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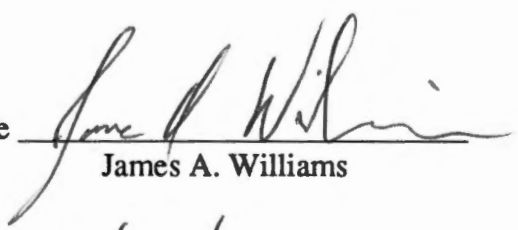
Signature 
James A. Williams

Date 7/26/91

MICROPROCESSOR-BASED ON-SITE CUSTOM GAS MIXING SYSTEM FOR CONTROLLED/MODIFIED ATMOSPHERIC PACKAGING

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

James Anthony Williams

August 1991

TO:

My parents, Mr. and Mrs. Roy A. Williams, for their love, understanding, and support throughout my studies.

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ABSTRACT

As the demand for quality goods increases in new world markets, more work is being put into development of machines that yield higher quality production at increased efficiencies. Controlled or modified atmospheric packaging (CAP/MAP) is frequently used to provide an environment more suitable to retaining freshness while a food product is moving through the marketing chain. With the recent introduction of multiple gas technology into CAP/MAP, greater emphasis is being placed on the production of precise gas mixtures for placement inside the food package. While use of this technology is rapidly growing, research in equipment to proportion the gas has not kept pace. Therefore, the purpose of this study was to design an economical and efficient means for on-site custom mixing of three gasses.

To formulate the gas mixtures, which may be suitable for use in CAP/MAP, flows of oxygen, carbon dioxide, and nitrogen from three tanks into a mixing chamber were regulated by time sequencing and cycling solenoid-actuated valves. The on-off valves were driven by an industrial programmable controller. A program was developed to allow the percentages of the various gasses in the mixture to be changed on-line. Time values were set for each valve, and the controller subsequently actuated each valve accordingly.

A series of experiments were conducted to verify the percentages of the various gasses present over time in a specified mixture. Gas samples were withdrawn using a 5-ml syringe. Gas concentrations were measured using gas chromatography. The mixer achieved a consistent target mixture of 74 percent nitrogen, 14 percent carbon dioxide, and 12 percent oxygen within 5 percent accuracy, on average. The mixer was also capable of returning to production of this mixture after being set to generate a different gas mixture.

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CHAPTER I

INTRODUCTION

Background and Statement of Problem

As the demand for quality goods increases in new world markets, more work is being put into machines which yield higher quality production with increased efficiencies. In 1990, the constant-dollar shipments for the total food and beverage industry rose two percent above those of 1989 (U.S. Department of Commerce, 1990). With greater emphasis upon quality, consumer demand for fresh refrigerated products is also rapidly growing. Such products offer convenience and provide high quality taste and appearance. According to the 1987 Census of Manufacturers, the number of fresh specialty establishments grew 6.5 percent between 1982 and 1987 to a total of 211, while the number of basic canned fruits and vegetables establishments declined 9.5 percent to 647. Fresh foods, if not properly packaged, can spoil rather quickly due to enzymatic and biochemical degradation.

Controlled or modified atmospheric packaging (CAP/MAP) is frequently used to provide a more suitable environment for retaining freshness while the food product is moving through the marketing chain. CAP/MAP also increases shelf life which can broaden distribution areas and decrease product return volume, potentially increasing profits. High-speed production lines require packaging equipment that is automated, yet simple to use.

With the recent introduction of multiple gas technology into CAP/MAP, greater emphasis is being placed on the production of precise gas mixtures for

placement inside the food package. While use of this technology is rapidly growing, research to develop equipment that proportions the gas has not kept pace. Documented reporting of such work is virtually non-existent. A problem exists in that an affordable machine to blend individual gasses to achieve a specific gas mixture which will be of consistent quality is not currently available. Additionally, simplifying the procedure for obtaining a specific gas mixture could reduce supervisory requirements on the processing line.

Objectives

The purpose of this study was to design an economical and efficient means for on-site mixing of three gasses used in CAP/MAP. The study was to include development of a prototype microprocessor-based gas mixing unit. Specifically, objectives of this research were:

1. To develop an apparatus capable of producing a consistent gas mixture containing approximately 15 percent oxygen, 15 percent carbon dioxide, and 70 percent nitrogen with a 5 percent accuracy;
2. To develop a calibration curve for each of three component gasses through solenoid-actuated valves for determining flow volume per unit time; and
3. To investigate the possibility of changing from one gas mixture to a new mixture while retaining the capability of returning to the first mixture by simply reprogramming the microprocessor-based controller.

CHAPTER II

REVIEW OF LITERATURE

Gas proportioning for Controlled/Modified Atmospheric Packaging (CAP/MAP) is a relatively new field. Published studies pertinent to this subject are very limited. Most work related to mixing gasses for food packaging is believed to be done by researchers in the food equipment industry. Due to competitive advantages associated with keeping new technologies secret, information detailing work done on gas mixing in the private sector remains unreported. However, there is abundant information on CAP/MAP and even some specifics on the proportions of mixtures used in research.

Gas Packaging

Gas packaging is a generic term describing alterations of the gaseous environment surrounding food products that are susceptible to microbial, chemical, and enzymic deterioration (Blenford, 1986). The term gas packaging includes both controlled atmospheric packaging and modified atmospheric packaging. The common function of both of these is to reduce the oxygen content of the environment while increasing the level of carbon dioxide and nitrogen, thereby increasing shelf life of the product (Blenford, 1986). Of all the foods produced worldwide, about 25 percent is not consumed due to spoilage (Salunkhe and Wu, 1974).

Modified atmospheric packaging involves use of a vacuum process to evacuate the space between product and package material, then refilling that space

with a particular gas mixture specifically designed to increase shelf life. Once the predetermined mixture is injected into the package, the package environment cannot be altered until the package is opened (Rice, 1987). However, changes may occur due to respiration or leakage. Controlled atmospheric packaging is the process of altering the environment around the product so that the environment can be controlled throughout the storage life of the product (Blenford, 1986).

Tyler Dunlap, Food Products Engineer for Air Products and Chemicals, Inc. was credited for explaining five key elements that must be considered in order to achieve an optimum effect with CAP/MAP: 1) The initial microbial state of the food, 2) Temperature control, 3) The gas mixture (which is very product specific), 4) The barrier film used, and 5) The packaging equipment used (Rice, 1987).

Gasses Used in Food Packaging

Gas mixtures containing nitrogen, oxygen, and/or carbon dioxide are commonly used in controlled and modified atmospheric packaging of food. (Blenford, 1986). Each gas performs a different role. For example, high levels of oxygen are used to retain color in instances where oxidation is not a threat. Low levels of oxygen are applied where anaerobic decay is a problem (Rice, 1987). Reducing oxygen concentrations below eight percent and/or elevating carbon dioxide concentrations above one percent retards fruit ripening. The lower the oxygen level and the higher the carbon dioxide level, the more retardation of ripening (Dewey, 1977). However, where oxygen levels are below two percent, anaerobic respiration may result in the development of off-flavors and off-odors (Morris, 1977). Carbon dioxide typically functions as a fungistatic or bacteriostatic agent by combining with water to form carbonic acid, which in turn inhibits mold

growth. Nitrogen serves as an inert filler or make-up gas to prevent package collapse and aerobic decay (Rice, 1987). Other gasses, such as carbon monoxide, ethylene, propylene, and acetylene have been infrequently used, but not on a commercial scale (Brecht, 1980). This optimum blend for a particular product is often determined empirically by in-plant trials. The optimum gas blend is very product specific (Morris, 1989b). Leeson (1987) discussed a variety of products with their respective optimum gas mixtures. Table 1 illustrates some optimum storage conditions for a selection of foods. To achieve best results other variables must be considered such as the maturity of the product and, in the case of meat products, moisture (Blenford, 1986).

Shelf Life of Products

Recognition of the capacity of CAP/MAP to extend the storage life of food commodities is not a recent phenomenon. Large transoceanic shipments of fresh meat within the United Kingdom during the 1960's were made in modified atmospheres, and scientific investigations preceded those shipments by a few years (Lawrie, 1974). Still, it has only been in the past five years or so that economics and packaging technology have supported controlled or modified atmosphere shipments on a continuous commercial basis (Wolfe, 1980).

Successfully extending the storage life of a fresh product requires that further ripening during the storage period be restrained. The ripening process can be returned to normal when the product is taken out of storage for display in retail stores or when it is consumed (Diglinger, 1986).

As discussed by Kader (1980), CAP/MAP can work effectively in inhibiting decay processes in a variety of agricultural commodities. Inert gasses are used to

Table 1. Optimum storage gas mixtures for some foods packaged under controlled or modified atmospheric conditions.

PRODUCT	PERCENTAGE O_2	CO_2	N_2
Red Delicious apples	2.5	2	95.5
Bramley apples	13	8	79
Strawberries	2.3	6	91.7
Lettuce	3	6	91
Beef	70	20	10
Poultry	60	40	--
Salmon	20	60	20

reduce the respiration rate. Carbon dioxide can have a more direct action as it appears to function to some degree by virtue of equilibrium principles offsetting the respiration rate of product inside the package. (Wolfe, 1980).

Of the various beneficial effects of CAP/MAP for fruits, prevention of ripening is the most important. Smock (1979) has reported reduced ripening of selected fruits and vegetables when oxygen concentrations were lower than that found in ambient air. Enriching the oxygen level to a concentration greater than that of air has been shown to hasten ripening of bananas and apples (Ulrich, 1975). Elevated carbon dioxide levels has been shown to retard ripening of cantaloupes (Dilley, 1977). For a more comprehensive review of CAP/MAP effects on ripening of fruits and vegetables, see Kader (1980).

Saunders (1987) reveals that a typical package of shredded vegetables would have a shelf life of 6 to 8 days. However, utilizing the same treatment (washing and shredding) plus the addition of CAP, the shelf life can be extended to a minimum of 15 days and up to 35 days (Rice, 1987). Packaging meat cuts in barrier trays using CAP reportedly extended the shelf life from 5 days to 17 days (Brecht, 1980). Morris (1989a) has shown that deli pizza, one of the newest applications for CAP, has a refrigerated shelf life of 14 days, more than double the 5 to 6 days for standard packaging.

Packaging Equipment

Mixing the packaging gasses in the proportions that maximize shelf life is difficult at the processing plant level. Most large-scale operators order their prescribed mixture in bulk quantities from the gas supplier or in manifold cylinders outfitted with flow-control equipment (Morris, 1989b). Having the predetermined

mixtures complicates the process of creating variable mixtures. The function of the proportioner is to blend individual constituent gasses to achieve a specific gas mixture that will be of consistent quality and less expensive to the average size processing plant. In addition, simplifying the procedure for obtaining a specific gas mixture could reduce handling of the gasses to the processing line.

Thermco manufactures gas proportioners that are capable of mixing to obtain two or three gas combinations (Thermco Instrument Corporation, La Porte, IN, 1989). The Model 8525 proportioners operate by regulating flow control valves on a continuous time basis. The mixer is controlled by a microprocessor that receives feedback from gas analyzers. Two analyzers are included in the system, one analyzer for oxygen and one for carbon dioxide. Nitrogen level is determined by calculating the balance after the other two gasses are analyzed and totaled.

Constituent gasses are fed from bulk storage tanks to the gas mixer. Regulators with the mixer hold the gasses at constant pressure. Downstream of the regulators, the gas streams flow into a custom mixing valve. This valve (usually a needle valve) is designed to create the correct mixture proportion. The mixture flows from the mixing valve through a solenoid valve and into a surge tank. When the pressure within the surge tank reaches the upper set point on a pressure switch, gas flow is halted by closing the solenoid actuated valve. As the mixed gas is removed from the accumulator tank, pressure within the surge tank falls until it reaches a lower set point. Flow into the tank then resumes. Based upon the desired gas mixture, the operator adjusts the switches on the apparatus to the desired position to allow a fixed flow rate of gas (Thermco, 1988).

Model 8525 gas analyzers continuously monitor the mixture in the surge tank. After the proper gas mixture is set, the operator may then observe the analyzers and change the mixture as needed to precisely establish the gas mixture.

Thermco claims the Model 8525 to be accurate within 2 percent. The price of this model at present is about $13,000.00.

Thermco also produces a gas proportioner that is less expensive than the Model 8525. Thermco's Model 8260 is essentially a pipe system with regulators and three needle valves mounted onto rotameters. The rotameters indicate flow rates that are established by the needle valve settings. The operator must calculate the flow rate needed for a particular mixture, then manually set the rate by adjusting the needle valves (Thermco, 1988). This process makes it difficult to change gas mixtures due to the labor involved. In addition, the percentage of error introduced tends to be increased when a series of valve settings must be made. Several other vendors also offer needle valve type mixers.

Fresh Pack Inc. also markets an expensive gas proportioner which is microprocessor driven. The mixer is advertised to be accurate to within one percent. Cost of the unit is comparable to that of the Thermco Model 8525 (Fresh Pack, Inc. Newark, NJ). The high cost of these units presents the need for research into development of a lower cost mixing unit.

CHAPTER III

APPROACH AND PROCEDURE

Prototype Design

The laboratory-scale mixing system for this project was designed based upon an actual industrial gas mixing system used for controlled/modified atmosphere packaging machines. Several important design considerations were identified while planning for equipment design and testing. These criteria are noted below.

Test conditions were to approximate actual industry conditions as closely as possible. Operating pressure would be set within a 70-207 kPa (10-30 psi) range. Obstructions to gas flow were to be minimized. Reducers, bends, tees, and other restrictions were to be used only when absolutely necessary.

Size was not considered to be a limiting factor in designing the prototype. However, in most food processing plant environments, a compact packaging apparatus is highly desirable. The prototype mixer layout was less compact than that typifying most food plant applications, but this layout was necessary to avoid flow restrictions.

As seen in the review of literature, valves used in industrial mixers proportion the gases by regulating flow rate. Design of the laboratory mixer differs from that of the industrial equipment in that gasses in the laboratory device are proportioned by opening and closing valves for set periods of time. The amount of constituent gasses in a mixture is thus determined by how long the valve is open rather than by how much it is opened.

The prototype design was to have three solenoid-actuated valves controlled by a programmable controller. The controller is capable of opening a particular valve for a specific time interval to allow the desired quantity of gas to flow through. The valve for the first gas was to remain open for a specified time and then close. Then, the valve for the next gas was to open for a specified time. Completing the cycle was to be the valve regulating the third gas. Reducing valve-open time would allow a smaller quantity of that gas to flow into the mixture, thus lowering the percentage of that particular gas in the mixture. Conversely, increasing the valve-open time would allow more flow, thereby raising the percentage of a particular gas in the mixture. The controller was to be outfitted with a series of switches to facilitate changing valve opening intervals, and thus produce various gas mixtures.

Materials and Construction

Three different gasses were used in the prototype mixer: carbon dioxide, oxygen, and nitrogen. These gasses are widely used throughout the food industry for packaging.

The gases were obtained from a commercial gas supplier and were contained in 76 500-liter (2700-ft^3) cylinders except for the carbon dioxide cylinder that had a capacity of 34 000 liters (1200 ft^3). The three tanks were each outfitted with a precision pressure regulator. The regulators selected were of the double-acting design, considered capable of maintaining constant pressure very accurately. Regulators were specified to withstand upstream pressures of 8 300 kPa (1200 psi) and produce regulated output from 7 to 345 kPa (1 to 50 psi), which included the selected design pressure of 206 kPa (30 psi). A 103-kPa (15-psi) upstream pressure

was initially considered because most packaging machines operate in the 70- to 207-kPa (10- to 30-psi) range. During construction of the surge tanks (discussed later), it was discovered that the only relief valves readily available operated at a pressure of 152 kPa (22 psi). Therefore, a decision was made to set the upstream pressure at 172 kPa (25 psi) to create a pressure drop forcing the gas mixture into the collection tank (also discussed later).

The conduit used for directing gas flow was 1.59-cm (5/8-inch) rigid copper tubing. The tubing was chosen for its rigidity and ease of installation in the system. The tubing was cut to a length of 50 cm (19.7 inches) for each gas and mounted onto a sheet of 1.27-cm (0.5-inch) plywood.

Solenoid Valves

Conduits were connected to the solenoid valves (one for each gas) that were actuated by 24-Volt Direct Current (VDC) coils. The 24-VDC coils were chosen to match the output supplied by the 24-VDC Texas Instruments output module operated by the programmable controller.

In choosing the solenoid valves, several criteria were of concern. First, the valve must be quick acting, capable of fully opening and fully closing the main orifice in a specified time interval. This time interval is referred to as the cycle rate of the valve. Second, the valve must be direct acting. In this type of valve, the magnetic force generated by the solenoid acts directly on the sealing mechanism of the valve. The direct acting valve provides a complete seal as opposed to the pilot-operated solenoid valve that was initially considered. The pilot-operated solenoid valve utilizes the energy stored in the pressurized gas to actuate the valve mechanism. This type of valve could not be used because a small pressure drop

across the valve is essential for operation, which would require constant gas flow. Third, the valve must function within the specified operating pressure differential. The operating pressure differential is the difference, between the pressure at the inlet port and the pressure at the outlet port required for proper operation of the solenoid valve.

The flow ratings of the valves considered were determined by using the flow charts in a commercial valve catalog (Honeywell Inc., 1988). Determining the suitability of a valve for a specific application by considering size or flow capacity requires knowledge of the following factors: the gas used, upstream and downstream pressures, and the flow coefficient (C_v) factor for the solenoid valve. The air flow charts for the solenoid valves were contained in the catalog. A typical chart is shown in Figure 1. By following the chart curve of the known or assumed downstream pressure of 152 kPa (22 psi) to where it intersects with the known upstream pressure of 207 kPa (30 psi), the flow can be found. Once flow is determined, a formula for the correction factor of gasses is used to correct for the gas density:

$$\text{Correction Factor} = (1/\text{Specific Gravity of gas})^{0.5}$$

This correction factor is then multiplied by the flow to give the volumetric flow rate for a particular gas.

The last requirement for the valve is compatibility of the gasses with the materials used in the valve. A table in the catalog (Honeywell Inc., 1988) lists media that are compatible with the sealing material inserted into the valves. In this tabulation, oxygen was given a satisfactory rating for the standard seals. Nitrogen was considered inert, and carbon dioxide was questionable because of its low

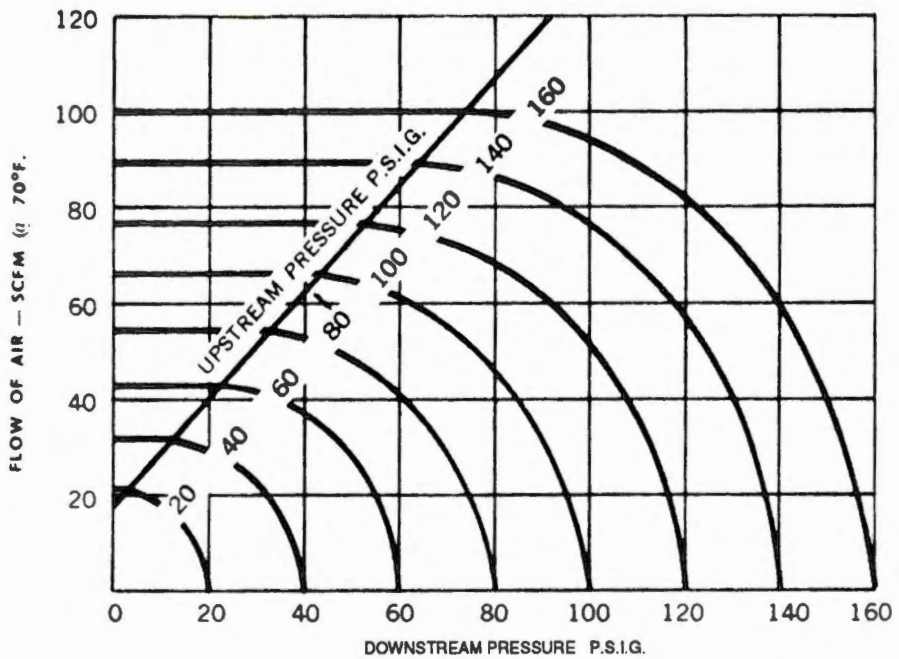

Figure 1. Air flow chart for solenoid valve with $C_v = 1$. (Honeywell Inc., 1988)

temperature. However, the representative of Skinner Valve Division of Honeywell, Inc. reported that the seal used in the Skinner Model 701N13 valve could withstand such temperatures. This valve, a normally-closed design, was thus chosen. The valve was compact and easy to mount. It measured 7.37 x 9.04 x 4.14 cm (2.19 x 3.56 x 1.63 inches) and had a port size of 1.59 cm (5/8 inch) with a flow factor of 0.84. After filling the tanks with compressed air, it was discovered that check valves were needed to prevent back flow through the solenoid valves. Three Schrader Bellows check valves with 1.59-cm (5/8-inch) pipe threads were installed.

A stainless steel plate was fabricated so the valves could be mounted to the plywood support side by side, with nitrogen and carbon dioxide valves on the outside and the oxygen valve in the center.

Mixing Manifold

Three 25-cm (10.4-in) lengths of rigid pipe were fitted to the outlets of the solenoid valves. A mixing manifold was constructed using two 90-degree, 1.59-cm (5/8-in) elbows. The elbows were attached to the ends of the rigid pipes on the two outside valves. A four-way connector was mounted to the pipe end of the center valve, and connected to the elbows. The connector was used to bring all three gasses into a single 1.59-cm (5/8-inch) pipe that directed the mixture into the surge tank (Figure 2).

Two 37.8-liter (10-gallon) tanks were purchased from a local air products supplier. The initial design specified a single tank but a second tank was later added as a surge tank or accumulator to keep the pressure constant in the first tank. Constant pressure was maintained by using a 152-kPa (22-psi) relief valve installed in the pipe connecting the two tanks. When the pressure in the first tank exceeded

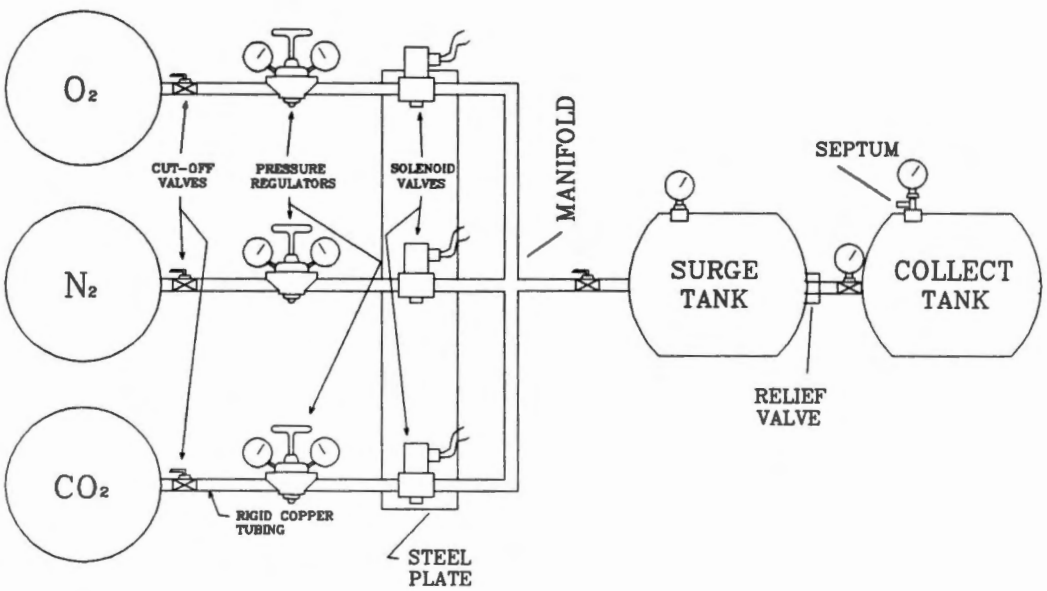

Figure 2. Schematic of prototype gas mixing system.

152 kPa (22 psi), the gas was released into the second tank to relieve the pressure. Thus, pressure and flow were constant across the valves, leaving time as the only variable to affect the mixture. The second tank was outfitted with a gas sampling facility, an industrial mixer would not need this facility since the mixer would be connected to the vacuum packaging apparatus and gas would flow directly into the package. The flow rate in an actual food packaging setting would be established by the rate of packaging. The amount of gas needed would be determined by the product package size and the gas mixtures.

Pressure gauges were installed at the inlet to the "surge" tank, just downstream of the relief valve, and at the top of the "collect" tank. A schematic of the mixing system is shown in Figure 2.

Programmable Controller

A Texas Instruments 530 programmable controller was installed in the system to control the opening and closing of the solenoid valves at very specific time intervals. A programmable controller is a microprocessor unit that interacts with inputs and outputs to perform preprogrammed functions. In traditional methods of machine control, mechanical sensing devices, such as limit switches, are connected to banks of relays. Circuits therein open or close causing electrical signals to be sent to output devices such as motors or valves. Programmable controllers can perform many functions of these traditional controllers. Sensing devices operate in the same way as they would with traditional controls. In a traditional control system panel, many wires provide physical electrical paths between the output and input devices. However, in a programmable controller, the quantity of electrical wiring is greatly reduced by eliminating the need for large

quantities of relays and other solid state devices. The programmable controller may be instructed, by a software program, to respond to the same conditions to that the device and relays react in a traditional controller (Green, 1986).

Controller Components

A typical programmable controller usually consist of four major components:

1) Processor,
2) Input,
3) Output, and
4) Power Supply.

The key to the operation of a programmable controller is the processor. The processor might be called the "brains" of the controller (Allen-Bradley Company, 1984) and consists of the central processing unit and the memory. The central processing unit acts upon the set of instructions it receives from the program commands. Memory serves three functions: first, it stores information that the central processing unit may need to carry out its instructions; second, it stores the program; and third, it stores operating parameters such as timer values, count values, or other pertinent data such as temperature or pressure (Teixeira and Shoemaker, 1989).

The second component is the input module, which provides connection from the field wiring to the sensing devices or switches. The electrical power used at a machine is usually not compatible with the signal wattage used within the

processor. Thus, the input module also functions as a signal conditioner. In this study, the mixture select switches were operated by the supplied 24 VDC. The input module converted the supply current to a 4-20 mA signal that was usable by the processor.

The third component is the output which performs functions similar to those of the input section. It provides connections from the field wiring to the control devices on the machine to be controlled. The output also functions as a signal conditioner (Allen-Bradley Company, 1984). In this study, the output device was the solenoid valve that operated at 24 VDC while the output signal from the processor was 4-20 mA. The output module sent the 24-VDC to the solenoid valves from a separate power supply that was wired to screw terminals on the output module.

The last component of the controller is the power supply. The power supply provides a low-level DC voltage source for the electronic circuitry of the processor. This supply converts the line voltages to the low-level voltages required by the electronic circuitry in the processor. For this application, a 24-volt DC power supply was obtained and mounted to provide the line voltage to the solenoid valves and output module and to supply voltage to the input switches and input module. A field wiring schematic is shown in Figure 3.

Controller Operation

When the controller was properly coupled to the gas mixing apparatus, a program to actuate the solenoid valves at certain time intervals was written. The software program was designed to allow the desired mixture to be formulated and changed quickly.

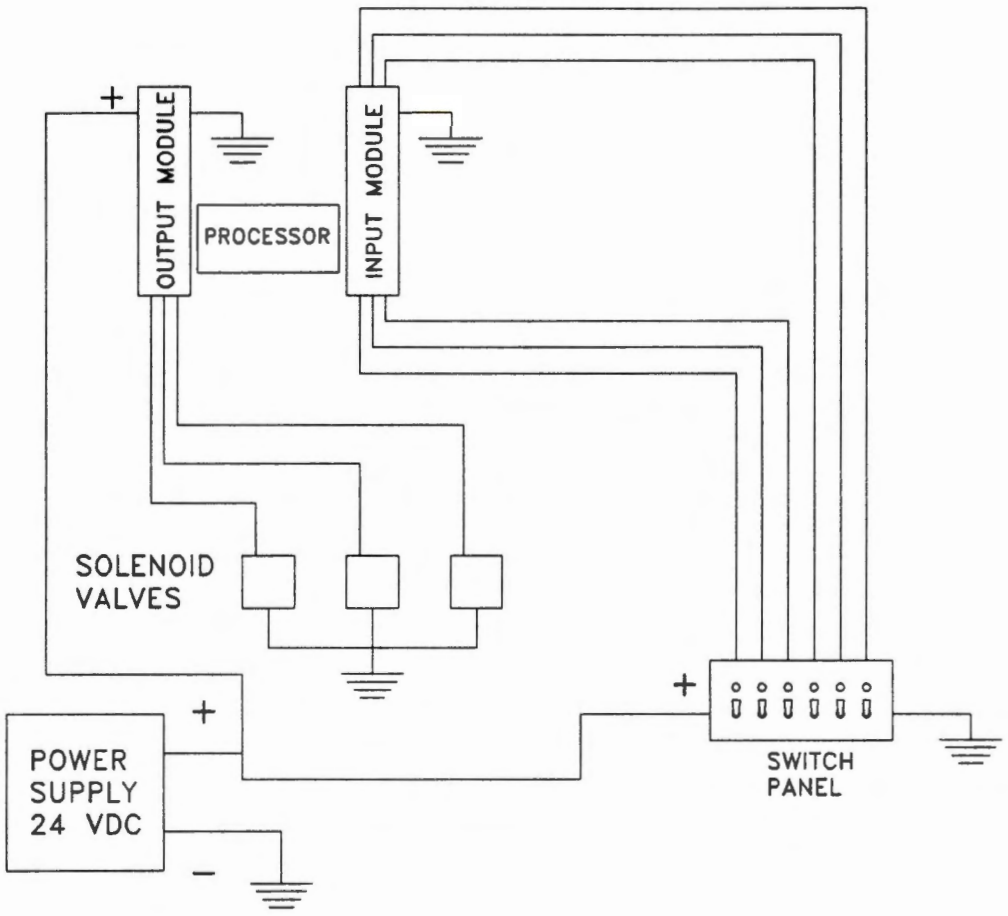

Figure 3. Field wiring schematic for the prototype gas mixer.

The program for the prototype mixer consisted primarily of an "event drum" which is an electronic representation of an electro-mechanical timer. An electro-mechanical timer has a set of contacts that opens at a specific time and then closes when the desired time interval has elapsed. For example, the contacts may remain open for the duration of a cycled process and then close. Upon closure to terminate a particular cycle, a different cycle involving a different set of contacts will commence, and so forth. An event drum acts very much in the same way except that it acts upon electronic rather than mechanical contacts. In this study, the event drum had designated outputs with corresponding addresses. The solenoid valves were the outputs, and their address were labeled Y29 for oxygen, Y30 for carbon dioxide, and Y31 for nitrogen (Figure 4). The letter "Y" used in the address is the Texas Instruments symbol for output. The letter "X" represents input and is used in the address for the switches X18, X19, X20, etc. The steps in the event drum were programmed, and a binary number of "1" or "0" was entered below the desired output to activate or deactivate the function. For example, a "1" placed under the Y29 column in the drum would open the oxygen valve for the length of time the processor was instructed to remain in that step. If a "0" was placed under an input, the valve would remain closed.

The time the controller would remain at each step was specified by entering the value for that step. The magnitude of this valve was the length that the valve would remain opened or closed. If step one was set for a particular time, the next step (step two) would be set for the time the second valve was to remain open. A list of the drum events with steps and outputs is shown schematically in Figure 4.

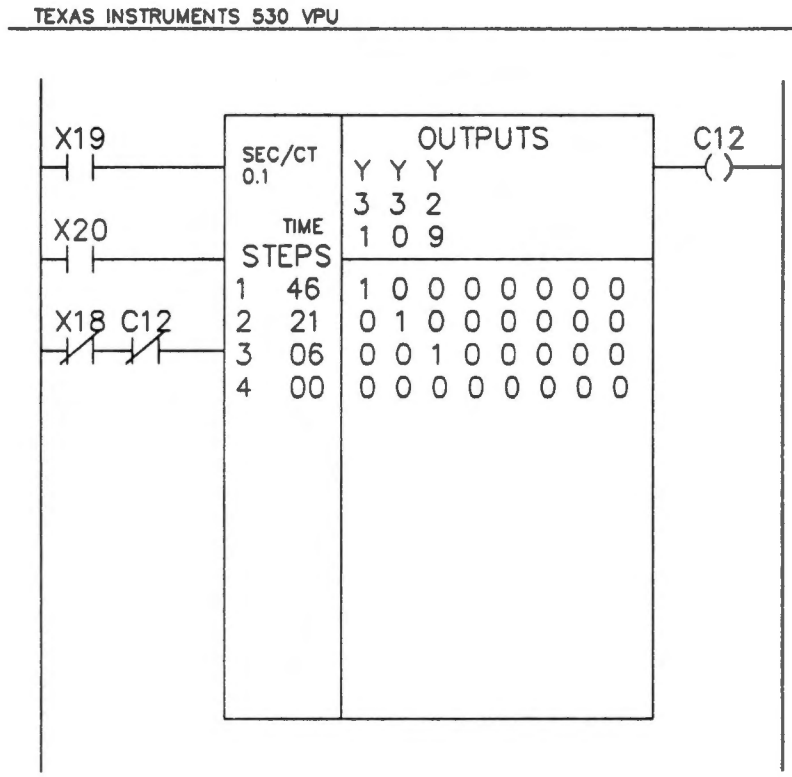

Figure 4. A programmable logic controller event drum program to cycle solenoid-actuated valves.

Computer Simulation Design

A model is a representation of a system and is intended to predict the system behavior if certain actions are taken (Random House, 1980). Virtually any useful model idealizes and simplifies. For a model to be useful, it is essential that, given a reasonable set of variables, all of its relevant properties can be determined by a practical method. These properties could be determined analytically, numerically, or by driving the model with certain inputs and observing the corresponding outputs. The latter process is called simulation (Shigley, 1967). The benefit of a computer simulation is that it gives a better understanding of the actual behavior of the system being modeled. The purpose of the model used in this study was to expedite determination of appropriate time increments for valve openings for use in calibrating the prototype mixer. By using the model, sample times can be entered and the output simulated, reducing the labor of trial-and-error adjustments when running various times manually.

The first step in a simulation study is to examine and identify the objective. The objective in this case was to determine what quantity of each gas will be in a mixture if the various valves are opened for specified intervals of time.

The model was designed to predict how long each gas valve must be open to produce a certain mixture of gasses. This involved trying to predict what will occur inside a poorly understood real system.

Development of a model is often times made complicated due to many steps involved and the complexity of each individual step. A flow diagram of the modeling procedure used to develop a performance curve algorithm is shown in Figure 5.

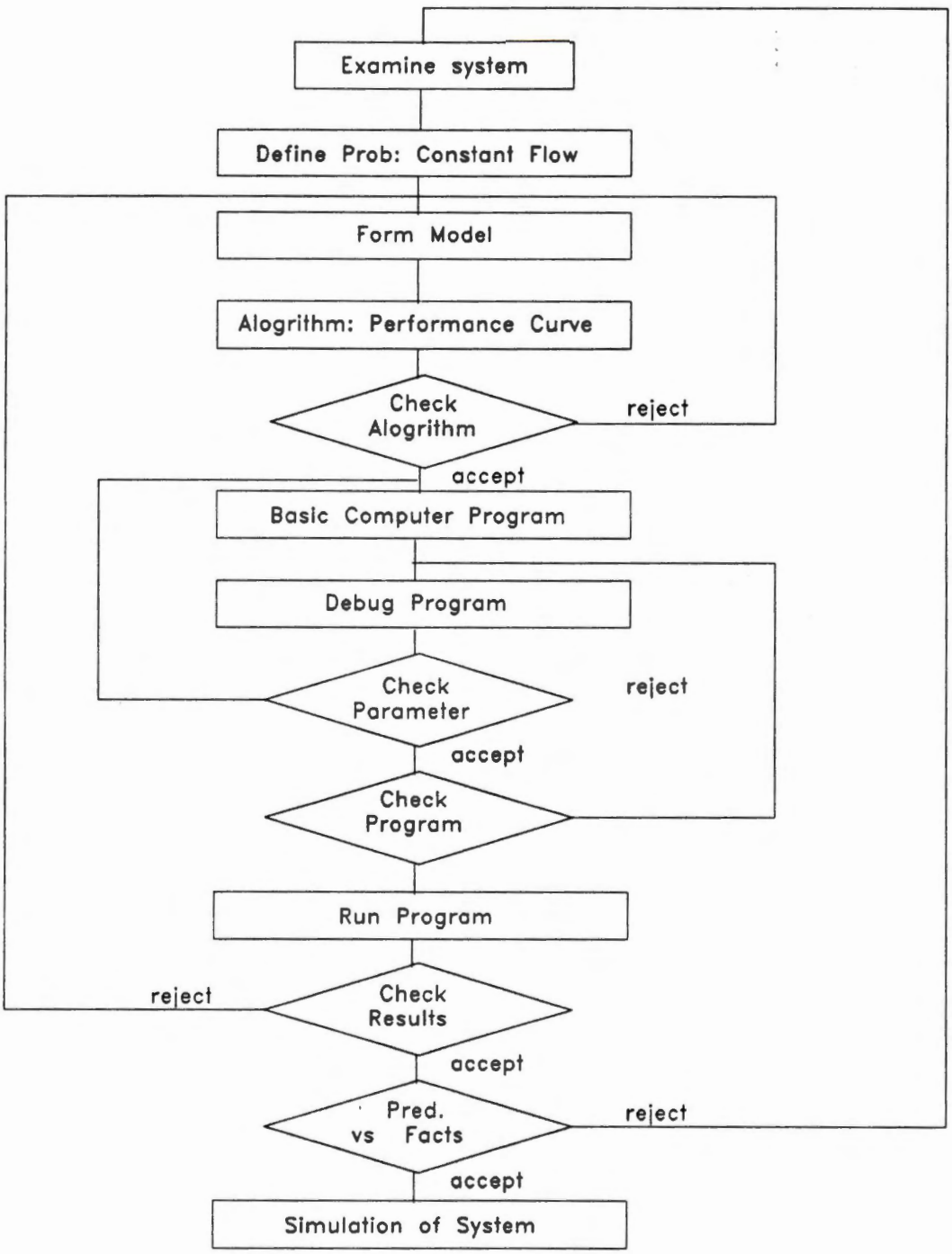

Figure 5. Phases in the development of a simulation model.

The algorithm was produced by considering the major facets of the gas mixing cycle. Facets that were considered important in determining the interrelationship of flow and time in the framework of this application included: 1) pressure, 2) gas density, 3) fluid flow rate, and 4) time.

Pressures within the mixing system were held constant by regulators. Therefore, in the equation, the variable for pressure remained constant for all gasses, namely 152 kPa (22 psig.). Using the valve literature, a flow rate could be obtained if the upstream and downstream pressures were known. With the pressure maintained constant by precision regulators, a performance curve could be developed. A polynomial equation was established by fitting the performance curve for the valves (using model development software on a Macintosh computer). Three equations, one for each gas, were developed. The only difference between the three equations was the flow coefficient (C_v), based upon the specific gravity of each gas. Specific gravity is the ratio of the density of a substance to the density of water or air at a reference temperature and pressure. The densities for the three gasses were as follows: carbon dioxide 0.0018 g/cm^3 (0.1146 lb/ft^3) (Quinn and Jones, 1947), nitrogen is 0.000927 g/cm^3 (0.058 lb/ft^3) (Schroder and Othmer, 1981), and oxygen is 0.0014 g/cm^3 (0.089 lb/ft^3) (Ardon, 1965).
The basic equation defining flow through the valve orifice using the curve data was:

$$Q = C_v (400\text{-}P)^{0.5}$$

where:

Q = Volumetric flow rate,

C_v = Constant based on density of the particular gas involved, and

P = Pressure in tank.

Programming the model could now be accomplished. The program was written in the BASIC language using nested loops (one loop for each gas) to calculate each gas flow over a time interval that would be entered by the user. The order in which the gasses were mixed could be changed by rearranging the loops in the program to the desired order. The program prompted the user for the length of time each valve was to be opened, then performed the calculations.

Model Results

Model validation is the process of substantiating the premise that the model, within its domain of applicability, is sufficiently accurate for the intended application (Schlesinger, 1979).

Evaluation of the model for this experiment began with the running of the program for three scenarios. For the first scenario, the oxygen gas valve was set at 1.5 seconds for the first test and 4.5 for the second test. Valve intervals for the remaining two gasses were maintained constant at three seconds. On the second scenario, the nitrogen gas valve was set at 1.5 seconds for the first test and 4.5 seconds for the second test. Valve intervals for the remaining two gasses were again maintained constant at three seconds. The third scenario was the same as the first two except that carbon dioxide was the principal gas. In addition to the three scenarios, one test was made with all three valve-open times set at three seconds. These methods provided a range of times for each gas. The range would display characteristics of a gas mixture for both long and short intervals. Once the model output data were collected, the prototype mixer was programmed to run the same tests in the same order. The results of the modeling evaluation are presented in Table 2.

Table 2. Gas mixture results from the computer simulation and from actual tests.

	VALVE TIME (SEC)			% GAS IN TANK OBSERVED			% GAS IN TANK SIMULATED		
RUN	CO_2	O_2	N_2	CO_2	O_2	N_2	CO_2	O_2	N_2
1	3.0	3.0	3.0	26.29	28.60	14.47	29.06	36.52	34.02
2	3.0	3.0	1.5	39.04	39.97	17.76	30.42	38.22	30.13
3	3.0	3.0	4.5	29.02	35.84	33.98	30.90	38.22	30.13
4	1.5	3.0	3.0	19.87	41.63	35.13	29.10	39.00	31.79
5	4.5	3.0	3.0	29.45	44.27	21.85	28.02	39.11	32.78
6	3.0	1.5	3.0	36.38	31.58	28.04	29.17	36.64	34.13
7	3.0	4.5	3.0	22.17	52.06	15.65	29.53	35.86	34.55

Figure 6 compares test data to the results of the model. The model predicted most accurately when oxygen and nitrogen valve times were set to generate mixtures that remained between 30 and 40 percent. The accuracy of the model was greatly reduced when any simulated valve time yielded predicted gas percentages of 50 or more.

Test Procedure

The first step of each test was to open valves on the gas cylinders allowing flow to the regulators. The regulators were set at a static value of 200 kPa (29 psi), causing flow pressure to the solenoid valves to be 172 kPa (25 psi).

The processor on the programmable controller was energized, and the program was loaded. Settings on the switch panel were selected to produce the desired mixture by assigning timers with preset values to be active in the event drum. A start/stop switch would activate or deactivate the program by energizing or terminating power to the event drum. Once this switch was activated, the mixing would begin. When the gasses began to flow, the pressure gauge on the surge tank was monitored. Pressure in this tank was not to exceed 152 kPa (22 psi). When that pressure was exceeded, gas escaped into the next tank through the pressure relief valve that actuated at 152 kPa (22 psi). Nitrogen was always allowed to flow first because it would, due its density, make up most of the mixture. After the nitrogen valve closed, the carbon dioxide valve opened. After it closed, the oxygen valve opened. Oxygen was to make up the smallest percentage of the mixture in all tests. The cycle was, for the most part, automatic and was repeated five times. At

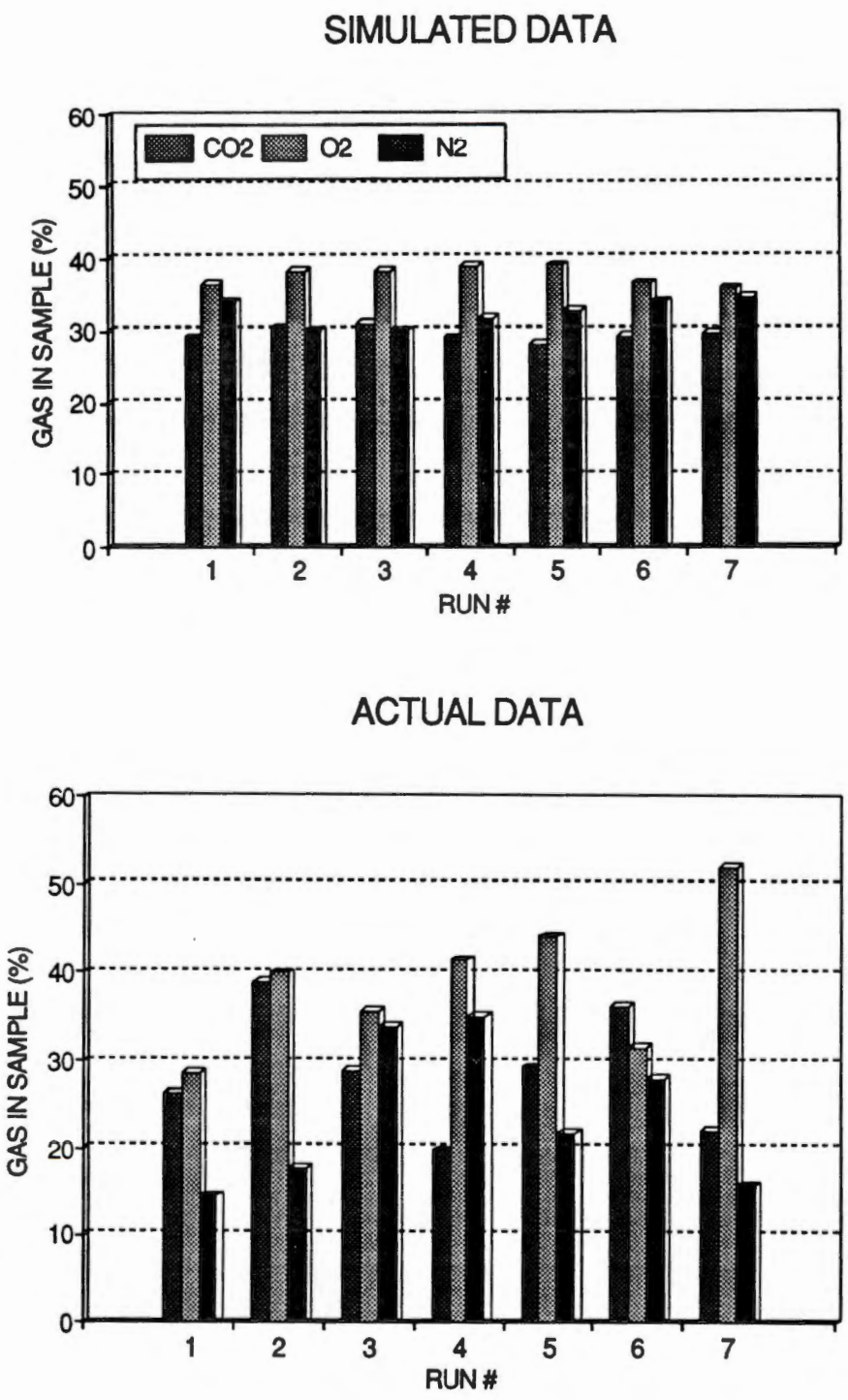

Figure 6. Simulated and actual gas mixture results by run.

the completion of five cycles the start/stop switch was used to stop the gas flow so that samples could be drawn. In an industrial system, the cycles would not be interrupted to draw samples and the mixing could be completely automatic.

At the beginning of each new test, the surge tank was manually emptied twice to purge the previous mixture. The collection tank was manually emptied three times to ensure that the mixture in the collection tank was the same consistency of that previously in the surge tank.

After purging of the tanks, the surge tank was again brought up to pressure and the excess mixture flowed into the collection tank. During this time the controller was automatically cycling the valves, and at each cycle the collection tank pressure increased. The cycling was suspended again by deactivating the start/stop switch when the pressure in the collection tank reached 69 kPa (10 psi.).

After sampling, the collection tank was discharged and the start/stop switch was activated, causing the cycle to start again. Three samples were taken for each filling of the collection tank. These three samples constituted one replication for that tank mixture. Three replications were considered a test, resulting in 9 data points per test. To better illustrate the collecting procedure, a diagram of steps is shown in Figure 7.

Sample Extraction

A ball valve mounted on the collection tank had threads to facilitate mounting a pressure gauge and attaching a gas line. At the line input connection, a brass fitting with a septum, a membrane that allows a hypodermic needle to be injected and withdrawn without leakage to the atmosphere, was installed so that gas samples could be drawn from the tank.

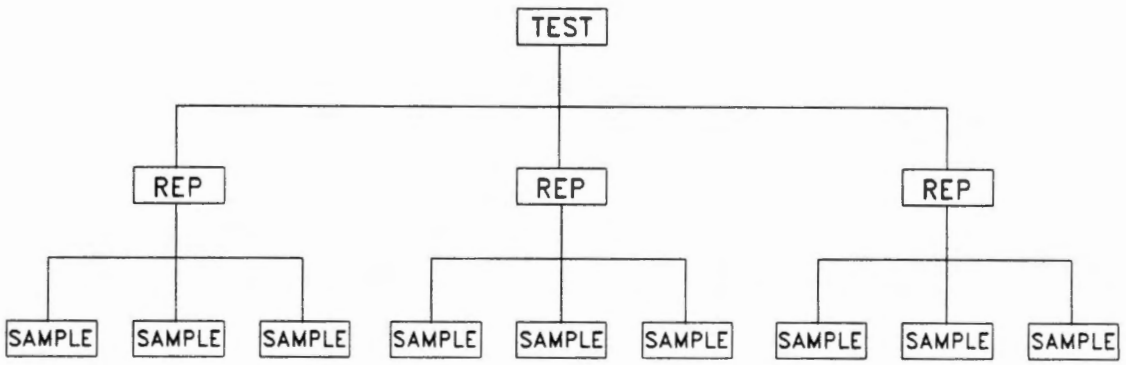

Figure 7. Schematic of testing procedures.

A 3-ml syringe was initially used for sampling. However, a 5-ml syringe was employed after the chromatograph factory representative stated that a sample size of 4-ml would produce more accurate analytical results.

When the valve cycling was complete and the pressure in the collection tank reached 69 kPa (10 psi), the cylinder of the syringe was fully evacuated and the needle inserted into the septum to collect a 4-ml gas sample. The procedure was repeated three times for three samples per run. When two test were completed, 18 syringes were full. No more than 18 syringes were filled because chromatographic analysis required considerable time and leakage from the syringes was to be minimized. The 18 syringes containing gas samples were taken to the Food Technology and Science laboratory. The contents of each was injected into the septum of the gas chromatograph for constituent gas analysis.

Gas Chromatography

Gas chromatography (GC), universally used in analytical laboratories, is a procedure for determining the types and levels of gasses present in a gas mixture. The term "chromatography" is difficult to define, due to the variety of systems and techniques to which it has been applied. Chromatography denotes a procedure in which a solution comprised of component substances to be separated is passed, in a direction determined by the arrangement of the apparatus, over a more or less finely divided and insoluble organic or inorganic solid, resulting in the retention of individual components to different extents (Randerath, 1966). In simpler terms, chromatography describes how each component in a mixture will migrate through a stationary medium under the influence of a mobile phase (Skoog and West, 1969). Each component becomes reversibly bound to the surface of the absorbent. A

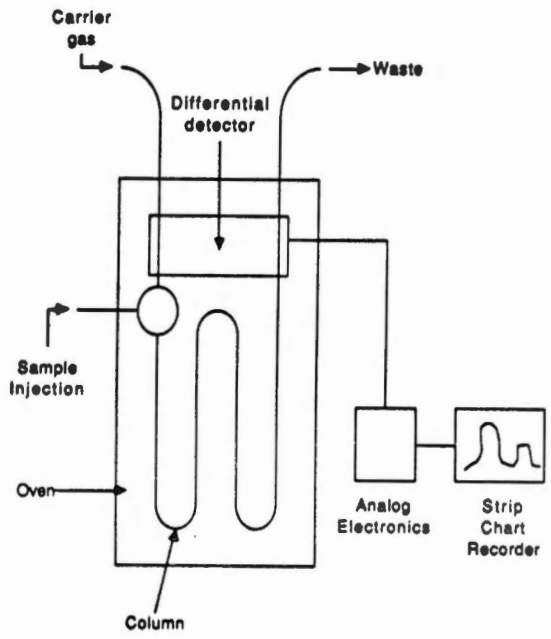

Figure 8. Schematic of a typical chromatography unit with data handling system.

schematic diagram of a typical GC unit and data handling system is shown in Figure 8. A mixture of compounds is introduced through the sample injection port into a steady stream of carrier gas. Separation occurs as the mixture is transported through the column.

Chromatography involves a diverse group of separation methods that are of great importance to the analytical chemist. Separation of the components in a mixture is accomplished by continuous partitioning of each component between the carrier gas, the mobile phase, and the stationary phase within the column. The partitioning ratio is normally different for each component of a mixture, which causes a separation of the components as they travel through a column (Teixeira and Shoemaker, 1985). Often, chromatography enables the chemist to isolate and identify the components of mixtures that might otherwise be resolved only with difficulty, or not at all (Skoog and West, 1969).

The GC is equipped with a detector to quantitatively sense the presence of compounds as they leave the column. The heart of the detector is the transducer, which produces an electrical signal of a magnitude proportional to the concentration of an eluted component (Teixeira and Shoemaker, 1985).

The Hewlett-Packard 5890A gas chromatograph system was used in this study. The 5890A consists of a 3.18-mm (1/8-inch) column, a carrier gas flow system, and two thermal conductivity detectors labeled detector A and detector B. The inlet system features a packed column inlet which purges the septum to eliminate ghost peaks and tailing due to septum bleed or septum-retained samples. Another feature of the inlet system is that the column inlet is thermally optimized to minimize injection-port discrimination against components with high boiling points and to provide excellent run-to-run reproducibility (Hewlett-Packard, Analytical Division, Atlanta, GA). The injectors and detectors are housed in the column,

which segregates the injected sample, allowing the detector to analyze each component and send a signal to the integrator.

Chromatogram Interpretation

To produce an observable record, a chromatogram, of the separation process, the electrical signal produced within the detector is converted to a physical form that is readable by the operator and convenient for numerical analysis. A gas chromatogram appears as a series of peaks (Figure 9). The position of a peak relative to the start of an analysis relates to the identity of a compound, and the area under the curve relates to the concentration. The shape of the peak provides other information pertinent to the analysis, including column type, carrier gas flow rate, and column temperature. The chromatogram is a analog and digital printout of the peak areas as detected over time. The HP3393A integrator processes these signals, records the peaks, and calculates the amounts of each component in the injected sample. For this experiment, the gas standards and the extracted sample curves were obtained by injecting 4-ml samples using a 5-ml syringe.

The measurements and calculations necessary to convert the graphic record into numerical values suitable for statistical analysis were straightforward but tedious, particularly when the number of components in a mixture or the number of analyses was large. Generating the graphic data from the chromatograph was time intensive, each test requiring an average of ten minutes. Translating the data from the chromatogram and manually entering it into the computer was also a time consuming task.

The calculation of percentage gas in an actual mixture was accomplished by using the peak areas from the standards and chromatographs. The mean of the gas

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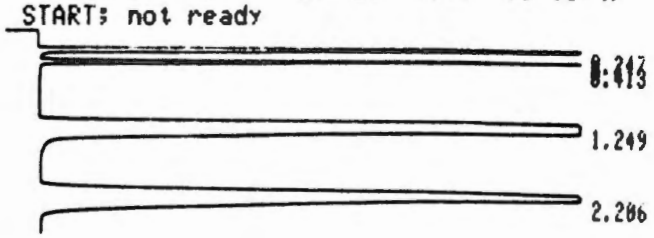


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    .413      14530   PB   .025    2.61665
   1.249     240184   PB   .106   43.25379
   2.206     100651   BB   .160   18.12585

TOTAL AREA= 555290
MUL FACTOR=1.0000E+00
```

Figure 9. A sample gas chromatogram.

standards was found by running several tests of the standard, then taking the mean peak area for a gas from the standards. Peak area for the particular gas in the test was multiplied by the percentage of the same gas in the standard; then, the product was divided by the mean standard, rendering the percentage of the particular gas in the sample:

$$\frac{(\%\ \text{IN STANDARD})\ (\text{PEAK AREA IN SAMPLE})}{\text{MEAN STANDARD.}}$$

The peak areas for the samples were read from the chromatogram and manually entered into a computer spreadsheet. The equation shown above was entered into a cell with the value of the standard inserted. Values for the peak areas of the standards were entered into the computer. The spreadsheet program performed the calculation and tabulated the results.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to determine if the mixer was capable of creating a specific mixture and if that mixture could be repeated with a five percent accuracy. Eight calibration tests (72 samples) were completed to develop the range of valve cycling times required to achieve a mixture containing about 70 percent nitrogen, 15 percent carbon dioxide, and 15 percent oxygen. After the calibration test, the prototype mixer was finely tuned by linear interpolation.

Statistical analyses of the data collected were performed on a personal computer equipped with the SAS (Statistical Analysis System) ANOVA (Analysis of Variance) procedure. The data used in evaluation of the computer model to determine valve timing were not analyzed statistically. These results were simply employed for comparison and to make adjustments to the system.

Valve Times

Valve-open times of 4.6 seconds for nitrogen, 1.9 seconds for carbon dioxide, and 0.5 seconds for oxygen were found to produce a gas mixture containing an average of 74 percent nitrogen, 14 percent carbon dioxide, and 12 percent oxygen. The mixer settings were then changed to 4.6 seconds nitrogen, 2.1 seconds for carbon dioxide, and 0.6 seconds oxygen to produce a second gas mixture of, on average, 61 percent nitrogen, 22 percent carbon dioxide, and 17 percent oxygen. The valve-open time for nitrogen was not changed between

mixtures. However, increasing the carbon dioxide valve-open time from 1.9 seconds to 2.1 seconds significantly changed the nitrogen and oxygen percentages. Valve-open times and corresponding test designations are shown in Table 3.

Mixture Analysis

Two target mixtures were to be analyzed. Test data used for the analyses are presented in Appendix A. The analyses compared each individual gas percentage to the percentage of the same gas in other tests seeking the same target mixture.

Tables 4, 5, 6, 7, and 8 show the mean percentages of the various gasses for tests and samples. Tables 9 and 10 present the analysis of variance for carbon dioxide tests. Tables 11 and 12 present the analysis of variance for the nitrogen tests, and Tables 13 and 14 present the analysis of variance for the oxygen tests. No significant differences were present among samples in any tests. Significant differences (95 percent level of probability) were present among tests and among replications. Table 15 presents characteristics of the gas mixtures produced during the several test. Examining the means and the standard deviations for the three gasses in the first mixture, the mixer can be considered accurate within five percent. The SAS program and the Duncan groupings for these analyses can be found in Appendix B.

Figure 10 shows the mean gas percentage by test for the 61 percent nitrogen, 22 percent carbon dioxide, 17 percent oxygen mixture. Test A results were significantly different from B and C for all three gas levels.

Figure 11 shows the gas percentages actually in the 74 percent nitrogen, 14 percent carbon dioxide, 12 percent oxygen target mixture. No significant differences were present among the carbon dioxide levels. Nitrogen levels showed

Table 3. Valve-open times for gas mixing tests.

TEST	TIME VALVE OPEN (SEC) N_2	O_2	CO_2
1	4.5	2.9	0.7
2	4.6	1.9	0.5
3	4.6	1.9	0.5
5	4.6	1.9	0.5
6	4.6	1.9	0.5
A	4.6	2.1	0.6
B	4.6	2.1	0.6
C	4.6	2.1	0.6
D	4.6	2.1	0.6
E	4.6	1.9	0.5

Table 4. Percentage of carbon dioxide in mixtures produced when carbon dioxide valve open time was constant at 2.1 seconds.

TEST	SAMPLE	CO_2 (%)	STANDARD DEV (CO_2)
A	1	18.63	0.16859
A	2	19.29	0.06944
A	3	19.26	0.45492
B	1	21.70	0.15923
B	2	21.91	0.24851
B	3	21.11	0.06848
C	1	20.67	0.33109
C	2	21.33	0.34721
C	3	21.32	0.53419
D	1	20.17	0.27435
D	2	19.31	0.13816
D	3	17.85	0.20418
AVG		20.79	

Table 5. Percentage of carbon dioxide in mixtures produced when carbon dioxide valve open time was constant at 1.9 seconds.

TEST	SAMPLE	CO_2 (%)	STANDARD DEV (CO_2)
E	1	17.69	0.134907
E	2	16.59	0.280832
E	3	15.24	0.107083
2	1	13.07	0.20155
2	2	11.54	0.26196
2	3	9.87	0.28083
3	1	12.01	0.150628
3	2	10.67	0.155421
3	3	8.99	0.169967
5	1	17.83	0.10274
5	2	15.97	0.285774
5	3	13.81	0.212968
6	1	15.79	0.012472
6	2	15.01	0.174611
6	3	13.80	0.196695
AVG		13.96	

Table 6. Percentage of oxygen in mixtures produced when oxygen valve open time was constant at 0.6 seconds.

TEST	SAMPLE	O_2 (%)	STANDARD DEV (O_2)
A	1	22.16	0.15195
A	2	20.93	0.11441
A	3	20.59	0.08576
B	1	15.32	0.03300
B	2	16.00	0.09463
B	3	17.27	0.34179
C	1	15.93	0.31633
C	2	14.11	0.23791
C	3	13.13	0.17613
AVG		17.27	

Table 7. Percentage of oxygen in mixtures produced when oxygen valve open time was constant at 0.5 seconds.

TEST	SAMPLE	O_2 (%)	STANDARD DEV (O_2)
E	1	9.06	0.432075
E	2	11.97	0.325679
E	3	14.75	0.457457
2	1	12.66	0.20237
2	2	13.47	0.11025
2	3	14.31	0.15107
3	1	9.44	0.115854
3	2	9.81	0.100333
3	3	10.75	0.072572
5	1	10.74	0.32602
5	2	12.24	0.224499
5	3	13.84	0.155421
6	1	12.01	0.037417
6	2	12.73	0.128323
6	3	13.76	0.175563
AVG		12.09	

Table 8. Percentage of nitrogen in mixtures produced when nitrogen valve open time was constant at 4.6 seconds.

TEST	SAMPLE	N_2 (%)	STANDARD DEV (N_2)
A	1	54.84	0.41772
A	2	56.00	0.15628
A	3	56.31	0.40357
B	1	60.70	0.12257
B	2	59.73	0.07789
B	3	58.83	0.27604
C	1	59.37	0.15578
C	2	61.17	0.30663
C	3	62.41	0.31316
D	1	78.31	0.27956
D	2	80.79	0.05558
D	3	82.28	0.25303
AVG		60.85	
E	1	73.38	0.387241
E	3	68.54	0.245357
2	1	71.67	0.06683
2	2	72.28	0.31000
2	3	72.93	0.05888
3	1	76.88	0.033993
3	2	76.83	0.351789
3	3	77.04	0.351789
5	1	73.44	0.26386
5	2	73.55	0.075865
5	3	73.65	0.030912
6	1	74.30	0.077889
6	2	74.32	0.134743
6	3	74.23	0.168193
AVG		73.82	

Table 9. Analysis of variance of carbon dioxide percentages resulting from the 74% nitrogen, 12% oxygen, 14% carbon dioxide mixture.

SOURCE	DF	SS	MS	F	Pr>F
REP	2	0.0060325	0.0030162	24.68	7E-07
TEST	4	0.0428481	0.0107120	87.65	2E-15
TEST*REP	8	0.0799793	0.0099974	81.8	2E-17
SAMPLE	2	0.0002704	0.0001352	1.11	0.34487

Table 10. Analysis of variance of carbon dioxide percentages resulting from the 61% nitrogen, 17% oxygen, 22% carbon dioxide mixture.

SOURCE	DF	SS	MS	F	Pr>F
REP	2	0.0016993	0.0008496	2.31	0.13153
TEST	2	0.0556331	0.0278116	75.59	7E-09
TEST*REP	4	0.0054110	0.0013528	3.68	0.02627
SAMPLE	2	0.0008317	0.0004158	1.13	0.34749

Table 11. Analysis of variance of nitrogen percentages resulting from the 74% nitrogen, 12% oxygen, 14% carbon dioxide mixture.

SOURCE	DF	SS	MS	F	Pr>F
REP	2	0.0027180	0.0013590	5.83	0.00766
TEST	4	0.1084319	0.0271080	116.21	5E-17
TEST*REP	8	0.0423986	0.0052998	22.72	3E-10
SAMPLE	2	0.0003987	0.0001994	0.85	0.43622

Table 12. Analysis of variance of nitrogen percentages resulting from the the 61% nitrogen, 17% oxygen, 22% carbon dioxide mixture.

SOURCE	DF	SS	MS	F	Pr>F
REP	2	0.0044006	0.0022003	16.06	0.00015
TEST	2	0.103579	0.0517895	378.05	3E-14
TEST*REP	4	0.0183052	0.0045763	33.41	1E-07
SAMPLE	2	0.0001829	0.0000915	0.67	0.52667

Table 13. Analysis of variance of oxygen percentages resulting from the 74% nitrogen, 12% oxygen, 14% carbon dioxide mixture.

SOURCE	DF	SS	MS	F	Pr>F
REP	2	0.0181618	0.0090809	67.38	2E-11
TEST	4	0.0227906	0.0056799	42.27	2E-11
TEST*REP	8	0.0538448	0.0067306	49.94	2E-14
SAMPLE	2	0.0008750	0.0004375	3.25	0.05397

Table 14. Analysis of variance of oxygen percentages resulting from the the 61% nitrogen, 17% oxygen, 22% carbon dioxide mixture.

SOURCE	DF	SS	MS	F	Pr>F
REP	2	0.0001760	0.0000880	0.98	0.39624
TEST	2	0.0534265	0.0267133	297.83	2E-13
TEST*REP	4	0.0234600	0.0058650	65.39	1E-09
SAMPLE	2	0.0000274	0.0000137	0.15	0.85957

Table 15. Characteristics of the gas mixtures produced during the several tests.

	CO_2	O_2	N_2
MIXTURE 1			
MEAN(%)	13.86	12.09	73.82
STD DEVIATION	2.69	1.75	2.22
MAX LEVEL (%)	17.96	14.49	77.73
MIN LEVEL (%)	8.82	8.60	68.23
MAX DEV FROM AVG (%)	36.30	28.80	7.50
MAX DEV FROM FULL SCALE AVG (%)	5.04	3.49	5.59
MIXTURE 2			
MEAN(%)	20.79	17.27	60.85
STD DEVIATION	1.17	3.04	2.46
MAX LEVEL (%)	22.25	22.33	62.82
MIN LEVEL (%)	18.39	12.98	54.35
MAX DEV FROM AVG (%)	11.60	29.20	10.60
MAX DEV FROM FULL SCALE AVG (%)	2.40	5.06	6.50

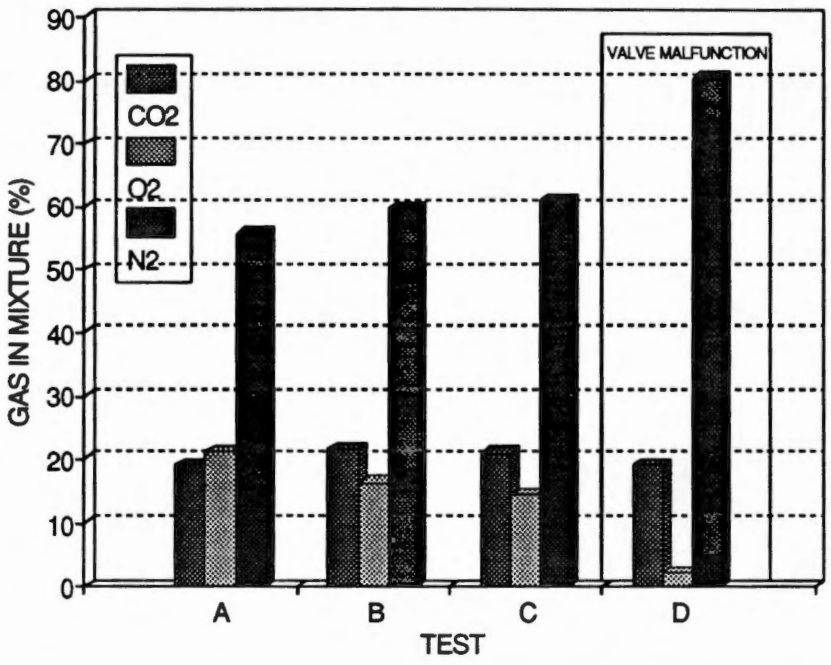

Figure 10. Mean gas percentage by test, with valve times of 4.6 sec. for N_2, 1.9 sec. for CO_2, and 0.5 sec. for O_2.

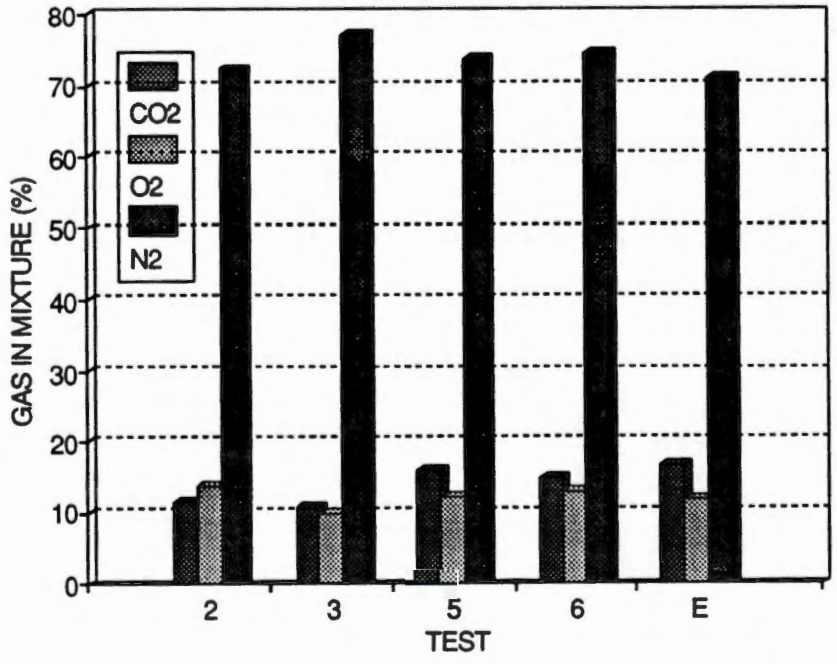

Figure 11. Mean gas percentage by test, with valve times of 4.6 sec. for N_2, 2.1 sec. for CO_2, and 0.6 sec. for O_2.

no significant difference among tests. Oxygen levels remained consistent, showing no significant variation except in test 3. Results from test 3 fell just inside the five percent accuracy target.

Once all the data were collected for both gas mixtures, the controls on the mixer were set again to the first mixture and another test was performed. This test (E) would show if the mixer could return to a previous mix. Results of Test E were not significantly different from other tests involving the same target mixture. Data from test D were omitted due to a malfunction in the oxygen valve. However, test D is presented (Figure 10) to illustrate the effects on the mixture when valve sequencing is disturbed.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The objectives of this study were: (1) to develop a programmable apparatus capable of producing a consistent gas mixture approximately to 15 percent oxygen, 15 percent carbon dioxide, and 70 percent nitrogen; (2) to develop data for each gas, using the three solenoid valves to determine percent gas per unit time; and (3) to investigate the possibility of changing from one mixture to another using the microprocessor-controlled system.

To formulate the gas mixture, a prototype mixer was designed and constructed. Three direct-acting solenoid valves, one for each of the three gasses, were mounted to the conduit. Outputs of the valves were merged in a mixing manifold and then directed into two 37.8-liter (10-gallon) tanks connected in series. The first tank was used as a surge tank, and the second was used to simulate the volume of an on-line industrial packaging machine and for collection of the test mixtures. Opening and closing of the valves was controlled by a Texas Instruments programmable controller. Time values were set for each valve, and the controller subsequently actuated each valve accordingly. The target mixture was obtained by sequentially opening and closing the three valves on an established time schedule. Time was the controlling variable rather than flow rate.

During equipment construction and testing, some minor modifications were made in the mixing system. A pressure relief valve was added between the surge

and collection tanks to maintain a constant pressure in the surge tank. Keeping pressure constant on the downstream side of the valves negated the effect of pressure variation.

A septum was installed on the collection tank to provide a way to sample the gas mixture. Tests were conducted to determine the repeatability of the mixer, if the target mixture could be produced, and if a second mixture could be produced.

Four-milliliter samples of each gas were withdrawn using 5-ml syringes. Three repetitions were included in each test. Three samples were drawn for each repetition. Once the samples had been collected, they were injected into a Hewlett-Packard 5890A gas chromatograph for analysis.

Conclusions

With minor modifications the prototype mixer performed as expected. The controller was capable of actuating the valves in proper sequence. The test results indicated the following:

1. The mixer achieved a consistent target mixture of 74 percent nitrogen, 14 percent carbon dioxide, and 12 percent oxygen within 5 percent accuracy.

2. The mixer was accurate within 5 percent in producing the second target mixture, namely, 61 percent nitrogen, 22 percent carbon dioxide, 17 percent oxygen.

3. The mixer was capable of returning to a previous mixture after running a different mixture.

4. The design could potentially be improved by replacing the solenoid-actuated valves with flow control valves actuated by stepping motors. This design would use the same flow circuitry and programmable controller but depend on a flow rate rather than time variable.

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APPENDICES

APPENDIX A

DATA FROM MIXTURE TEST

	SECONDS	PEAK AREAS			% IN SAMPLE			MEAN %		
TEST 1 N2=4.5 CO2=2.0 O2=0.7										
Rep 1	SAMPLE	CO2	O2	N2	CO2	O2	N2	CO2	O2	N2
	1	32138	73165	280500	14.26	15.86	67.15	14.15	15.83	67.34
	2	31634	72938	282063	14.04	15.81	67.52			
Rep 2	SAMPLE	CO2	O2	N2						
	1	29471	76672	283525	13.08	16.62	67.87	12.90	16.71	67.82
	2	28670	77497	283093	12.72	16.79	67.77			
Rep 3	SAMPLE	CO2	O2	N2						
	1	26248	82644	281689	11.65	17.91	67.43	11.42	17.99	67.51
	3	25224	83346	282332	11.19	18.06	67.59			
								12.83	16.84	67.56
TEST 2	N2=4.6 CO2=1.9 O2=0.5									
Oct. 3, 1990										
Rep 1	SAMPLE	CO2	O2	N2						
	1	29911	57176	299774	13.28	12.39	71.76			
	2	28842	59431	299069	12.80	12.88	71.60	13.07	12.66	71.67
	3	29599	58602	299306	13.14	12.70	71.65			
Rep 2	SAMPLE	CO2	O2	N2						
	1	26750	61522	300528	11.87	13.33	71.94			
	2	25935	62155	302155	11.51	13.47	72.33	11.54	13.47	72.28
	3	25297	62762	303112	11.23	13.60	72.56			
Rep 3	SAMPLE	CO2	O2	N2						
	1	23072	65147	304318	10.24	14.12	72.85			
	2	21533	66853	304732	9.56	14.49	72.95	9.87	14.31	72.93
	3	22098	66055	304900	9.81	14.31	72.99			
								11.49	13.48	72.29
TEST 3	N2=4.6 CO2=1.9 O2=0.5									
Rep 1	SAMPLE	CO2	O2	N2						
	1	26712	44310	321087	11.86	9.60	76.87			
	2	27532	42994	320999	12.22	9.32	76.85	12.01	9.44	76.88
	3	26963	43445	321334	11.97	9.42	76.93			
Rep 2	SAMPLE	CO2	O2	N2						
	1	24010	45517	323005	10.66	9.86	77.33			
	2	23634	45693	320028	10.49	9.90	76.61	10.67	9.81	76.83
	3	24500	44605	319789	10.87	9.67	76.56			
Rep 3	SAMPLE	CO2	O2	N2						
	1	19870	49938	322158	8.82	10.82	77.12			
	2	20767	49161	321386	9.22	10.65	76.94	8.99	10.75	77.04
	3	20109	49754	321885	8.92	10.78	77.06			
								10.56	10.00	76.92
TEST 5	N2=4.6 CO2=1.9 O2=0.5									
Nov. 7, 1990										
Rep 1	SAMPLE	CO2	O2	N2						
	1	40461	47432	307268	17.96	10.28	73.56			
	2	39899	50867	307797	17.71	11.02	73.68	17.83	10.74	73.44
	3	40135	50364	305231	17.81	10.91	73.07			
Rep 2	SAMPLE									
	1	36879	55115	306811	16.37	11.94	73.45			
	2	35636	56743	307364	15.82	12.30	73.58	15.97	12.24	73.55
	3	35429	57578	307551	15.72	12.48	73.63			
Rep 3	SAMPLE									
	1	30983	63891	307591	13.75	13.85	73.64			
	2	31768	62954	307843	14.10	13.64	73.70	13.81	13.84	73.65
	3	30631	64693	307568	13.59	14.02	73.63			
TEST 6	N2=4.6 CO2=1.9 O2=0.5									
Rep 1	SAMPLE	CO2	O2	N2						
	1	35604	55391	310809	15.80	12.00	74.41			
	2	35561	55228	310165	15.78	11.97	74.25	15.79	12.01	74.30
	3	35541	55655	310109	15.77	12.06	74.24			
Rep 2	SAMPLE									
	1	34073	58601	309668	15.12	12.70	74.13			
	2	33257	59540	310628	14.76	12.90	74.36	15.01	12.73	74.32
	3	34116	58112	310996	15.14	12.59	74.45			
Rep 3	SAMPLE									
	1	31450	62518	310876	13.96	13.55	74.42			
	2	31339	63497	309161	13.91	13.76	74.01	13.80	13.76	74.23
	3	30472	64489	310174	13.52	13.98	74.25			

TEST A	N2=4.6 CO2=2.1 O2=0.6								
JAN 25, 1991									
Rep 1	SAMPLE	CO2	O2	N2	CO2	O2	N2			
	1	42183	103026	227034	18.72	22.33	54.35			
	2	41434	101332	231288	18.39	21.96	55.37	18.63	22.16	54.84
	3	42291	102365	228856	18.77	22.18	54.79			
Rep 2	SAMPLE									
	1	43695	96051	234170	19.39	20.82	56.06			
	2	43321	97325	233051	19.23	21.09	55.79	19.29	20.93	56.00
	3	43397	96374	234583	19.26	20.89	56.16			
Rep 3	SAMPLE									
	1	41961	94488	237613	18.62	20.48	56.88			
	2	44130	95469	234121	19.59	20.69	56.05	19.26	20.59	56.31
	3	44119	95022	233942	19.58	20.59	56.00			
TEST B	N2=4.6 CO2=2.1 O2=0.6									
JAN 25, 1991									
Rep 1	SAMPLE	CO2	O2	N2						
	1	49380	70878	252821	21.92	15.36	60.52			
	2	48577	70513	253898	21.56	15.28	60.78	21.70	15.32	60.70
	3	48696	70736	253890	21.61	15.33	60.78			
Rep 2	SAMPLE									
	1	50136	73281	249065	22.25	15.88	59.62			
	2	49122	73918	249745	21.80	16.02	59.79	21.91	16.00	59.73
	3	48830	74351	249729	21.67	16.11	59.78			
Rep 3	SAMPLE									
	1	47786	77441	247395	21.21	16.78	59.22			
	2	47454	80758	244864	21.06	17.50	58.62	21.11	17.27	58.83
	3	47475	80819	244983	21.07	17.51	58.65			
TEST C	N2=4.6 CO2=2.1 O2=0.6									
JAN 28, 1991										
Rep 1	SAMPLE	CO2	O2	N2						
	1	46517	71596	248457	20.65	15.52	59.48			
	2	45692	73726	249896	20.28	15.98	59.82	20.67	15.93	59.37
	3	47513	75173	245604	21.09	16.29	58.80			
Rep 2	SAMPLE									
	1	48778	65416	253899	21.65	14.18	60.78			
	2	46974	66254	255608	20.85	14.36	61.19	21.33	14.11	61.17
	3	48447	63615	257018	21.50	13.79	61.53			
Rep 3	SAMPLE									
	1	49195	60174	259224	21.83	13.04	62.06			
	2	48527	59889	260464	21.54	12.98	62.35	21.32	13.13	62.41
	3	46380	61732	262407	20.58	13.38	62.82			
TEST D	N2=4.6 CO2=2.1 O2=0.6									
FEB 1, 1991										
Rep 1	SAMPLE	CO2	O2	N2	CO2	O2	N2			
	1	44659	14236	325610	19.82	3.09	77.95			
	2	45505	12741	328467	20.20	2.76	78.63	20.17	2.85	78.31
	3	46163	12437	327326	20.49	2.70	78.36			
Rep 2	SAMPLE									
	1	43408	8288	336333	19.27	1.80	80.52			
	2	43188	8892	335915	19.17	1.93	80.42	19.31	1.85	80.49
	3	43942	8396	336484	19.50	1.82	80.55			
Rep 3	SAMPLE									
	1	40883	6118	342186	18.14	1.33	81.92			
	2	39964	4688	344543	17.74	1.02	82.48	17.85	1.17	82.28
	3	39836	5403	344330	17.68	1.17	82.43			
TEST E	N2=4.6 CO2=1.9 O2=0.5									
FEB 1, 1991										
Rep 1	SAMPLE	CO2	O2	N2	CO2	O2	N2			
	1	40104	41284	305992	17.80	8.95	73.25			
	2	39438	44503	304912	17.50	9.64	72.99	17.69	9.06	73.38
	3	40044	39698	308723	17.77	8.60	73.91			
Rep 2	SAMPLE									
	1	36539	56194	297016	16.22	12.18	71.10			
	2	38073	53105	297730	16.90	11.51	71.27	16.59	11.97	71.05
	3	37514	56374	295656	16.65	12.22	70.78			
Rep 3	SAMPLE									
	1	34062	65912	286398	15.12	14.28	68.56			

APPENDIX B

PROGRAM, DATA, AND PARTIAL LISTING OF STATISTICAL ANALYSES

```
data a;
 infile 'b:newdata.prn';
 input Trt Test $ rep sample gas $ percent;
 if trt=1 then do;
  if gas='N2' THEN ERROR = PERCENT-74;
   else if gas='CO2' then error=percent-14;
   else error=percent-12;
  end;
 else do;
  if gas='N2' then error=percent-61;
   else if gas='CO2' then error=percent-22;
   else error=percent-17;
  end;
 error = abs(error);
 TRANS = ARSIN(SQRT(ERROR/100));
RUN;

proc GLM DATA=A;
 class Test rep SAMPLE GAS;
 model TRANS = rep Test REP*Test SAMPLE GAS SAMPLE*GAS / SS3;
 TEST H=REP Test E=REP*Test ;
 means rep Test /duncan E=REP*Test;
 means GAS /duncan;
QUIT;

PROC SORT;
 BY GAS trt;
RUN;

proc GLM DATA=A;
 BY GAS trt;
 class Test rep SAMPLE;
 model TRANS = rep Test REP*Test SAMPLE / SS3;
 TEST H=REP Test E=REP*Test ;
 means rep Test /duncan E=REP*Test;
QUIT;
```

Trt	Test	Rep	Sample	Gas	Percent
1	2	1	1	CO2	13.28
1	2	1	2	CO2	12.80
1	2	1	3	CO2	13.14
1	2	1	1	O2	12.39
1	2	1	2	O2	12.88
1	2	1	3	O2	12.70
1	2	1	1	N2	71.76
1	2	1	2	N2	71.60
1	2	1	3	N2	71.65
1	2	2	1	CO2	11.87
1	2	2	2	CO2	11.51
1	2	2	3	CO2	11.23
1	2	2	1	O2	13.33
1	2	2	2	O2	13.47
1	2	2	3	O2	13.60
1	2	2	1	N2	71.94
1	2	2	2	N2	72.33
1	2	2	3	N2	72.56
1	2	3	1	CO2	10.24
1	2	3	2	CO2	9.56
1	2	3	3	CO2	9.81
1	2	3	1	O2	14.12
1	2	3	2	O2	14.49
1	2	3	3	O2	14.31
1	2	3	1	N2	72.85
1	2	3	2	N2	72.95
1	2	3	3	N2	72.99
1	3	1	1	CO2	11.86
1	3	1	2	CO2	12.22
1	3	1	3	CO2	11.97
1	3	1	1	O2	9.60
1	3	1	2	O2	9.32
1	3	1	3	O2	9.42
1	3	1	1	N2	76.87
1	3	1	2	N2	76.85
1	3	1	3	N2	76.93
1	3	2	1	CO2	10.66
1	3	2	2	CO2	10.49
1	3	2	3	CO2	10.87
1	3	2	1	O2	9.86

Trt	Test	Rep	Sample	Gas	Percent
1	3	2	2	O2	9.90
1	3	2	3	O2	9.67
1	3	2	1	N2	77.33
1	3	2	2	N2	76.61
1	3	2	3	N2	76.56
1	3	3	1	CO2	8.82
1	3	3	2	CO2	9.22
1	3	3	3	CO2	8.92
1	3	3	1	O2	10.82
1	3	3	2	O2	10.65
1	3	3	3	O2	10.78
1	3	3	1	N2	77.12
1	3	3	2	N2	76.94
1	3	3	3	N2	77.06
1	5	1	1	CO2	17.96
1	5	1	2	CO2	17.71
1	5	1	3	CO2	17.81
1	5	1	1	O2	10.28
1	5	1	2	O2	11.02
1	5	1	3	O2	10.91
1	5	1	1	N2	73.56
1	5	1	2	N2	73.68
1	5	1	3	N2	73.07
1	5	2	1	CO2	16.37
1	5	2	2	CO2	15.82
1	5	2	3	CO2	15.72
1	5	2	1	O2	11.94
1	5	2	2	O2	12.30
1	5	2	3	O2	12.48
1	5	2	1	N2	73.45
1	5	2	2	N2	73.58
1	5	2	3	N2	73.63
1	5	3	1	CO2	13.75
1	5	3	2	CO2	14.10
1	5	3	3	CO2	13.59
1	5	3	1	O2	13.85
1	5	3	2	O2	13.64
1	5	3	3	O2	14.02
1	5	3	1	N2	73.64
1	5	3	2	N2	73.70

Trt	Test	Rep	Sample	Gas	Percent
1	5	3	3	N2	73.63
1	6	1	1	CO2	15.80
1	6	1	2	CO2	15.78
1	6	1	3	CO2	15.77
1	6	1	1	O2	12.00
1	6	1	2	O2	11.97
1	6	1	3	O2	12.06
1	6	1	1	N2	74.41
1	6	1	2	N2	74.25
1	6	1	3	N2	74.24
1	6	2	1	CO2	15.12
1	6	2	2	CO2	14.76
1	6	2	3	CO2	15.14
1	6	2	1	O2	12.70
1	6	2	2	O2	12.90
1	6	2	3	O2	12.59
1	6	2	1	N2	74.13
1	6	2	2	N2	74.36
1	6	2	3	N2	74.45
1	6	3	1	CO2	13.96
1	6	3	2	CO2	13.91
1	6	3	3	CO2	13.52
1	6	3	1	O2	13.55
1	6	3	2	O2	13.76
1	6	3	3	O2	13.98
1	6	3	1	N2	74.42
1	6	3	2	N2	74.01
1	6	3	3	N2	74.25
2	A	1	1	CO2	18.72
2	A	1	2	CO2	18.39
2	A	1	3	CO2	18.77
2	A	1	1	O2	22.33
2	A	1	2	O2	21.96
2	A	1	3	O2	22.18
2	A	1	1	N2	54.35
2	A	1	2	N2	55.37
2	A	1	3	N2	54.79
2	A	2	1	CO2	19.39
2	A	2	2	CO2	19.23
2	A	2	3	CO2	19.26

Trt	Test	Rep	Sample	Gas	Percent
2	A	2	1	O2	20.82
2	A	2	2	O2	21.09
2	A	2	3	O2	20.89
2	A	2	1	N2	56.06
2	A	2	2	N2	55.79
2	A	2	3	N2	56.16
2	A	3	1	CO2	18.62
2	A	3	2	CO2	19.59
2	A	3	3	CO2	19.58
2	A	3	1	O2	20.48
2	A	3	2	O2	20.69
2	A	3	3	O2	20.59
2	A	3	1	N2	56.88
2	A	3	2	N2	56.05
2	A	3	3	N2	56.00
2	B	1	1	CO2	21.92
2	B	1	2	CO2	21.56
2	B	1	3	CO2	21.61
2	B	1	1	O2	15.36
2	B	1	2	O2	15.28
2	B	1	3	O2	15.33
2	B	1	1	N2	60.52
2	B	1	2	N2	60.78
2	B	1	3	N2	60.78
2	B	2	1	CO2	22.25
2	B	2	2	CO2	21.80
2	B	2	3	CO2	21.67
2	B	2	1	O2	15.88
2	B	2	2	O2	16.02
2	B	2	3	O2	16.11
2	B	2	1	N2	59.62
2	B	2	2	N2	59.79
2	B	2	3	N2	59.78
2	B	3	1	CO2	21.21
2	B	3	2	CO2	21.06
2	B	3	3	CO2	21.07
2	B	3	1	O2	16.78
2	B	3	2	O2	17.50
2	B	3	3	O2	17.51
2	B	3	1	N2	59.22

Trt	Test	Rep	Sample	Gas	Percent
2	B	3	2	N2	58.62
2	B	3	3	N2	58.65
2	C	1	1	CO2	20.65
2	C	1	2	CO2	20.28
2	C	1	3	CO2	21.09
2	C	1	1	O2	15.52
2	C	1	2	O2	15.98
2	C	1	3	O2	16.29
2	C	1	1	N2	59.48
2	C	1	2	N2	59.82
2	C	1	3	N2	59.80
2	C	2	1	CO2	21.65
2	C	2	2	CO2	20.85
2	C	2	3	CO2	21.50
2	C	2	1	O2	14.18
2	C	2	2	O2	14.36
2	C	2	3	O2	13.79
2	C	2	1	N2	60.78
2	C	2	2	N2	61.19
2	C	2	3	N2	61.53
2	C	3	1	CO2	21.83
2	C	3	2	CO2	21.54
2	C	3	3	CO2	20.58
2	C	3	1	O2	13.04
2	C	3	2	O2	12.98
2	C	3	3	O2	13.38
2	C	3	1	N2	62.06
2	C	3	2	N2	62.35
2	C	3	3	N2	62.82
1	E	1	1	CO2	17.80
1	E	1	2	CO2	17.50
1	E	1	3	CO2	17.77
1	E	1	1	O2	8.95
1	E	1	2	O2	9.64
1	E	1	3	O2	8.60
1	E	1	1	N2	73.25
1	E	1	2	N2	72.99
1	E	1	3	N2	73.91
1	E	2	1	CO2	16.22
1	E	2	2	CO2	16.90

Trt	Test	Rep	Sample	Gas	Percent
1	E	2	3	CO2	16.65
1	E	2	1	O2	12.18
1	E	2	2	O2	11.51
1	E	2	3	O2	12.22
1	E	2	1	N2	71.10
1	E	2	2	N2	71.27
1	E	2	3	N2	70.78
1	E	3	1	CO2	15.12
1	E	3	2	CO2	15.38
1	E	3	3	CO2	15.22
1	E	3	1	O2	14.28
1	E	3	2	O2	14.60
1	E	3	3	O2	15.37
1	E	3	1	N2	68.56
1	E	3	2	N2	68.83
1	E	3	3	N2	68.23

GAS = CO_2

General Linear Models Procedure

Duncan's Multiple Range Test for variable: GAS

Alpha= 0.05 df= 8 MSE= 0.009997

Critical Range 0.109 0.113 0.116 0.1
Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	TEST
A	0.1835	9	3
A			
A	0.1554	9	E
A			
A	0.1526	9	2
A			
A	0.1286	9	5
A			
A	0.0913	9	6
A	0.1719	9	A
B	0.0899	9	C
B			
B	.0658	9	B

GAS = N_2

General Linear Models Procedure

Duncan's Multiple Range Test for variable: GAS

Alpha= 0.05 df= 8 MSE= 0.0053

Critical Range .0790 .0824 .0844 .0854
Means with the same letter are not significantly different

Duncan Grouping	Mean	N	TEST
A	0.1716	9	3
A			
A	0.1603	9	E
A			
A B	0.1294	9	2
B			
B	0.0661	9	5
B			
B	0.0501	9	6
A	0.2314	9	A
B	0.1049	9	B
B			
B	0.0956	9	C

GAS = O2

General Linear Models Procedure

Duncan's Multiple Range Test for variable

Alpha= 0.05 df= 8 MSE= 0.002028

Critical Range .0891 .0929 .0951 .0962
Means with the same letter are not significantl

Duncan Grouping	Mean	N	TEST
A	0.1403	9	3
A			
A	0.1303	9	E
A			
A	0.1179	9	2
A			
A	0.0990	9	5
A			
A	0.0774	9	6

General Linear Models Procedure

Duncan's Multiple Range Test for variable: SAMPLE

Alpha= 0.05 df= 14 MSE= 0.005572

Critical Range .0266 .0279

Means with the same letter are not significantly different

Duncan Grouping	Mean	N	SAMPLE
A	0.1475	72	1
A			
A	0.1340	72	2
A			
A	0.1287	72	3

APPENDIX C

SIMULATION PROGRAM LISTING

```
10 ' ****************************************************
20 '
30 '          Gas flow simulation program
50 '               Tony Williams
60 '
70 ' ****************************************************
80 '
90  CLS:KEY OFF
100  LOCATE 8,10:PRINT "This gas mixing model simulates the flow"
110  PRINT TAB(10) "of Carbon Dioxide, Oxygen and Nitrogen through"
120  PRINT TAB(10) "individual solenoid valves. The volume of each"
130  PRINT TAB(10) "gas is printed in tabular form and percent of"
140  PRINT TAB(10) "each gas to the tank volume is calculated."
150  LOCATE 23,25:PRINT "Press any key to continue..."
160  ZX$="":ZX$=INKEY$:IF ZX$="" THEN 160 ELSE CLS
170  VT=1.3368
180  PT=1
190 '
200 '  ### Get time inputs ###
210 '
220  PRINT TAB(10) "Do you wish to save output to a file ?"
230  INPUT "                        Enter <Y/N> ===>";F$
240  IF F$="Y" OR F$="y" THEN 270
250  IF F$="N" OR F$="n" THEN 280 ELSE CLS
260  GOTO 220
270  OPEN "B:GASFLOW.DAT" FOR OUTPUT AS #1
280  CLS
290  INPUT "Time carbon dioxide valve is open ===> ";DTCO2
300  INPUT "Time nitrogen valve is open ===> ";DTN2
310  INPUT "Time oxygen valve is open ===> ";DTO2:CLS
320  PRINT   "         O2              N2          CO2"
330 '
340 '  ### Draw the output ASCII box ###
350 '
360   FOR H=1 TO 21
370    PRINT TAB(70) STRING$ (1,179)
380   NEXT H
390  LOCATE 2,53
400   FOR I= 1 TO 21
410    PRINT TAB(53) STRING$ (1,179)
420   NEXT I
430  LOCATE 1,53:PRINT STRING$(1,218);:PRINT STRING$(16,196);
440  PRINT STRING$ (1,191)
450 '
460 '  ### Calculate flow, volume in tank & vol of CO2 ###
```

```
470 '
480  FOR C=1 TO 5 STEP DTCO2
490   VCO2=.812*(400-PT^2)^.5
500   DVCO2=VCO2*DTCO2
510   PT=PT*VT/(VT+DVCO2)
520   VT=VT+DVCO2
530   VTCO2=VTCO2+DVCO2
540   IF F$="y" OR F$="Y" THEN 550 ELSE 560
550   PRINT #1,VTCO2
560   PRINT TAB(40) VTCO2
570  NEXT C
580 '
590 ' ### Calculate same thing for Nitrogen ###
600 ' ### just a seperate loop...          ###
610 '
620  LOCATE 2,22
630   FOR N=1 TO 5 STEP DTN2
640   VN2=1.02*(400-PT^2)^.5
650   DVN2=VN2*DTN2
660   PT=PT*VT/(VT+DVN2)
670   VT=VT+DVN2
680   VTN2=VTN2+DVN2
690   IF F$="y" OR F$="Y" THEN 700 ELSE 710
700   PRINT #1,VTN2
710   PRINT TAB(25) VTN2
720  NEXT N
730 '
740  LOCATE 1,15
750 '
760 ' ### Calculate again for oxygen ###
770 ' ### still another loop...      ###
780 '
790   FOR O=1 TO 5 STEP DTO2
800   VO2=.95*(400-PT^2)^.5
810   DVO2=VO2*DTO2
820   PT=PT*VT/(VT+DVO2)
830   VT=VT+DVO2
840   VTO2=VTO2+DVO2
850   IF F$="y" OR F$="Y" THEN 860 ELSE 870
860   PRINT #1,VTO2
870   PRINT TAB(10) VTO2
880  NEXT O
890 '
900 ' ### Find percent of each gas in tank ###
910 '
```

```
920  LOCATE 5,55:PRINT USING "Total = ###.##";VT
930  PERCENTCO2=(VTCO2/VT)*100
940  PERCENTN2=(VTN2/VT)*100
950  PERCENTO2=(VTO2/VT)*100
960  A$="CO2 = ##.##%"
970  B$="N2 = ##.##%"
980  C$="O2 = ##.##%"
990  LOCATE 10,55:PRINT USING A$;PERCENTCO2
1000  LOCATE 12,55:PRINT USING B$;PERCENTN2
1010  LOCATE 14,55:PRINT USING C$;PERCENTO2
1020 '
1030 ' ### finish drawing the box, output is in it ###
1040 '
1050  LOCATE 22,53:PRINT STRING$(1,192);:PRINT STRING$(16,196);
1060  PRINT STRING$ (1,217)
1062  INPUT ">";GA$
1063  IF GA$="y" OR GA$="Y" THEN 280
1070  END
```

VITA

James Anthony Williams was born in Chattanooga, Tennessee on July 24, 1964. He attended elementary school in Chattanooga and was graduated from East Ridge High School in June 1982.

The following September he entered The University of Tennessee at Chattanooga, and in September 1985 transferred to The University of Tennessee at Knoxville where he received a Bachelor of Science degree in June 1988. During his undergraduate career he was awarded memberships in the Alpha Zeta Honor Fraternity, Outstanding College Students of America, and was a student member of the American Society of Agricultural Engineers.

In August 1988 he accepted a research assistantship and entered The Graduate School of The University of Tennessee at Knoxville. He completed his graduate studies in August 1991 and received a Master of Science degree with a major in Agricultural Engineering Technology.

He is presently employed as project engineer with Pet, Incorporated.