hazardous Materials Laboratory at OSU where the building is well designed and suited for our experiments. The three factors which demanded caution were the high voltage electricity, production of toxic gases, and the possibility of a glass vessel exploding.

Any time electricity is employed in a laboratory setting, extreme caution should be taken. This caution is further warranted by the high voltages. A shock from our system could be fatal. The transformer and reactor are located outside in a blow-out bay. This isolates the high voltage equipment from the controlling and analytical equipment, but it also limits anyone in the blow out bay from visually being able to tell if the system is on or off. I added a switch in the bay that would visually assure a person that the system is off when inside the bay. Just having the power disconnected is not enough to allow any part of the open circuit (including reactor) to be touched. Our reactor is electrically a capacitor and as such, it should be remembered that it could possibly hold a charge. Therefore, I added a few safety features to the circuit to insure no one would be shocked when replacing reactors in the circuit. The first feature is a good ground, insured by driving an 8 foot copper pipe into the ground to which all electrical equipment within the bay was connected. The second is an electrical short produced by contacting the live electrode with the ground using a heavy 04 AWG wire. The contact can be made from a distance via a dry, six foot, wooden rod. This contact effectively discharges the capacitor within a fraction of a second, after which it is safe to touch.

The toxic nature of potential products should be a concern of any experiment. For my experiments, I created a plasma using air, which could produce both ozone and nitrous oxides (NO_X). Both of these products are considered photochemical oxidants and they can cause changes in respiratory mechanics at levels as low as 0.3 ppm. [Christiani, p.20] "...current epidemiological data show that exposure to photochemical oxidants, particularly ozone, can cause bronchoconstriction in both normal and asthmatic people." [Christiani, p.21] With this in mind, I did not want to release exit gas into the bay where it would accumulate and possibly affect the researcher when adjusting anything outside. I released the gas to the atmosphere through a tube emitting the pollutants well away from the bay where they could disperse.

Another safety factor that should be remembered is the possibility of rupturing the glass vessel. This has not occurred, but possible pressure build ups or fatigued glass could cause a rupture with flying glass.

The last safety factor I will address deals with the proximity of the researcher to the reactor setup. Many of the high voltage experiments push the limits of the electrical equipment and the magnetic fields and radiation losses could be quite high. I was able to light a fluorescent bulb in my hand by holding it within six feet of the reactor setup. I would suggest this minimum range be adhered to at all times and that the researcher's presence in the bay be minimized during testing.

Experimental Procedure

In order to achieve my objective, I began working with researchers G. Sidhu and S. Magunta to observe difficulties they were experiencing with the reactors prior to my taking over the research. Due to the fact that electrical problems were not the focus of their research, these occurrences were avoided rather than investigated. Even though I was not taking my own personal data, this was the true starting point of my research which led me to observe many interesting things.

Both researchers experienced electrical difficulties operating their laboratory setup. From their perspective, the main problems could be partially avoided by keeping the secondary voltage below some arbitrary amount where arcing would occur for a given frequency. For most instances, this was simply a limitation on the range in which they could operate their experiments. Other times, they would do such things as trying to insulate something a little bit or adjusting the setup slightly hoping to avoid completely shorting out the equipment. The temporary shorting out of the equipment usually didn't result in any completely detrimental affect, although this may have been a large factor for the destruction of the now defective laboratory equipment.

Being primarily concerned with the chemical reactions, they were more than happy to pass the configurational electrical problems on to me, but this was delayed until they could finish their research. It was essential for maintaining a consistent basis for the research being finished by Magunta and Sidhu that I did not alter the setup which they were using. So before I could make any configurational changes I was allowed to run a few experiments that were intended to confirm some fundamental understanding about plasma and familiarize me with operational procedure. As part of my initial training period, I started plasma type experiments under the guidance of these two researchers which were intended to discourage my ambition for using these reactors with PCB.

The first test I conducted with the plasma research was whether or not a plasma could be created with glass beads in the annulus. I assembled a test vessel, filled it with large glass beads, capped it and then created a plasma, see Figure 4. The inner capped tube was not centered and therefore I had a nonuniform plasma, which was not atypical for this time period. This luminous glow (the visual evidence of a plasma) was enough to establish that a plasma could be created amongst glass beads.

The test with glass beads was the precursor for some future ideas. If glass beads were acceptable then maybe a catalyst or other insulating solid could be used for future research. Dr. Johannes was willing to allow me to attempt to use the glass beads to try and establish a discharge with liquid. Dr. Johannes was relatively sure liquids would not sustain a plasma, but was willing, for purposes of putting the idea of using PCB to rest, to allow me to try with the presence of glass beads. We had previously discussed the idea of PCB and we were in agreement that the reactors would not be practical for PCB if we could not produce a plasma from the liquid state.

I set up reactor C with small glass beads, because the larger beads would not fit in the annulus of this reactor. Runs with air produced bright, acceptable plasma, so I was now ready to try liquids.

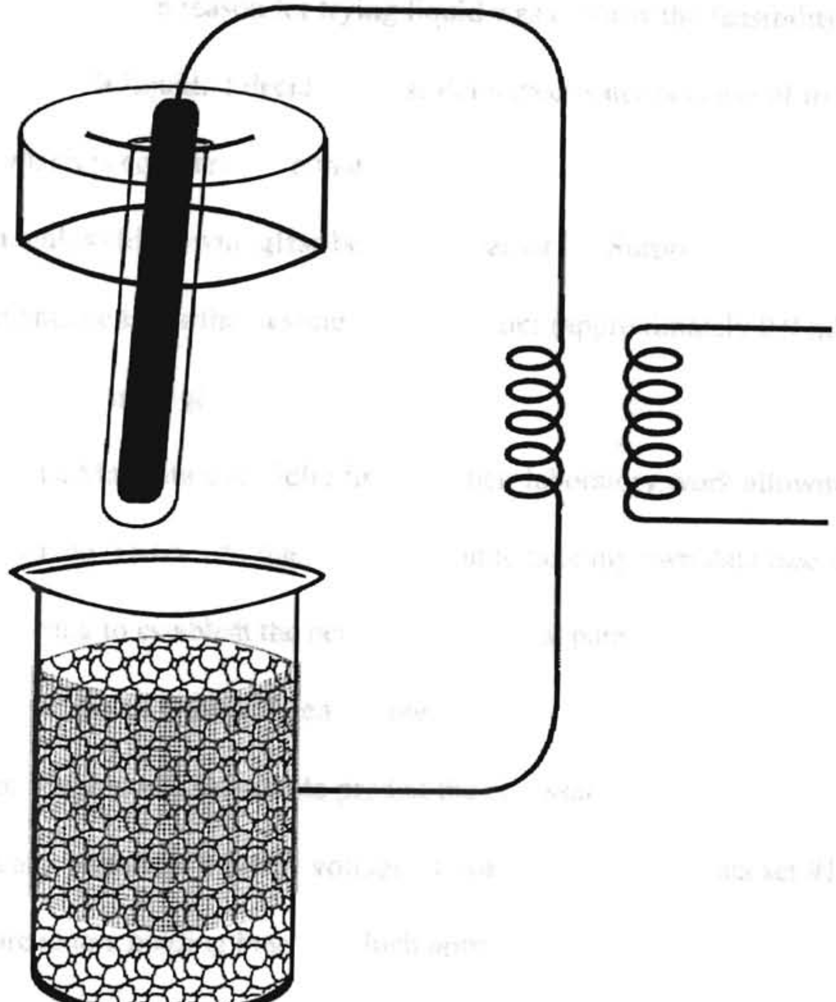

Figure 4. Glass Beads Test Vessel -- Temporary setup used to establish effect of glass beads, used stagnant air without perfectly centered inner electrode.

I was originally very interested in the possibility of creating a discharge within a liquid. I knew that plasma was supposedly restricted from occurring within a liquid, but I could not think of any safety hazards that should keep OSU from experimentally reaching the same conclusion. The main reason for trying liquid was to show the feasibility for using our reactor with PCB liquid. I decided to use deionized water because of its high dielectric constant which is comparable to that of PCB oil. I slowly flowed the deionized water through the annulus (filled with glass beads) of reactor C. Surprisingly, a bright luminous glow was obtained. Further testing with tap water (approximately 0.9 mho) produced a less bright luminous glow.

After these tests, Magunta and Sidhu finished their laboratory work allowing me to alter the setup when necessary. At this point I began to take my own data (see data set #1 in Appendix B) hoping to establish the necessary electrical parameters to tune the reactor. Tuning was a concept that had been adopted at OSU that basically found a peak in secondary voltage which could be used to predict the necessary frequency for producing a plasma at a particular primary voltage. Looking in depth at data set #1, we see that electricity arced to a holding bracket which apparently partially shorted out the transformer. At this time I attempted to eliminate the possibility of this happening again by removing all unrelated objects and insulating all necessary objects.

Producing a plasma from a liquid was an unexpected phenomena, but before I could further investigate their potential for plasma reactions, I had to eliminate the problems with the current setup. It was decided that the most logical approach to getting back to my objective would be to start with the more familiar and well known "non-destructive" tests that produce plasma from air. Previous research at OSU had used "non-destructive" tests to establish the electrical operating parameters for the plasma reactors. "Non-destructive" tests used an air stream flowing through the annulus to measure the relationships between the electrical factors (specifically frequency and voltage) and the formation of plasma. These tests had become the standard preliminary work for plasma research at OSU.

The term "non-destructive" is slightly misleading. The process does still induce a chemical reaction with a significant production of ozone, which is a destruction of air, but they used the term because destruction of air was not a factor in previous analysis. Previously, they were only concerned with the destruction of their compound of interest, giving results in terms of these destruction efficiencies.

As a precautionary measure I completely rewired the system to insure that all meters and gauges were properly setup. Upon commencing my "non-destructive" tests, I began with voltages both below those needed for creating a plasma and for creating the well known plethora of discouraging electrical phenomena. I took typical, non-destructive test measurements while noting anything out of the ordinary for future reference. I then proceeded to run experiments that would increase the voltage working my way into the range where I experienced both more plasma production and more electrical problems.

As I approached higher primary voltages, it became apparent that I must make significant changes before proceeding. The most obvious and easily remedied problems were those between the wire leads and unrelated metal objects in close proximity to the reactor setup. Having previously removed the unrelated objects, I still had problems between necessary items such as the reactor holders and the wire leads. The potential between the wire leads and random objects was still a little disturbing, because it suggested that the wire insulation was ineffective and that this setup was hazardous.

The wire leads that had been chosen were spark plug wires. I actually think this was a pretty good choice, but the very thin wire was hard to connect to the transformer and I thought the small size of the wire could be causing too much resistance for effective operation. Because of this, I looked for an alternative wire lead.

After data set #8, I switched to using a 2 AWG copper wire with an insulation rating of 600 volts. Of course this wire would not provide the necessary voltage insulation for the setup, but it should conduct with less resistance thereby possibly alleviating some of the problem. This wire was also intended to provide a better connection to the transformer. Realizing this wire lead was not perfect, it was temporarily used while a better more appropriate wire lead was sought.

In order to fully grasp electrically the plasma process, I felt that it was essential that I be able to measure both the voltage and current on the secondary side. While switching to the new 600 volt wire leads, I also installed an ammeter in series with one of the secondary wire leads. This was intended to provide secondary current. Looking at data set #9, it becomes apparent that either the secondary voltage or this new secondary current was providing erroneous readings because the total calculated power from these two measurements were approximately 250 times larger than was possible with our power supply. Research into this ammeters capabilities revealed that it was only accurate at 60 Hz and 110 volts, therefore it was eliminated from the circuit before proceeding with data set #10. This brought the rest of the equipment under close scrutiny revealing previous research had been operating outside the range of both the high voltage probe and the transformer. Although desiring to remedy the situation, financial limitations for our project combined with the high prices for proper electrical equipment made this impossible.

Trying to focus on one problem at a time I attacked the question of electrode uniformity before dealing with the equipment problem. It became apparent, see data set #14, that if the electrode was not uniform, then we would have different variations of potential across the reactor which would produce local areas of plasma. In an effort to make a more uniform inner electrode, I initially replaced the roll of copper mesh with copper tubing in data set #15. Replacing the inner electrode with a copper pipe that very nearly filled the entire space available for the inner electrode was relatively easy. I capped a pipe with a standard plumbers cap for copper pipe and then drilled a hole in the top just large enough to wedge bare wire from the wire lead into the hole. I could not replace the outer electrode with a similar replacement because of the nozzles on the sides of the reactor. I was also hesitant to use any outer electrode which was not at least semi-transparent because it was important for my research to visualize the plasma.

For safety reasons, the reactor setup did not lend itself well to visual observations. The major problem was that it required physically leaving the building and entering the bay to make visual observations. This required leaving the power supply and controls unattended. Therefore, I decided to set up a better observation method using a video camera and monitor to allow observation from inside. To test the setup, I recreated the plasma with the glass beads and the liquid as was done in the past. The plasma discharges were not visible to the camera. While testing the video camera setup, a surprising observation (the outer lead was left unconnected and plasma formation still occurred) was recorded in data set #17 that led to tests that were intended to better analyze our electrical setup.

Even though the production of a plasma with only a single electrode attached was interesting, I first returned back to completing the work with the water to try to establish a bright enough plasma for camera observation. After data set #19 I decided that the camera setup would not work, discouraging further endeavors into this area at this time. I then went back in data set #20 and tried to recreate the plasma with only one electrode attached (repeat data set #17) to satisfy my curiosity. The only difference was this time there were no beads. Again, there was some type of plasma type activity, but it appeared to originate from the small space surrounding the inner electrode. Also, electricity from the abandoned wire lead arced to a random nail in the wall. So the secondary lead was, again, a concern.

I found a 2 AWG wire with an insulation rating of 15 kV which we decided to use for the secondary wire leads. The 15 kV rating was twice as high as the transformer rating, so this wire seemed promising, despite being bulky and difficult to bend. With the new 15 kV wire leads attached I returned again to test with air only to now be hindered by end effects. I made a major effort to insulate the ends of the reactor with special putties to limit the potential for electrode to electrode interaction that appeared to be occurring around the top of the reactor, which was bypassing the plasma zone. I ran stagnant air tests and observed weird end effects, similar to arcing, that persisted in the bottom of the reactor. Examining the reactor, after data set #22, revealed a cracked bottom.

Having discovered one defective reactor, I thoroughly studied each reactor for defects. I found pin hole size piercings that had penetrated straight through both dielectric walls. One older, previously destroyed reactor was likewise pierced with a black scar remaining from where the arcing had penetrated the walls. I had the reactors repaired and I proceeded with my experiments. But this observation brought to light the importance of minimizing hot spots. A hot spot was a result of an increased potential at one location in the reactor compared with the rest of the plasma zone. To avoid hot spots, it was obvious we needed more work on finding the most uniform electrode system.

Attempting to minimize the uninitiated variance of the primary voltage, I tried making equipment changes with the oscillator in data set #28, but the use of this oscillator for my work was short lived because the original equipment was easier for my application. In data set #29, I began tracking the effect of airflow through the reactors. I started making more observations as to how airflow could affect the formation of plasma. It had previously been thought that airflow (hydrodynamics) would not affect the plasma.

At this point, my research took an alternative route to test the need for dielectric walls. This was partially spurred by the time period it took to get the reactors repaired from the piercings and cracks. Data sets #31-#43 are a mix of various temporary plasma reactor setups created either without both or without one dielectric wall.

Being very unsatisfied with the ability to effectively analyze the plasma reactor system effectively, I began work to reduce as many unknowns as financially possible often acquiring the equipment from other OSU departments. I introduced an oscilloscope in data set #44 which provided a trace of the sine wave on the secondary side. This also provided checks for frequency, and secondary voltage, along with a check for the distortion of the sine waves. Before data set #46, I installed both an ammeter and a voltmeter to regulate the overall system power including the power supply. These were relatively easy because the main electrical power was at the standard 120 volts, and 60 Hz condition. It was becoming apparent that the transformer had shorted out significantly and would not be sufficient for future work, so I replaced the transformer with an identified replacement. With confidence in the direction the analytical components of the apparatus were proceeding and lacking more money for further improvements, I returned to improving the physical setup.

After replacing the transformer, I quickly tested the new setup and found it to again be sufficient for producing a plasma. The Fluke high voltage probe, seemingly coincidentally, shorted out when I began to test the new transformer. Having a replacement probe in the lab, I opened the new package and discovered the probe was only rated for 60 Hz operation. It had appeared that these probes previously worked, but the validity of the main testing apparatus was now in jeopardy. After consulting the Technical Engineers for Fluke, I learned the probes should not be operated in our frequency ranges for safety reasons. The probe could potentially short and become a conductor of electricity.

I spent a considerable amount of time searching for both an affordable and applicable probe for my research, and I settled for a Hewlett Packard probe that would work for my lower voltage operations. I was unsatisfied with operating components outside their manufactured range and had I wanted to advance to a system that could operate at the normal 60 Hz specified for most off the shelf electrical wiring and equipment. I had made enough observations to realize our power supply had many shortcomings when operated below 100 Hz, so I setup a circuit to use a Variac for producing a plasma at 60 Hz. Upon arrival of the new Hewlett Packard probe, I had a temporary test vessel ready to be tried for producing a plasma with the Variac and this was the first use of the new probe, see data set #49. This first attempt to use the Variac did not produce a visible plasma. Because I had just received the new high voltage probe for purposes of properly measuring across frequency ranges, the experiments to use the constant frequency (60 Hz) Variac were delayed. The first successful use of the Variac in data set #59 spurred my interest for the potential of a constant frequency power source. I modified the electrical setup to allow for quick subsitution of either power supply into the circuit and I alternated use of the Variac with the variable frequency California Instruments power supply for subsequent work..

Before discovering the success of using the Variac, I used the probe to provide data (see data set #53) for a particular setup which had been surprisingly unsuccessful. I had created a container allowing tap water to serve as the inner and outer electrodes for the reactor, but for some reason I could not produce a plasma with this setup.

Such things as insulating the ends of the reactors and reducing the length of the electrodes from both ends attempting to minimize end effects had only been partially successful. These types of solutions were helpful overall, but they did not eliminate the perverse electrical phenomena seemingly produced due to the nonuniformity of the electrodes or from the attachment to the secondary leads. Theoretically I was convinced liquid electrodes would eliminate the majority of the electrical problems and in data set #53, I attempted to use liquid electrodes made from tap water hoping they would solve the electrode problems and provide the means for producing a good uniform plasma. I initially used tap water for the electrodes, but after this did not produce a bright uniform plasma I added salt to the electrodes to increase the conductivity to 36 mho. It was not until the introduction of propylene glycol electrodes in data set #54 that some sign of hope for the use of liquid electrodes was developed. I continued with liquid electrodes for the remainder of my experiments.

Most subsequent work involved the use of the liquid electrodes and the bulk of these experiments were captured on video tape. A newer, better video camera could picture the plasma clearly and this made observation more clear. This is encouraging for future research at OSU, because of the enhanced observation abilities, but it was too late in my research for me to take full advantage of this new capability.

Trying to create a longer plasma discharge zone I used silicon to fuse the bodies from plastic 3 liter bottles and this contained the outer electrode. In data set #69, the intensity of the plasma produced was very high and visible lines of intensity were recorded both visually and with the video camera. The Hewlett Packard probe shorted out during this run. I continued these experiments with the Fluke Probe observing heat buildup within the liquid electrodes and the extension of the plasma above the outer electrode level. It wasn't until the observation of sparks from a dripping outer electrode that the electrical configuration was rethought.

In data set #82, I grounded the outer electrode putting the outside of the reactor and container at the same potential as the surroundings. Grounding the outer electrode only allows for half the windings of the transformer to be used for producing a plasma. I continued switching between the tests using the California Instruments power supply (variable frequency) and the Variac (60 Hz only).

With a center tap transformer, I was limited to using half of the windings. I then pushed for getting an appropriate transformer, only to be partially successful. The Central Rural Electric power company donated an end taped transformer, but it only had half the voltage potential of the previously used transformers. The last experiments were with this power company transformer. Data set #84 is the first experiment with this new transformer and this was the setup with which I ended my research.

CHAPTER VI

RESULTS

The results of my research with the Silent Electric Discharge type plasma reactor at Oklahoma State University (OSU) show great promise for industrial applications in the future. My research shows there is the possibility to use pressure above atmospheric with solids or liquids in the presence of a silent discharge to serve as an effective chemical reactor. The proper electrical configuration is crucial to the eventual scale up of these reactors, as could be expected by the intense electrical nature of the process.

Each data set with each individual data analysis is presented chronologically in Appendix B, so I will not duplicate the specific data analysis in this section. This section will present a categorized overview of the observations from my research.

<u>Glass Beads</u>

The tests with glass beads show that a nonconducting solid could be used within the plasma reactor. The glass beads were directly introduced within the plasma zone as both a packed bed and as a fluidized bed without electrically hindering the process. One of the early experiments resulted in two wedged beads within the annulus which were discovered later while examining the reactors for defects. There was no way to tell if the beads become wedged from the process of filling the annulus or from thermal expansion, but fused quartz expands much less than glass with temperature change. These two wedged beads may provide a reason to consider thermal expansion for any solid put into the reactors. The fluidized bed technique recorded in the last data set appears to be very effective, the glass beads rolled and tumbled around while the air continually lifted them off the bed of beads. Bright acceptable plasma was created in the presence of glass beads, as shown in Figure 5, without any noticeable side effects.

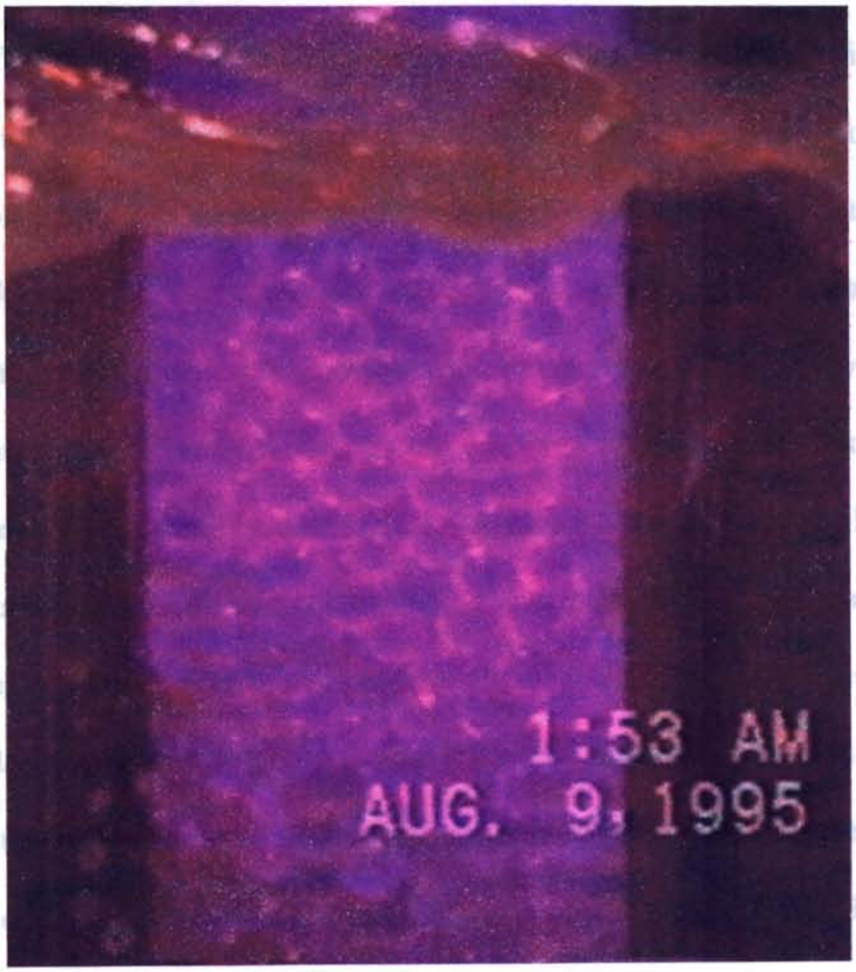

Figure 5. Plasma In The Presence Of Glass Beads -- This picture is from data set #89 where air flows through the annulus of reactor B. The smudge across the top of the picture is the silicon that holds the outer electrode container together.

Wire Leads

Replacing the secondary wire leads from the transformer to the reactor required some consideration. At this location in the circuit, we often have high voltages with frequencies causing the "skin effect". The "skin effect" is a phenomenon that occurs at frequencies above approximately 400 Hz where electric current only travels on the outside surface of wire. A multistranded wire with each strand individually insulated would provide less resistance to current flow at our frequencies if it wasn't for our high voltage application. The insulation would be ineffective for separating the strands at our voltages. For our applications only the size of the total wire strand was important, with solid wire preferred for conduction purposes and stranded wire for flexibility. The wire size determines the amount of current the wire can carry. Because of the "skin effect" this size should be overcompensated to avoid resistive build up in the wire. For our experiments the 2 AWG wire was excessively over-sized to minimize resistance.

The first experiments, through data set #8, used spark plug wires for the secondary leads. The spark plug wires were not a poor choice, but the small conducting wire made the leads difficult to attach to the transformer (the conducting wire was small and would easily break). Suspecting a part of the electrical problems could be stemming from the small size of the wire (increased resistance) and realizing the insulation was ineffective, I temporarily substituted 600 volt insulated 2 AWG wire. As expected, corona formation between the wire lead and outside objects was observed in data set #20 reinforcing the idea that the insulation level was still inadequate.

In data set #21, I introduced 15 kilovolt insulated 2 AWG wire and I thought this would be more than adequate insulation. For 60 Hz the applications these wires would insulate up to 30 kilovolts for the setup used, but the bulk of the experiments used higher frequencies. I used these leads throughout the rest of my experiments, but corona formation between the leads and the ground were commonplace. Understanding the shortcomings of the wire, I did my best to isolate the leads.

Dielectric Walls

Questioning the necessity of dielectric walls for creating a uniform plasma, I tested the idea with temporary reactors I assembled for this specific purpose. I first built a test vessel with no dielectric walls, see data set #31, which was simply a copper pipe with a wire down the center. The setup was as concentric as possible, but it did not work to establish a glow. I attempted other similar setups, data sets #31-#40, but the vessels without dielectric walls could only produce plasma arcs and this was not acceptable for my research.

In data set #41, I began tests with single dielectric wall vessels. I felt a single dielectric wall would prevent arcing and I wanted to see if a single dielectric wall would suffice for producing a glow. The test vessels which I made were similar to before, but I insulated the inner electrode with Tygon tubing. It was difficult to determine if a plasma was created because I could not effectively see within the pipe. Data sets #41-#43 produced a cracking sound and hissing which could not be easily distinguished.

In data set #49, I tested a setup using plastic pop bottles with a copper pipe down the center and wire mesh wrapped around the outside. These vessels produced a semi-arc type discharge which danced around the open space in the center. In data set #51, I used a smaller bottle and slipped a Tygon tube over the bare copper pipe to see if the newly created second dielectric barrier would allow for a glow discharge, and it appeared to work momentarily. These were just flimsy test vessels, but they did suggest that two dielectric walls would help for creating a uniform glow discharge. It is possible that the outer wall (plastic container) was too thin to serve as an effective dielectric barrier.

Electrodes

Some of the previous work at OSU, and a few experiments, had been performed with a loosely spaced coil of wire serving as the outer electrode and these experiments actually produced the slightly different Corona discharge. Attempting to complete the transition to the uniform SED required electrode uniformity. Evaporated silver electrodes had been previously used and these electrodes worked well because they formed uniformly to the glass, but they did not allow for easy visual inspection of the annulus. Mesh wraps of copper provided for convenient visual inspection, and could closely follow the curvature of the glass walls.

Part of the problem using wire mesh involved connecting the mesh to the electric lead. At one stage of data set #7, the only point of visible glow was located in the annulus, but at the connection between the outer electrode (copper mesh) and the secondary lead (spark plug wire). Another problem with mesh, was that it was wrapped around the reactor meaning an edge always existed at the start and stop of the wrap. This small edge would seem insignificantly different than the rest of the mesh, but in data set #9 I could tell a slight discharge was actually forming along an edge of the inner electrode. In data set #14, points of glow along the outer electrode edges were observed.

Trying to improve uniformity, I replaced the inner roll of copper mesh with a copper pipe in data set #15. In data set #19 I observed that a glow was emitted from the air space around the inner electrode. Problems with this electrode setup persisted, but it was not until data set #53 that I tested a new electrode setup. In data set #53, I attempted to use saltwater to serve as both the inner and outer electrode and I was unsuccessful for producing a plasma.

In data set #54, propylene glycol liquid electrodes were used to create a plasma that extended well above the outer liquid electrode level. Attempting to use longer plasma zones, I diluted the outer liquid electrode with water and the electrodes remained effective. It was not until data set #69 that a problem with the outer diluted propylene glycol electrode was observed. End effects within the outer liquid pulsed as if a discharge was occurring within the liquid near the end of the container near the ground. There was obviously an electric potential between the ground and the outer electrode.

Using pure propylene glycol electrodes, see data set #72, the end effects were minimized and extending bright plasma was created with the glow extremely well above the outer liquid level. It was not until data set #74 that tap water electrodes effectively produced a plasma. In data set #76 I observed the tap water electrodes temperature did not increase significantly within the operation. Decreasing the resistance of the electrodes with salt helped to keep the plasma from extending above the outer liquid level.

Data set #80 exemplifies the worst outside electrical effects that occurred with the liquid electrodes. Drips from the outer electrodes sparked when making contact with the base and actually started a small fire on the table. The extreme negative electrical aspects were removed in data set #82 when the circuit was changed to a grounded outer electrode configuration.

Grounding Reactor

Grounding the outer electrode was quite possibly the most important change made to the reactor setup. With proper choice of transformers, grounding the outer electrode only improves the setup. Grounding the outer electrode essentially matches the potential of the outer shell with the surroundings. This setup provided an enhanced safety factor while eliminating the outside effects.

Well before the use of liquid electrodes, one of my experiments, data set #17, created a plasma with the outer electrode removed from the wire lead. This phenomena provided the original base for grounding the reactor and is explained thoroughly in the subsection about grounding the outer electrode in Chapter VII - Conclusions.

It was not until data set #82 that I first purposely implemented a true outer electrode ground. This change to the electrical circuit does not have any negative attributes when operating with a properly configured transformer as in data set #84.

As previously mentioned in regards to the liquid electrodes, in data set #82, the first leak was experienced with a grounded outer electrode. It can be seen in Figure 6 that a bright plasma was produced while a puddle of the liquid from the outer liquid electrode was formed under and to the left of the reactor. Previously without a grounded outer electrode, leaks produced violent sparks and temporarily electrically shorted the system. Leaks with the grounded electrode did not have any effect because the outer electrode was already at the ground potential.

Figure 6. **Plasma With Grounded Outer Electrode --** An example from data set #84 of a grounded outer electrode with the container resting in a puddle of the leaked outer electrode contents.

Tuning

The concept of "tuning" the plasma reactors was addressed throughout my experiments and plots are included with each appropriate data set. Previous research of OSU had used "tuning" to predict the operating parameters for the reactors. The typical tuning plots were supposed to graph like the plot in Figure 18 with the intensity of the plasma coinciding with the peak in the curve, but this was not a common observation of my research.

As early as data sets #4 and 5, multiple resonance peaks were observed. Plasma intensity often did not coincide with the highest voltage plotted. Data set #10 exemplifies a plot where the high voltage previous to the resonance peak did not produce a plasma, but yet plasma was formed as predicted through the resonance peak. Data set #11 is another example that apparently follows the predicted trend, but the plasma did not remain through the second resonance peak even though there was an increase in voltage. First glance of data set #17 appears to be exactly the predicted trend, but the plasma exists on the curve approaching the peak and ceases before the peak where the maximum intensity should be observed.

I observed experiments where the second resonance curve was much higher than the first, and yet the plasma did not continue through the peak of the second curve. Data set #58 is an interesting plot because the plasma started near the peak of the first curve and was observed on the second curve, but the plasma dimmed with increase in voltage.

The last of my experiments used a drastically different type of transformer and the curves appeared to be approaching a "tune point" above the limitations of the power supply. In data set #84, the intensity of the plasma produced increased as the frequency approached the higher frequencies.

Transformers

The luminous tube transformers were not perfectly suited to our research. They worked rather well when new, but they slowly lost their effectiveness with continued operation. It appears that operating with a "skin effect" built up resistance and therefore heat, which caused coils to fuse together reducing the number of turns until they finally shorted. The transformer from the power company seems to work well except for the high frequencies necessary to establish resonance. The peak point for resonance was never reached, see data set #86. The secondary voltage continued to increase all the way to the frequency limits of the power supply.

Power Supply

Both the California Instruments power supply with the adjustable frequency and the Variac were capable of producing plasma. The Variac was capable of producing plasma only when it approached the 120 volt limit, see data set #59. The power supply was better suited at the time of the experiments because we could tune the system by adjusting frequency. I attempted to use the BK Precision oscilloscope, in data set #28 in place of the California Instruments oscillator, but I found the BK Precision brand was too hard to control.

Probes

The original high voltage probes used were not satisfactory for measuring at frequencies above 60 Hz. Replacing the Fluke probes with Hewlett Packard probes, in data set #49, greatly improved analytical capabilities. At increased frequencies the Fluke 80K-40 were nowhere near the values obtained with the HP probes. Along with the probes, erroneous watt meters and ammeters were removed that were not configured properly for use with the increased frequencies.

Residence Time

Without product analysis, the effect of varying residence time is hard to determine. It was easier to electrically try to analyze the effect of varying the plasma length. It was difficult to assess, but it appears that an increase in plasma zone length is proportional to total power required.

Pressure

Even though pressure dependence was not thoroughly investigated, I was able to maintain a nice uniform plasma with pressures ranging up to approximately three atmospheres with the use of liquid electrodes. It was possible to eliminate the silent discharges by greatly increasing the pressure, but this should be expected.

Plasma From Liquid

All observations concerning the production of plasma with liquid in the annulus are uncertain. The electrode configuration used could have produced the plasma from air occupying the void space around the electrodes.

CHAPTER VII

CONCLUSIONS

Developing the plasma reactors for research and future industrial applications proved to be quite a challenge. I found many limitations that must be addressed before some of the final design parameters can be established, but enough has been done to warrant a good conceptual design to be used in future research at OSU. This chapter contains an explanation of the results in order of importance followed by the conceptual design of the plasma reactor.

Explanation of Results

Grounding Outer Electrode

The circuit used for the plasma reactor setup is important. The initial electrical setup at OSU was plagued by negative electrical effects. Grounding the outer electrode changes the setup only slightly (schematic shown in Figure 7), but the improvements are of utmost importance.

Tracing the electric potential for the initial electrical schematic helps anticipate problems between the high voltage electrode and the surroundings. Where an electric potential existed between the reactor and any object of close proximity for the initial setup, the circuit with the grounded outer electrode is electrically neutral to

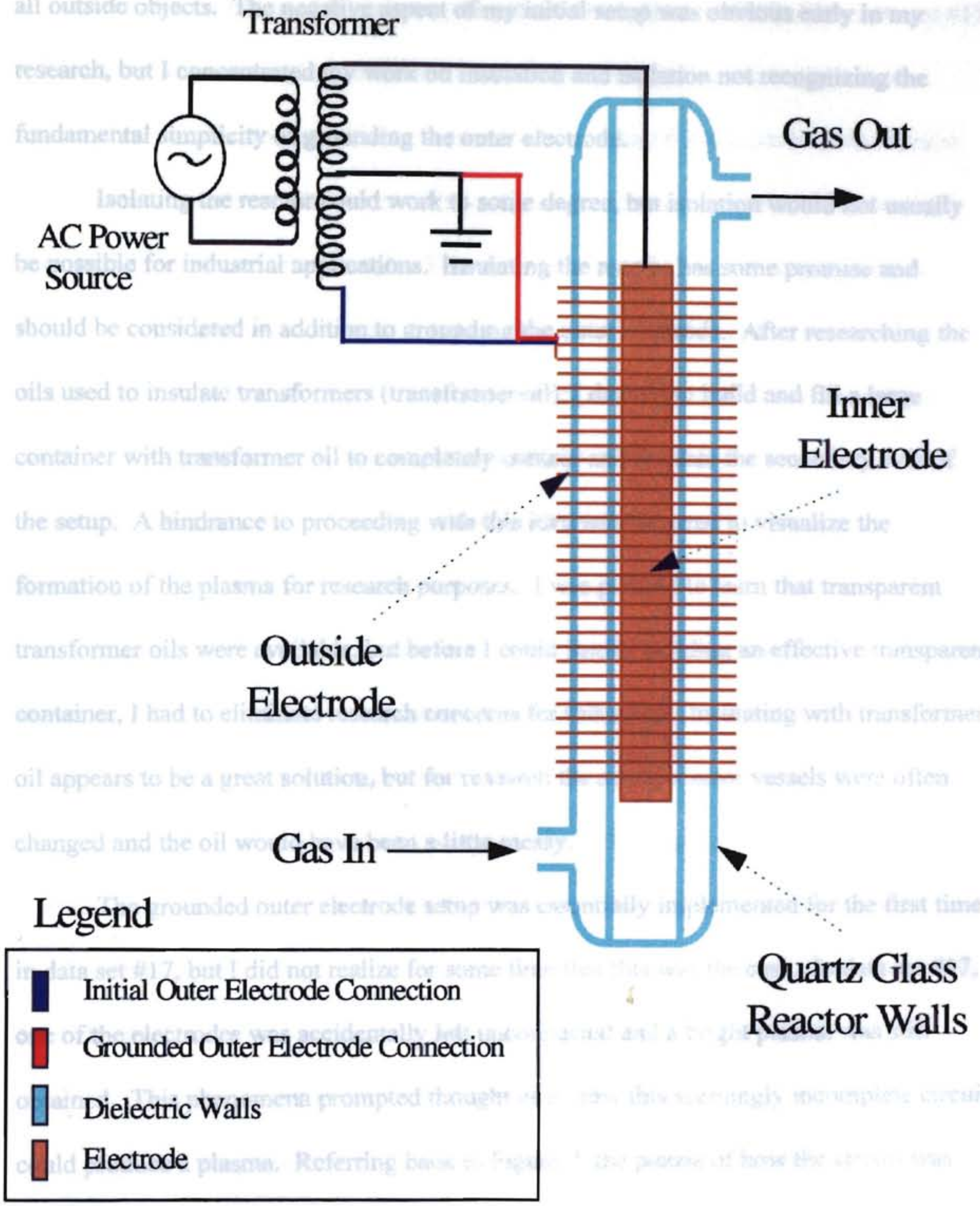

Figure 7. **Electrical Setup** -- The alternating current power source allowed for adjustment of both frequency and primary voltage. The transformer was center tapped (grounded at the center of the windings) and is not optimized for a grounded outer electrode.

all outside objects. The negative aspect of my initial setup was obvious early in my research, but I concentrated my work on insulation and isolation not recognizing the fundamental simplicity of grounding the outer electrode.

Isolating the reactor could work to some degree, but isolation would not usually be possible for industrial applications. Insulating the reactor has some promise and should be considered in addition to grounding the outer electrode. After researching the oils used to insulate transformers (transformer oil), I desired to build and fill a large container with transformer oil to completely contain and insulate the secondary side of the setup. A hindrance to proceeding with this idea was the need to visualize the formation of the plasma for research purposes. I was pleased to learn that transparent transformer oils were available, but before I could justify building an effective transparent container, I had to eliminate research concerns for this setup. Insulating with transformer oil appears to be a great solution, but for research the actual reactor vessels were often changed and the oil would have been a little messy.

The grounded outer electrode setup was essentially implemented for the first time in data set #17, but I did not realize for some time that this was the case. In data set #17, one of the electrodes was accidentally left unconnected and a bright plasma was still obtained. This phenomena prompted thought as to how this seemingly incomplete circuit could produce a plasma. Referring back to Figure 7, the puzzle of how the circuit was completed can be explained through a grounded outer electrode. Great electrical insight was gained through this mishap and the thoughts which this instigated served to develop the grounded outer electrode circuit.

When I investigated this puzzle, the pieces fit together perfectly. For data set #17, I flowed tap water through the annulus. I was suspicious of my observations that appeared to create a plasma with tap water. Understanding the plasma process, I knew that a plasma was the result of converting a dielectric material from a non-conducting state to the conducting plasma state. Tap water was initially a conducting substance, so I did not expect a plasma formation. I recreated the setup with the outer electrode not attached and without glass beads in the annulus in data set #20. Without the beads, I could tell the luminous glow was emitting not from the annulus, but from the small space around the inner electrode. With this new observation, I was eventually able to identify this missing connection for the circuit.

The tap water was the missing connection. At this phase of my research, the center tap for the transformer had been wired to the plumbing to insure a good ground. The plumbing from where the tap water flowed was grounded. The conductivity of the tap water insured a good ground was provided within the annulus of the reactor. This annulus ground completes the circuit the same way as the grounded outer electrode configuration shown in Figure 7. The inner electrode is identical; the plasma was created from the air directly around the inner electrode (only one dielectric barrier), and the annulus essentially served as the outer electrode for this setup.

I placed the grounding of the outer electrode as the most important of conclusion because it introduces a safety factor. Theoretically if someone touched the outside of the reactor while operating, there would not be any effect because both the person and the outside of the reactor are at the ground potential. Data set #82 confirms the advantage of grounding the outer electrode with the example of the leaking electrode that did not cause any observable electrical effects, see Figure 6.

Electrodes

The original electrodes that consisted of wraps of copper mesh stuffed into the space for the inner electrode and copper mesh or a coil of wire spiraling up the reactor serving as the outer electrode were frustrating because of arcing at the ends and within the reactors. The cracks and burn through holes brought to light an interesting problem we were experiencing due to local effects. The local effect could be seen during almost any experimental run, and the problem with localized areas of intensity could only be solved with a more uniform setup.

This setup appeared to work much better than the previous reactors, but the luminous glow originating within the air between the inner electrode (pipe) and the inner glass wall made it difficult to determine if a plasma was formed in the annulus. I realized that if we were to concentrate all discharge to the annulus, I would have to isolate the air from the electrodes.

A previously used method at OSU for producing a uniform glow had previously been used by Tsai. He used an evaporated silver paint to form the electrodes on the glass. Electrically, this was a great idea, but for my work it was not practical because these electrodes are not transparent. My work used visual observations to determine the presence of a plasma and therefore the electrodes of choice needed to be at least semi-transparent. I tried using mirrors to set up a top end view of the reactor, which by changing the viewpoint possibly wouldn't require transparent electrodes, but this was not extremely effective.

Using a transparent conducting liquid to serve as the electrodes seemed like a logical choice because the liquid would completely fill the space against the wall, eliminating any air gaps and providing a uniform electrode. The first attempt to use liquid electrodes was a fiasco. I tried to use a salt-water solution to serve as my liquid electrodes, but the outer electrode was not grounded and therefore this was unsuccessful. At the time I hypothesized that the electricity served to drive a corrosive chemical reaction because of the wear on the copper secondary lead where it was submerged in the liquid electrode to make the electrical connection. I now realize this was not the reason , but it did coincidentally serve to help me think of a liquid that would work with the present electrical circuit.

I attempted to use antifreeze (propylene glycol) to serve as the liquid electrode because it was available at the time and I did not expect it to promote a chemical reaction between the wire lead and the liquid electrode. For the first run, I assumed the conductivity of propylene glycol was high, and I was therefore not surprised when the liquid electrodes worked. The surprising thing was how well the reactor worked.

The reason the propylene glycol worked was because it did not conduct electricity very well. Because the liquid did not conduct well an intensity gradient was established from top (where the secondary lead made contact with the electrode) to bottom. The poor conductivity of the electrode results in a lower potential in the bottom of the container thereby reducing end effects between the electrode and the ground. I checked the

the resistance of propylene glycol and it was much higher than tap water. The electrodes were also very warm after operating suggesting heat build up due to resistance.

Further support for my conclusion is provided by Figure 8, where the plasma extends far above the outer electrode due to the intensity gradient. This was originally mistaken for increased intensity because the dark green antifreeze was difficult to see through. Figure 9 shows the visible lines of intensity within the plasma that extended above the outer liquid electrode. These lines are always present, but they are elongated and oriented vertically because of the developed potential gradient; normally these lines would cross straight across the annulus.

Figure 8. **Reactor B With Ungrounded Propylene Glycol Electrodes --** The plasma formation in the annulus extends above the outer liquid electrode due to the potential gradient from the top to the bottom of both the electrodes.

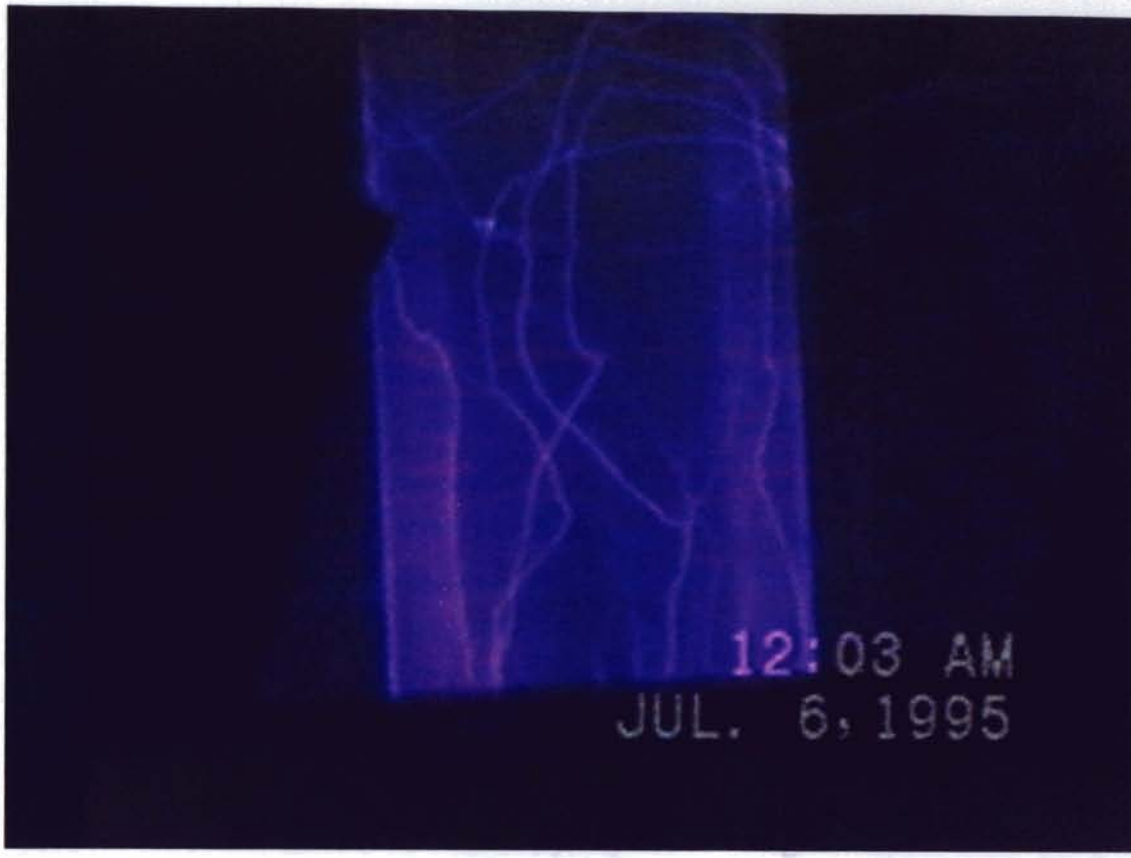

Figure 9. **Plasma Extending Above Outer Liquid Electrode Level --** The liquid electrodes (propylene glycol) did not conduct very well resulting in the extended plasma.

I kept diluting the propylene glycol and it kept working, so much that it became apparent that tap water should work as the liquid electrode. I measured both the conductivity of tap water and propylene glycol and I found that the conductivity of the tap water was about ten times higher than the propylene glycol.

A return to using a water electrode worked as I had previously thought it should, but the end effects were still present until I grounded the outer electrode. I tried the addition of salt to increase conductivity of the liquid and this also worked. The better conducting liquid electrodes produced plasma that was uniform throughout the range of the liquid electrodes, not extending above the outer liquid level. The choice of the electrodes should not be important as long as it conducts well, completely and uniforms adheres to the walls of the reactor, attaches easily to the secondary leads, and does not corrode the secondary leads.

Dielectric Walls

The temporary reactors I created for testing the need for dielectric walls were too crude to serve as a vessel for a uniform SED. Other forms of discharge were created, but the test vessels left much to be desired. Inadvertently I did operate a setup that proved that both dielectric walls are not necessary to prevent arcing. When the outer electrode was unhooked (data sets #17 and #20), the liquid I flowed through the annulus served as a grounded electrode. I produced a bright plasma from the air around the inner electrode with only one dielectric wall between the electrodes.

Looking back on all experiments with tap water flowing through the annulus, I realize these are actually single dielectric wall setups. When both electrodes were connected, it was equivalent to having two of these single dielectric reactors in parallel. In these setups, the tap water flowing through the annulus was only the grounded electrode.

The dielectric walls serve two purposes for the plasma reactors. First of all, they separate the electrodes from the material in the annulus. Secondly, they prevent arcing between the electrodes.

Tuning

Graphs of my data do not consistently follow the predicted "tuning plot" as predicted by past research at OSU. Harmonics are prevalent, but I contend that these are not based on the actual plasma. Rather, these harmonics are primarily based on the electrical equipment. These plots are equipment sensitive, changing the transformers completely changes these tuning plots. This had been assessed to matching the capacitance of the reactors to the inductance of the transformers, but this is not the main factor for these tuning plots.

To explain the results effectively for tuning, a more advanced analytical system is needed. These tuning plots do not present the entire picture. As an example, Figure 71 is a graph of a somewhat predicted tuning curve. These graphs can be deceiving. Notice the plasma formation ends with increase in voltage, which is not expected. The unseen factor is the secondary current is decreasing with increase in voltage due to either a lack of available power from the power supply or a saturation of the transformer. I suspect the latter explaination based on inherent problems with operating above design conditions. This is an anomaly due to frequency.

By setting the frequency constant (i.e., data set #64), the increase in voltage only serves to increase the intensity of the plasma as expected. The need exists to operate at a standard 60 Hz or with equipment that has sufficient power to produce acceptable plasma.

With a good understanding of the mechanism for producing the plasma discharge, the mystery of frequency is minimized. The main effect of frequency on the actual discharge is the number of discrete discharges that occur per second. The extreme variations experienced with the discharge in relation to the frequency at OSU are completely setup and equipment sensitive. These effects are nothing more than resonance effects.

Lacking an optimal setup at OSU, we are forced to vary frequency to take advantage of harmonics to push our equipment to operate better than intended. This form of operation is very complex because it encourages and supports harmonics that the equipment is not designed to handle.

With the proper inductance/capacitance ratios in our circuit we could have a tune point near 60 Hz, which is a standard frequency, but this would be a backwards way of approaching the problem. The choice of transformers should first be considered.

Transformers

This section is basically a continuation of the thoughts concerning "tuning". The transformers all had very different responses to change in frequency as would be expected. Transformer modeling is a very complex science and the support of harmonics is sometimes questionable. The complexity of the transformer response to the frequency is much more significant than the small capacitance offered by the reactor at OSU. Data set #86 shows the transformer responded identically (with my level of analytical observation) with or without the reactor in the circuit. Looking back at the entry work in this field, this same knowledge was the basis used for finding the tune point before the reactors were introduced to the circuit. Obviously these effects are not solely dependent on the plasma reactors. Transformers are available which meet the needs of this research effort and should be considered for future research.

Power Supply

The successful use of the Variac for producing plasma enforces the idea that this reactor setup can be optimized for 60 Hz operation. Most plasma generation with the Variac only occured for high primary input, but this is another limitation of the transformer. Either a smaller reactor (less load and less voltage required) or a larger transformer would fix this shortcoming. The California Instruments power supply was not effective for 60 Hz operation and I would prefer it was phased out. The present setup still requires the adjustable frequency to produce enough power for an intense plasma.

Wire Leads

The tests with the wire leads demonstrate the difficulty for insulating with frequencies above 60 Hz. The wires used for the circuit are rated for 60 Hz only, because when the frequency is increased the capacitive reactants of the wire alters and the insulator is near worthless. At night when operating at frequencies near 300 Hz, the wires glow and form corona discharge with grounded objects of close proximity. It appeared first that I could purchase insulated wire capable of insulating at our optimum frequencies, but this was not the case. As a potential solution to the insulation problem, I considered using a transformer oil bath to insulate the wires. I think it was a good idea, but it would be preferable if we could use standard 60 Hz frequency. All wire leads used were ineffective for insulation, but the leads appeared to be sufficient for minimizing resistance to flow with the excessively oversized wire. There problems could possibly be avoided by operating at 60 Hz or below or by insulating the entire secondary side of the circuit.

Glass Beads

Transferring a dielectric from an insulating to a conducting state is a destructive process and the glass beads remained intact. Therefore, the glass beads did not conduct electricity. The glass beads were nothing more than an electrically inert filler of the annulus. The plasma produced in the annulus packed with glass beads was signified by a bright luminous glow. An increased intensity should be expected because effective volume of the gas is decreased due to the space occupied by the beads. Decreasing the amount of gas to be ionized decreases the load on the power supply, making it possible for the same power to increase the intensity of the plasma.

The use of the glass beads made observations more complicated by producing an optical illusion. The reflective nature of the beads made it difficult to determine where the luminous glow was emitted. The successful use of beads with the annulus suggest that other insulating solids (possible catalyst) could be used with the plasma reactors.

Plasma From Liquid

The unexpected presence of a plasma within a liquid is now regarded as having been an optical illusion. This conclusion was reached much later in my research, but all evidence suggests this is the proper answer. The illusion was most likely due to the presence of a corona discharge within the void space for the electrode. I suspect I was misled, and the glow did not actually originate from the annulus of the reactor. Copper electrodes were employed for this experiment and it was later observed that a corona type discharge could form within the space left void by the electrodes.

Figure 10. Liquid Effects Within the Ungrounded Outer Electrode -- This is an early run with a crude tower made from 3 liter pop bottles that had obvious negative electrical effects.

I do still have reason to question the idea that a plasma can not be created within a liquid and would have liked to have been able to perform further experimentation in this area for confirmation. When working with liquid electrodes, strange luminous patterns were observed originating from within the liquid electrode, see Figure 10. These electrical effects may not have been plasma, but they were some type of electric discharge.

Conceptual Design

In analyzing the proper conceptual design for a plasma reactor to be used research future industrial applications, I had to analyze the critical factors. The important factors proved to be: discharge type, physical characteristics, and the power supply mechanism.

Discharge Type

The types of discharges used at OSU have been silent electrical discharges. These discharges definitely have their place for industrial applications. These discharges operate without a significant increase in temperature, thereby earning the classification of a cold plasma. The idea of a chemical reactor operating at room temperature is in itself a promising enough quality for continued research, but this in no way is the highlight or limit of the plasma reactor's potential. These discharges have a unique driving force which creates possibilities for rather unique chemical reaction processes. Corona and silent discharges can be produced by the generation of a high voltage field across a gas space utilizing two dielectric barriers to shield the gas from the electrodes. This setup has advantages over other forms of cold plasmas which only operate well below atmospheric pressure. Our reactor operates at atmospheric pressure and above and it is this characteristic which is crucial to industry, because it is usually uneconomical to try and operate any large process under a vacuum.

> "Other forms of discharge which operate at higher pressure (about one atmosphere) have been used for chemical investigations such as the point discharge, the corona discharge and the silent electric discharge as produced in an ozonizer. These three forms of discharge are closely related to the glow discharge in the sense that

> the electrical phenomena taking place in them are essentially the same." [Glockler, p.29]

For the research at OSU, various degrees of these three forms of discharges have been used with the differences being based on the uniformity of the plasma.

In choosing between the various classifications of uniformity for SED, the application becomes important. Point discharges, even more so than corona discharges, provide local regions of intensity which could be beneficial for obtaining regions of intense ionization. If applied to my intended research, this phenomena would produce a complicated condition which would make analysis more difficult than a uniform plasma would. Also, I am skeptical of local intensity because of previous signs at OSU of glass fatigue and failure associated with these hot spots. It appears that most of the work in the past at OSU operated using a combination of these types of discharges.

The term for the silent electrical discharge (SED) associated with the ozonizer was never referred to as anything but an "ozonizer" type discharge. Many chemical reactions studied by pioneers in this field have been classified ambiguously under "ozonizers", even though they usually have nothing to do with the production of ozone. It would be more accurate and less confusing to refer to ozonizer type discharges as a uniform SED. The conceptual design should operate with a uniform SED.

Physical Characteristics

The physical design of the reactor will determine how effectively the reactor will work to produce an SED. Geometrical configurations are an important consideration for obtaining a uniform plasma. Available options for the geometric shape of the reactor range include plate, cylindrical, and spherical configurations. The spherical geometry would adopt least easily to industrial applications. Plate configurations are well suited for producing a uniform discharge, but grounding would be a problem. Previous work at OSU has used a cylindrical configuration which is well suited for the process because it allows for grounding the outer electrode.

Choosing between plate and cylindrical configurations depends again on application. The advantages of the plate are ease of establishing voltage and gap width relationships and the ease of changing apparatus to vary plasma width.

The plate type reactor if built properly should be easier to disassemble and clean. This is a major drawback of the cylindrical geometry's. For research purposes, the plate type configuration could prove useful, but the cylindrical configuration is still slightly preferable because of the completely surrounded inner, high-voltage electrode. The cylindrical design is less adjustable than the plate configurations, but the cylindrical configuration is more easily adapted to process situations.

The wall material for the reactors should be composed of fused quartz glass until a better substitute is found. Fused quartz is a great choice except for its low impact strength. If the reactor was built within another container (possibly an insulative transformer oil bath) then there shouldn't be any problem with using the fused quartz. Fused quartz will not expand very much with increases in temperature, so we must consider thermal expansion effects for anything that attaches to the fused quartz. This is a major reason I did not propose forming a fused quartz sleeve around a copper tube to serve as an electrode.

Liquid electrodes appear to be ideal for creating a good uniform electrode and a good conducting liquid should be chosen. $CuSO_4$ is ideal. $CuSO_4$ would not be corrosive to the wire leads, it conducts very well, and it is transparent. The nozzles for the outer electrode are an important consideration to aid level control and temperature control. Grounding the outer electrode allows for this component to be treated as an electrically neutral component. Therefore, we can continually renew this liquid electrode by creating a flow path through the outer electrode. This could be important for maintaining a desired temperature. A cool or warm liquid electrode could be cycled through the reactor to vary the reactor wall temperature. Another reason for the nozzles is to allow for easily varying the liquid level, which directly corresponds to the plasma length that can be established. This feature would allow for much easier experimental procedure.

Power Supply Mechanism

To operate a plasma reactor, we must provide a high voltage potential across the reactor in order to create a discharge. A continuously maintained voltage across the reactor would not be very effective because charge gradients would build up across the annulus, decreasing the driving force for continued discharges. At first, it seemed that a true AC potential would be necessary and it is true that this works, but after analyzing the discharge process in detail, I find that true AC is not mandatory.

Repeated pulses with the same sign configuration (AC with a DC bias) will produce the same result. This does not appear to be true unless you consider the rapid speed at which the charged species re-equilibrate. From an equilibrium standpoint, it does not matter which direction the potential is applied. After understanding how pulsing affects the discharges, we understand that increasing frequency increases the number of discharges per second. With alternating current, there are two discharges for each cycle. I do not think this effect has any relevance to the tuning effect. We are nowhere near the order of magnitude where we could match the frequency of the discharge to the frequency of chemical bonds. I am under the impression that the tuning of our plasma reactors is solely due to an impedance match. We needed maximum energy, under resonance with our current setup, to achieve a secondary voltage high enough for a sustained discharge. Our electrical setup operates outside the suggested range of most of the equipment, and this makes it very hard to predict the accuracy of the measurements. The main source of difficulty for our experiments has been the transformers. Operating at high frequencies puts too much load on the transformers and the coils short-out.

Electrically, our system needs to be completely rearranged! Using an inappropriate probe associates too many questions with the measurements. With our setup, the question was always: "When did the probe start to go bad?" We should not operate outside of the range for any of the electrical equipment. Poor analytical equipment was responsible for a significant amount of useless data. For example: the Fluke 80-40K probe appeared to work fine above the 60 Hz limit for some time, but then after countless runs it had digressed to providing completely useless numbers. This puts the researcher in the situation of guessing when the probe was working because it doesn't tell you when it is giving false readings.

Analytically, we added an oscilloscope to the high voltage probe. This allowed for a visual determination of a well developed plasma. The sign wave becomes distorted at the peaks, see Figure 11, when a plasma is being sustained. This distortion is a result of a voltage which is slightly out of phase with the displacement current and is associated only with a well developed plasma.

Without some measure of current in the secondary side of the circuit, it would be hard to estimate the work put into the reaction and thereby be able to analyze reaction efficiencies. This should be added to the measurement capabilities now available. Most chemical reactions in discharges have been analyzed on a basis of electron volts and we would need to either calculate or measure both current and potential to obtain this unit of measure. At this time, conservation of energy is probably not a very accurate way to try and obtain these values because of huge losses experienced when operating the transformer at frequencies near 100 times the recommended values. Also the use of the power supply adds another degree of uncertainty to the system.

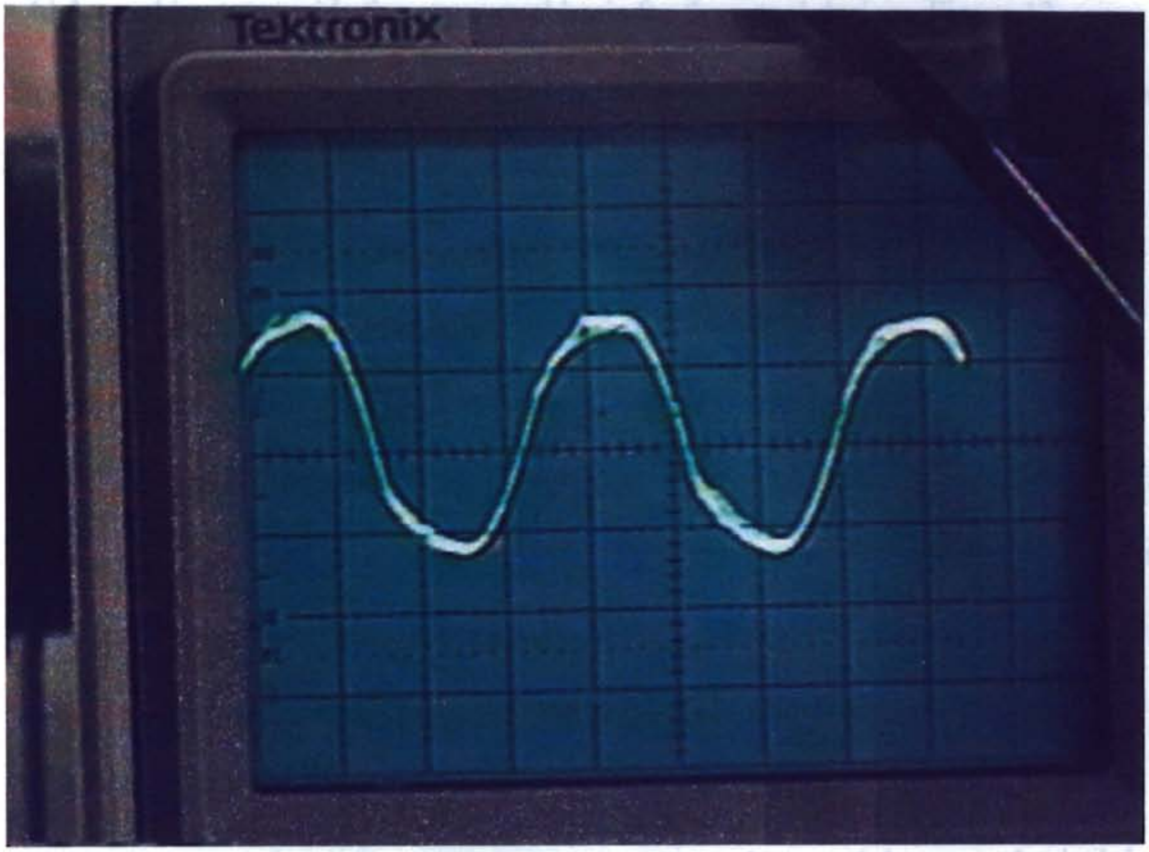

Figure 11. Bent Sine Wave Indicating Plasma -- A well developed plasma introduces a load to the circuit and changes the phase slightly of the sine wave.

The task of optimizing the electrical circuit is still incomplete, but I believe the work of Warburg which was mentioned in the background section of this thesis to be a good source of information for future endeavors. I also feel that our efforts at OSU should include an Electrical Engineer to help optimize the circuit.

Design

The previous results presented in this section provide the necessary basis for my conceptual design. These results are not quantitative, but rather simply observations which combine to provide the conceptual basis for the actual design. Figure 12 represents my conceptual design. Even though not shown, for practical purposes the top should be removable to allow access to the annulus.

After making my conclusions concerning the conceptual design for the plasma reactors at OSU, I came across an old reference by Glocker and Lind. The reference presented a more comprehensive study which was performed by E. Warburg that had hints of similar design to what I was proposing. With a little investigation, I was able to find figures showing reactors used in the 1920's which upon close examination showed most of the design features which I was proposing. I found this discouraging because we had overlooked much of the original effort in this field, and we had thought we were doing something of a more pioneering nature. At the same time, I also found this information encouraging, because I had apparently implemented the same physical design characteristics that had been used by these early pioneers. By reaching the same design considerations experimentally, we have developed an increased appreciation for the design of the reactor. Some of the design characteristics are not easy to recognize because they were not addressed in the text and were only shown in the diagrams of the actual reactor setups. It is quite possible that these subtle design features would have been overlooked or their potential not realized if the problems concerning the operation of our reactors at OSU had not brought about similar design features. I found it encouraging to have my design changes validated by past examples

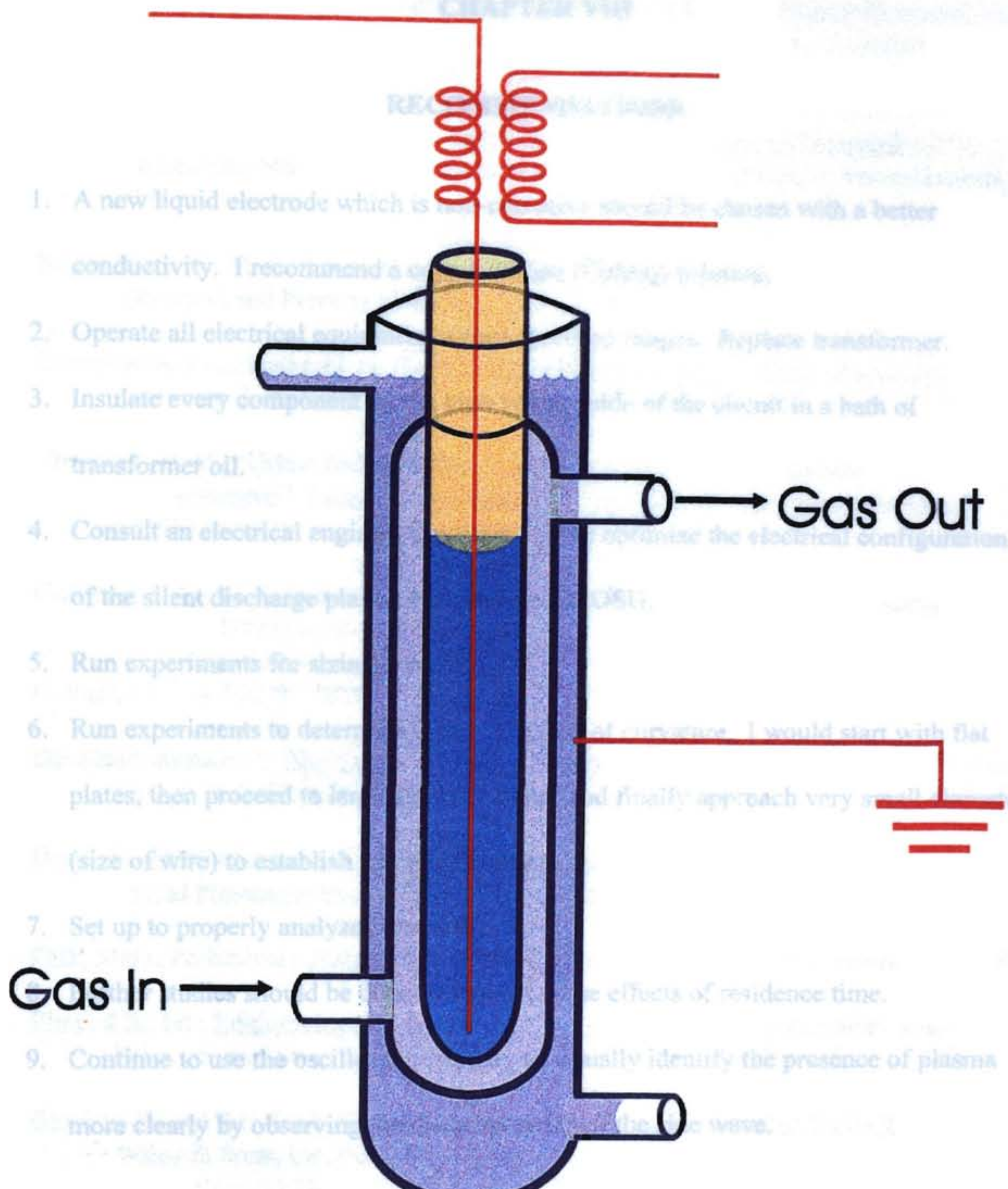

Figure 12. **Conceptually Designed Plasma Reactor** -- Designed to produce the most uniform SED plasma possible. The light blue is $CuSO_4$ solution for good conduction of electricity and the yellow is transformer oil for insulating purposes.

CHAPTER VIII

RECOMMENDATIONS

1. A new liquid electrode which is non-corrosive should be chosen with a better conductivity. I recommend a copper sulfate ($CuSO_4$) solution.
2. Operate all electrical equipment within specified ranges. Replace transformer.
3. Insulate every component on the high voltage side of the circuit in a bath of transformer oil.
4. Consult an electrical engineer/physicist to help optimize the electrical configuration of the silent discharge plasma reactors used at OSU.
5. Run experiments for sizing reactors.
6. Run experiments to determine effect of radius of curvature. I would start with flat plates, then proceed to large diameter tubes, and finally approach very small diameter (size of wire) to establish this relationship.
7. Set up to properly analyze operation.
8. Further studies should be done to determine the effects of residence time.
9. Continue to use the oscilloscope and try to visually identify the presence of plasma more clearly by observing the distorted peaks of the sine wave.

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APPENDIX A

Equipment Specifications

The experiments recorded in Appendix B used the equipment listed in this section. The equipment used for the majority of the experiments is noted below in italics.

APPENDIX

TRANSFORMERS

Magnetek Jefferson - *Used [illegible] experiments unless otherwise noted*
CAT # 721411
Outdoor – non-weatherproof
Primary: [illegible]
Secondary: [illegible]
Midpoint grounded

France
Franceformer 15060P
Outdoor – non-weatherproof
Primary: 120 V, 60 Hz, 900 VA
Secondary: 15000 V, 60 mA
Midpoint grounded

Wagner
13200 GRD Y/7620 to 120/240
3 kVa
From Central Rural Electric Company

PROBES

Fluke High Voltage Probe - *Used for all experiments unless otherwise noted*
Model 80K-40
Maximum Input Voltage: 28 kV rms ac (0 to 60 Hz)

Hewlett Packard High Voltage Probe
Model # 1137A
1000:1 Voltage Divider
Maximum Input Voltage: ac Voltage (0 to 250 kHz) [illegible] rms

APPENDIX A

Equipment Specifications

The experiments recorded in Appendix B used the equipment listed in this section.

The equipment used for the majority of the experiment is noted below in italics.

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Magnetek Jefferson - *Used for all experiments unless otherwise noted.*
CAT # 721411
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Wagner
13200 GRD Y/7620 to 120/240
3 kVa
From Central Rural Electric Company

PROBES

Fluke High Voltage Probe - *Used for all experiments unless otherwise noted.*
Model 80K-40
Maximum Input Voltage: 28 kV rms ac (0 to 60 Hz)

Hewlett Packard High Voltage Probe
Model # 1137A
1000:1 Voltage Divider
Maximum Input Voltage: ac Voltage (0 to 250 kHz) - 5 kV rms

METERS

Fluke Digital Multimeter
Model # 8050A
Maximum Input Voltage: 750 V rms or 1000 V peak continuous, not to exceed the volt-hertz product of 10E7

OSCILLATORS

California Instruments Invertron Oscillator - *Used for all experiments unless otherwise noted.*
Model # 850T
Maximum Frequency: 5200 Hz
Maximum Voltage: 120 V

BK Precision Oscillator
Model # 3011B
Frequency Range: 0.2 Hz to 2 MHz (7 ranges). Four digit frequency counter display.

POWER SOURCES

California Instruments Power Source - *Used for all experiments unless otherwise noted.*
Model # 1001TC
Full Power Frequency Range: 45 Hz to 5 kHz
Full Power Voltage Range: 110 to 120 V rms for normal single phase 115 V applications

Variac
0-140 volts
60 Hz only
10 amps maximum

APPENDIX B

The dimensions for the various reactors used are provided in Figure 13, and the range of possible capacitance for each reactor (based on effective plasma zone length) are recorded in Table I. This is my experimental data. Figure 14 provides the key for the Figures presented in this appendix. Each data set is followed by a data analysis

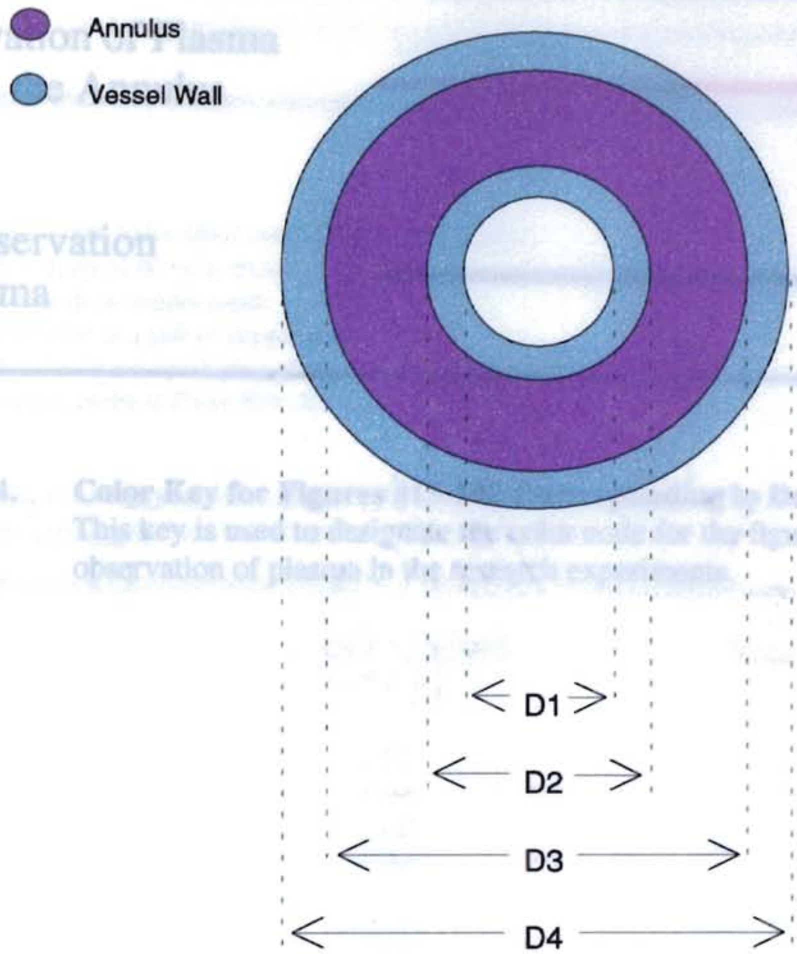
TABLE I

Capacitance Measurements

	Plasma Zone Electrode Length (inches)	Insulating Annulus Air in Annulus (pF)	Conducting Annulus Ionized Water in Annulus (pf)
Reactor A	10	32.7	602
	15	48.6	738
	20	60.4	816
	25	73.7	891
	30	87	966
	35	102.4	1072
Reactor B	6	28.6	126.6
Reactor C	6	23.8	240
Reactor D	5 3/4	17.1	3600
Reactor E	8	33	500

Measurements performed with:

Impedence Meter 253
Electro Scientific Industries
Portland, OR
Supplied OSU Engineering Technology for our temporary use.



These are all concentric tube type reactors
Dimensions in millimeters
Inside and Outside Space are reserved for the electrodes.

Reactor	Material	D1 (mm)	D2 (mm)	D3 (mm)	D4 (mm)
A	Cleared Fused Quartz	27	30	48	52
B	Quartz	18	20	27	30
C	Quartz	18	20	27	30
D	Pyrex	13.5	16	25	28
E	Pyrex	15.5	18	22	25

Figure 13. **Cross Sectional View of OSU Plasma Reactors --** These are the dimensions and the materials for the body of the reactors used for plasma research at OSU.

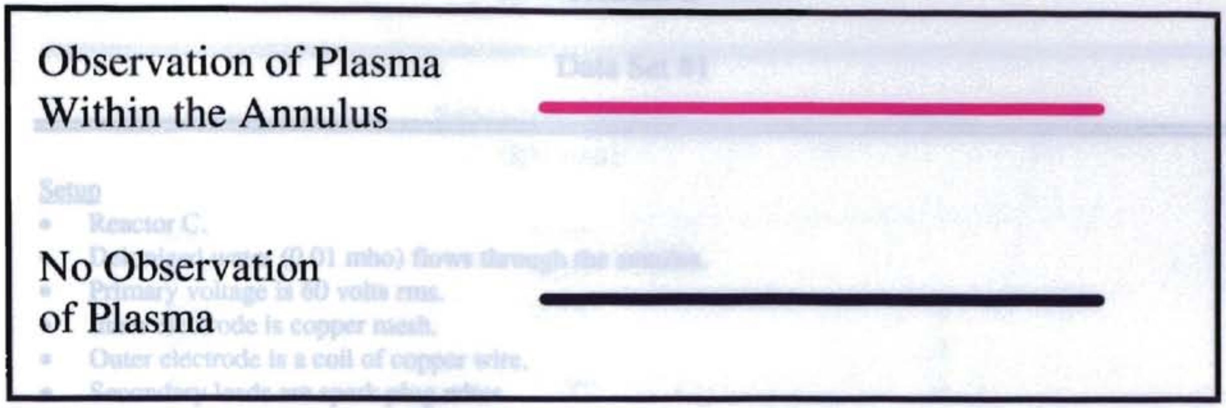


Figure 14. **Color Key for Figures #15-102 Corresponding to Data Sets #1-89 --** This key is used to designate the color code for the figures modeling the observation of plasma in the research experiments.

TABLE II

Data Set #1

Setup
- Reactor C.
- Deionized water (0.01 mho) flows through the annulus.
- Primary voltage is 60 volts rms.
- Inner electrode is copper mesh.
- Outer electrode is a coil of copper wire.
- Secondary leads are spark plug wires.
- High voltage probe is Fluke 80K-40.

Notes
A. Electricity from outer electrode arced to the reactor holding bracket.
B. A nearby unplugged fluorescent light bulb was partially lit.

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
70	7.94	
75	7.94	
80	7.90	
85	7.88	
90	7.86	
95	7.84	
100	7.76	
105	7.72	
110	7.70	
120	7.64	
130	7.56	
140	7.48	
150	7.40	
160	7.32	
170	7.24	
180	7.18	
190	7.06	
200	6.98	
210	6.90	
220	6.84	
230	6.76	
240	6.68	
250	6.62	

(con't.)

TABLE II (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
260	6.56	
270	6.50	
280	6.44	B
290	6.38	B
300	6.38	B
310	6.34	B
320	6.32	B
330	6.30	
340	6.30	
350	6.32	
360	6.34	
370	6.38	
380	6.46	
390	6.54	
400	6.68	
410	6.82	
420	7.02	
430	7.22	A
430	4.16	
440	4.12	
450	4.08	
460	4.06	
470	4.04	
480	4.04	
490	4.04	
500	4.06	
510	4.08	
520	4.10	
530	4.14	
540	4.18	
550	4.24	
560	4.30	
580	4.48	
590	4.60	
600	4.74	
610	4.88	
620	5.04	

(con't.)

TABLE II (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
630	5.24	
640	5.46	
650	5.70	B
660	6.00	B
670	6.32	B
680	6.68	B
690	7.12	B

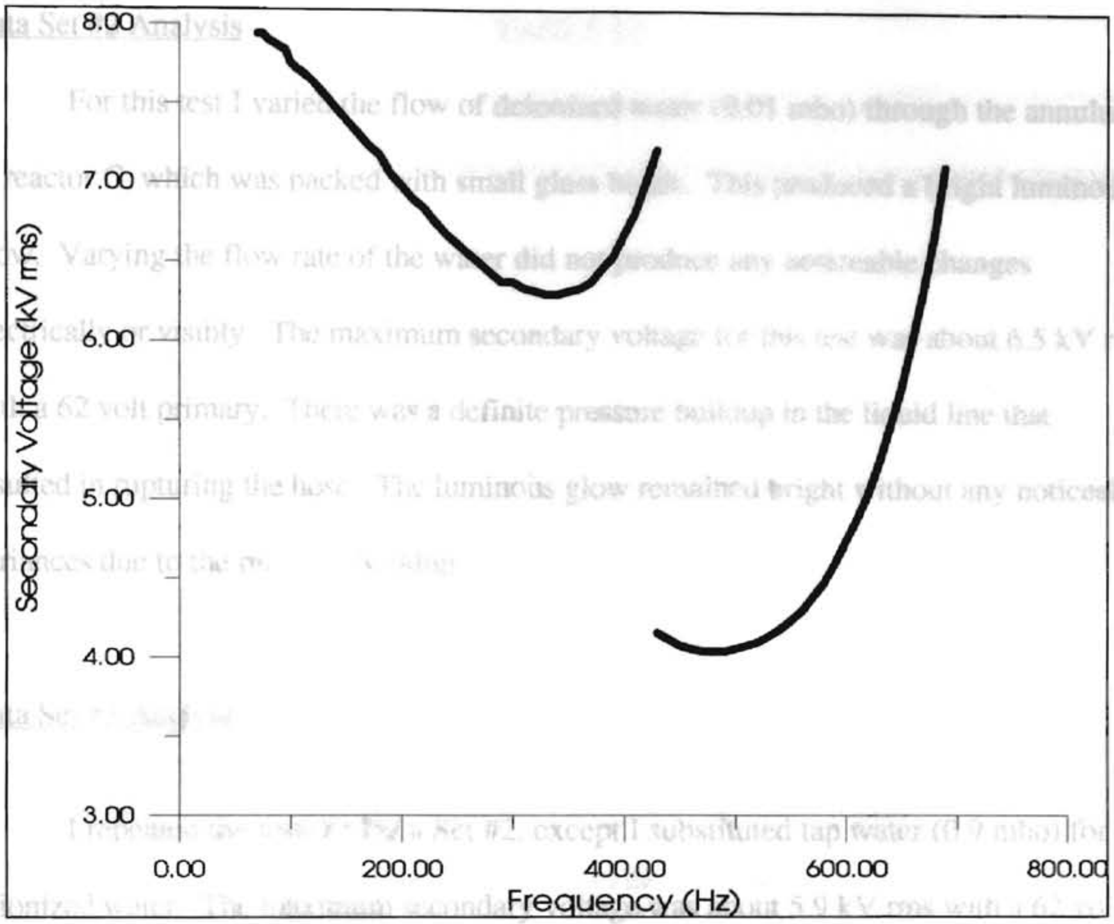


Figure 15. Typical Tuning Plot For Data Set #1.
Reactor C with deionized water flowing through the annulus.

Data Set #1 Analysis

The arc that occurred at 430 Hz apparently shorted out the transformer. Some discontinuity at the arcing was expected because I temporarily shut down the system to remove outside objects, but the large decrease in secondary voltage is evidence the transformer was most likely partially shorted out at this point and would not have as many coils available for subsequent experiments (lower secondary voltages would be expected until a new transformer could be substituted).

Data Set #2 Analysis

For this test I varied the flow of deionized water (0.01 mho) through the annulus of reactor C, which was packed with small glass beads. This produced a bright luminous glow. Varying the flow rate of the water did not produce any noticeable changes electrically or visibly. The maximum secondary voltage for this test was about 6.5 kV rms with a 62 volt primary. There was a definite pressure buildup in the liquid line that resulted in rupturing the hose. The luminous glow remained bright without any noticeable variances due to the pressure buildup.

Data Set #3 Analysis

I repeated the tests of Data Set #2, except I substituted tap water (0.9 mho) for the deionized water. The maximum secondary voltage was about 5.9 kV rms with a 62 volt primary. This setup produced a dim luminous glow. There were no noticeable changes with varying flow rate.

TABLE III

Data Set #4

Setup
- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 5 volts rms.
- Inner and outer electrodes are copper mesh.
- Secondary leads are spark plug wires.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 51 degrees Fahrenheit.
- Deionized water (0.01 mho) flows through the annulus.
- Time between steps is approximately 1 minute.

Notes
A. Readjusted amplitude to attain 5.00 volt primary reading.
B. Hear a hum.
C. No more hum.
D. At this point, I had to change oscillator range x100.
E. Limit, power supply automatically shut off.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
60	5.00	2.14	
70		1.46	
80		1.46	
90		1.46	
100	4.97	1.44	A
110		1.44	
120		1.42	
130		1.42	
140		1.42	
150		1.42	
160		1.4	
170		1.4	
180	5.02	1.4	A
190		1.38	
200	4.96	1.38	A
210	5.02	1.36	A
220		1.36	
230	5.01	1.36	A

(con't.)

TABLE III (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
240		1.36	
250	4.99	1.34	A
260	4.99	1.34	A
270	4.98	1.34	A
280		1.34	
290		1.32	
300		1.34	
310		1.32	
320		1.32	
330		1.32	
340		1.30	
350		1.30	
360		1.30	
370		1.30	
380		1.30	
390		1.30	
400		1.32	
410		1.32	
420		1.32	
430		1.32	
440		1.32	
450		1.34	
460		1.34	
470		1.36	
480		1.36	
490		1.38	
500	4.97	1.40	A
510		1.42	
520	4.96	1.44	A
530		1.46	
540		1.46	
550		1.46	
560		1.42	
570		1.36	B
580	4.96	1.30	A
590		1.24	

(con't.)

TABLE III (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
600		1.20	
610		1.18	
620		1.16	
630		1.14	
640		1.14	
650		1.12	C
660		1.12	
670		1.12	
680		1.12	
690		1.12	
700	4.95	1.12	A
710		1.12	
720		1.14	
730		1.14	
740		1.14	
750		1.14	
760		1.14	
770		1.14	
780	5.05	1.16	A
790		1.16	
800		1.16	
810	5.06	1.16	A
820		1.16	
830		1.18	
840	5.06	1.18	A
850		1.20	
860	4.96	1.20	A
870		1.22	
880		1.22	
890		1.22	
900		1.24	
910		1.24	
920		1.24	
930		1.24	
940		1.24	
950		1.22	

(con't.)

TABLE III (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
960		1.22	
970		1.22	
980		1.20	
990		1.20	
1000	5.40	1.18	D
1050		1.16	
1100		1.14	
1150		1.14	
1200		1.12	
1250		1.12	
1300		1.12	
1350		1.12	
1400		1.10	
1450		1.10	
1500		1.10	
1600		1.10	
1700		1.10	
1800	5.09	1.10	A
1900		1.10	
2000		1.12	
2060		1.10	
2160		1.10	
2260		1.10	
2360		1.10	
2460		1.10	
2560		1.10	
2660		1.10	
2760		1.10	
2860		1.10	
2960		1.10	
3960		1.10	
3160		1.10	
3260		1.10	
3360		1.10	
3460		1.10	
3560		1.10	

(con't.)

TABLE III (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
3660		1.10	
3760		1.10	C
3860		1.10	
3960		1.10	
3990		1.10	
4090		1.10	
4190		1.10	
4199		1.10	B
4299		1.10	
4399		1.10	
4499		1.10	
4599		1.10	B
4699		1.10	C
4799		1.10	
4899		1.10	
4999		1.10	
5099		1.10	
5100		1.10	
5110		1.10	
5115		1.10	
5119		1.10	
5120			E

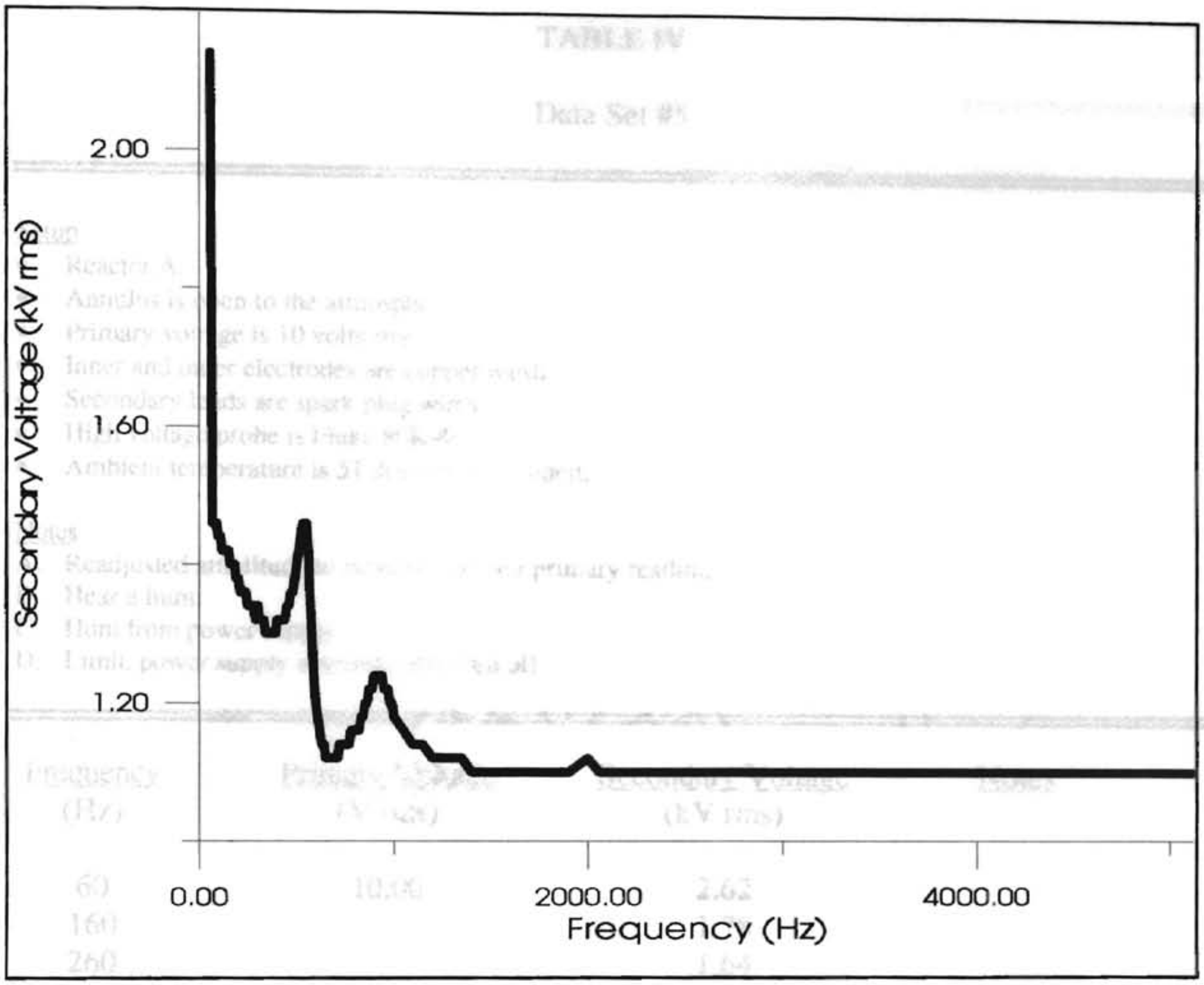


Figure 16. **Typical Tuning Plot For Data Set #4.**
Reactor A open to the atmosphere.

Data Set #4 Analysis

During operation I noticed a surge when changing the frequency by thousands with the oscillator (California Instruments Model #850T), it appears there is a momentary zero amplitude between these adjustments. The power supply (California Instruments Model #1001TC) had an upper limit of 5120 Hz. There was not a large tune point in the graph, but there were two frequency ranges showing signs of resonance resulting in peaks of increased secondary voltages.

TABLE IV

Data Set #5

Setup
- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 10 volts rms.
- Inner and outer electrodes are copper mesh.
- Secondary leads are spark plug wires.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 51 degrees Fahrenheit.

Notes
A. Readjusted amplitude to attain 10.00 volt primary reading.
B. Hear a hum.
C. Hum from power supply.
D. Limit, power supply automatically shut off.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
60	10.00	2.62	
160		1.78	
260		1.64	
360	10.20	1.58	A
460		1.68	
560		1.78	
660		1.12	
760		1.16	
860	10.30	1.38	A
960		1.36	
1060		1.20	
1100		1.18	
1200		1.14	
1300		1.12	
1400		1.10	
1500	10.25	1.10	A
1600		1.10	
1700		1.10	
1800		1.10	
1900		1.10	
2000		1.10	

(con't.)

TABLE IV (continued)

Frequency (Hz)	Primary Voltage (v rms)	Secondary Voltage (kV rms)	Notes
2100		1.10	
2200		1.10	
2300		1.10	
2400		1.10	
2500		1.10	
2600		1.10	
2700		1.10	
2800		1.08	
2900		1.08	
3000		1.10	
3100		1.10	
3200		1.08	
3300		1.10	
3400		1.10	
3500		1.10	
3600		1.10	
3700		1.10	
3800		1.11	
3900		1.10	
4000		1.10	
4100		1.10	B
4200		1.10	
4300		1.10	
4400		1.10	
4500		1.10	C
4600		1.08	
4700		1.08	
4800		1.08	
4900		1.08	
5000		1.08	
5100		1.08	
5110		1.10	
5119		1.10	
5120			D

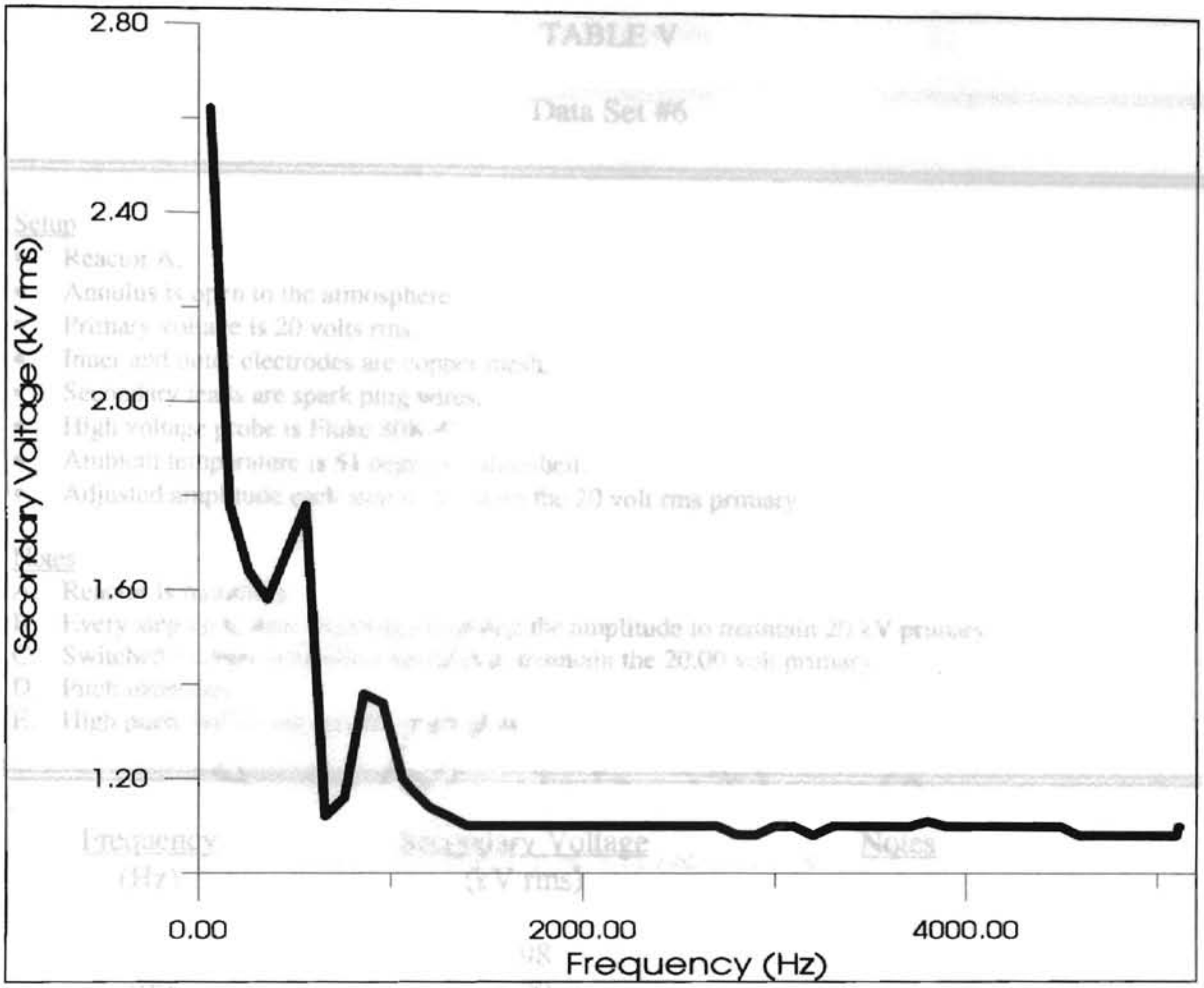


Figure 17. **Typical Tuning Plot For Data Set #5.**
Reactor A with the annulus open to the atmosphere.

Data Set #5 Analysis

Tuning plot was nearly identical to data set #4. The power supply appears to have a built in limit of 5120 Hz.

TABLE V

Data Set #6

Setup

- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 20 volts rms.
- Inner and outer electrodes are copper mesh.
- Secondary leads are spark plug wires.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 51 degrees Fahrenheit.
- Adjusted amplitude each step to maintain the 20 volt rms primary.

Notes

A. Reactor is humming.
B. Every step up to here required increasing the amplitude to maintain 20 kV primary.
C. Switched to decreasing the amplitude to maintain the 20.00 volt primary.
D. Pitch increases.
E. High pitch, but do not see the violet glow.

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
90	2.98	
190	2.70	
200	2.66	
300	2.42	
400	2.38	
400	2.38	
410	2.42	
420	2.44	
430	2.48	
440	2.52	
450	2.60	A
460	2.66	
480	2.84	
490	2.92	
500	2.98	
510	3.00	
520	2.94	
530	2.84	
540	2.66	B
550	2.46	C

(con't.)

TABLE V (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
560	2.26	
570	2.04	
580	1.86	
590	1.68	D
600	1.52	
610	1.40	
620	1.32	
630	1.24	
640	1.20	E
650	1.18	
660	1.16	
670	1.16	
680	1.14	
690	1.14	
700	1.16	F

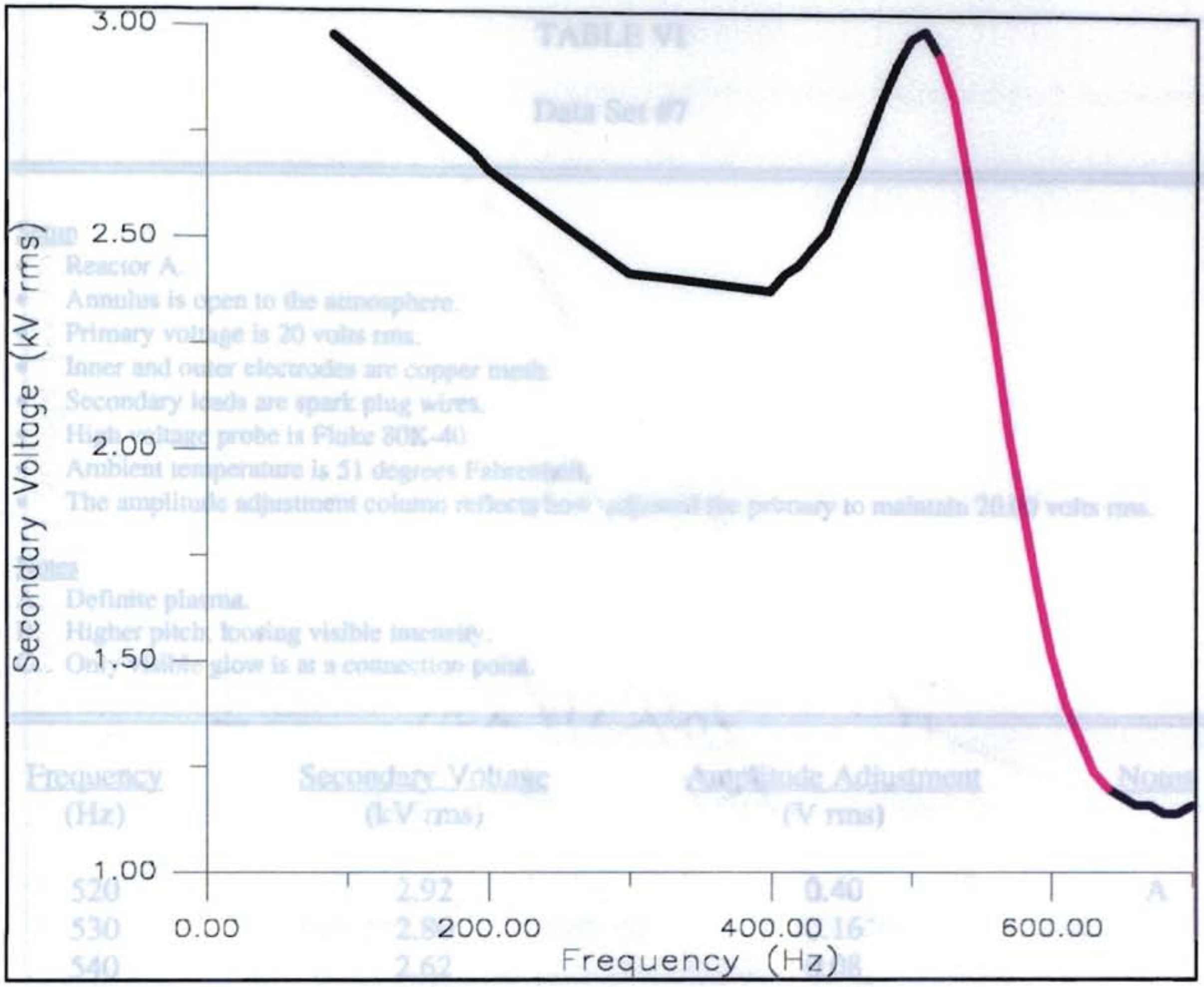


Figure 18. **Typical Tuning Plot For Data Set #6.**
Reactor A with the annulus open to the atmosphere.

Data Set #6 Analysis

Suspected plasma through peak portion of the curve, data set #7 is a recreation of the suspected plasma region that I passed without a visual observation. Data set #7 shows a definite plasma in this frequency range, therefore I included the plasma region in Figure 18. It is possible the plasma developed before the starting point shown.

TABLE VI

Data Set #7

Setup
- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 20 volts rms.
- Inner and outer electrodes are copper mesh.
- Secondary leads are spark plug wires.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 51 degrees Fahrenheit.
- The amplitude adjustment column reflects how adjusted the primary to maintain 20.00 volts rms.

Notes
A. Definite plasma.
B. Higher pitch, loosing visible intensity.
C. Only visible glow is at a connection point.

Frequency (Hz)	Secondary Voltage (kV rms)	Amplitude Adjustment (V rms)	Notes
520	2.92	0.40	A
530	2.80	0.16	
540	2.62	0.08	
550	2.44	-0.02	
560	2.22	-0.06	
570	2.02	-0.06	
580	1.82	-0.05	
590	1.66	-0.06	B
600	1.52	-0.08	B
610	1.38	-0.07	B
620	1.30	-0.09	B
630	1.24	-0.05	B
640	1.20	-0.02	B
650	1.16	-0.02	C

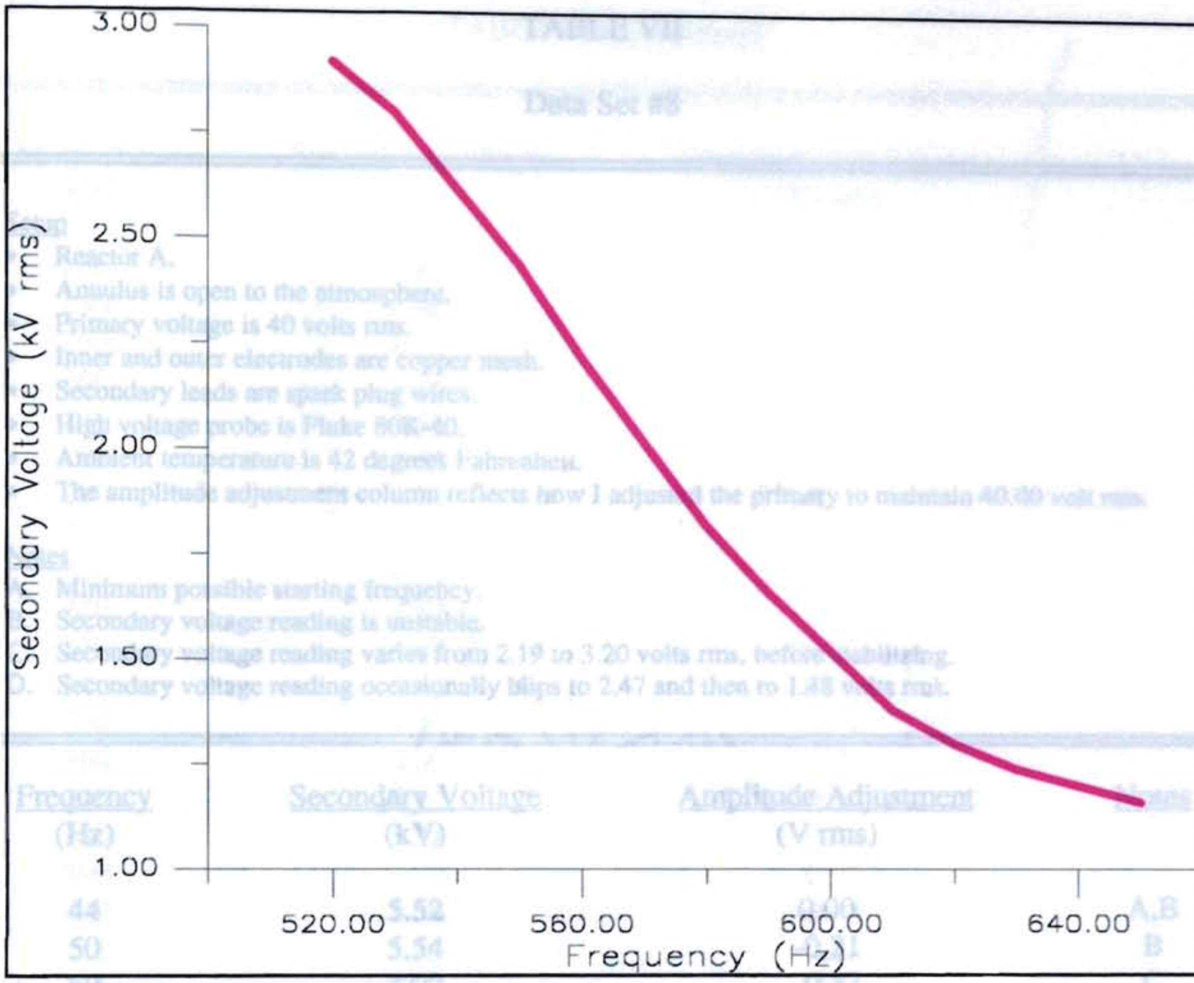


Figure 19. Typical Tuning Plot For Data Set #7.
Reactor A with annulus open to the atmosphere.

<u>Data Set #7 Analysis</u>

This data set was a recreation of the suspected plasma region from data set #20 and a plasma was observed. The connection point for the outer electrode marked the only location of plasma at 650 Hz.

TABLE VII

Data Set #8

Setup

- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 40 volts rms.
- Inner and outer electrodes are copper mesh.
- Secondary leads are spark plug wires.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 42 degrees Fahrenheit.
- The amplitude adjustment column reflects how I adjusted the primary to maintain 40.00 volt rms.

Notes

A. Minimum possible starting frequency.
B. Secondary voltage reading is unstable.
C. Secondary voltage reading varies from 2.19 to 3.20 volts rms, before stabilizing.
D. Secondary voltage reading occasionally blips to 2.47 and then to 1.48 volts rms.

Frequency (Hz)	Secondary Voltage (kV)	Amplitude Adjustment (V rms)	Notes
44	5.52	0.00	A,B
50	5.54	-0.21	B
60	????	-0.37	C
60	6.40	0.00	
70	5.48	-0.15	
80	5.44	-0.04	
90	5.40	-0.05	
100	5.36	-0.06	
110	5.30	-0.02	
120	5.26	-0.20	
130	5.22	-0.03	
140	5.18	-0.01	
150	5.12	-0.02	
160	5.08	-0.02	
170	5.04	-0.01	
180	5.00	-0.02	
190	4.96	-0.02	D
200	4.92	-0.02	
210	4.88	-0.01	
220	4.84	0.00	

(con't.)

TABLE VII (continued)

Frequency (Hz)	Secondary Voltage (kV)	Amplitude Adjustment (V rms)	Notes
230	4.82	-0.02	
240	4.80	-0.02	
250	4.76	-0.01	
260	4.74	-0.01	
270	4.72	-0.02	
280	4.74	-0.02	
290	4.72	-0.02	
300	4.74	-0.01	
310	4.74	-0.02	
320	4.80	-0.02	
330	4.82	0.00	
340	4.86	0.00	
350	4.92	-0.01	
360	5.00	-0.01	
370	5.10	-0.01	
380	5.22	-0.02	
390	5.38	-0.03	
400	5.56	-0.03	
410	5.80	-0.03	
420	6.10	-0.02	
430	6.44	0.00	
440	6.80	0.15	
450	6.96		B

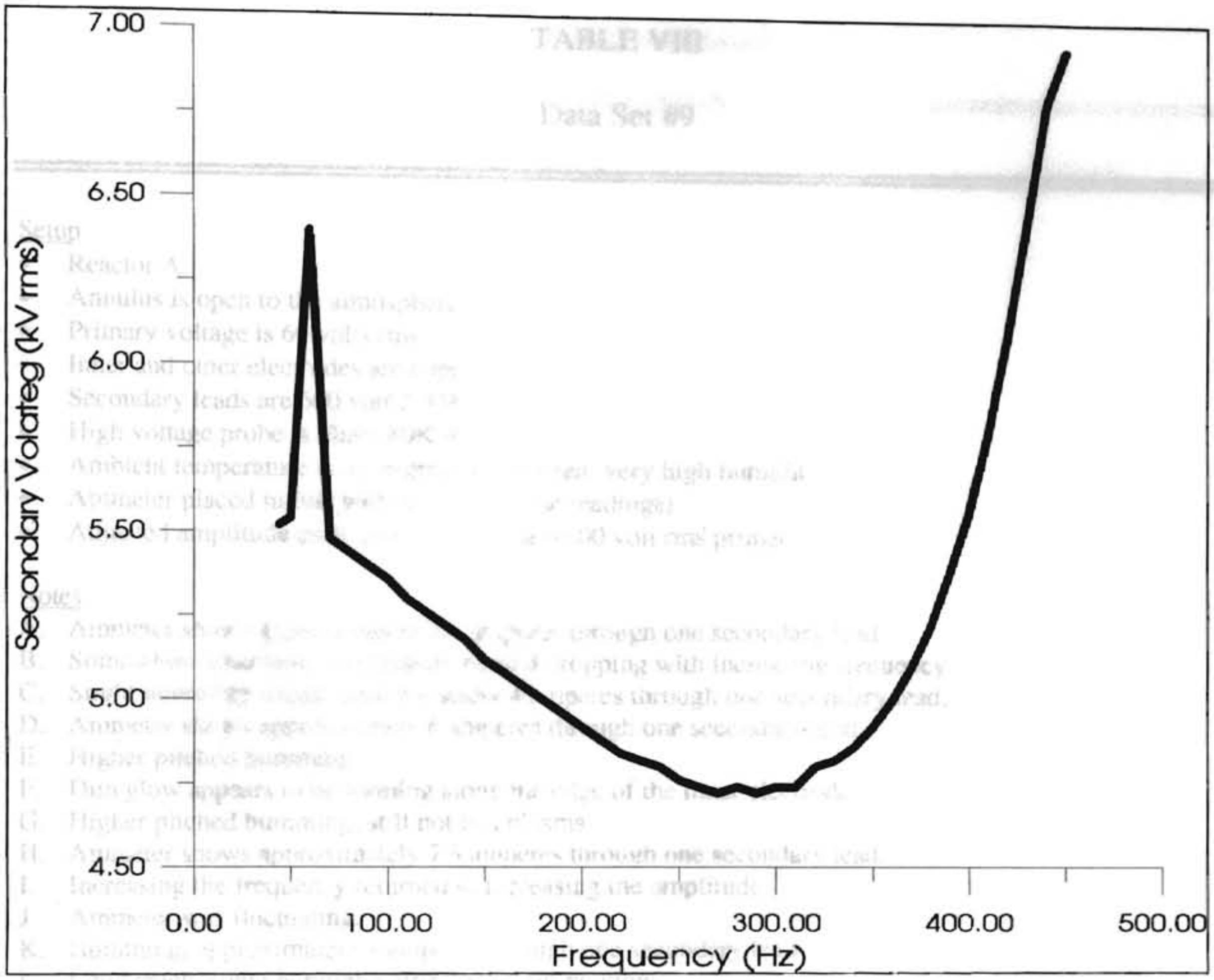


Figure 20. **Typical Tuning Plot For Data Set #8.**
Reactor A with annulus open to the atmosphere.

Data Set #8 Analysis

The graph relates the instabilities of the power supply below 60 Hz. Adjusting the amplitude every step did not produce any noticeable effects. It is possible a plasma was present, but there was not a visual observation. I suspected the problem related to the secondary wire leads.

TABLE VIII

Data Set #9

Setup
- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 60 volts rms.
- Inner and outer electrodes are copper mesh.
- Secondary leads are 600 volt 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 32 degrees Fahrenheit, very high humidity.
- Ammeter placed in line with one lead (false readings).
- Adjusted amplitude each step to maintain 60.00 volt rms primary.

Notes
A. Ammeter shows approximately 2.5 amperes through one secondary lead.
B. Somewhere near here, the primary started dropping with increasing frequency.
C. Slight humming sound, approximately 4 amperes through one secondary lead.
D. Ammeter shows approximately 6 amperes through one secondary lead.
E. Higher pitched humming.
F. Dim glow appears to be forming along the edge of the inner electrode.
G. Higher pitched humming, still not full plasma.
H. Ammeter shows approximately 7.5 amperes through one secondary lead.
I. Increasing the frequency returned to increasing the amplitude.
J. Ammeter was fluctuating.
K. Humming, approximately 7 amperes through one secondary lead.
L. Loud crack, some humming afterwards, but no glow.
M. Plasma formed between lead and an abandoned bracket even through the insulation. I removed the abandoned brackets then proceeded.

Frequency (Hz)	Secondary Voltage (kV rms)	Time (a.m.)	Notes
60	6.54	1:25	
70	7.62	1:27	
80	7.68	1:28	
90	7.70	1:29	
100	7.68	1:30	
110	7.66	1:31	
120	7.64	1:32	A
130	7.80	1:34	
140	8.02	1:44	
150	8.18	1:45	
160	8.36	1:46	

(con't.)

TABLE VIII (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Time (a.m.)	Notes
170	8.56	1:47	
180	8.78	1:47	
190	9.06	1:48	B
200	8.72	1:48	
210	9.06	1:49	
220	9.40	1:49	
230	9.80	1:49	
240	10.20	1:50	C
250	10.66	1:51	
260	11.24	1:53	
270	11.72	1:53	
280	12.24	1:55	
290	12.84	1:55	D
300	13.42	1:56	
310	14.08	1:57	
320	14.72	1:58	
330	15.44	1:58	
340	16.24	1:58	
350	17.14	1:59	E,F
360	18.06	1:59	
370	19.20	2:02	
380	20.30	2:03	
390	21.40	2:03	
400	22.50	2:04	
410	23.40	2:05	
420	24.00	2:05	
430	25.04	2:07	G
440	26.46	2:07	H
450	27.66	2:08	
460	28.48	2:08	
470	29.16	2:09	I
480	29.98	2:09	
490	30.66	2:10	
500	31.20	2:10	
510	31.66	2:10	
520	31.88	2:12	J,K
520	27.72	2:17	L

TABLE VIII (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Time (a.m.)	Notes
520	28.78	2:19	
520	29.50	2:20	
520	31.08	2:23	
520	31.70	2:24	
520	32.30	2:25	M

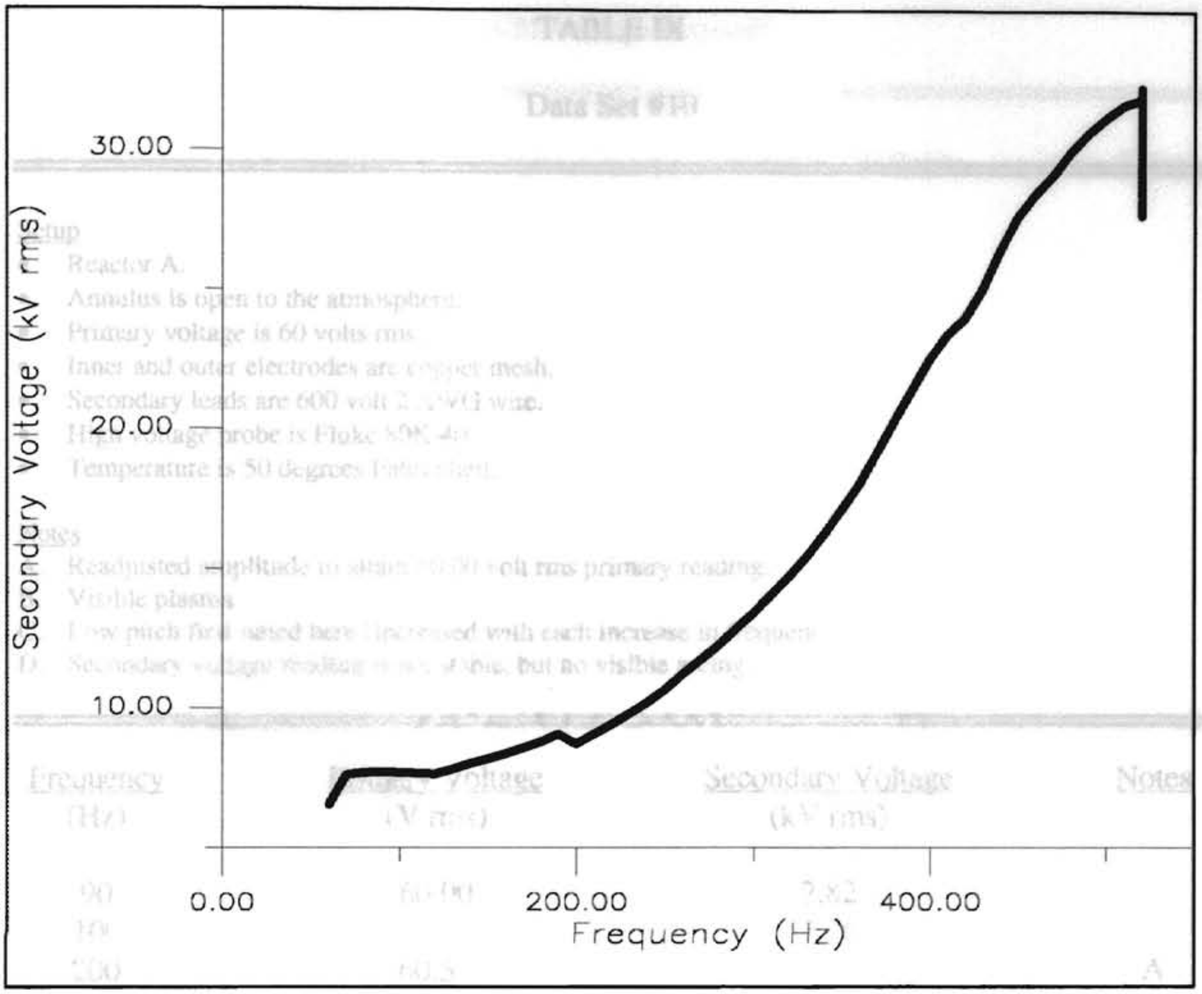


Figure 21. Typical Tuning Plot For Data Set #9 --
Reactor A with annulus open to the atmosphere.

Data Set #9 Analysis

Either the ammeter or the high voltage probe were providing erroneous readings. The power calculated from the readings from these two instruments is near 250 times greater than the maximum power of the power supply. The vertical line in the above plot is the result of multiple readings over a period of time.

TABLE IX

Data Set #10

Setup

- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 60 volts rms.
- Inner and outer electrodes are copper mesh.
- Secondary leads are 600 volt 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Temperature is 50 degrees Fahrenheit.

Notes

A. Readjusted amplitude to attain 60.00 volt rms primary reading.
B. Visible plasma.
C. Low pitch first noted here (increased with each increase in frequency).
D. Secondary voltage reading is not stable, but no visible arcing.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
90	60.00	7.82	
100		7.76	
200	60.51	7	A
300		6.36	
400		6.68	B
300		6.32	B
200		6.96	C
210		6.88	
220		6.8	
230	60.05	6.72	A
240		6.64	
250		6.58	
260		6.52	
270		6.46	
280	60.06	6.42	A
290		6.36	
300		6.32	
310		6.3	
320	60.07	6.26	A
330		6.26	
340		6.28	

(con't.)

TABLE IX (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
360		6.28	
370	60.04	6.32	A
380		6.38	
390	60.10	6.46	A
400		6.62	
410	60.16	6.72	A
420		6.92	
430		6.76	
440		6.6	
450			D

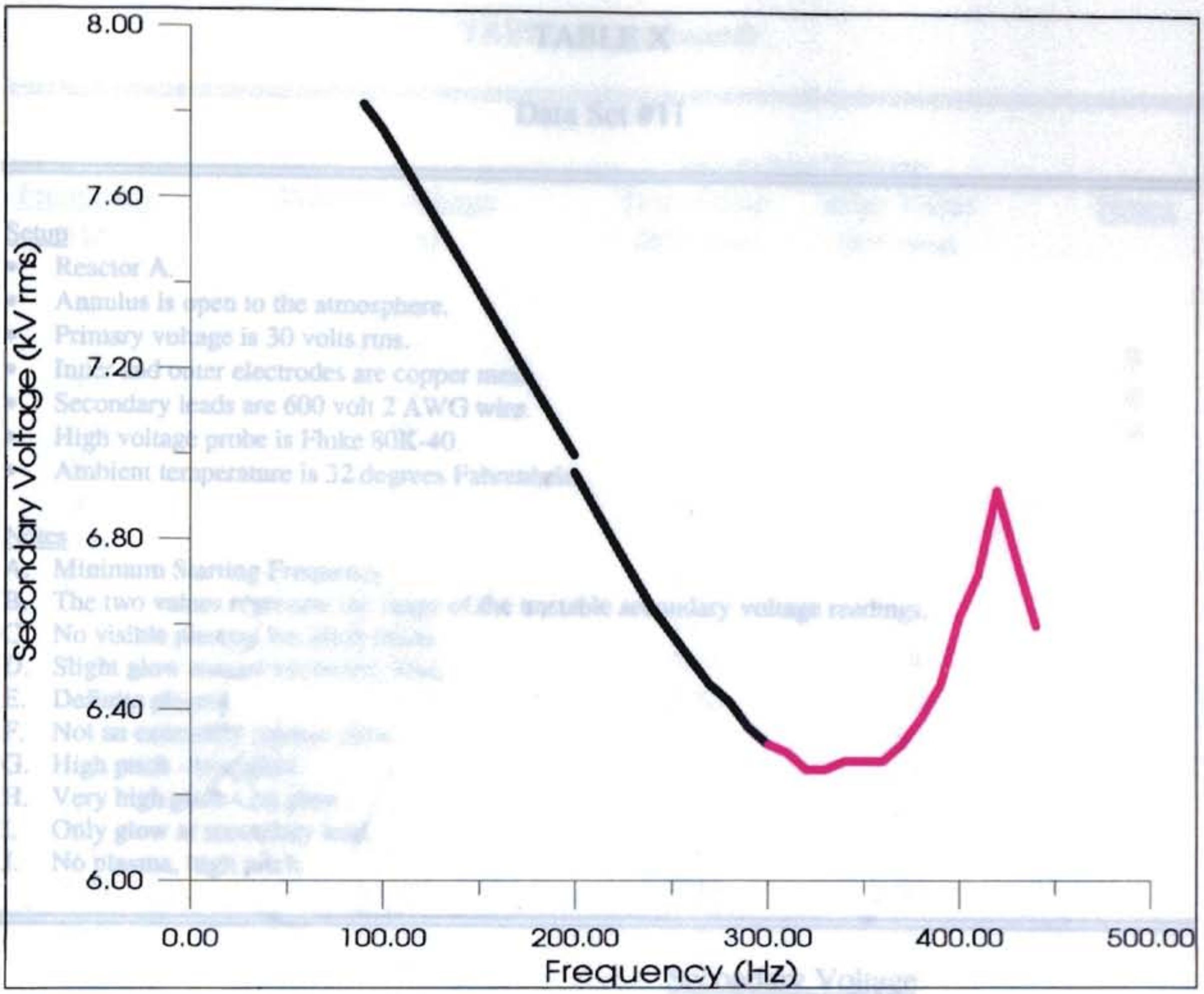


Figure 22. Typical Tuning Plot For Data Set #10.
Reactor A with annulus open to the atmosphere.

Data Set #10 Analysis

Direction of approach does not matter. This discontinuity in the graph is the result of taking 100 Hz frequency steps and then returning back to 200 Hz, quick check and then opposite direction approach.

TABLE X

Data Set #11

Setup
- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 30 volts rms.
- Inner and outer electrodes are copper mesh.
- Secondary leads are 600 volt 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 32 degrees Fahrenheit.

Notes
A. Minimum Starting Frequency
B. The two values represent the range of the unstable secondary voltage readings.
C. No visible plasma, but pitch exists.
D. Slight glow around secondary lead.
E. Definite plasma.
F. Not an extremely intense glow.
G. High pitch - low glow.
H. Very high pitch - no glow.
I. Only glow at secondary lead.
J. No plasma, high pitch.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage Low Value (kV rms)	Secondary Voltage High Value (kV rms)	Notes
44		4.34	4.34	A
45		4.34	4.34	
50		4.32	4.32	
60	30.23	3.08	3.08	
51	30.02	4.30	4.30	
52	30.26	4.26	4.36	B
53	30.26	4.22	4.42	B
54	30.30	4.16	4.48	B
55	30.34	4.04	4.56	B
56	30.36	3.90	4.68	B
57	30.39	3.70	4.80	B
58	30.41	3.40	5.02	B
59	30.45	3.12	5.28	B
60	30.51	5.02	5.02	
70	30.66	4.26	4.26	

(con't.)

TABLE X (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage Low Value (kV rms)	Secondary Voltage High Value (kV rms)	Notes
71	30.67	4.26	4.28	
72	30.68	4.24	4.28	B
73	30.69	4.24	4.28	B
74	30.69	4.24	4.24	B
80	30.72	4.24	4.24	
90	30.76	4.20	4.20	
100	30.79	4.16	4.16	
110	30.82	4.12	4.12	
120	30.84	4.06	4.06	
120	30.84	4.08	4.08	
120	30.84	4.06	4.06	
130	30.86	4.04	4.04	
140	30.92	4.00	4.00	
150	30.93	3.94	3.94	
160	30.94	3.90	3.90	
170	30.95	3.86	3.86	
180	30.96	3.80	3.80	
190	30.97	3.76	3.76	
200	30.98	3.76	3.76	
210	30.99	3.68	3.68	
220	31.00	3.64	3.64	
230	31.01	3.60	3.60	
240	31.02	3.56	3.56	
250	31.03	3.54	3.54	
260	31.04	3.50	3.50	
270	31.05	3.46	3.46	
280	31.05	3.44	3.44	
290	31.06	3.42	3.42	
300	31.08	3.38	3.38	
310	31.10	3.38	3.38	
320	31.10	3.96	3.96	
330	31.11	3.36	3.36	C
340	31.11	3.36	3.36	
350	31.12	3.36	3.36	
360	31.13	3.36	3.36	
370	31.14	3.38	3.38	B

(con't.)

TABLE X (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage Low Value (kV rms)	Secondary Voltage High Value (kV rms)	Notes
380	31.13	3.40	3.40	
390	31.14	3.42	3.42	
400	31.15	3.46	3.46	
410	31.17	3.52	3.52	
420	31.18	3.58	3.58	
430	31.18	3.64	3.64	
440	31.18	3.72	3.72	
450	31.17	3.78	3.78	
460	31.10	3.86	3.86	E
470	31.02	3.92	3.92	
480	30.95	3.94	3.94	
490	30.95	3.94	3.94	F
500	30.88	3.84	3.84	
510	30.78	3.70	3.70	
510	30.78	3.72	3.72	
520	30.70	3.54	3.54	
530	30.70	3.32	3.32	
540	30.70	3.08	3.08	
550	30.73	2.82	2.82	
560	30.77	2.58	2.58	
570	30.82	2.36	2.36	
580	30.84	2.14	2.14	G
590	30.90	1.96	1.96	
600	30.96	1.78	1.78	
600	30.96	1.80	1.80	H
610	31.02	1.64	1.64	
620	31.09	1.54	1.54	
630	31.16	1.44	1.44	I
640	31.26	1.38	1.38	
650	31.31	1.34	1.34	
660	31.33	1.34	1.34	
670	31.34	1.30	1.30	
680	31.37	1.30	1.30	
690	31.38	1.30	1.30	
700	31.39	1.32	1.32	
710	31.40	1.34	1.34	

(con't.)

TABLE X (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage Low Value (kV rms)	Secondary Voltage High Value (kV rms)	Notes
720	31.40	1.36	1.36	J
730	31.42	1.40	1.40	
740	31.42	1.42	1.42	
750	31.44	1.46	1.46	
760	31.46	1.52	1.52	
770	31.47	1.48	1.48	
780	31.48	1.64	1.64	
790	31.49	1.70	1.70	J
800	31.50	1.78	1.78	
810	31.52	1.88	1.88	
870	31.59	2.40	2.40	
880	31.60	2.44	2.44	
890	31.60	2.48	2.48	
900	32.60	2.48	2.48	
910	33.61	2.44	2.44	
920	33.62	2.40	2.40	
930	33.60	2.34	2.34	
940	33.62	2.28	2.28	
950	33.63	2.22	2.22	
960	33.64	2.14	2.14	
970	33.65	2.08	2.08	
980	33.66	2.00	2.00	
990	33.67	1.94	1.94	
1000	33.68	1.88	1.88	
1010	33.69	1.82	1.82	
1020	33.70	1.78	1.78	
1030	33.71	1.74	1.74	
1040	33.72	1.70	1.70	
1050	33.73	1.66	1.66	
1060	33.74	1.62	1.62	
1070	33.75	1.58	1.58	
1080	33.75	1.56	1.56	
1090	33.76	1.54	1.54	
1100	33.77	1.50	1.50	
1110	33.78	1.48	1.48	
1120	33.80	1.46	1.46	

(con't.)

TABLE X (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage Low Value (kV rms)	Secondary Voltage High Value (kV rms)	Notes
	33.80	0.00	0.00	
1200	33.85	1.38	1.38	
1300	33.90	1.28	1.28	
1400	33.94	1.24	1.24	
1500	33.96	1.22	1.22	
1600	33.97	1.22	1.22	
1700	34.03	1.20	1.20	
1800	34.03	1.20	1.20	
1900	34.03	1.20	1.20	
2000	34.04	1.18	1.18	
2100	34.05	1.18	1.18	

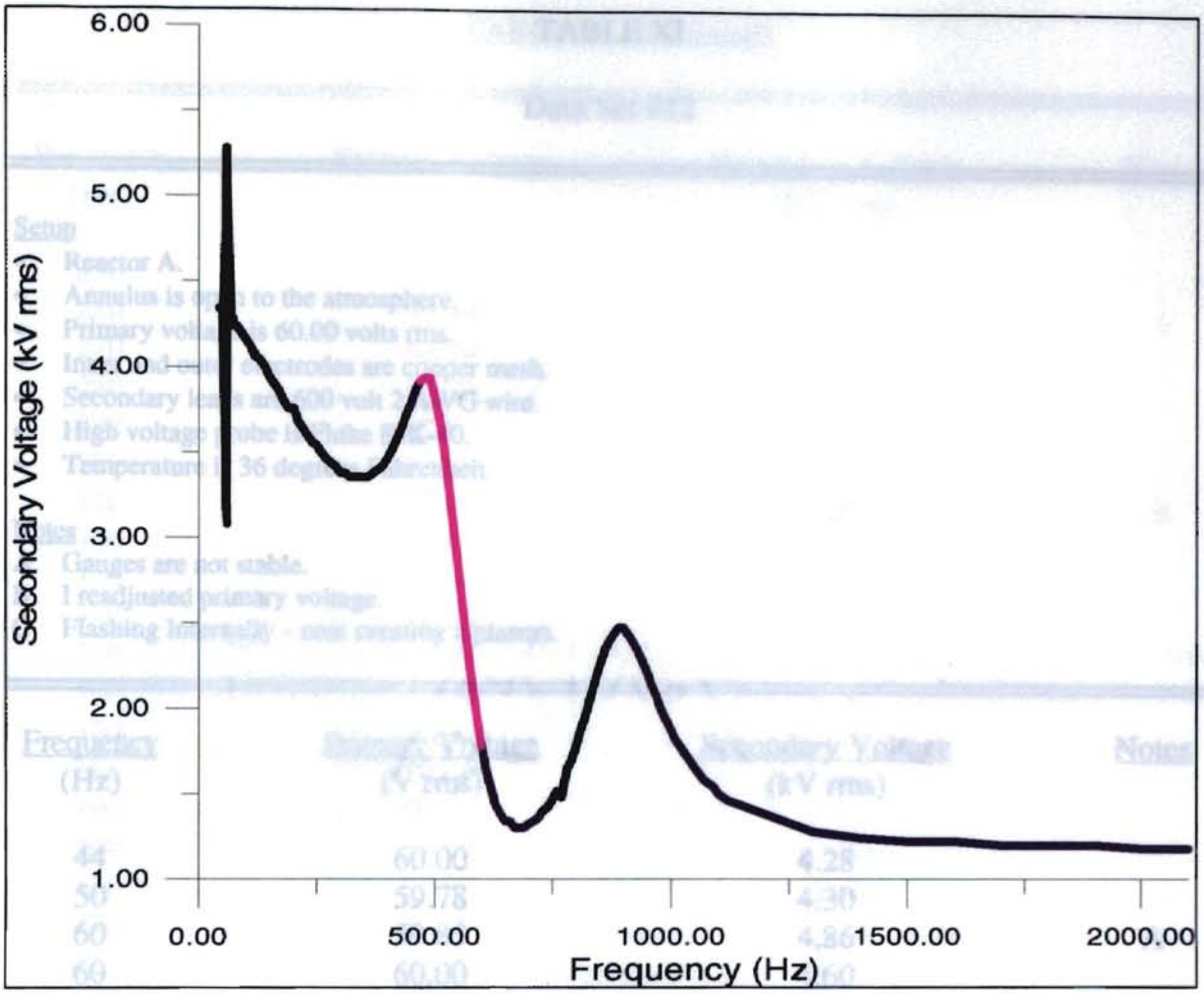


Figure 23. Typical Tuning Plot For Data Set #11.
Reactor A with annulus open to the atmosphere.

Data Set #11 Analysis

Above 74 Hz the secondary reading stabilized, and the plot shows two definite regions of resonance. Looking at Figure 23, the formation of a plasma is not entirely dependent on secondary voltage, otherwise only the highest peaks would have produced plasma.

TABLE XI

Data Set #12

Setup
- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 60.00 volts rms.
- Inner and outer electrodes are copper mesh.
- Secondary leads are 600 volt 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Temperature is 36 degrees Fahrenheit.

Notes
A. Gauges are not stable.
B. I readjusted primary voltage.
C. Flashing Internally - near creating a plasma.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
44	60.00	4.28	
50	59.78	4.30	
60	59.85	4.86	A
60	60.00	4.60	
70	60.00	4.24	
80	59.94	4.22	
90	59.97	4.20	
100	59.97	4.20	
110	60.02	4.20	
120	59.98	4.20	
130	59.98	4.20	
140	59.98	4.20	B
150	59.99	4.22	
160	59.98	4.26	
170	59.99	4.30	
180	59.99	4.38	
190	59.99	4.42	
200	59.98	4.48	
210	59.99	4.56	
220	59.99	4.64	
230	59.99	4.76	
240	60.00	4.88	B

(con't.)

TABLE XI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
250	59.98	5.00	
260	59.99	5.18	
270	59.99	5.34	
280	59.99	5.54	
290	59.99	5.76	
300	59.99	6.04	
310	59.99	6.28	B
320	59.99	6.56	
330	59.99	6.90	
340	59.99	7.26	
350	59.99	7.68	
360	59.99	8.14	
370	60.00	8.66	
380	59.99	9.24	
390	59.97	9.92	
400	59.99	10.70	
410	59.98	11.58	
420	59.99	12.56	
430	59.99	13.78	
440	60.01	15.26	
450	59.99	17.02	
460	59.99	19.20	
470	60.00	21.86	
480	60.18	24.74	
470	60.00	21.78	B
471	60.01	22.06	
472	60.00	22.36	
473	60.00	22.64	
474	60.01	22.92	
475	60.02	23.20	
476	60.02	23.48	
477	60.03	23.78	B
478	60.02	24.16	
479	60.02	24.46	
480	60.02	24.78	
481	60.02	25.10	
482	60.02	25.40	B

(con't.)

TABLE XI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
482	60.00	25.50	
483	60.02	25.82	B
483	60.00	25.86	
484	60.03	26.18	
485	60.02	26.50	
486	60.02	26.70	
487	60.02	27.08	
488	60.02	27.34	
489	60.02	27.82	C

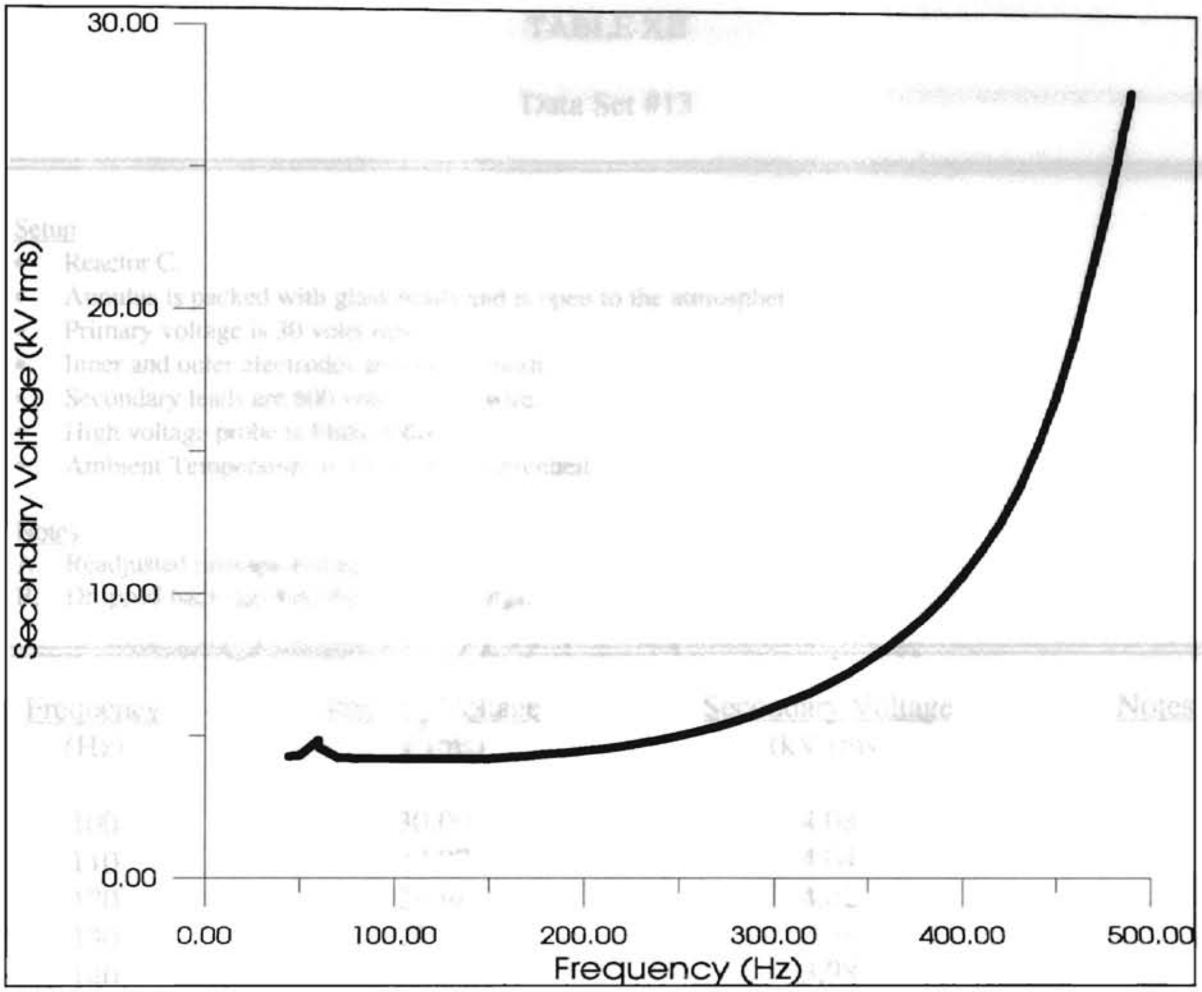


Figure 24. **Typical Tuning Plot For Data Set #12.**
Reactor A with the annulus open to the atmosphere.

Data Set #12 Analysis

Suggest starting above 60 Hz for this power supply - it is unstable below this frequency. Very high secondary voltage reading, I suspect an electrical problem.

TABLE XII

Data Set #13

Setup
- Reactor C.
- Annulus is packed with glass beads and is open to the atmosphere.
- Primary voltage is 30 volts rms.
- Inner and outer electrodes are copper mesh.
- Secondary leads are 600 volt 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Ambient Temperature is 33 degrees Fahrenheit.

Notes
A. Readjusted primary voltage
B. Dropped back and repeated these settings.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	30.00	4.08	
110	29.97	4.04	
120	29.98	4.02	
130	29.98	3.98	
140	29.99	3.98	
150	29.98	3.96	A
150	30.00	3.94	
160	29.99	3.92	
170	29.99	3.92	
180	29.98	3.92	
190	29.99	3.92	
200	30.00	3.94	
210	29.98	3.96	
220	29.99	3.98	
230	29.99	4.02	
240	30.00	4.06	
250	30.00	4.12	
260	30.00	4.18	
270	29.99	4.24	A
280	29.99	4.30	
290	29.98	4.38	
300	29.98	4.48	
310	30.00	4.58	

(con't.)

TABLE XII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
320	30.00	4.68	
330	29.99	4.80	
340	29.99	4.92	
350	30.00	5.06	
360	29.99	5.20	
370	29.99	5.34	
380	30.00	5.50	
390	29.99	5.68	A
370	30.00	5.30	B
380	29.98	5.46	B
390	29.98	5.62	B
400	30.00	5.82	
410	30.00	6.00	
420	30.00	6.20	
430	29.99	6.42	
440	29.99	6.64	
450	29.99	6.90	
460	29.99	7.14	
470	29.99	7.42	
480	30.00	7.72	
490	29.99	8.02	A
500	29.99	8.34	
510	29.99	8.70	
520	29.98	9.10	
530	29.99	9.54	
540	29.99	10.00	
550	29.99	10.48	
560	29.99	11.02	
570	29.99	11.58	
580	29.99	12.16	A
590	29.99	12.72	
600	29.99	13.34	
610	29.99	13.92	
620	29.99	14.40	
630	29.99	14.78	
640	29.99	15.12	
650	29.99	15.38	

(con't.)

TABLE XII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
660	29.99	15.60	A
670	30.00	15.70	
680	30.00	15.76	
690	29.99	15.80	
700	30.00	15.80	
710	30.00	15.80	
720	29.99	15.74	
730	30.00	15.70	
740	29.99	15.66	
750	29.99	15.60	
760	30.00	15.54	
770	30.00	15.40	
780	29.99	15.34	
790	29.99	15.24	
800	30.00	15.12	
810	29.98	14.98	A
810	30.00	14.98	
820	29.98	14.84	
830	29.97	14.70	
840	30.00	14.50	
850	29.99	14.34	
860	29.99	14.16	
870	30.00	14.00	
880	29.99	13.80	A
880	30.00	13.74	
890	29.98	13.54	
900	29.99	13.32	
910	29.99	13.08	
920	29.99	12.82	
930	29.99	12.52	
940	29.99	12.16	
950	29.99	11.78	
960	29.99	11.34	
970	30.00	10.88	
980	29.99	10.38	A
980	30.00	10.36	
990	29.99	9.86	

(con't.)

TABLE XII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
1000	29.98	9.36	
1010	29.99	8.86	
1020	29.99	8.40	
1030	30.00	7.92	
1040	29.99	7.50	
1050	29.99	7.12	
1060	30.00	6.74	
1070	30.00	6.42	
1080	30.00	6.12	
1090	29.99	5.84	
1100	29.99	5.60	

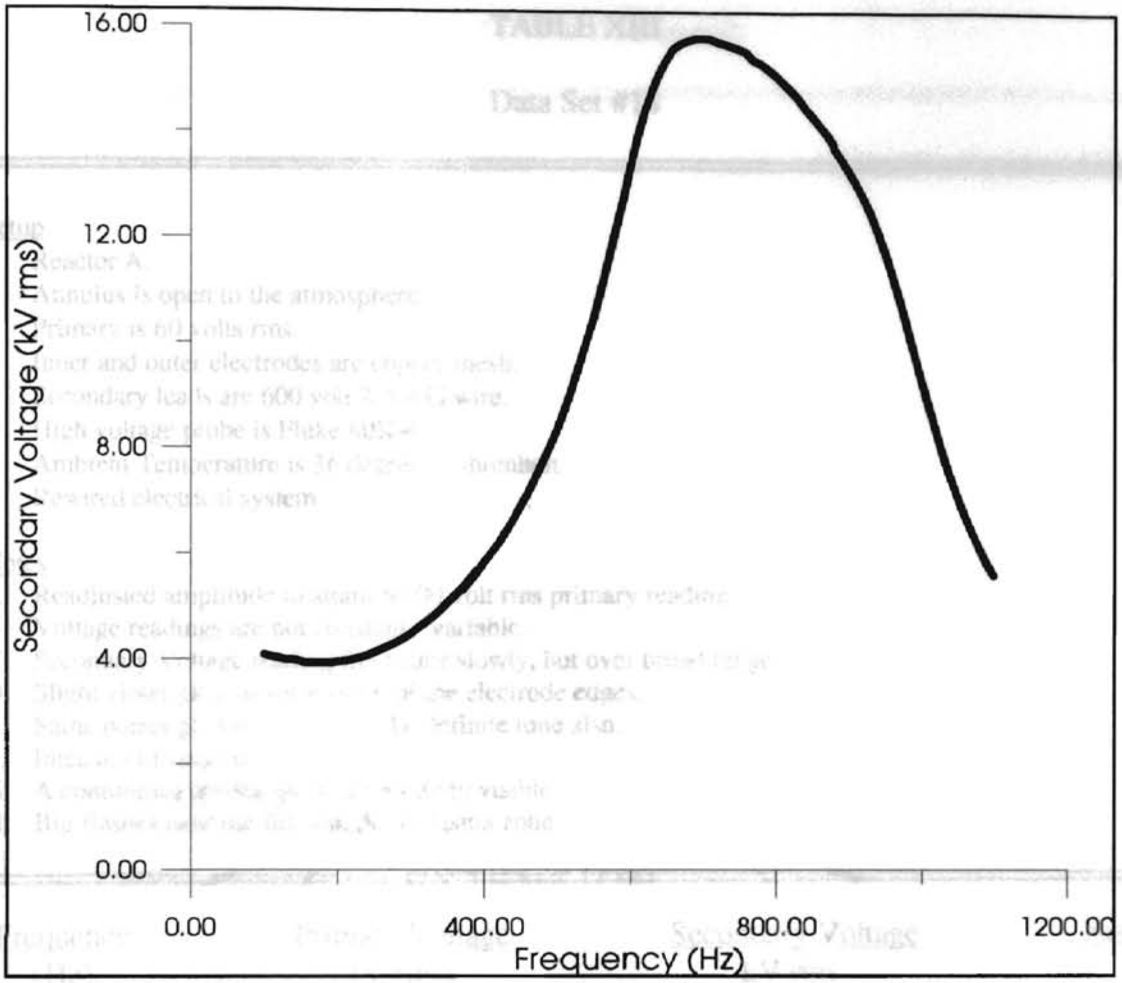


Figure 25. Typical Tuning Plot For Data Set #13.
Reactor C with annulus open to the atmosphere.

<u>Data Set #13 Analysis</u>

The secondary voltage is higher than the 15 kV transformer rating. The graphed voltages should be more than sufficient to produce a plasma, but there is not an observation.

TABLE XIII

Data Set #14

Setup

- Reactor A.
- Annulus is open to the atmosphere.
- Primary is 60 volts rms.
- Inner and outer electrodes are copper mesh.
- Secondary leads are 600 volt 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Ambient Temperature is 36 degrees Fahrenheit.
- Rewired electrical system.

Notes

A. Readjusted amplitude to attain 60.00 volt rms primary reading.
B. Voltage readings are not constant - variable.
C. Secondary Voltage reading fluctuates slowly, but over broad range.
D. Slight violet glow at some point of the electrode edges.
E. Same points glowing as in note D, definite tone also.
F. Intensity of spots is increasing.
G. A continuous plasma glow is becoming visible.
H. Big flashes near the full length of plasma zone.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage kV rms)	Notes
100	60.00	7.66	
90	59.95	7.72	
80	59.98	7.76	A
80	60.00	7.80	
70	59.80	7.84	
60	59.56	7.78	A,B
100	60.00	7.66	
110	60.05	7.60	A
110	60.00	7.60	
120	60.04	7.52	A
120	60.00	7.52	
130	60.03	7.44	A
130	60.00	7.44	
140	60.03	7.38	A
140	60.00	7.36	
150	60.03	7.30	A
150	60.00	7.30	

(con't.)

TABLE XIII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage kV rms)	Notes
160	60.02	7.22	A
160	60.00	7.22	
170	60.02	7.16	A
180	60.02	7.10	A
180	60.00	7.08	
190	60.03	7.02	A
200	60.03	6.96	A,C
210	60.03	6.90	A
220	60.02	6.86	A
220	60.00	6.86	
230	60.02	6.82	A
240	60.02	6.78	A
250	60.03	6.76	A
260	60.02	6.74	A
270	60.02	6.74	A
280	60.02	6.76	A,D
290	60.01	6.78	A
300	60.01	6.86	A
310	60.02	6.90	A
320	60.02	7.00	A,E
330	60.03	7.12	A
340	60.01	7.26	A
350	60.02	7.44	A
360	60.01	7.64	A
370	60.02	7.92	A
380	60.01	8.22	A,E,F
390	60.01	8.60	A
400	60.00	9.10	A,G
410	60.01	9.66	A
420	59.85	10.44	H

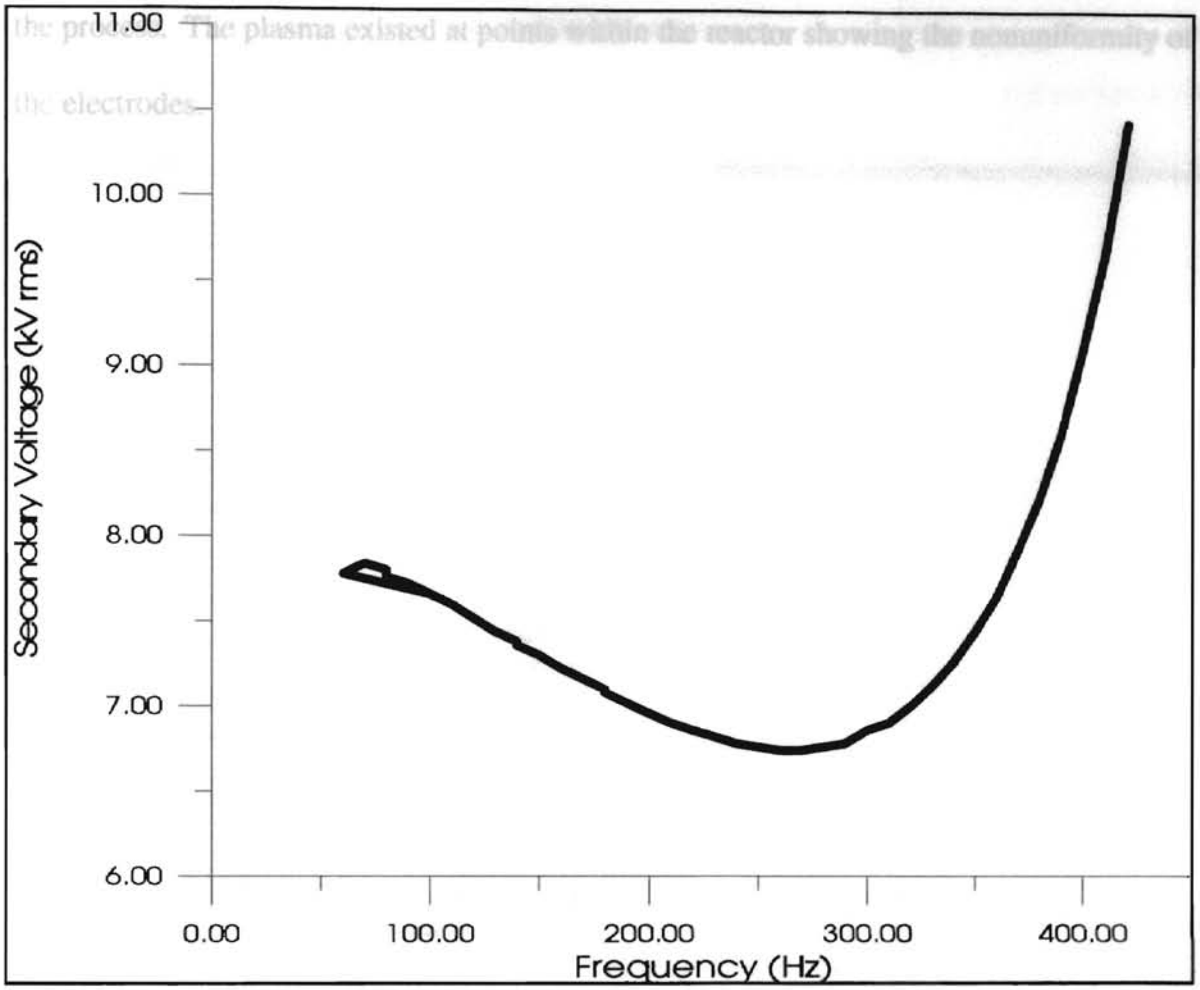


Figure 26. Typical Tuning Plot For Data Set #14.
Reactor A with the annulus open to the atmosphere.

Data Set #14 Analysis

I have had problems operating with frequencies below 100 Hz, I assume this is dependent on the power supply. Secondary reading fluctuation slowly holds longest on 3.48 (3.48 --> 3.47 --> 2.48 --> 3.48). At the last data entry, readings varied. The plasma began flashing from the top of the electrode to within four inches down. This was not arcing, but flashed with a loud buzz and intense violent flashes. The meters vary during the process. The plasma existed at points within the reactor showing the nonuniformity of the electrodes.

Data Set #15

Setup
- Reactor A
- Annulus is open to the atmosphere
- Primary voltage is 60 volts rms
- Inner electrode is 304" copper [illegible]
- Outer electrode is copper mesh
- Secondary leads are 600 volt 2 AWG wire
- High voltage probe is Fluke 80k-[illegible]
- Temperature is 38 degrees [illegible]

Notes
A. Readjusted primary [illegible]
B. Secondary voltage [illegible] constant (3.48-> 3.4[illegible]-> 2.[illegible]-> 3.48)
C. Left the [illegible] the amount of time
D. Did not [illegible]
E. [illegible]
F. High [illegible]
G. Stayed [illegible]
H. Meters are not [illegible]
    - Primary [illegible] approximately 60.5 volts rms
    - Secondary [illegible] approximately 5.15, which corresponds to 10.3 kV rms
    - [illegible] radio interference
    - Readjusting [illegible] was not successful; still fluctuating
    - [illegible] in the reactor

Frequency (Hz)	Primary Voltage (rms)	Secondary Voltage (kV rms)	Notes
100	60.[illegible]	7.64	
110	[illegible]	[illegible].58	
120	60.0[illegible]	7.50	
130	[illegible]	7.44	
140	[illegible]	7.36	
150	60.08	7.30	
160	[illegible]	7.24	
170	6[illegible]	7.18	
17[illegible]	[illegible]	[illegible]	
180	[illegible]	[illegible]	
190	[illegible]	[illegible]	
200	[illegible]	[illegible]	
210	[illegible]		B, (con't.)

TABLE XIV

Data Set #15

Setup
- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 60 volts rms.
- Inner electrode is 3/4" copper pipe.
- Outer electrode is copper mesh.
- Secondary leads are 600 volt 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Temperature is 38 degrees Fahrenheit.

Notes
A. Readjusted primary voltage.
B. Secondary voltage readings are not constant. (3.48--> 3.47--> 2.48--> 3.48).
C. Left this running here for considerable amount of time.
D. Did not readjust primary voltage.
E. Humming.
F. High pitch.
G. Stayed steady for prolonged time.
H. Meters are not stable.
    - Primary is reading approximately 60.5 volts rms.
    - Secondary is reading approximately 5.15, which corresponds to 10.3 kV rms.
    - Causing radio interference.
    - Readjusting primary to 60 was not successful; still fluctuating!
    - I could see some plasma in the reactor.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	60.00	7.64	
110	60.04	7.58	
120	60.08	7.50	
130	60.12	7.44	A
140	60.03	7.36	
150	60.06	7.30	
160	60.08	7.24	
170	60.11	7.18	A
170	60.00	7.16	
180	60.01	7.10	
190	60.03	7.04	
200	60.04	7.00	
210	60.06	6.94	B

(con't.)

TABLE XIV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
220	60.08	6.92	
230	60.10	6.88	A
240	60.02	6.86	
250	60.04	6.86	
260	60.05	6.86	C
260	60.01	6.86	D
270	60.04	6.88	E
280	60.05	6.92	
290	60.07	6.98	
300	60.08	7.04	
310	60.09	7.16	
320	60.10	7.28	
320	60.00	7.28	A, F
330	60.02	7.44	
330	59.98	7.44	
340	60.00	7.62	
350	60.01	7.84	
360	60.03	8.12	
370	60.05	8.46	G
380	60.06	8.84	H

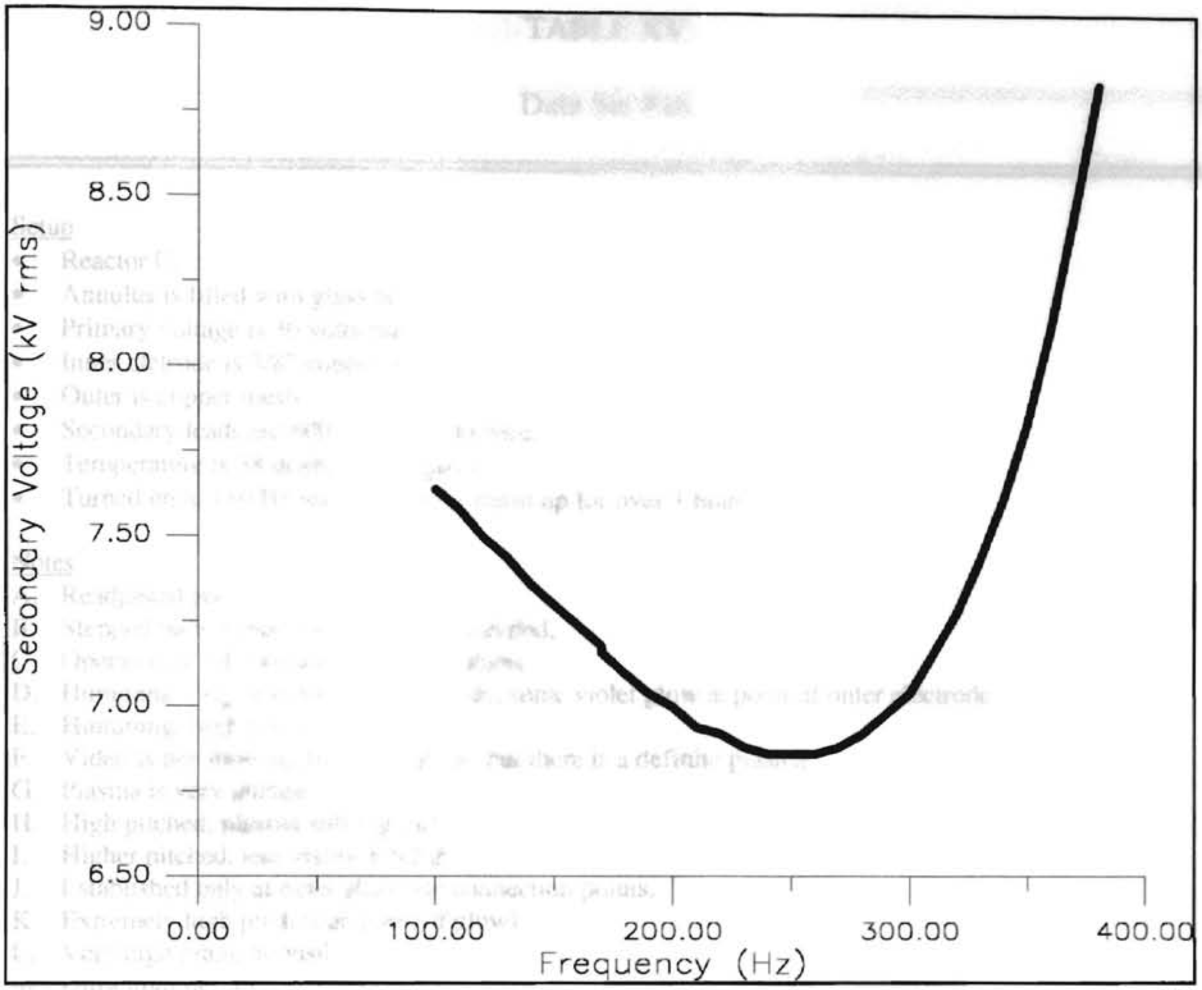


Figure 27. Typical Tuning Plot For Data Set #15.
Reactor A with the annulus open to the atmosphere.

Data Set #15 Analysis

This setup was on the verge of creating a plasma at the last setting but the meters were unstable.

TABLE XV

Data Set #16

Setup

- Reactor C.
- Annulus is filled with glass beads.
- Primary voltage is 30 volts rms.
- Inner elctrode is 3/8" copper pipe.
- Outer is copper mesh.
- Secondary leads are 600 volt 2 AWG wire.
- Temperature is 38 degrees Fahrenheit.
- Turned on at 110 Hz and allowed to warm up for over 1 hour.

Notes

A. Readjusted primary voltage.
B. Stepped back to 100 Hz and then proceeded.
C. Operated at this frequency for 20 minutes.
D. Humming, very uneven outer electrode, some violet glow at point of outer electrode.
E. Humming; high pitch.
F. Video is not showing luminous glow, but there is a definite plasma.
G. Plasma is very intense
H. High pitched, plasma still present.
I. Higher pitched, less visible after time.
J. Established only at outer electrode connection points.
K. Extremely high pitch (one point of glow).
L. Very high pitch, no visible glow.
M. Ultra high pitch.
N. Quieter, but higher pitch.
O. Almost impossible to hear now.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
110	30.00	3.94	
110	30.08	3.96	A
110	30.00	3.94	
100	29.97	4.00	B
110	29.99	3.94	
120	30.02	3.88	
130	30.04	3.84	
140	30.05	3.78	
150	30.07	3.72	
160	30.08	3.66	
170	30.09	3.60	

(con't.)

TABLE XV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
180	30.10	3.52	A
180	30.00	3.54	
190	30.02	3.48	
200	30.03	3.42	
210	30.04	3.36	
220	30.05	3.30	
230	30.06	3.24	B
240	29.98	3.20	
250	29.98	3.14	
260	29.99	3.10	
270	30.00	3.04	
280	30.02	3.00	
290	30.04	2.98	
300	30.07	2.94	
310	30.08	2.90	
320	30.09	2.88	
330	30.09	2.86	
340	30.11	2.84	A
340	30.00	2.82	
350	30.02	2.82	
360	30.04	2.80	
370	30.05	2.80	
380	30.05	2.80	
390	30.07	2.80	
400	30.08	2.82	C
400	30.02	2.82	
410	30.04	2.84	
420	30.05	2.86	D
430	30.08	2.90	
440	30.10	2.94	A
440	30.00	2.92	
450	30.02	2.98	
460	30.04	3.02	
470	30.05	3.10	E
480	30.07	3.16	
490	30.08	3.24	
500	30.10	3.34	A

(con't.)

TABLE XV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
510	30.01	3.44	
520	30.02	3.56	
530	30.03	3.70	
540	30.04	3.84	
550	30.04	3.98	
560	30.06	4.14	F
560	30.04	4.22	
570	30.05	4.36	
580	30.06	4.48	
590	30.05	4.60	
600	30.05	4.64	
610	30.06	4.68	
620	30.06	4.70	
620	30.04	4.64	
630	30.05	4.66	
640	30.06	4.64	
650	30.06	4.64	
660	30.08	4.60	
670	30.09	4.58	
680	30.10	4.54	A
690	30.01	4.52	
700	30.02	4.48	G
710	30.04	4.44	
720	30.04	4.42	
730	30.05	4.40	
740	30.05	4.34	
750	30.07	4.30	
760	29.98	4.26	G
770	30.00	4.24	
780	30.01	4.20	
790	30.02	4.16	
800	30.01	4.14	
810	30.02	4.10	
820	30.04	4.08	H
830	30.05	4.04	
840	30.07	4.00	
850	30.07	3.98	I

(con't.)

TABLE XV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
860	30.09	3.94	
870	30.10	3.92	A
880	30.01	3.88	
890	30.02	3.84	I
900	30.03	3.80	
910	30.04	3.74	
920	30.05	3.66	J
930	30.06	3.58	
940	30.06	3.48	J
950	30.07	3.36	
960	30.08	3.24	
970	30.08	3.12	K
980	30.10	2.96	
990	30.11	2.86	A
1000	30.02	2.76	
1010	30.03	2.64	
1020	30.04	2.52	
1030	30.04	2.42	
1040	30.04	2.30	
1050	30.04	2.22	
1060	30.05	2.00	L
1070	30.06	2.04	
1080	30.07	1.96	
1090	30.09	1.90	
1100	30.08	1.84	
1110	30.09	1.78	
1120	30.11	1.72	A, M
1130	30.00	1.68	
1140	30.01	1.64	
1150	30.01	1.60	
1160	30.02	1.56	
1170	30.02	1.52	
1180	30.03	1.50	
1190	30.03	1.46	
1200	30.04	1.44	M
1210	30.04	1.42	
1220	30.04	1.38	

(con't.)

TABLE XV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
1230	30.05	1.36	
1240	30.06	1.36	
1250	30.06	1.34	
1260	30.07	1.32	N
1270	30.07	1.30	
1280	30.07	1.28	
1290	30.08	1.26	
1300	30.08	1.26	O

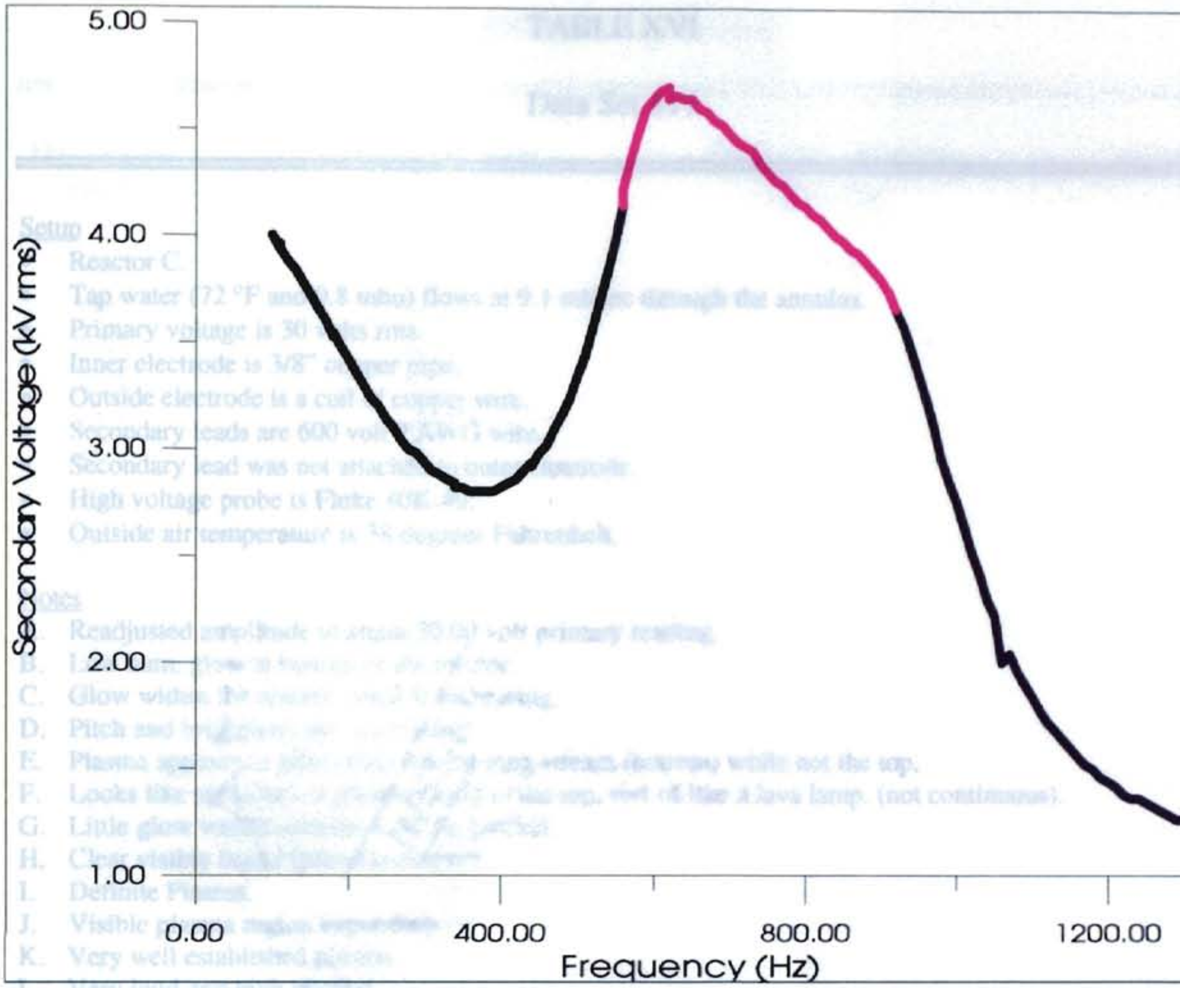


Figure 28. Typical Tuning Plot For Data Set #16.
Reactor C with moist glass beads and air occupying the annulus.

<u>Data Set #16 Analysis</u>

I attempted to improve observation by using a fixed video camera in the bay to view the plasma reactor. My video camera would not film the plasma discharge. The plot shows signs of resonance with the plasma coinciding with the peak of the curve.

TABLE XVI

Data Set #17

Setup

- Reactor C.
- Tap water (72 °F and 0.8 mho) flows at 9.1 ml/sec through the annulus.
- Primary voltage is 30 volts rms.
- Inner electrode is 3/8" copper pipe.
- Outside electrode is a coil of copper wire.
- Secondary leads are 600 volt 2 AWG wire.
- Secondary lead was not attached to outer electrode.
- High voltage probe is Fluke 80K-40.
- Outside air temperature is 38 degrees Fahrenheit.

Notes

A. Readjusted amplitude to attain 30.00 volt primary reading.
B. Low hum, glow at bottom of the reactor.
C. Glow within the reactor, pitch is increasing.
D. Pitch and brightness are increasing.
E. Plasma appears to affect only the entering stream (bottom) while not the top.
F. Looks like splotches of plasma rising to the top, sort of like a lava lamp. (not continuous).
G. Little glow within annulus near the bracket.
H. Clear visible liquid (plasma) channel.
I. Definite Plasma.
J. Visible plasma region expanding.
K. Very well established plasma.
L. Very loud and high pitched.
M. Plasma appears to be losing intensity.
N. Full plasma, but faint glow, high pitch.
O. Glow is almost gone.
P. Super high pitch, no visible glow.
Q. High soft pitch, almost silent.
R. Nothing.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	30.00	1.98	
110	30.03	1.95	
120	30.05	1.92	
130	30.06	1.89	
140	30.08	1.85	
150	30.09	1.82	
160	30.11	1.79	A
160	30.00	1.78	

(con't.)

TABLE XVI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
170	30.02	1.75	
180	30.03	1.71	
190	30.04	1.67	
200	30.05	1.64	
210	30.07	1.61	
220	30.08	1.57	
230	30.08	1.54	
240	30.10	1.51	A
240	30.00	1.50	
250	30.02	1.48	
260	30.03	1.44	
270	30.04	1.41	
280	30.05	1.38	
290	30.06	1.36	
300	30.08	1.33	
310	30.09	1.31	B
320	30.08	1.28	
330	30.09	1.26	
340	30.10	1.24	A,C
350	30.03	1.22	
360	30.04	1.20	
370	30.05	1.19	D
380	30.06	1.17	E
390	30.07	1.16	
400	30.07	1.15	F
410	30.08	1.14	
420	30.10	1.13	A,G
430	30.01	1.12	
440	30.04	1.12	D
450	30.05	1.12	D
460	30.06	1.12	D
470	30.06	1.12	
480	30.07	1.12	
490	30.08	1.13	H
500	30.10	1.13	A
510	30.02	1.14	
520	30.03	1.15	I

(con't.)

TABLE XVI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
530	30.03	1.16	
540	30.04	1.17	J
550	30.05	1.19	
560	30.03	1.21	
570	30.04	1.23	
580	30.05	1.26	
590	30.06	1.29	
600	30.07	1.32	K
610	30.08	1.36	
620	30.09	1.40	
630	30.10	1.44	A
640	30.02	1.48	
650	30.03	1.54	
660	30.04	1.59	
670	30.05	1.65	
680	30.06	1.71	
690	30.07	1.78	
700	30.08	1.85	
710	30.09	1.94	
720	30.10	2.02	A,L
730	30.01	2.11	
740	30.01	2.20	L
750	30.02	2.31	
760	30.03	2.43	M
770	30.04	2.55	
780	30.05	2.70	N
790	30.06	2.85	
800	30.07	3.04	N
810	30.08	3.23	
820	30.10	3.45	A
820	30.00	3.44	
830	30.02	3.68	N,O
840	30.02	3.95	O
850	30.02	4.25	
860	30.03	4.56	
870	30.05	4.89	
880	30.06	5.19	P

(con't.)

TABLE XVI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
890	30.05	5.42	
900	30.05	5.58	
910	30.05	5.66	
920	30.05	5.67	P
930	30.05	5.59	
940	30.05	5.45	
950	30.05	5.25	
960	30.05	5.01	P
970	30.05	4.77	
980	30.06	4.50	
990	30.06	4.24	
1000	30.08	3.99	Q
1010	30.09	3.76	
1110	30.17	2.20	R
1220	30.24	1.43	

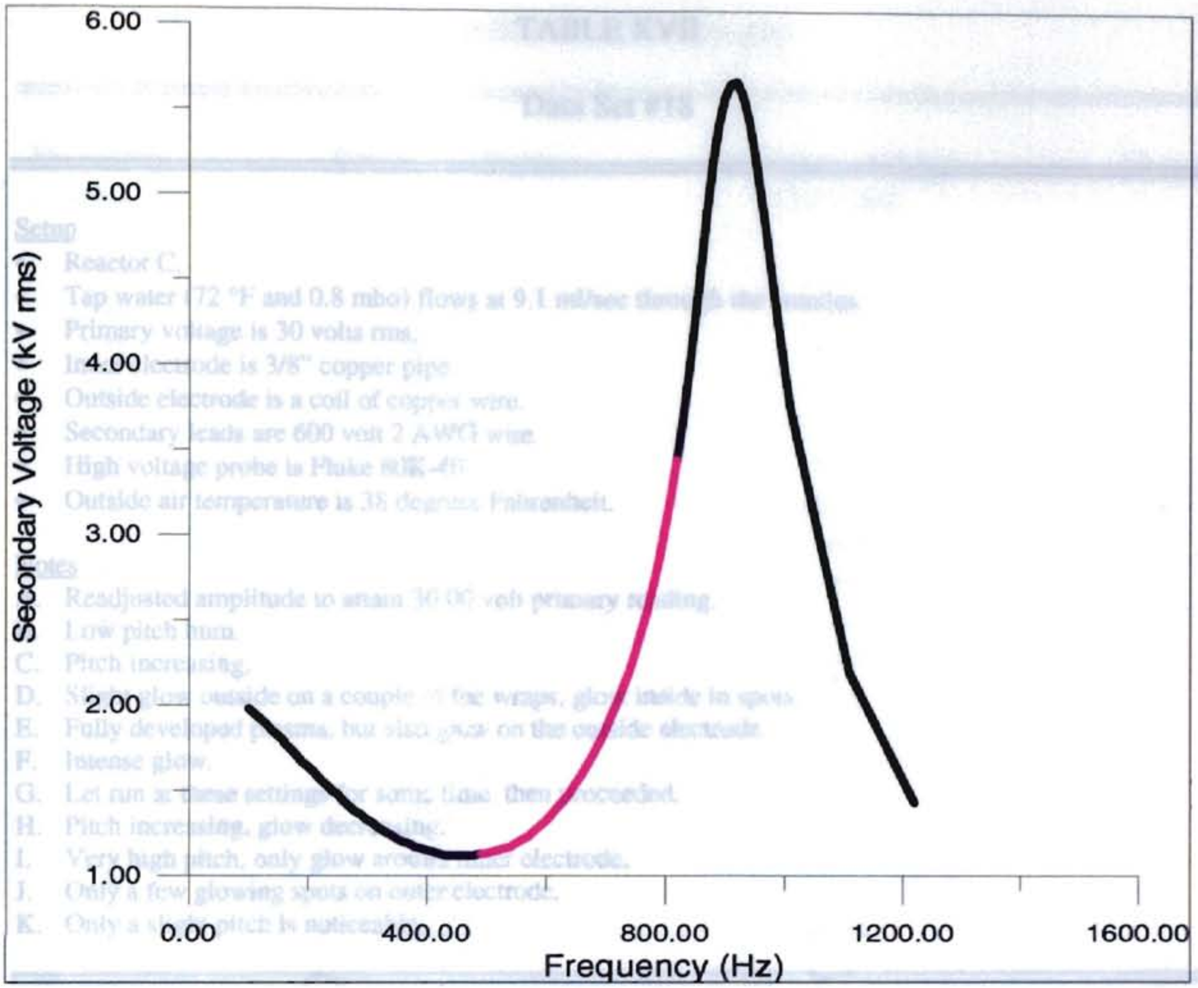


Figure 29. **Typical Tuning Plot For Data Set #17.**
Reactor C with tap water flowing through the annulus filled with glass bead. Only one electrode is attached.

Data Set #17 Analysis

The plasma does not exist at the peak in this curve where the most intense plasma is expected. Would not have expected a plasma with only one electrode attached, and yet there was a bright plasma and a distinct resonance type curve is present.

TABLE XVII

Data Set #18

Setup
- Reactor C.
- Tap water (72 °F and 0.8 mho) flows at 9.1 ml/sec through the annulus.
- Primary voltage is 30 volts rms.
- Inner electrode is 3/8" copper pipe.
- Outside electrode is a coil of copper wire.
- Secondary leads are 600 volt 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Outside air temperature is 38 degrees Fahrenheit.

Notes
A. Readjusted amplitude to attain 30.00 volt primary reading.
B. Low pitch hum.
C. Pitch increasing.
D. Slight glow outside on a couple of the wraps, glow inside in spots.
E. Fully developed plasma, but also glow on the outside electrode.
F. Intense glow.
G. Let run at these settings for some time, then proceeded.
H. Pitch increasing, glow decreasing.
I. Very high pitch, only glow around inner electrode.
J. Only a few glowing spots on outer electrode.
K. Only a slight pitch is noticeable.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	30.00	3.98	
110	30.03	3.92	
120	30.04	3.86	
130	30.06	3.82	
140	30.07	3.76	
150	30.08	3.70	
160	30.10	3.64	A
170	30.02	3.58	
180	30.03	3.52	
190	30.05	3.46	
200	30.06	3.40	
210	30.07	3.34	
220	30.09	3.28	B
230	30.10	3.24	A
240	30.01	3.18	C

(con't.)

TABLE XVII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
250	30.02	3.14	
260	30.03	3.08	
270	30.05	3.04	
280	30.06	3.00	
290	30.07	2.98	
300	30.08	2.94	C
310	30.10	2.92	A
310	30.00	2.90	
320	30.02	2.88	
330	30.04	2.88	
340	30.05	2.86	
350	30.07	2.86	
360	30.06	2.84	D
370	30.07	2.86	
380	30.08	2.86	
390	30.09	2.90	
400	30.11	2.92	A
410	30.02	2.96	
420	30.03	3.00	
430	30.02	3.04	E
440	30.04	3.12	
450	30.06	3.22	
460	30.07	3.32	
470	30.08	3.46	
480	30.10	3.62	A
480	30.00	3.58	
490	30.02	3.78	F,G
490	30.01	3.66	
500	30.02	3.84	
510	30.03	4.04	
520	30.04	4.20	
530	30.05	4.36	
540	30.06	4.46	
550	30.07	4.54	
560	30.08	4.60	
570	30.08	4.64	F,G

(con't.)

TABLE XVII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
570	30.04	4.32	
580	30.05	4.34	
590	30.05	4.34	G
590	30.04	4.24	
600	30.06	4.24	
610	30.00	4.24	
620	30.08	4.20	
630	30.09	4.20	
640	30.10	4.18	A,F
650	30.01	4.14	
660	30.02	4.10	
670	30.03	4.10	
680	30.05	4.06	
690	30.06	4.06	
700	30.08	4.02	
710	30.08	4.00	E
720	30.09	3.96	
730	30.10	3.92	A
730	30.00	3.90	
740	30.01	3.86	
750	30.02	3.82	
760	30.02	3.76	
770	30.03	3.72	
780	30.04	3.68	
790	30.05	3.62	
800	30.06	3.56	
810	30.07	3.52	H
820	30.07	3.46	
830	30.07	3.40	
840	30.09	3.34	
850	30.11	3.28	A
850	30.00	3.26	
860	30.01	3.20	I
870	30.02	3.12	
880	30.04	3.06	

(con't.)

TABLE XVII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
890	30.05	3.00	
900	30.06	2.94	I
910	30.07	2.84	
920	30.08	2.78	
930	30.09	2.70	
940	30.10	2.64	A
950	30.02	2.56	J
960	30.03	2.48	
970	30.04	2.40	
980	30.06	2.34	
990	30.07	2.26	
1000	30.09	2.20	K

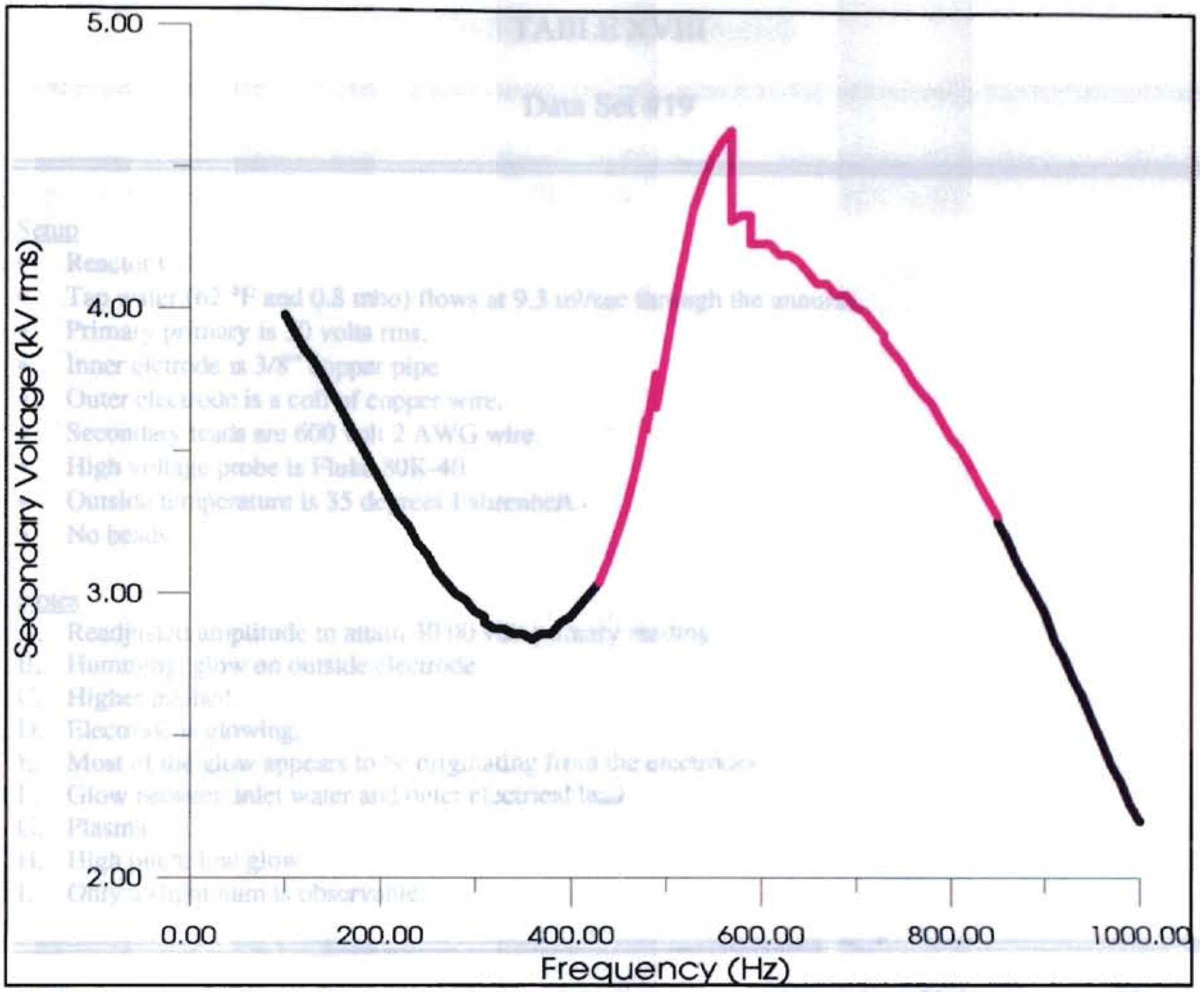


Figure 30. **Typical Tuning Plot For Data Set #18.**
Reactor C with tap water flowing through the annulus filled with glass beads.

Data Set #18 Analysis

Same as data set #17, but with both electrodes attached. The secondary voltage decreased significantly when ran for extended time at 590 Hz.

TABLE XVIII

Data Set #19

Setup

- Reactor C.
- Tap water (62 °F and 0.8 mho) flows at 9.3 ml/sec through the annulus.
- Primary primary is 30 volts rms.
- Inner elctrode is 3/8" copper pipe.
- Outer electrode is a coil of copper wire.
- Secondary leads are 600 volt 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Outside temperature is 35 degrees Fahrenheit.
- No beads.

Notes

A. Readjusted amplitude to attain 30.00 volt primary reading.
B. Humming, glow on outside electrode.
C. Higher pitched.
D. Electrode is glowing.
E. Most of the glow appears to be originating from the electrodes.
F. Glow between inlet water and outer electrical lead.
G. Plasma.
H. High pitch, low glow.
I. Only a slight hum is observable.

Time (pm/am)	Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
8:15	100	30.00	4.00	
9:20	100	30.00	4.00	
9:20	110	30.03	3.96	
9:21	120	30.02	3.90	
9:48	120	30.03	3.90	
9:48	130	30.02	3.84	
9:49	140	30.03	3.78	
9:49	150	30.04	3.72	A
9:52	150	30.04	3.72	
9:52	160	30.05	3.66	A
9:53	170	30.02	3.60	
9:53	180	30.03	3.54	
9:54	190	30.04	3.46	
9:54	200	30.05	3.42	
9:54	210	30.07	3.36	A

(con't.)

TABLE XVIII (continued)

Time (pm/am)	Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
9:55	220	30.07	3.30	
9:56	230	30.00	3.24	
9:56	240	30.00	3.18	
9:56	250	30.01	3.12	
10:06	260	30.02	3.08	
10:06	270	30.03	3.04	A
12:00	270	30.04	3.04	
12:00	280	30.06	3.00	
12:00	290	30.07	2.96	
12:00	300	30.08	2.92	
12:02	310	30.07	2.90	
12:03	320	30.07	2.88	
	330	30.08	2.88	
	340	30.10	2.86	
	350	30.11	2.86	
	360	30.02	2.86	
12:05	370	30.03	2.88	
12:07	380	30.03	2.88	
	390	30.04	2.92	
	400	30.05	2.96	A
	410	30.06	3.02	
12:09	420	30.06	3.08	B
	430	30.07	3.18	
	440	30.08	3.30	
12:10	450	30.09	3.44	
	460	30.10	3.60	C
	470	30.10	3.80	D
	480	30.11	4.08	
	490	30.11	4.30	
	500	30.11	4.52	E
	510	30.11	4.66	
	520	30.11	4.80	
	530	30.11	4.88	
	540	30.12	4.92	
	550	30.13	4.96	
	560	30.14	4.96	
	570	30.13	4.98	

(con't.)

TABLE XVIII (continued)

Time (pm/am)	Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
12:15	580	30.15	5.00	
12:40	580	30.23	5.02	
1:32	580	30.20	5.08	
1:33	590	30.00	5.06	
1:33	600	30.03	5.06	
1:50	600	30.05	5.08	
1:50	610	30.06	5.06	
1:51	620	30.07	5.04	A,F
2:27	620	30.09	5.02	
	630	30.09	5.00	
2:28	640	30.11	4.96	
	650	30.01	4.90	
	660	30.02	4.88	
	670	30.02	4.80	
2:29	680	30.04	4.76	
	690	30.04	4.68	A
	700	30.05	4.64	
	710	30.06	4.56	
2:31	720	30.05	4.50	
	730	30.06	4.42	
	740	30.07	4.34	
	750	30.08	4.26	
2:32	760	30.09	4.18	G
	770	30.10	4.12	
	780	30.01	4.02	
	790	30.02	3.94	
2:33	800	30.02	3.86	
2:35	810	30.03	3.78	
	820	30.04	3.68	
	830	30.05	3.60	
	840	30.06	3.50	
	850	30.06	3.42	
	860	30.07	3.34	H
	870	30.08	3.24	
	880	30.09	3.18	
	890	30.10	3.10	
	900	30.13	3.04	

(con't.)

TABLE XVIII (continued)

Time (pm/am)	Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
	910	30.13	2.94	
	920	30.14	2.86	
	930	30.15	2.78	
2:37	940	30.16	2.68	
	950	30.02	2.58	
	960	30.03	2.50	
	970	30.04	2.42	
	980	30.05	2.34	
	990	30.06	2.30	A
	1000	30.09	2.24	
	1000	30.00	0.00	

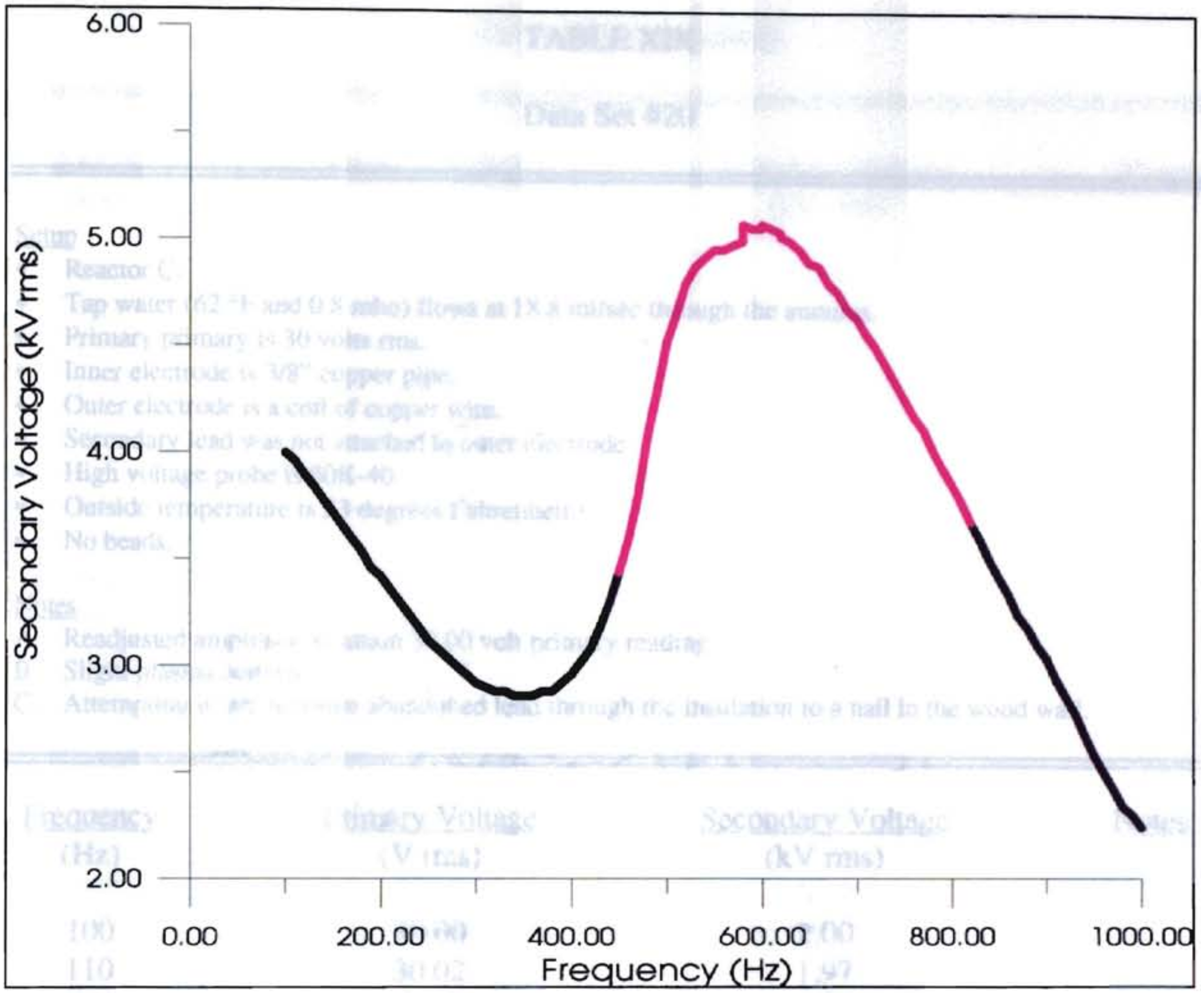


Figure 31. **Typical Tuning Plot For Data Set #19.**
Reactor C with tap water flowing through the annulus filled with glass beads.

Data Set #19 Analysis

The plasma formation coincides with the tuning plots described by previous researchers. Very surprising to obtain a luminous glow (plasma) when flowing tap water through the annulus. A luminous glow was present around the electrodes.

TABLE XIX

Data Set #20

Setup
- Reactor C.
- Tap water (62 °F and 0.8 mho) flows at 18.8 ml/sec through the annulus.
- Primary primary is 30 volts rms.
- Inner electrode is 3/8" copper pipe.
- Outer electrode is a coil of copper wire.
- Secondary lead was not attached to outer electrode.
- High voltage probe is 80K-40.
- Outside temperature is 33 degrees Fahrenheit.
- No beads.

Notes
A. Readjusted amplitude to attain 30.00 volt primary reading.
B. Slight plasma activity.
C. Attempting to arc between abandoned lead through the insulation to a nail in the wood wall.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	30.00	2.00	
110	30.02	1.97	
120	30.04	1.93	
130	30.06	1.90	
140	30.07	1.87	
150	30.08	1.84	
160	30.10	1.80	
170	30.11	1.77	A
180	30.01	1.73	
190	30.02	1.69	
200	30.03	1.66	
210	30.04	1.62	
220	30.05	1.59	
230	30.06	1.55	
240	30.07	1.52	
250	30.08	1.49	
260	30.09	1.45	
270	30.10	1.42	A
280	30.01	1.38	
290	30.02	1.35	

(con't.)

TABLE XIX (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
300	30.04	1.31	
310	30.05	1.30	
320	30.06	1.27	
330	30.07	1.24	
340	30.08	1.22	
350	30.09	1.19	
360	30.11	1.17	A
370	30.02	1.14	
380	30.03	1.12	
390	30.04	1.10	
400	30.05	1.08	
410	30.06	1.06	
420	30.08	1.05	
430	30.09	1.03	
440	30.10	1.02	A
450	30.01	1.00	
460	30.03	0.99	
470	30.04	0.98	
480	30.05	0.97	
490	30.06	0.96	
500	30.07	0.95	
510	30.08	0.94	
520	30.10	0.94	A
530	30.01	0.93	
540	30.01	0.93	B
550	30.02	0.93	
560	30.03	0.93	
570	30.04	0.93	
580	30.05	0.93	
590	30.06	0.94	
600	30.07	0.95	
610	30.08	0.96	
620	30.08	0.97	
630	30.09	0.98	
640	30.10	1.00	
650	30.11	1.02	A
660	30.01	1.03	

(con't.)

TABLE XIX (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
670	30.03	1.06	
680	30.04	1.08	
690	30.04	1.11	
700	30.06	1.15	
710	30.07	1.08	
720	30.07	1.22	
730	30.08	1.27	
740	30.09	1.32	
750	30.10	1.37	A
760	30.01	1.43	
770	30.03	1.49	
780	30.04	1.57	
790	30.05	1.65	
800	30.05	1.74	
810	30.06	1.84	
820	30.06	1.96	
830	30.07	2.09	
840	30.08	2.22	
850	30.09	2.37	
860	30.10	2.53	A
870	30.00	2.67	
880	30.00	2.81	
900	30.00	2.97	
910	30.00	2.99	
920	30.00	2.97	C

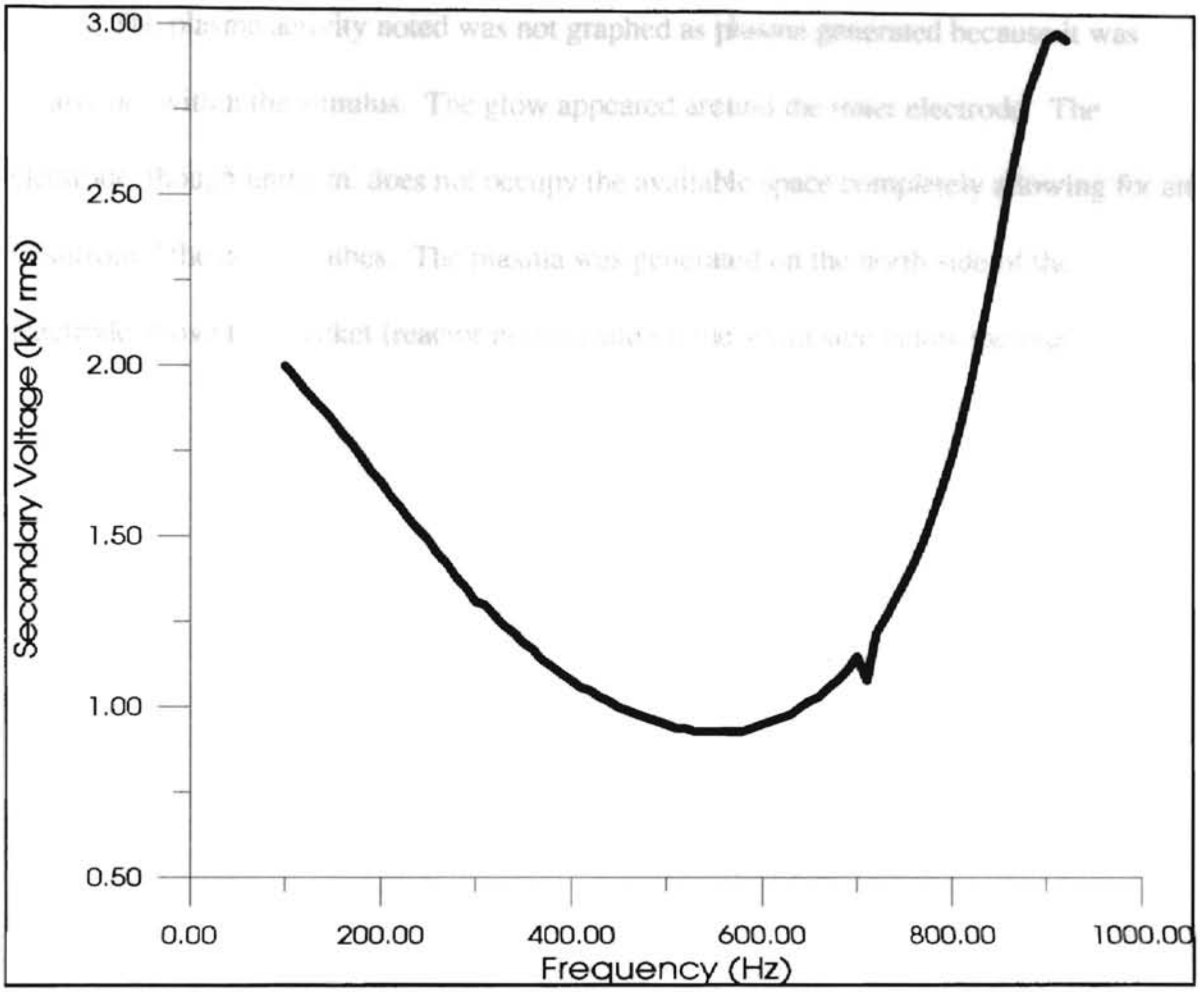


Figure 32. Typical Tuning Plot For Data Set #20.
Reactor C with tap water flowing through the annulus.

Data Set #20 Analysis

Outer electrode was not attached (repeat of data set #17). The secondary leads are not adequately insulated and this could be causing a considerable amount of disturbance for the experiments. A conducting liquid would not be expected to allow the generation of a plasma, but a liquid with a high conductivity measured without frequency may not conduct fast enough to be considered conducting at higher frequencies, thereby making the generation of plasma again possible.

The plasma activity noted was not graphed as plasma generated because it was clearly not within the annulus. The glow appeared around the inner electrode. The electrode, though uniform, does not occupy the available space completely allowing for air to surround the copper tubes. The plasma was generated on the north side of the electrode above the bracket (reactor holder) and on the south side below the bracket.

TABLE XX

Data Set #21

Setup

- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 30 volts rms.
- Inner electrode is 3/4" copper pipe.
- Outer electrode is copper mesh outer electrode.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 41 degrees Fahrenheit.

Notes

A. Readjusted primary to attain 30.00 volts primary reading.
B. Humming slightly.
C. Point glowing at top, shut down and insulated top, then resumed.
D. High pitched, no visible glow.
E. Light glow appears to be going around putty, shut down, taped putty down, resumed.
F. Sounds associated with a plasma are becoming audible.
G. Six localized places of spots glowing near the bottom and top.
H. Glow in the bottom (slight).
I. Gauges are too sporadic to read.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Time (pm)	Notes
100	30.00	4.12	10:40	
110	30.03	4.10	11:07	
120	30.05	4.06		
130	30.07	4.04		
140	30.09	4.02		
150	30.11	3.98		A
150	30.00	3.96		
160	30.02	3.94		
170	30.02	3.90		
180	30.04	3.86	11:11	
190	30.04	3.84		
200	30.05	3.80		
210	30.07	3.78		
220	30.08	3.76		
230	30.08	3.74		
240	30.09	3.74		

(con't.)

TABLE XX (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Time (pm)	Notes
250	30.11	3.72		A
250	30.00	3.70		
260	30.02	3.70	11:18	
260	29.99	3.70	11:22	
270	30.01	3.70		
280	30.02	3.70		
290	30.03	3.72		
300	30.05	3.74		
310	30.06	3.76		
320	30.07	3.80		
330	30.08	3.84		
340	30.09	3.90		
350	30.11	3.98		A,B
360	30.01	4.06		
370	30.02	4.18		
380	30.03	4.34		C
380	30.00	4.34		D
390	31.00	4.52		D
400	30.01	4.76		
410	29.89	5.06		E
410	30.00	5.06	11:45	
420	29.92	5.38		F
430	29.83	5.86		A
430	30.00	5.90		G
440	29.83	6.28		
440	30.00	6.30		F,H
450	29.89			I

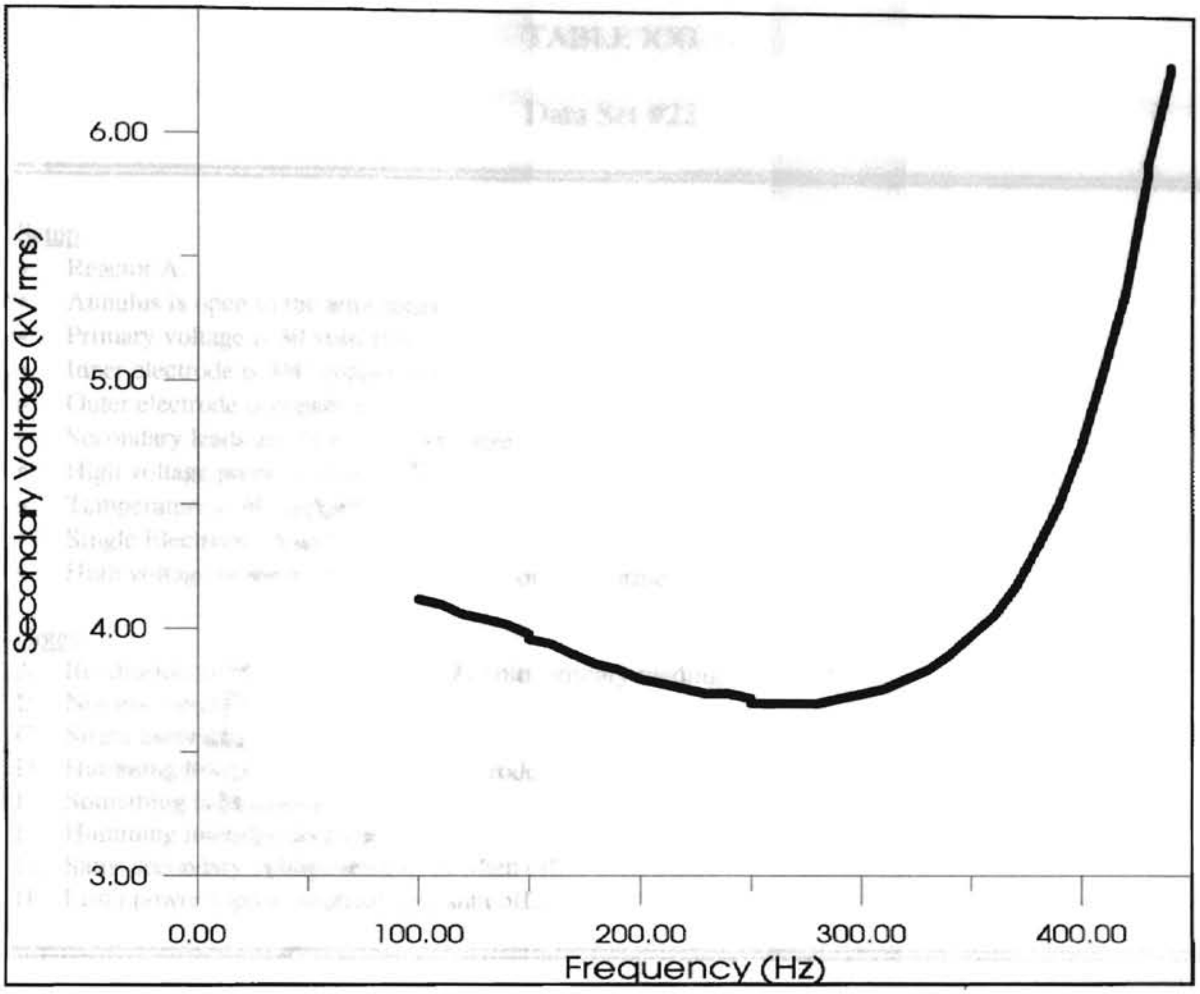


Figure 33. **Typical Tuning Plot For Data Set #21.**
Reactor C with deionized water flowing through the annulus.

Data Set #21 Analysis

The electrical problems (localized points of glow) suggest there could be some strange end effects which could be avoided by decreasing the electrode length from both ends.

TABLE XXI

Data Set #22

Setup

- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 30 volts rms.
- Inner electrode is 3/4" copper pipe.
- Outer electrode is copper mesh.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Temperature is 40 degrees Fahrenheit.
- Single Electrode - Center only, no outer.
- High voltage probe is on unhooked pole of transformer.

Notes

A. Readjusted amplitude to attain 30.00 volts primary reading.
B. Nothing observable occurring.
C. Slight humming, no visual.
D. Humming from end of unhooked electrode.
E. Something is humming.
F. Humming intensity decreases.
G. Same secondary voltage reading as when off.
H. Limit power supply automatically shut off..

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	30.00	2.01	
110	30.04	1.98	
120	30.06	1.95	
130	30.07	1.93	
140	30.09	1.91	
150	30.10	1.88	A
150	30.00	1.87	
160	30.02	1.85	
170	30.03	1.82	
180	30.04	1.79	B
190	30.05	1.76	
200	30.07	1.73	
210	30.08	1.70	
220	30.09	1.67	
230	30.10	1.64	A

(con't.)

TABLE XXI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
240	30.02	1.61	
250	30.03	1.59	
260	30.04	1.56	B
270	30.05	1.53	
280	30.05	1.51	
290	30.07	1.48	
300	30.08	1.46	
310	30.09	1.43	
320	30.10	1.41	A
320	30.00	1.40	
330	30.02	1.38	
340	30.03	1.36	
350	30.04	1.34	
360	30.05	1.32	B
370	30.06	1.30	
380	30.07	1.28	
390	30.08	1.26	A
400	30.10	1.25	
410	30.02	1.23	
420	30.03	1.21	
430	30.04	1.20	
440	30.06	1.19	
450	30.07	1.17	
460	30.10	1.16	A
470	30.01	1.15	
480	30.02	1.13	
490	30.03	1.12	C
500	30.05	1.11	
510	30.06	1.10	
520	30.07	1.09	
530	30.09	1.07	
540	30.10	1.05	A
550	30.02	1.03	
560	30.03	1.00	
570	30.04	0.97	
580	30.05	0.93	
590	30.03	0.89	D

(con't.)

TABLE XXI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
600	30.04	0.86	
610	29.97	0.85	E
620	29.97	0.88	
630	29.96	0.93	
640	30.03	1.01	E
650	30.04	1.09	
660	30.06	1.09	E
670	30.08	1.09	
680	30.08	1.09	F
690	30.10	1.47	A
700	30.01	1.57	F
710	30.03	1.66	
720	30.03	1.77	
730	30.05	1.88	F
740	30.06	2.00	
750	30.07	2.13	
760	30.09	2.28	
770	30.09	2.44	
780	30.10	2.61	A
790	30.02	2.81	
800	30.03	3.02	
810	30.03	3.23	
820	30.03	3.40	
830	30.03	3.52	
840	30.03	3.58	
850	30.02	3.57	
860	30.02	3.50	
870	30.03	3.37	
880	30.04	3.22	
890	30.05	3.04	
900	30.06	2.85	
910	30.06	2.67	
920	30.07	2.49	
930	30.08	2.33	
940	30.09	2.19	
950	30.10	2.05	A
960	30.02	1.93	

(con't.)

TABLE XXI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
970	30.03	1.81	
980	30.04	1.71	
990	30.05	1.63	
1000	30.07	1.54	
1010	30.08	1.47	
1020	30.08	1.40	
1030	30.09	1.33	
1040	30.10	1.27	A
1050	30.00	1.22	
1060	30.01	1.17	
1070	30.01	1.12	
1080	30.03	1.08	
1090	30.03	1.04	
1100	30.04	1.01	
2000	30.32	0.52	
3000	30.22	0.51	G
4000	29.96	0.51	G
5000	29.48	0.51	G,H

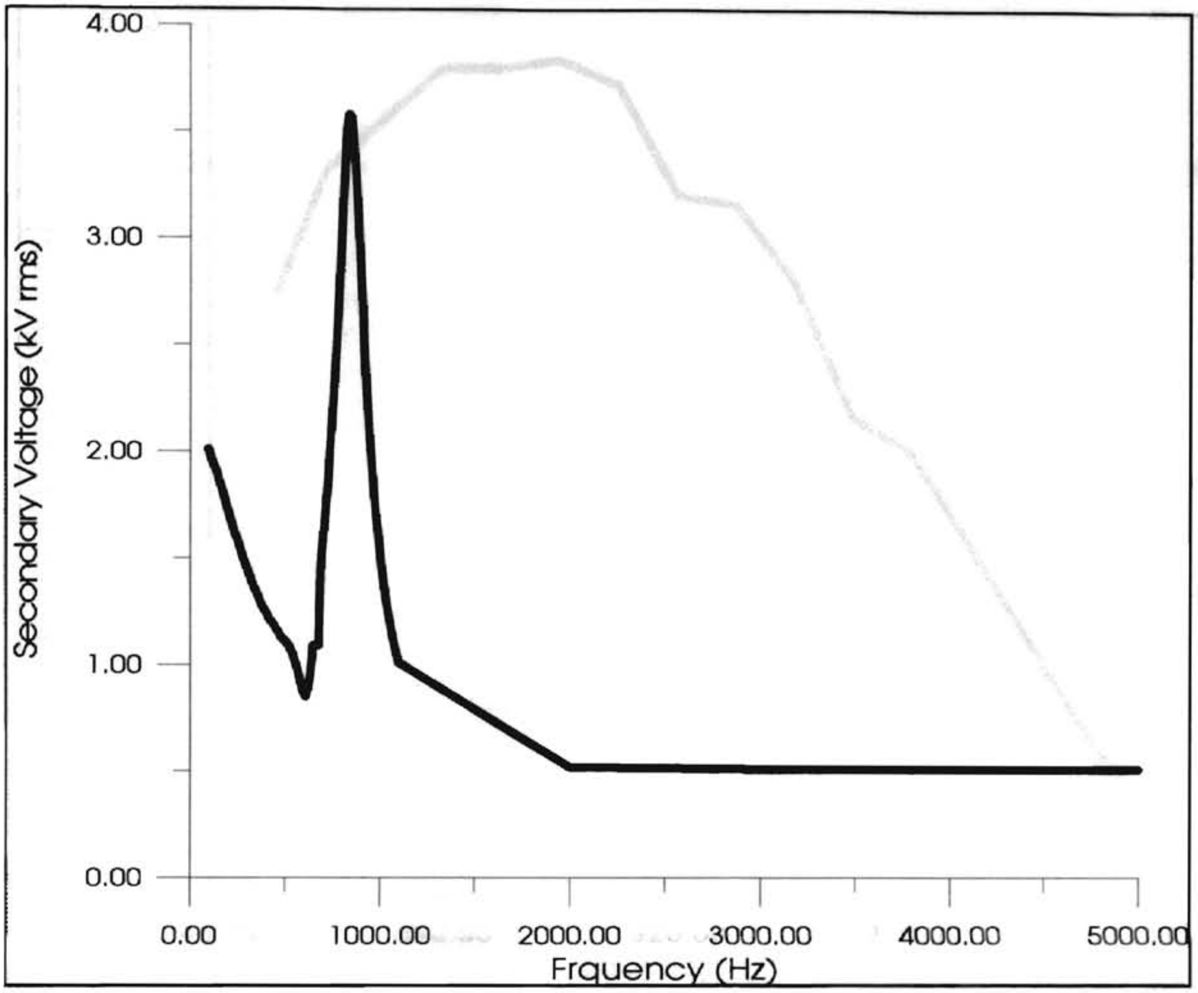


Figure 34. **Typical Tuning Plot For Data Set #22.**
Reactor A with the annulus open to the atmosphere.

Data Set #22 Analysis

After removing the reactor, I noted the bottom was broken where the strange end effects had appeared in data set #21.

TABLE XXII

Data Set #23

Setup
- Reactor B.
- Annulus is open to the atmosphere.
- Primary voltage is 12 volts rms.
- Inner electrode is 3/8" copper pipe.
- Outer electrode is copper mesh.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.

Notes
A. Stayed at this setting for 1 hour to allow for power supply warm up.
B. Readjusted amplitude to attain 12.00 volt primary reading.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Not
100	12.00	2.00	A
110	12.00	1.98	
120	12.01	1.96	
130	12.01	1.94	
140	12.02	1.92	
150	12.02	1.90	
160	12.03	1.86	
170	12.04	1.86	
180	12.04	1.84	
190	12.04	1.80	
200	12.04	1.78	
210	12.05	1.76	
220	12.05	1.74	
230	12.05	1.72	
240	12.06	1.70	
250	12.06	1.68	
260	12.06	1.66	
270	12.07	1.64	
280	12.08	1.62	
290	12.08	1.60	
300	12.08	1.56	
310	12.10	1.56	B
320	12.00	1.54	

(con'

TABLE XXII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
330	12.01	1.52	
340	12.01	1.52	
350	12.02	1.50	
360	12.02	1.48	
370	12.03	1.46	
380	12.03	1.46	
390	12.04	1.44	
400	12.04	1.42	
410	12.05	1.40	
420	12.06	1.40	
430	12.07	1.40	
440	12.07	1.38	
450	12.08	1.38	
460	12.09	1.36	
470	12.10	1.36	
480	12.11	1.36	
490	12.11	1.34	
500	12.11	1.34	
530	12.14	1.32	
560	12.16	1.26	
590	12.16	1.14	
620	12.16	1.06	
650	12.18	1.12	
680	12.21	1.24	
710	12.23	1.36	
740	12.25	1.50	
770	12.28	1.70	
800	12.30	1.96	
830	12.32	2.30	
860	12.34	2.68	
890	12.35	2.80	
920	12.37	2.60	
950	12.38	2.26	
980	12.39	1.96	
1010	12.42	1.72	
1040	12.44	1.52	B (con't.)

TABLE XXII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
1070	12.03	1.28	
1100	12.04	1.28	

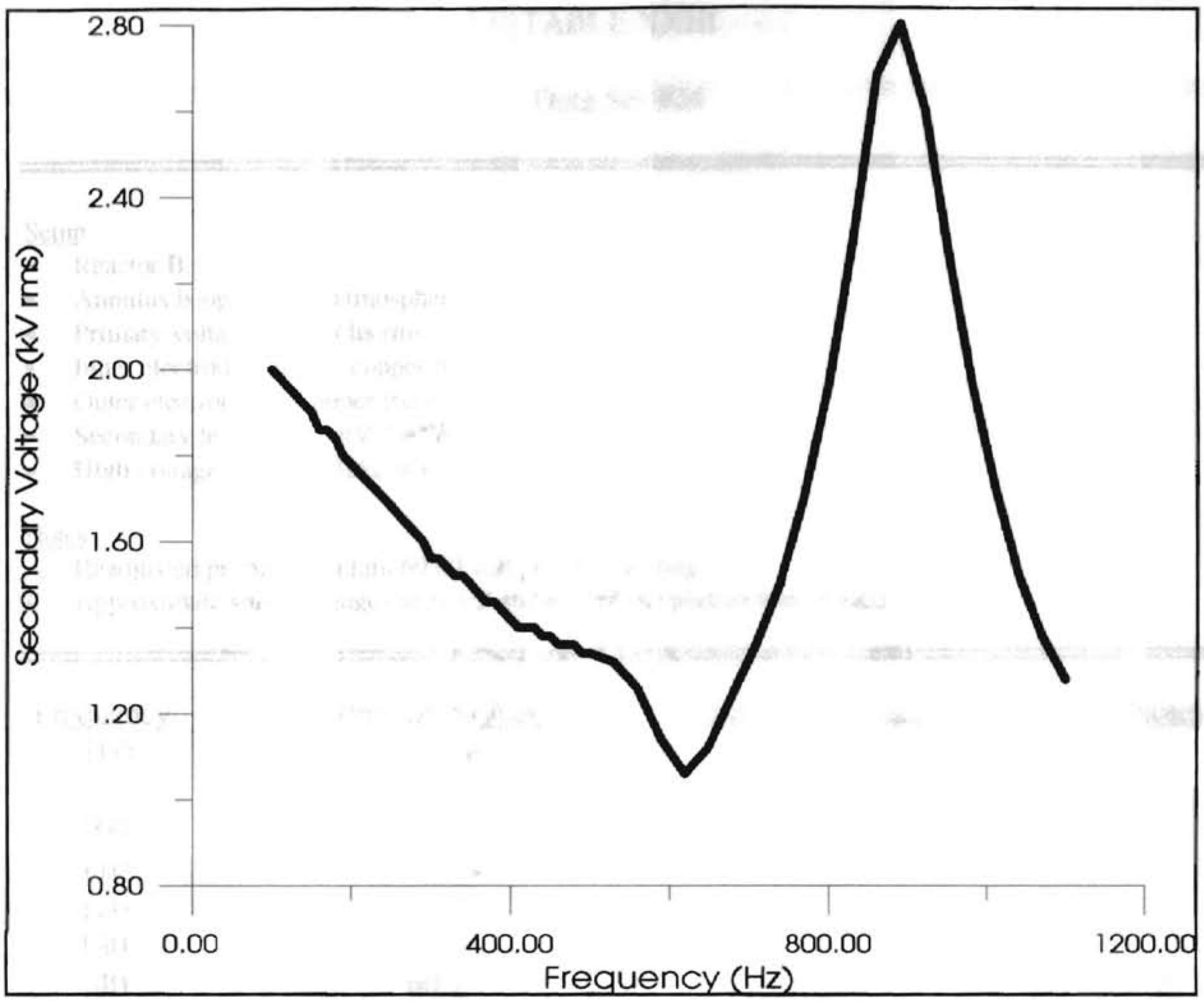


Figure 35. **Typical Tuning Plot For Data Set #23.**
Reactor B with the annulus open to the atmosphere.

Data Set #23 Analysis

The primary voltage was not high enough to create a plasma.

TABLE XXIII

Data Set #24

Setup

- Reactor B.
- Annulus is open to the atmosphere.
- Primary voltage is 60 volts rms.
- Inner electrode is a 3/8" copper pipe.
- Outer electrode is a copper mesh.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.

Notes

A. Readjusted primary to attain 60.00 volt primary reading.
B. Approximate values, gauges were not stable, definite plasma was created.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	60.00	7.64	
110	60.14	7.58	A
120	60.05	7.46	
130	60.08	7.38	
140	60.12	7.28	A
150	60.02	7.18	
160	60.05	7.06	
170	60.07	6.96	
180	60.08	6.84	
190	60.11	6.74	A
200	60.01	6.62	
210	60.03	6.52	
220	60.04	6.40	
230	60.06	6.30	
240	60.08	6.18	
250	60.09	6.08	
260	60.11	5.98	
270	60.13	5.88	
280	60.15	5.78	
290	60.16	5.68	
300	60.18	5.58	A
310	60.02	5.50	
320	60.04	5.40	

(con't.)

TABLE XXIII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
330	60.05	5.32	
340	60.07	5.24	
350	60.09	5.16	
360	60.08	5.08	
370	60.12	5.02	
380	60.14	4.96	
390	60.15	4.92	
400	60.16	4.86	
410	60.18	4.80	A
420	60.02	4.76	
430	60.05	4.72	
440	60.07	4.72	
450	59.35	5.28	B

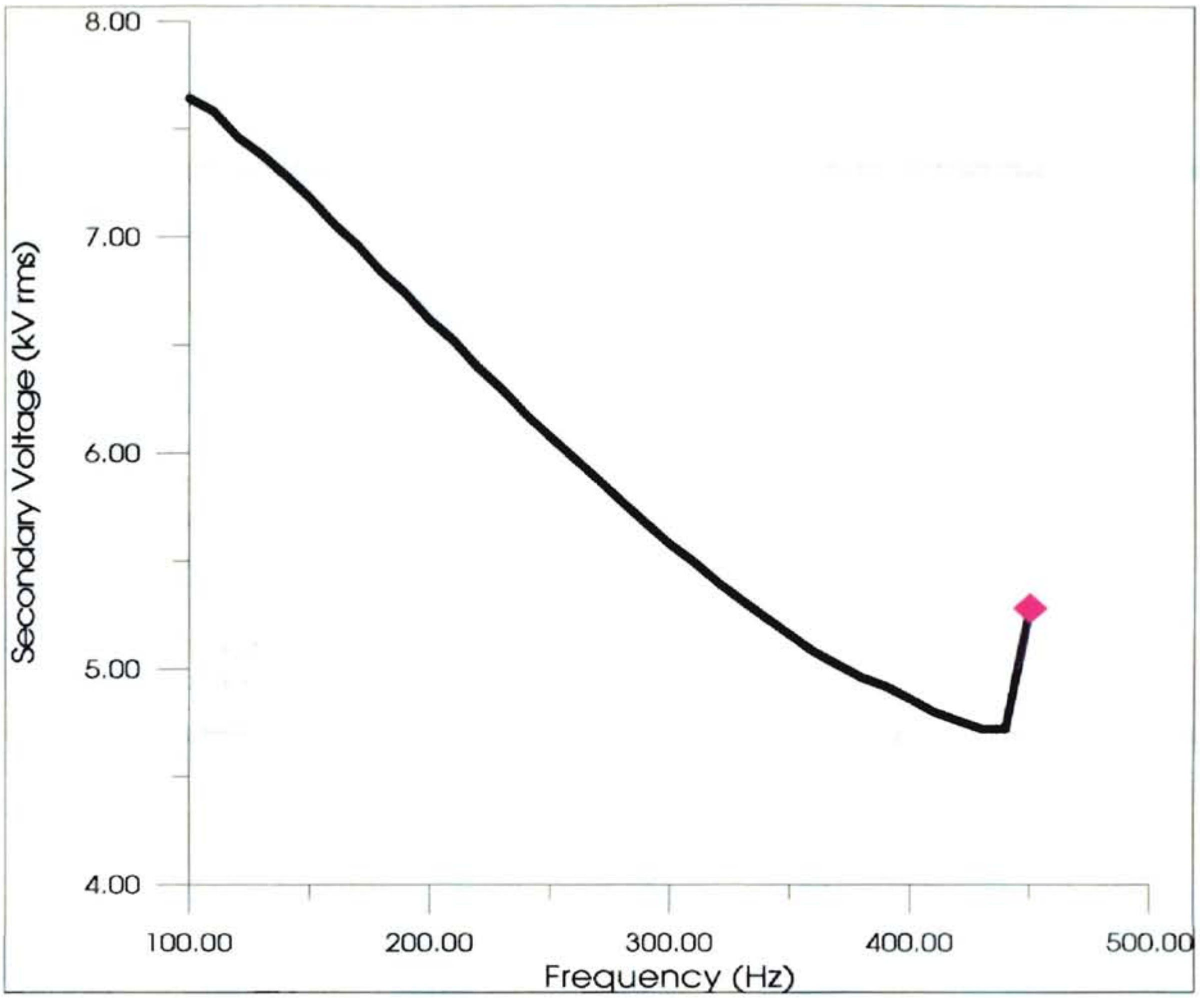


Figure 36. Typical Tuning Plot For Data Set #24.
Reactor B with the annulus open to the atmosphere.

Data Set #24 Analysis

This experiment was limited by the stability of the measuring equipment. Using a fluorescent light bulb, I was able to light the bulb holding it above the secondary leads.

TABLE XXIV

Data Set #25

Setup

- Reactor B.
- Deionized water (52 °F and 0.024 mho) flows at 22.3 ml/sec through the annulus.
- Primary voltage is 60 volts rms.
- Inner electrode is a 3/8" copper pipe.
- Outer electrode is a copper mesh.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 52 degrees Fahrenheit.

Notes

A. Readjusted amplitude to attain 30.00 volts primary reading.
B. Gauges are unstable at this point.
C. Plasma formed around inner electrode and not within the annulus.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	30.00	4.06	
110	30.00	4.02	
120	30.04	3.98	
130	30.06	3.94	
140	30.08	3.90	
150	30.10	3.84	A
160	30.02	3.78	
170	30.04	3.74	
180	30.05	3.68	
190	30.07	3.64	
200	30.08	3.60	
210	30.10	3.56	A
220	30.01	3.50	
230	30.02	3.44	
240	30.03	3.42	
250	30.04	3.38	
260	30.06	3.34	
270	30.06	3.30	
280	30.07	3.28	
290	30.08	3.24	
300	30.09	3.24	

(con't.)

TABLE XXIV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
310	30.10	3.20	A
320	30.00	3.18	
330	30.01	3.18	
340	30.02	3.18	
350	30.03	3.18	
360	30.04	3.22	
370	30.04	3.28	
380	30.05	3.36	
390			B,C

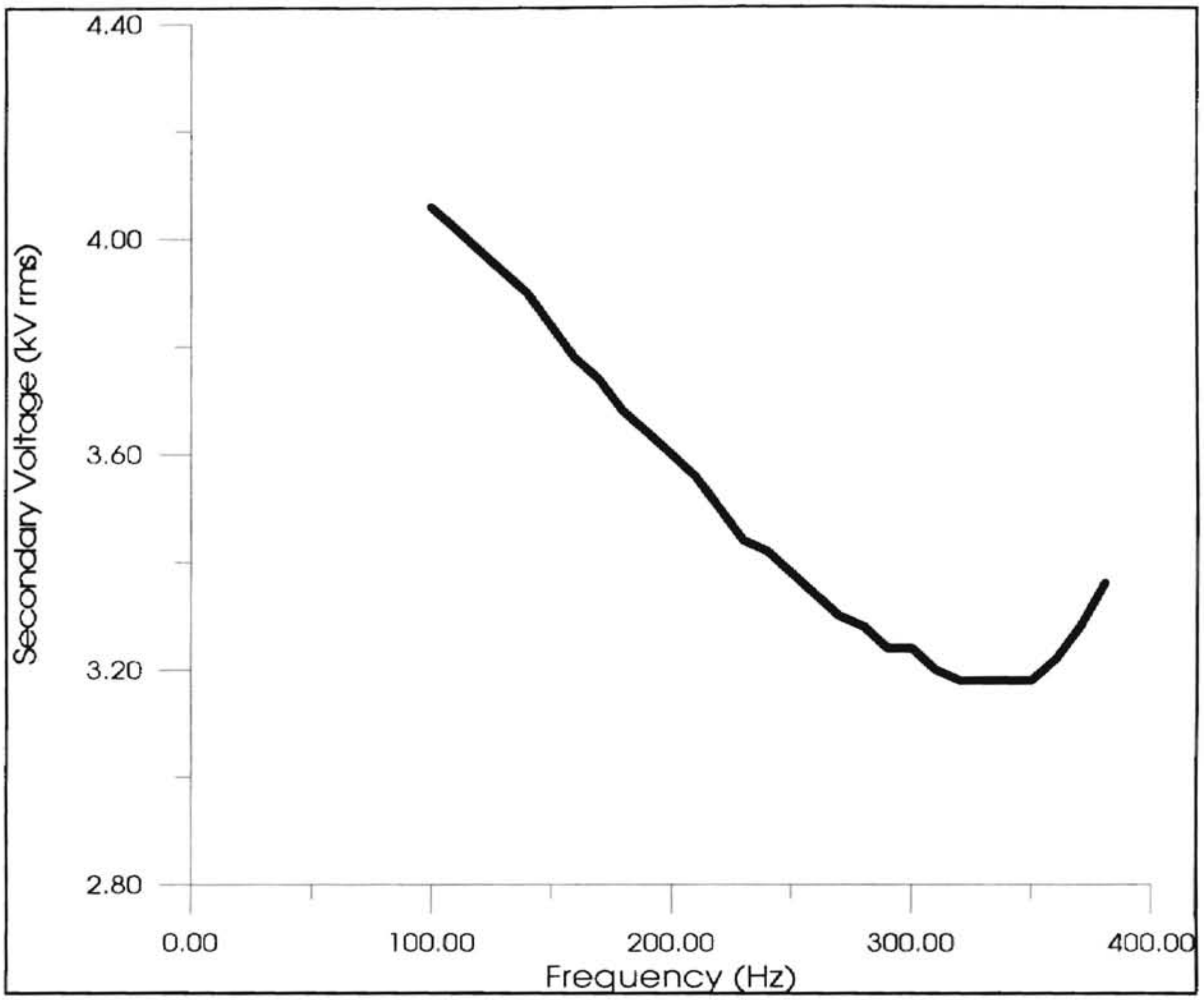


Figure 37. Typical Tuning Plot For Data Set #25.
Reactor B with deionized water flowing through the annulus.

Data Set #25 Analysis

Plasma was formed around the inner electrode and not formed within the annulus. This puts the earlier experiments that showed a plasma with liquid in doubt, being that the plasma could have originated around the electrodes and only appeared to be coming from the annulus.

TABLE XXV

Data Set #26

Setup

- Reactor B.
- Deionized water (0.024 mho conductivity) flows at 22.3 ml/sec through the annulus.
- Inner electrode is 3/8" copper pipe.
- Outer electrode is copper mesh.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 52 degrees Fahrenheit.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)
100	30.00	4.06
110	30.03	4.02
120	30.05	3.98
130	30.07	3.94
140	30.08	3.90
150	30.10	3.84
160	30.01	3.78
170	30.03	3.74
180	30.04	3.68
190	30.04	3.64
200	30.06	3.60
210	30.07	3.54
220	30.09	3.50
230	30.00	3.46
240	30.10	3.42
250	30.02	3.36
260	30.04	3.34
270	30.05	3.30
280	30.07	3.28
290	30.08	3.24
300	30.41	3.24
310	30.03	3.20
320		

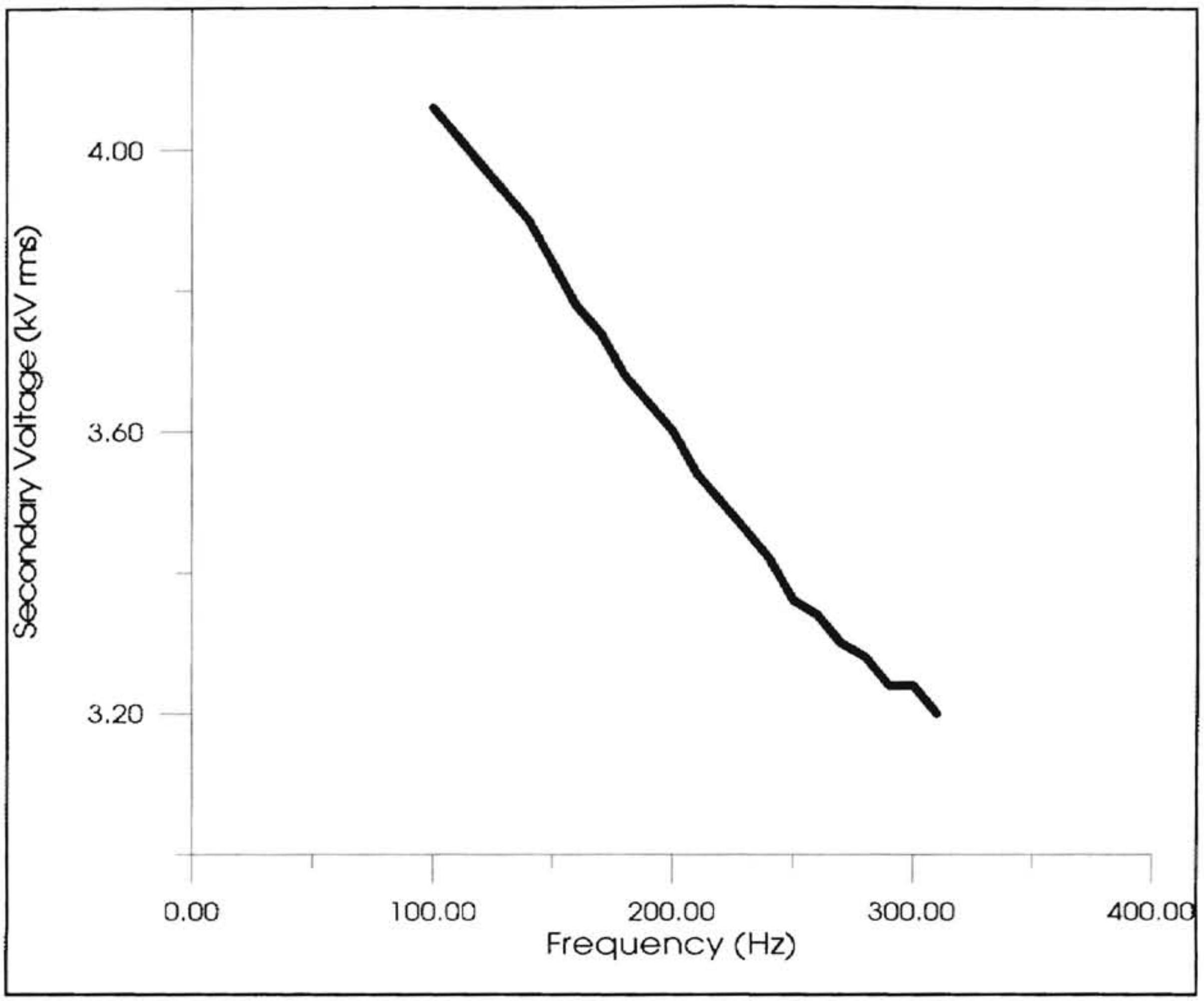


Figure 38. **Typical Tuning Plot For Data Set #26.**
Reactor B with deionized water flowing through the annulus.

Data Set #26 Analysis

There was some plasma generated, but it was only around the inner electrode and not within the annulus. This was basically a recreation of data set #26 and it was reproducible.

TABLE XXVI

Data Set #27

Setup

- Reactor B
- Tap Water (0.81 mho) flows at 10.86 ml/sec through the annulus.
- Primary voltage is 30 volts rms.
- Inner electrode is 3/8" copper pipe.
- Outer electrode is copper mesh.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage is Fluke 80K-40.
- Ambient temperature is 52 degrees Fahrenheit.

Notes

A. Readjusted primary to attain 30.00 volt primary reading.
B. Meter fluctuated -- unable to take readings, skipped to next readable frequency.
C. Possibly glowing in the annulus - inconclusive.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV peak)	Notes
100	30.00	4.06	
110	30.04	4.02	
120	30.06	4.00	
130	30.08	3.94	
140	30.09	3.88	
150	30.11	3.84	A
160	30.03	3.78	
170	30.05	3.72	
180	30.06	3.66	
190	30.08	3.62	
200	30.26	3.60	A
210	30.03	3.52	
220	30.04	3.48	
230	30.05	3.42	
240	30.06	3.38	
250	30.08	3.34	
260	30.09	3.30	
270	30.10	3.26	A
280	30.02	3.22	
290	30.03	3.20	
300	30.05	3.18	

(con't.)

TABLE XXVI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV peak)	Notes
310	30.06	3.14	
320	30.07	3.14	
330	30.09	3.14	
340	30.11	3.20	A,B
380	30.02	3.60	
390	29.75	3.86	B,C
500	29.75	2.60	

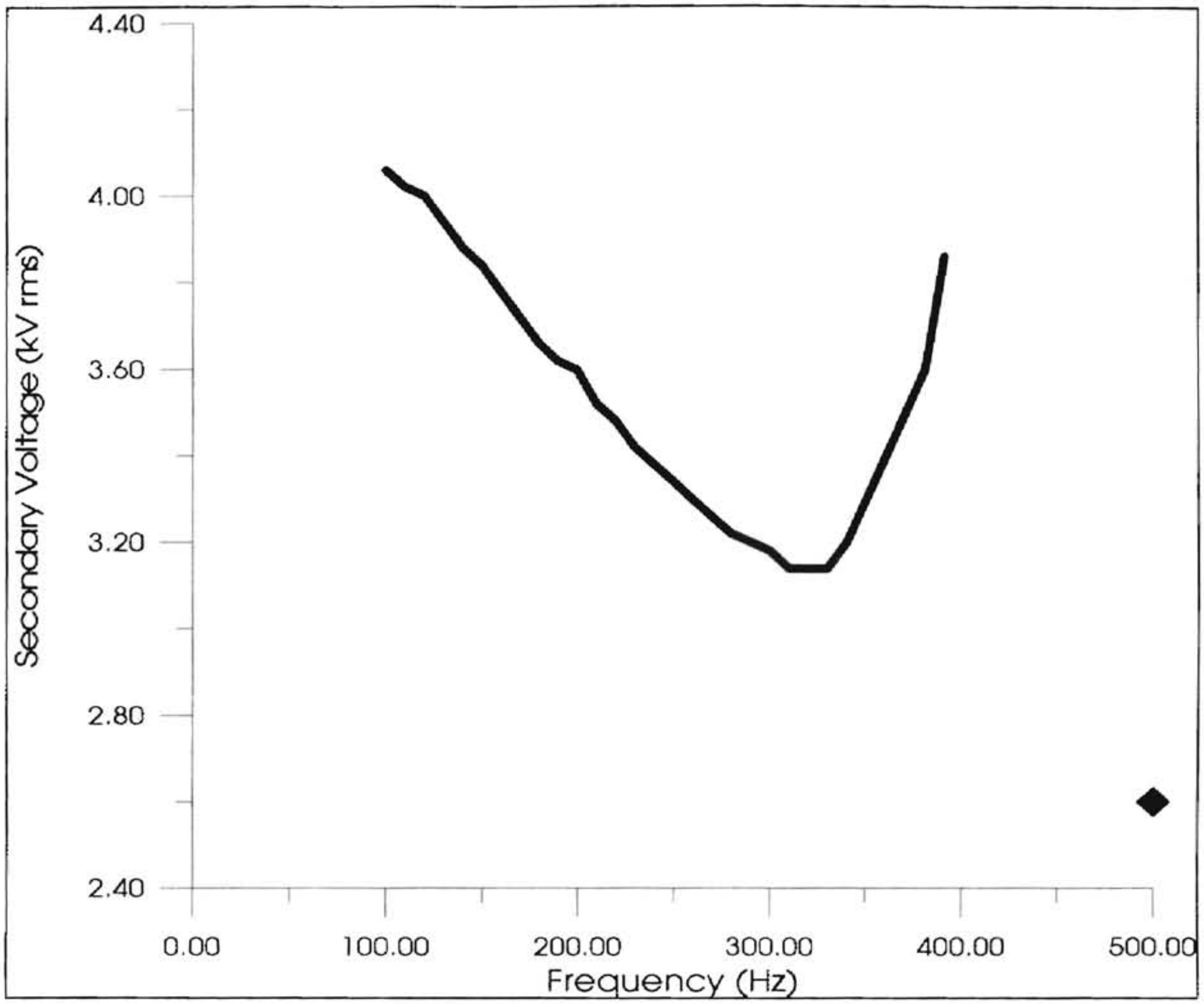


Figure 39. Typical Tuning Plot For Data Set #27.
Reactor B with tap water flowing through the annulus

Data Set #27 Analysis

Possibly glowing in the annulus within unstable region between 400 and 500 Hz. Large discontinuous region represents the range where the meters fluctuated too much to take readings.

TABLE XXVII

Data Set #28

Setup
- Reactor B.
- Tap water (72 °F and 0.81 mho) flows at 10.86 ml/sec through the annulus.
- Primary voltage is 30 volts rms.
- Inner electrode is 3/8" copper pipe.
- Outer electrode is copper mesh.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage is Fluke 80K-40.
- Ambient temperature is 51 degrees Fahrenheit.
- BK Precision Oscillator.

Notes
A. Readjusted primary.
B. Plasma around inner electrode.
C. Adjusted calibration on BK oscillator.
D. Secondary voltage reading was not stable.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
26	30.03	4.30	
96	31.98	4.34	A
96	30.10	4.10	
100	30.11	4.10	
125	30.16	3.98	
143	30.18	3.90	
163	30.20	3.80	
174	30.20	3.74	
200	30.23	3.60	
222	30.24	3.50	
242	30.26	3.42	
269	30.28	3.32	
300	30.31	3.24	
314	30.32	3.20	
325	30.33	3.20	B
345	30.34	3.26	
353	30.34	3.30	
357	30.34	3.34	
364	30.35	3.40	

(con't.)

TABLE XXVII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
372	30.35	3.50	
386	30.34	3.78	
411	30.03	4.24	
429	29.86	4.08	
445	29.83	3.78	
457	29.85	3.46	
470	29.89	3.12	
477	29.90	3.02	
480	29.91	2.92	
			C
56	29.90	?	D
100	30.39	4.12	
135	30.46	3.96	
162	30.49	3.82	
182	30.51	3.72	

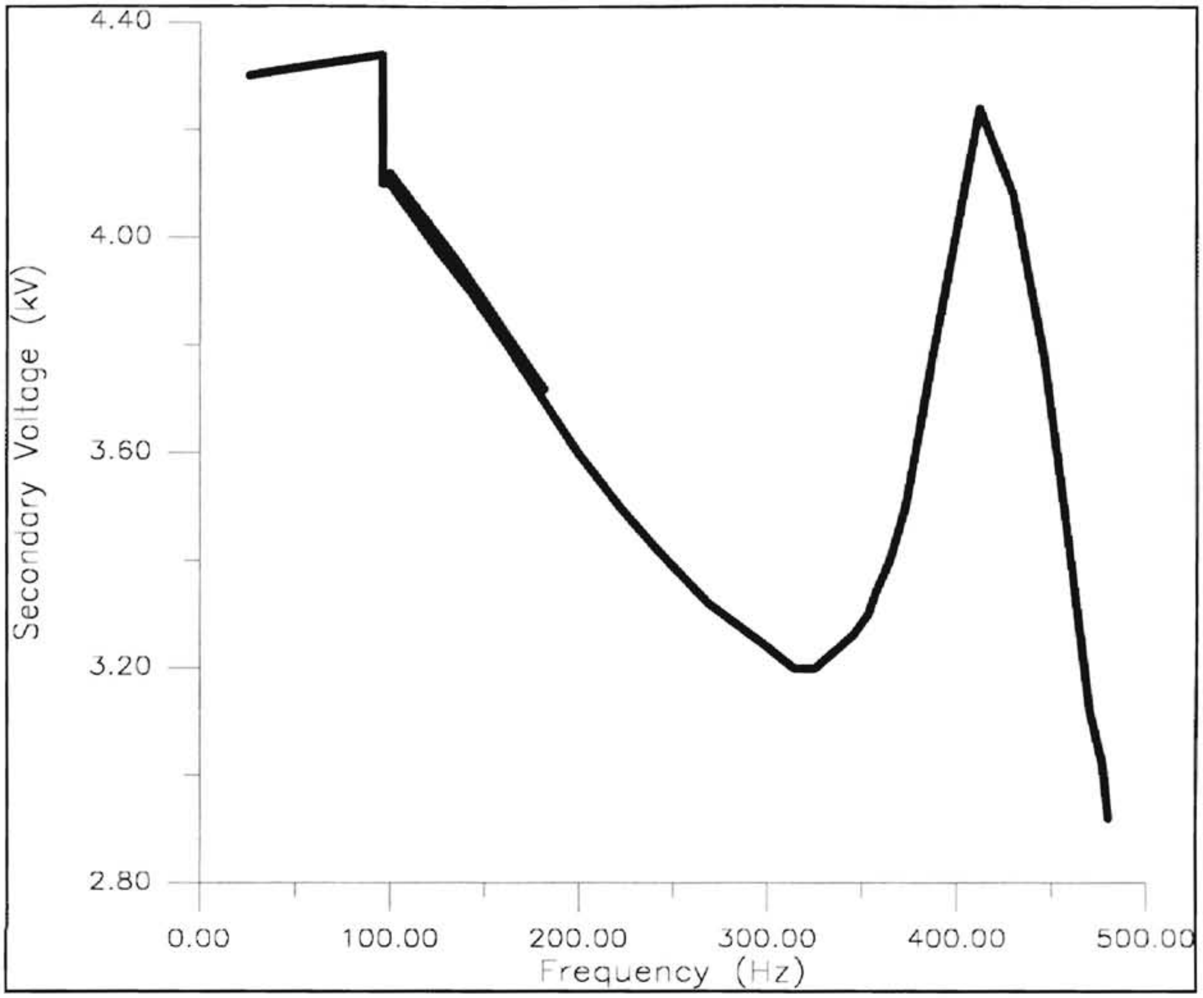


Figure 40. **Typical Tuning Plot For Data Set #28.**
Reactor B with tap water flowing through the annulus.

Data Set #28 Analysis

Adjustment to test how much this would affect operation. This BK Precision, like the California Instruments, oscillator was a little difficult to use under 100 Hz. The region with two lines represent the repeat through the range with the calibration adjusted and this made no significant difference.

TABLE XXVIII

Data Set #29

Setup
- Reactor B.
- Compressed air 30 psi enters reactor annulus, and exits to the atmosphere via long tube.
- Primary voltage is 60 volts rms.
- Inner electrode is 3/8" copper pipe.
- Outer electrode is copper mesh.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 51 degrees Fahrenheit.
- BK Precision Oscillator.

Notes

A. At this point manually increased pressure and plasma disappeared.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	59.97	7.60	
110	60.11	7.50	
120	60.20	7.44	
140	60.26	7.22	
149	60.21	7.12	
159	60.22	7.02	
165	60.22	6.94	
185	60.25	6.72	
197	60.27	6.58	
206	60.28	6.48	
220	60.30	6.34	
230	60.31	6.22	
240	60.33	6.16	
250	60.35	6.10	
260	60.38	6.06	
279	60.38	5.86	
290	60.39	5.74	
310	60.41	5.52	
320	60.42	5.44	
330	60.43	5.38	
359	60.44	5.28	
376	60.51	5.46	

(con't.)

TABLE XXVIII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
381	60.51	5.60	
394	60.53	5.86	
404	60.23	6.12	
410	60.18	6.24	
426	59.95	6.20	A

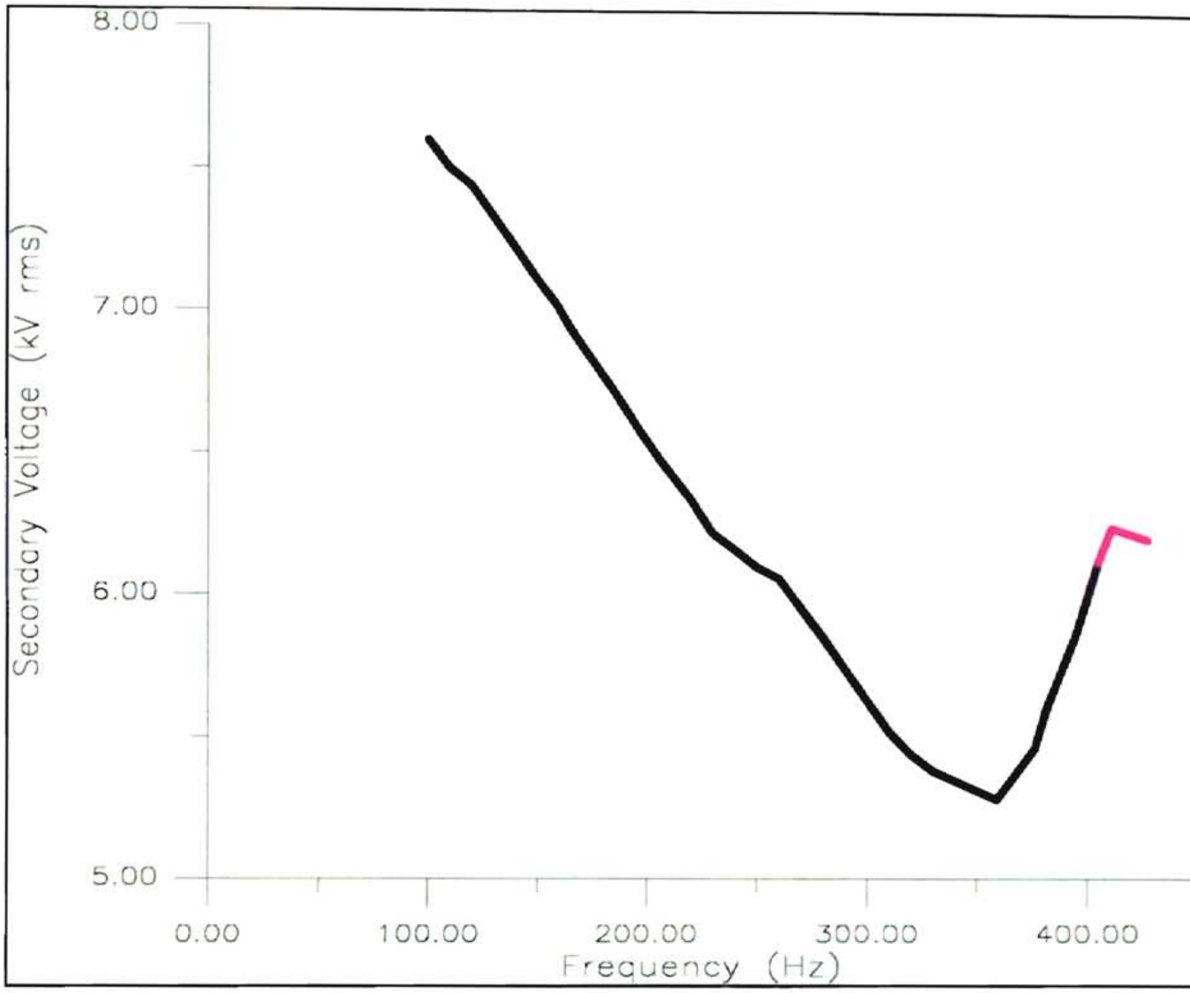


Figure 41. Typical Tuning Plot For Data Set #29.
Reactor B with air flowing through the annulus.

Data Set #29 Analysis

Unsure exactly where plasma began, but increasing the pressure by pinching the outlet tube quenched the luminous glow. This suggests some pressure dependence for plasma. The plasma occurred in a peak, but this was at a lower voltage than where a plasma was not apparent.

TABLE XXIX

Data Set #30

Setup

- Reactor B.
- Compressed air 30 psi enters reactor annulus, and exits to the atmosphere via long tube.
- Primary voltage is 60 volts rms.
- Inner electrode is 3/8" copper pipe.
- Outer electrode is copper mesh.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- BK Precision Oscillator.

Notes

A. Two locations of glow, not a full plasma.
B. Checking with fluorescent light bulbs, enough radiation from wires to light bulb.
C. Gauges are jumping.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
160	60.36	7.06	
185	60.41	6.78	
246	60.50	6.14	
270	60.54	6.00	
293	60.56	5.74	
317	60.57	5.50	
332	60.59	5.38	
350	60.62	5.30	
368	60.65	5.32	
385	60.68	5.52	A
407	60.49	5.94	
419	60.34	6.10	
426	60.11	6.18	B,C

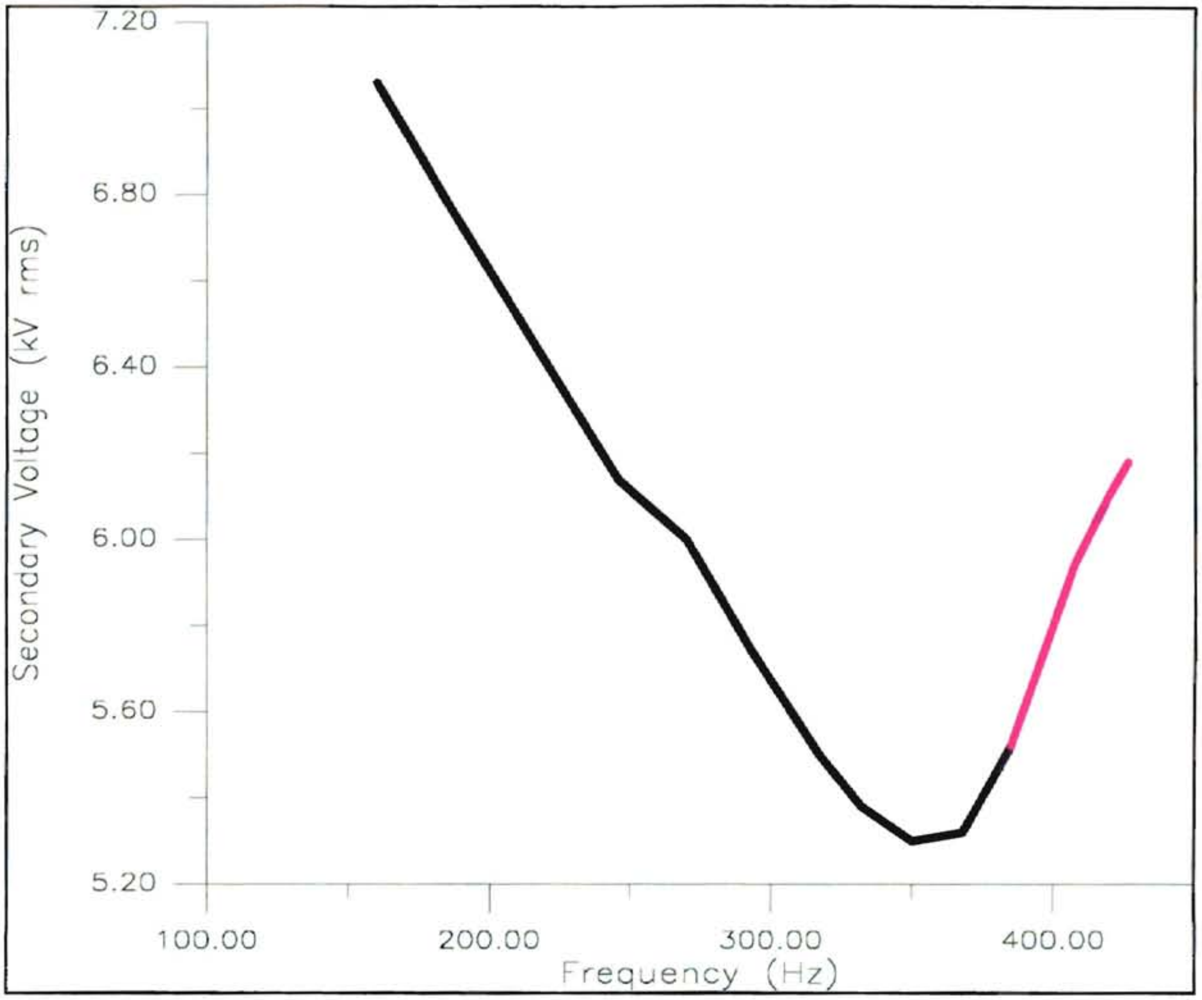


Figure 42. Typical Tuning Plot For Data Set #30.
Reactor B with air flowing through the annulus.

Data Set #30 Analysis

The radiation from this experiment was a little disturbing. Plasma formed only at discrete points.

TABLE XXX

Data Set #31

Setup
- Reactor without dielectric walls.
- Primary voltage is 12 volts rms.
- Reactor was simply a copper tube with a wire down the center.
- High voltage probe is Fluke 80K-40.

Notes

A. Slight spark.

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
100	2.02	
110	2.00	
120	1.98	
130	1.96	
140	1.94	
150	1.92	
160	1.90	
170	1.88	
180	1.84	
190	1.82	
200	1.80	
210	1.80	
220	1.76	
230	1.74	
240	1.72	
250	1.70	
260	1.68	
270	1.66	
280	1.64	
290	1.64	
300	1.64	
310	1.60	
320	1.58	
330	1.56	
340	1.54	
350	1.52	

(con't.)

TABLE XXX (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
360	1.52	
370	1.50	
380	1.50	
390	1.48	
400	1.46	
410	1.44	
420	1.44	
430	1.44	
440	1.42	
450	1.42	
460	1.40	
470	1.40	
480	1.38	
490	1.38	
500	1.38	
550	1.36	
600	1.30	A

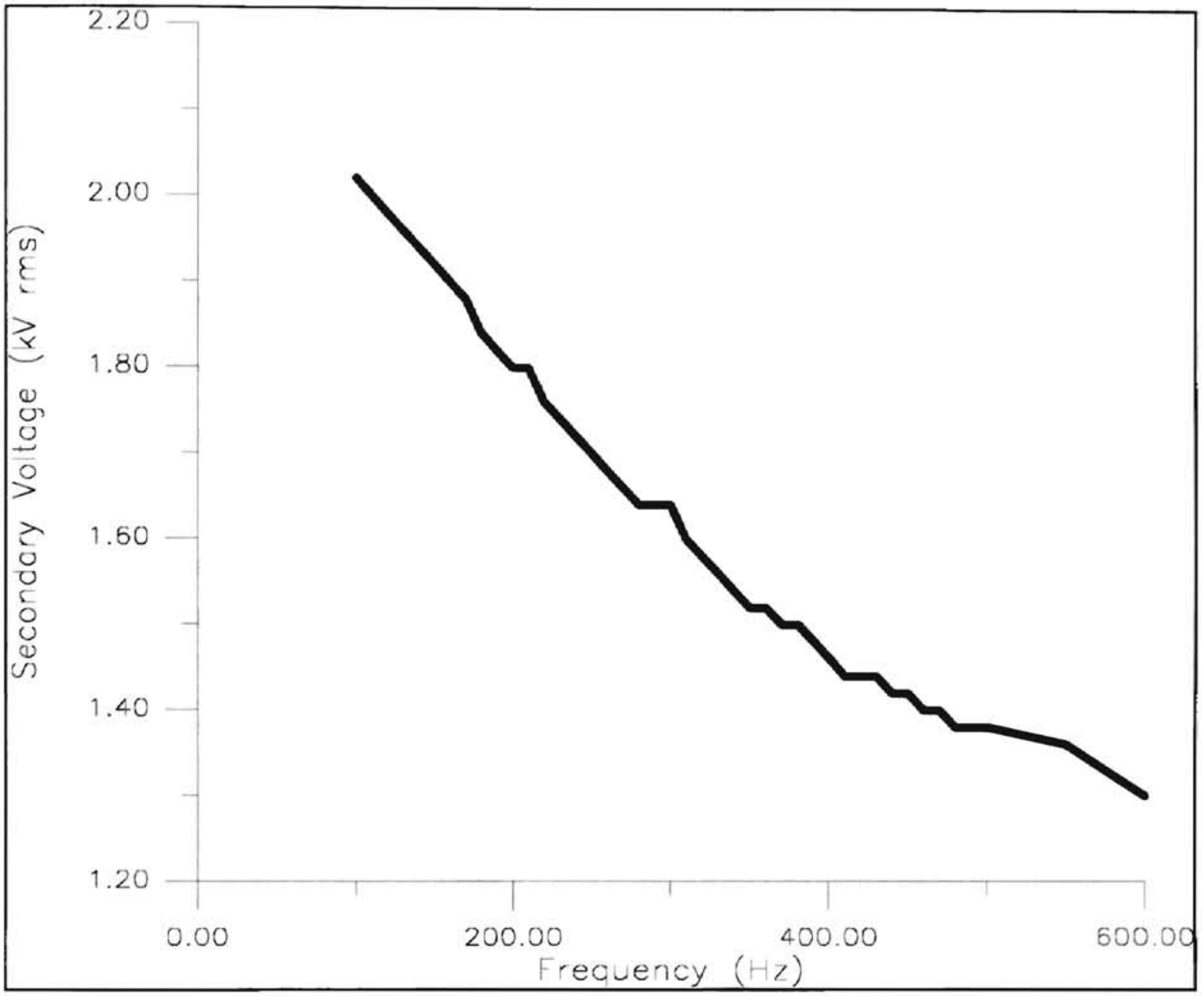


Figure 43. Typical Tuning Plot For Data Set #31.
Concentric copper tube trial reactor with tubes serving as electrodes and air between.

Data Set #31 Analysis

No dielectric test. Too hard to perfectly center wire down tube. One point would always have least resistance and arc on spark. Crude technique.

TABLE XXXI

Data Set #32

Setup

- Primary voltage is 40 volts rms.
- Inner electrode is copper pipe.
- Outer electrode is wire mesh.
- High voltage probe is Fluke 80K-40.
- A beaker housed this setup. The wire mesh was wrapped around the inside surface of the beaker and the copper tube was centered in the middle leaving air between the electrodes.

Notes

A. Hear tone.
B. Slight plasma under inner electrode.

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
100	5.20	
110	5.12	
120	5.08	
130	5.00	
140	4.92	
150	4.84	
160	4.76	
170	4.68	
180	4.60	
190	4.52	
200	4.44	
210	4.36	
220	4.28	
230	4.20	
240	4.12	
250	4.04	
260	3.96	
270	3.90	
280	3.82	
290	3.74	
300	3.66	
310	3.62	
320	3.58	
330	3.48	

(con't.)

TABLE XXXI (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
340	3.42	
350	3.36	
360	3.30	
370	3.24	
380	3.20	
390	3.14	
400	3.10	
410	3.06	
420	3.00	
430	2.96	
440	2.92	
450	2.88	
460	2.86	
470	2.82	
480	2.80	
490	2.76	
500	2.74	
510	2.70	
520	2.68	
530	2.64	
540	2.60	A
550	2.58	
560	2.54	
570	2.50	
580	2.46	
590	2.38	B
600	2.28	
610	2.16	
620	2.00	
630	1.82	
640	1.64	
650	1.58	
660	1.62	
670	1.80	
680	2.06	
690	2.36	
700	2.66	

(con't.)

TABLE XXXI (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
710	2.92	
720	3.18	
730	3.44	
740	3.68	
750	3.92	
760	4.18	
770	4.24	
780	4.72	
790	5.04	
800	5.40	
810	5.80	
820	6.22	
830	6.68	
840	7.16	
850	7.20	
860	8.04	
870	8.36	
880	8.52	
890	8.56	
900	8.52	
910	8.32	
920	8.08	
930	7.76	
940	7.44	
950	7.12	
960	6.74	
970	6.38	
980	6.00	
990	5.64	
1000	5.30	

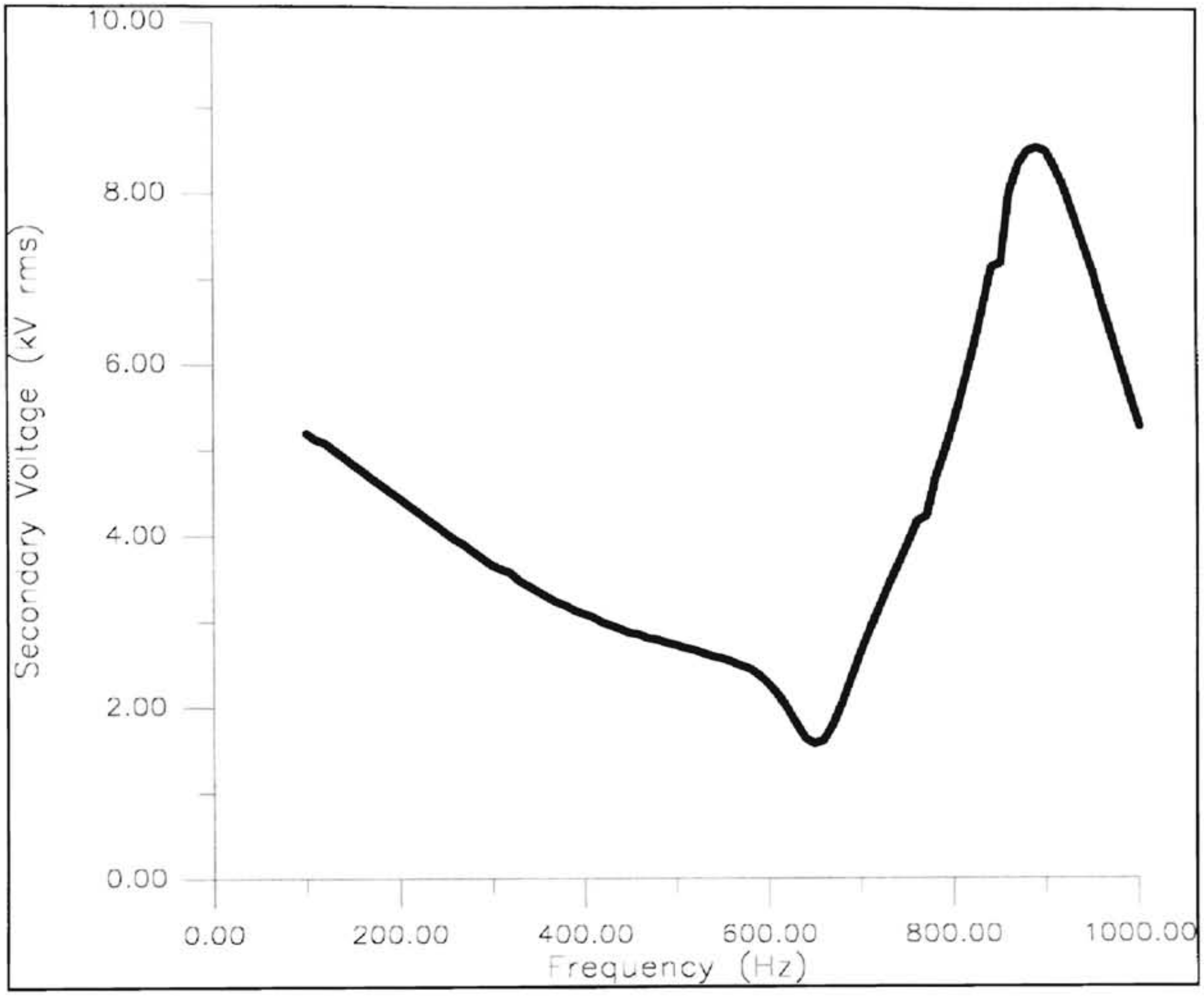


Figure 44. Typical Tuning Plot For Data Set #32.
Reactor without dielectric barriers housed in a beaker.

Data Set #32 Analysis

The only plasma activity was in the bottom of the beaker.

TABLE XXXIII

Data Set #33

Setup

- No dielectric barrier reactor.
- Primary voltage is 60 volts rms.
- Inner electrode is copper pipe.
- Outer electrode is wire mesh.
- High voltage probe is Fluke 80K-40.
- A beaker housed this setup. The wire mesh was wrapped around the inside surface of the beaker and the copper tube was centered in the middle leaving air between the electrodes.

Notes

A. Backed up to 400 Hz and decreased step size.
B. Plasma in bottom only.
C. Plasma in bottom only.
D. Plasma distribution along bottom.
E. Starting to develop throughout container.
F. Arced across bottom.

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
100	7.58	
110	7.50	
120	7.40	
130	7.30	
140	7.20	
190	6.62	
200	6.50	
300	5.40	
400	4.50	
450	4.20	
500	3.98	A,B
410	4.42	
420	4.36	
430	4.30	
440	4.24	
450	4.20	
460	4.14	
470	4.10	
480	4.06	
490	4.02	B

(con't.)

TABLE XXXII (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
500	3.96	C
510	3.92	
520	3.88	
530	3.84	
540	3.78	
550	3.72	
560	3.66	
570	3.56	
580	3.44	D
590	3.28	E
600	3.00	F

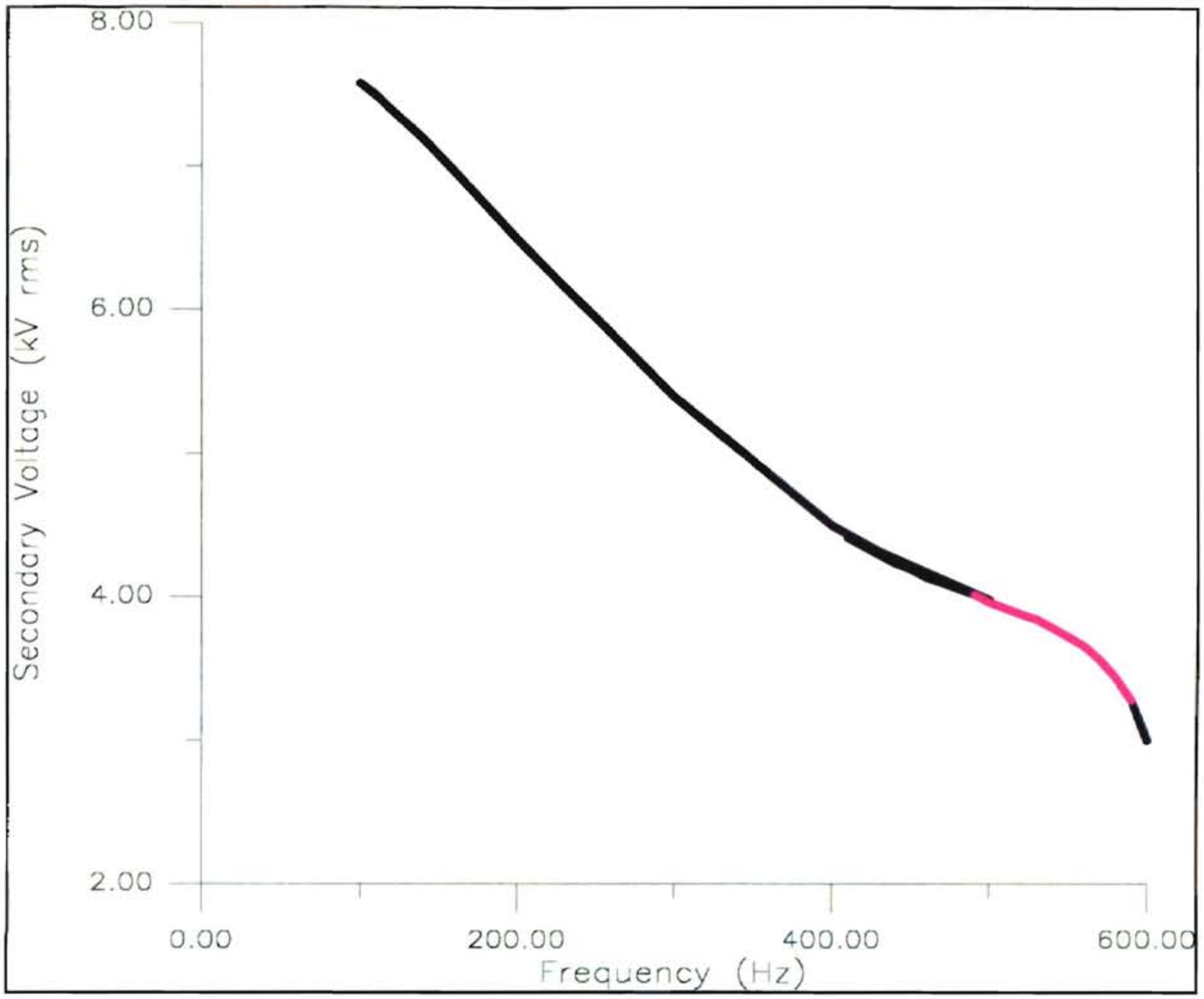


Figure 45. Typical Tuning Plot For Data Set #33.
Reactor without dielectric barriers housed in a beaker.

Data Set #33 Analysis

Plasma was only in the bottom, therefore tried insulating bottom of electrode on next data set. Probably trying to create plasma between inner electrodes and outside base ground instead of the other electrode.

TABLE XXXIII

Data Set #34

Setup

- No dielectric barrier reactor.
- Primary voltage is 60 volts rms.
- Inner electrode is copper pipe.
- Outer electrode is copper mesh.
- High voltage probe is Fluke 80K-40.
- A beaker housed this setup. The wire mesh was wrapped around the inside surface of the beaker and the copper tube was centered in the middle leaving air between the electrodes.
- Rubber insulated around bottom of pipe within the beaker.

Notes

A. At this point primary has fluctuated to 60.87 Volts.
B. Slight plasma around bottom edge of outer electrode only.
C. Meters stuck, frozen at current reading.

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
100	7.58	
110	7.50	
120	7.42	
130	7.30	
140	7.20	
150	7.10	
200	6.46	
250	5.90	
300	5.32	
350	4.88	
400	4.48	
450	4.18	
500	3.96	
510	3.90	
520	3.86	
530	3.82	A
540	3.78	
550	3.70	
560	3.62	

(con't.)

TABLE XXXIII (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
570	3.54	
580	3.42	
590	3.26	B,C

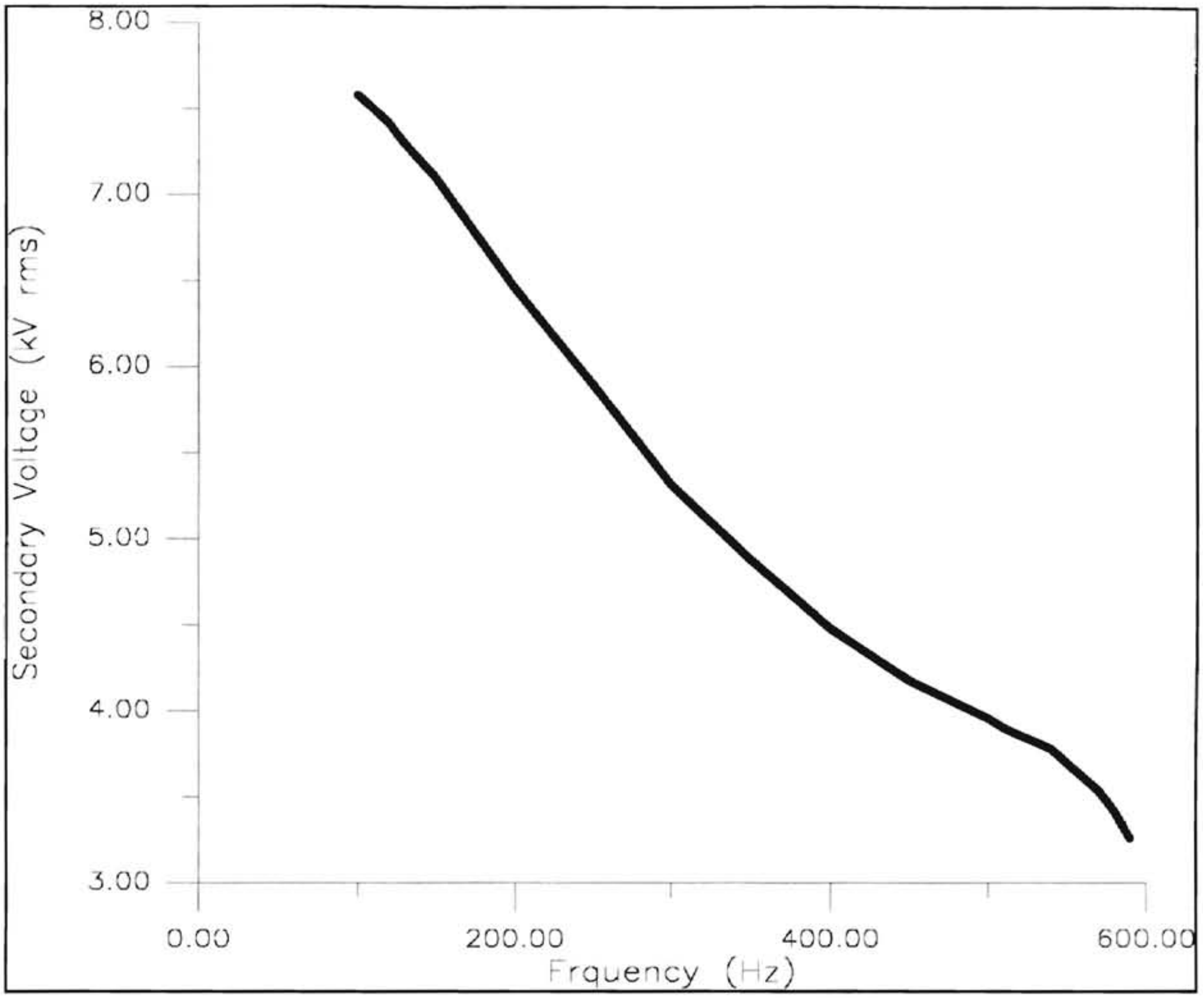


Figure 46. Typical Tuning Plot For Data Set #34.
Reactor without dielectric barriers housed in a beaker.

Data Set #34 Analysis

Same as data set #33, but insulated bottom of inner electrode. The insulation did not appear to help.

TABLE XXXIV

Data Set #35

Setup

- No dielectric barrier reactor.
- Primary voltage is 30 volts rms.
- Inner electrode is a copper wire.
- Outer electrode is steel tube 14" long 2" I.D. 2.25 O.D." slightly corroded.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 32 degrees Fahrenheit.

Notes

A. Meter is becoming unstable.
B. Meter is back to normal operation.
C. Slight sound.
D. Strong plasma type sound, no obvious smell of ozone.
E. Crackling sound, stepped through without reading to next non-crackling frequency.
F. Sound is decreasing.
G. Silent.
H. Backed up and went through the region that was crackling before.
I. Crackling Sound.
J. Attempted retaking measurements at this frequency, but the meters were not stable.
K. Secondary voltage reading jumps from 1.47 V --> 1.48 V --> 0.48 V --> 1.47 V.
L. Audible plasma.
M. Loosing sound.
N. No sound.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	30	4.06	
110	30	4.02	
120	30.07	3.98	
130	30.08	3.92	
140	30.10	3.86	
150	30.12	3.80	
160	30.13	3.74	
170	30.14	3.68	
180	30.14	3.64	
190	30.15	3.56	
200	30.16	3.50	
210	30.17	3.44	
220	30.18	3.38	
230	30.18	3.32	

(con't.)

TABLE XXXIV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
240	30.19	3.26	
250	30.20	3.20	
260	30.20	3.14	
270	30.21	3.10	
280	30.22	3.04	
290	30.23	2.98	
300	30.23	2.92	A
310	30.24	2.88	B
320	30.25	2.84	
330	30.26	2.78	
340	30.27	2.74	
350	30.28	2.68	
360	30.29	2.62	
370	30.30	2.60	
380	30.31	2.56	
390	30.32	2.52	
400	30.33	2.48	
410	30.34	2.44	
420	30.35	2.40	
430	30.36	2.38	
440	30.37	2.34	
450	30.39	2.32	C
460	30.40	2.28	
470	30.41	2.26	
480	30.42	2.22	
490	30.43	2.20	
500	30.44	2.18	
510	30.46	2.16	
520	30.47	2.12	
530	30.48	2.10	
540	30.49	2.08	
550	30.49	2.06	
560	30.51	2.02	
570	30.52	2.00	
580	30.53	1.96	
590	30.54	1.92	
600	30.55	1.88	

(con't.)

TABLE XXXIV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
610	30.56	1.80	
620	30.56	1.70	D
630	30.56	1.54	
640	30.55	1.40	
650	30.55	1.24	
660		1.12	E
680	30.52	1.00	
690	30.52	1.06	F
700	30.53	1.16	
710	30.54	1.28	
720	30.56	1.40	
730	30.57	1.54	G
740	30.59	1.66	
750	30.60	1.76	H
650	30.52	1.22	I
660			E
750			J
800	30.02	2.32	
810	30.03	2.44	
820	30.04	2.60	
830	30.05	2.78	
840	30.07	2.94	K
850	30.08	3.14	
860	30.09	3.34	
870	30.10	3.52	
880	30.10	3.70	
890	30.11	3.82	
900	30.11	3.88	
910	30.11	3.88	L
920	30.11	3.80	
930	30.11	3.70	
940	30.11	3.56	
950	30.12	3.20	
960	30.12	3.06	M
970	30.12	3.04	
980	30.13	2.86	
990	30.14	2.72	

(con't.)

TABLE XXXIV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
1000	30.15	2.54	
1010	30.16	2.30	
1020	30.16	2.30	
1030	30.17	2.20	N
1040	30.18	2.08	
1050	30.19	2.00	

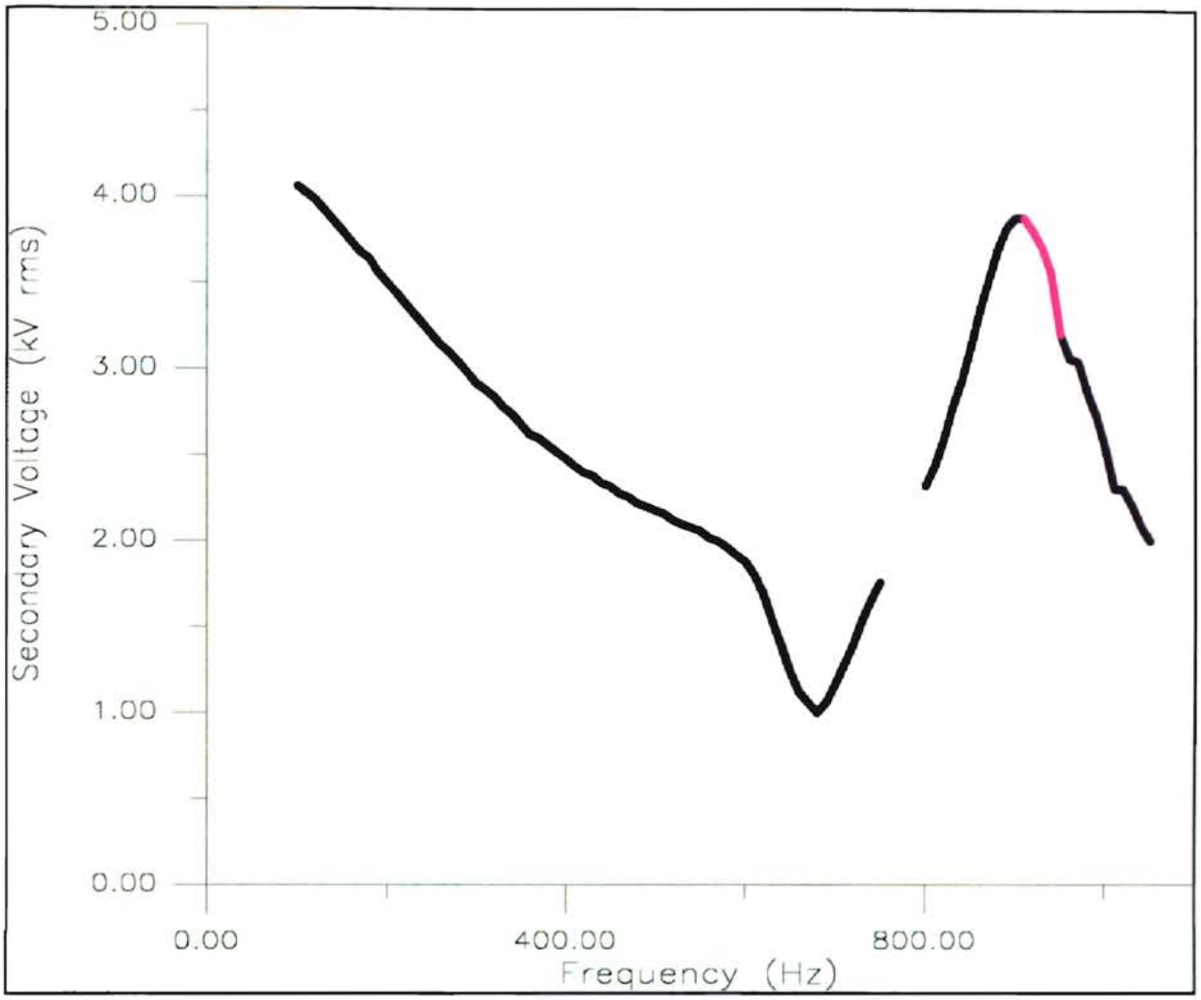


Figure 47. Typical Tuning Plot For Data Set #35.
Reactor without dielectric barriers.

Data Set #35 Analysis

It is difficult to be sure a plasma was created because of the inability to see into the vessel, but there was some glow inside and it sounded like a plasma was generated.

TABLE XXXV

Data Set #36

Setup
- No dielectric barrier reactor.
- Primary voltage is 30 volts rms.
- Inner electrode is a copper wire.
- Outer electrode is steel tube 14" long 2" I.D. 2.25 O.D." slightly corroded.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 32 degrees Fahrenheit.

Notes
A. Slight hum.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
1000	40.01	3.16	
990	39.99	3.34	
980	39.98	3.56	
970	39.97	3.78	
960	39.96	4.00	
950	39.95	4.08	
940	39.96	4.40	
930	39.95	4.58	
920	30.95	4.60	
910	39.94	4.86	A
900	39.94	4.92	
890	39.94	4.90	
880	39.94	4.90	
870	39.94	4.78	
860	39.93	4.66	
850	39.92	4.32	

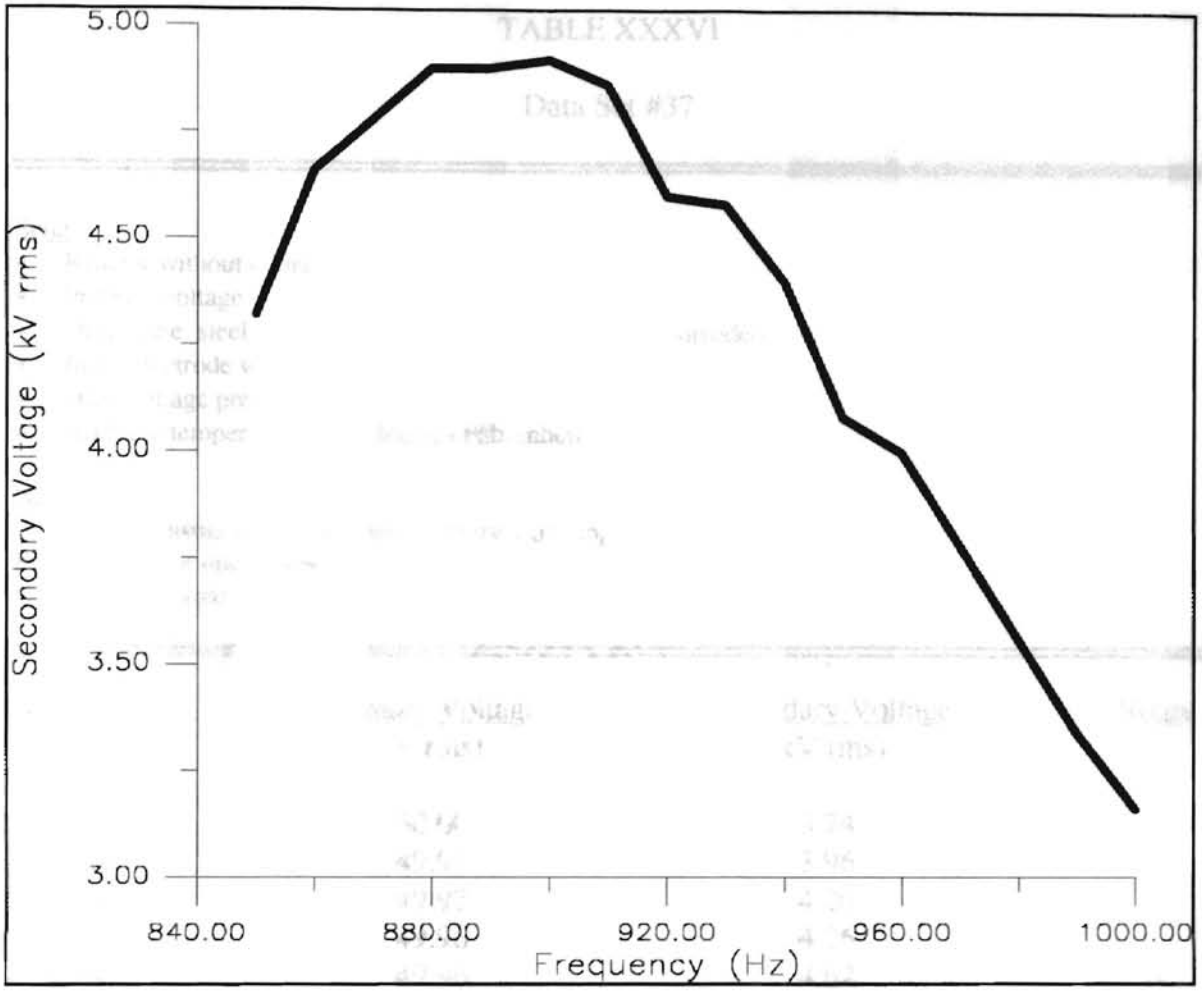


Figure 48. Typical Tuning Plot For Data Set #36.
Reactor without dielectric barriers.

Data Set #36 Analysis

A direct continuation from data set #35. I just approached from higher frequencies hoping to avoid the strange effects experienced around 650 Hz.

TABLE XXXVI

Data Set #37

Setup

- Reactor without dielectric walls.
- Primary voltage is 50 volts rms.
- Outer tube steel 14" long 2" I.D. 2.25 " O.D. slightly corroded.
- Inner electrode wire copper.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 32 degrees Fahrenheit.

Notes

A. Strong plasma sound, attempted observation, appears local.
B. Sparked for one second.
C. Loosing sound.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
1000	50.00	3.74	
990	49.98	3.96	
980	49.97	4.20	
970	49.96	4.26	
960	49.96	4.62	A
950	49.95	4.66	
940	49.95	4.94	
930	49.96	4.96	
920	49.95	5.04	
910	49.95	5.28	
900	49.94	5.40	B
890	49.94	5.48	
880	49.94	5.52	
870	49.93	5.56	
860	49.93	5.48	
850	49.91	5.34	C
840	49.90	5.08	
830	49.90	4.86	
820	49.89	4.60	
810	49.87	4.30	
800	49.85	3.92	

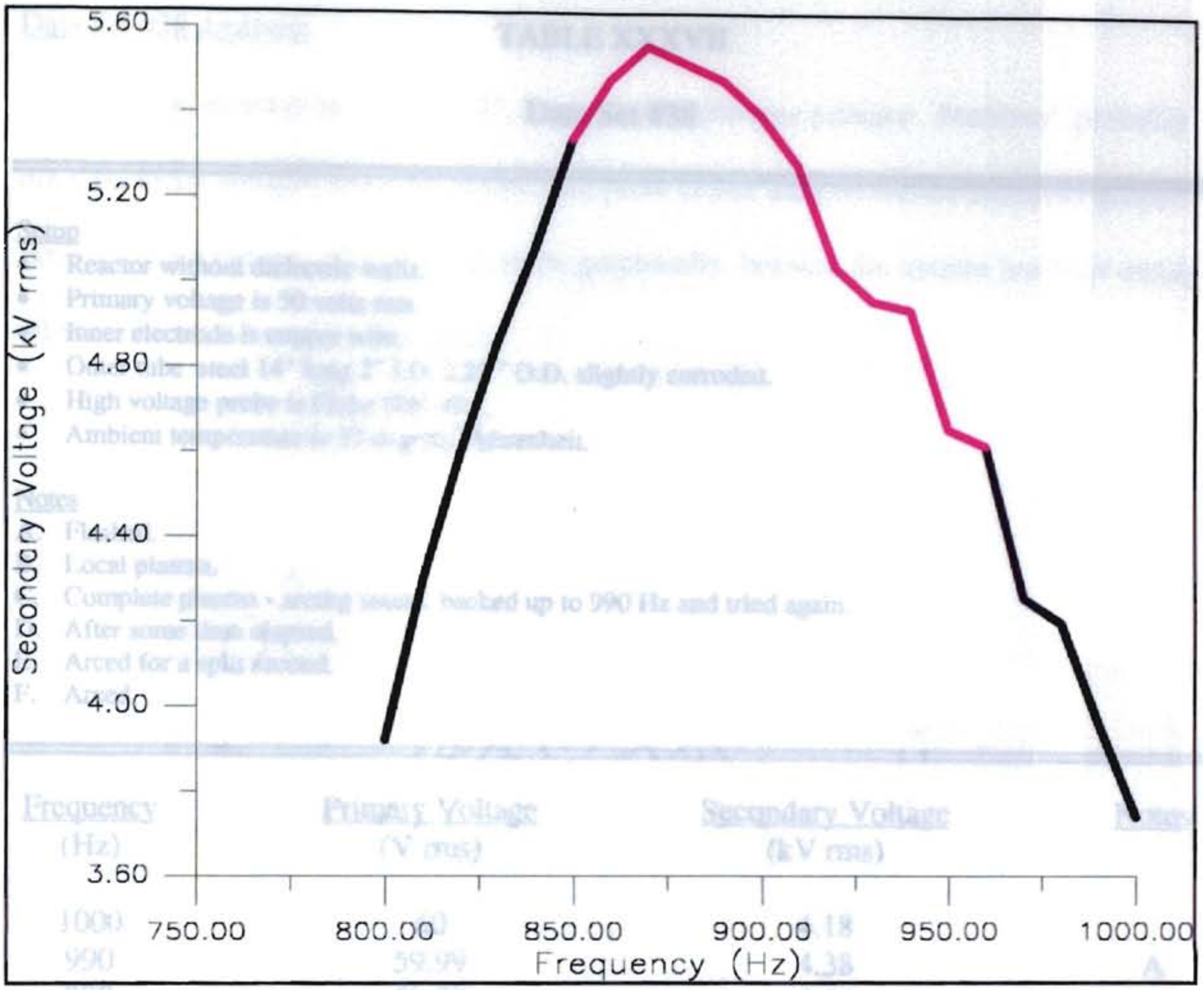


Figure 49. **Typical Tuning Plot For Data Set #37.**
Reactor without dielectric barriers.

Data Set #37 Analysis

Same as data set #36, except for increased primary voltage. It is possible there was just a local plasma.

TABLE XXXVII

Data Set #38

Setup
- Reactor without dielectric walls.
- Primary voltage is 50 volts rms.
- Inner electrode is copper wire.
- Outer tube steel 14" long 2" I.D. 2.25 " O.D. slightly corroded.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 32 degrees Fahrenheit.

Notes
A. Flashed.
B. Local plasma.
C. Complete plasma - arcing sound, backed up to 990 Hz and tried again.
D. After some time elapsed.
E. Arced for a split second.
F. Arced.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
1000	60	4.18	
990	59.99	4.38	A
980	59.98	4.56	
970	59.97	4.74	B
960			C
990	60.01	4.38	
980	60	4.58	
970	60	4.58	
970		4.76	D
969	60.02	4.74	
968	60.01	4.62	E
968		4.76	D
967	60.01	4.78	
966	60	4.64	F

Data Set #38 Analysis

Same as setup as data set #37, but with 60 volts rms primary. Problem: probably not a perfectly straight inner electrode. Arc point closer than all others; therefore greatest potential --> local arc. Not much to show graphically, because the system just kept arcing after minor adjustments in frequency.

TABLE XXXVIII

Data Set #39

Setup
- Reactor without dielectric walls.
- Primary voltage is 40 volts rms.
- Inner electrode is steel pipe (I.D. = 1/4", O.D. = 3/8").
- Outer electrode is a slightly corroded 14" long steel pipe (I.D. = 2", O.D. = 2 1/4").
- High voltage probe is Fluke 80K-40.
- Temperature is 32 degrees Fahrenheit.

Notes
A. Slight plasma like sound.
B. Had to stop to resecure apparatus, then proceeded.
C. Sound is fading.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
990	40.00	3.10	
980	40.00	3.28	
970	39.99	3.48	
960	39.98	3.68	
950	39.98	3.88	
940	39.98	4.10	A
930	39.97	4.30	
920	39.97	4.46	
910	39.97	4.60	
900	39.96	4.70	
890	39.96	4.74	
880	39.96	4.72	
870	39.96	4.62	B
870	40.00	4.72	
860	39.99	4.50	
850	39.98	4.26	
840	39.97	5.02	C

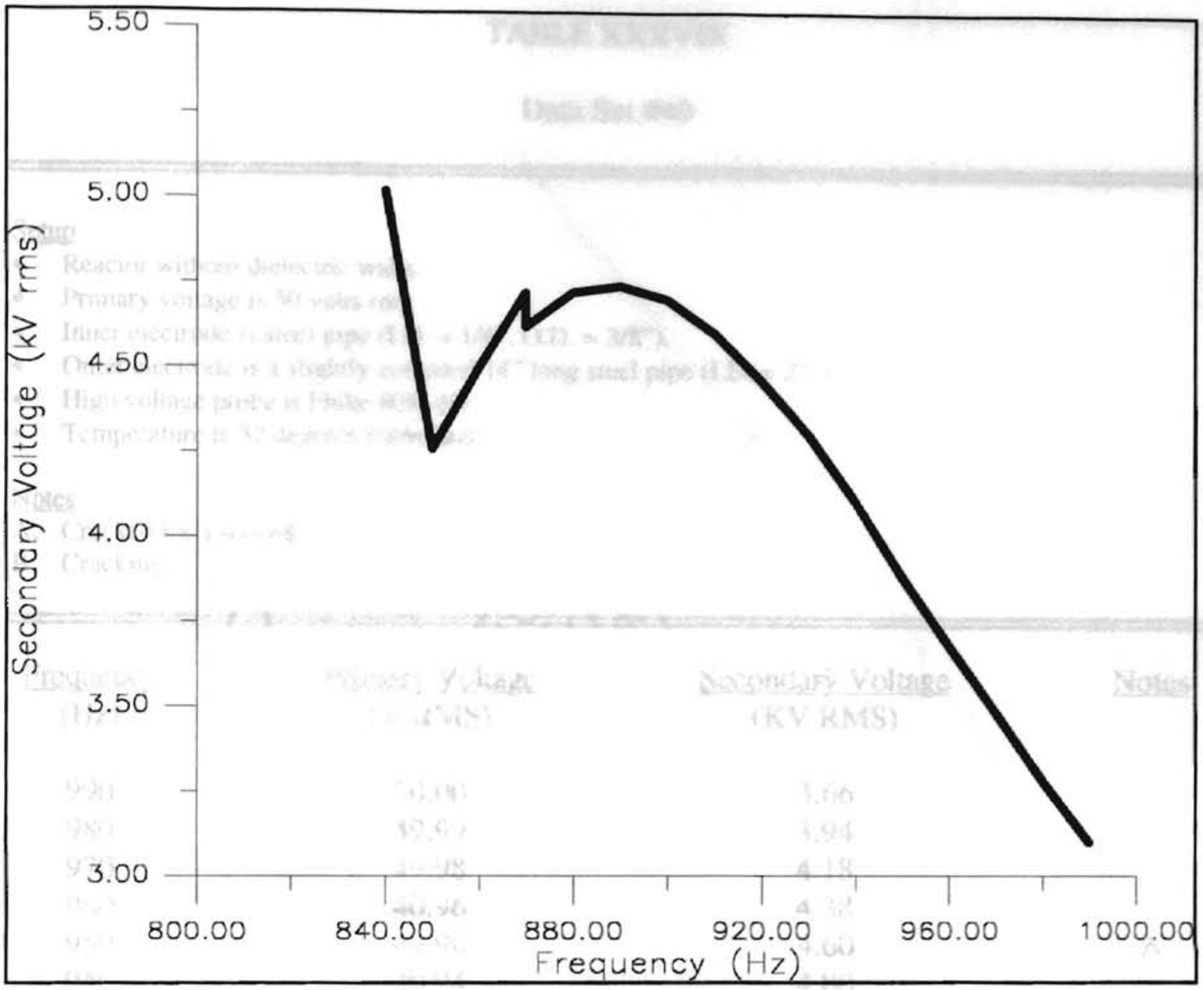


Figure 50. Typical Tuning Plot For Data Set #39.
The reactor is two concentric pieces of pipe.

Data Set #39 Analysis

The curve resembled previous curves, but it was impossible to tell if a plasma was created within the pipe.

TABLE XXXVIX

Data Set #40

<u>Setup</u>

- Reactor without dielectric walls.
- Primary voltage is 50 volts rms.
- Inner electrode is steel pipe (I.D. = 1/4", O.D. = 3/8").
- Outer electrode is a slightly corroded 14" long steel pipe (I.D. = 2", O.D. = 2 1/4").
- High voltage probe is Fluke 80K-40.
- Temperature is 32 degrees Fahrenheit.

<u>Notes</u>

A. Cracked for a second.
B. Cracking.

Frequency (Hz)	Primary Voltage (V RMS)	Secondary Voltage (KV RMS)	Notes
990	50.00	3.66	
980	49.99	3.94	
970	49.98	4.18	
960	40.96	4.38	
950	49.96	4.60	A
940	49.94	4.80	
930	49.93	5.02	
920	49.92	5.16	B

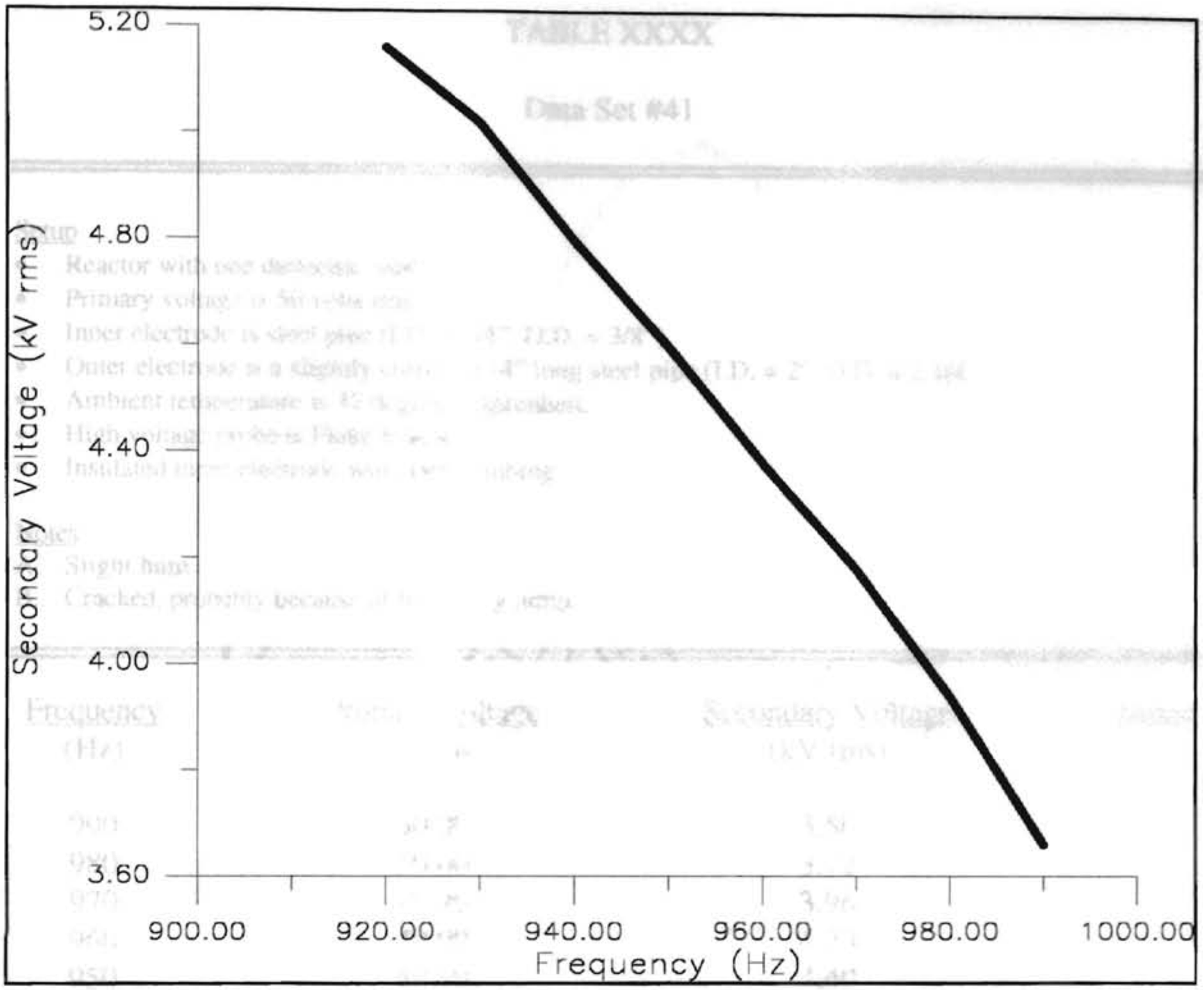


Figure 51. **Typical Tuning Plot For Data Set #40.**
The reactor is two concentric pieces of pipe.

Data Set #40 Analysis

Does not appear to be experiencing any form of resonance within this short range of frequency limited by this disturbing cracking sound.

TABLE XXXX

Data Set #41

Setup
- Reactor with one dielectric wall.
- Primary voltage is 50 volts rms.
- Inner electrode is steel pipe (I.D. = 1/4", O.D. = 3/8").
- Outer electrode is a slightly corroded 14" long steel pipe (I.D. = 2", O.D. = 2 1/4").
- Ambient temperature is 32 degrees Fahrenheit.
- High voltage probe is Fluke 80K-40.
- Insulated inner electrode with Tygon tubing.

Notes
A. Slight hum.
B. Cracked, probably because of frequency jump.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
990	50.00	3.50	
980	50.00	3.72	
970	49.99	3.96	
960	49.99	4.20	A
950	49.99	4.40	
940	49.99	4.62	
930	49.98	4.86	
920	49.96	5.06	
910	49.97	5.24	
900	49.97	5.40	
890	49.97	5.54	
880	49.97	5.60	
870	49.98	5.52	
860	49.97	5.46	
850	49.96	5.28	
840	49.96	5.06	
830	49.96	4.76	
820	49.93	4.46	
810	49.91	4.14	
800	49.91	3.86	
790	49.87	3.56	B

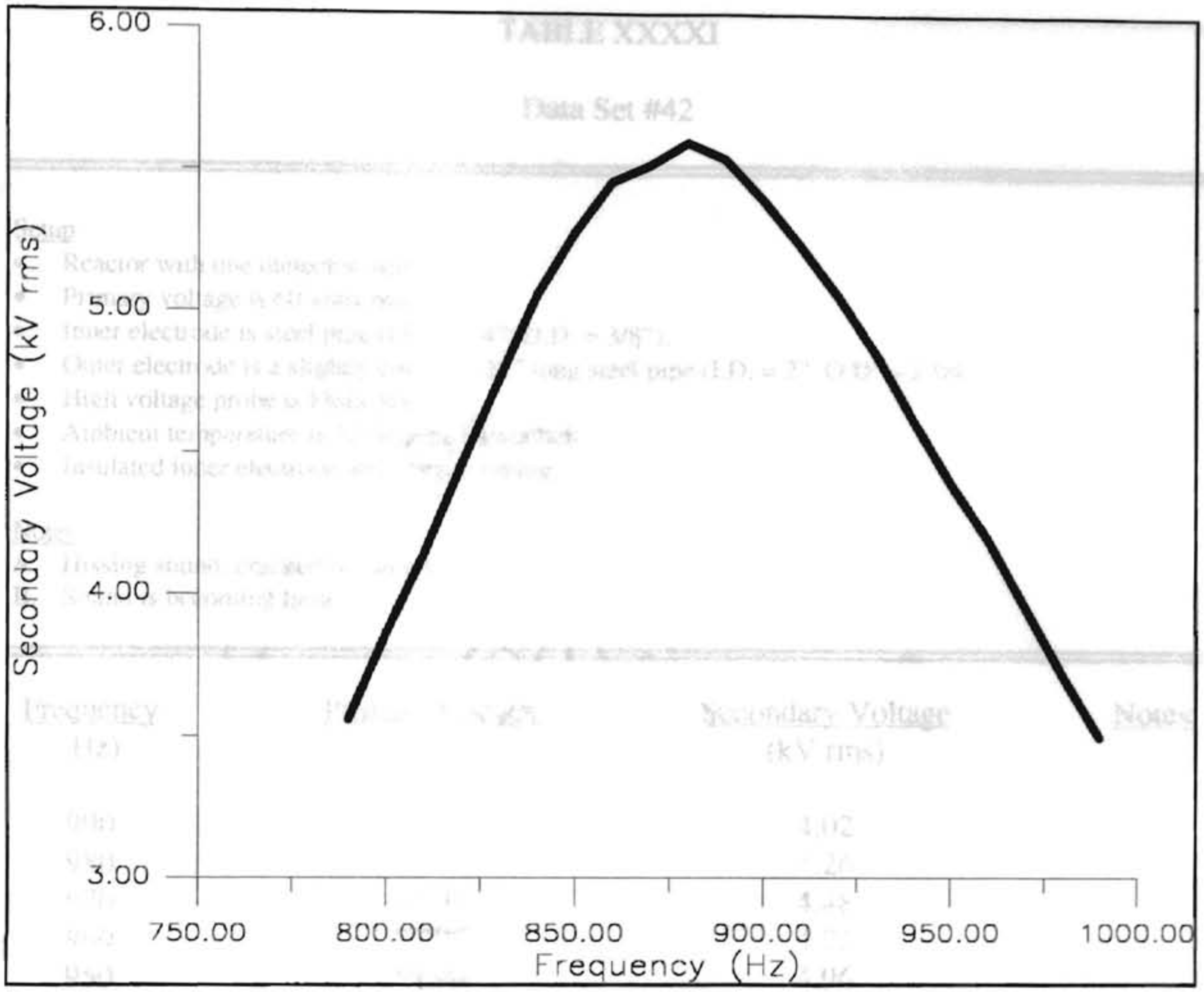


Figure 52. **Typical Tuning Plot For Data Set #41.**
The reactor is two concentric pieces of pipe with one dielectric barrier provided by sliding Tygon tubing over the inner pipe..

Data Set #41 Analysis

Same as data set #40 except one dielectric barrier was added around the inner electrode by means of sliding on Tygon tubing over the inner electrode. I was able to increase the frequency range.

TABLE XXXXI

Data Set #42

Setup
- Reactor with one dielectric wall.
- Primary voltage is 60 volts rms.
- Inner electrode is steel pipe (I.D. = 1/4", O.D. = 3/8").
- Outer electrode is a slightly corroded 14" long steel pipe (I.D. = 2", O.D. = 2 1/4").
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 32 degrees Fahrenheit.
- Insulated inner electrode with Tygon tubing.

Notes
A. Hissing sound, cracked for an instant.
B. Sound is becoming faint.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
990	60.00	4.02	
980	59.98	4.26	
970	59.97	4.48	
960	59.95	4.72	
950	59.90	4.96	
940	59.87	5.20	
930	59.87	5.48	
920	59.87	5.64	A
910	59.85	5.84	
900	59.81	6.02	
890	59.78	6.20	
880	59.76	6.32	
870	59.75	6.38	
860	59.76	6.32	
850	59.78	6.20	B
840	59.83	5.98	
830	59.89	5.72	
820	59.88	5.40	
810	59.87	5.04	
800	59.83	4.70	
790	59.83	4.38	B

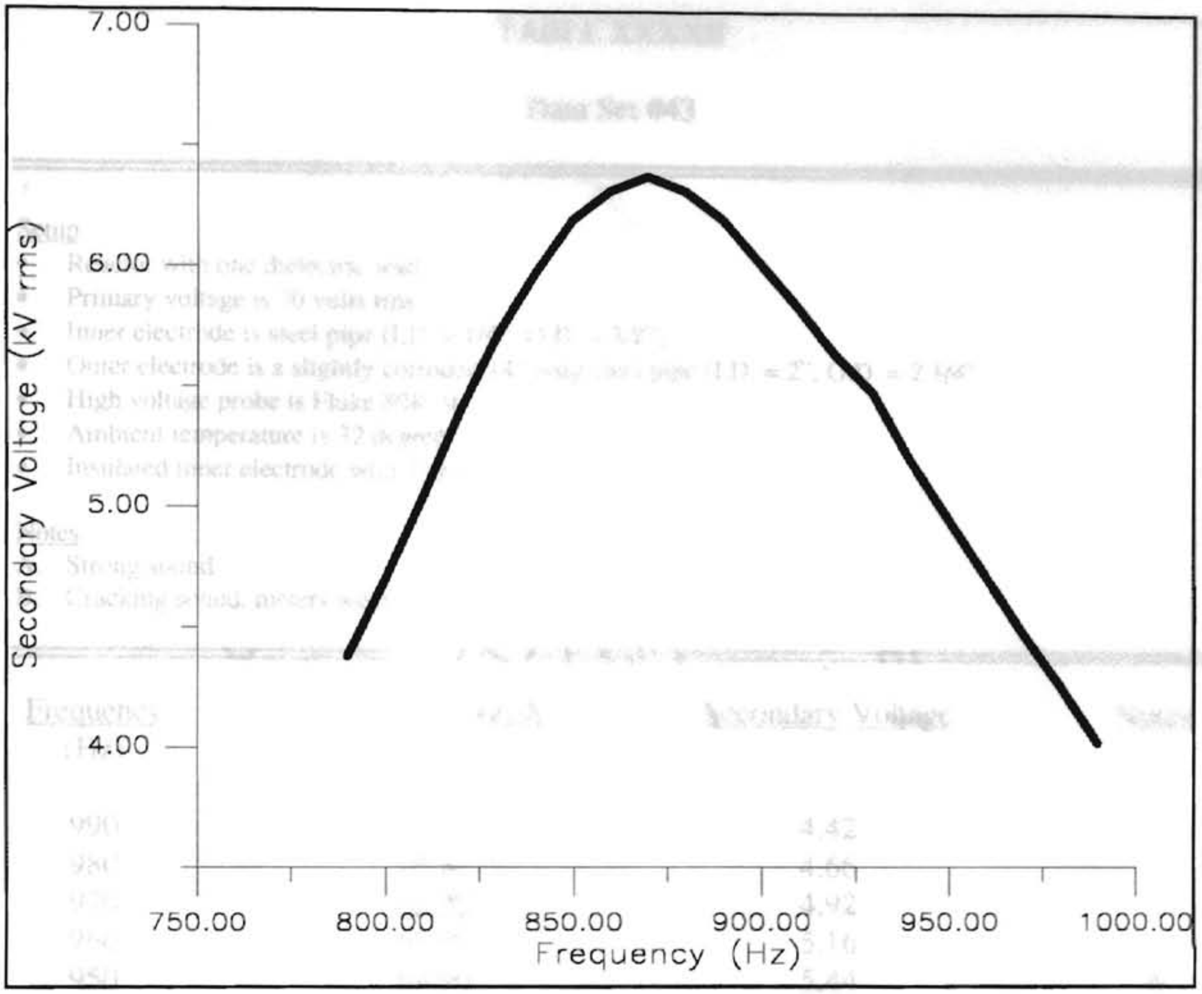


Figure 53. **Typical Tuning Plot For Data Set #42.**
The reactor is two concentric pieces of pipe with one dielectric barrier provided by sliding Tygon tubing over the inner pipe.

Data Set #42 Analysis

The curve shows resonance, but no signs of plasma.

TABLE XXXXII

Data Set #43

Setup

- Reactor with one dielectric wall.
- Primary voltage is 70 volts rms.
- Inner electrode is steel pipe (I.D. = 1/4", O.D. = 3/8").
- Outer electrode is a slightly corroded 14" long steel pipe (I.D. = 2", O.D. = 2 1/4").
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 32 degrees Fahrenheit.
- Insulated inner electrode with Tygon tubing.

Notes

A. Strong sound.
B. Cracking sound, meters went haywire.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
990	70.00	4.42	
980	69.94	4.66	
970	69.90	4.92	
960	69.90	5.16	
950	69.90	5.44	A
940	69.88	5.66	
930			B

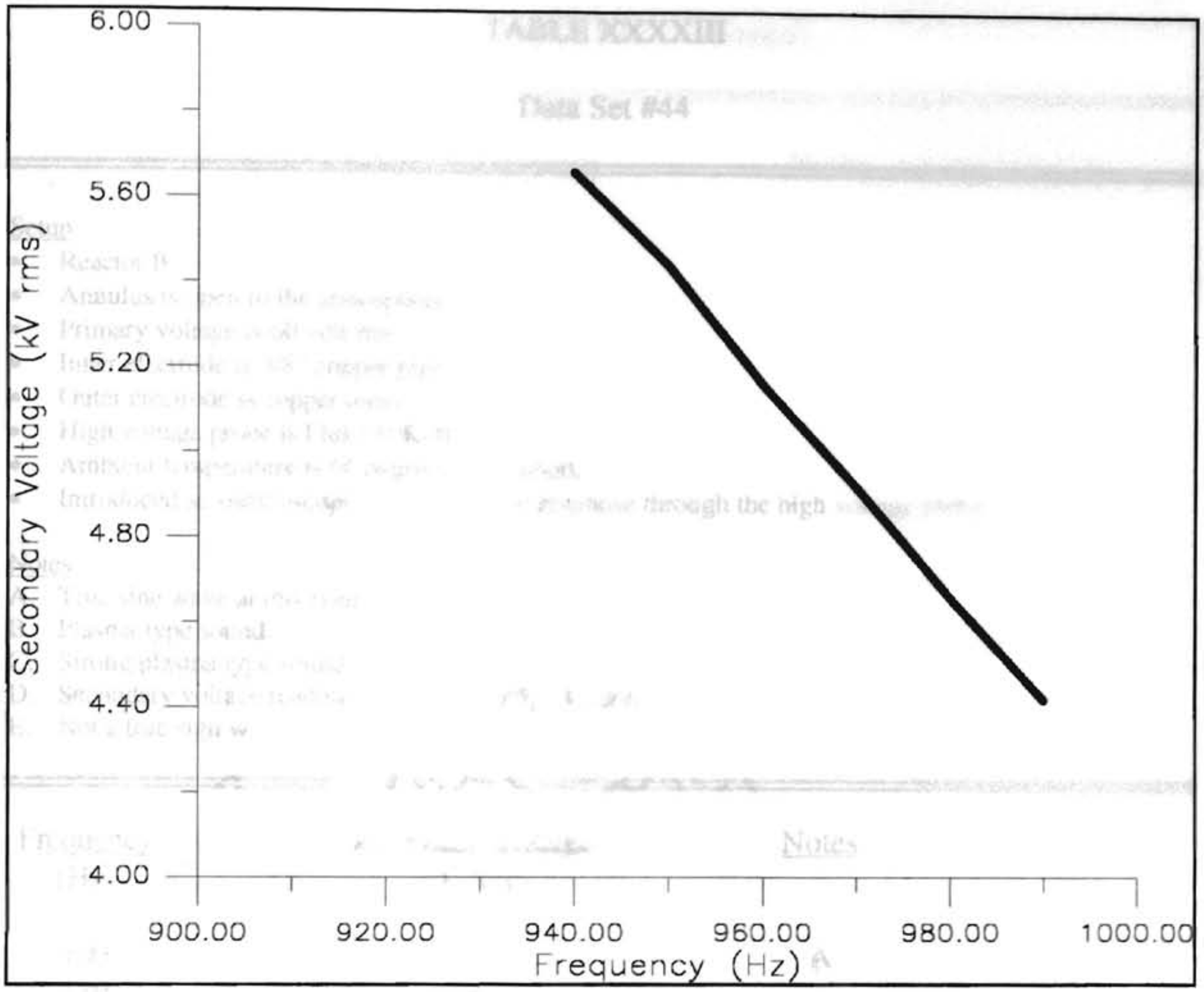


Figure 54. **Typical Tuning Plot For Data Set #43.**
The reactor is two concentric pieces of pipe with one dielectric barrier provided by sliding Tygon tubing over the inner pipe.

<u>Data Set #43 Analysis</u>

I proceeded from higher frequencies to lower frequencies and as the voltage increased the system made a cracking sound and the meters became very unstable. It probably arced inside the space between the pipes well hidden from my viewpoint.

TABLE XXXXIII

Data Set #44

Setup
- Reactor B
- Annulus is open to the atmosphere.
- Primary voltage is 60 volt rms.
- Inner electrode is 3/8" copper pipe.
- Outer electrode is copper mesh.
- High voltage probe is Fluke 80K-40.
- Ambient temperature is 66 degrees Fahrenheit.
- Introduced an oscilloscope to visualize the response through the high voltage probe.

Notes
A. True sine wave at this point.
B. Plasma type sound.
C. Strong plasma type sound.
D. Secondary voltage reading fluctuates wildly. (Crazy)
E. Not a true sign wave.

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
100	3.94	A
110	3.92	
120	3.88	
130	3.84	
140	3.82	
150	3.78	
160	3.74	
170	3.70	
180	3.66	
190	3.62	
200	3.58	
210	3.54	
220	3.50	
230	3.46	
240	3.44	
250	3.40	
260	3.36	
270	3.30	
280	3.28	
290	3.24	

(con't.)

TABLE XXXXIII (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Notes
300	3.20	
310	3.18	
320	3.14	
330	3.10	
340	3.08	
350	3.04	
360	3.02	
370	3.00	
380	2.98	
390	2.96	
400	2.96	
410	2.94	B
420	2.94	
430	2.92	C
440		D
450		D
460		D
470		D
480		D
490		D
500		D,E
510		D,E
520		D,E
530		D,E
540		D,E
550		D,E
560		D,E
570		D,E
580		D,E
590		D,E
600		D,E
610		D,E
620		D,E

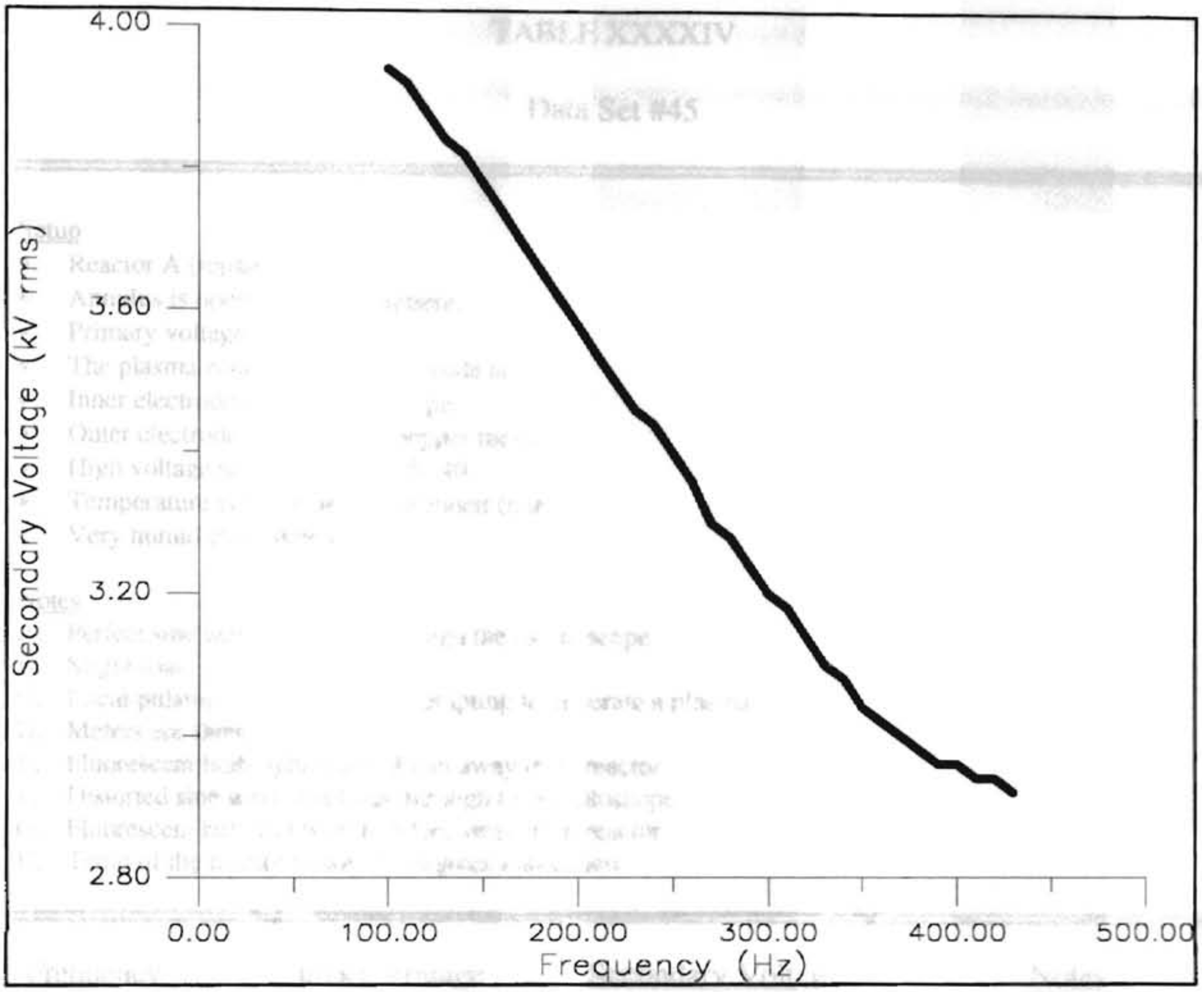


Figure 55. Typical Tuning Plot For Data Set #44.
Reactor B with the annulus open to the atmosphere.

Data Set #44 Analysis

From the oscilloscope the peak to peak voltages were difficult to read precisely, but they did provide a good reference to check the meters. The oscilloscope showed a distorted sine wave, as in Figure 13,occuring with the frequencies above 500 Hz. After this experiment I noted the reactor was warm.

TABLE XXXXIV

Data Set #45

Setup
- Reactor A (repaired version).
- Annulus is open to the atmosphere.
- Primary voltage is 80 volts rms.
- The plasma zone (length of electrode is 12 ").
- Inner electrode is 3/4" copper pipe.
- Outer electrode is 3 wraps of copper mesh.
- High voltage probe is Fluke 80K-40.
- Temperature is 62 degrees Fahrenheit (humid).
- Very humid environment.

Notes
A. Perfect sine wave displayed through the oscilloscope.
B. Slight tone.
C. Local pulsing , appears to be attempting to generate a plasma.
D. Meters are fluctuating.
E. Fluorescent bulb lights up to 3 feet away from reactor.
F. Distorted sine wave displayed through the oscilloscope.
G. Fluorescent bulb lights up to 5 feet away from reactor.
H. Temp of the reactor is now 85 degrees Fahrenheit.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	80.00	5.28	A
110	80.15	5.26	
120	80.27	5.24	
130	80.40	5.20	
140	80.45	5.18	
150	80.48	5.14	
160	80.52	5.12	
170	80.54	5.08	
180	80.57	5.04	
190	80.59	5.00	
200	80.61	4.98	
210	80.64	4.92	
220	80.66	4.90	
230	80.68	4.86	
240	80.70	4.82	B
250	80.72	4.78	

(con't.)

TABLE XXXXIV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
260	80.74	4.74	
270	80.76	4.72	
280	80.79	4.68	
290	80.80	4.66	
300	80.82	4.62	
310	80.85	4.60	
320	80.87	4.58	
330	80.90	4.56	
340	80.92	4.54	
350	80.94	4.52	
360	80.95	4.50	
370	80.96	4.50	
380	80.99	4.50	
390	80.99	4.50	
400	81.00	4.50	
410	81.02	4.50	
420	81.04	4.52	
430	81.02	4.54	
440	80.98	4.56	
450	80.97	4.62	T of reactor = 85 F
460			C,D,E
470			D,F
480			D
490			D,G,H

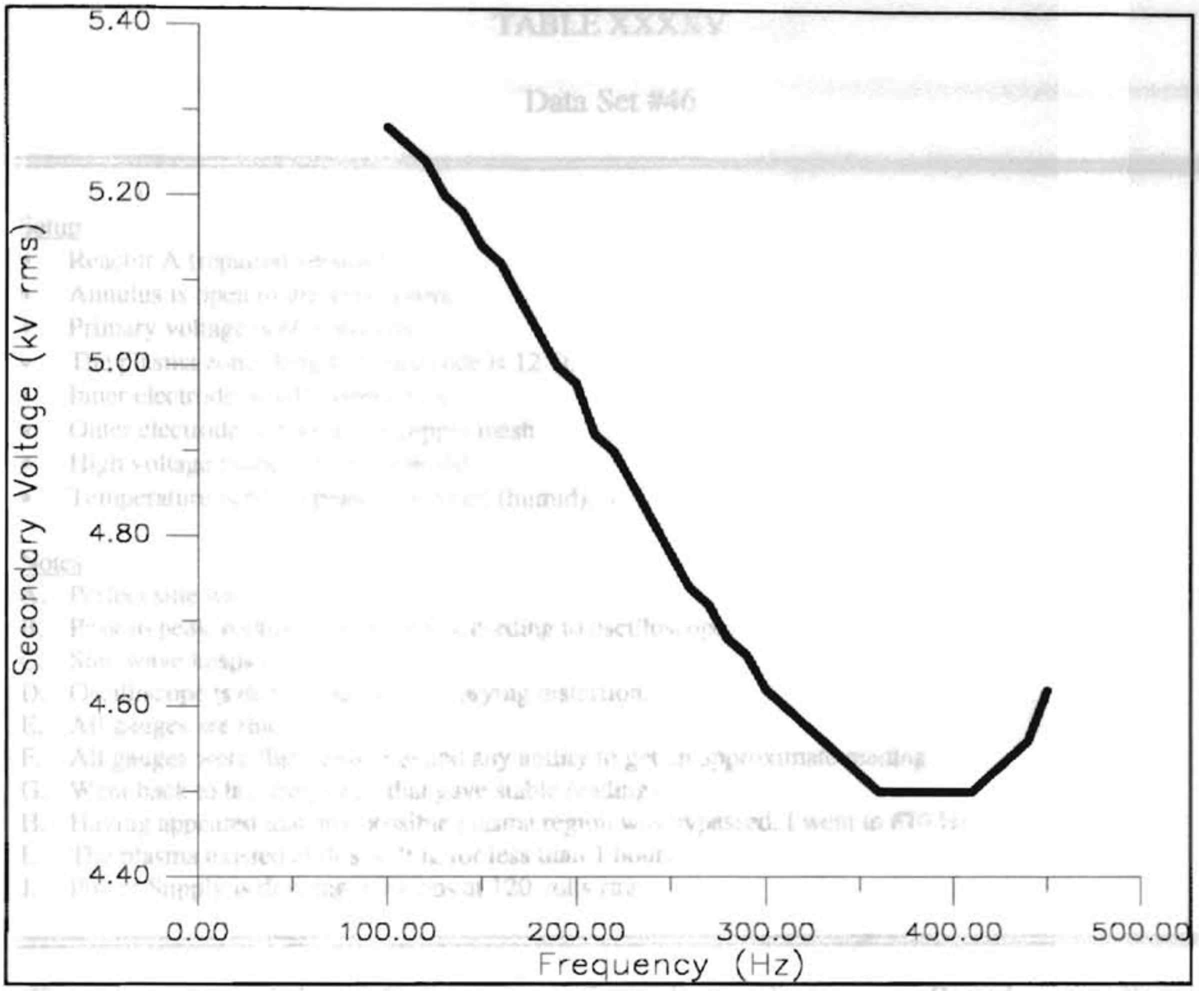


Figure 56. **Typical Tuning Plot For Data Set #45.**
Reactor A with the annulus open to the atmosphere.

Data Set #45 Analysis

Put the possible plasma zone in the middle of the reactor trying to avoid end effects. Checked frequency from the oscilloscope and it was the same value. High amount of radiation evident by lighting the fluorescent light bulbs at a distance removed of 5 feet.

TABLE XXXXV

Data Set #46

Setup

- Reactor A (repaired version).
- Annulus is open to the atmosphere.
- Primary voltage is 60 volts rms.
- The plasma zone (length of electrode is 12 ").
- Inner electrode is 3/4" copper pipe.
- Outer electrode is 3 wraps of copper mesh.
- High voltage probe is Fluke 80K-40.
- Temperature is 68 degrees Fahrenheit (humid).

Notes

A. Perfect sine wave.
B. Peak to peak voltage is near 5 kV according to oscilloscope.
C. Sine wave keeps inverting.
D. Oscilliscope is displaying rapidly varying distortion.
E. All gauges are fluctuating.
F. All gauges were fluctuating beyond any ability to get an approximate reading.
G. Went back to last frequency that gave stable readings.
H. Having appeared that any possible plasma region was bypassed, I went to 670 Hz.
I. The plasma existed at this setting for less than 1 hour.
J. Power Supply is drawing 5.9 amps at 120 volts rms.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Period (ms)	Notes
100	60.00	3.96		A
110	60.07	3.94		
120	60.13	3.92		
130	60.15	3.88		
140	60.20	3.84	36	
150	60.22	3.82		
160	60.23	3.78	32	
170	60.26	3.74		
180	60.27	3.72		
190	60.29	3.68		
200	60.32	3.64	25	
210	60.34	3.62		
220	60.36	3.58		
230	60.38	3.54		
240	60.39	3.50		

(con't.)

TABLE XXXXV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Period (ms)	Notes
250	60.40	3.48	20	
260	60.42	3.44		
270	60.43	3.40		B
280	60.45	3.38		
290	60.47	3.34		
300	60.48	3.32	17	
310	60.50	3.30		
320	60.51	3.26		
330	60.54	3.24		
340	60.54	3.22		
350	60.59	3.20	14	
360	60.59	3.18		
370	60.63	3.18		
380	60.64	3.16		
390	60.66	3.16		
400	60.66	3.14	12.5	
410	60.68	3.14		
420	60.69	3.16		
430	60.71	3.16		
440	60.71	3.18		
450	60.74	3.18	11.25	
460	60.76	3.20		
470	60.76	3.24		
480	60.72	3.28		C
490	60.66	3.28		D
500	60.64	3.32		E
510				F
520				
530				
470	60.73	3.16		G
570				F
700	60.35	0.90		
710	60.43	1.14		
720	60.49	1.36		
730	60.54	1.60		
740	60.58	1.82		H
670				F,I,J

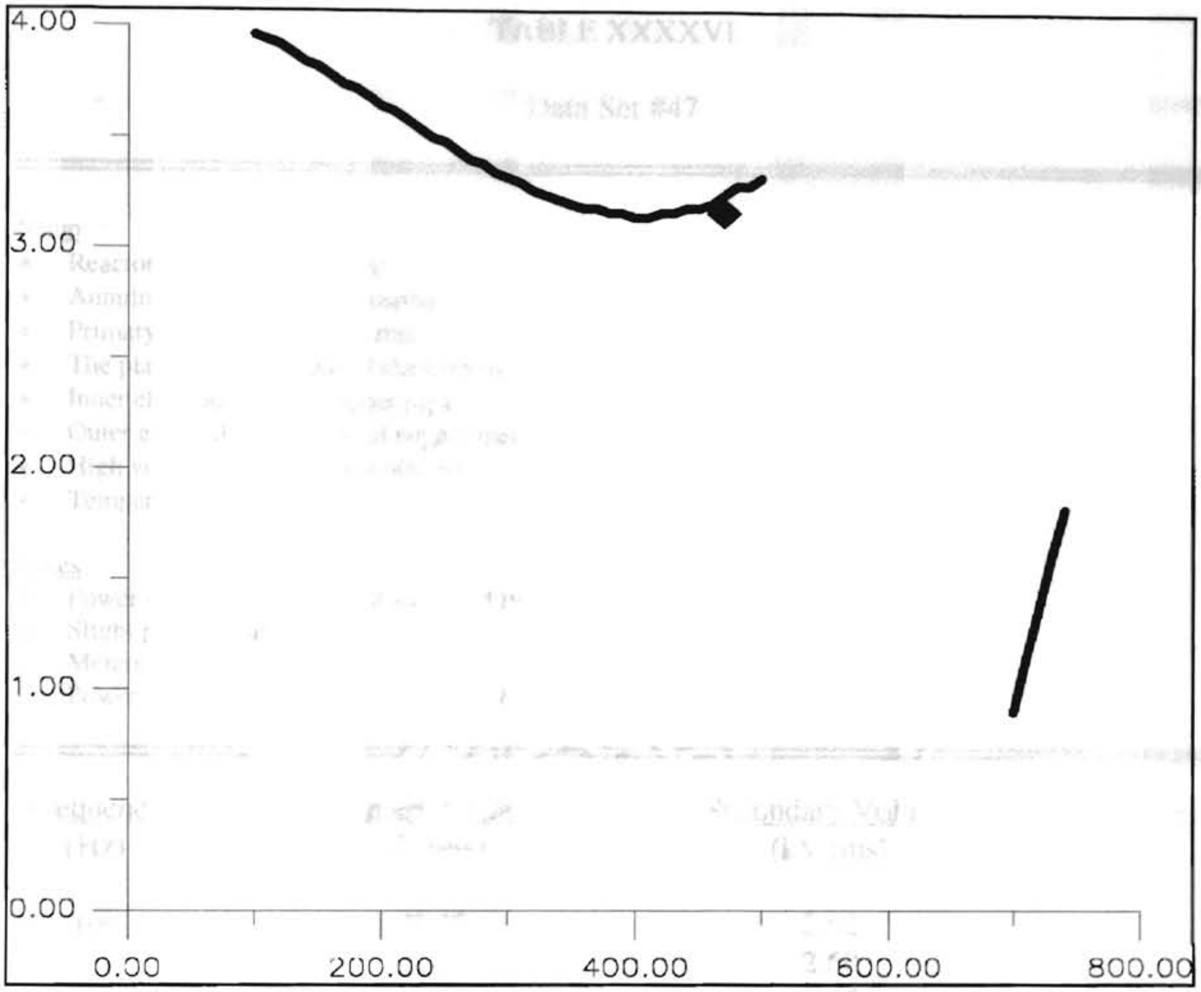


Figure 57. **Typical Tuning Plot For Data Set #46.**
Reactor C with deionized water flowing through the annulus

Data Set #46 Analysis

The total power must be some value below the power supply consumption, which was approximately 710 watts. The power supply is rated to supply a maximum of 750 watts, so I was nearing the maximum power available.

TABLE XXXXVI

Data Set #47

Setup

- Reactor A (repaired version).
- Annulus is open to the atmosphere.
- Primary voltage is 40 volts rms.
- The plasma zone (length of electrode is 12 ").
- Inner electrode is 3/4" copper pipe.
- Outer electrode is 3 wraps of copper mesh.
- High voltage probe is Fluke 80k-40.
- Temperature is 68 degrees Fahrenheit (humid).

Notes

A. Power supply is drawing 3.8 amps at 119 volts.
B. Slight plasma sound.
C. Meters are unstable.
D. Power supply is drawing 3.6 amps at 119 volts.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
100	40.00	2.62	
110	40.05	2.60	
120	40.08	2.56	
130	40.11	2.54	
140	40.13	2.50	
150	40.15	2.48	
160	40.16	2.44	
170	40.18	2.40	
180	40.19	2.36	
190	40.21	2.34	
200	40.23	2.30	
210	40.25	2.26	
220	40.27	2.22	
230	40.29	2.16	
240	40.30	2.14	
250	40.31	2.12	
260	40.29	2.08	
270	40.31	2.04	
280	40.32	2.00	
290	40.34	1.96	

(con't.)

TABLE XXXXVI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
300	40.35	1.92	
310	40.37	1.88	
320	40.38	1.84	
330	40.41	1.80	
340	40.42	1.76	
350	40.44	1.72	
360	40.44	1.68	
370	40.48	1.64	
380	40.50	1.62	
390	40.51	1.58	
400	40.50	1.54	
410	40.57	1.50	
420	40.57	1.46	
430	40.59	1.42	
440	40.60	1.40	
450	40.62	1.36	
460	40.66	1.34	
470	40.69	1.30	
480	40.71	1.28	
490	40.73	1.24	
500	40.74	1.22	
510	40.75	1.20	
520	40.77	1.18	
530	40.79	1.16	
540	40.80	1.14	
550	40.82	1.10	
560	40.82	1.08	
570	40.83	1.06	
580	40.84	1.06	
590	40.85	1.04	
600	40.90	1.02	
610	40.91	1.02	
620	40.92	1.00	
630	40.93	0.98	
640	40.94	0.96	B
650	40.94	0.96	
660	40.95	0.96	

(con't.)

TABLE XXXXVI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
670	40.95	0.96	
680	41.11	0.94	
690	41.11	0.94	
700	41.13	0.92	
710	41.13	0.92	
720	41.14	0.92	
730	41.15	0.92	
740	41.15	0.90	
750	41.15	0.90	
760	41.16	0.96	
770	41.18	0.94	C
780	41.17	0.96	D
790	41.17	0.96	
800	41.17	0.96	
810	41.20	0.96	
820	41.21	0.96	
850	41.24	0.94	
900	41.28	0.94	
950	41.31	0.92	

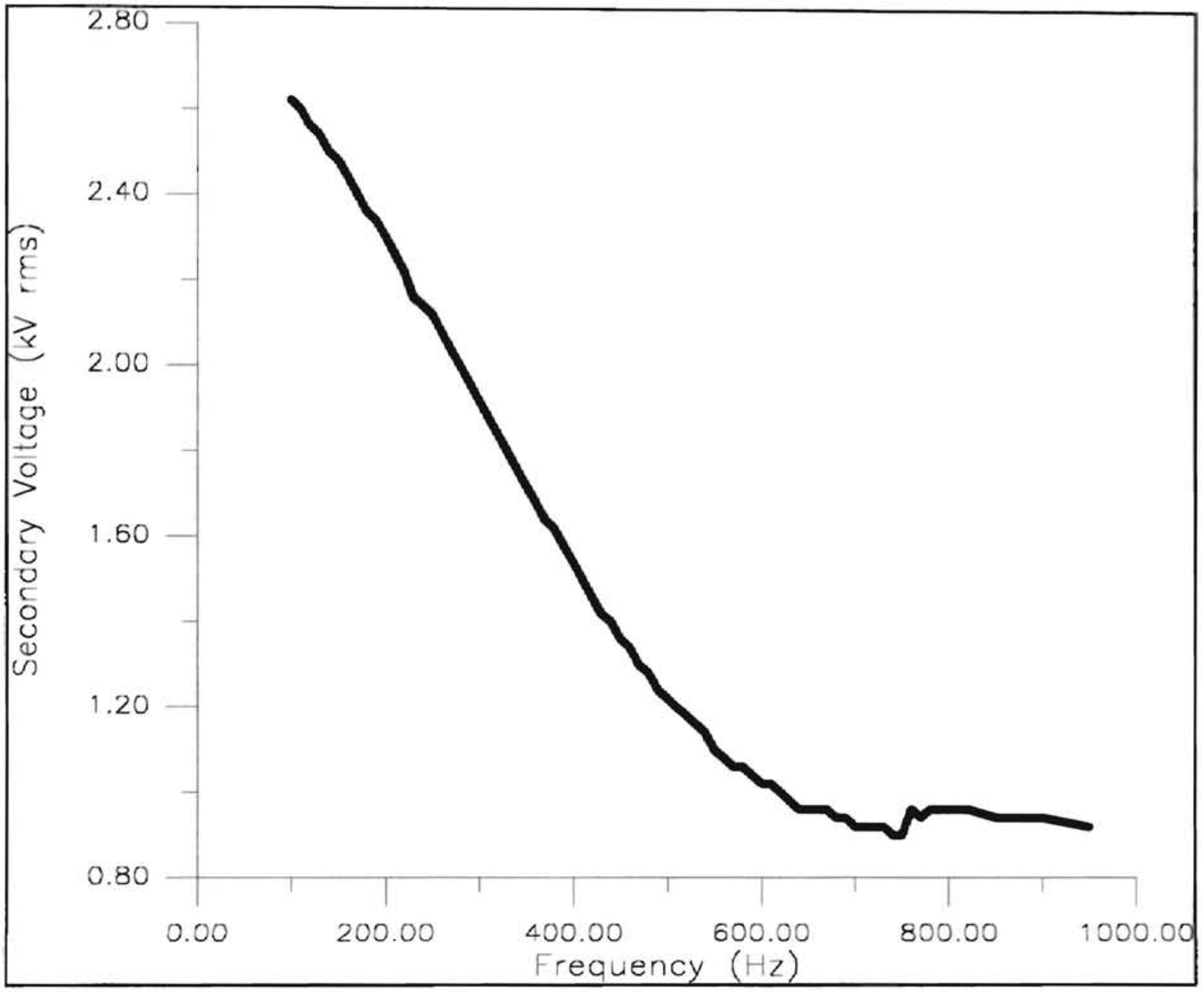


Figure 58. **Typical Tuning Plot For Data Set #47.**
Reactor A with the annulus open to the atmosphere.

Data Set #47 Analysis

The secondary voltage is surprisingly low. It could be the prolonged operation in data set #46 burned out the transformer. The high voltage probe appears to be working, because the period of the sine wave corresponded to the operating frequency throughout the experiment.

TABLE XXXXVII

Data Set #48

Setup
- Large Reactor A (new repaired version).
- Annulus is open to the atmosphere.
- Primary voltage is 60 volts rms.
- Plasma Zone is 12 ".
- Outer electrode is 3 wraps of copper mesh.
- 3/4" pipe and cap inner electrode connection.
- High voltage probe is Fluke 80k-40.
- Temperature is 68 degrees Fahrenheit.
- The current is the current drawn by the power supply from the 120 volt receptacle.

Notes
A. Shut down to check probe, it is attached.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Current (Amps)	Notes
100	50.06	0.42	9.8	
110		0.42	9.1	
120		0.40	8.5	
130	50.23	0.40	8	
140	50.27	0.40	7.6	
150	50.30	0.38	7.2	
160	50.34	0.38	6.9	
170	50.36	0.36	6.5	
180	50.39	0.36	6.4	
190	50.38	0.34	6.3	
200	50.41	0.34	6.1	
210	50.45	0.32	5.7	
220		0.32		A
230	50.01	0.32	5.5	
240	50.03	0.30	5.4	
250	50.04	0.30	5.25	
260	50.07	0.28	5.1	
270	50.08	0.26	5	
280	50.11	0.26	5	
290	50.13	0.26	4.8	
300	50.15	0.24	4.7	

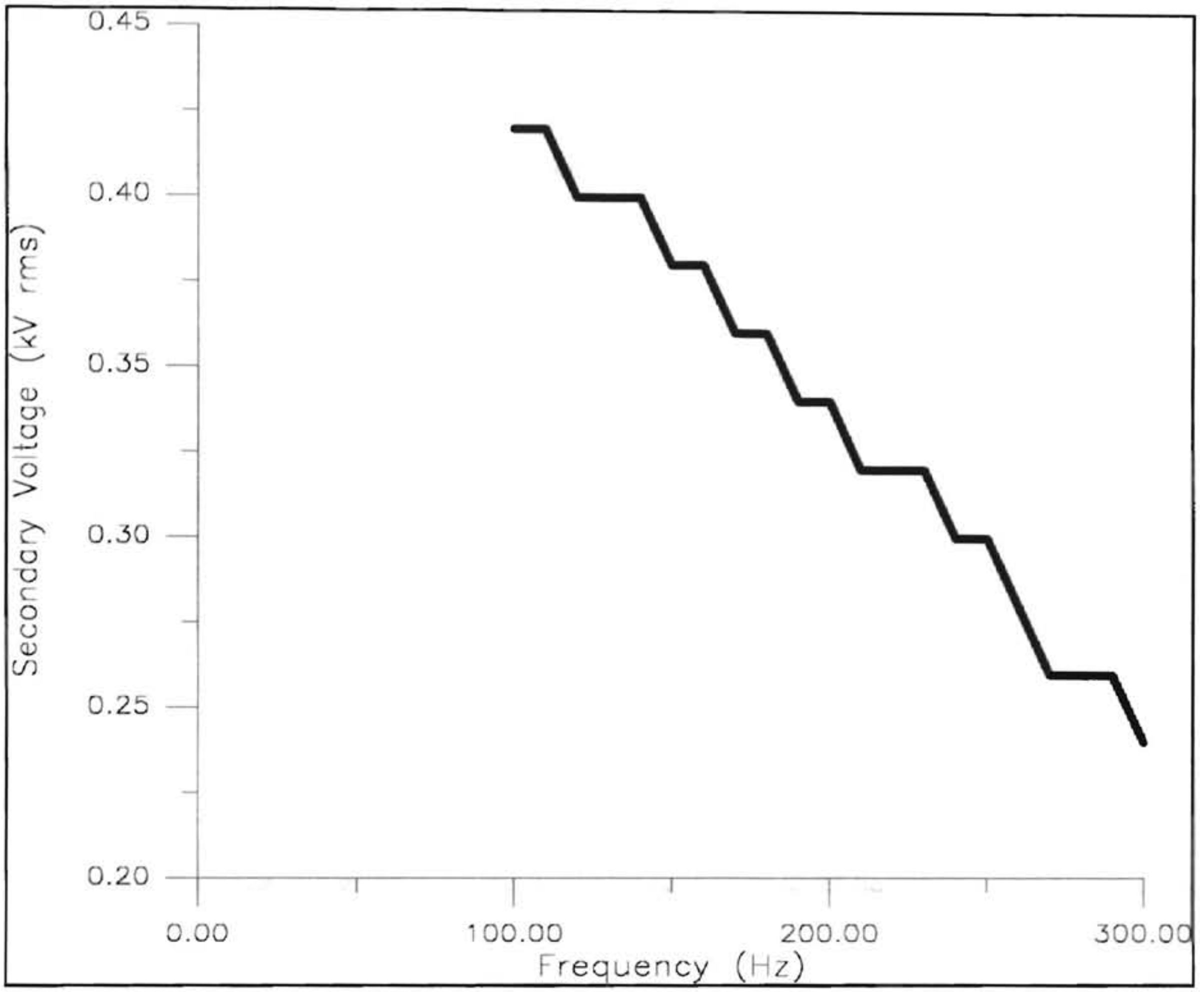


Figure 59. Typical Tuning Plot For Data Set #48.
Reactor A with the annulus open to the atmosphere.

Data Set #48 Analysis

It was obvious the transformer had near completely shorted out making it useless for producing a plasma with this setup. I replaced this transformer with an identical replacement (Magnetek Jefferson).

TABLE XXXXVIII

Data Set #49

Setup

- The power supply is a variable transformer (Variac).
- 2 liter plastic Pepsi bottle serves as vessel.
- Frequency is constant 60 Hz.
- Inner electrode is a copper pipe forced through the opening of the bottle.
- Outer electrode is copper mesh wrapped outside the bottle.
- High voltage probe is Hewlett Packard 1137A.

Notes

A. Distorted steady sine wave shown on oscilloscope.
B. Noise only.

Primary Voltage (V rms)	Secondary Voltage (kV rms)	Current (amps)	Notes
142	17.6	2.5	A,B

Data Set #49 Analysis

The large air space required more power than can be supplied with the Variac.

TABLE XXXXIX

Data Set #50

Setup

- 2 liter Pepsi bottle serves as vessel.
- Inner electrode is a copper pipe forced through the opening of the bottle.
- Outer electrode is copper mesh wrapped outside the bottle.
- High voltage probe is Hewlett Packard 1137A.

Notes

A. Perfect sine wave shown on oscilloscope.
B. Lightning like semi-arc quickly rotates through the reactor.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Current (amps)	Notes
100	85.8	10.84	4.5	A
110	85.8	10.86	4.2	A
120	85.9	10.88	4.0	A,B

Data Set #50 Analysis

This appeared to create a plasma just before the arc-like discharge began rotating through the vessel.

TABLE L

Data Set #51

Setup

- The power supply is simply a variable transformer (Variac).
- 20 ounce plastic Pepsi bottle serves as vessel.
- Frequency is constant 60 Hz.
- Inner electrode is a copper pipe forced through the opening of the bottle.
- Outer electrode is copper mesh wrapped outside the bottle.
- High voltage probe is Hewlett Packard 1137A.

Notes

A. Local effects at places of previous mechanical stress in bottle.
B. Began arcing -- developed point of local fatigue.

Current (amps)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
0.20	10	0.85	
0.30	20	1.65	
0.30	30	2.46	
0.40	40	3.32	
0.40	50	4.20	
0.40	60	5.20	
0.50	70	6.05	
0.50	80	7.00	A
0.50	85	7.50	
0.60	90	8.18	
0.50	95	8.60	
0.40	100	9.20	
0.50	105	9.70	
	110		B

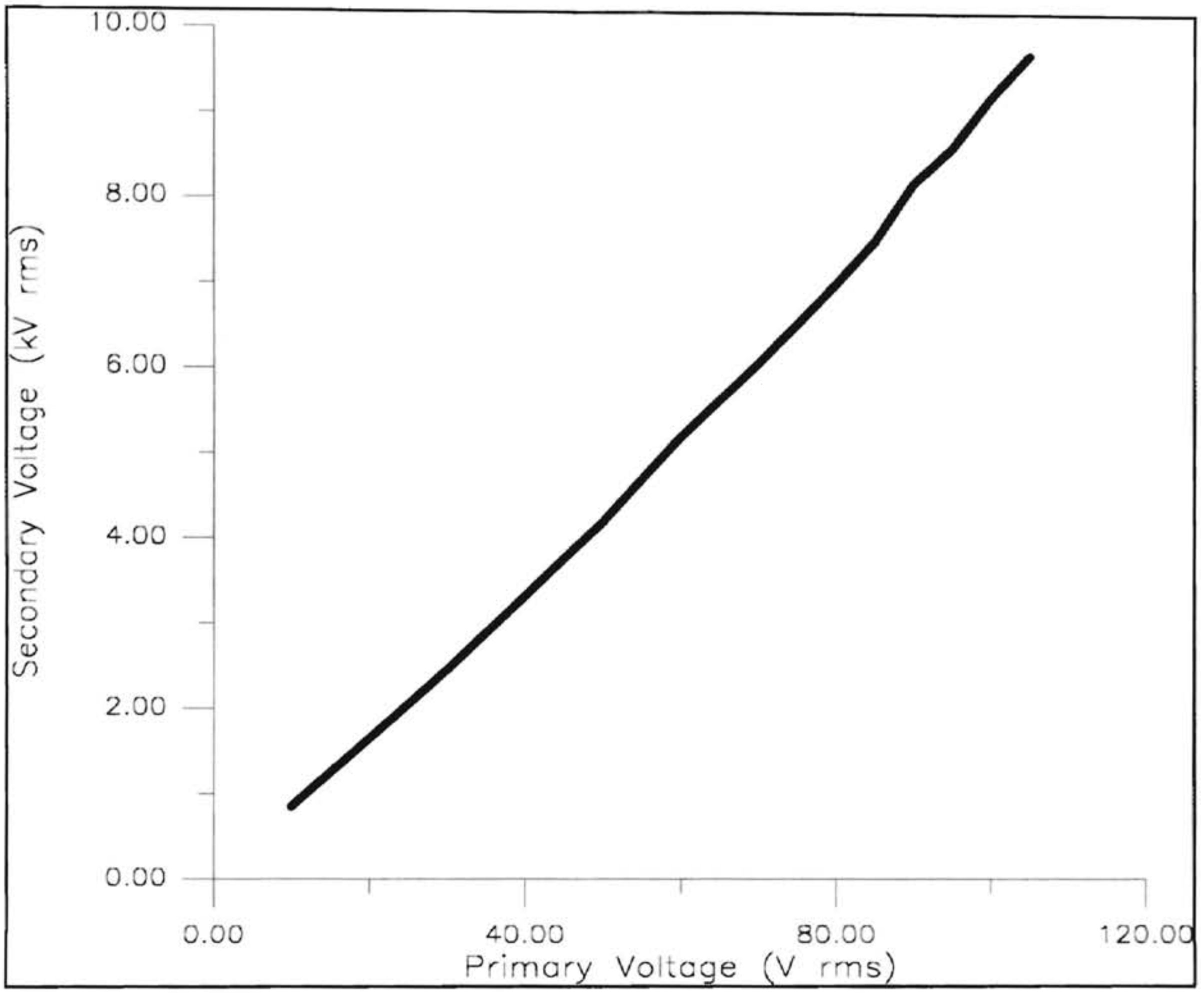


Figure 60. **Primary Versus Secondary Voltage For Data Set #51.**
A two liter plastic Pepsi bottle serves as the reactor vessel.

Data Set #51 Analysis

The copper tube barely fit inside the coke bottle and the bottle had been mechanically stressed in a few locations. The locations of the mechanical stress were the same spots where the negative electrical effects were noted.

TABLE LI

Data Set #52

Setup

- The power supply is simply a variable transformer (Variac).
- 20 ounce plastic Pepsi bottle serves as vessel.
- Frequency is constant 60 Hz.
- Inner electrode is a copper pipe forced through the opening of the bottle.
- Outer electrode is copper mesh wrapped outside the bottle.
- High voltage probe is Hewlett Packard 1137A.

Notes

A. Arc swirled around the inside of the bottle.

Current (amps)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Notes
0.50	120		A

Data Set #52 Analysis

I let the bottle cool after data set #51, and I applied a 120 volt primary with the Variac. It was a lightning type effect where the semi-arc swirled inside the bottle.

TABLE LII

Data Set #53

Setup

- Reactor B.
- Annulus is open to the atmosphere.
- Primary voltage is 30 volts rms.
- The inner and outer electrode was 36 mho saltwater.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.

Notes

A. Stopped at this point, because I felt the high voltage should have already produced a plasma.

Frequency (Hz)	Secondary Voltage (kV peak)	Notes
100	7.00	
110	7.50	
120	7.90	
130	8.00	
140	8.50	
150	10.00	
160	10.30	
170	12.00	
180	13.50	
190	16.30	
200	20.00	A

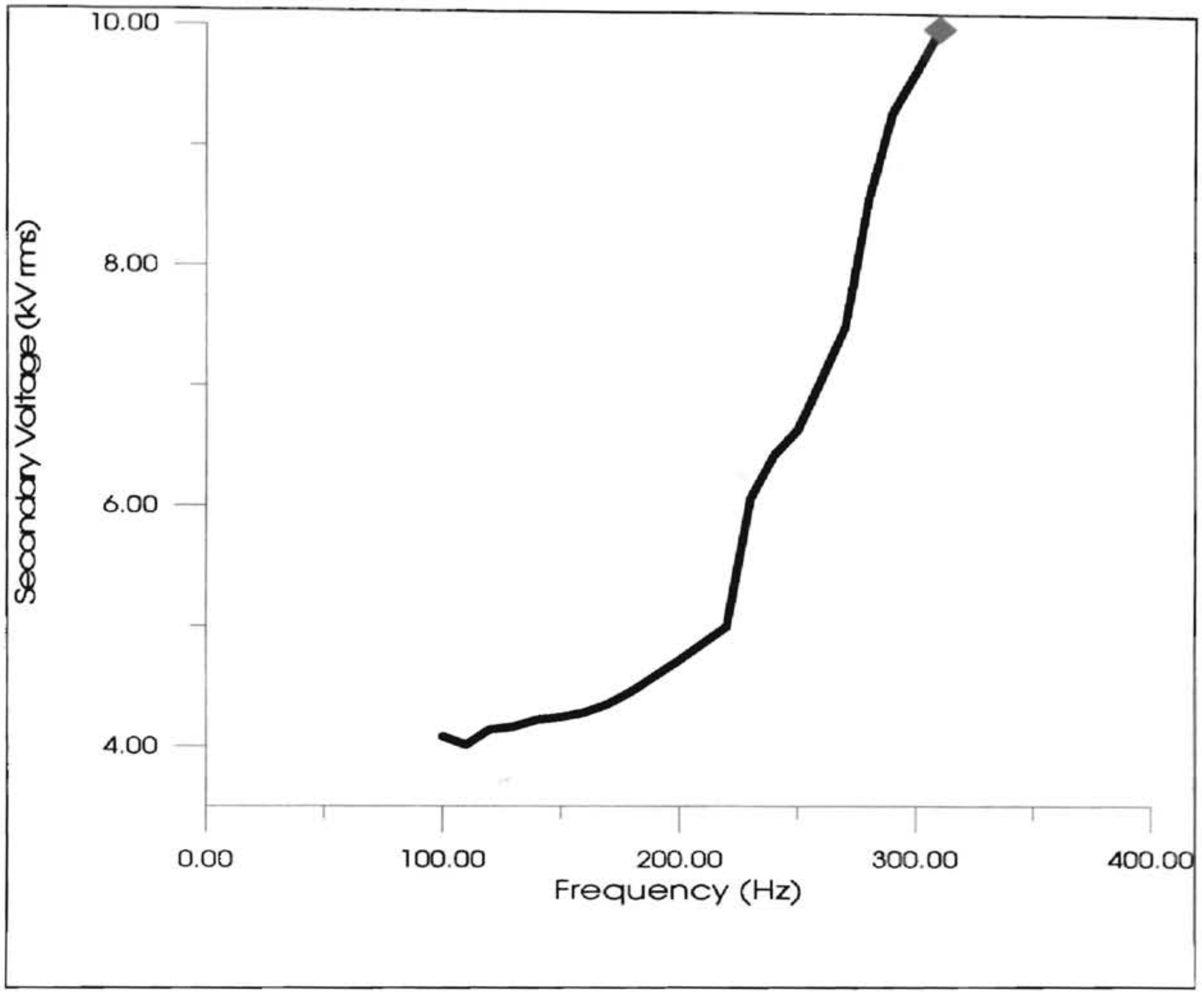


Figure 61. Typical Tuning Plot For Data Set #53.
Reactor B with the annulus open to the atmosphere.

Data Set #53 Analysis

I was surpised that this better conducting liquid could not effectively serve as the electrodes.

TABLE LIII

Data Set #54

Setup
- Reactor B.
- Air flows through the annulus.
- Primary voltage is 60 volts rms.
- Inner and outer electrode are green Sierra antifreeze (propylene glycol).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Cut off 2 liter plastic Pepsi bottle contains the outer electrode.
- Ambient temperature is 83 degrees Fahrenheit.

Notes
A. Fluke meters are displaying varying pieces of numbers.
B. Intense plasma exists within the annulus above the outer liquid electrode level.
C. Plasma is not as bright.
D. Plasma intensity is definitely decreasing.
E. No visible plasma.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
60	7.54	4.15	
70	7.58	3.90	
80	7.58	3.70	
90	7.56	3.55	
100	7.54	3.45	
110	7.54	3.30	
120	7.52	3.20	
130	7.50	3.20	
140	7.48	3.20	
150	7.48	3.20	
160	7.46	3.20	
170	7.46	3.15	
180	7.46	3.15	
190	7.46	3.15	
200	7.46	3.10	
210	7.48	3.10	
220	7.48	3.15	
230	7.52	3.15	
240	7.54	3.15	

(con't.)

TABLE LIII (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
250	7.58	3.15	
260	7.62	3.15	
270	7.66	3.15	
280	7.72	3.15	
290	7.82	3.15	
300	7.90	3.10	
310	8.00	3.10	
320	8.10	3.10	
330	8.24	3.10	
340	8.40	3.10	
350	8.56	3.10	
360	8.74	3.10	
370	8.94	3.10	
380	9.16	3.10	
390	9.36	3.10	
400	9.56	3.10	
410	9.84	3.10	
420	10.12	3.20	
430	10.46	3.25	
440	10.92	3.30	
450	11.38	3.45	
460	11.80	3.55	
470	12.54	3.70	
480	13.26	3.85	
490	14.00	4.10	
500		4.35	A
510		4.85	A,B
520		5.30	A
530		5.40	A
540		5.45	A
550		5.50	A
560		5.50	A
570		5.50	A
580		5.45	A
590		5.45	A
600		5.40	A,C
610		5.35	A

(con't.)

TABLE LIII (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
620		5.30	A
630		5.25	A
640		5.18	A,D
650		5.10	A
660		5.00	A
670		4.95	A
680		4.90	A,E
690	8.60	4.80	
700	8.82	4.60	
710	9.22	4.40	
720	9.86	4.30	
730	10.62	4.15	
740	11.58	4.05	
750	12.74	4.00	
760	13.92	3.90	
770	14.88	3.90	
780	15.88	3.90	
790	16.62	3.90	
800	17.08	3.85	
810	17.34	3.85	
820	17.34	3.80	
830	17.12	3.80	
840	16.76	3.80	
850	16.04	3.75	
860	15.26	3.70	
870	14.42	3.60	
880	13.68	3.55	
890	13.86	3.50	
900	12.94	3.50	
910	12.06	3.45	
920	11.22	3.40	
930	10.48	3.35	
940	9.84	3.30	
950	9.18	3.30	
960	8.66	3.25	

(con't.)

TABLE LIII (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
970	8.16	3.20	
980	7.72	3.15	
990	7.30	3.15	
1000	7.02	3.10	

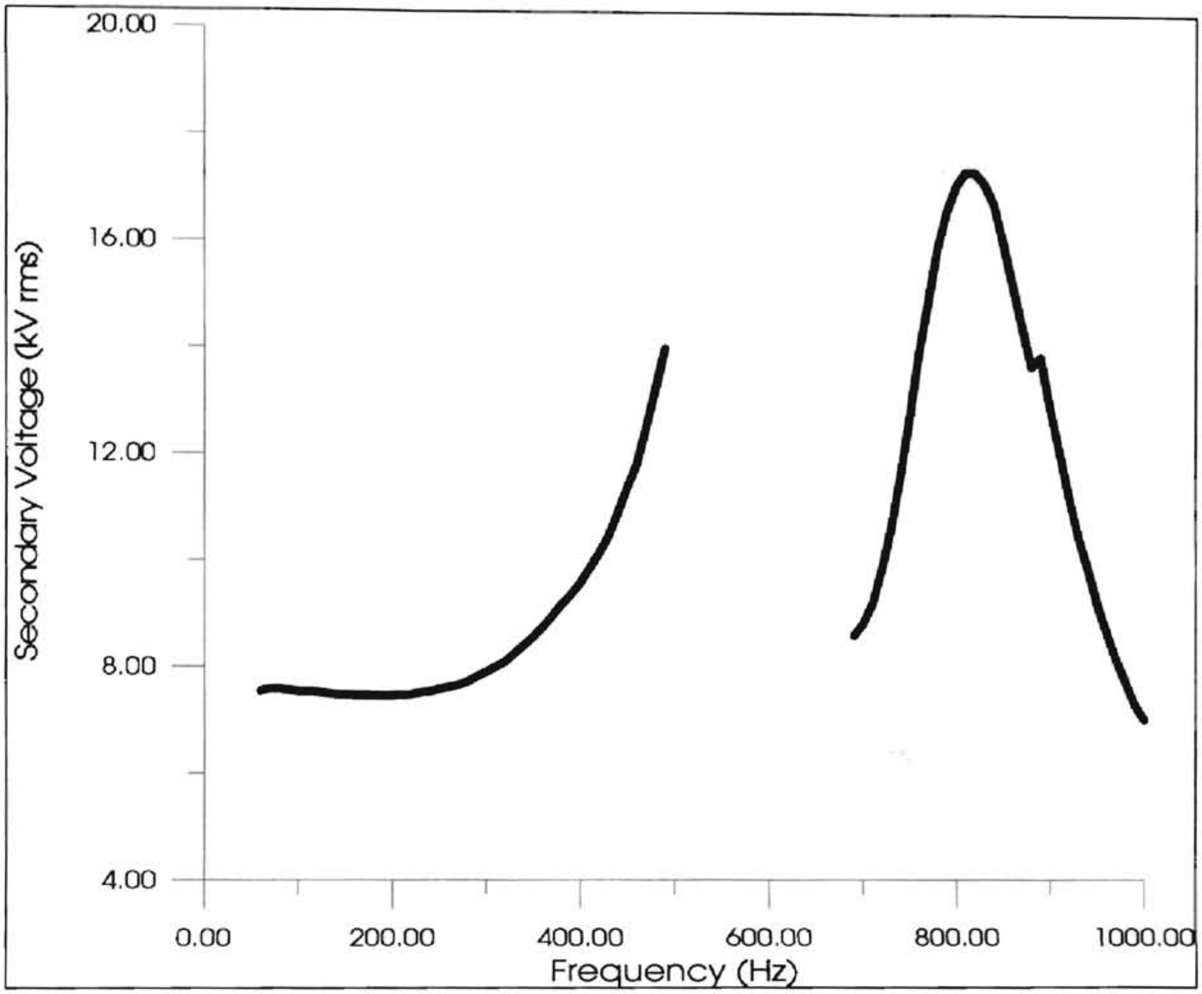


Figure 62. Typical Tuning Plot For Data Set #54.
Reactor B with air flowing through the annulus.

Data Set #54 Analysis

The second resonance peak is high, but there is not a plasma produced. The large discontinuity during the plasma region is the result of the meters not providing readings through this range. Comparing the Hewlett Packard 1137A probe to the Fluke 80K-40, it appears the Fluke provides lower readings with increase in frequency.

TABLE LIV

Data Set #55

Setup

- Reactor B.
- Air flows through the annulus.
- Primary voltage is 60 volts rms.
- Inner and outer electrode are green Sierra antifreeze (propylene glycol).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Cut off 2 liter plastic Pepsi bottle contains the outer electrode.
- Ambient temperature is 83 degrees Fahrenheit.

Notes

A. Used scope value of peak voltage to derive secondary voltage rms.
B. This was outside of the range of both the scope and the meters.
C. Even the primary meter quit reading.
D. Ammeter is fluctuating.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
400	9.32	2.95	
410	9.56	3.00	
420	9.86	3.05	
430	10.24	3.15	
440	10.62	3.20	
450	11.02	3.30	
460	11.52	3.45	
470	12.12	3.60	
480	12.76	3.75	
490	13.56	3.95	
500	13.57	4.20	A
510	14.29	4.45	A
520	15.00	4.85	A
530	15.71	5.10	A
540		5.35	B
550		5.55	C
560		5.60	
570		5.60	D
580		5.55	
590		5.55	

(con't.)

TABLE LIV (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
600		5.50	
590		5.50	
580		5.50	
570		5.50	D
560		5.50	

Data Set #55 Analysis

This was an attempt to recreate the portion of data set #52 that was outside the analytical capabilities of the equipment and references to where the plasma started were not recorded. This was near identical to the portion of data set #52 with the same frequency.

TABLE LV

Data Set #56

Setup

- Reactor A.
- 1 inch plasma zone.
- 5 psi compressed air enters the annulus and exits via long air line.
- Primary voltage is 60 volt rms.
- Inner electrode is dark green Sierra antifreeze (propylene glycol).
- Outer electrode is a pink RV antifreeze (propylene glycol mixture), 3/4 volume is additional tap water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- The power supply is a variable transformer (Variac)
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.
- Wavelength remains constant at 16.5 ms, corresponding approximately to 60 Hz.
- Ambient temperature is 82 degrees Fahrenheit.
- Daylight run -- no visual possible.

Notes

A. Suspected plasma.
B. Sine wave is jagged.
C. Jump secondary voltage reading.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
100	7.46	4.15	
110	7.44	4.00	
120	7.42	3.90	
130	7.40	3.80	
140	7.38	3.75	
150	7.36	3.70	
160	7.34	3.65	
170	7.34	3.65	
180	7.32	3.60	
190	7.34	3.60	
200	7.32	3.55	
210	7.32	3.50	
220	7.34	3.50	
230	7.36	3.45	
240	7.38	3.45	

(con't.)

TABLE LV (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
250	7.40	3.45	
260	7.44	3.45	
270	7.48	3.45	
280	7.52	3.40	
290	7.56	3.40	
300	7.64	3.40	
310	7.70	3.40	
320	7.78	3.40	
330	7.86	3.40	
340	7.94	3.35	
350	8.04	3.35	
360	8.16	3.35	
370	8.16	3.35	
380	8.46	3.35	
390	8.60	3.30	
400	8.76	3.30	
410	8.94	3.30	
420	9.12	3.30	
430	9.30	3.30	
440	9.54	3.25	
450	9.78	3.30	
460	10.04	3.40	
470	10.32	3.45	
480	10.62	3.55	
490	10.96	3.65	
500	11.44	3.75	
510	11.82	3.90	B
520	12.12	4.10	
530	12.54	4.35	A
540	12.96	4.55	
550	13.20	4.70	
560	13.36	4.90	
570	13.30	5.10	
580	13.14	5.25	
590	12.80	5.30	
600	12.60	5.35	
610	12.44	5.35	

(con't.)

TABLE LV (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
620	12.40	5.30	
630	12.46	5.20	
640	12.78	5.15	C
650	13.40	5.05	
660	14.40	5.00	
670	15.48	4.90	
680	16.12	4.75	
690	16.96	4.60	
700	17.96	4.50	
710	19.20	4.40	
720	20.80	4.35	
730	22.40	4.30	

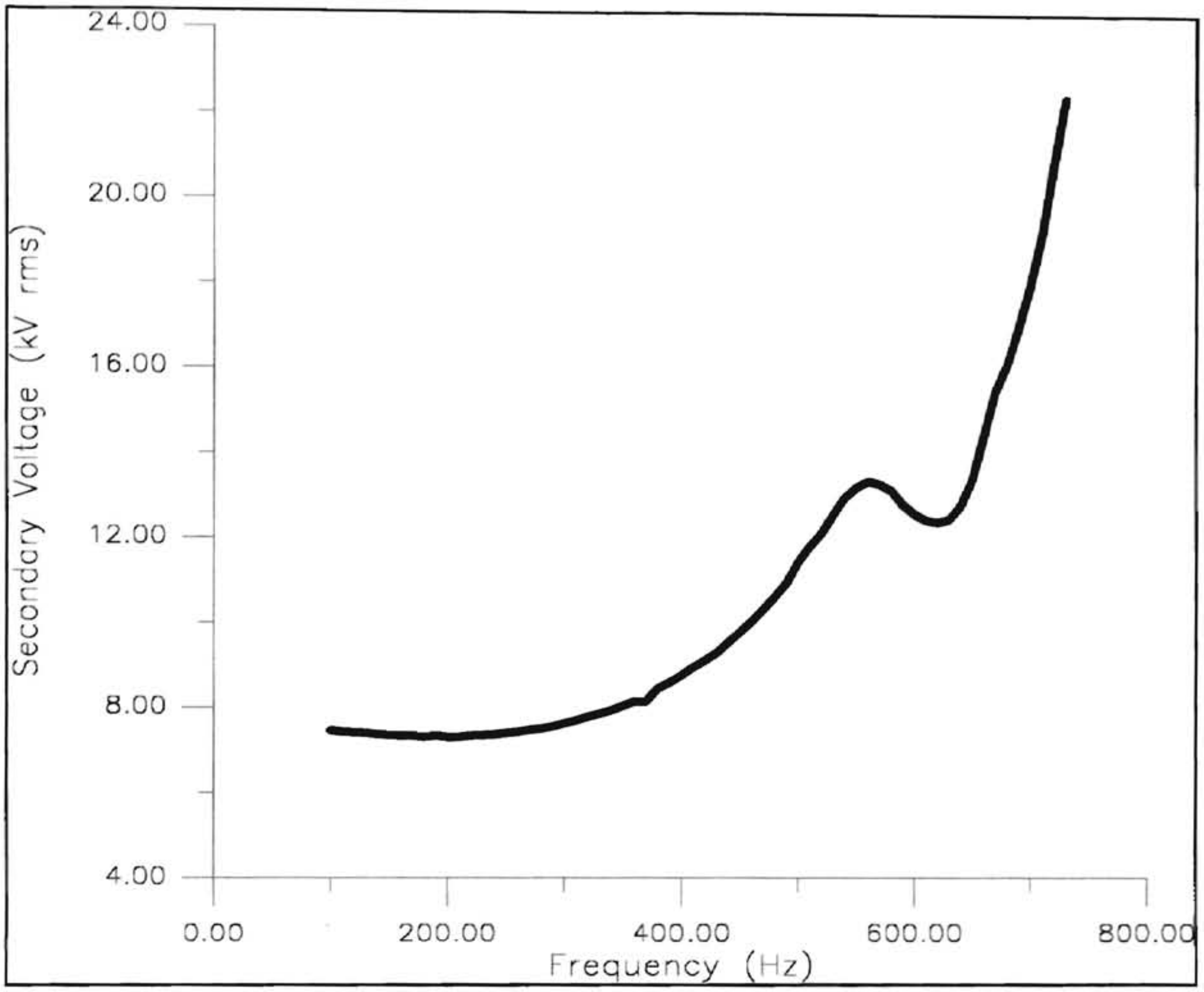


Figure 63. Typical Tuning Plot For Data Set #56.
Reactor A with air flowing through the annulus.

Data Set #56 Analysis

A visual observation was not possible for this experiment, but a plasma was suspected.

TABLE LVI

Data Set #57

Setup
- Reactor A.
- 1 inch plasma zone.
- 5 psi compressed air enters the annulus and exits via long air line.
- Primary voltage is 60 volt rms.
- Inner electrode is dark green Sierra antifreeze (propylene glycol).
- Outer electrode is pink RV antifreeze (propylene glycol mixture, 3/4 volume is additional tap water).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.
- Ambient temperature is 82 degrees Fahrenheit.

Notes
A. Uncertain if any air flow, the air flow line was discovered pinched at 510 Hz.
B. The visible plasma disappeared and reappeared with the restored air flow.
C. More even plasma.
D. Uniform plasma.
E. Plasma is dimmer.
F. No visible plasma.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
100	7.42	4.30	A
150	7.36	4.10	A
200	7.36	3.95	A
250	7.50	3.85	A
300	7.80	3.80	A
350	8.36	3.70	A
400	9.16	3.65	A
450	10.18	3.60	A
500	11.54	3.90	A
510	11.74	3.90	B
520	12.24	3.95	
530	12.86	4.10	C
540	13.50	4.45	
550	13.82	4.70	
560	14.00	4.95	
570	14.00	5.20	

(con't.)

TABLE LVI (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
580	13.74	5.35	D
590	13.40	5.40	
600	13.08	5.45	
610	12.80	5.45	
620	12.70	5.45	
630	12.78	5.35	
640	12.90	5.30	
650	12.80	5.15	
660	12.68	4.95	
670	13.22	4.80	E
680	14.30	4.65	
690	15.60	4.55	
700	17.54	4.50	F

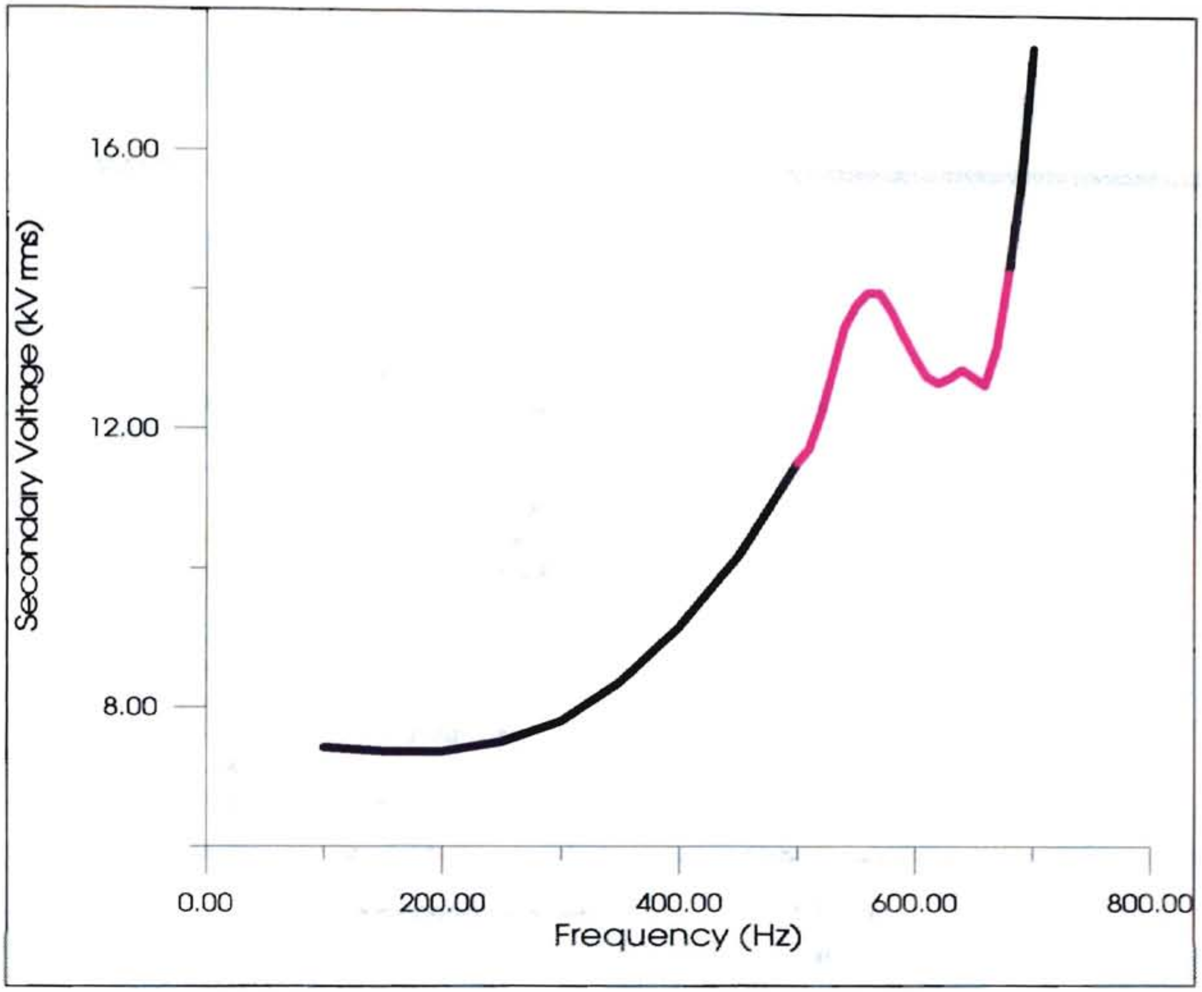


Figure 64. Typical Tuning Plot For Data Set #57.
Reactor A with air flowing through the annulus.

Data Set #57 Analysis

Unsure where the plasma first appeared, but the frequency where the glow diminished was closely followed. The disappearance of the plasma from the restricted air flow situation at 510 Hz suggests that ozone (the product of the plasma reaction in air) may not sustain a plasma as easily as air.

TABLE LVII

Data Set #58

Setup

- Reactor A.
- 3 inch plasma zone.
- 5 psi compressed air enters the annulus and exits via long air line.
- Inner electrode is dark green Sierra antifreeze (propylene glycol).
- Outer electrode is pink RV antifreeze (propylene glycol mixture, 5/6 volume is additional tap water).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.
- Ambient temperature is 82 degrees Fahrenheit.

Notes

A. Beautiful uniform plasma.
B. More even plasma.
C. Plasma is dimming, wave is bending over.
D. Plasma disappeared.
E. Secondary reading fluctuates.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
100	7.44	3.25	
150	7.38	2.90	
200	7.40	2.90	
250	7.58	2.95	
300	7.90	2.95	
350	8.46	2.95	
400	9.40	3.00	
450	10.88	3.35	
500	13.30	4.70	A
510	13.70	4.90	E
520	13.84	5.10	
530	13.60	5.25	B
540	13.20	5.35	
550	12.70	5.40	E
560	10.90	6.08	
570	10.90	5.76	
580	10.80	5.40	
590	10.00	5.25	

(con't.)

TABLE LVII (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
600	9.50	5.20	
610	9.22	5.15	
620	9.26	5.45	E,C
630	9.20	5.05	
640	9.48	5.00	
650	10.08	4.90	
660	10.94	4.85	
670	12.26	4.80	
680	13.50	4.70	
690	15.10	4.60	D
700	16.20	4.45	

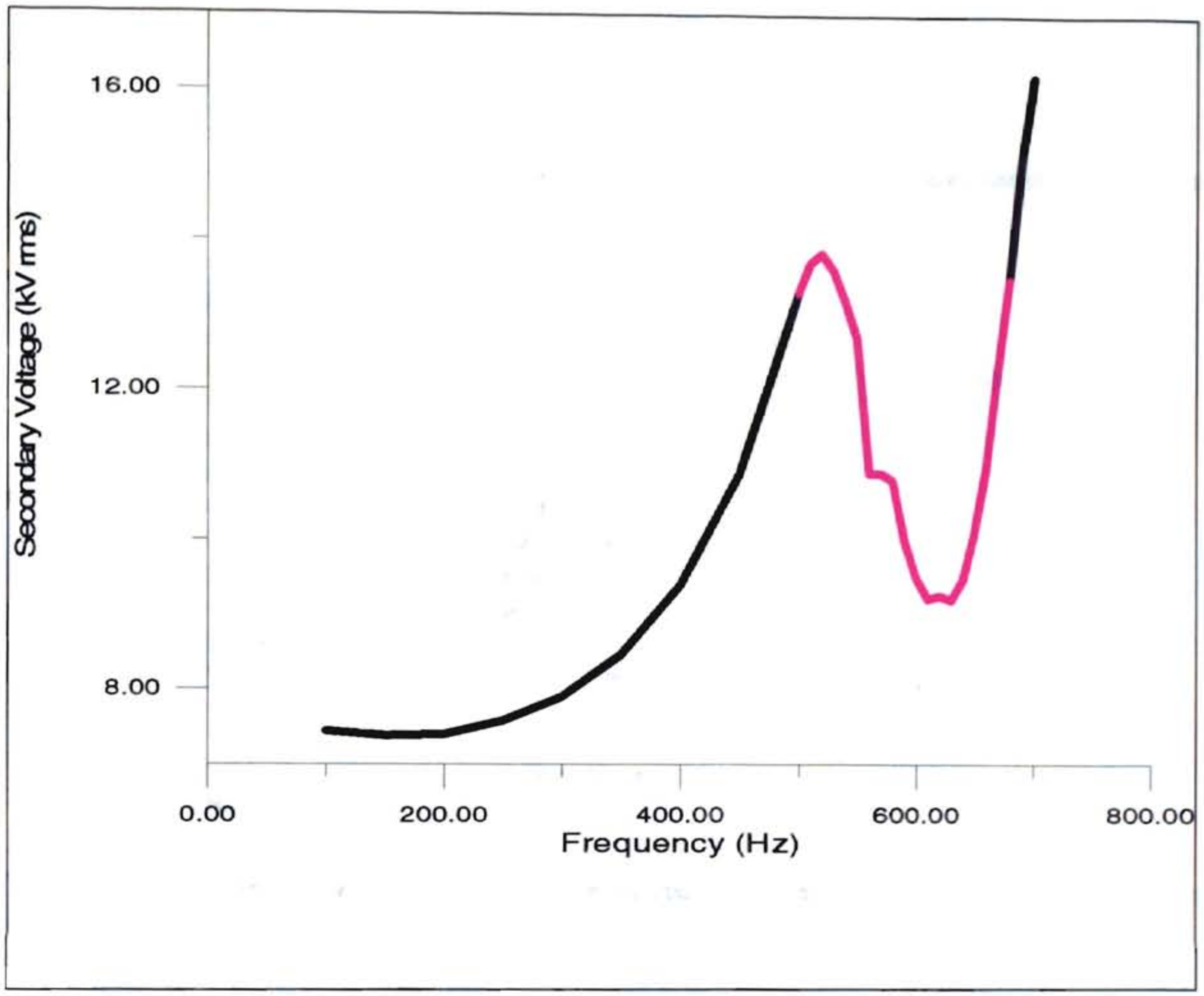


Figure 65. Typical Tuning Plot For Data Set #58.
Reactor A with air flowing through the annulus.

Data Set #58 Analysis

Similar to previous experiments, the plasma disappeared as the voltage was increasing.

TABLE LVIII

Data Set #59

Setup

- Reactor A.
- 6 inch plasma zone.
- Inner electrode is dark green Sierra antifreeze (propylene glycol).
- Outer electrode is a pink RV antifreeze (propylene glycol mixture, 7/8 volume is additional tap water).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- The power supply is a variable transformer (Variac).
- 5 psi compressed air enters the annulus and exits via long air line.
- Ambient temperature is 82 degrees Fahrenheit.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.
- Wavelength remains constant at 16.5 ms, corresponding approximately to 60 Hz.

Notes

A. No visible plasma or ozone smell at or before this point.
B. Plasma becoming visible.
C. Plasma uniform, but not intense.

Primary Voltage (V rms)	Secondary Voltage (kV rms)	Secondary Voltage (kV peak)	Current (amps)	Notes
10	1.18	1.6	<1	
20	2.4	3.35	<1	
30	3.64	5	<1	
40	4.84	6.8	<1	
50	6.08	8.5	<1	
60	7.32	10.25	<1	
70	8.56	12	<1	
80	9.8	14	<1	
90	11.04	15	<1	
100	12.28	17	<1	
110	13.5	19	<1	
120	14.68	21	<1	
130	15.8	22.5	1	A
140	16.9	25	2	B
143.5	17.3	27	2.4	C

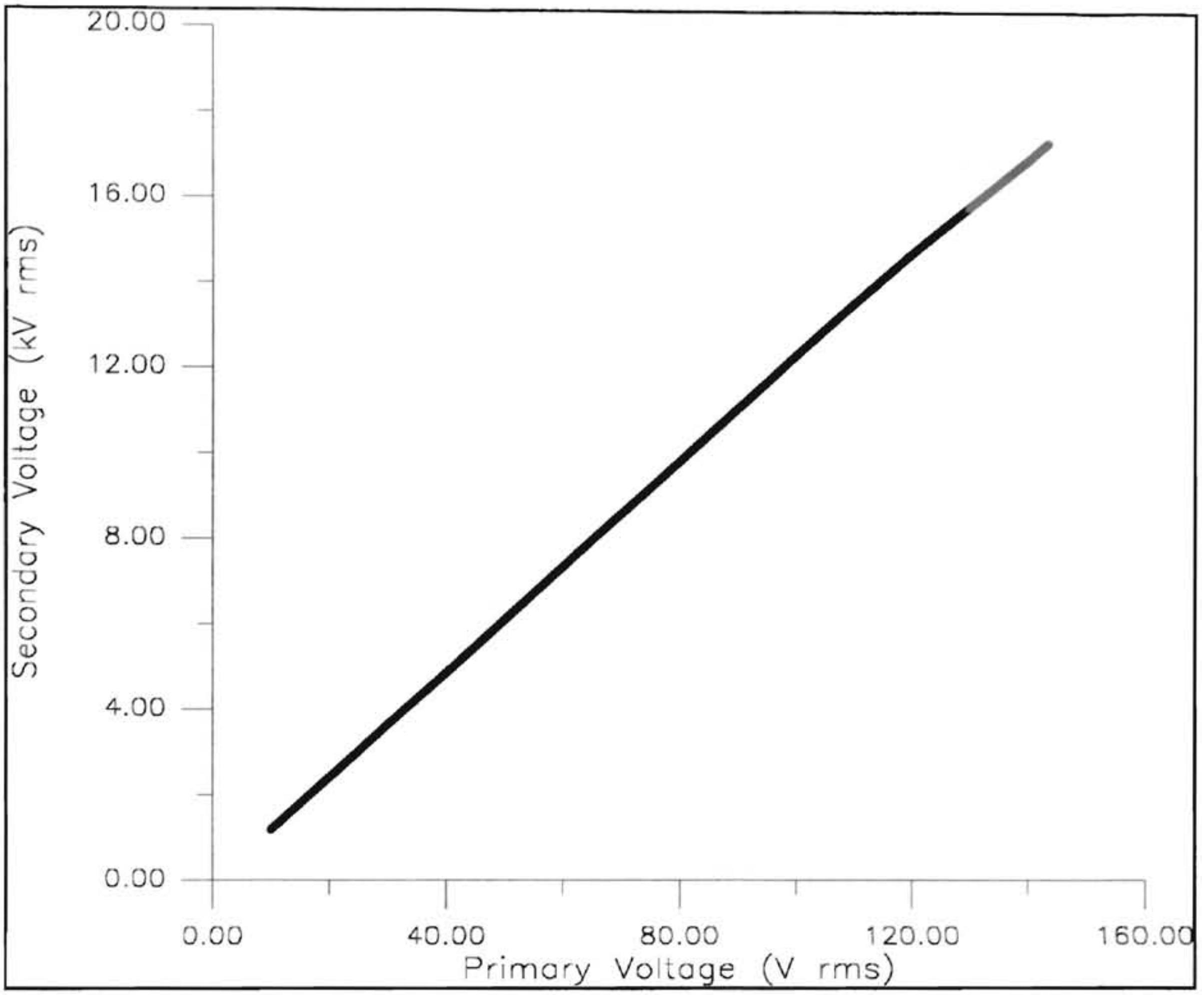


Figure 66. Primary Versus Secondary Voltage For Data Set #59.
Reactor A with air flowing through the annulus.

Data Set #59 Analysis

Sine wave is jagged. Definite ozone production. A plasma was created at the maximum voltage attainable with the Variac.

TABLE LIX

Data Set #60

Setup

- Reactor A.
- 6 inch plasma zone.
- 5 psi compressed air enters the annulus and exits via long air line.
- Primary voltage is 60 volt rms.
- Inner electrode is dark green Sierra antifreeze (propylene glycol).
- Outer electrode is pink RV antifreeze (propylene glycol mixture, 7/8 volume is additional tap water).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Ambient temperature is 82 degrees Fahrenheit.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.

Notes

A. Extremely light plasma.
B. Uniform plasma.
C. Plasma is dimming.
D. No visible.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
100	7.46	3.90	
150	7.42	3.75	
200	7.48	3.65	
250	7.76	3.50	
300	8.16	3.40	
350	8.90	3.30	
400	10.08	3.25	
410	10.38	3.30	
420	10.70	3.35	
430	11.10	3.45	A
440	11.54	3.55	
450	12.14	3.80	
460	12.66	4.25	
470	12.76	4.60	
480	12.66	4.85	
490	12.46	4.95	
500	12.22	5.10	B
510	11.90	5.15	

(con't.)

TABLE LIX (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
520	11.58	5.20	
530	11.20	5.25	
540	10.88	5.25	
550	10.50	5.25	
560	10.14	5.25	
570	9.80	5.30	
580	9.46	5.30	C
590	9.18	5.25	
600	8.96	5.25	
610	8.80	5.20	
620	8.80	5.15	
630	8.96	5.10	
640	9.26	5.05	
650	9.86	4.95	
660	10.74	4.90	
670	11.76	4.80	D
680	12.40	4.60	
690	13.20	4.45	
700	14.20	4.35	
710	15.40	4.25	
720	16.60	4.20	
730	17.90	4.15	
740	19.00	4.15	
750	19.80	4.15	
760	20.40	4.15	
770	20.60	4.10	
780	20.30	4.10	
790	19.80	4.05	
800	19.06	4.00	

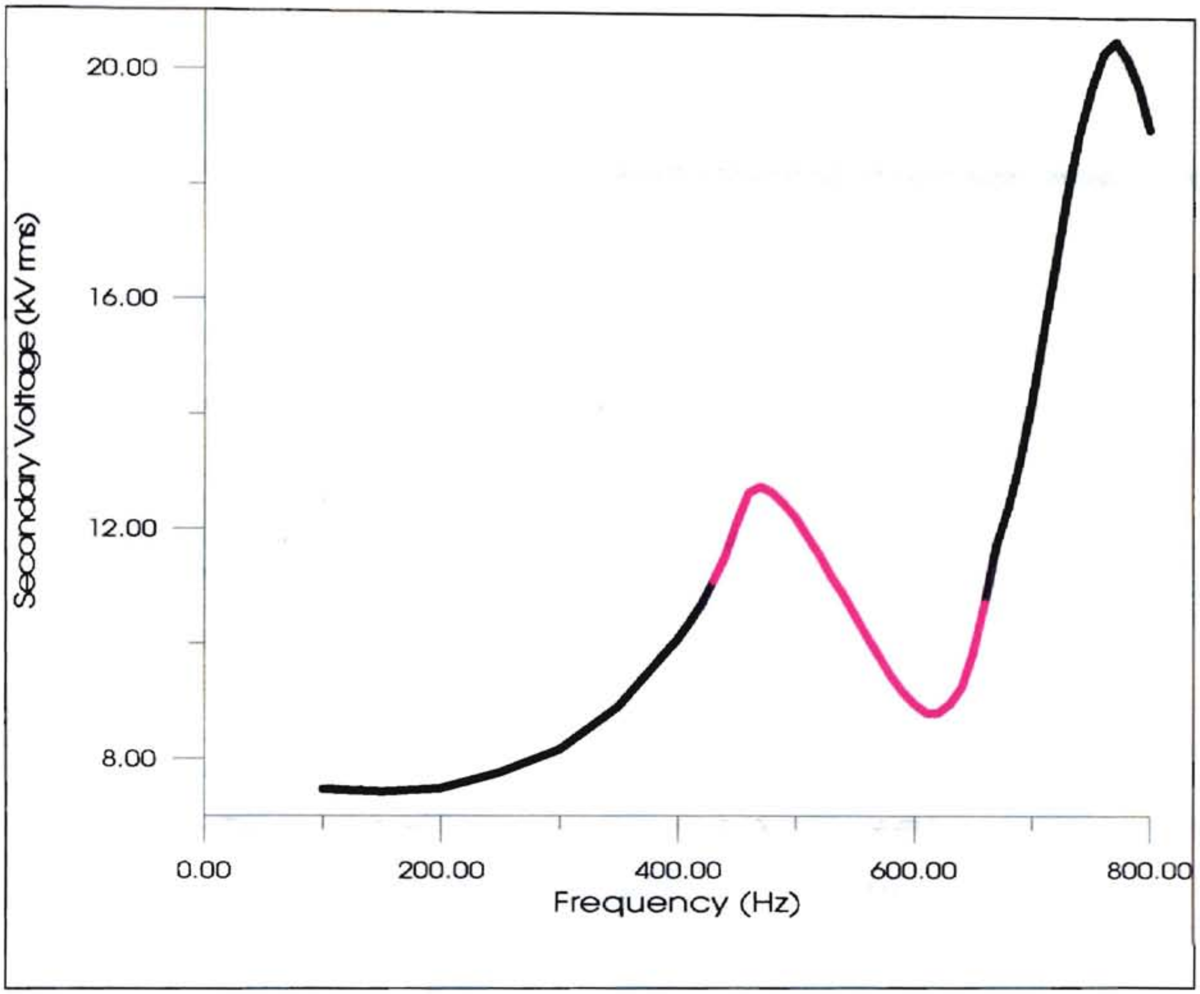


Figure 67. **Typical Tuning Plot For Data Set #60.**
Reactor A with air flowing through the annulus.

Data Set #60 Analysis

It is interesting that the second peak is much higher than the first and yet the plasma only existed during the first peak.

TABLE LX

Data Set #61

Setup

- Reactor A.
- 6 inch plasma zone.
- The power supply is a variable transformer (Variac).
- Inner electrode is dark green Sierra antifreeze (propylene glycol).
- Outer electrode is a pink RV antifreeze (propylene glycol mixture, 7/8 volume is additional tap water).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- 5 psi compressed air enters the annulus and exits via long air line.
- Ambient temperature is 82 degrees Fahrenheit.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.

Notes

A. Uniform plasma, ozone smell, jagged sine wave on oscilloscope.
B. Plasma appears to be dimming.

Primary Voltage (V rms)	Secondary Voltage (kV rms)	Secondary Voltage (kV peak)	Current (amps)	Notes
10	1.18	1.60	<1	
20	2.40	3.35	<1	
30	3.64	5.00	<1	
40	4.84	6.80	<1	
50	6.08	8.50	<1	
60	7.32	10.25	<1	
70	8.56	12.00	<1	
80	9.80	14.00	<1	
90	11.04	15.00	<1	
100	12.28	17.50	<1	
110	13.50	19.00	<1	
120	14.68	21.00	<1	
130	15.94	25.00	1	A
140	17.04	27.00	2	A
142.9	17.38	28.00	2.4	A,B

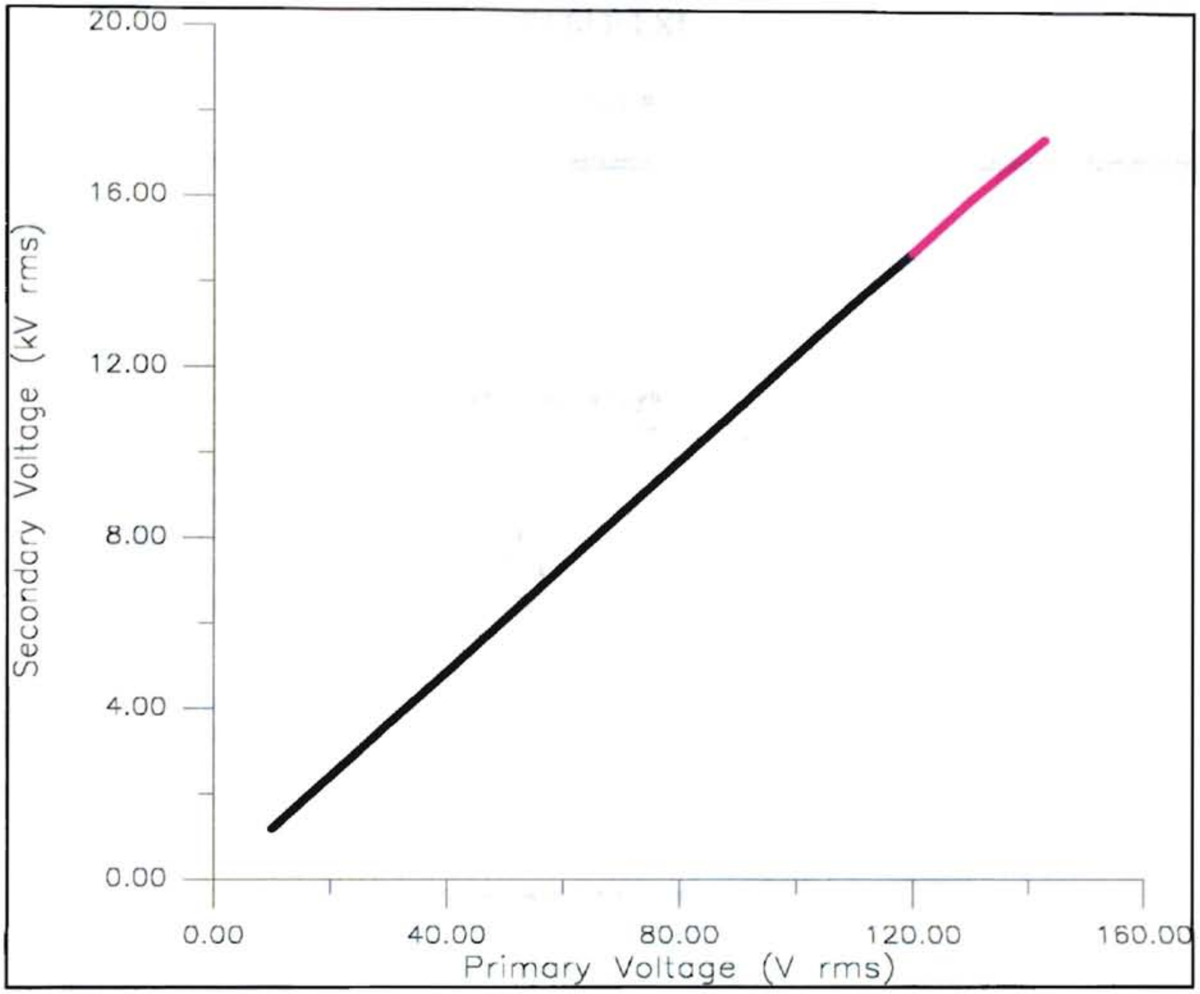


Figure 68. **Primary Versus Secondary Voltage For Data Set #61.**
Reactor A with air flowing through the annulus.

Data Set #61 Analysis

Definite chemical reaction determined by the smell of ozone with the appearance of a luminous glow.

TABLE LXI

Data Set #62

Setup

- Reactor A.
- 6 inch plasma zone.
- Air flows at 0.21 cubic feet per second.
- Primary voltage is 90 volt rms.
- Inner electrode is dark green Sierra antifreeze (propylene glycol).
- Outer electrode is pink RV antifreeze (propylene glycol mixture, 7/8 volume is additional tap water).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.
- Ambient temperature is 82 degrees Fahrenheit.

Notes

A. No visible plasma.
B. Ozone production.
C. Plasma lasted 15 seconds.
D. Plasma lasted 20 seconds.
E. Plasma lasted 30 seconds.
F. Plasma lasted 40 seconds.
G. Plasma lasted 40 seconds. Flowmeter showed a zero reading (no gas flow).
H. Resumed flow.
I. Definite ozone detection.
J. Plasma and ozone present.
K. Sine wave disturbed to a square wave.

Frequency (Hz)	Secondary Voltage (kV rms)	Secondary Voltage (kV peak)	Current (amps)	Notes
100	11.16	16	3.70	
110	11.24	16	3.50	
120	11.26	16	3.40	
130	11.28	16	3.30	
140	11.32	16	3.20	
150	11.38	16	3.10	
160	11.42	16	3.05	
170	11.48	16.5	3.00	
180	11.54	16.5	3.00	
190	11.60	16.5	3.00	
200	11.66	16.5	3.00	
210	11.74	16.5	3.00	

(con't.)

TABLE LXI (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	(kV peak)	Current (amps)	Notes
220	11.84	16.5	3.00	
230	11.94	16.5	3.00	
240	12.06	16.5	3.00	
250	12.20	16.5	3.00	A
260	12.36	17	3.00	
270	12.52	17	3.00	
280	12.70	17	3.00	
290	12.90	17.5	2.95	
300	13.10	18	3.00	
310	13.20	18	3.00	B
320	13.54	18	3.05	
330	13.80	19	3.10	C
340	14.30	19	3.15	D
350	14.44	20	3.20	
360	14.84	20	3.30	E
370	15.24	21	3.35	F
380	15.60	21	3.40	G
390	16.08	21.5	3.55	
400	20.44	29	6.10	H
410	20.86	30	6.45	I
420	21.12		6.70	
430	21.00		6.50	
440	20.70		7.05	
450	20.00		7.05	
460	19.20		7.05	
470	18.40		7.00	
480	17.40		6.95	
490	16.60		6.85	
500	15.80		6.80	
510	15.00		6.75	
520	13.60		6.55	J
530	13.00		4.10	
540	12.80		6.45	
550	12.00		6.30	
560	11.30		6.20	
570	10.80		6.10	K
580	10.34		6.00	

(con't.)

TABLE LXI (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	(kV peak)	Current (amps)	Notes
590	10.00		5.95	
600	9.74		5.90	
610	9.82		5.85	
620	9.70		5.75	
630	10.00		5.70	
640	10.60		5.65	
650	11.54		5.55	
660	12.92		5.50	
670	14.50		5.40	
680	16.36		5.35	
690	18.40		5.25	
700	20.40		5.15	

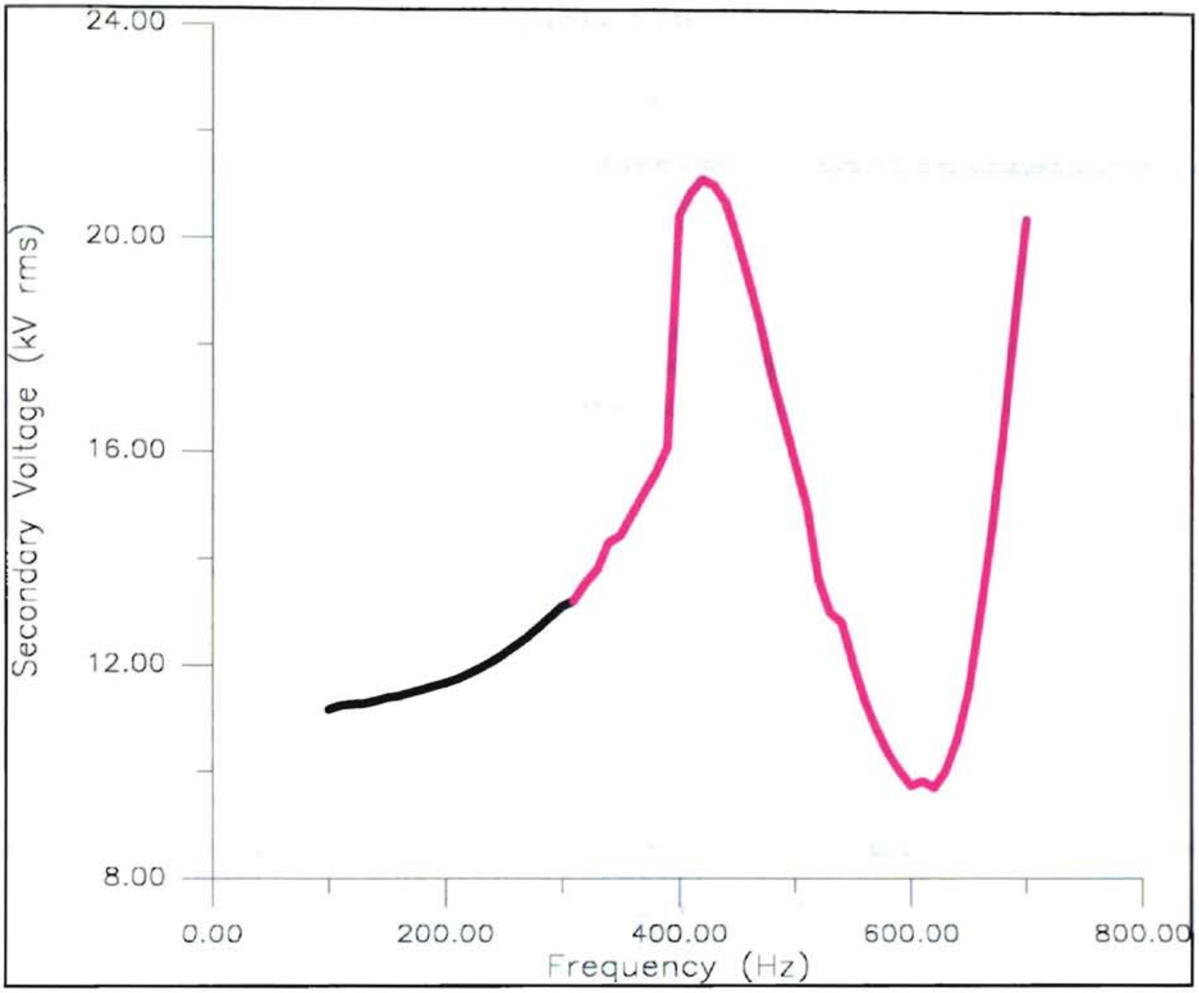


Figure 69. Typical Tuning Plot For Data Set #62.
Reactor A with air flowing through the annulus.

Data Set #62 Analysis

A lot of white residue deposited in bottom of the outer electrode container. Plasma would not remain for significant time when the air flow was shut off. I replaced my air supply at 400 Hz, but I suspect the air was not flowing between 330 Hz and 400 Hz.

TABLE LXII

Data Set #63

Setup
- Reactor A.
- 7 1/2 inch plasma zone.
- Air flows at 0.21 cubic feet per second through the annulus.
- Inner and outer electrodes are dark green Sierra antifreeze (propylene glycol).
- Outer electrode is diluted (9/10 volume is tap water).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Ambient temperature is 73 degrees Fahrenheit.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.

Notes

A. Plasma is present.
B. 5 minutes after previous step.
C. 10 more minutes after previous step.
D. 10 more minutes after previous step, gauges are varying.
E. 10 more minutes after previous step, gauges are varying too much to read.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Secondary Voltage (kV peak)	Current (amps)	Notes
500	0	0	0	3.7	
500	10	1.86	2.6	3.65	
500	20	3.88	5.5	3.6	
500	30	6	8.5	3.5	
500	40	8.5	12	3.5	
500	50	11.1	15	3.45	
500	60	13.8	19	3.5	
500	70	16.7	22.5	3.65	
500	80	20.6	27	4.5	A
500	82.5	23.2	30	4.95	
500	85	24.9	33	5.3	
500	87.5	26.4	35	5.7	
500	90	27.64	37.5	6.1	
500	92.5	31.4	40	6.45	
500	95	33.5		6.8	
500	96.45	34.8		7	
500	96.45	35.2		7	B

(con't.)

TABLE LXII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	(kV peak)	Current (amps)	Notes
500	96.45	35.6		7.3	C
500	96.45	34.6		7.5	D
500	96.45	32		7.45	E

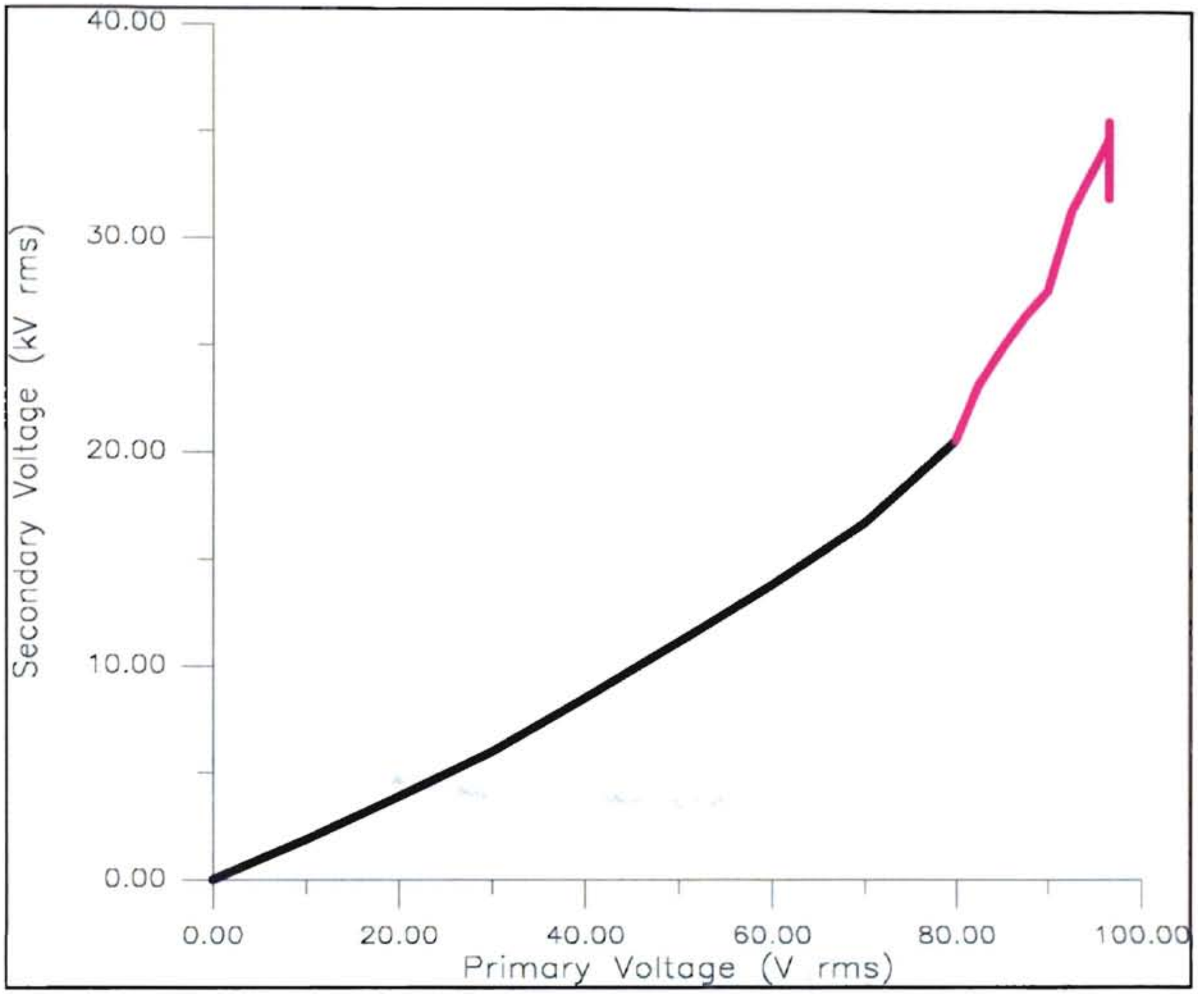


Figure 70. **Primary Versus Secondary Voltage For Data Set #63.**
Reactor A with air flowing through the annulus.

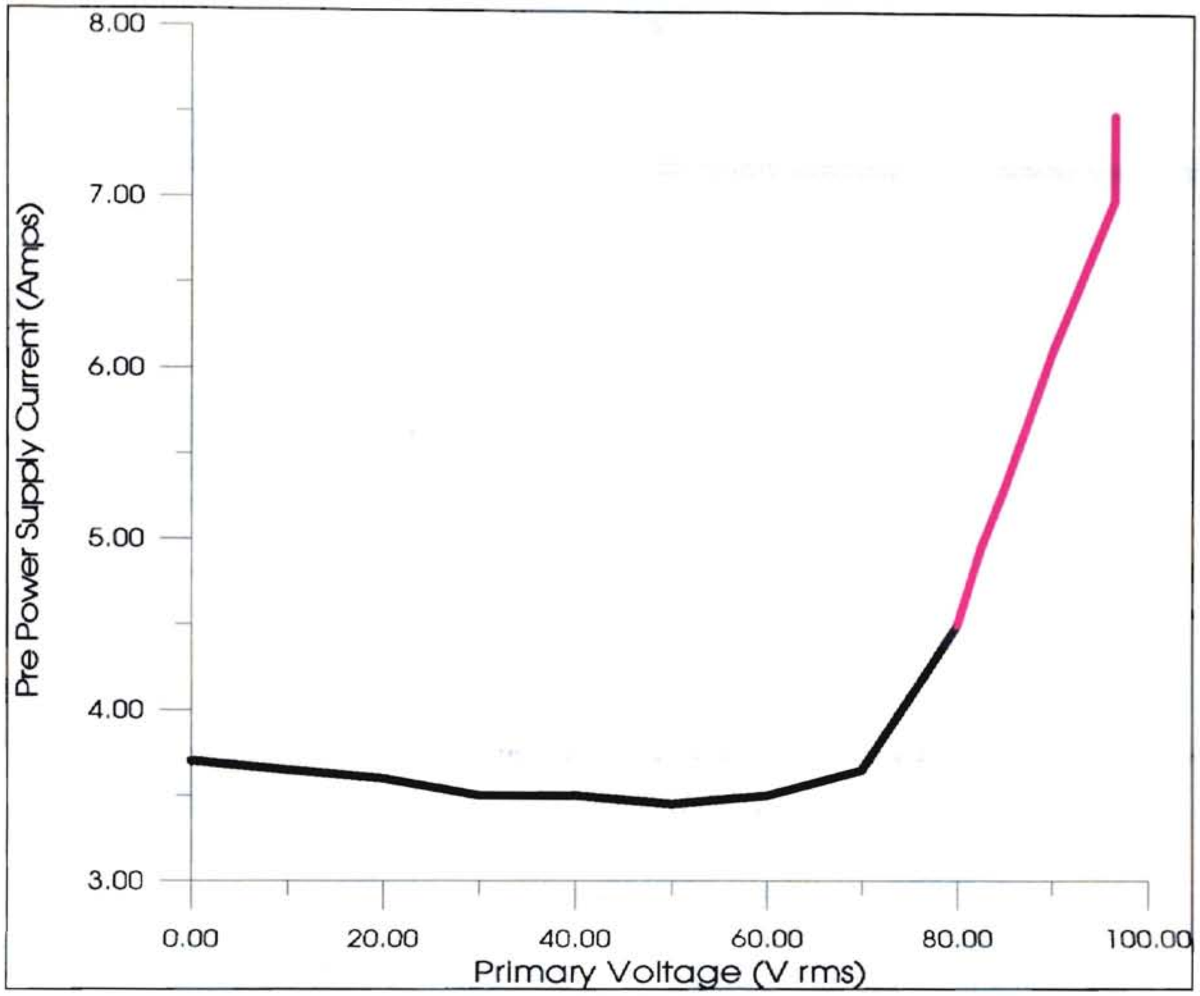


Figure 71. Primary Versus Total Current Draw For Data Set #63.
Reactor A with air flowing through the annulus.

Data Set #63 Analysis

The continuous operation at one frequency varied slightly resulting in the vertical line at the end of the plot. The secondary voltage is high for this setup, and is much higher than the high voltage probe rating. As expected the plasma existed at the higher primary voltages. The curve showing the primary current draw shows the increase in load with the ionization of the gas.

TABLE LXIII

Data Set #64

Setup
- Reactor A.
- 6 inch plasma zone.
- Air flows at 0.015 cubic feet per second through the annulus.
- Inner and outer electrodes are dark green Sierra antifreeze (propylene glycol).
- Outer electrode is diluted (9/10 volume is tap water).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Ambient temperature is 73 degrees Fahrenheit.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.

Notes

A. Plasma.

B. 15 minutes after previous step.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Secondary Voltage (kV peak)	Current (amps)	Notes
400	0	0.00	0.00	3.00	
400	10	1.56	2.25	2.95	
400	20	3.26	4.50	3.00	
400	30	5.04	7.00	3.00	
400	40	6.86	9.50	3.00	
400	50	8.94	12.50	3.00	
400	60	11.02	15.50	3.00	
400	70	13.14	18.50	2.95	
400	80	15.74	21.00	3.25	A
400	82.5	16.46	22.00	3.35	
400	85	17.18	23.00	3.40	
400	87.5	17.70	24.00	3.40	
400	90	18.20	25.00	3.45	
400	92.5	18.80	26.00	6.45	
400	95	19.40		3.50	
400	97.25	19.96		3.55	
400	97.25	19.92		3.55	B

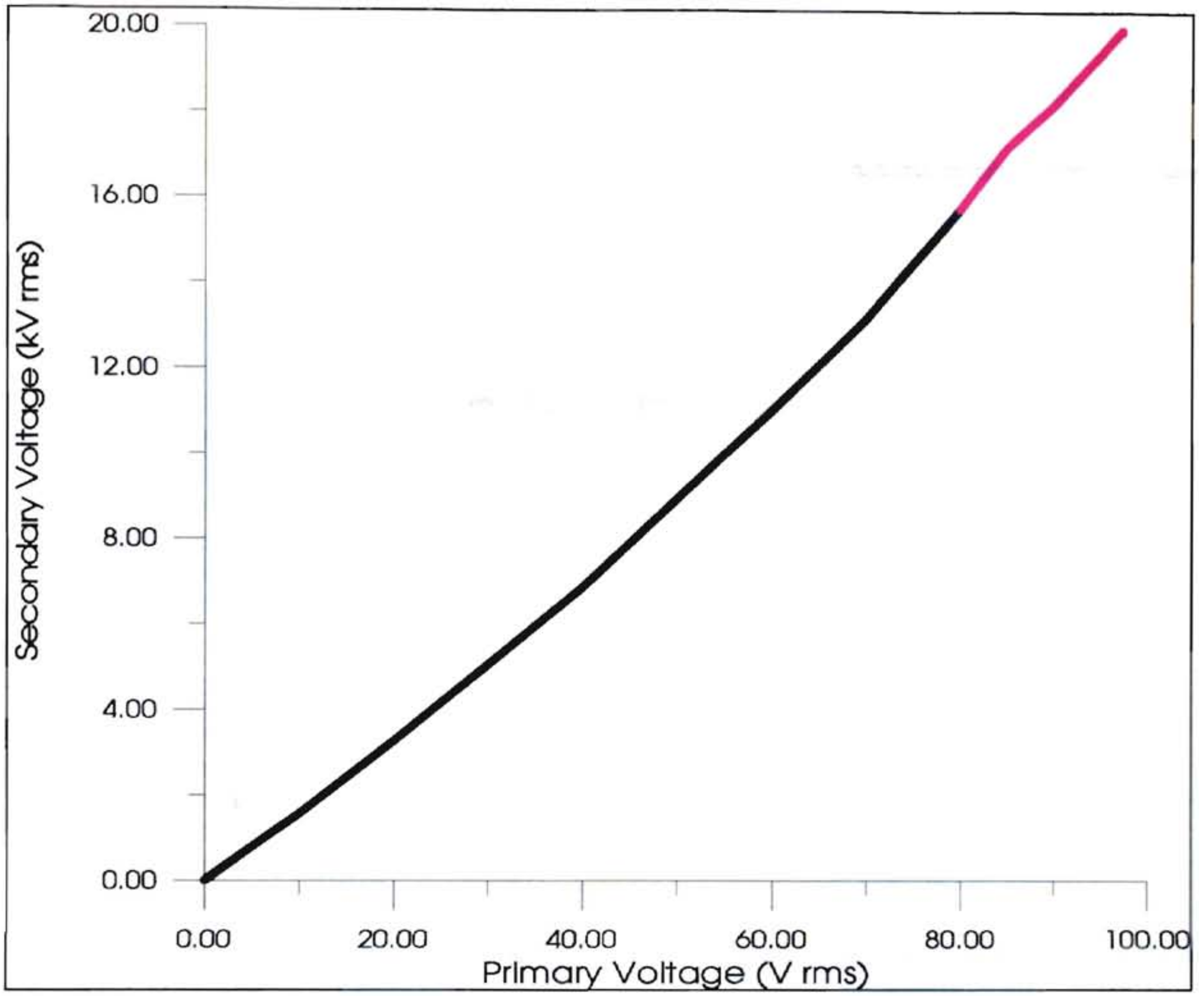


Figure 72. Primary Versus Secondary Voltage For Data Set #64.
Reactor A with air flowing through the annulus.

Data Set #64 Analysis

Set the frequency at 400 Hz and increased the amplitude, this is an easier way to analyze the reactors. The plasma exists as expected, at the top of the plot.

TABLE LXIV

Data Set #65

Setup

- Reactor A.
- 7.5 inch plasma zone.
- Air flows at 0.03 cubic feet per second through the annulus.
- Primary voltage is 90 volts rms.
- Inner and outer electrodes are dark green Sierra antifreeze (propylene glycol).
- Outer electrode is diluted with a large amount of water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Ambient temperature is 73 degrees Fahrenheit.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.

Notes

A. Plasma started.
B. Gauges are fluctuating
C. Very well established beautiful uniform plasma.
D. Plasma is dimming.
E. Splotches of luminous glow.
F. Very near gone.
G. Plasma is gone.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
60	12.88	5.30	
70	12.88	4.85	
80	12.96	4.60	
90	13.00	4.40	
100	13.12	4.25	
150	13.38	3.65	
200	13.80	3.65	
250	14.36	3.65	
300	15.88	3.60	A
320	17.50	3.90	B
340	19.30	4.40	
360	21.80	5.30	C
380	24.20	6.20	C
400	24.30	6.25	
420	25.30	7.15	

(con't.)

TABLE LXIV (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
440	24.50	7.10	
460	23.30	7.00	
480	21.80	6.75	B
500	20.60	6.65	
520	19.60	6.45	
540	18.50	6.25	D
560	17.70	6.15	
580	16.60	6.00	
600	15.50	5.75	
620	14.70	5.65	E
640	14.12	5.55	
660	13.66	5.45	F
680	13.16	5.35	
700	12.80	5.25	
720	12.38	5.15	
740	12.20	5.10	
760	12.28	5.00	
780	12.70	4.90	
800	13.50	4.80	
820	14.24	4.70	
840	15.20	4.65	G
860	15.56	4.55	
880	15.40	4.40	
900	14.14	4.25	
920	12.84	4.10	
940	11.70	4.00	
960	10.68	3.90	
980	9.80	3.80	
1000	9.08	3.75	

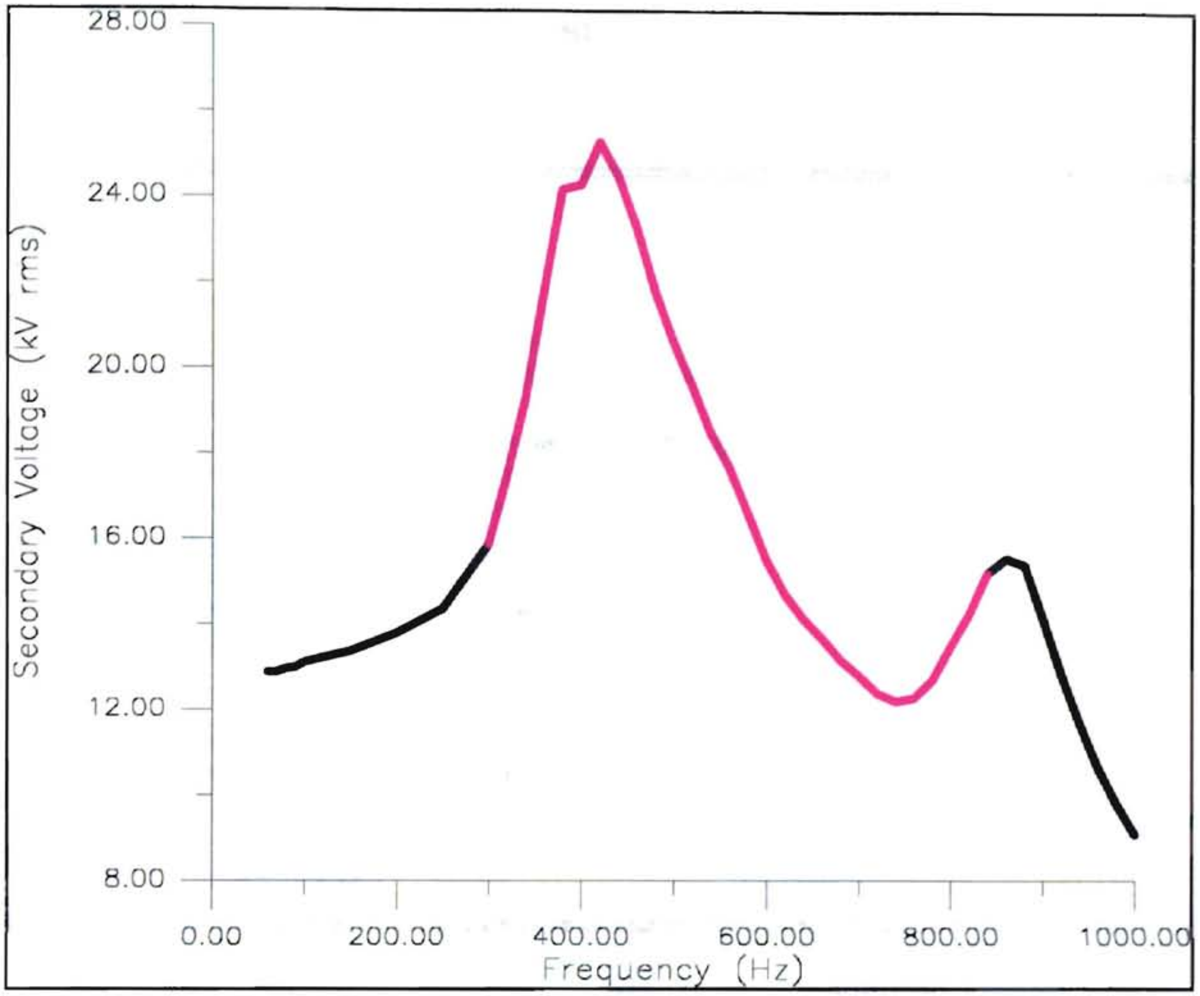


Figure 73. Typical Tuning Plot For Data Set #65.
Reactor A with air flowing through the annulus.

Data Set #65 Analysis

At the end of this run, I set the frequency to 800 Hz and increased the flow rate. No changes with the increased air flow were noticed. This curve is typical of early tuning curves from my experiments.

TABLE LXV

Data Set #66

Setup

- Reactor A.
- 7.5 inch plasma zone.
- The power supply is a variable transformer (Variac).
- Air flows at 0.03 cubic feet per second through the annulus.
- Primary voltage is 90 volts rms.
- Inner and outer electrodes are dark green Sierra antifreeze (propylene glycol).
- Outer electrode is diluted with a large amount of water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Ambient temperature is 73 degrees Fahrenheit.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.

Notes

A. Flow rate was cut off and there was no plasma.
B. Plasma appeared with the added flow rate.
C. Light but full plasma.
D. Triangle sine wave.
E. Plasma is not super intense.

Primary Voltage (V rms)	Secondary Voltage (kV rms)	Current (amps)	Notes
10	1.40	<1	
20	2.84	<1	
30	4.30	<1	
40	5.76	<1	
50	7.20	<1	
60	8.66	<1	
70	10.10	<1	
80	11.56	<1	
90	13.00	<1	
100	14.42	<1	
110	15.82	<1	A
120	17.24		B
80	11.58	<1	
90	13.00	<1	
100	14.40	<1	
110	15.92	<1	C

(con't.)

TABLE LXV (continued)

Primary Voltage (V rms)	Secondary Voltage (kV rms)	Current (amps)	Notes
120	17.36	<1	D
130	18.70	1.00	
140	19.92	2.00	
142.9	20.26	2.30	E

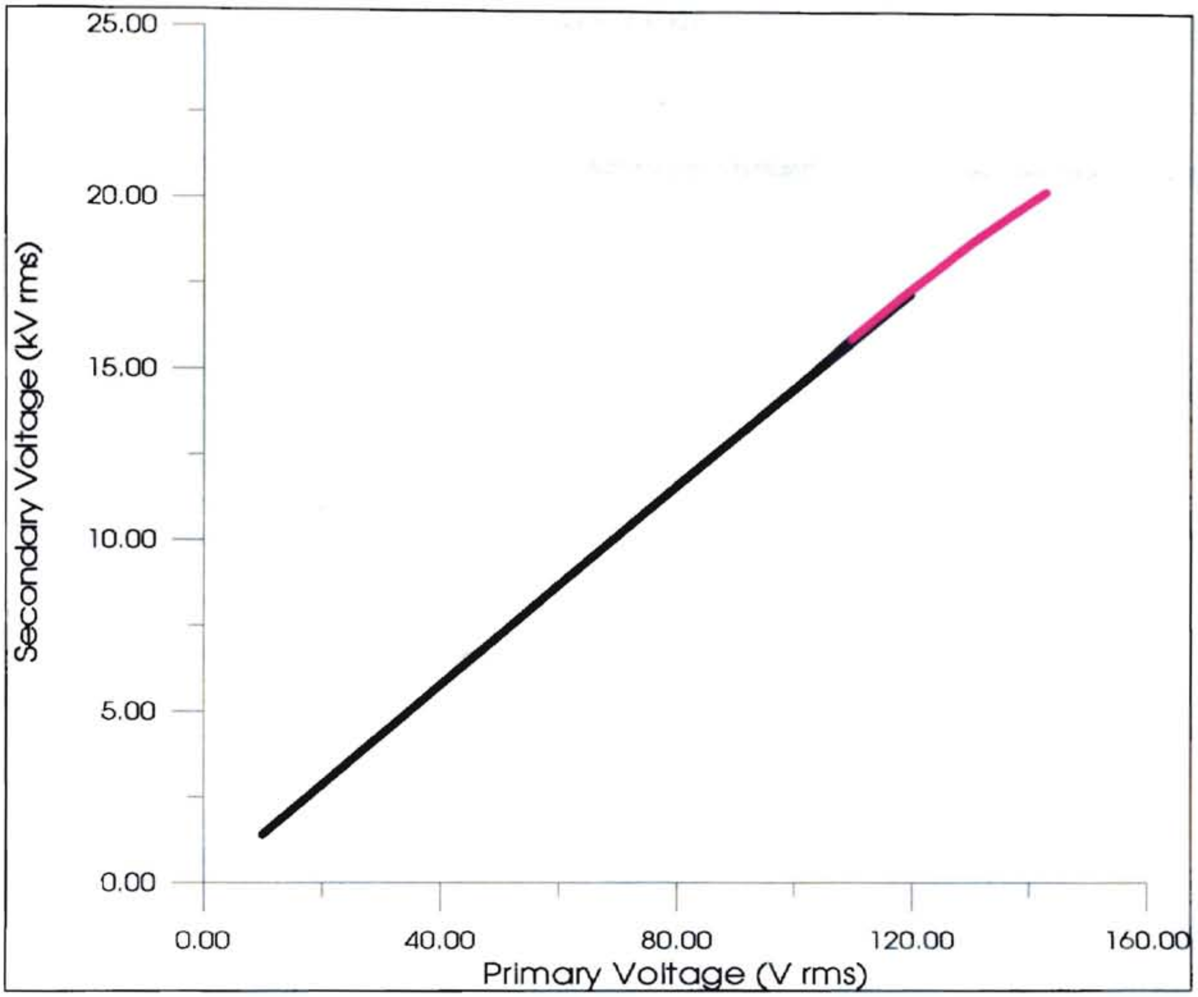


Figure 74. Primary Versus Secondary For Data Set #66.
Reactor A with air flowing through the annulus.

Data Set #66 Analysis

Plasma was produced only at the high end of the plot as expected.

TABLE LXVI

Data Set #67

Setup
- Reactor A.
- 7.5 inch plasma zone.
- Air flows at 0.020 cubic feet per second through the annulus.
- Primary voltage is 30 volts rms.
- Inner and outer electrodes are dark green Sierra antifreeze (propylene glycol).
- Outer electrode is diluted with a large amount of water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Ambient temperature is 77 degrees Fahrenheit.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.

Frequency (Hz)	Secondary Voltage (kV rms)	(kV peak)	Current (amps)
100	4.22	6	3.5
150	4.2	6	3.45
200	4.22	6	3.45
250	4.32	6	3.45
300	4.54	6	3.45
350	4.9	7	3.4
400	5.5	7.5	3.35
450	6.42	9	3.35
500	8	11	3.35
550	11.06	15.5	3.6
600	14.94	21	4.25
650	13.2	18.5	4.4
700	8.78	12	3.9
750	5.8	8.25	3.45
800	4.52	6.5	3.2
850	4.12	5.75	3.25
900	3.7	5	3.2
950	3.14	4.5	3.25

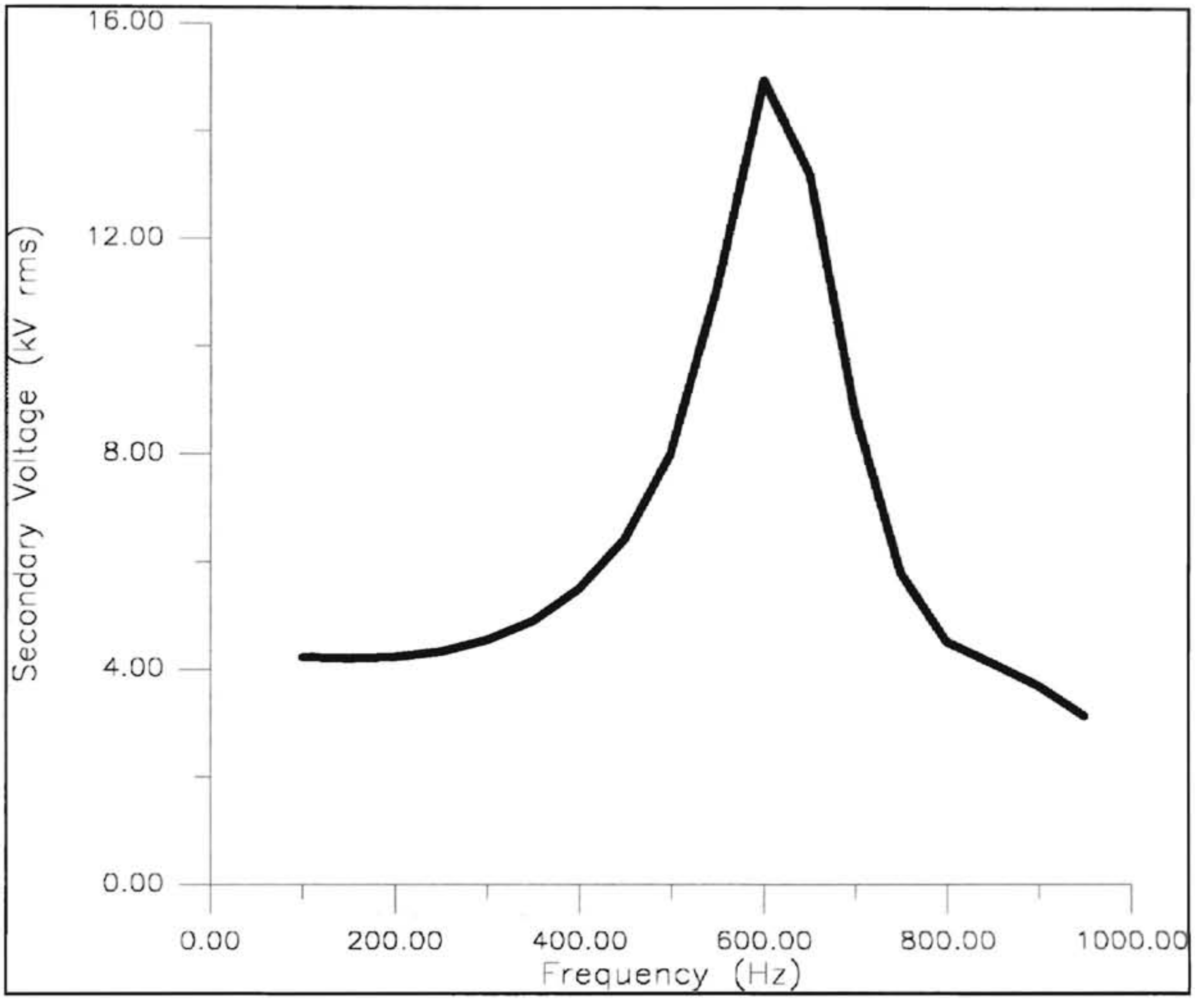


Figure 75. Typical Tuning Plot For Data Set #67.
Reactor A with air flowing through the annulus

Data Set #67 Analysis

The primary was probably too low to initiate a plasma.

TABLE LXVII

Data Set #68

Setup
- Reactor A.
- 7.5 inch plasma zone.
- Air flows at 0.20 cubic feet per second through the annulus.
- Primary voltage is 40 volts rms.
- Inner and outer electrodes are dark green Sierra antifreeze (propylene glycol).
- Outer electrode is diluted with a large amount of water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Ambient temperature is 77 degrees Fahrenheit.
- Large glass vessel contains the outer electrode.
- The vessel sits directly on the concrete floor.

Notes
A. Partial plasma.
B. Never fully develops.
C. Plasma gone.
D. Ran out of air.

Frequency (Hz)	Secondary Voltage (kV rms)	(kV peak)	Current (amps)	Notes
100	5.64	8	3.20	
150	5.60	8	3.15	
200	5.66	8	3.15	
250	5.82	8	3.15	
300	6.12	8.5	3.20	
350	6.62	9.5	3.15	
400	7.44	10.5	3.15	
450	9.00	12.5	3.15	
500	11.38	16	3.35	
520	12.64	17.5	3.50	
540	14.42	20	3.80	
560	15.30	21	4.15	A
580	15.30	21	4.35	
600	15.12	21	4.50	
620	14.66	20	4.55	
640	14.16	19.5	4.55	B
660	13.60	19	4.55	
680	13.00	18	4.50	

(con't.)

TABLE LXVII (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	(kV peak)	Current (amps)	Notes
700	12.12	17	4.40	C
720	10.20	14	4.15	
740	8.64	12	3.90	
760	7.38	10.5	3.75	
780	6.64	9	3.60	
800	6.16	8.5	3.45	
820	5.92	8	3.40	
840	5.76	8	3.30	
860	5.56	8	3.25	
880	5.38	7.5	3.15	
900	5.10	7	3.10	
920	4.78	7	3.10	
940	4.46	6	3.10	
960	4.14	5.5	3.10	
980	3.84	5	3.10	
1000	3.56	5	3.10	D

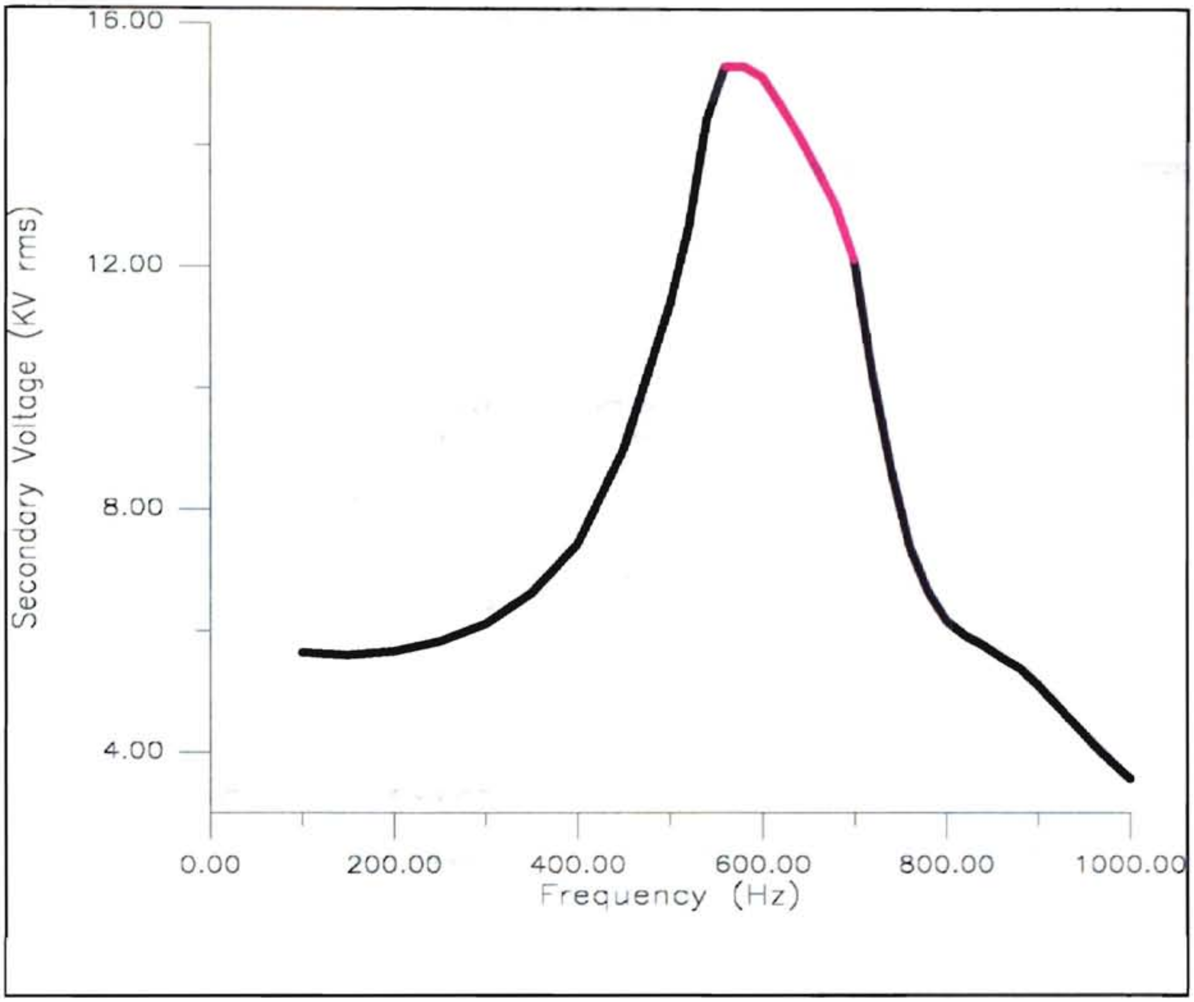


Figure 76. Typical Tuning Plot For Data Set #68.
Reactor A with air flowing through the annulus.

Data Set #68 Analysis

The 40 volt primary voltage was sufficient for creating a plasma, but it was never intense.

TABLE LXVIII

Data Set #69

Setup
- Reactor A.
- 7.5 inch plasma zone.
- Annulus is open to the atmosphere.
- Primary voltage is 60 volts rms.
- Inner and outer electrodes are dark green Sierra antifreeze (propylene glycol).
- Outer electrode is diluted with a large amount of water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Ambient temperature is 72 degrees Fahrenheit.
- A tower of silicon adhered 3 liter plastic bottles contains the outer electrode.
- The container sits directly on the concrete floor.

Notes
A. End effects occurring in the bottom of the container.
B. Air tube appears to be glowing.

Frequency (Hz)	2 Voltage (kV RMS)	Current (amps)	Notes
100	9.48	3.70	
150	9.92	3.60	
200	10.64	3.55	
250	11.76	3.45	
300	14.18	3.45	
350	18.00	4.00	A
400	22.00	5.50	
450	23.00	6.50	B
480	22.80	6.70	
500	23.30	6.80	
520	22.34	6.80	
540	21.20	6.65	
560	17.80	6.20	
580	13.80	5.60	
600	11.00	5.10	
620	8.82	4.80	
640	7.38	4.50	
660	6.26	4.25	
680	5.36	4.10	
700	4.62	3.95	

(con't.)

TABLE LXVIII (continued)

Frequency (Hz)	2 Voltage (kV RMS)	Current (amps)	Notes
720	4.04	3.80	
740	3.58	3.70	
760	3.30	3.60	
780	3.14	3.50	
800	3.18	3.40	
820	3.36	3.35	
840	3.60	3.30	
860	3.80	3.25	
880	3.88	3.20	
900	3.84	3.15	
920	3.72	3.15	
940	3.52	3.10	
960	3.32	3.10	
980	3.12	3.10	
1000	2.94	3.10	

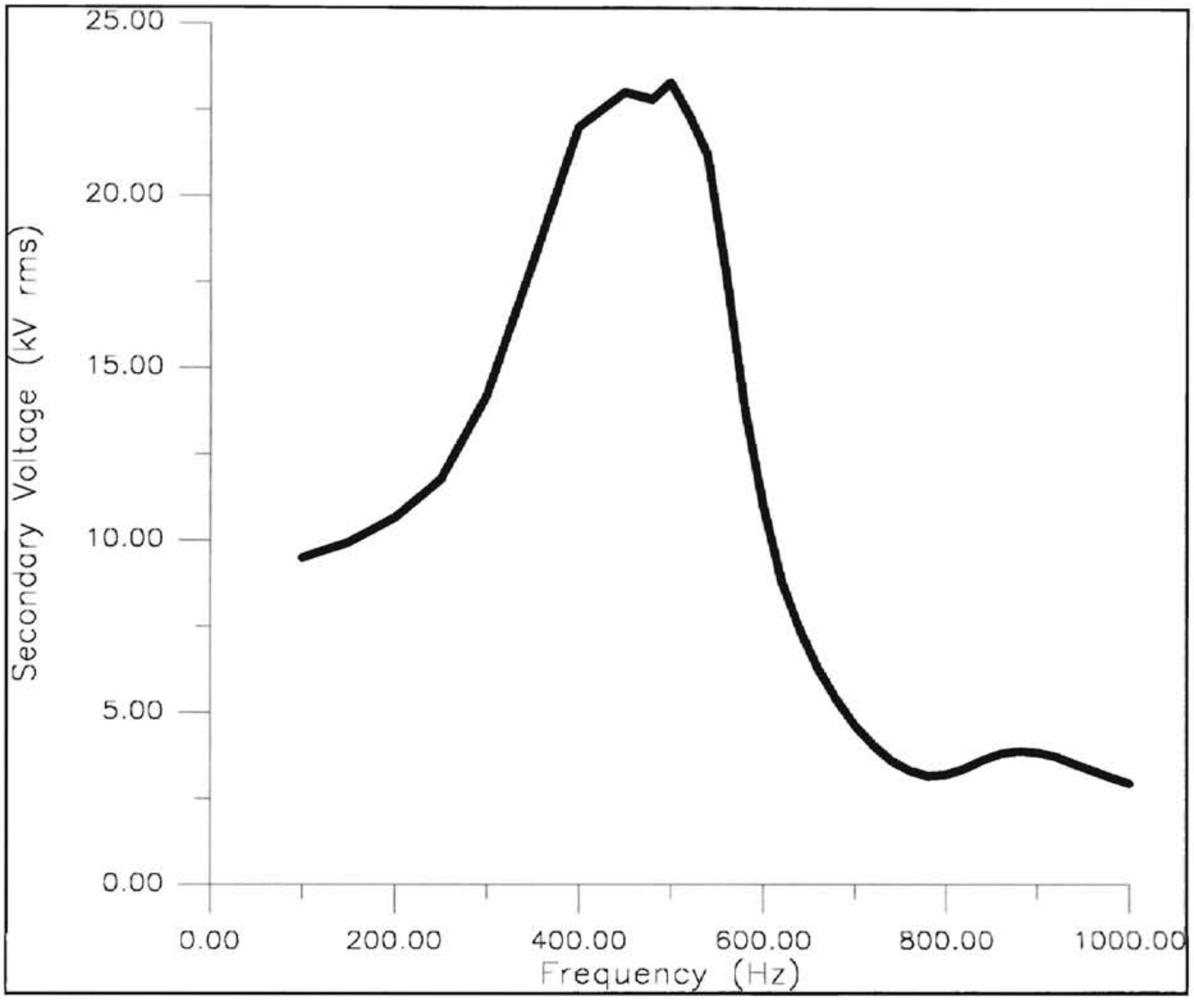


Figure 77. **Typical Tuning Plot For Data Set #69.**
Reactor A with the annulus open to the atmosphere via long tubes.

Data Set #69 Analysis

First run with the tower of 3 liter bottles serving as the outer electrode container. The end effects in the bottom of the container along with the glowing air tube were not expected. There was a pulsing glow emitted from within the outer electrode near the bottom of the container.

TABLE LXIX

Data Set #70

Setup
- Reactor A.
- 7.5 inch plasma zone.
- Annulus is open to the atmosphere.
- Primary voltage is 90 volts rms.
- Inner and outer electrodes are dark green Sierra antifreeze (propylene glycol).
- Outer electrode is diluted with a large amount of water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Ambient temperature is 72 degrees Fahrenheit.
- A tower of silicon adhered 3 liter plastic bottles contains the outer electrode.
- The container sits directly on the concrete floor.

Notes
A. Bottom effect and outer copper wire (flashing).
B. Full length air tube is lit.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
100	14.62	3.65	
150	15.46	3.20	
200	16.50	3.10	
250	18.42	3.20	
300	21.84	3.60	
320	24.46	3.90	A
340	27.60	5.20	B
360	29.60	6.65	
380	30.26	7.30	
400	30.00	7.60	
420	29.20	7.75	
440	28.50	7.70	
460	27.60	7.70	
480	26.90	7.70	
500	26.10	7.65	

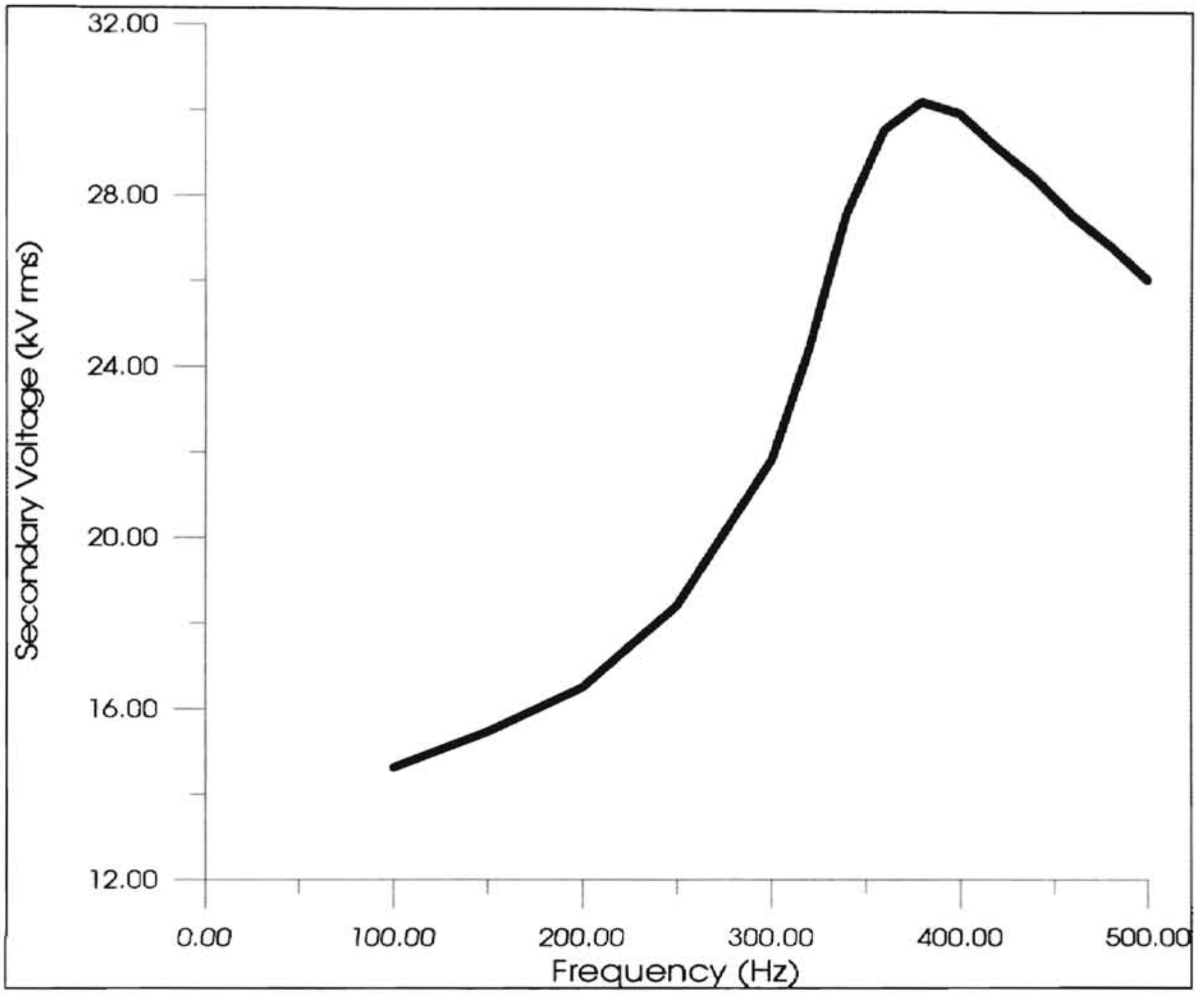


Figure 78. **Typical Tuning Plot For Data Set #70.**
Reactor A with the annulus open to the atmosphere via long tubes.

Data Set #70 Analysis

I put the container in an insulated holder and this helped reduce the end effects some.

TABLE LXX

Data Set #71

Setup

- Reactor B.
- Annulus is open to the atmosphere.
- Primary voltage is 90 volts rms.
- Inner and outer electrodes are dark green Sierra antifreeze (propylene glycol).
- Outer electrode is diluted with a large amount of water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Ambient temperature is 72 degrees Fahrenheit.
- A tower of silicon adhered 3 liter plastic bottles contains the outer electrode.
- The container sits on a wooden stand.

Notes

A. One point of glow.
B. Holding arm is glowing.
C. Outside annulus glow.
D. Plasma some.
E. Gauges are fluctuating.
F. Pretty much all plasma in annulus.
G. Glow is only in the annulus I think, then arced.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
100	14.76	4.25	A
150	15.60	3.75	B
200	16.90	3.55	
250	19.20	3.50	
300	21.60	4.20	C
320	22.60	5.50	D
340	23.40	5.85	E
360	24.00	6.40	
380	24.00	6.75	
400	24.00	7.00	
420	24.00	7.10	
440	23.70	7.15	
460	23.20	7.50	F
480	22.52	7.10	
500	21.80	7.05	G

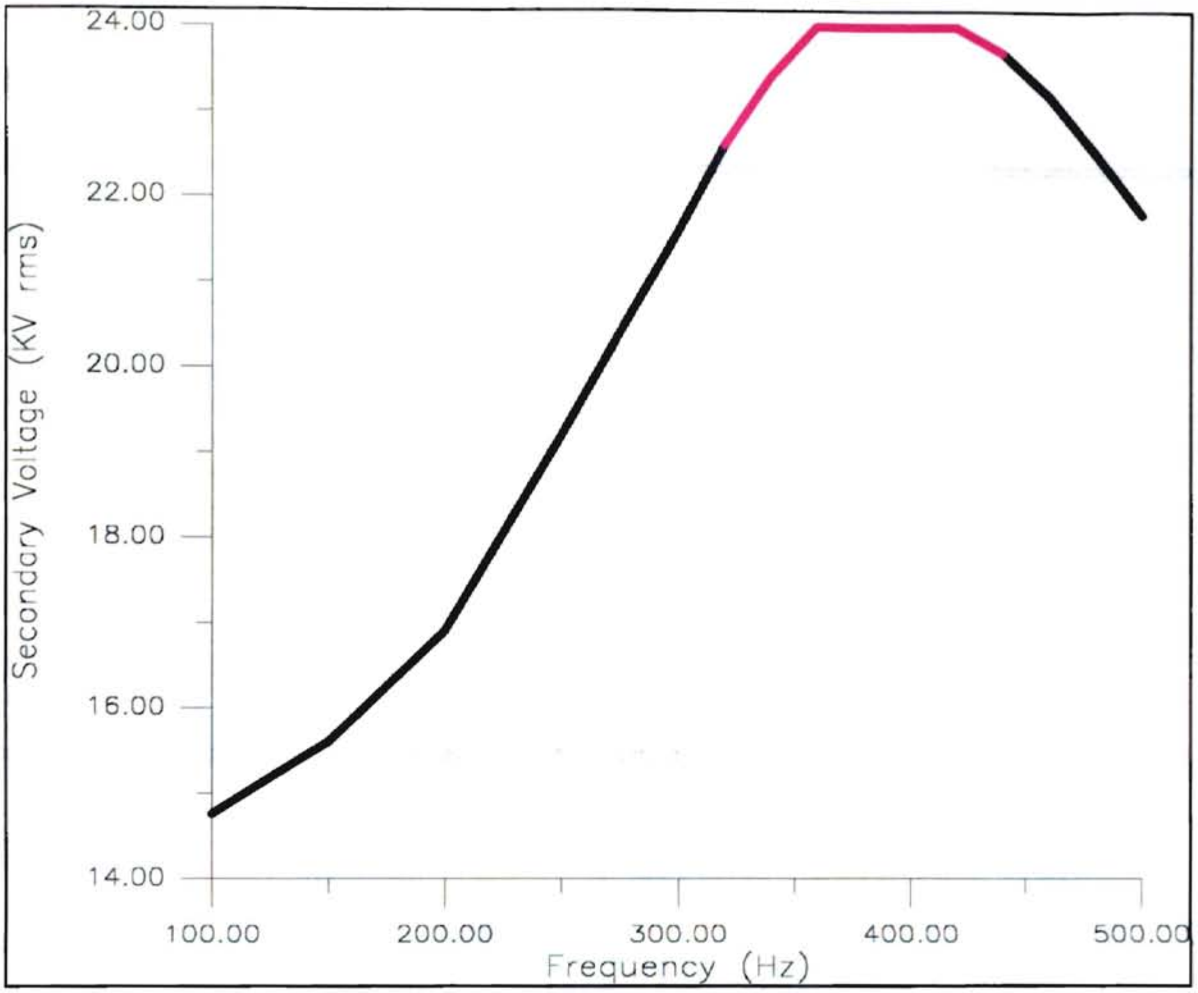


Figure 79. Typical Tuning Plot For Data Set #71.
Reactor A with the annulus open to the atmosphere via long tube.

Data Set #71 Analysis

Negative electrical effects are persisting. I tried introducing a copper wire throughout the outer electrode in case there was a problem with the resistance of the liquid from top to bottom of the electrode and this appeared to produce more negative end effects.

TABLE LXXI

Data Set #72

Setup

- Reactor B.
- 7.5 inch plasma zone.
- Annulus is open to the atmosphere.
- Primary voltage is 90 volts rms.
- Inner and outer electrodes are dark green Sierra antifreeze (propylene glycol).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- Ambient temperature is 72 degrees Fahrenheit.
- One cut off 3 liter plastic bottle contains the outer electrode.

Notes

A. Plasma began.
B. Very bright plasma.
C. No probe.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
60	13.04	4.70	A
70	13.20	4.40	
80	13.26	4.20	
90	13.32	4.05	
100	13.40	3.90	
110	13.44	3.80	
120	13.58	3.65	
130	13.64	3.55	
140	13.60	3.50	
150	13.64	3.35	
160	13.76	3.30	
170	13.92	3.30	
180	14.12	3.30	
190	14.44	3.40	
200	14.50	3.45	
210	14.30	3.40	
220	14.04	3.35	
230	13.96	3.30	
240	14.00	3.25	
250	14.08	3.20	

(con't.)

TABLE LXXI (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
260	14.20	3.20	
270	14.42	3.20	
280	14.68	3.20	
290	15.16	3.20	B
300	15.68	3.25	
310	16.10	3.30	
320	16.60	3.35	
330	17.14	3.40	
340	17.60	3.45	
350	18.22	3.55	
360	19.26	3.70	
370	20.20	3.90	
380	22.90	4.45	
390	32.80	5.80	
400	lost probe		
200		3.50	C
300		3.60	C
400		6.20	C
410		6.85	C
420		7.50	C
430		8.10	C
440		8.70	C
440		3.40	C

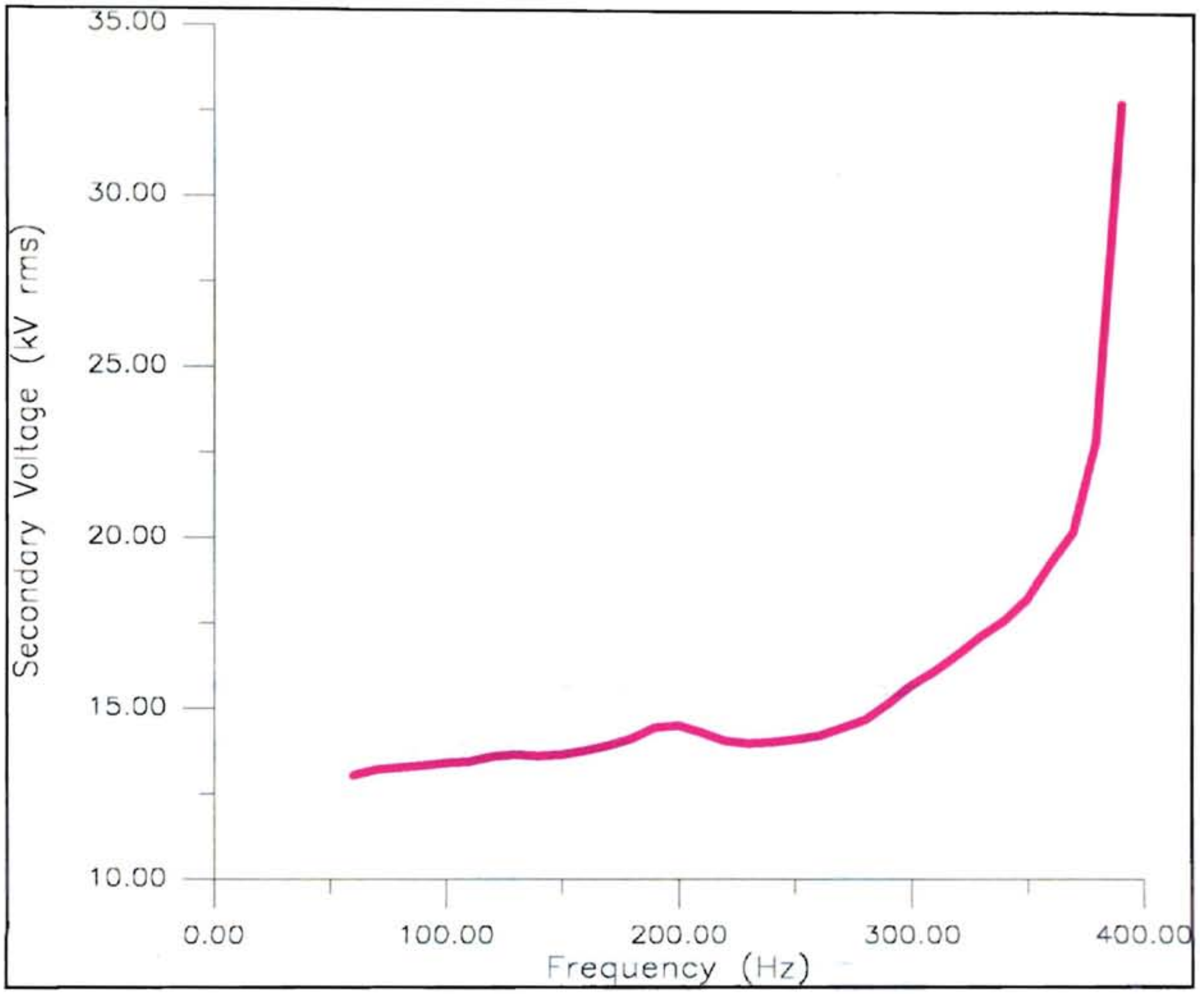


Figure 80. Typical Tuning Plot For Data Set #72.
Reactor B with the annulus open to the atmosphere.

Data Set #72 Analysis

This was one intense plasma! I didn't think our transformers could pull out that level of secondary voltage. The probe glowed just before shorting out, but there wasn't enough time to salvage the probe.

TABLE LXXII

Data Set #73

Setup

- Reactor B.
- 7.5 inch plasma zone.
- The power supply is a variable transformer (Variac).
- Annulus is open to the atmosphere.
- Primary voltage is 90 volts rms.
- Inner and outer electrodes are dark green Sierra antifreeze (propylene glycol).
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- One cut off 3 liter plastic bottle contains the outer electrode.

Notes

A. No plasma

Primary Voltage (V rms)	Secondary Voltage (kV rms)	Current (amps)	Notes
141.30	8.28	7.50	A
90.00	5.50	2.40	A

Data Set #73 Analysis

Very high primary voltage did not create a plasma.

TABLE LXXIII

Data Set #74

Setup
- Reactor B.
- 7.5 inch plasma zone.
- The power supply is a variable transformer (Variac).
- Annulus is open to the atmosphere.
- Primary voltage is 60 volts rms.
- Inner and outer electrodes are tap water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- One cut off 3 liter plastic bottle contains the outer electrode.

Notes
A. Light flash.
B. Faint plasma.
C. Full plasma.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
100	3.52	7.15	
150	3.20	5.55	
200	2.88	4.65	
250	2.56	4.15	
300	2.28	3.80	
350	2.06	3.55	
400	1.86	3.30	A
450	1.72	3.30	
500	1.62	3.25	
550	1.58	3.15	
600	1.62	3.15	
610	1.64	3.15	B
620	1.66	3.15	
630	1.68	3.15	
640	1.72	3.15	C
650	1.76	3.15	
660	1.78	3.15	
670	1.80	3.15	
680	1.84	3.15	
690	1.86	3.25	

(con't.)

TABLE LXXIII (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
700	1.86	3.30	
710	1.86	3.40	
720	1.84	3.45	
730	1.82	3.55	
740	1.82	3.60	
750	1.80	3.65	
760	1.78	3.70	
770	1.76	3.70	
780	1.74	3.75	
790	1.72	3.75	
800	1.68	3.75	

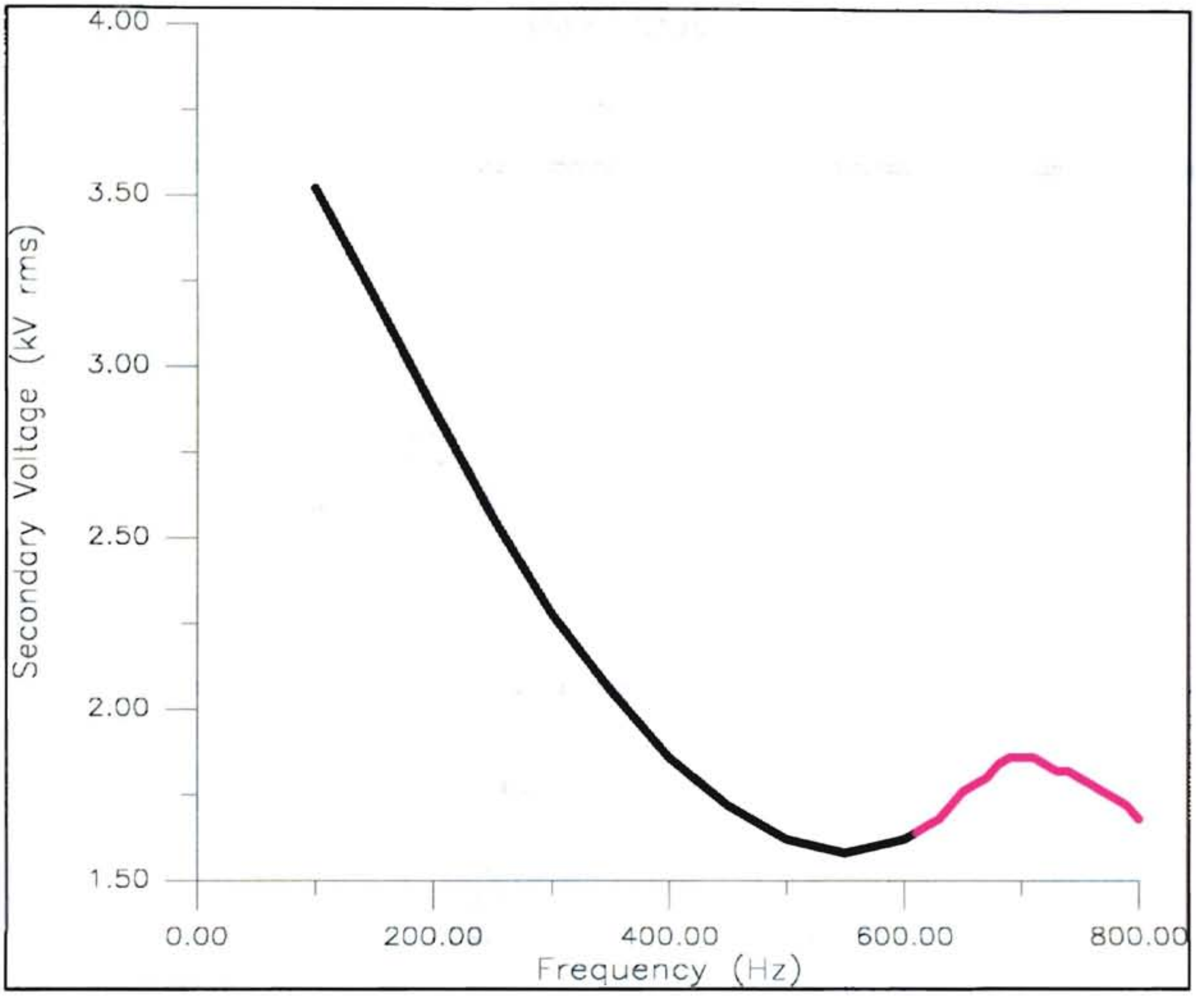


Figure 81. Typical Tuning Plot For Data Set #74.
Reactor B with the annulus open to the atmosphere.

Data Set #74 Analysis

The transformer may have been partially shorted out during data set #70, or the Fluke probe could be showing lower values than are really present. Produced a full uniform plasma.

TABLE LXXIV

Data Set #75

Setup
- Reactor B.
- 7.5 inch plasma zone.
- Air flows through the annulus at 9 ml/sec.
- Primary voltage is 60 volts rms.
- Inner and outer electrodes are tap water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- One cut off 3 liter plastic bottle contains the outer electrode.

Notes
A. Uniform plasma, thin.
B. Good uniform plasma.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
100	3.52	6.85	
150	3.20	5.25	
200	2.88	4.45	
250	2.56	3.90	
300	2.30	3.55	
350	2.06	3.30	
400	1.86	3.10	
450	1.72	2.95	
500	1.62	2.95	
550	1.58	3.00	
590	1.66	2.95	
600	1.70	2.90	
610	1.74	2.90	A
620	1.78	3.00	
630	1.80	3.05	
640	1.82	3.15	
650	1.82	3.20	
660	1.82	3.30	
670	1.82	3.40	
680	1.78	3.45	
690	1.76	3.50	

(con't.)

TABLE LXXIV (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
700	1.72	3.60	
710	1.70	3.60	
720	1.66	3.60	
730	1.62	3.65	B
740	1.58	3.65	
750	1.54	3.65	
760	1.52	3.65	
770	1.48	3.65	
780	1.46	3.65	
790	1.42	3.65	
800	1.40	3.65	

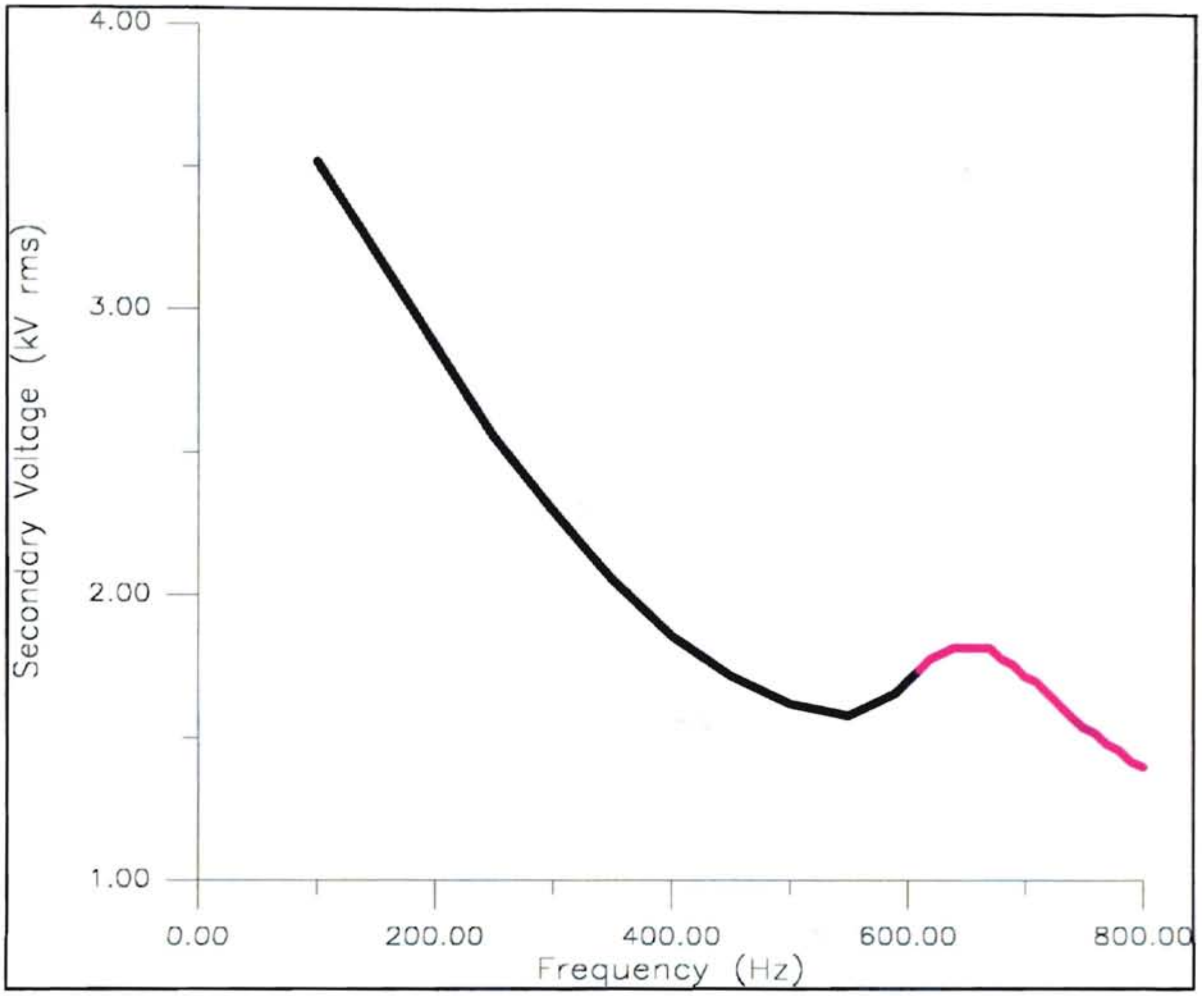


Figure 82. Typical Tuning Plot For Data Set #75.
Reactor B with air flowing through the annulus.

Data Set #75 Analysis

Produced a good uniform plasma.

TABLE LXXV

Data Set #76

Setup

- Reactor B.
- 7.5 inch plasma zone.
- Air flows through the annulus at 9 ml/sec.
- Primary voltage is 60 volts rms.
- Inner and outer electrodes are saturated salt water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- One cut off 3 liter plastic bottle contains the outer electrode.
- The container sits on a wooden stand.

Notes

A. Plasma below air flow.
B. Full plasma.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
100	3.56	7.05	
150	3.24	5.35	
200	2.90	4.50	
250	2.60	3.95	
300	2.32	3.60	
350	2.08	3.35	
400	1.88	3.15	
450	1.74	2.95	
500	1.64	2.85	A
550	1.60	2.90	
580	1.62	2.90	B
590	1.66	2.90	
600	1.72	2.90	
610	1.78	3.00	
620	1.82	3.10	
630	1.84	3.20	
640	1.86	3.30	

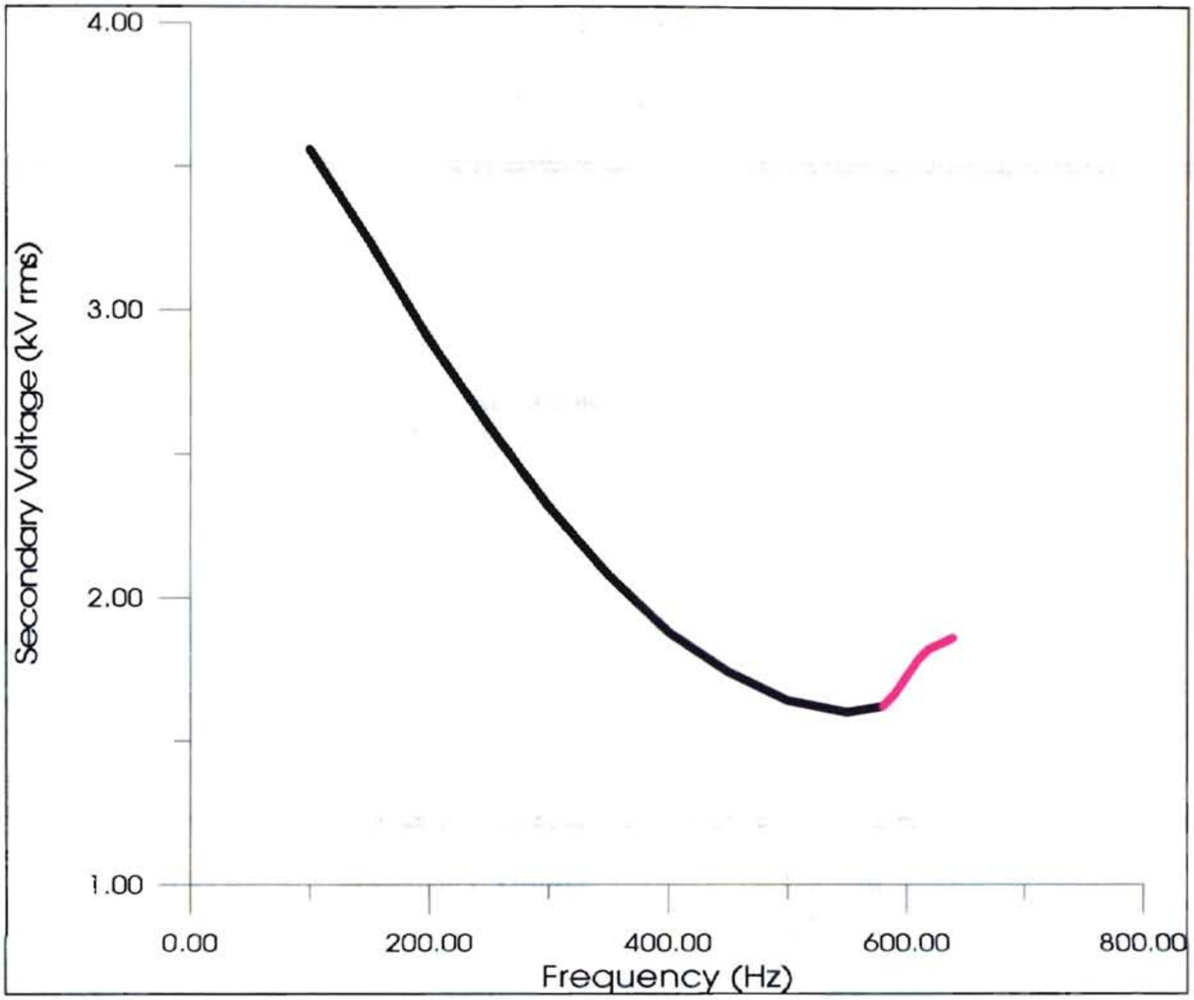


Figure 83. Typical Tuning Plot For Data Set #76.
Reactor B with air flowing through the annulus.

Data Set #76 Analysis

Plasma was created and there was very little heat buildup within the liquid electrodes.

TABLE LXXVI

Data Set #77

Setup
- Reactor A.
- 10 inch plasma zone.
- Air flows through the annulus at 9 ml/sec.
- Primary voltage is 60 volts rms.
- Inner and outer electrodes are saturated salt water.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Fluke 80K-40.
- One cut off 3 liter plastic bottle contains the outer electrode.

Notes
A. Start air same rate.
B. Pulsing plasma.
C. Dimming.
D. Air flow hooked.
E. Stopped and unhooked probe, not hot.
F. The air flow was never hooked up before.

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
100	5.62	9.55	
200	4.64	5.65	
300	3.80	4.20	A
400	3.20	3.40	
500	3.02	3.05	B
540			
580			
600		3.75	
610		3.95	
620		4.20	
630		4.35	
640		4.50	
650		4.60	
660		4.65	
670		4.70	C
680		4.70	
690		4.65	
700		4.65	

(con't.)

TABLE LXXVI (continued)

Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
710		4.80	
720		4.90	D
730		4.70	E

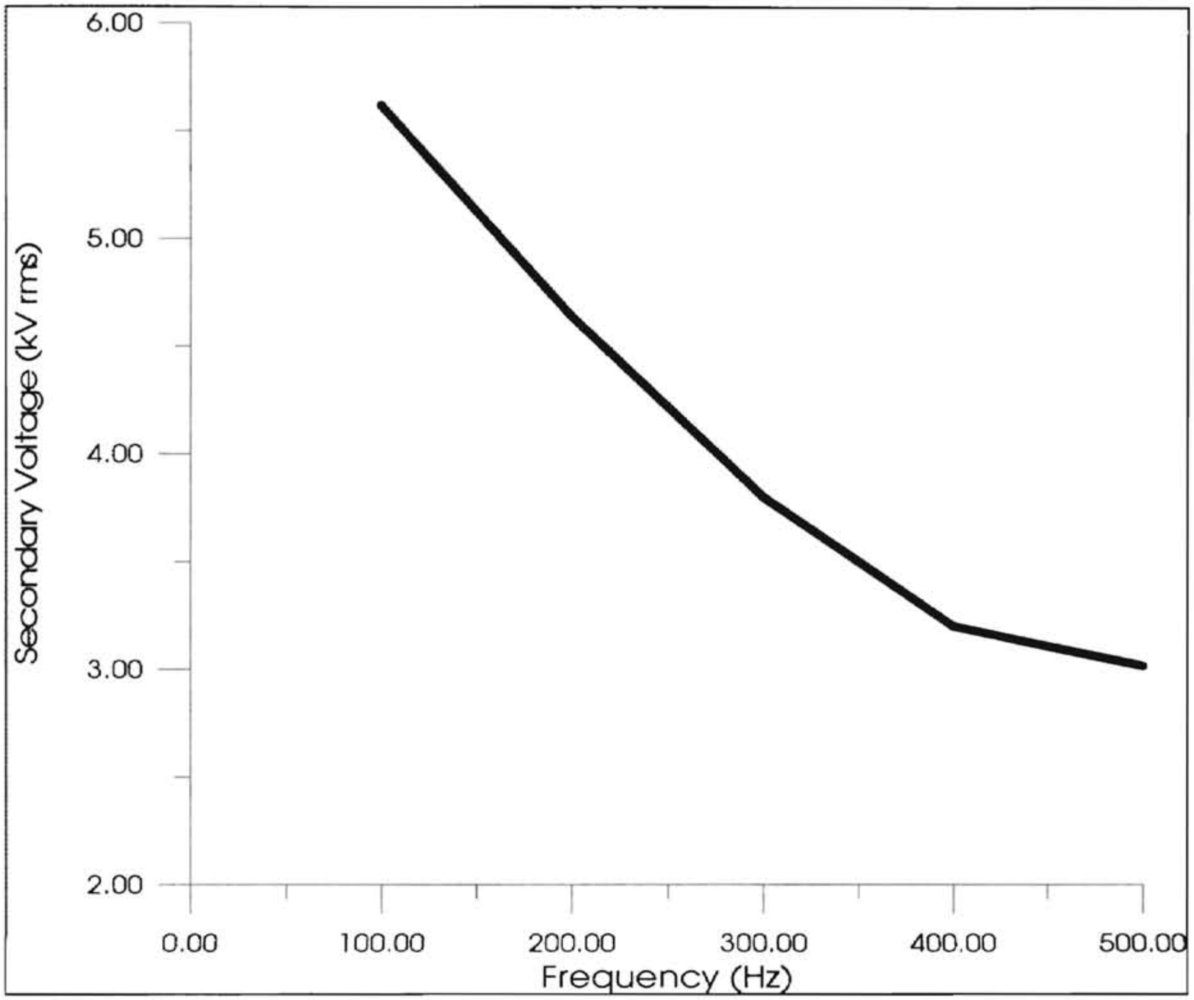


Figure 84. Typical Tuning Plot For Data Set #77.
Reactor B with air flowing through the annulus.

Data Set #77 Analysis

There was very little heat build up in the liquid electrodes. The plasma does not extend way above the outer liquid electrode level with the salt water electrodes. The Fluke probe quit working after just a few frequency readings.

TABLE LXXVII

Data Set #78

Setup

- Reactor A.
- 10 inch plasma zone.
- Air flows through the annulus at 9 ml/sec.
- Primary voltage is 60 volts rms.
- Inner and outer electrodes are saturated salt water.
- Secondary leads are 15 kV 2 AWG wire.
- No high voltage probe.
- One cut off 3 liter plastic bottle contains the outer electrode.

Notes

A. Partial plasma.
B. Brighter, splotchy.
C. Full length but weak.
D. Trying to die.
E. Gone.

Frequency (Hz)	Primary Voltage (V rms)	Current (amps)	Notes
100	97	9.50	A
200		5.60	B
300		4.20	
400		3.40	
500		2.90	C
570		3.10	
580		3.30	D
590		3.65	
600		3.95	
610		4.20	
620		4.30	
630		4.35	
640		4.50	
650		4.60	
660		4.65	
670		4.70	
680		4.70	
690		4.75	
700	123.22	4.80	
710		4.75	

(con't.)

TABLE LXXVII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Current (amps)	Notes
720		4.75	E
730		4.75	
740		4.75	
750		4.75	
760		4.65	
770		4.60	

Data Set #78 Analysis

Plasma formation was very weak.

TABLE LXXVIII

Data Set #79

Setup

- Reactor A.
- 10 inch plasma zone.
- The power supply is a variable transformer (Variac).
- Air flows through the annulus at 9 ml/sec.
- Primary voltage is 95 volts rms.
- Inner and outer electrodes are saturated salt water.
- Secondary leads are 15 kV 2 AWG wire.
- One cut off 3 liter plastic bottle contains the outer electrode.

Primary Voltage (V rms)	Current (amps)
60	1.00
70	1.50
80	2.00
90	2.50
100	3.20
110	3.90
120	4.70
130	5.90
140	7.50

Data Set #79 Analysis

Unable to create a plasma with this setup.

TABLE LXXIX

Data Set #80

Setup
- Reactor A.
- 10 inch plasma zone.
- Air flows through the annulus at 9 ml/sec.
- Primary voltage is 60 volts rms.
- Inner and outer electrodes are saturated salt water.
- Secondary leads are 15 kV 2 AWG wire.
- No high voltage probe.
- A tower of silicon adhered 3 liter plastic bottles contains the outer electrode.
- The container sits directly on the concrete floor.

Notes
A. Weird one sided plasma.
B. Plasma appears to be outside the annulus, possibly within the outer electrode.
C. Interesting flashes within the outer electrode.
D. Sparks on ground when outer electrode drips.

Running Time (minutes:seconds)	Notes
0:00	A
1:40	B
10:47	
11:19	C
12:40	C,D
13:44	C,D
13:52	C,D
14:04	C,D

Data Set #80 Analysis

I put the large holder inside an insulated container to remove electrical effects with the ground and operated with improved success, but some degree of these electrical effects still existed. The sparks that resulted from a small leak in the outer electrode container would violently spark like an arc when they made contact with the ground. The difference in potential between the ground and the outer electrode is most likely the reason for the strange electrical effects. I put the container on a wooden stand and a spark lit the stand producing a small fire.

TABLE LXXX

Data Set #81

Setup
- Reactor A.
- Annulus is open to the atmosphere.
- Primary voltage is 95 volts rms.
- Inner electrode is propylene glycol.
- Outer electrode is copper mesh.
- Secondary leads are 15 kV 2 AWG wire.
- No high voltage probe.

Notes
A. Plasma appeared one sided.

Frequency (Hz)	Notes
440	A

Data Set #81 Analysis

This appeared to be the optimum frequency for producing the most intense plasma. The plasma was bright with visible lines of intensity showing within the plasma.

TABLE LXXX

Data Set #82

Setup

- Reactor A
- Primary voltage is 97 volts rms.
- Inner and outer electrode is salt water.
- Outer electrode is grounded.
- Secondary leads are 15 kV 2 AWG wire.
- High voltage probe is Hewlett Packard 1137A.
- France transformer; used half the windings.

Notes

A. Partial plasma.
B. Plasma is more full.
C. Sine wave is bent.
D. Brighter plasma.
E. The secondary voltage is near this value.
F. The secondary voltage is not available.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Current (Amps)	Notes
100	96.90	6.10	5.55	
200	97.30	6.47	4.2	
300	97.54	6.98	3.7	
400	97.55	8.06	3.65	
500	97.55	10.70	3.6	A
510	97.50	11.30	3.6	
520	97.45	11.70	3.6	
530	97.37	12.27	3.7	B
540	97.26	12.70	3.85	B
550	97.18	13.40	4	C
560	97.16	14.40	4.15	D
570	97.00	15.20	4.3	
580	97.00	15.40	4.4	
590	96.99	15.60	4.45	
600	96.96	15.80	4.5	E
610	96.96	15.70	4.5	E
620	96.94		4.4	F
630	96.93	15.80	4.4	E
640		15.70		

(con't.)

TABLE LXXXI (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV rms)	Current (Amps)	Notes
700		14.60		E
800		13.30		
900		10.80	4.8	
1000		9.22	4.7	

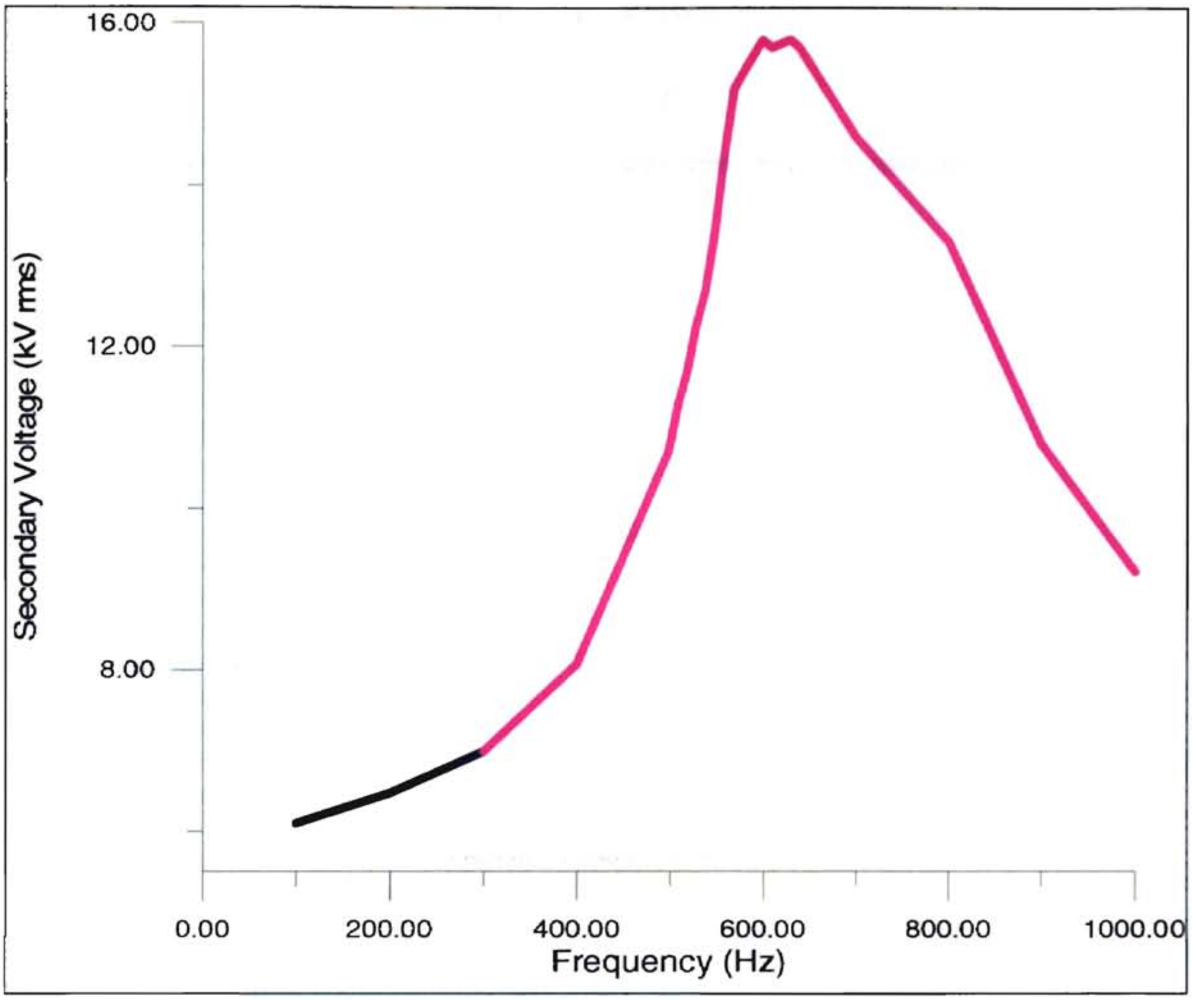


Figure 85. Typical Tuning Plot For Data Set #82.
Reactor A with the annulus open to the atmosphere via long tubes.

Data Set #82 Analysis

The intensity of the plasma was surprisingly high considering only half the windings of the transformer were used. This shows great promise for future experiments with the outer electrode grounded. The outer electrode container leaked significantly and there were no electrical effects observable.

TABLE LXXXII

Data Set #83

Setup

- Reactor A
- Primary voltage is 97 volts rms.
- Inner and outer electrode is salt water.
- Outer electrode is grounded.
- Secondary leads are 15 kV 2 AWG wire.
- France transformer; used half the windings.

Notes

A. Sine wave is bent.
B. Noticed valve had leaked allowing some air flow.
C. Plasma is dimming.
D. Air enters the annulus at 3 psig.
E. Air enters the annulus at 7 psig.
F. Air enters the annulus at 19 psig.
G. Air enters the annulus at 20 psig.
H. Air enters the annulus at 25 psig.
I. Air enters the annulus at 40 psig.
J. The plasma is brighter.
K. I pinched the annulus exit tube, completely stopping all air flow.
L. Air enters the annulus at 15 psig.

Time (hr:min)	Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
1:27	600			A
1:28	600			
1:29	600	16.10	4.40	
1:30	600	16.40	4.35	
1:31	600	16.60	4.30	
1:32	600	16.60	4.25	
1:33	600	16.70	4.20	
1:34	600	16.60	4.60	
1:35	600	15.00	4.60	
1:36	600	15.00	4.60	
1:37	600	14.85	4.55	
1:38	600	14.75	4.55	
1:39	600	14.75	4.55	B
1:41	600	15.71	4.30	C,D
1:42	600	16.70	4.15	E

(con't.)

TABLE LXXXII (continued)

Time (hr:min)	Frequency (Hz)	Secondary Voltage (kV rms)	Current (amps)	Notes
1:43	600			F
1:45	600	14.80	4.40	G
1:47	600			H
1:48	600			I,J
1:49	600			K
1:51	600			L

Data Set #83 Analysis

The effective airflow is not conclusive from this experiment. The grounded outer electrode is still proving to be an effective setup. Later use of this setup for demonstration purposes was successful but the intensity started declining suggesting the France transformer was partially shorting out due to the operation at the frequencies above 60 Hz.

TABLE LXXXIII

Data Set #84

Setup
- Reactor B.
- Annulus is open to the atmosphere.
- Primary voltage kept at maximum.
- Inner and outer electrodes are tap water with the addition of alum.
- Outer electrode is grounded.
- Secondary leads are 15 kV 2 AWG wire.
- Wagner transformer.
- High voltage probe is Hewlett Packard 1137A.
- A tower of silicon adhered 3 liter plastic bottles contains the outer electrode.

Notes
A. No Visible plasma.
B. Primary Voltage slowly increased with each step until next recording.
C. Plasma/Spark.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV peak)	Notes
60	96.16	5.83	A
100		5.83	B
200		5.80	
300		5.73	
400		5.60	
500		5.54	
600		5.46	
700		5.40	
800		5.36	
900		5.33	
1000		5.31	
1100		5.30	
1200		5.33	
1300	97.70	5.31	
1400		5.31	
1500		5.34	
1600		5.38	
1700		5.40	
1800		5.42	
1900	98.08	5.44	

(con't.)

TABLE LXXXIII (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV peak)	Notes
2000	98.16	5.46	
2100	98.26	5.50	
2200	98.39	5.53	
2300	98.52	5.59	
2400	98.65	5.62	
2500	98.77	5.68	
2600	98.89	5.75	
2700	99.06	5.82	
2800	99.23	5.89	
2900	99.40	5.97	
3000	99.60	6.03	
3100	99.86	6.11	
3200	100.12	6.18	
3300	100.37	6.27	
3400	100.64	6.36	
3500	100.92	6.46	
3600	101.23	6.58	
3700	101.50	6.69	
3800	101.72	6.91	C
3900	101.83	7.02	

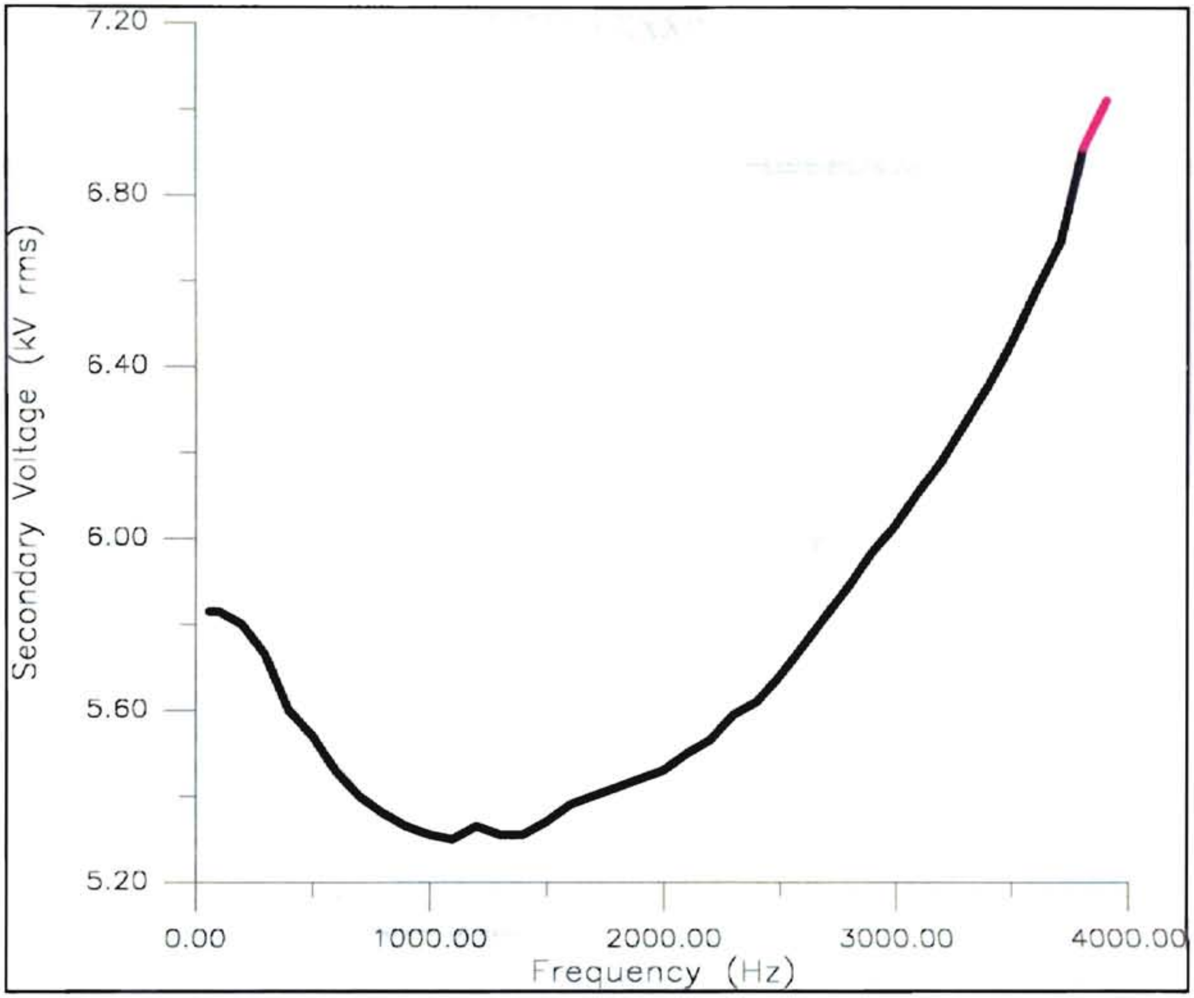


Figure 86. **Typical Tuning Plot For Data Set #84.**
Reactor B with the annulus open to the atmosphere.

Data Set #84 Analysis

Oscillator does not work below 60 Hz. The primary increased with increase in frequency. There were not any negative outside electrical effects noticeable, but a good plasma was not created..

TABLE LXXXIV

Data Set #85

Setup
- Reactor B.
- Annulus is open to the atmosphere.
- Primary voltage kept at maximum.
- Inner and outer electrodes are tap water with the addition of alum.
- Outer electrode is grounded.
- Secondary leads are 15 kV 2 AWG wire.
- Wagner transformer.
- High voltage probe is Hewlett Packard 1137A.
- A tower of silicon adhered 3 liter plastic bottles contains the outer electrode.

Notes
- A. 9.6 amps.
- B. Amps off scale (10+).
- C. On then off plasma.
- D. Full plasma for one second.
- E. Short zone of plasma sustained.
- F. Trying to light full length.
- G. Full zone - spotty plasma.
- H. Almost complete plasma.
- I. Complete/full bright plasma.
- J. Intense blue/white - limit of power supply.
- K. Power supply shut-off (limit).
- L. Outer electrode had leaked producing a pool around the bottom.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV peak)	Time	Notes
3000	99.60	6.09	12:37	A
3100	99.87	6.17		B
3200	100.14	6.24		
3300	100.41	6.35		
3400	100.69	6.45		
3500	100.99	6.54		
3600	101.30	6.65		
3700	101.58	6.76		
3800	101.80	6.89		
3900	101.96	7.02	12:39	C
4000	101.99	7.17		C
4100	102.21	7.30		D
4200	102.61	7.45	12:40	E

(con't.)

TABLE LXXXIV (continued)

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV peak)	Time	Notes
4300	103.16	7.62		
4400	103.79	7.82	12:42	F
4500	104.69	8.07		G
4600	105.71	8.40		H
4700	107.08	8.84		I
4800	108.35	9.13		
4900	109.86	9.33		
5000	111.49	9.70		
5100	113.30	10.27		J
5200				K,L

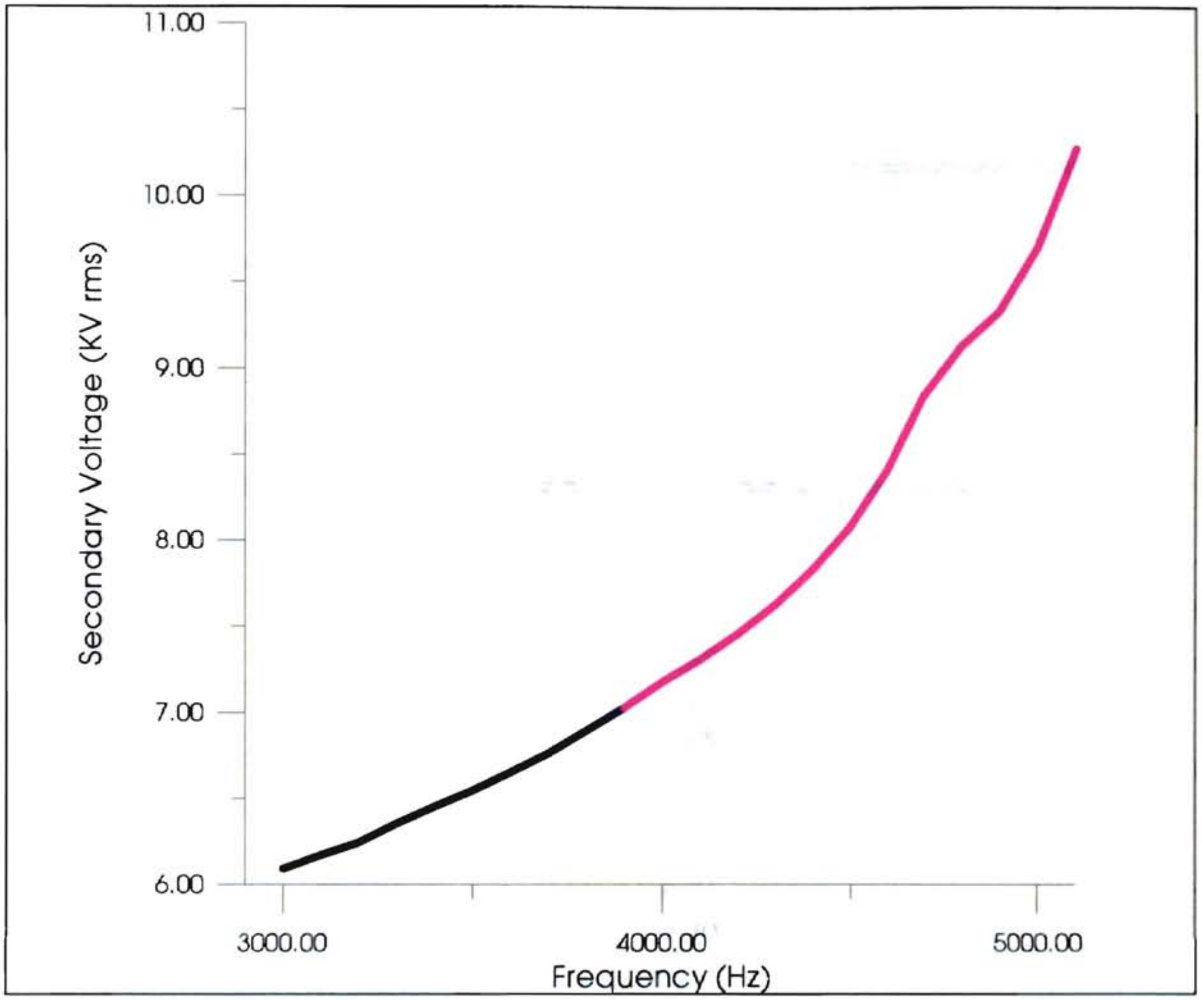


Figure 87. Typical Tuning Plot For Data Set #85.
Reactor B with the annulus open to the atmosphere.

Data Set #85 Analysis

This transformer tunes at a much higher frequency. The plasma created within the annulus is both full and intense. The grounded outer electrode is successful for removing outside electrical effects. The outer electrode has a leak and the container rests in a pool of water and no electrical effects are present.

TABLE LXXXV

Data Set #86

Setup
- No reactor (no load on the secondary side).
- Wagner transformer.
- High voltage probe is Hewlett Packard 1137A.

Notes
A. Limit of power supply.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV peak)	Current (amps)	Notes
100	97.06	5.88	3.5	
200	97.46	5.75	2.8	
300	97.64	5.68	2.8	
1000	97.63	5.30	3.5	
2000	98.08	5.37	5.8	
3000	99.10	5.78	8.3	
4000	101.31	6.54		
5000	104.90	7.70		
5100	105.50	7.80		
5200				A

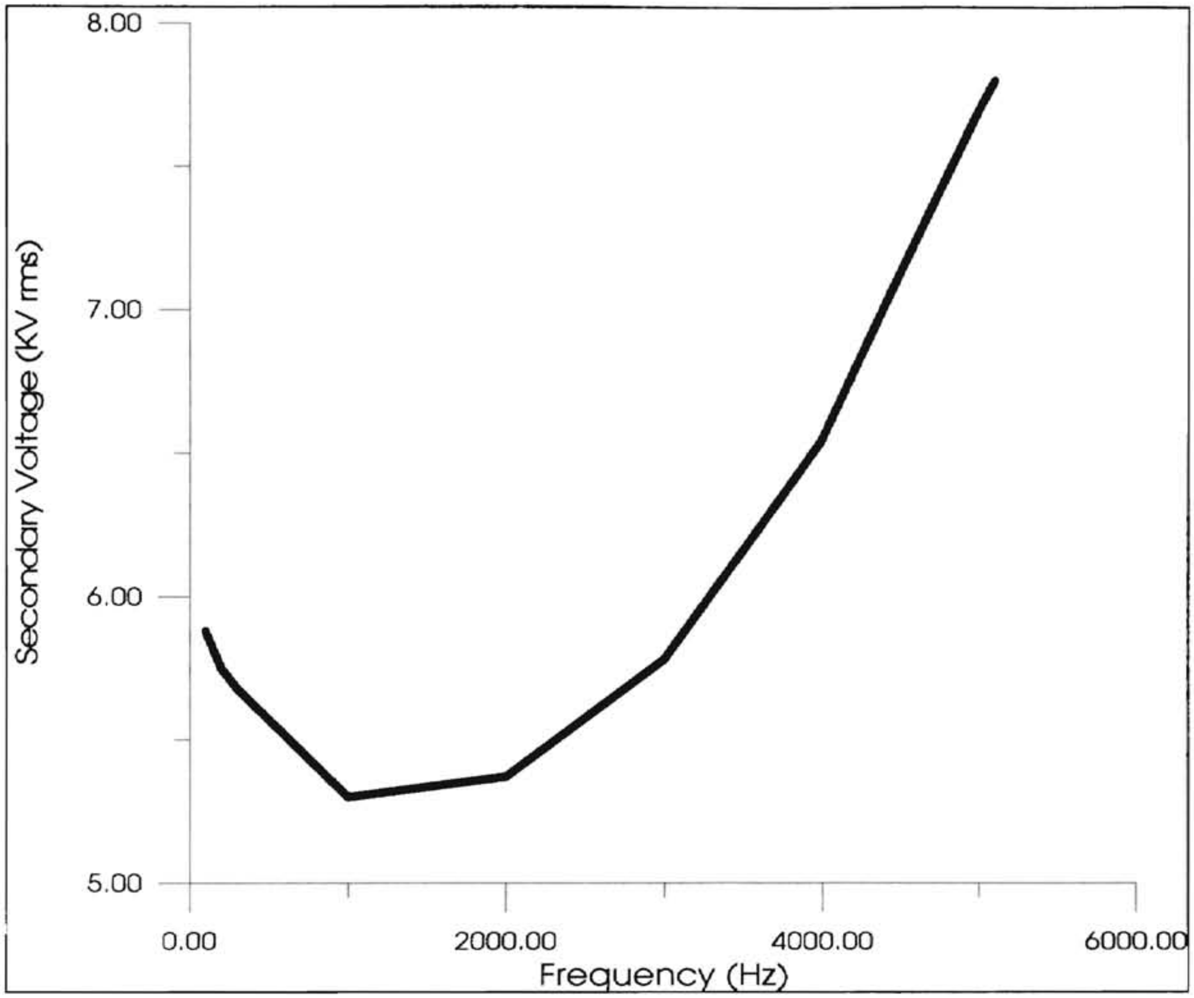


Figure 88. Typical Tuning Plot For Data Set #86.
No reactor is attached (No load).

Data Set #86 Analysis

The tuning plot is the same with or without the reactor.

TABLE LXXXVI

Data Set #87

Setup

- Reactor B.
- Annulus is open to the atmosphere.
- Primary voltage is 95 volts rms.
- Inner and outer electrodes are tap water with the addition of alum.
- Outer electrode is grounded.
- Secondary leads are 15 kV 2 AWG wire.
- Wagner transformer.
- High voltage probe is Hewlett Packard 1137A.
- A tower of silicon adhered 3 liter plastic bottles contains the outer electrode.

Notes

A. Flashed, but no sustained plasma
B. Previously stagnant air, forced flow at this point.
C. Secondary voltage shot up to 97.2 kV, I readjusted the amplitude back to 95kV.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV peak)	Current (Amps)	Notes
60	95	5.70	3	
100	95	5.70	3.2	
500	95	5.35	2.7	
1000	95	5.15	3.8	
2000	95	5.25	6.3	A
3000	95	5.60	9.2	A
4000	95	6.35	10+	
5000	95	7.30	10+	
5100	95	7.44	10+	
5190	95	7.57	10+	
5190	95	7.73	10+	B,C

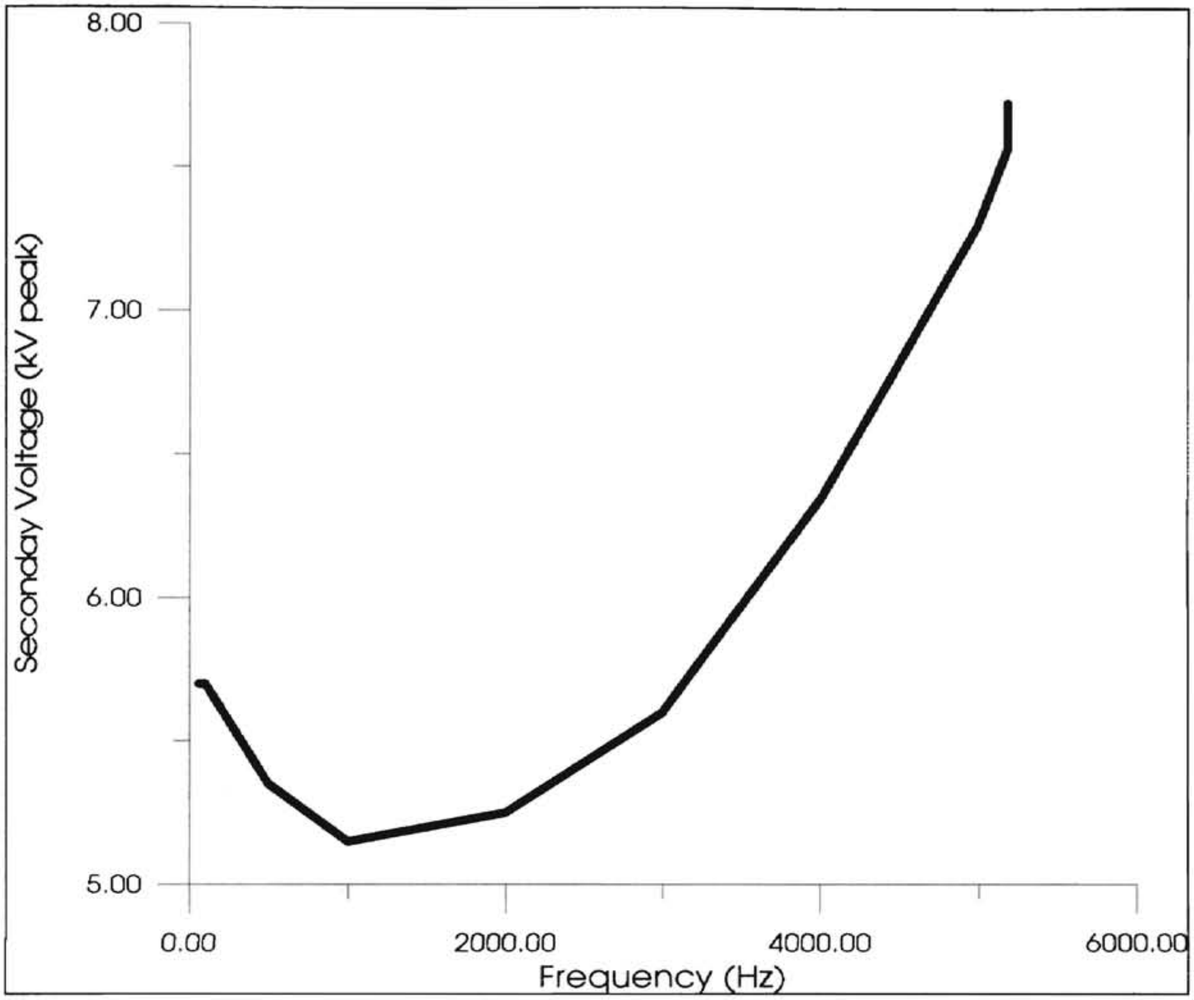


Figure 89. Typical Tuning Plot For Data Set #87.
Reactor B with the annulus open to the atmosphere.

Data Set #87 Analysis

Keeping the primary at 95 volts rms keeps the plasma from establishing.

TABLE LXXXVII

Data Set #88

Setup

- Reactor B.
- Annulus is open to the atmosphere.
- Inner and outer electrodes are tap water with the addition of alum.
- Outer electrode is grounded.
- Secondary leads are 15 kV 2 AWG wire.
- Wagner transformer.
- High voltage probe is Hewlett Packard 1137A.
- A tower of silicon adhered 3 liter plastic bottles contains the outer electrode.

Notes

A. Stagnant air, plasma is trying to develop (light flashes).
B. Initiated air flow to stagnant system; plasma develops.
C. Cut off air flow; plasma develops.
D. Increased amplitude (primary voltage).
E. Further increase of amplitude caused the power supply to shut-off.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV peak)	Current (Amps)	Time (am)	Notes
5190	95	7.57	10 +	1:11	A
5190	95	7.73	10 +	1:12	B
5190	100	8.50	10 +	1:13	
5190	105	9.25	10 +	1:14	C
5190	108	10.15	10 +	1:15	
5190	107.5	10.08	10 +	1:16	
5190	108	10.15	10 +	1:17	
5190	105	9.35	10 +	1:18	
5190	104.91	9.28	10 +	1:19	D
5190	110.14	10.05	10 +		
5190	115	10.8	10 +	1:20	E

Data Set #87 Analysis

It is difficult to analyze the effect of varying the flowrate, but it does seem to effect the formation of a plasma by supplying the annulus with air.

TABLE LXXXVIII

Data Set #89

Setup

- Reactor B.
- Air flows through the annulus.
- Inner and outer electrodes are tap water with the addition of alum.
- Outer electrode is grounded.
- Secondary leads are 15 kV 2 AWG wire.
- Wagner transformer.
- High voltage probe is Hewlett Packard 1137A.
- A tower of silicon adhered 3 liter plastic bottles contains the outer electrode.
- Glass beads in the annulus.

Notes

A. Plasma is initiated

B. Tried to flow a liquid through the annulus at this point. Primary increased to 120V and plasma disappeared.

Frequency (Hz)	Primary Voltage (V rms)	Secondary Voltage (kV peak)	Current (amps)	Notes
1000	97.62	5.33	4	A
1100	97.67	5.32	4.4	
1200	97.75	5.30	4.6	
1500	97.89	5.35	5.4	
2000	98.28	5.50	5.5	
2500	98.93	5.76	5.76	
3000	99.90	6.04	6.04	
3500	101.35	6.62	6.62	
4000	102.75	7.23	7.23	
4500	105.37	7.92	7.92	
5000	111.91	9.79	9.79	B

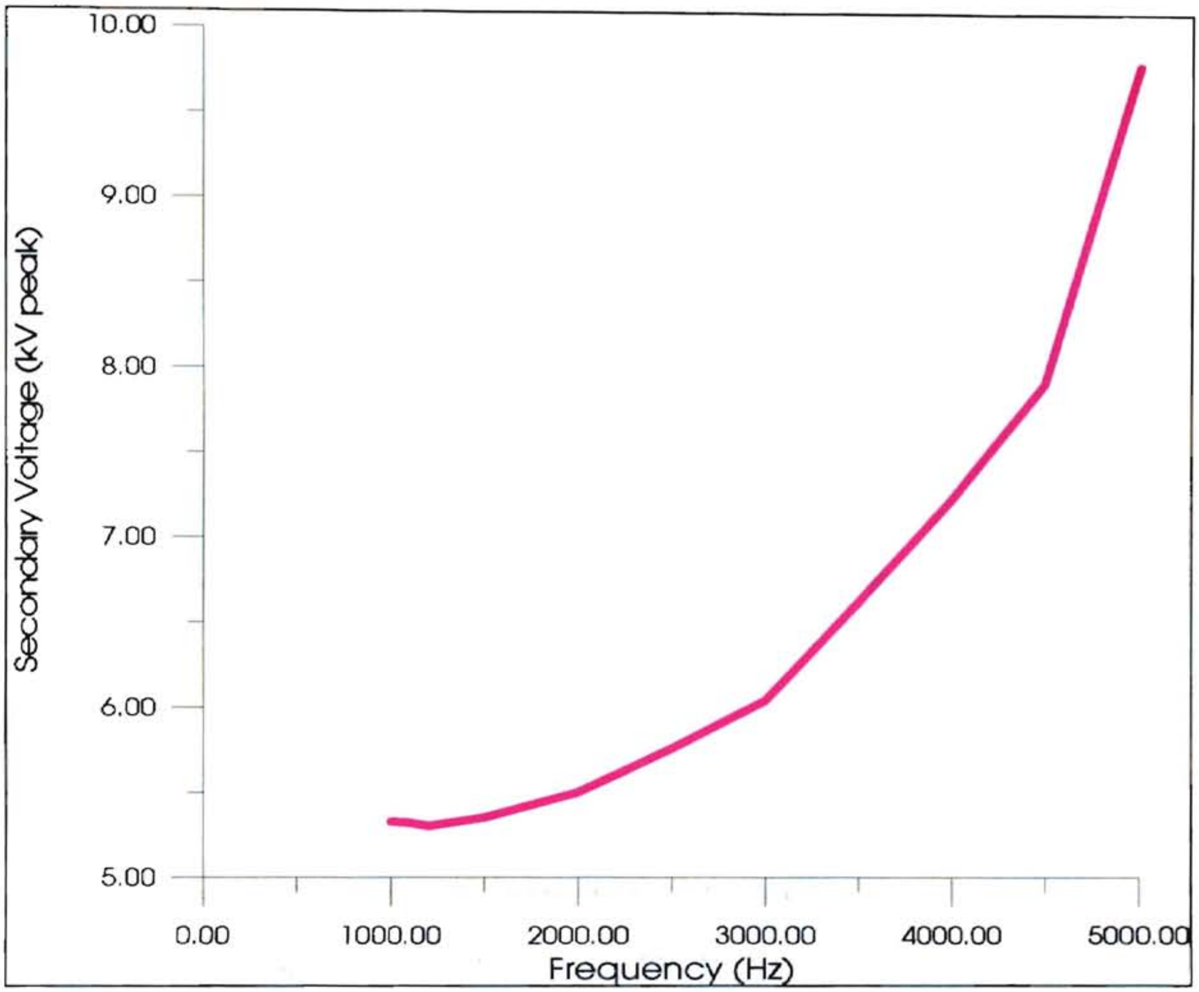


Figure 90. Typical Tuning Plot For Data Set #89.
Reactor B with the annulus open to the atmosphere.

Data Set #89 Analysis

The glass beads were not packed tightly and they rolled and tumbled like a fluidized bed. The packing of the beads did not appear to affect the plasma. The introduction of the liquid extinguished the plasma. After extinguishing with water, I flowed air through the annulus and a partial plasma was created amongst the glass beads, some water, and air.

VITA 2

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