A feasibility study of the utilization of residual engine heat for the operation of an automotive, absorption type, air conditioner

Daniel Dow Jackson

Iowa State University
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A feasibility study of the utilization of residual engine heat for
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Jackson, Daniel Dow, Ph.D.
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A feasibility study
of the utilization of residual engine heat
for the operation of an automotive, absorption
type, air conditioner

by

Daniel Dow Jackson

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
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DEDICATION

I wish to dedicate this work to the late Charlie Cohron who once told me, "Hosea, whether you like it or not, you're stuck with automotives."
CHAPTER 1:  INTRODUCTION

There are two major air conditioner systems; the compressor system and the absorber system. The compressor system, the most commonly used, compresses a gas with a mechanically driven pump into a condenser. There, hot gas is cooled and condensed into a high pressure liquid. The liquid is then released through an expansion valve into an evaporator at a regulated rate which quickly reduces the pressure. With this decrease in pressure, vapor is formed and heat is removed from the surrounding area of the evaporator. The gas is then pumped back into high pressure where the cycle begins again.

The absorber system employs a mixture of two substances in a vessel, called the absorber; one substance is soluble in the other. The refrigerant (usually ammonia) is absorbed by an absorber (usually water) and is pumped into the generator. In the generator, the mixture is heated until the two substances are separated and the refrigerant gas is pressurized. This replaces the mechanical operation in the compressor system. The refrigerant, now a gas, is vented into the condenser where it follows the same path as a compressor system. As the refrigerant flows from the condenser it is released into the evaporator through the
expansion valve. This system, as in the compressor system, removes heat from the surrounding area. Once the refrigerant leaves the evaporator, it moves back into the absorber. The temperature in the absorber is low enough to attract the refrigerant because of less pressure and allows the gas to be absorbed by the absorber. The absorber solution is continuously circulated between the generator and the absorber to complete the cycle.

The compressor type is the most common. Refrigerators, residential and industrial air conditioners, and automobile air conditioners are usually compressor systems. The absorber systems were used in gas and wood burning refrigerators although general use of these systems is now obsolete. Some manufacturers still produce these absorber refrigerators for the international market where electricity is not used in abundance. The absorber system is currently used, however, in some industries that produce chemicals and heat as by products. These by products, that would normally be wasted, are used in the system providing an economical way to remove heat from either the plant, product or both. The advantage of the absorber system over the compression system is a matter of economics; however, most absorption systems are large and are made to remove a large quantity of heat which makes the absorber system a much more complex design and tends to be more difficult to
maintain. The large systems are complex, but the use of a small absorber system to remove a small amount of heat would reduce this complexity of design. The size and desired cooling capacity of the absorber system can be thought of as being directly proportional to complexity and difficulty of maintenance. Therefore, small cooling jobs may be more economically achieved by using the absorber system. Both compressor type systems and absorber type systems are covered in more detail, and illustrated, in Chapter 2.

Statement of the Problem

The problem of this study was to investigate the utilization of residual engine heat for the operation of an automobile air conditioner by converting an existing compressor type system into an absorption type system. The cooling system passages in the block of the engine became the generator. Here, the refrigerant was heated and separated from the water based absorber; thus the utilization of residual engine heat. The gas moved into the condenser, then into the accumulator, was released into the evaporator, and then absorbed again in the radiator of the engine. The refrigerant mixture was then pumped back into the engine block through the existing engine water pump. Use of the existing pump provided for less power
consumption from the system. An illustration of this system can be found on page 41.

Purpose of the Study

The purpose of this study was to ascertain the feasibility of an absorber type automobile air conditioner using the engine block as the generator and the radiator as the absorber, thus, utilizing residual engine heat that would normally be wasted. An air conditioning system of this type would be less expensive to operate, would increase the thermal efficiency of the engine, and would aid in the control of fluorocarbon pollution in the atmosphere.

Currently used compressor type systems require 5 - 10 percent of the engines power output to operate the compressor (Organization for Economic Co-Operation and Development, 1982), which translates to approximately 1 - 2 million barrels of oil a day worldwide (Ford Energy Report, 1982). It is imperative that research be done toward providing more ways to reduce the consumption of oil. The gasoline shortage of 1974 was only a sample of our possible future. With the present consumption of oil, it has been estimated the resources will be depleted by the year 2060 (Chaddock, Cocks, Harman, & Shepard, 1977). John McElroy (1980), performance editor of "Automobile Illustrated", 
suggests to "experiment and theorize" on any substance or engine design that may be used, whether or not it has been disregarded in the past (p. 15). This philosophy would naturally include the design of an accessory such as an air conditioner that would reduce the consumption of oil. With adequate research in this area, the overall demand on oil in the U.S. would be lowered which would, in turn, lessen our dependency on other countries. An absorber system would require no extra power from the engine, and would utilize residual engine heat that would normally be wasted. This would save the engine fuel that would have been used to generate that energy. In addition, by using residual engine heat, some thermal efficiency of the engine would be reclaimed, as 40 - 60 percent of a typical engine's thermal efficiency is lost through heat radiation (Blackmore & Thomas, 1977). Therefore, the absorber system would reduce the overall fuel consumption of the vehicle, and would provide air conditioned comfort at minimal additional cost to the consumer.

The absorber system, in addition to the above, will serve to reduce the seepage of fluorocarbons into the atmosphere. Pollutive seepage of fluorocarbon has frighteningly deteriorated the ozone layer of the atmosphere. This ozone layer blocks out 90 percent of the ultraviolet rays from the sun. An increase in ultraviolet
radiation to the earth's surface will cause an increase in skin cancer, an increase in the average temperature of the earth, and potentially massive climatic changes such as a reduction in rainfall in the agricultural areas and flooding of coastal cities (Lowther, 1986).

Commonly known as the "greenhouse effect", the ultraviolet rays will enter the earth's atmosphere unblocked by the ozone layer and strike the earth's surface. This will increase the earth's surface temperature which will, in turn, radiate into the atmosphere. The heat will be trapped by the atmosphere, thus, raising the average temperature. A 2.5 percent reduction in the ozone layer will increase the temperature enough to cause 15,000 additional deaths by skin cancer (Lowther, 1986).

The area in the ozone layer that is of most concern is the area over Antarctic. During October of 1985 this area experienced a 50 percent reduction (Kerr, 1986). A 2 degree Fahrenheit increase in the average temperature of earth will double the number of tropical storms. As ice caps melt, flooding will occur in coastal areas. Already, typhoons and other tropical storms are increasing in severity. According to Sharon Begley and Bob Cohn of Newsweek (June 23, 1986), New Orleans, Ciro, San Francisco, and other cities, as well as the country of Bangla Desh,
will be under water by the year 2030.

The United States Environmental Protection Agency has already banned the use of fluorocarbons in aerosol cans and Canada has done likewise. However, only two European countries have done so. Additional regulations banning the use of fluorocarbons in refrigeration is imminent and will be decided on by November of 1987 (Begley & Cohn, 1986). The absorber system is readily capable of using refrigerants other than fluorocarbons such as ammonia in water or water in brine. The absorber system is not only an economical means of air conditioning but may be the only choice available in the near future.

Objectives of the Study

The specific objectives of this study are listed as follows:

1. To convert an existing compressor type automotive air conditioning system into an absorption type system. The cooling passages in the engine were used as the generator and the radiator was used as the absorber.

2. To compare engine and radiator temperature differences between trials with the absorber system operating to trials with the absorber system not operating; each at five selected revolution per minute levels. This was intended to reveal any high temperature levels that
could be potentially damaging to the engine, and allow inferences to be drawn concerning the effect the absorber system has on these components.

3. To compare temperature differences of the evaporator to five selected revolution per minute levels.

4. To determine any increase in the operational efficiency of the absorber system at five selected revolution per minute levels.

5. To determine if the pressure of the absorption system was harmful to the power plant.

Operational efficiency is the relationship between the amount of residual engine heat used to operate the absorber system and the amount of heat removed from the passenger compartment.

6. To determine any increase in fuel consumption when the absorber system was in operation.

Hypotheses to be Tested

Hypothesis one was the overall working hypothesis of the entire study, and is stated as follows:

1. Residual engine heat can be effectively used to operate an absorber type automotive air conditioner using the engine as the generator and the radiator as the absorber.

The subjective retention of hypothesis one depended on
information gained by testing the remaining hypotheses. Hypotheses two and three follow, respectively.

2. The effect the absorber system has on internal pressure was not harmful to the power plant.

3. There was no observational change in fuel consumption due to the operation of the absorber system.

Subsequent hypotheses concerning objectives two, three, and four can be stated statistically in the null form as follows:

4. There were no significant differences between temperature levels in the engine cooling system when the absorber system was in operation and when it was not in operation. This includes the engine block and the radiator with data recorded at five selected revolution per minute levels.

5. There was no significant decrease in the temperature level of the evaporator in relation to increasing revolutions per minute.

6. There was no significant increase in the operational efficiency of the absorber system in relation to increasing revolutions per minute.

Basic Assumptions

The basic assumptions directly concerning the hypotheses of the study and otherwise concerning the nature
of the study were as follows:

1. Residual engine heat can be effectively used to operate an absorber type air conditioner using the engine as the generator and the radiator as the absorber.

2. While in operation, the absorber system will produce a decrease in the normal operating temperature of the engine and an increase in the normal operating temperature of the radiator.

3. The absorber system will decrease the temperature of the evaporator within tolerable limits.

4. The operational efficiency of the system will be low; however, it is assumed that any residual engine heat that is utilized by the system would have normally been lost.

5. The pressures of the engine and radiator will increase, but will not exceed damaging limits.

6. The system will decrease the fuel consumption of the vehicle.

Delimitations and Scope

Delimitations that were imposed on the study are as follows:

1. The experimental manipulation of only one vehicle.

2. The use of a vehicle equipped with a V-eight type engine with cast iron heads and a cast iron block.
3. Experimentation will be done in a stationary laboratory setting.

4. Use of the normal copper based vessels during experimentation with the recommendation that a noncorrosive material be selected for any permanent system that may use a corrosive refrigerant.

5. The use and experimental testing of only one refrigerant.

Definition of Terms

The following is a short definition of terms that may be used in a particularly specific sense dealing with the nature of this study:

ABSORBER:

The vessel containing the absorbing solution or the solution possessing the absorption qualities.

ABSORBER SYSTEM:

An air conditioning system that uses chemical absorption qualities to transport the refrigerant from low pressure to high pressure.

AIR CONDITIONER:

A thermodynamically oriented cycle used to remove or
add sensible or latent heat from a given area increasing or decreasing the relative humidity and temperature.

**AUTOMOTIVE AIR CONDITIONER:**

A thermodynamically oriented cycle used to remove specific heat within the automotive passenger compartment for the purpose of personal comfort.

**BOILING POINT:**

The point at which a given fluid contains enough heat to produce instantaneous effervescence while in its liquid form.

**COMPRESSOR:**

The mechanically driven unit providing compression of refrigerant gasses in the compressor type system.

**COMPRESSOR SYSTEM:**

An air conditioning system using a mechanically driven compressor to provide high and low pressures where needed.

**CRITICAL POINT:**

The point at which a fluid contains enough heat to instantaneously change in state from a liquid to a gas.
ENTHALPY:

The total amount of energy including both sensible and latent heat.

EVAPORATOR:

The low pressure vessel which allows the expanded refrigerant gas to absorb heat from the surrounding area.

EXPANSION VALVE:

The unit placed before the evaporator to aid in the vaporization of the high pressure refrigerant liquid.

FUEL CONSUMPTION:

The amount of fuel consumed at a given load over a given period of time.

FUEL EFFICIENCY:

The relationship between the Btu (British thermal unit) rating of the amount of fuel used to the Btu rating of the power produced.

GENERATOR:

The vessel that heats the refrigerant/absorber solution to the extent the refrigerant separates from the absorber.
LATENT HEAT:

The portion of total heat that can not raise the temperature of a given substance.

MELTING POINT:

The point at which a substance contains enough heat to change in state from a solid to a liquid.

OPERATIONAL EFFICIENCY:

The relationship between the amount of residual engine heat used to operate the absorber system and the amount of heat removed from the passenger compartment.

REFRIGERANT:

The working fluid used in all refrigeration cycles for the purpose of transforming from a high pressure to a low pressure producing the heat absorption.

RESIDUAL ENGINE HEAT:

Heat left over from the internal or external combustion of fuel that was not used for purposes of power generation.

SENSIBLE HEAT:

The portion of total heat that is able to raise the temperature of a given substance.
THERMAL EFFICIENCY:

The relationship between the Btu rating of the fuel input to the Btu rating of the heat output.
CHAPTER 2:
REVIEW OF LITERATURE

The review of literature for this study is provided in three parts. First, is a general overview of air conditioning systems with emphasis given on automobile air conditioning. In this part, the history, state-of-the-art, and future aspects of the air conditioner are covered. Next, is a discussion of some basic theory of heat and thermodynamics as it pertains to air conditioning. Finally, a survey of refrigerants is included. This includes refrigerants 12, 22, 11, ammonia, water, and alcohol. Emphasis was placed on absorption type refrigerants.

The Rankine Cycle

Air conditioners, heat pumps, refrigerators, and certain types of steam engines all operate on a thermodynamic cycle called the Rankine cycle (Figure 2-1). The Rankine cycle was first used in the early steam engines wherever there was a condenser used in a closed system. This included the engines of Newcomen, Smeaton, and Watt, but excluded the engines of Evans and Trevithick. Engines such as Trevithick's were not Rankine cycle steam engines because they eliminated the condenser, exhausting the steam into the atmosphere. Basically, the Rankine cycle employs
four main components: the boiler, prime mover, condenser, and the pump leading back to the boiler. This describes what is commonly known as the Rankin engine. The Rankine engine incorporates a working fluid which is irreversibly transferred into the boiler, is passed into the prime mover where it undergoes adiabatic expansion, moves to the condenser where it irreversibly gives up heat, and then to the pump where it undergoes adiabatic pressurization.

Figure 2-1. Rankine cycle
(Stoever, 1951).

By replacing the boiler with an evaporator, the prime mover with a compressor, and the pump with an accumulator, the Rankine cycle, that was an engine, becomes a compressor type air conditioner or refrigerator (Figure 2-2). Moreover, by simply reversing the direction of the working fluid (in this case a refrigerant), the air conditioner becomes a heat pump. The compressor type system, as explained in Chapter 1, uses a gas compressor to compress

![Figure 2-2. Compressor type system](image-url)
the refrigerant into high pressure which moves it into a condenser. There, hot gas is cooled and condensed into a high pressure liquid. The high pressure liquid is then released through an expansion valve into an evaporator at a regulated rate which quickly reduces the pressure. With this decrease in pressure, vapor is formed and heat is removed from the surrounding area of the evaporator. The gas then moves back into the compressor because of the low

![Diagram of Absorber Type System]

**Figure 2-3. Absorber type system**
pressure, and the cycle begins again.

By substituting the compressor with what is called a generator, and adding another vessel to the system called an absorber, the compressor type system becomes an absorption type system (Figure 2-3). Where the compressor system uses mechanical means of producing pressure, the absorber system uses thermodynamic and solubility principles to produce pressure. In the generator, the temperature is increased to the extent that the refrigerant is separated from the absorber. The absorber is a liquid that the refrigerant can be dissolved in but has a higher heat capacity. Therefore, as the refrigerant’s temperature is lowered, it is absorbed by the absorber. This elemental compatibility provides for the high and low pressure necessary for the system to operate. When the high pressure gas leaves the generator, it is condensed in the condenser. Then it is released into an evaporator through an expansion valve as it does in the compressor system. The low pressure/temperature combination of the gas as it leaves the expansion valve enables it to be absorbed back into the absorber vessel. As the refrigerant is continuously circulated back and forth between the generator and the absorber, the cycle continues. Once again, by reversing the flow of the refrigerant, the absorber system is made into a heat pump.
Automotive Air Conditioning

The application of air conditioning to the automobile in the early 1950s was really a simple matter of designing a small system for a small volumetric space. The first automobile air conditioners, made by the Oldsmobile company, were located in the back of the car in the luggage compartment. The basic system, however, was the same as it is today. Through the conversion of heat, by combustion of fuel, into usable mechanical energy, the system had a power source to operate the compressor. The refrigerant was pressurized by a compressor and circulated throughout the body compartment through an evaporator. Then the refrigerant was vented back into the low pressure port of the compressor. Soon after the introduction of the automobile air conditioner, the design was modified to locate the air conditioner in the engine compartment of the vehicle. This allowed for a more effective condensing of the refrigerant because the condenser was placed parallel to the radiator which was cooled by the engine fan.

In addition to the basic system there were controls to ensure a safe and comfortable operation of the system. The high variance in the pressure at the high pressure side of the compressor necessitated hot gas relief valves. These valves vented the gas to the outlet of the evaporator if the pressure became too high. In a similar manner,
pressure sensitive switches were placed on the condensers to shut down the entire system if it became too hot. For comfort control, devices to regulate the flow of the refrigerant into the evaporator were included. There were manually controlled systems and automatically controlled systems. With the automatic system, the operator could simply select the desired temperature on a dial and the system would maintain that temperature.

Since then, the design of the system has not changed drastically, and there have not been many attempts by the major car companies to design an absorber system for use in the automobile. What has changed, however, is the compressor. A typical air conditioner compressor requires 5 - 10 percent of the engine's power output to operate the system (Organization for Economic Co-Operation and Development, 1982). This was recognized fairly soon when oil became expensive in the early 1970s. In addition to fuel conservation, increased production of smaller vehicles necessitated compressor designs that required less power for operation and would be small enough to be installed in the engine compartment of the smaller automobiles. New designs, such as the radial and rotary compressors, and compressors that vary in displacement, were developed in the late 1970s and early 1980s (Rotary Air Conditioner Compressor Developed, 1981; Air Conditioner Compressor
Varies Displacement, 1984). These designs reduced the power consumption of conventional compressors. This reduction in required power enabled the reduction of size which made their use ideal for compact automobiles (Yamaguchi, 1982). One such design, found in the February of 1982 issue of Automotive Engineering, reduced the weight by 60 percent (Compressor/Clutch Redesign Trims 60% of Weight, 1982). Other design modifications that would lead to less power consumption would be fewer control devices, examination of tubing and other air conditioner components, and improvement of materials to reduce seepage (Trexler, 1983; Climate Control System Eliminates Vacuum Actuators, 1980; Julier, 1985).

Considerable research has been done, and is currently in progress, concerning compressor and compressor type component design. However, compressors still require mechanical power taken from the engine, and risk the possibility of seepage of fluorocarbons resulting in atmospheric ozone depletion. Absorption type air conditioners have not been as popular because of the simplicity of the compressor type systems but would aid in the solution to these problems. Since 1970, there have been few studies conducted on this topic; prior to 1970 it was also minimal.

A variety of interest is displayed concerning
absorption type air conditioners. The U.S. government has been responsible for most research in this area. For example, in 1970 the military developed an absorption system that utilized waste exhaust heat (MERDC Uses Waste Heat for New Air Conditioner, 1970). The Department of Energy has been involved extensively and so has Ford Motor Co. to a lesser extent.

In 1971, the Ford Motor Co. sponsored the development of an absorption air conditioner in an automobile. The system included all the absorption vessels mentioned earlier in Chapter 1, but the generator was half generator and half compressor. This generator/compressor vessel was located on the exhaust pipe of the vehicle to utilize the heat for operation. The circulation of the refrigerant provided the momentum the refrigerant needed to move though a ventura nozzle in the generator. This compressed the refrigerant and, at the same time, cooled the refrigerant bringing it back into the liquid state for the cycle to begin again. A suitable refrigerant was undetermined and the conclusion was that an absorption type system for automotive use was impractical (Akerman, 1971). Through the 1970s, little interest was displayed in the U.S; but internationally, the research continued.

Research conducted at the University of Melbourne was more optimistic than the Ford research in that it was
determined that the notion was thermodynamically sound. The problems that arose with this study were locating the generator where there was sufficient heat and selection of a refrigerant (Charters & Megler, 1974). Asian influence was generated through research conducted, in the U.S., at The University of Pennsylvania by Mahadvian Balasubramanium. This system proved to be successful but was not a true absorption system. This system, like the Ford system, utilized engine waste heat, but the generator was a vapor jet that forced the refrigerent into circulation (Balasubramanium, 1975). A similar study was conducted in India at the Delhi College of Engineering. In this study, an absorption system was installed in a Fiat and tests were conducted using two different refrigerant mixtures; ammonia/water, and water/lithium bromide. It was concluded that the water and lithium bromide system gave more desirable results than the ammonia in water, and that the absorption system was suited for automotive use (Ballaney, Grover, & Kapoor, 1977).

Toward the end of the decade, research interest was stimulated in the U.S.; possibly as result of the success in the experiments mentioned above. David Scott, in his May 5, 1978 article in Automotive Engineering entitled, "Hydrogen Fuel Ready for Bus Fleet," said, "according to Daimler-Benz, air conditioning or heating can be provided
as a by-product without any additional equipment or power drain, and can function even with the engine stopped."
This, of course, was in reference to hydrogen powered external combustion engine vehicles that could provide the combustion of fuel without power generation (Scott, 1978). With foreign influence evident, interest in further research within the U.S. came, primarily, as result of high oil prices and the poor efficiency of the compressor system. By 1980, the Department of Energy became interested and sponsored two consecutive projects. The first project was conducted in Puerto Rico and was plagued with problems. The final report shows evidence of a lack of professional involvement, participant illnesses, and lack of planning. None of the objectives were fulfilled (Piedras, 1980). The second was done in Tuscaloosa, Alabama by W. J. Schaetzle and Associates Inc. This project, again, used thermal compression in the generator vessel to force the refrigerant though the system. This system was unique, however, because of the intermittent compression process. This enabled the system to have the pressure it needed to operate without using mechanical energy from the engine. Schaetzle reports a 20 percent energy savings compared to conventional systems, and claims up to 50 percent savings is possible (Schaetzle 1982).

In 1980, Zenon Popinski invented a true absorber system
and was granted a patent. This system not only utilized waste engine heat, but also collected solar heat from a roof top collector to aid in the operation of the system. Since then, speculation has continued on Popinski's invention as to its commercial development and use in electric and hybrid vehicles (Popinski, 1980). With continued research in this area it may be possible in the future to have cooling in the automobile with no increase in fuel consumption. The use of the absorption type system without fluorocarbon refrigerants will also help prevent further deterioration of the ozone layer of the atmosphere.

Basic Theoretical Principles

Thermodynamics is the study of systems that display a dynamic treatment of heat. In other words, the operation of the system requires that heat changes in temperature at various stages in the cycle. For heat to be used in this manner, thermodynamic systems require a heat medium. This heat medium is called the working fluid in systems that produce mechanical energy and refrigerants in systems that are meant to cool a given area. Because these systems utilize mediums, several aspects of fluid, and how heat affects these fluids, must be explained.

Heat is the most fundamental form of energy and is highly versatile in use. Heat energy can be readily
converted into other forms of energy, such as electrical or mechanical, and the dissemination of all other forms of energy ends in the production of heat. The efficiency of this conversion process does, however, depend largely on the heat medium. The total amount of heat in a given substance is divided into sensible heat and latent heat. Sensible heat is the amount of heat that is used to raise the temperature of a given substance over a given temperature range and is measured in British thermal units (Btu). All substances are compared to the standard substance of water. To raise 1 pound of water 1 degree Fahrenheit, 1 Btu is required. All substances, including refrigerants, possess numerical coefficients, in relation to water, that describe how it will react to sensible heat. This property is referred to as the specific heat capacity. For example, 1 pound of eutectic ammonia requires 1.12 British thermal units to raise the temperature 1 degree Fahrenheit. Therefore, its specific heat capacity is 1.12.

As a vapor, ammonia has a specific heat capacity between 0.402 and 0.54 depending on the pressure and volume. The specific heat capacity can be thought of as how easily a given substance absorbs or disperses heat.

Another aspect of heat is latent heat. Latent heat is then further divided into two parts; latent heat of vaporization, and latent heat of fusion. Latent heat of
vaporization is the amount of heat, again, measured in British thermal units, that transforms a fluid into the state of vapor. Once a fluid reaches the boiling point, the heat input remains constant while the temperature stabilizes. That latent heat that appears to be lost represents the energy used to make that change in state. Similarly, latent heat of fusion occurs at the change of state between a solid and a liquid. Again, as an example, ammonia has a latent heat of vaporization of 589.3. To calculate the total amount of heat over a given range in temperature, we must add the various aspects of heat together. Starting at the low temperature in the given temperature range, the sensible heat is calculated up to the point of fusion, assuming of course that the substance is in a solid state. At this point the latent heat of fusion is added to the sum. Then the sensible heat of the liquid is calculated up to the point of vaporization and added to the sum. Upon adding the latent heat of vaporization, we arrive at the total heat (Gunther, 1957).

As mentioned earlier, heat is basic energy. However, not all the energy can be accounted for in the calculation of the total heat. Some of the energy is represented in overcoming the pressure that these increases in temperature and changes of state take place in, and some is the sensible heat up to the low temperature of the given scale.
Therefore, the total heat energy plus this additional energy is called the enthalpy. Enthalpy is the total energy of a given substance at a given temperature and pressure. It can be seen that pressure and temperature display a certain relationship. Pressure is directly proportional to temperature. As the temperature increases the pressure increases. Likewise, the temperature can be raised by increasing the pressure without external heat input.

One more aspect of the total energy is that of entropy. Entropy is the unuseable amount of energy a given substance has at a given state at a given temperature and pressure. This must be subtracted from the enthalpy to arrive at the useable amount of energy. It is always desirable in choosing a refrigerant, to choose one with a low entropy (Obert & Young, 1962; Faires, 1970; Gunther, 1957).

Refrigerants

Any fluid will react to heat according to the principles explained above. As the liquid is exposed to heat, the temperature rises and it becomes less saturated. In other words, the fluid changes from a liquid to a gas. This is where the phenomenon of heat absorption occurs. All fluids display this phenomenon hence all fluids display refrigerant characteristics. There are, however, some fluids that possess more desirable characteristics when
being used as a refrigerant. Characteristics such a low boiling point, low toxicity, and noncorrosivity are desired. A low boiling point serves to provide heat absorption at the evaporator with less heat input. It also means, however, it will require a greater cooling capacity in the system to condense the gas back into a liquid. Therefore, the correct fluid should be chosen for the system according to the temperature limits in the generator and the absorber. In a compressor type system, the same is true. The pressure at the compressor and the heat removed at the evaporator generate heat which has to be removed by condensation. Therefore, a boiling point at too low of an extreme would inhibit the system's thermodynamic effect.

Other characteristics should also be examined such as the likelihood of seepage. With a low boiling point comes a high pressure; if that fluid is enclosed in a system. A high pressure, naturally, takes the path of least resistance which may occur as seepage into the atmosphere. This seepage poses two more problems; expense and pollution. The latter provides the most severe consequence but is typically ignored. As mentioned in Chapter 1, leakage of certain refrigerants into the atmosphere are believed to deteriorate the ozone layer of the atmosphere (Lowther, 1986).
Compressor type refrigerants

Typical refrigerants for the compressor type systems are refrigerants 12, 22, and in some cases, 11. Refrigerant 12 is the most common. Its use is primarily included in automobile engines and small systems such as refrigerators and freezers. It is, however, being used more frequently in the larger systems such as heat pumps, central air conditioning, and industrial cooling. The reason for the wide use of refrigerant 12 is that it is inexpensive, is low in relative toxicity, and is noncorrosive to most materials used in air conditioning systems. Refrigerant 22 has a much lower boiling point than refrigerant 12. Refrigerant 12 boils at -21.6 degrees Fahrenheit, whereas refrigerant 22 boils at -41.4 degrees Fahrenheit. In addition, refrigerant 22 is toxic and is highly corrosive to most synthetic materials (Granet, 1980). Refrigerant 11 is different from both of the other refrigerants in that it boils at 74.7 degrees Fahrenheit. The advantage to this relatively high boiling point is the ability to control medium temperatures. The toxicity and corrosiveness of refrigerant 11 is much like that of refrigerant 12 (Gunther, 1957). Table 2-1 compares some corrosive characteristics of the refrigerants 12, 22, and 11. Figure 2-4 shows the pressure vapor curves for each of those refrigerants including their boiling points and
Table 2-1. Compatibility of refrigerants (Granet, 1980)

<table>
<thead>
<tr>
<th>Material</th>
<th>Brass</th>
<th>Copper</th>
<th>Aluminum</th>
<th>Stainless Steel</th>
<th>Nitrile Rubber</th>
<th>Nylon</th>
<th>PVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia (Anhydrous)</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Ammonia (30% solution)</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Freon 11, 12, 113 &amp; 114</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freon 22</td>
<td>C</td>
<td>C</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>Water (Distilled)</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Water (Acidic or Basic)</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
</tr>
</tbody>
</table>

A = Little or no effect
B = Moderate effects
C = Severe effects - use not recommended
Figure 2-4. Compressor type refrigerants

critical temperatures. Refrigerants 11, 22, and other fluorocarbons are primarily compressor type refrigerants, however, they have been used in absorption machines as indicated earlier in this chapter.

Absorption type refrigerants

There are two commonly used refrigerant solutions in the absorber type system. The most common combination is
ammonia and water. The other is a water and brine or water in lithium bromide combination. Both refrigerants work on the same principle, however, ammonia has more desirable thermodynamic properties than does water. The boiling point is lower (-28 degrees Fahrenheit) and its solubility in water is excellent. In addition, Figure 2-5 shows that the pressure temperature curve for ammonia displays a

![Figure 2-5. Absorber type refrigerants](image-url)
moderately low pressure. This aids in the design of the system as there is no need for heavy duty components. Another ideal property of ammonia is its low heat capacity. The fact that ammonia possesses a low specific heat capacity means less area is needed in the heat exchangers. Water, on the other hand, displays somewhat undesirable thermodynamic properties in many respects. Compared to ammonia, the heat capacity is high, necessitating the need for large areas in the heat exchangers. The boiling point is 212 degrees Fahrenheit requiring a very high heat input to operate the system. Due to the high temperatures, the components of the system need to be heavy duty. The advantage of using water as a refrigerant, however, is that high temperatures found in many industrial processes can be reduced inexpensively. In comparison, water is less corrosive than ammonia. Ammonia refrigerant is highly corrosive to copper based metals but has little affect on ferrous metals. Water is also less toxic than ammonia. Ammonia is believed to be harmful if as little as 0.5 percent by volume is inhaled for more than 30 minutes (Gunther, 1957). Table 2-2 contains data concerning toxicity of selected refrigerants.

Other refrigerants used in absorption systems include sulfur dioxide, carbon dioxide, and various forms of alcohol. Several of these are extremely toxic, such as
sulfur dioxide and methanol, which make their use in automobile air conditioners prohibitive. In addition to toxicity, many of these refrigerants, including ammonia, are flammable. Ethanol possesses many desired thermodynamic properties but forms an extremely explosive mixture when vented into the air. Ammonia is explosive, but only when compressed or exposed to an open flame.

Table 2-2. Toxicity of refrigerants (Perry et al., 1963)

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Amount (%)</th>
<th>Poisonous by-product</th>
<th>N.F.U. #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>0.5-0.6</td>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>Freon 11</td>
<td>10</td>
<td>Yes</td>
<td>5</td>
</tr>
<tr>
<td>Freon 12</td>
<td>30</td>
<td>Yes</td>
<td>6</td>
</tr>
<tr>
<td>Freon 22</td>
<td>--</td>
<td>Yes</td>
<td>5a</td>
</tr>
<tr>
<td>Freon 113</td>
<td>--</td>
<td>Yes</td>
<td>5</td>
</tr>
<tr>
<td>Methyl Chloride</td>
<td>2-2.5</td>
<td>Yes</td>
<td>4</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>0.7</td>
<td>No</td>
<td>1</td>
</tr>
</tbody>
</table>
CHAPTER 3:
METHODOLOGY

The problem of this study was to ascertain the feasibility of an absorber type air conditioner to be used in an automobile. The procedure that was followed to accomplish this study included several parts, and is covered, in detail, in this chapter. First, the basic design decisions that were made and how they were arrived at, and the modifications to the vehicle used that were necessary for the system to operate, are covered. Then the instrumentation for collecting the data is discussed. This includes the various computer programs that were written, discussion of the heat measuring devices, and explanation of the modifications made to the computer used to collect the data. Finally, the statistical designs for the analyses of the system are presented along with the justification for selecting those designs.

System Design and Vehicle Modification

As stated in the first chapter in the delimitations, the engine selected for this study was restricted to an V-eight iron block. In addition to this, the vehicle had to be equipped with a conventional air conditioning system (compressor type). A 1970 Oldsmobile 98 met these
criteria, and was selected for the experiment. To convert the air conditioning system into the absorber type system, several modifications were necessary. Modifications had to be made to the engine, to the existing air conditioning system, and to the radiator.

The existing air conditioner compressor was eliminated from the power plant and the high and low pressure hoses were to be rerouted for the absorption system. The high pressure hose was placed on the engine block in a location where the engine coolant would be hot. It had to be high enough in elevation to allow the coolant to circulate while at the same time release a strong refrigerant gas. This location was determined to be the heater core hose outlet at the rear and on top of the intake manifold. The heater regulator valve was removed and the high pressure piping for the absorption system was installed. This piping involved a series of one inch standard cast iron fittings extending to a 120 pound per square inch adjustable regulator. In order to maximize the strength of the refrigerant before it entered the condenser, it was necessary to install some kind of a separator. This problem was solved by installing a discarded, 14 ounce, propane tank in line with these fittings (see Figure 3-1). The tank had three terminals to accept the various lines. The gas intake was located on the side of the tank. This
enabled the heavier liquid solution to fall to the bottom of the tank. At the bottom of the tank was an opening to allow the liquid solution to return to the engine. On top of the tank, where the gas would flow, was an opening leading to the condenser. At that point the high pressure hose from the compressor system was used to extend to the condenser.

As the engine became warm from the internal combustion of fuel, the refrigerant, having been absorbed into the coolant, heated up and liberated the gas into the absorption apparatus. Then it moved into the existing air conditioning system until it left the evaporator. At this point, the refrigerant had to be absorbed back into the absorber (coolant). This necessitated attaching the low pressure hose to the radiator. The radiator was removed from the vehicle and modified to accept this connecting hose. A hose nipple was installed on the top of the radiator near the radiator cap. It was located there because the coolant reaching this side of the radiator would be cooler than the opposite side. Not far from the cap was located a pressure gauge that was used to monitor the pressure in the radiator. Once the refrigerant was absorbed back into the coolant at the radiator, the weak refrigerant solution was circulated back into the engine for the cycle to continue.
Figure 3-1. System schematic

After securing the absorption apparatus to the vehicle, the conversion was completed (Figure 3-1). With the regulator closed, so the coolant could not enter the air conditioning system, the engine was prepared for the first phase of data collection. The first phase of data collection was done without any refrigerant in the coolant. These data were collected to determine the normal operating temperatures of the engine and the radiator. The second
phase of the data collection was done with the refrigerant added to the coolant. This provided data to be compared with the first set of data so that an analysis of the system performance could be made. The refrigerant was selected primarily on characteristics of toxicity and flammability. The actual thermodynamic qualities of the refrigerant were considered second in contrast to the nature of the above. The primary objective was to determine if cooling did occur in the evaporator using this kind of a system while maintaining the stability of the power plant. Therefore, the refrigerant used did not necessarily have to be the ideal refrigerant. The use of water was considered as it is nonexplosive, nontoxic, inexpensive, and can still obtain evaporator temperatures as low as 32 degree Fahrenheit. However, the temperatures and pressures were anticipated to be too high for the sodium nitrate and lithium bromide systems. Ethenol was also considered for the refrigerant because of the low pressures at the system's operating temperatures and because of its low relative toxicity. However, ethenol is highly explosive if vented into the atmosphere and exposed to a high source of heat. The system's likelihood of seepage, along with the close proximity of the engines ignition system, made the use of this refrigerant prohibitive. Ammonia is highly explosive, but only under
conditions of high compression and exposure to an open flame. Ammonia also has a high relative toxicity, but it was determined that the experiment could be conducted in an environment with adequate ventilation. The high toxicity was easier to control than the occurrence of an explosion. Ammonia displays very corrosive characteristics after having been associated with water, especially toward copper based materials such as brass (refer to Table 2-1). However, for the experiment, this posed no problem.

As discussed in Chapter 1, inferences concerning how the system reacted to five revolution per minute levels had to be made. The testing was conducted using 800 (idle), 1100, 1400, 1700, and 2000 revolution per minute levels. These levels were determined by associating miles per hour with revolutions per minute under normal driving conditions with the given vehicle.

Instrumentation

The two criteria that were of use to this study were, temperature and fluid ounces of fuel. The temperature measurement was necessary for the statistical evaluations concerning how the air conditioner would affect the components of the engine. Excessively high temperatures, as a result of the experimental air conditioner, may have become the source of engine damage. In addition to this,
temperature data were acquired from the evaporator to provide information concerning the effectiveness of the air conditioner. To draw conclusions pertaining to the fuel consumption of the engine, it was necessary to measure the fuel consumption with and without the air conditioner operating. Pressure measurements were also monitored as a safety precaution. If the pressure had attained a dangerously high level, the data collection would have been aborted.

The first step in measuring the temperature of the engine, radiator, and evaporator was the selection of the temperature measuring device. The two devices that were considered were thermocouples and thermistors. Thermocouples are defined as an active temperature measuring device because of the voltage that is generated as a result of an anode/cathode reaction. Thermistors, on the other hand, are passive temperature measuring devices. Thermistors, like common resistors, vary the resistance of the flow of electrons. The difference is, thermistors are composed of material that will vary in resistance as a function of temperature. Resistors change as a function of temperature as well but thermistor material amplifies this characteristic. Since it was deemed necessary to collect data using a computer, thermistors were selected because of the computer's built in potentiometers. These
potentiometers measured changes in resistance as a function of the time constant of a capacitor. The less time it took for the capacitor to charge depended on the voltage supply. The voltage supply, that was provided by the computer, was determined by the resistance of the thermistor which was altered accordingly by the temperature.

**Thermistors**

There are two types of thermistors; those with positive temperature correlations, and those with negative temperature correlations. The positive correlation thermistors are directly proportional to temperature, and the negative correlation thermistors are indirectly proportional to temperature. The most common of these is the negative correlation thermistors which was the type acquired for this study. The positive correlation thermistors would have been adequate for this study, however, due to their recent development, they were difficult to acquire. The thermistors used were rated at 10,000 ohms at 72 degrees Fahrenheit, and were placed in three different locations. One was placed on the cylinder head of the engine, to record engine temperature, near the front where the warmer temperatures would develop. The second was located on the radiator to measure the absorption temperatures. The third was on the evaporator
and only recorded temperatures while the air conditioner was operating. These thermistors were attached to the game control ports of a Commodore SX-64 computer.

Computer usage

The Commodore SX-64 has two game control ports. These ports enable the measurement of temperature as a function of variable resistance. As stated above, the computer computes the resistance by measuring the time taken to fully charge the 0.001 micro farad capacitor. Two measurements may be read from each of the two control ports of the computer. This enables the periodic recording of four data at the same time. As the computer can open up to seven files at one time, the creation of three data files, one for each temperature, could be accomplished. The difficulty lies, however, with the computer's scaling system. The computer measures any resistance between 0 and 370,000 ohms and then relates it to a 255 value scale. This means it would necessitate a change of 1451 ohms to change the value of that scale. This presents two problems; the recorded values would not be constant, and to utilize the entire range from 0 to 370,000 ohms restricts the use of common thermistors. The first problem was solved by using a linear regression calibration program developed by Dr. William Miller (Department of Industrial
Technology and Education, Iowa State University). This was modified to suit the experiment and resulted in a constant temperature reading. This program can be found in Appendix A. The second problem necessitated the modification of the game control ports. Since the thermistors used were rated at 10,000 ohms it was ideal to present a range of 0 to 10,000 ohms to the 255 value scale. This was done by adding more capacitance (externally) to the existing 0.001 micro farad capacitor. The time constant of the existing capacitor was determined by the equation $T = RC$, where $T$ was the time constant, $R$ was the resistance (370,000 ohms), and $C$ was the capacitance (1000 pico farads). This value was found to be 0.000037 of a second. To retain this time constant but change to the desired resistance range, the capacitance had to be changed. The equation became $C = \frac{T}{R} (R = 10,000)$, and the new capacitance was determined as being 0.037 micro farads. With the existing 0.001 micro farad capacitor, and a needed 0.037 micro farads capacitance, 0.036 micro farads had to be added. Two capacitors in parallel were added to the computer; one with 0.0039 micro farads, and one with 0.03 micro farads. Due to the manufacturing of standardized parts, these were the closest capacitors to the desired ratings. This gave a total of 0.0349 micro farads capacitance (Van Sloun, 1984). A schematic of these modifications is given in Appendix B.
The thermistors were donated by Kearney State College, Kearney, Nebraska; however, there were no specifications available. Therefore, it was assumed that the heat conductivity of the thermistor material was such that it required 10 seconds to detect a temperature change. To collect data for a period of 20 minutes, a minimum of 120 data were necessary at each revolution per minute level. With two treatments, five levels, and three thermistors, that amounted to a total of 3,000 collected data. Those data were analyzed by the statistical methods described below in the next portion of the chapter. The engine and radiator data were merged into one file to accommodate the statistical programs that were written. This entailed another computer program which can be found in Appendix C.

Fuel consumption

Fuel consumption was determined by starting with a given amount of fuel (4 U.S. gallons) and measuring how much was remaining after the testing was completed. This was done with and without the air conditioner in operation. Through observation of the results, information could be gained concerning how the operating absorption system affected fuel consumption.
Statistical Design

There were three statistical designs used in this study. One, to indicate whether or not the absorber system had any adverse effects on the power system of the vehicle, second, to ascertain the cooling effects of the absorber system, and third, to illustrate the operational efficiency of the system. The first, respectively, was a analysis of variance. Two treatments were used pertaining to the engine operating without the air conditioner system operating (treatment A), and the engine operating with the air conditioner system operating (treatment B). The design further included, under each treatment, the operation of the system at five preselected revolution per minute levels. The measurement taken, at each of these revolution per minute levels under each of the treatments, was temperature degrees in Fahrenheit. The second design was a linear regression concerning temperature data collected from the evaporator. These data were graphically illustrated which can be found in the discussion within Chapter 4. The third design involved computing correlational coefficients between normal heat used in the engine and heat absorbed by the system at each of the selected revolution per minute levels. These coefficients were to be calculated using British thermal units converted from temperature degree in Fahrenheit. Then the
coefficients were to be tested in the same manner the evaporator temperatures were with the linear regression and were to be illustrated graphically in Chapter 4. The following is a brief explanation of each of the statistical procedures used in this study.

Analysis of variance

The analysis of variance was used to test the differences between more than two means, or in other words, in instances where more than one variance was present. The same results could be obtained by conducting multiple $t$ tests. However, testing all the means at one time with the $F$ test would be less time consuming. To use the $F$ test, $t$ test, and other statistical tests, a comparison is made between the distribution of the data and theoretical distributions. There are several different designs of analysis of variance such as completely randomized, randomized block, and various factorial designs, among others. The design used for this study was the completely randomized factorial with two treatments and five levels of each treatment. The term "factorial" is in reference to collecting data at five levels of each treatment. This design is known in abbreviated form as CRF-pg (Kirk, 1982). The $p$ refers to the number of treatments, and the $q$ refers to the number of levels at each treatment. Data were
collected under the first treatment at each individual level and then under the second treatment at each individual level. The data were then tabulated.

Using hypothetical data, it was possible to present the experiment of this dissertation as an example. First it was necessary to run the engine without the air conditioning system and measure five temperatures for each of the five selected revolution per minute levels. Then again with the air conditioning system in operation, measurements were recorded once more. In the actual study, there were 120 temperatures collected for each revolution per minute level; however, five is sufficient for this example. The data were tabulated as follows in Table 3-1, showing each temperature datum for both treatments at each

Table 3-1. ANOVA ABS tabulation

<table>
<thead>
<tr>
<th>a1</th>
<th>a1</th>
<th>a1</th>
<th>a1</th>
<th>a1</th>
<th>a2</th>
<th>a2</th>
<th>a2</th>
<th>a2</th>
<th>a2</th>
</tr>
</thead>
<tbody>
<tr>
<td>b1</td>
<td>b2</td>
<td>b3</td>
<td>b4</td>
<td>b5</td>
<td>b1</td>
<td>b2</td>
<td>b3</td>
<td>b4</td>
<td>b5</td>
</tr>
</tbody>
</table>

| 180 | 182 | 184 | 186 | 188 | 184 | 186 | 188 | 190 | 192 |
| 181 | 183 | 185 | 187 | 189 | 185 | 187 | 189 | 191 | 193 |
| 181 | 183 | 185 | 187 | 189 | 185 | 187 | 189 | 191 | 193 |
| 182 | 184 | 186 | 188 | 190 | 186 | 188 | 190 | 192 | 194 |
| 182 | 184 | 186 | 188 | 190 | 186 | 188 | 190 | 192 | 194 |
revolution per minute level.

Continuing with the procedures given in Kirk's "Experimental Design", this preliminary table is used to develop a second table showing the summation of the temperature data for each revolution per minute level for both treatments. This is shown in Table 3-2 as follows:

Table 3-2. ANOVA AB tabulation

<table>
<thead>
<tr>
<th></th>
<th>b1</th>
<th>b2</th>
<th>b3</th>
<th>b4</th>
<th>b5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>a1</td>
<td>906</td>
<td>916</td>
<td>926</td>
<td>936</td>
<td>946</td>
<td>4630</td>
</tr>
<tr>
<td>a2</td>
<td>926</td>
<td>936</td>
<td>946</td>
<td>956</td>
<td>966</td>
<td>4730</td>
</tr>
<tr>
<td></td>
<td>1832</td>
<td>1852</td>
<td>1872</td>
<td>1892</td>
<td>1912</td>
<td></td>
</tr>
</tbody>
</table>

Next, it is necessary to calculate values used in computing the analysis summary table as follows:

\[
\text{SUMMATION} = \sum_{i=1}^{n} \sum_{j=1}^{p} \sum_{k=1}^{q} Y_{ijk} = 180 + 181 + \ldots + 194 = 9360.
\]

\[
\bar{Y} = \frac{(\sum_{i=1}^{n} \sum_{j=1}^{p} \sum_{k=1}^{q} Y_{ijk})^2}{npq} = \frac{(9360)^2}{(5)(2)(2)} = 1752192.
\]
\[ \text{ABS} = \sum_{i=1}^{n} \sum_{j=1}^{p} \sum_{k=1}^{q} Y_{ijk}^2 = (180)^2 + \ldots + (194)^2 = 1752820. \]

\[ A = \left( \sum_{i=1}^{n} \sum_{k=1}^{q} Y_{ijk}^2 \right) = \frac{(4630)^2 + (4730)^2}{(5)(2)(5)(2)} = 1752392. \]

\[ B = \left( \sum_{i=1}^{n} \sum_{j=1}^{p} Y_{ijk}^2 \right) = \frac{(1832)^2 + \ldots + (1912)^2}{(5)(2)(5)(2)} = 1752592. \]

\[ AB = \left( \sum_{i=1}^{n} Y_{ijk} \right)^2 = \frac{(906)^2 + \ldots + (966)^2}{5} = 1752792. \]

Then, \( \text{SSTO} = \text{ABS} - \bar{Y} = 628, \text{SSA} = A - \bar{Y} = 200, \text{SSB} = B - \bar{Y} = 400, \text{SSAB} = AB - A - B + \bar{Y} = .0004, \) and \( \text{SSWCELL} = \text{ABS} - AB = 28. \)

Table 3-3 shows the final analysis summary table. The greatest variance can be attributed to \( A \) with an \( F \) value of 286. This is compared to a tabulated \( F \) (1, 40) value of 7.31 and is considered significant beyond the .01 alpha level. As these data represent engine temperature, the conclusion would be that temperature increased as a result
of engine revolutions per minute. The remaining variance, for B and AB, can be treated the same way for purposes of inference and description.

Table 3-3. ANOVA summary table

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>200</td>
<td>1</td>
<td>200</td>
<td>286</td>
</tr>
<tr>
<td>B</td>
<td>400</td>
<td>4</td>
<td>100</td>
<td>143</td>
</tr>
<tr>
<td>AB</td>
<td>0.0005</td>
<td>4</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>WCELL</td>
<td>28</td>
<td>40</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>630</td>
<td>49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A computer program was written using these same procedures to calculate any CRF-pq design. The program was written in the Basic language for use on the Commodore SX-64. This program is located in Appendix D.

**Linear regression**

Linear regression entails the calculation of the intercept, the slope, and, thus, formulating the regression equation. The intercept is the value of the dependent variable when the independent variable is zero. The slope refers to the increase in the dependent variable over a
given increase in the independent variable. The regression equation provides the means by which we can predict measurements. The intercept and slope allow inferences to be made concerning the correlation between the independent and dependent variables. For this study, inferences were made (in Chapter 5), concerning the slope of the line, or in other words, the effect that engine revolutions per minute had on temperature in the evaporator.

As discussed in the section above, concerning analysis of variance, hypothetical data can show how linear regression is accomplished. Five temperatures were recorded in the evaporator for each of the five revolution per minute levels. Temperature is the dependent variable and revolutions per minute is the independent variable. Using the least squares method as described by Lyman Ott in his book, "An Introduction to Statistical Methods and Data Analysis", the data can be tabulated as shown in Table 3-4 (Ott, 1984).

The intercept and the slope can then be calculated as follows:

\[ \alpha = y - \beta x = 72.8 - (-.02 \times 1400) = 100.8. \]
\[ B = \frac{S_{xy}}{S_{xx}} = \frac{-19200}{900000} = -0.02. \]

\[ S_{xy} = \frac{\sum xy - (\sum x)(\sum y)}{n} = 490400 - \frac{(7000)(364)}{5} = -19200 \]

and

\[ S_{xx} = \frac{\sum x^2 - (\sum x)^2}{n} = 10700000 - \frac{49000000}{5} = 900000. \]

Table 3-4. Linear regression tabulation

<table>
<thead>
<tr>
<th>x</th>
<th>x^2</th>
<th>y</th>
<th>y^2</th>
<th>xy</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>640000</td>
<td>84</td>
<td>7056</td>
<td>67200</td>
</tr>
<tr>
<td>1100</td>
<td>1210000</td>
<td>80</td>
<td>6400</td>
<td>88000</td>
</tr>
<tr>
<td>1400</td>
<td>1960000</td>
<td>74</td>
<td>5476</td>
<td>103600</td>
</tr>
<tr>
<td>1700</td>
<td>2890000</td>
<td>68</td>
<td>4624</td>
<td>115600</td>
</tr>
<tr>
<td>2000</td>
<td>4000000</td>
<td>58</td>
<td>3364</td>
<td>116000</td>
</tr>
</tbody>
</table>

| 7000| 10700000| 364| 26920 | 490400|

Finally, the regression equation is presented as \( \hat{y} = 100.8 + (-0.02 \times x) \).
In order to gain information necessary for inference concerning the slope, the standard error must be calculated as shown:

\[
Se = \sqrt{\frac{SEE}{n-2}} = \sqrt{\frac{12.27}{5-2}} = 3.3
\]

where \( SEE = Syy - \beta \cdot Sxy = 420.8 - (-0.02 \cdot -19200) = 36.8 \) and

\[
Syy = \frac{\sum y^2}{n} - \left( \frac{\sum y}{n} \right)^2 = 26920 - \frac{132496}{5} = 420.8.
\]

Using the t test for inferences concerning the slope,

\[
t = \frac{Se}{\sqrt{Sxx}} = \frac{-0.02}{0.004} = -5,
\]

it is possible to test the null hypothesis, "there is no significant decrease in the slope of the evaporator data." The \( t \) (4) value of -5 for a one tailed test is significant.
beyond the .005 alpha level. This leads to the rejection of the null hypothesis meaning that there was a significant decrease in the evaporator data. As with the analysis of variance, a computer program was written for linear regression. Although linear regression can be done easily using a hand calculator, the large number of data necessitated the computer program. This computer program is located in Appendix E. A simple number generator program was written to provide a file representing revolutions per minute. This computer program can be found in Appendix F.
CHAPTER 4: RESULTS

This chapter will cover the results of the statistical and observational treatment of the collected data that were discussed in Chapter 3. First is presented the analysis of variance concerning the engine and radiator temperatures. Then, a linear regression of the evaporator temperatures as a function of the revolution per minute levels is given. A graph illustrates the slope of the evaporator data. As the data were being collected, it became apparent that the refrigerant may have caused different slopes in the radiator temperatures. A further critical observance of the engine data indicated the same occurrence only to a lesser extent. Linear regression was used to obtain prediction equations, and these data were graphed to illustrate the differences. Finally, hypotheses two and three are presented concerning fuel consumption and pressure conditions.

Respective hypotheses are presented with each analysis and the significance was determined for each test. Discussion and actual conclusions for each hypothesis, including the overall working hypothesis, are presented in Chapter 5.
Analysis of Engine Data

As explained in Chapter 3, the engine data were treated with a completely randomized factorial analysis of variance. There were two treatments, representing the air conditioner being turned on or off, and five factors, representing the five selected revolution per minute levels. At each revolution per minute level, there were 120 data collected. This accounted for 600 data for each treatment or 1,200 for the analysis of variance.

Hypothesis four, provided in Chapter 1 in the null form, indicated there would be no significant difference in temperature as a result of the air conditioner. It can be seen, given the analysis of variance summary table (Table 4-1), that each of the F ratios reached significance at alpha levels less than .01. The largest variance can be attributed to the effect of the air conditioner being on with an F ratio of 2717.63. This is compared to the tabulated F (1,∞) value of 6.63. The factors representing the five revolution per minute levels were also significant with an F ratio of 1930.27. The tabulated F (4,∞) value is 3.32. According to the F ratio of 84.72 and a tabulated F (4,∞) value of 3.32, there was a significant interaction between treatments and factors.
Table 4-1. ANOVA summary table for engine data

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2129.89</td>
<td>1</td>
<td>2129.89</td>
<td>2717.63</td>
</tr>
<tr>
<td>B</td>
<td>6051.27</td>
<td>4</td>
<td>1512.82</td>
<td>1930.27</td>
</tr>
<tr>
<td>AB</td>
<td>265.58</td>
<td>4</td>
<td>66.39</td>
<td>84.72</td>
</tr>
<tr>
<td>WCELL</td>
<td>932.64</td>
<td>1190</td>
<td>0.78</td>
<td></td>
</tr>
</tbody>
</table>

TOTAL   | 9379.37 | 1199|

It is evident that the treatment of the system caused the engine to produce an increase in the average running temperature. In addition, this temperature increased in proportion to revolutions per minute. This led to the rejection of the null hypothesis in that the operation of the system does cause a significant increase in engine temperature.

Analysis of Radiator Data

In similar manner to the analysis of the engine data, the radiator data were treated with a completely randomized analysis of variance. The treatments and factors remained the same as they were for the engine data. The number of subjects for each factor was 120, which accounted for 1,200 data.
Again, Hypothesis four stated there would be no significant difference in temperature as a result of the air conditioner being turned on and subjected to the five varying revolution per minute levels. According to the $F$ ratios obtained by the analysis (Table 4-2), the hypothesis should be rejected. The $F$ ratio for the treatments was 1169.81 compared to a tabulated $F(1, \infty)$ value of 6.63. The factors accounted for a variance that led to an $F$ ratio of 1085.94. The tabulated $F(4, \infty)$ value is 3.32. As with the engine data, the radiator data revealed significant variance due to interaction. The AB effect $F$ ratio was 213.15 with a tabulated $F(4, \infty)$ of 3.32. Each of these $F$ ratios was significant beyond the .01 alpha level. Similar to the engine data, it is evident that there was a

Table 4-2. ANOVA summary table for radiator data

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>26818.48</td>
<td>1</td>
<td>26818.48</td>
<td>1169.81</td>
</tr>
<tr>
<td>B</td>
<td>99582.23</td>
<td>4</td>
<td>24895.56</td>
<td>1085.94</td>
</tr>
<tr>
<td>AB</td>
<td>19545.81</td>
<td>4</td>
<td>4886.45</td>
<td>213.15</td>
</tr>
<tr>
<td>WCELL</td>
<td>27281.23</td>
<td>1190</td>
<td>22.93</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>173227.77</td>
<td>1199</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


significant increase in radiator temperature as a result of the treatment. Therefore, hypothesis four is rejected.

Analysis of Evaporator Data

The evaporator was the vessel in the air conditioning system that was intended to absorb heat as a result of having refrigerant released through an expansion valve to a lower pressure. The temperature data were suspected to change as a result of the changing engine revolutions per minute. Therefore, the data were treated with a linear regression procedure with evaporator temperature as the dependent variable and revolutions per minute as the independent variable. Hypothesis five stated, in the null form, there would be no significant decrease in the temperature of the evaporator as affected by the engine revolutions per minute. The slope and the intercept were calculated along with the standard error of measurement. Then a t test for the slope was performed as explained in Chapter 3. The intercept was 97.31 and the slope was 0.037 showing an increase in temperature as a result of changing revolutions per minute. The t value, significant beyond the .005 alpha level, was 58.39. With an alpha level of .005, this value compares to a tabulated t (∞) value of 2.58. In conclusion, although the t value was significant, the significance was in regard to an increase in
temperature. As there was no decrease in temperature level of the evaporator, hypothesis five was retained. Figure 4-1 illustrates the slope that was established by the temperature increase in the evaporator over the revolutions per minute. Further discussion will be provided in Chapter 5 concerning why this increase in temperature took place and if any cooling did actually occur.

Figure 4-1. Evaporator temperature slope
Since there was actually an increase in temperature rather than a decrease, there was zero efficiency in utilizing residual engine heat for the removal of heat in the passenger compartment of the vehicle. Without the operational efficiency data, the linear regression concerning hypothesis six could not be performed. This left no basis to reject the null hypothesis. Therefore, it was undetermined as to whether or not there was an increase in the operational efficiency of the absorber system in relation to engine revolutions per minute. Recommendations will be given to prevent this in future studies and perhaps provide for a negative slope.

AB Interaction

As the testing was in progress it became apparent, by observing the data, that although the radiator was producing higher temperatures with the air conditioner turned on than when it was turned off, the slope was less. This was further supported by the high $F$ ratio of 213.15 concerning the AB effect revealed in the analysis of variance. The engine temperatures were also given consideration because of the $F$ ratio of 84.72. Therefore, linear regression analyses were performed on both engine and radiator temperature data to acquire the regression equation so these data could be graphed. Two linear
regression analyses were done for both engine and radiator temperature data to represent the two treatments. The temperature increase per treatment was the dependent variable and revolutions per minute was the independent variable. This provided 600 data for each test. The radiator data, without the air conditioner operating, produced an intercept of 131.4 and a slope of 0.03. With the air conditioner turned on, the intercept was 163.88 and the slope was 0.01. For the engine data without the air conditioner operating, the intercept was 188.01 and the slope was 0.0056. Finally, the engine data with the air conditioner turned on gave an intercept of 192.87 and a slope of 0.004. This indicates, although the treatment resulted in an increase in engine temperature, there was an increased cooling potential over the given temperature range.

There were no additional tests of significance concerning the intercepts and slopes because significance had already been established in the analysis of variance. Figure 4-2 graphs the change in radiator temperature slopes and Figure 4-3 shows the difference in engine temperature slopes. More discussion concerning this interaction will be given in Chapter 5.
Fuel Usage

The fuel was measured for each testing session by starting with 4 US gallons and measuring the difference upon completion of the testing. During the first data collection phase it became evident that the fuel would not last through the 2000 revolution per minute level. Therefore, the pump was diverted to accept unmeasurable fuel from the automobile fuel tank. During the second session, the tanks were switched accordingly. The comparison, then, is how much fuel was used for the first four revolution per minute levels.

Figure 4-2. Radiator temperature slopes
During the first testing session, the engine consumed 2.875 US gallons of fuel. During the second session, the engine consumed 3.00 US gallons. Given an inherent fluctuation of fuel consumption in typical power systems, and in consideration of possible error in measurement, subjective observation led to the conclusion that 0.125 of a gallon represents a negligible difference. This therefore, indicates a retention of hypothesis three.
stating there would be no observational change in fuel consumption.

Pressure

The pressure in the radiator was monitored throughout testing to prevent damage to the power system of the vehicle. During the first testing session, the pressures became high enough toward the end of the 2000 revolution per minute level to abort the testing (17 - 20 psi). However, the warning light never appeared and the testing was completed. After the engine was turned off, the coolant spewed from the relief valve. With the air conditioner in operation, the pressures remained quite low (5 - 7.5 psi) even at the higher revolution per minute levels. The coolant solution was not lost after the second testing session. Therefore, regarding hypothesis two, which stated the absorber system would not cause pressures that would be harmful to the power plant, there was no indication through visual observation that harmful pressures were reached.

Recommendations for further study concerning pressure will be given in Chapter 5.
In Chapter 4, the data were treated with various statistical and observational analyses. This chapter serves to explain the results of those analyses. First, the problem statement and objectives of this study are restated. Then, conclusions are drawn concerning each hypothesis. A summary and discussion follows in order to explain what and why the events of the study took place. Finally, recommendations are provided for further study in this area. This includes recommendations for repeating the study as well as proposed topics similar to this study.

Problem Statement and Objectives

The problem of this study was to utilize residual engine heat for the operation of an automobile air conditioner by converting an existing compressor type system into an absorption type system. The cooling system passages in the block of the engine became the generator. Here, the refrigerant was heated and separated from the water based absorber; thus the utilization of residual engine heat. The gas moved into the condenser, was released into the evaporator, and was then absorbed again in the radiator of the automobile. The refrigerant mixture
was then pumped back into the engine block through the existing engine water pump.

The specific objectives of this study are repeated as follows from Chapter 1.

1. To convert an existing compressor type automotive air conditioning system into an absorption type system. The cooling passages in the engine were used as the generator and the radiator was used as the absorber.

2. To compare engine and radiator temperature differences between trials with the absorber system operating to trials with the absorber system not operating; each at five different revolution per minute levels. This was intended to reveal any high temperatures that could be potentially damaging to the engine, and allow inferences to be drawn concerning the effect the absorber system has on these components.

3. To compare temperature differences of the evaporator to five different revolutions per minute levels.

4. To determine any increase in the operational efficiency of the absorber system at five different revolution per minute levels.

5. To determine if the pressure of the absorption system was harmful to the power plant.

6. To determine any increase in fuel consumption when the absorber system was in operation.
Conclusions

The following is a list of conclusions that were developed concerning the problem of this study and in regard to each hypothesis. They are based on the statistical and observational analyses covered in Chapter 4.

1. The compressor type system was converted into an absorption type system as designated by the problem of this study. However, it was concluded, in regard to hypothesis one, using the engine as the generator and the radiator as the absorber, as done in this study, was not feasible for passenger compartment cooling.

2. Visual monitoring during testing indicated the system caused a reduction of pressure in the radiator. This led to the conclusion that the system did not produce pressure levels that were harmful to the power plant.

3. For practical purposes, there was no significant change in fuel consumption as a result of the absorber system being turned on.

4. The temperature levels in the engine increased as a result of experimentation but were not high enough to cause damage to the power plant. The radiator temperature was also higher than normal. Therefore, regarding hypothesis four, it was concluded that the air conditioner system caused a significant increase in temperature in both the
5. The t test revealed a significantly positive slope in the evaporator temperature as a result of the revolution per minute levels. This strongly indicated, given the refrigerant mixture in this study, there was no cooling. In fact, this indicated a definite increase in temperature. This was supported by the difference in slopes of the radiator and the evaporator. If the slopes had been equal, removal of heat could have still taken place given the intercept of the evaporator data. If the slope of the evaporator had been less than that of the radiator, regardless of it being positive or negative, it would have indicated removal of heat provided the intercept was less. However, the slope of the evaporator was positive and was greater than the slope of the radiator. This led to the retention of hypothesis five in that there was no significant decrease in evaporator temperature.

6. As there was no removal of heat in the evaporator, the operational efficiency was zero at all revolution per minute levels. This voided hypothesis six as there was no measurement to analyze.

Researcher's Discussion

The following section includes a short summary of the study, with the findings and conclusions, followed by a
discussion concerning the results of the study.

Summary

The problem of this study was to build and test an absorption type air conditioning system for automotive use that would utilize residual engine heat. The waste heat was to be reclaimed from the engine which was being used as the system's generator. The radiator was used as the system's absorber. The intent of the testing was to determine changes and potential damage resulting from operation of the system. The engine and radiator were of primary concern regarding potentially dangerous effects. The evaporator was tested to determine how effective the system was and operational efficiencies were to be calculated and graphed to support the results. Fuel consumption was measured to determine a possible difference, and pressure was monitored to control exceeding limits.

A review of literature was given in Chapter 2 providing information concerning the history, state-of-the-art, and future aspects of air conditioning; basic heat and thermodynamic theory; and refrigerants. Particular attention was given to studies dealing with automotive absorption air conditioning.

Temperature data were collected, using a Commodore
SX-64, and were analyzed using the respective statistical and observational designs. The engine and radiator data were analyzed using a completely randomized factorial analysis of variance. The evaporator data were analyzed with linear regression and graphed. As an interaction occurred in the engine and radiator data, linear regression was used to gain further information. These data were also graphed. Fuel consumption was measured for both treatments and subjectively compared, and pressure was visually monitored throughout testing.

The variance attributed to the effect between groups and within groups, for both engine and radiator data, was significant beyond the .005 alpha level. The interaction in both cases was significant to that same capacity. The slope was positive in the evaporator data indicating no removal of heat took place. Therefore the operational efficiency was zero. The difference in fuel consumption was negligible and the pressure maintained safe limits.

As stated elsewhere in this chapter, it was determined the system, as used in this study, was not feasible. The temperatures in the engine and radiator were too high, inhibiting the removal of heat in the evaporator. Since there was a positive slope in the evaporator data, the operational efficiency was zero for all revolution per minute levels. The pressure did not exceed safe limits and
the difference in fuel consumption was negligible.

Discussion

The utilization of residual engine heat for the operation of an absorption type air conditioner is quite feasible. Several studies, found in Chapter 2, support this notion. However, using the engine as the generator and the radiator as the absorber in the absorber type system, as it was done in this study, is not feasible. Even with the very low mixture of ammonia used in this study (2 percent), the engine was considerably warmer than normal. In addition, the radiator, experiencing the same condition, proved to be ineffective in the absorption of the refrigerant. The main problem with this type of system concerns the volume of the cooling passages in the engine and radiator. As the refrigerant mixture increased in temperature and more ammonia was liberated from the engine, the cooling capacity of the original system became deficient. This caused higher temperatures and potential overheating.

The pressure in the system during testing remained lower than normal. This finding at first seemed contradictory to the relationship of pressure with temperature. However, the pressure, to a certain extent, was being controlled by a greater area of heat exchangers.
In addition to the radiator, the cooling system was losing heat through the condenser and evaporator of the air conditioning system. This is also a possible explanation for the AB interactions mentioned in Chapter 4. The average temperature increased as the system was employed which was caused by a deficient cooling fluid capacity. However, the proportional gain in temperature to revolutions per minute was less because of the increased area of heat exchangers.

To accomplish cooling in the evaporator with the given system of this study, more refrigerant would have to be used. The 2 percent solution that was used for this study was too little an amount to overcome the high temperatures given the temperature and pressure difference between the engine and radiator. Thermodynamically, the eutectic ammonia solution would be 20 percent. However, given a cooling fluid capacity of 4.5 gallons, this would reduce the fluid level by approximately 1 gallon. This, of course, would ensure overheating and possible damage to the power plant. This simple but unforeseen problem led to the general conclusion that conversion from a compressor to absorption type system as attempted in this study was not feasible.
Recommendations

The following recommendations are intended for further study in aspects of repeating the given study or pursuing related research.

1. The design of a system to increase the cooling fluid capacity of the power plant. This would enable a stronger aqua-ammonia solution to be used while preventing increased temperatures.

2. The utilization of an auxiliary heat exchanger connected to the radiator to be used as the absorber. This would increase the temperature difference between the generator and the absorber and ensure greater circulation of refrigerant.

3. The utilization of a pressure regulated flow valve to automatically regulate the flow of refrigerant into the system.

4. The use of an ammonia expansion valve to provide for a greater efficiency in the release of the refrigerant into the evaporator. This increased efficiency will maximize the cooling effect of the refrigerant moving into a lower pressure.

5. The use of noncorrosive materials when working with ammonia solutions. Ammonia, when exposed to water, is corrosive to copper based metals.

6. The study of an absorber system with varying
degrees of refrigerant mixtures and how that affects pressure.

7. The design of an absorber type system unincorporated with the cooling system of the power plant. Residual heat would still be used but would be claimed from the exhaust system. This type of design would necessitate the use of an additional pump to circulate the refrigerant solution. This pump could possibly be incorporated in the design of the existing water pump.

8. The design of a Rankine system utilizing residual heat to create pressure with the working fluid and power a prime mover. This prime mover could, in turn, be used to power accessories on the power plant such as alternators, water pumps, and oil pumps.
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These consist of pages:

APPENDIX A: 80-89

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____________________

____________________

____________________

____________________
APPENDIX B:

INTERFACE SCHEMATIC

JOY 3  JOY 1

JOY 2  JOY 0

POT Y

POT X  GND

+5 VOLTS  BUTTON

0.0349 mf CAPACITANCE

10000 OHM THERMISTER
APPENDIX C:

MERGE

READY.

18 OPEN 5,8,5,"0:ENG1,S,R"
20 OPEN 6,8,6,"0:ENG2,S,R"
30 OPEN 3,8,3,"@:ENG,S,W"
35 PRINT"RFILE ONEr"
40 FOR I=1 TO 600
45 INPUT# 5,ENG1
50 PRINT# 3,ENG1
55 PRINT ENG1
60 NEXT I
62 PRINT
65 PRINT"RFILE TWOR"
70 FOR L=1 TO 600
75 INPUT# 6,ENG2
80 PRINT# 3,ENG2
85 PRINT ENG2
90 NEXT L
92 CLOSE 5
94 CLOSE 6
96 CLOSE 3
98 PRINT
100 PRINT"***********************"
110 PRINT"***RNEXT MERGER***"
115 PRINT"***********************"
120 PRINT
180 OPEN 7,8,7,"0:RAD1,S,R"
200 OPEN 8,8,8,"0:RAD2,S,R"
300 OPEN 4,8,4,"@:RAD,S,W"
350 PRINT"RFILE ONEr"
400 FOR I=1 TO 600
450 INPUT# 7,RAD1
500 PRINT# 4,RAD1
550 PRINT RAD1
600 NEXT I
620 PRINT
650 PRINT"RFILE TWOR"
700 FOR L=1 TO 600
750 INPUT# 8,RAD2

READY.
800 PRINT# 4, RAD2
850 PRINT RAD2
900 NEXT L
920 CLOSE 7
940 CLOSE 8
960 CLOSE 4
1000 END

READY.
APPENDIX D:

CRF-pq

READY.

10 REM ****************************
12 REM ***** SET UP ROUTINE *****
14 REM ****************************
16 PRINT"s"
20 PRINT"BEFORE RUNNING THIS PROGRAM, WRITE"
30 PRINT"FILE NAME IN LINES 100, 300, 330 AND"
40 PRINT"335 IN THE SPACE PROVIDED"
46 PRINT
47 PRINT"HAS THIS BEEN DONE?":INPUT S$
48 IF S$ = "N" THEN 5000
50 PRINT"s"
60 PRINT"THIS PROGRAM ALLOWS YOU TO COMPUTE A"
61 PRINT"COMPLETELY RANDOMIZED FACTORIAL"
62 PRINT"ANALYSIS OF VARIANCE WITH A CRF-PQ"
63 PRINT"DESIGN"
65 PRINT
66 PRINT"HOW MANY A TREATMENTS?":INPUT P
67 PRINT"HOW MANY B TREATMENTS?":INPUT Q
68 PRINT"NUMBER OF VARIABLES IN EACH"
69 PRINT"B TREATMENT?":INPUT N
70 PRINT
71 PRINT"MAKE SURE DATA DISK IS IN DRIVE 8"
75 PRINT"PRESS RETURN WHEN READY"
80 GET P$: IF P$<>CHR$(13) THEN 80
82 PRINT"s"
84 PRINT"PLEASE WAIT"
93 REM ****************************
96 REM ***** DATA RETRIEVAL *****
99 REM ****************************
100 OPEN 8,8,8,"O:BEEP,S,R"
130 AS=0
150 A=1
160 FOR F=1 TO (Q*P)
200 X=0

READY.
250 FOR I=1 TO N
300 INPUT# 8, BEEP
330 X=X+BEEP
335 AS=AS+(BEEP^2)
500 NEXT I
510 A(I)=X
515 SM=SM+X
540 A=A+1
550 NEXT F
600 CLOSE 8
630 Y=((SM^2)/(N*P*Q))
650 A=0
690 PRINT
700 REM *********************************************
702 REM ** PRELIMINARY COMPUTATIONS **
704 REM *********************************************
706 PRINT
708 REM *** A DESIGNATION ***
710 PRINT
725 O=Q
745 R=0
747 K=0
748 T=1
750 FOR Z=1 TO P
760 FOR L=T TO O
780 R=R+A(L)
785 NEXT L
790 T=T+Q
795 O=O+Q
800 B(Z)=R
810 K=K+(B(Z)^2)
815 R=0
820 NEXT Z
830 A=K/(N*Q)
1000 PRINT
1002 REM *** B DESIGNATION ***
1004 PRINT
1009 K=0
1010 R=0
1020 O=P
1030 FOR Z=1 TO Q
1040 FOR L=Z TO (O*Q) STEP Q
1050 R=R+A(L)
1060 NEXT L
1070 C(Z)=R
1080 K=K+(C(Z)^2)
1090 R=0

READY.
95

1100 NEXT Z
1110 B=K/(N*P)
2000 PRINT
2010 REM ***** AB DESIGNATION *****
2020 PRINT
2030 R=0
2040 FOR Z=1 TO (P*Q)
2050 R=R+(A(Z)^2)
2060 NEXT Z
2070 AB=R/N
3000 REM ******************************
3010 REM *** FINAL COMPUTATIONS ***
3020 REM ******************************
3030 S1=AS-Y
3040 S2=A-Y
3050 S3=B-Y
3060 S4=(AB-A-B)+Y
3070 S5=AS-AB
4000 REM ******************************
4010 REM ***** ANOVA SUMMARY *****
4020 REM ******************************
4025 G=S5/(P*Q*(N-1))
4030 PRINT"RA TREATMENT"
4040 PRINT"SS="S2
4050 PRINT"DF="P-1:DF=P-1
4060 PRINT"MS="S2/DF:MS=S2/DF
4070 PRINT"F="MS/G
4080 DF=0:MS=0:F=0
4090 PRINT"RB TREATMENT"
4100 PRINT"SS="S3
4110 PRINT"DF="Q-1:DF=Q-1
4120 PRINT"MS="S3/DF:MS=S3/DF
4130 PRINT"F="MS/G
4140 DF=0:MS=0:F=0
4150 PRINT"RAB EFFECT"
4160 PRINT"SS="S4
4170 PRINT"DF="(P-1)*(Q-1):DF=(P-1)*(Q-1)
4180 PRINT"MS="S4/DF:MS=S4/DF
4190 PRINT"F="MS/G
4200 DF=0:MS=0:F=0
4210 PRINT"WITHIN CELL"
4220 PRINT"SS="S5
4230 PRINT"DF="P*Q*(N-1):DF=P*Q*(N-1)
4240 PRINT"MS="S5/DF
4250 DF=0
4270 PRINT"RTOTAL"

READY.
4280 PRINT"SS="S1
4290 PRINT"DF="(N*P*Q)-1
4400 REM *** HARD COPY ***
4410 PRINT"DO YOU WANT A HARD COPY?":INPUT O$ 
4415 IF O$="N" THEN 5000
4420 OPEN 1,4,0
4422 CMD 1
4425 G=S5/(P*Q*(N-1))
4430 PRINT"RA TREATMENTS"
4440 PRINT"SS="S2
4450 PRINT"DF="P-1:DF=P-1
4460 PRINT"MS="S2/DF:MS=S2/DF
4470 PRINT"F="MS/G
4480 DF=0:MS=0:F=0
4490 PRINT"RB TREATMENTS"
4500 PRINT"SS="S3
4510 PRINT"DF="Q-1:DF=Q-1
4520 PRINT"MS="S3/DF:MS=S3/DF
4530 PRINT"F="MS/G
4540 DF=0:MS=0:F=0
4550 PRINT"RAB EFFECT"
4560 PRINT"SS="S4
4570 PRINT"DF="(P-1)*(Q-1):DF=(P-1)*(Q-1)
4580 PRINT"MS="S4/DF:MS=S4/DF
4590 PRINT"F="MS/G
4600 DF=0:MS=0:F=0
4610 PRINT"WITHIN CELL"
4620 PRINT"SS="S5
4630 PRINT"DF="P*Q*(N-1):DF=P*Q*(N-1)
4640 PRINT"MS="S5/DF
4650 DF=0
4670 PRINT"RTOTAL"
4680 PRINT"SS="S1
4690 PRINT"DF="(N*P*Q)-1
4695 CLOSE 1
5000 END

READY.
APPENDIX E:
LIN REG

READY.

10 PRINT"s"
20 PRINT"THIS PROGRAM ENABLES THE COMPUTATION OF"
30 PRINT"LINEAR REGRESSION"
40 PRINT
42 PRINT"N = "; INPUT N
44 PRINT
46 DIM X(N):DIM Y(N)
47 PRINT
48 PRINT"NAME FILES ON LINES 90 AND 122"
49 PRINT
50 PRINT"PLACE DISK IN DRIVE"
60 PRINT
70 PRINT"PRESS RETURN WHEN READY"
80 GET B$: IF B$<>CHR$(13) THEN 80
82 PRINT"s"
84 PRINT"PLEASE WAIT"
90 OPEN 3,8,3,"0:NAME,S,R"
100 FOR I=1 TO N
110 INPUT# 3,X(I)
120 NEXT I
121 CLOSE 3
122 OPEN 4,8,4,"0:NAME,S,R"
123 FOR L=1 TO N
124 INPUT# 4,Y(L)
125 NEXT L
126 CLOSE 4
131 :
132 REM *****MEAN AND SUMATION OF X***
133 :
135 MX=0:EX=0:XS=0
140 FOR I=1 TO N
150 EX=EX+X(I)
160 XS=XS+(X(I)^2)
170 NEXT I
180 MX=EX/N

READY.
190 :  
200 REM *****MEAN AND SUMATION OF Y***  
210 :  
220 MY=0: EY=0: YS=0  
230 FOR L=1 TO N  
240 EY=EY+Y(L)  
242 YS=YS+(Y(L)^2)  
244 NEXT L  
246 MY=EY/N  
250 :  
260 REM *****SUMATION OF XY***  
270 :  
275 XY=0  
280 FOR H=1 TO N  
290 XY=XY+(X(H)*Y(H))  
300 NEXT H  
450 :  
460 REM *****SXX AND SXY***  
470 :  
480 SX=XS-((EX^2)/N)  
490 SY=XY-((EX*EY)/N)  
500 :  
510 REM *****FINAL COMPUTATIONS***  
520 :  
530 B=SY/SX  
540 A=MY-(B*MX)  
550 SL=YS-((EY^2)/N)  
560 SE=SL-(B*SY)  
570 ER=SQR(SE/(N-2))  
580 T=B/(ER/SQR(SX))  
585 PRINT"s"  
590 PRINT"SLOPE = "B  
595 PRINT  
600 PRINT"INTERCEPT = "A  
605 PRINT  
610 PRINT"STANDARD ERROR = "ER  
615 PRINT  
620 PRINT"T-TEST = "T  

READY.
APPENDIX F:
RPM GENERATOR

READY.

10 OPEN 4,8,4,"0:RPM,S,W"
20 F=800
30 FOR T=1 TO 5
40 FOR I=1 TO 120
50 PRINT# 4,F
60 PRINT F
70 NEXT I
80 F=F+300
90 NEXT T
100 CLOSE 4

READY.
APPENDIX G:
EXPERIMENTATION NOTES

July 2, 1987 (Treatment A)

1. Engine was let to run for 15 minutes while engine and radiator warmed up. There were exactly 4 gallons of fuel prior to data collection and warm up. Thermisters were in place.

2. No gas leaks, no evidence of overheating, and engine appears to be running smooth. No abnormal build up of pressure, RPM is stable. Will commence 800 RPM collection.

3. Half way through 800 RPM. Engine in stable at 192.29. Radiator temperature is 157.11. I anticipate an increase in temperature when the thermostat opens.

4. 800 RPM session complete. All systems OK. Engine = 192.29, radiator = 154.48 and fluctuating. Moving to 1100 RPM.

5. 1100 RPM in progress. Engine = 191.02, radiator = 163.44.

6. Half way through 1100 RPM. No problems. Engine = 194.74, radiator = 171.02.

7. 1100 RPM now complete. Engine = 195.98, radiator = 170.05. All systems OK. Now going to 1400 RPM. I hope the fuel holds out.
8. 1400 RPM in progress. Engine unchanged, radiator 175.93.

9. Half way through 1400 RPM. Everything performing as expected. Engine = 197.23, radiator = 175.93.

10. 1400 RPM now complete. No problems. Engine = 197.23, radiator = 173.95. Now going to 1700 RPM.

11. 1700 RPM in progress. Radiator up to 179.96. Radiator temperature progressively increasing. Engine running well, pressures are still low. I wonder if the gauges works?

12. Half way through 1700 RPM. Pressure has increased to 10 psi. Temperature remains unchanged. Still no obvious problems.

13. Automobile fuel tank spewed fuel from the intake hose. I think it is because of the heat and completely unrelated to the testing.

14. Temperature differences have decreased to point that I do not think the air conditioner will work.

15. I believe the fuel will run out. I am switching to the auxiliary tank for the 2000 RPM. Engine = 198.48, radiator = 179.96. 1700 RPM now complete.

16. 2000 RPM in progress. Pressure increased, temperature remains the same.

17. Will revise design to measure first four RPM levels only.
18. Radiator starting to discharge pressure. Red light is not on. One third way through 2000 RPM.

19. Half way through. Temperature remains the same.

20. Radiator pressure = 15 psi. Continues to discharge slightly. Two thirds through 2000 RPM. All systems seem to be stable.

21. No leaks this far. 2000 RPM coming to a close.

22. 2000 RPM now complete.

23. Radiator discharged a considerable amount of fluid when engine was turned off.

July 10, 1987 (Treatment B)

1. Installed a 2 percent mixture of ammonia in the cooling system.

2. Warm up taking place, thermisters in place, all systems go. Commencing 800 RPM. Air conditioner flow valve opened.

3. Half way through 800 RPM. All systems OK. Heating has occurred in the evaporator. Evaporator temperature = 122.48, engine = 194.77, radiator = 169.94. No smell of ammonia this far.

4. Nearing completion of 800 RPM level. No excessive pressures, no leaks. Temperature of the evaporator
continues to increase (129.03). Now going to 1100 RPM.

5. Half way through 1100 RPM. Temperatures are high. Engine = 199.77, radiator = 182.54, evaporator = 142.76. Pressure has increased slightly.

6. Heard a whistling noise for just a second. I do not know what it was.

7. Nearing end of 1100 RPM. Engine 199.77, radiator 184.63, evaporator = 146.24. Moving to 1400 RPM.

8. Half way through 1400 RPM. Temperatures are the same. Evaporator = 153.51.

9. The refrigerant is circulating in the correct direction as can be seen through the sight bubble in the accumulator.

10. Approaching completion of 1400 RPM. Engine same, radiator = 177.00, evaporator = 157.29. Moving now to 1700 RPM. Pressure unchanged.

11. Pressure increased to approximately 7.5 psi.

12. It appears, through the sight bubble, that the refrigerant has stopped or at least slowed down.

13. Evaporator temperature = 162.16, radiator = 182.45.

14. Half way through 1700 RPM. No apparent problems. Pressure fluctuating between 5 and 7.5 psi.

15. 1700 RPM near complete. Switching fuel to auxiliary tank and moving to 2000 RPM.

16. Engine = 199.77, radiator = 180.31, evaporator
17. Is the pressure being controlled by the evaporator?
19. Refrigerant flow appears to have stopped.
20. A study should be done using pressure as the criterion.
22. Although pressure increased after turning the engine off as expected, the coolant did not spew out.
REFERENCES


