A WOOD FUELED REDUCTION KILN FEASIBILITY STUDY CONDUCTED TO DETERMINE THE EFFECT OF PREHEATED COMBUSTION AIR ON KILN TEMPERATURE OUTPUT AND FUEL CONSUMPTION

A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF MASTER OF ARTS IN FINE ARTS

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CHAPTER ONE

STATEMENT OF THE PROBLEM

Purpose of the Study

The purpose of the study is to identify an effective method for improving the efficiency of a wood fueled downdraft kiln.

Rationale

The rationale for the study is in the development of a method for:

1. Economically fueling a kiln. With the ever present rise in fossil fuel costs comes the need for efficient means with which to fire ceramic ware. Identifying an effective method of fueling a kiln becomes a very significant endeavor. The writer has seen little documentation of research on preheated combustion air as it relates to the potter craftsman.
2. Fueling a kiln that is environmentally efficient. With proper recycling of waste, wood is a replenishable resource rather than a diminishing one, i.e., fossil fuels.
3. Firing a kiln that allows the craftsperson insight into the nature of fire and energy itself. When fueling a wood kiln, the craftsperson becomes an integral part of

the growth and development of the fire. A lot of the energy consumed in the firing is the actual physical exertion in the stoking of the fireboxes. The crafts-person learns quickly to appreciate this energy and avoids waste.

4. Aesthetically enhancing the surface texture of the ware. As early as the Fourteenth Century, the Japanese potters appreciated the aesthetic potential of fluxing wood ash on their ware. The wood ash gives the ware a true burnt lustre.

Background

The writer's initial experience with wood kilns was a two day workshop sponsored by the North Texas Crafts Guild in the Spring of 1977. The workshop was conducted under the direction of ceramic artist Howard Shapiro. The writer participated in constructing and firing a large tunnel kiln, a smoking pit kiln, and a Raku kiln, all fueled with wood. This experience gave the writer a sense for the tremendous heat and the importance of a good air and fuel mixture.

In March 1978, the writer attended a wood kiln building workshop at the studio home of Finn and Ishmael Soto. The ten day workshop convinced him that an efficient wood kiln was possible. The idea for the experiment began at this workshop.

Delimitations

The study is not intended to represent an inclusive investigation of all variables dealing with the topic of preheated combustion air and its effects on the functioning of a wood kiln. The scope of the study is as follows:

1. Construct a brick, wood fueled, downdraft kiln with two fireboxes.

   MATERIALS: Standard sizes of refractory hard and soft brick, fireclay for mortar, refractory setter tiles, angle iron, and expanded sheet metal.

   EQUIPMENT: Oxygen/gas cutting equipment, welder, level and trowel.

2. Prepare fuel.

   MATERIALS: Chain saw and wood rack.

3. Monitor vital signs of kiln during firing cycles.

   a. Monitor temperature in ware chamber.

   b. Monitor fuel consumption.

   MATERIALS: Pyrometric cones, pyrometer, woodrack and clock.

4. Redesign the fire boxes to allow for the preheating of combustion air.

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[1]Note: The monitoring of the kiln was done for five firings.

MATERIALS: Refer to Materials Chart, Appendix I, Figure 5.

Methods and Procedures

The study is not intended to represent an inclusive investigation of all variables dealing with the topic of preheating combustion air and its effects on the function of a wood kiln. The scope of the study is as follows:

1. The construction of the kiln is accomplished by incorporating traditional masonry techniques with fireclay for mortar. Angle iron is welded for the frame support of the kiln. The foundation is one layer of refractory setter tiles and one layer of refractory hardbrick on a concrete slab. The kiln walls and fireboxes are constructed in alternating patterns of header courses and soldier courses. Because of its strength and radiant properties, refractory hard brick is used on the inside soldier course. Because of its insulating properties, refractory softbrick is used on the outside soldier course. (Refer to Appendix I, Figure 1 for details of floor design and layout.) The chamber arch is constructed with hard arch brick, nine inches thick. A very high grog castable is used on top for insulation. The chimney is constructed nine inches thick with hard brick and setter tiles. The last nine

feet is three thirty-gallon barrels welded together. After all masonry work is completed, angle iron is cut and welded at every corner. The firebox doors are constructed of ¼" sheet metal with a Kaowool lining. Ceramic buttons and nicrome wire are used to secure the Kaowool in place.

2. The fuel is in the form of throw-away wooden pallets. The wood is of hard and soft varieties. Preparation is accomplished by cutting the pallets with a chain saw to desired lengths.

3. The temperature of the ware chamber is monitored with Orton Pyrometric cones and pyrometers. The temperature of the preheated air is monitored with a pyrometer. Weather conditions are taken from local weather fore-casts for the day.

Definition of Terms

1. Ashpit floor - term used for bottom of firing chamber. Michael Cardew, Pioneer Pottery (New York: St. Martin's Press, Inc., 1969), p. 176.

2. Bourry Firebox - firebox design developed by Emile Bourry. Emile Bourry, Treatise on Ceramic Industries, trans. A. B. Searle, 4th English ed. (London: Scott Greenwood, 1926), p. 206.

3. B.T.U. (British Thermal Unit) - the amount of heat required to raise one pound of water one degree F. Robert T. Haslam, Fuels and Their Combustion (New York: McGraw-Hill Book Company, 1926), p. 138.
4. Calorific value - the number of units of heat produced by the complete combustion of unit weight of the fuel. Robert T. Haslam, Fuels and Their Combustion (New York: McGraw-Hill Book Company, 1926), p. 138.
5. Damper - a valve or plate for regulating the draft. Webster's New Collegiate Dictionary (1977), p. 287.
6. Efficiency - effective operation as measured by a comparison of production with cost (as in energy, time and money). Webster's New Collegiate Dictionary (1977), p. 362.
7. Hobb - a ledge in the firebox which elevates the wood off the ashpit floor. (Buck, 1980.)
8. Primary Air - main source for air to mix with fuel for combustion. Michael Cardew, Pioneer Pottery (New York: St. Martin's Press, Inc., 1969), p. 177.
9. Pyrometer - instrument for measuring temperatures. Webster's New Collegiate Dictionary (1977), p. 941.
10. Reduction - term used to describe atmosphere of the kiln chamber when the air supply is decreased to achieve specific desired results on the ware. (Buck, 1980.)

11. Secondary air - alternate source of air that will join primary air inside of throat arch for combustion of the fuel. Michael Cardew, Pioneer Pottery (New York: St. Martin's Press, Inc., 1969), p. 177. (Refer also to Appendix I, Figure 2.)

12. Waste wood - wood that is discarded, thus not being fully consumed. (Buck, 1980.)

CHAPTER II

REVIEW OF RELEVANT LITERATURE

Most potters will agree "it is a very efficient kiln which can gather 30% of the heat generated."[1] We can assume that waste heat (heat that leaves the kiln unused) is 60-70% of the heat generated. To recapture any of this waste heat can only increase the efficiency of the kiln. The chief means of recovering this waste heat is by "recuperators or generators which transfer the greater part of the heat to the air entering the kilns and used for the combustion of the fuel."[2] If this secondary air can be preheated, the flames become hotter and an energy savings can be realized.[3]

Historically, according to F. W. Hodkin, glass manufacturers first used waste heat to preheat gases before they were burned.[4] "The Siemen's regenerative furnace was

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[1]Bernard Leach, A Potter's Book (New York: Trans-atlantic Arts, Inc., 1946), p. 178.

[2]Emile Bourry, A Treatise on Ceramic Industry, trans. A. B. Searle, 4th English ed. (London: Scott Greenwood, 1926), p. 206.

[3]Bernard Leach, A Potter's Book (New York: Trans-atlantic Arts, Inc., 1946), p. 205.

[4]F. W. Hodkin and A. Cousen, A Textbook of Glass Technology (London: Constable and Company, Ltd., 1925), p. 335.

first tried successfully in 1868 at the plate-glass works in St. Gobain, France."[1] The use of preheated combustion air has had wide use in the brick and glass industries where continuously fired kilns are employed. The most efficient utilization of heat is in kilns that work continuously.[2] The more the kiln is used the more economical it becomes to invest in a heat recovery system.[3] The use of heat recovery systems is not widespread in the pottery craft. One reason is "because no one produces for sale the kind of equipment necessary for such a system.[4] The energy consumed in the purchase, fabrication and installation of such a system often absorbs any energy savings realized.

Because of the various stages of combustion with wood, secondary combustion air becomes essential. The main purpose of secondary air, in the wood fueled kiln, is to burn the gas produced by the primary combustion of the

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[1]F. W. Hodkin and A. Cousen, A Textbook of Glass Technology (London: Constable and Company, Ltd., 1925), p. 335.

[2]Emile Bourry, A Treatise on Ceramic Industry, trans. A. B. Searle, 4th English ed. (London, Scott Greenwood, 1926), p. 203.

[3]Buddy, Francis, "Heated Air Combustion Systems for Pottery Kilns," Studio Potter (Spring 1979), p. 61.

[4]Ibid., p. 61.

fuel.[1] According to Michael Cardew, secondary combustion air "represents about 40% of the calorific value of the fuel. If no secondary air were admitted, the firebox would act as a gas producer, the valuable gases from which would be unable to burn where they are needed."[2] When wood burns it releases resins which do not ignite until they have sufficient oxygen. In a wood kiln, this sufficient supply of oxygen may be found in the ware chamber rather than in the firebox.[3] This release of energy in the ware chamber, according to Bourry is "in theory, the most economical, because it uses the heat as soon as it is liberated, and should be preferred to all others whenever it can be used."[4]

This secondary combustion air becomes even more valuable when preheated. "Cold secondary air is almost as bad as no secondary air at all, since it is unable to burn

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[1]Emile Bourry, A Treatise on Ceramic Industry, trans. A. B. Searle, 4th English ed. (London, Scott Greenwood, 1926), p. 204.

[2]Michael Cardew, Pioneer Pottery (New York: St. Martin's Press, 1969), p. 178.

[3]William Alexander, "Wood," Pottery Quarterly, 12 (1978): 45, p. 12.

[4]Emile Bourry, A Treatise on Ceramic Industry, trans. A. B. Searle, 4th English ed. (London, Scott Greenwood, 1926), p. 204.

the particles of solid carbon which are mixed with the gases liberated in the firebox.[1] An excess of air causes a reduction in the temperature of combustion, but the reduction is less pronounced when the air is preheated. This creates a higher temperature of combustion which in turn creates a higher flame temperature.[2]

Until recent times, wood was the fuel most often used in ceramic production. Japanese high temperature stoneware and porcelain are still fired with a wood kiln as is the salt-glazed stoneware of Germany.[3] Because of the present abundance of natural gas, wood is seldom used today as a fuel to fire pottery. Only where sufficient waste, i.e., from sawmills and fabrication shops, can be found is wood considered an economic energy alternative. According to William Alexander, there are several good reasons for using wood as a fuel: "It is relatively pure, i.e., it has in its composition no materials which are detrimental to the ware such as sulphur compounds, etc.; it burns with a long flame

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[1]Michael Cardew, Pioneer Pottery (New York: St. Martin's Press, 1969), p. 178.

[2]F. W. Hodkin and A. Cousen, A Textbook of Glass Technology (London: Constable and Company, Ltd., 1925), p. 328.

[3]William Alexander, "Wood," Pottery Quarterly, 12 (1978):45, p. 12.

which is helpful in producing even kiln temperatures; it leaves little residue; and it is capable of reaching the highest temperatures used in pottery."[1]

Certain varieties of wood burn much more efficiently than do others. For the generation of high temperatures the wood must combust quickly, releasing large quantities of heat rapidly. Hardwood produces less heat than softwood.[2] (See Appendix II, Figure 1.) There are two distinct advantages apparent in softwoods for fuel. One "lies in its greater resin content (than hardwood), and two, it has a lower specific gravity which exposes more surface per unit of weight thereby speeding combustion."[3]

Moisture content is the most important variable that affects the value of wood and bark as fuel.[4] Wood containing 20% water (a normal figure for air dried wood) uses more than one-third of its energy for water vaporization.[5]

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[1]William Alexander, "Wood," Pottery Quarterly, 12 (1978):45, p. 12.

[2]Ibid.

[3]Ibid.

[4]Michael L. Hiser, Wood Energy, Proceedings of Governor William G. Milliken's Conference (Ann Arbor, Michigan: Ann Arbor Science Publishers, Inc., 1977), p. 45.

[5]William Alexander, "Wood," Pottery Quarterly, 12 (1978):45, p. 13.

For wood with 10% moisture content, approximately 100 B.T.U.'s are required to vaporize the 0.1 pound of water per pound of fuel; whereas wood with 50% moisture content requires about 500 B.T.U.'s to vaporize the half pound of water per pound of fuel.[1]

Since this study focuses principally on a combustion system for wood, a discussion of the stages of wood combustion becomes relevant. According to R. A. Arola, "there are three primary stages associated with the combustion of wood; the evaporation of the moisture in the fuel, the distillation and the burning of the volatiles, and the combustion of the fixed carbon."[2] (See Appendix II, Figure 2.) As was stated earlier, "the resin content of wood contributes greatly to these gases [in stage I, see chart Appendix II, Figure 2] and the greater the resin content, the greater the heat release in this initial combustion."[3] In stage III [see chart Appendix II, Figure 2] the combustion of the

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[1]R. A. Arola, quoted in <u>Wood Energy</u>, Proceedings of Governor William G. Milliken's Conference by Michael L. Hiser (Ann Arbor, Michigan): Ann Arbor Science Publishers, Inc., 1977), p. 45.

[2]Ibid.

[3]William Alexander, "Wood," <u>Pottery Quarterly</u>, 12 (1978):45, p. 13.

volatile gases may not occur until they reach the chamber itself, where sufficient secondary air is available.

Besides being an efficient fuel in terms of heat production, wood also contributes greatly to the aesthetic beauty of the ceramic ware. "There are certain subtleties and qualities of colour, texture and depth which woodfiring, properly managed, will give you as it were a free gift."[1] Bernard Leach addresses the topic of the effects of wood-firing on the beauty of the ware. "Quite a large proportion of the most pleasing kiln effects were, in the days of manual labor, due to accidental happenings only partly under the control of the potters. The use of wood in firing has always contributed largely to such effects."[2] Ceramics is the art of the fire, the fire making the final statement on the work itself. A wood fire gives to the work "an accidental charm which is at once comforting and somehow flattering, since it comes not from the artist himself, but from his materials."[3]

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[1]Michael Cardew, Pioneer Pottery (New York: St. Martin's Press, 1969), p. 171.

[2]Bernard Leach, A Potter's Book (New York: Trans-atlantic Arts, Inc., 1946), p. 179.

[3]Michael Cardew, Pioneer Pottery (New York: St. Martin's Press, 1969), p. 179.

CHAPTER III

THE STUDY

This study of preheated combustion air was conducted on a two firebox, downdraft wood fueled kiln. A wood kiln was used because of the writer's desire to use waste wood for fuel. Preheated combustion air systems could be adapted to any type of kiln.

The writer constructed the kiln using traditional materials and techniques of kiln construction. A list of materials may be found in Appendix I, Figure 5. The kiln had thirty-five cubic feet of stacking space for the ware. (See floor plan of kiln in Appendix I, Figure 1.) The ware was bisque fired in a gas kiln to 1800^{o}F, then glazed and fired in the wood kiln to 2380^{o}F. Bisque firing was used only because of the writer's lack of experience firing glazed greenware. The glazes were used as liners only, leaving the outside of the ware raw. This allows for the accumulation of ash residue on the outside of the ware. The ware was stacked as tightly as possible so that a consistent radiation effect could be maintained.

The wood used in the study was kiln dried pallets or flats of both hard and soft wood. Businesses that use forklifts in their operation often discard these pallets in great numbers. The writer secured his pallets from a single business in Denton. This source would easily supply enough wood for one firing per month. Hardwoods were used in the beginning of the firing and softwoods toward the end. A chain saw cut the pallets into pieces ranging in size from 16 inches to 24 inches. The wood pieces were usually 4 inches to 6 inches wide, though some larger pieces could be burned. Wood preparation, i.e., transportation, cutting, and stacking, consumed approximately twelve man hours per firing. The wood was stacked on a metal rack, which held 100 cubic feet of loosely stacked wood. To insure dryness, the wood was covered with plastic at least two weeks prior to a firing.

Six firings were done without the addition of forced preheated combustion air. This gave the writer a general understanding of how the kiln functioned. Clear, dry days were chosen whenever possible so that weather conditions would not hamper test results. When the atmosphere is dry the draft of the chimney is very good. When the air is heavy with moisture (high humidity) the draft is lessened considerably. The firings were recorded by time in relation to temperature and fuel consumption. (See Appendix III, Figures 1-10.) Orton pyrometric cones were used to determine temperature. The temperature and wood consumption were charted every thirty minutes during the firing cycle. At the end of each firing a measurement was taken to determine the exact cubic feet of fuel consumed.

After the first six firings the fireboxes were redesigned incorporating the use of preheated combustion air. The tops of the fire boxes were removed and the heat exchangers were installed. The heat exchangers were made of three stainless steel tubes, 3 inches in diameter, 30 inches in length. The tubes were exposed to the flame in the top part of the fire boxes. Air was forced through the tubes with two Dayton 1/125 horse power blowers. These blowers are specified to move 60 cubic feet of air per minute (CFM). The author estimates due to resistence of air flow through the heat exchanger, that together they moved approximately 100 CFM. This volume of secondary air becomes very important in the combustion of a solid fuel like wood. The heated air was then piped down the outside of the firebox, through a 6 inch pipe, underneath the ashpit floor, entering the kiln inside the bagwall. (See Appendix I, Figures 2 and 3.) The 6 inch pipe was insulated with fiberglass house insulation.

A release bypass cap was placed on the 6 inch pipe to allow a free flow of air through the heat exchanger at all times. This bypass was installed in case it was decided not to use the heat exchanger at some time during the firing.

Without the bypass there could be possible damage to the stainless steel tubes through overheating. A damper was installed along the 6 inch pipe for control of the air flow and to direct air out of the bypass.

Each firing with this new system was monitored with Orton pyrometric cones and pyrometers. The ratio of time to fuel consumption and temperature output was charted every thirty minutes. (See Appendix IV, Figures 1-6.) A pyrometer was used to check the temperature of the preheated air flowing through the heat exchanger. At the end of each firing a measurement of wood was taken to determine the exact amount of fuel consumed.

Typical Firing Schedule

7:00 a.m. - A large fire is started inside chimney, then bricked up. This creates a good draught for the fire boxes. A small fire is kindled in one fire box to thoroughly evaporate any moisture in the ware. The wood is fed through lower fire box door. Primary air source coming from lower fire box door only. Forced secondary air off. Mouseholes closed. (See Appendix I, Figures 2 and 3, for fire box design.)

8:00 a.m. - A small fire is started in second fire box.

8:30 a.m. - Begin increasing fires slowly, feeding wood in lower fire box doors. Occasionally wood is fed through upper door, making sure it falls to the ash pit floor rather than resting on Hobbs. Mouseholes remain closed to build up coal bed.

9:00 a.m. to 1:00 p.m. - Temperature increases from 800°F to 1900°F. Forced secondary combustion air turned on during this period. The wood is almost exclusively fed in through the upper fire box doors. Primary air coming from lower fire box door. At 1800°F, the lower fire box door is bricked up, except for small opening 8 to 10 square inches. This allows combustion to take place principally in ware chamber where secondary air and volatile gases meet, rather than in the fire box. At 1800°F the forced secondary air is dampered to hold a 20 minute reduction.

1:00 p.m. to 4:00 p.m. - Temperature increase from 1900°F to 2050°F. Wood is fed through upper fire box door resting it on the Hobbs. Wood is stoked in approximately 10 minute intervals, filling the fire boxes completely. Mouseholes are opened to allow coal bed to maintain a good depth. (12 to 15 inches is optimum.)

4:00 p.m. to 7:00 p.m.	- Forced secondary heated air is turned off. The blowers are removed, allowing the natural draft to pull in necessary secondary air. Temperature increases from 2050°F to 2380°F. Towards the end of the cycle intermittent stirring of ash pits is done to increase ash flying through the kiln. A light glaze reduction is maintained for the last 30 to 40 minutes of the firing.

CHAPTER IV

FINDINGS

The first two firings were unsuccessful in reaching the desired temperature. (See Appendix III, Figures 1-4.) Various factors contributed to this failure, the principal ones being: 1) the use of large amounts of green wood, and 2) insufficient pull on part of the chimney. Before the third firing the chimney height was increased 6 feet and dry pallet wood was used as fuel. As a result of these changes, the third firing was successful in reaching the desired temperature. The top section of the kiln was colder than the bottom section though, and an increase in the height of the bagwall was necessary to improve this problem. After these initial three firings the writer was more knowledgeable of how the kiln would function. The writer began to understand what type of firing cycle could be expected.

Firings 3, 4, and 5 each had an average time of 16 hours, consuming 143 cubic feet of wood per firing. (See Appendix III, Figures 2-12.) The average time from 900°F to 2000°F was 5.5 hours, and from 2000°F to 2300°F was 7 hours. These three firings were conducted with no heated combustion air forced in. The primary and secondary air were pulled in by the draught of the chimney. A steady rise in temperature could be maintained throughout the firing.

Firings 6, 7, and 8, with the addition of heated combustion air, had an average time of 15.8 hours, consuming 133 cubic feet of wood. The average time from 900°F to 2000°F was 3.9 hours and from 2000°F to 2300°F was 5.5 hours. As was true for firings 3, 4, and 5, a steady rise in temperature could be maintained. In terms of overall temperature output and fuel consumption, the use of heated combustion secondary air (to 300°F) seemed to contribute little to the efficiency of the kiln. Particular significance to the usefulness of heated combustion air lies in its participation in keeping the ware chamber clean burning whenever desired. With this excess of heated air to combust any volatiles released in the firebox, a real control on the kiln atmostphere could be maintained. This excess air allowed the stoker the ability to load large amounts of wood into the firebox without significantly reducing the chamber atmosphere. Therefore the stoking intervals could be further apart, making the firing easier on the stokers. This clean burning atmosphere becomes important during the bisque temperatures in order to burn any organic matter that may still be in the clay. If not properly burned away, this organic matter may cause bloating of the clay body. Also, when a reduction atmostphere was desired, the forced heated combustion air could be dampered to create whatever type of reduction was desired.

Although the heated combustion air kept the kiln atmosphere clear, it was only useful with temperatures up to 2000°F. After this temperature was reached, the kiln would decrease in speed of temperature rise. What seemed to be taking place was that the heated air (300°F) was too cool to be of any effect later in the firing. There was too much of this air being forced in, thus causing a cooling of the kiln temperature. Also, the forced air created a back pressure in the kiln chamber which had a negative effect on the pull of the chimney. When it was realised that this forced air was cooling the kiln at 2000°F, the air was dampered. What was realised was that any forced air, no matter how small, still created a negative effect on the pull of the chimney. Therefore, a decrease in the forced air did not increase the draw significantly enough to pull in needed combustion air through the other air ports. As a result, when the forced air was dampered, a significant reduction took place, further affecting the decrease in temperature. Therefore, when temperatures of 2000°F or so were reached, the forced air was turned off. The chimney resumed a natural draw and the flame throughout the kiln increased in length significantly. At this point the temperature rose steadily to 2300°F.

Wood as a Fuel

It was found to be more advantageous to use a hardwood and softwood mixture until 2000°F was reached. The hardwood creates a very hot coal bed and also burns much cleaner in the beginnning of the firing than does pine. This is due to the higher resin content in softwood. Using pine during the entire firing is necessary to keep a long flame moving through the chamber. The long flame helps to thoroughly saturate the chamber, contributing to even kiln temperatures. After 2000°F was reached, pine was used because of its higher B.T.U. output. It would be very difficult to reach 2300°F with hardwood only, though it would be possible, the main factor being the time it would take to do so.

Hardwood could be eliminated completely and no temperature would be sacrificed, but the ash flying through the kiln would be significantly reduced. Oak, for instance, has 1.97% ash per pound as compared to 0.37% per pound in pine.[1] The larger the quantity of ash moving through the kiln, the more ash is deposited on the ware. Stirring the ashpits during the last 30 minutes of the firing also contributed to the ash build-up on the work.

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[1]William Alexander, "Wood," <u>Pottery Quarterly</u>, 12 (1978):45, p. 13.

The writer also found that a consistent stoking schedule produced the most positive results. Undivided attention was very necessary during the course of a firing cycle, in order to maintain hard won temperature. A pyrometer proved very valuable in determining when the temperature had stopped increasing, thus signaling that closer attention must be paid to the fire. In order to gain temperature it was necessary to take two steps forward in order to secure one. A heavy stoking would produce a surge in temperature rise, then a slight drop would occur. This see-saw effect would go on and on until the last necessary surge.

It was found useful to prepare the wood well in advance of a firing, rather than at the same time as the firing. This saves a lot of energy that is sure to be needed toward the end of a firing cycle.

CHAPTER V

CONCLUSION

It can be concluded that a healthy supply of secondary air proves to be very valuable when burning a solid fuel such as wood. Wood, being a bulky fuel, is often times overloaded into the fireboxes releasing too much gas at once, which makes its way out the chimney unburned. This results in an inefficient utilization of the fuel. With this excess secondary air available, little wood gas escapes combustion, thus increasing efficiency.

The system tested in this study proves to have merit up to 2000°F. The heat exchanger heats the combustion air to 300°F. It stands to reason that the hotter this combustion air, the more useful it is to the efficiency of combustion. To redesign this heat exchanger to heat the combustion air to a higher temperature would increase the efficiency of the kiln.

The heat exchanger system is shown also to have a negative effect on the pull of the chimney. The writer feels that a preheat system should be compatible with the type of kiln employed. In other words, a forced air preheat system should be installed on a kiln that relies on forced air for all its air source, rather than partly on the draught from the chimney and partly on forced air. If the kiln relies on its primary air source from natural draught, then the preheat system should rely on the same natural draft power source. Regarding the latter, the writer feels there could be more research done; that is, to create a preheat combustion air system that operates on natural draught principles. A natural draught system would eliminate the electric blowers which are a major cost factor in this type of system (approximately $48.00). Also, a pulling type kiln (natural draught) as opposed to a pushing type kiln (forced draught) seems more compatible to the long flame produced during wood combustion.

Wood is found to be a very clean burning fuel. Only two gallons of ash and melted nails remained after each firing. In terms of dollars and cents, wood is no more costly to use than gas or oil, and it is gaining on these fossil fuels. The energy consumed in transportation, preparation, storage and stoking easily absorbs any monetary savings dreamed of. Yet waste wood exists in numerous forms, desperately needing to be put to use. The aesthetic effects on the ware prove to be the most positive aspect of using wood as a fuel for firing pottery. It becomes difficult to place a cost value on the unique accidental effects one achieves using wood as a fuel.

APPENDIX I

Kiln Construction

Fig. 1

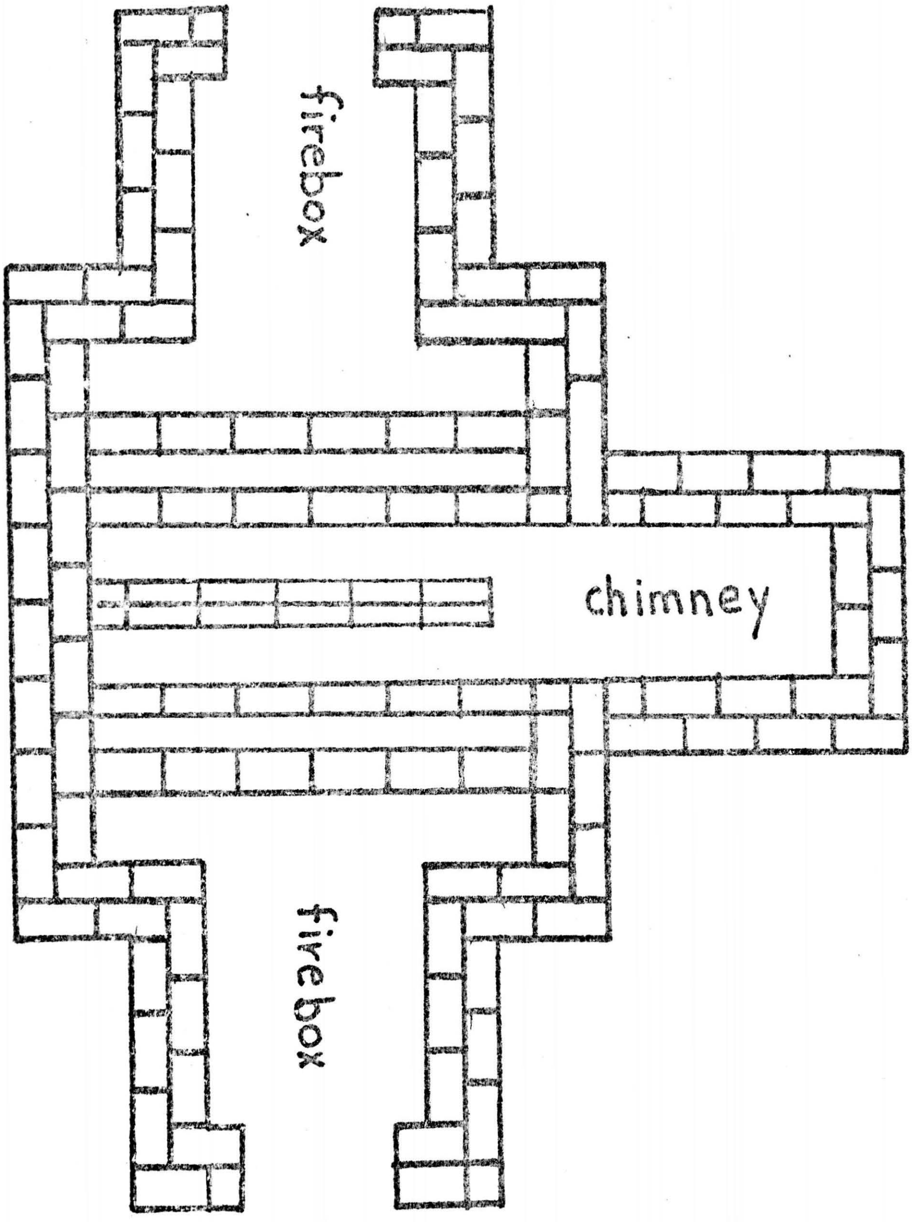


Fig. 2

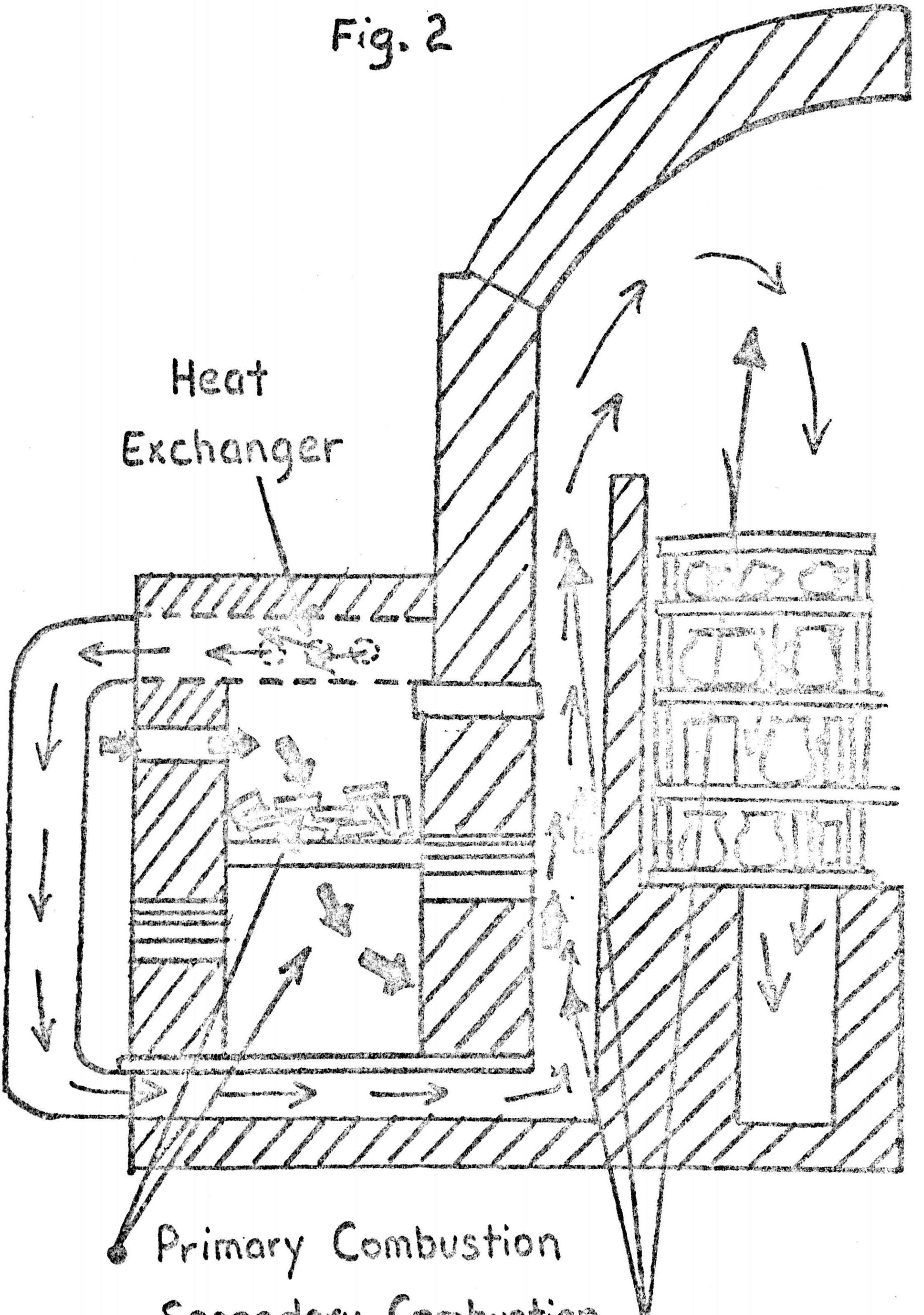
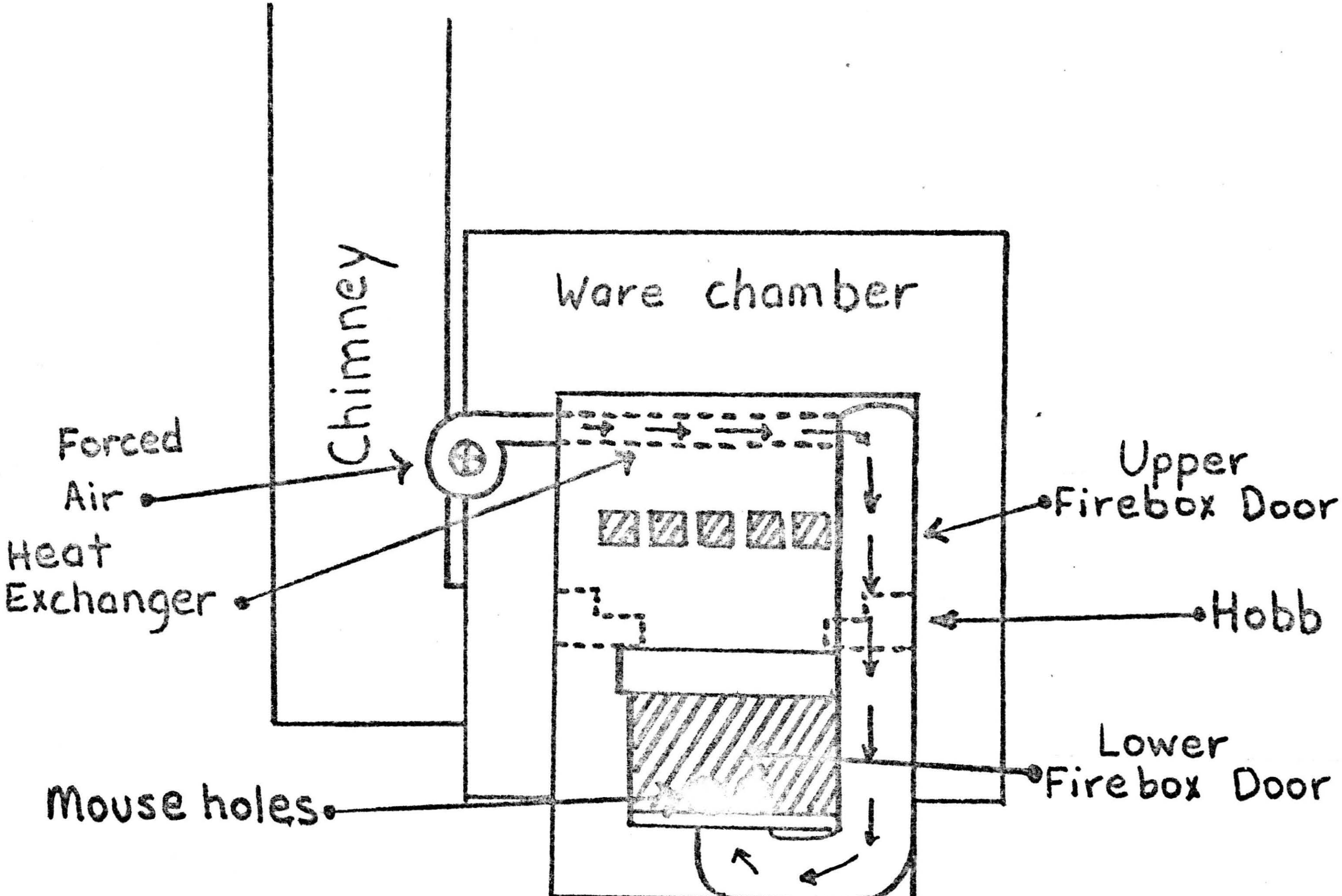
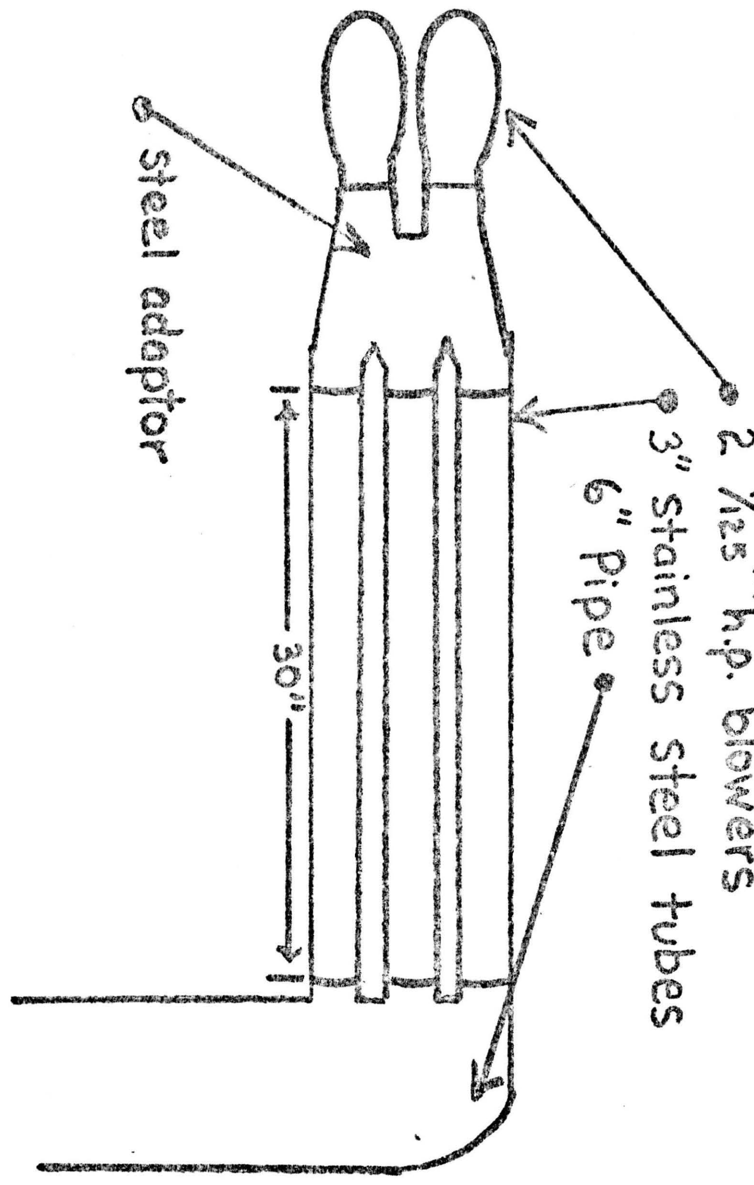


Fig. 3



Preheated Air Flow System

Fig. 4



Heat Exchanger Unit

Figure 5

MATERIALS CHART FOR KILN

Material	Size	Quantity	Estimated cost new	Estimated cost used
Firebrick (hard)	straight	2,900	$1,943.00	$435.00
Firebrick	# 1 arch	105	$ 64.35	$ 15.75
Firebrick	# 2 arch	15	$ 10.05	$ 2.25
Firebrick (soft)	straight	220	$ 198.00	$132.00
Angle Iron	2x3x3/8 inch		$ 200.00	$100.00
Sheet Iron (damper)	18x24x1/4 inch	1	$ 3.00	$ 1.50
Sheet Iron (firebox door)	12x14x1/4 inch	2	$ 2.00	$ 1.00
Kaowool	12x14x1 inch	2	$ 10.00	$ 10.00
Nicrome Wire	12 g.	2 feet	$ .50	$ .50
Castable		150#	$ 24.00	$ 24.00
TOTAL ESTIMATED COST			$2,454.90	$692.00

Figure 6

MATERIALS CHART FOR PREHEATED AIR SYSTEM

Material	Size	Quantity	Estimated cost new	Estimated cost used
Stove Pipe	6 inches	250 inches	$ 26.00	$10.00
Elbow	6 inches	6	$ 15.00	$ 6.00
Stainless Steel Pipe	3x30 inches	6	$ 18.00	$ 9.00
Electric	1/125th hp	4	$ 48.00	$32.00
TOTAL ESTIMATED COST			$107.00	$57.00

APPENDIX II

Wood as a Fuel

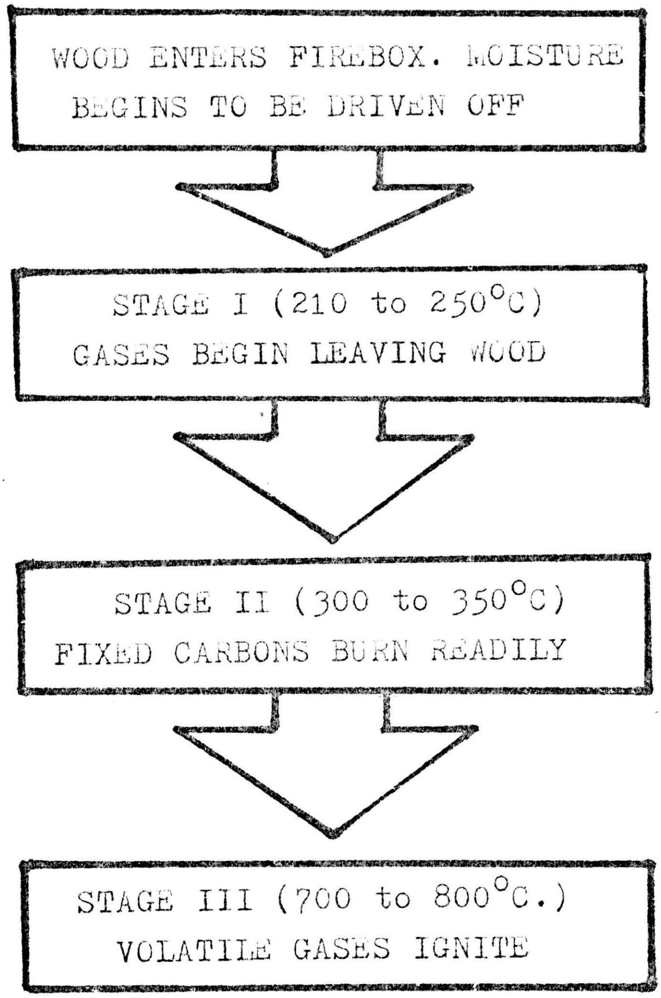
WEIGHTS AND COMPOSITIONS OF AIR-DRIED WOODS

Wood	Pounds per cu. ft.	Pounds per Cord	Per cent					B.t.u. per pound
			Carbon	Hydrogen	Oxygen	Nitrogen	Ash	
Ash	46	3,520	49.18	6.27	43.91	0.07	0.57	5,420
Beech	43	3,250	49.36	6.01	42.69	0.91	1.06	5,400
Birch	45	2,880	50.20	6.20	41.62	1.15	0.81	5,580
Elm	35	2,350	48.99	6.20	44.25	0.06	0.50	5,400
Oak	52	3,850	49.64	5.92	41.16	1.29	1.97	5,460
Pine	30	2,000	50.31	6.20	43.08	0.04	0.37	6,700
Poplar	36	2,130	49.37	6.21	41.60	0.96	1.86	6,660
Willow	25	1,920	49.96	5.96	39.56	0.96	3.37	6,830

*Chart p. 133, Fuels and Their Combustion.

Figure 2

STAGES OF WOOD COMBUSTION



APPENDIX III

Graphs of Firings

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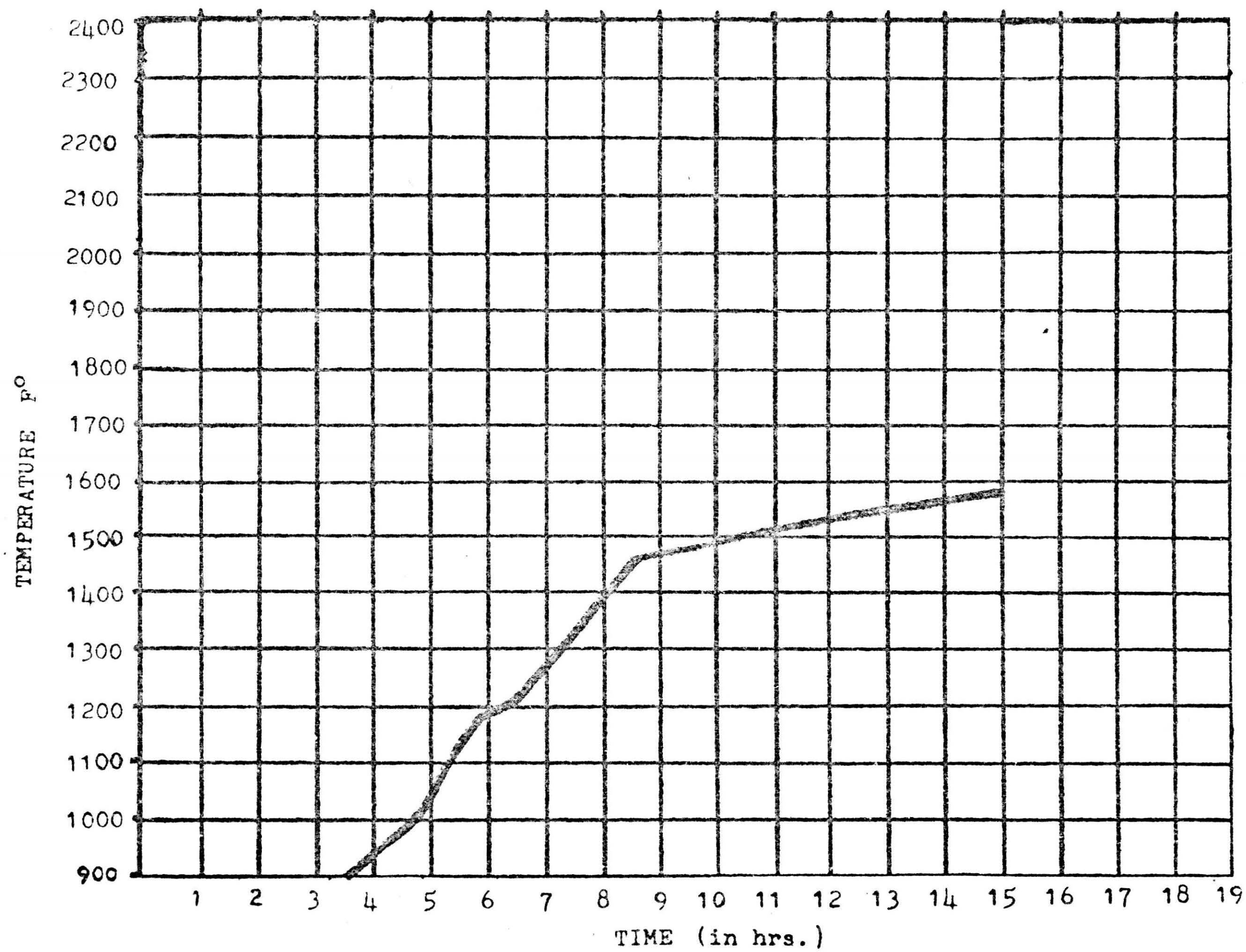
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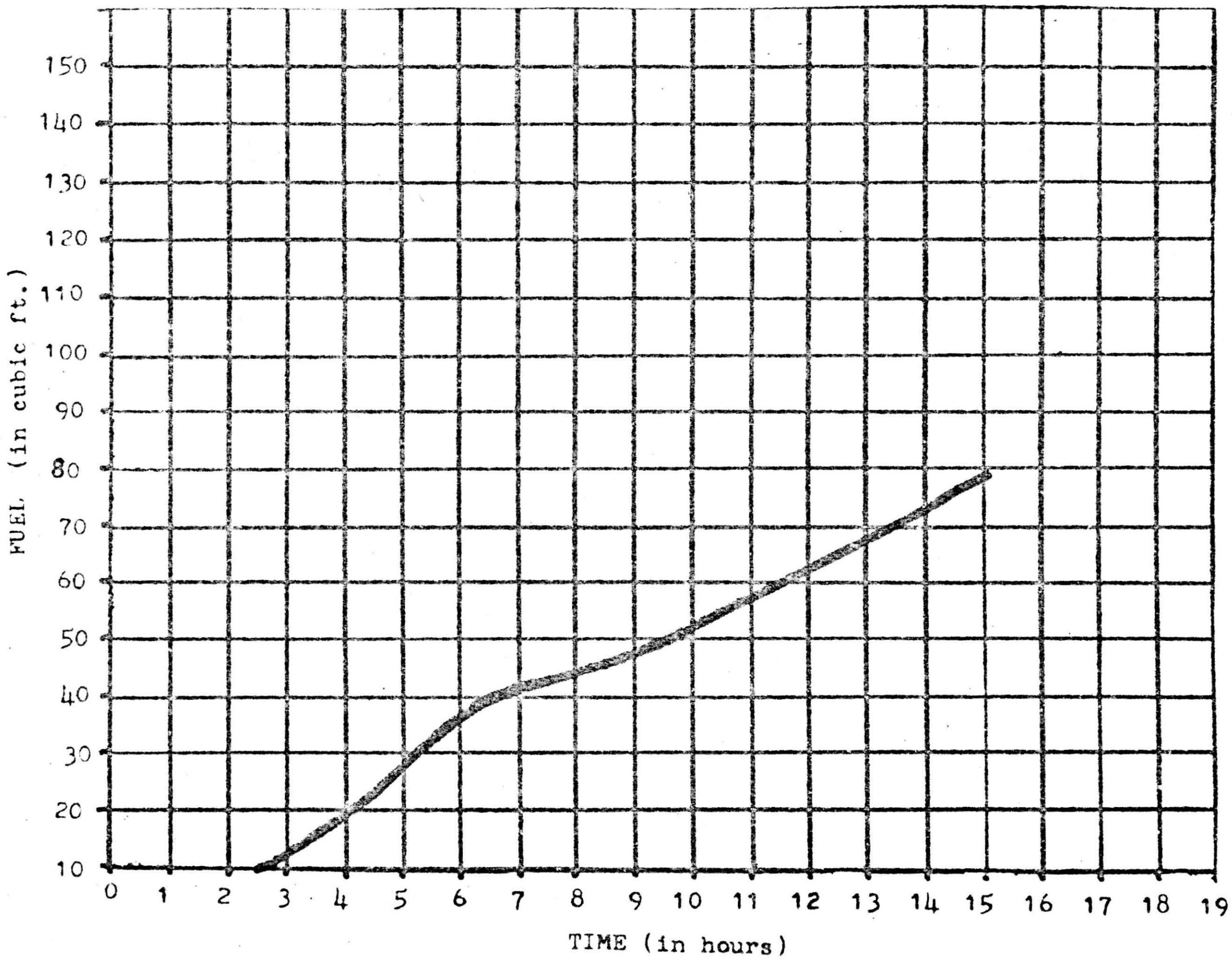
TIME (in hrs.)

FIRING 1



FUEL (in cubic ft.)
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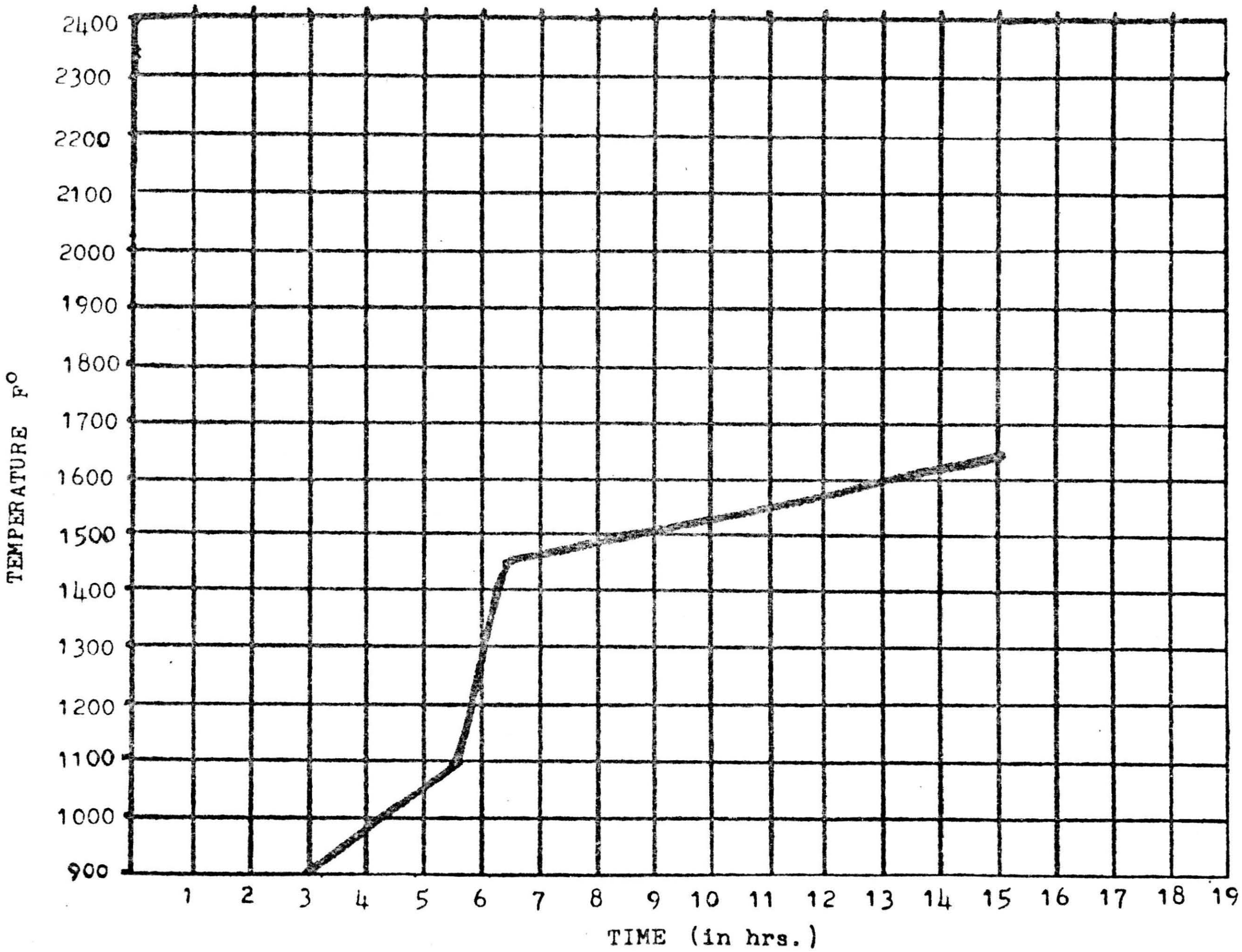
TIME (in hours)

FIRING 2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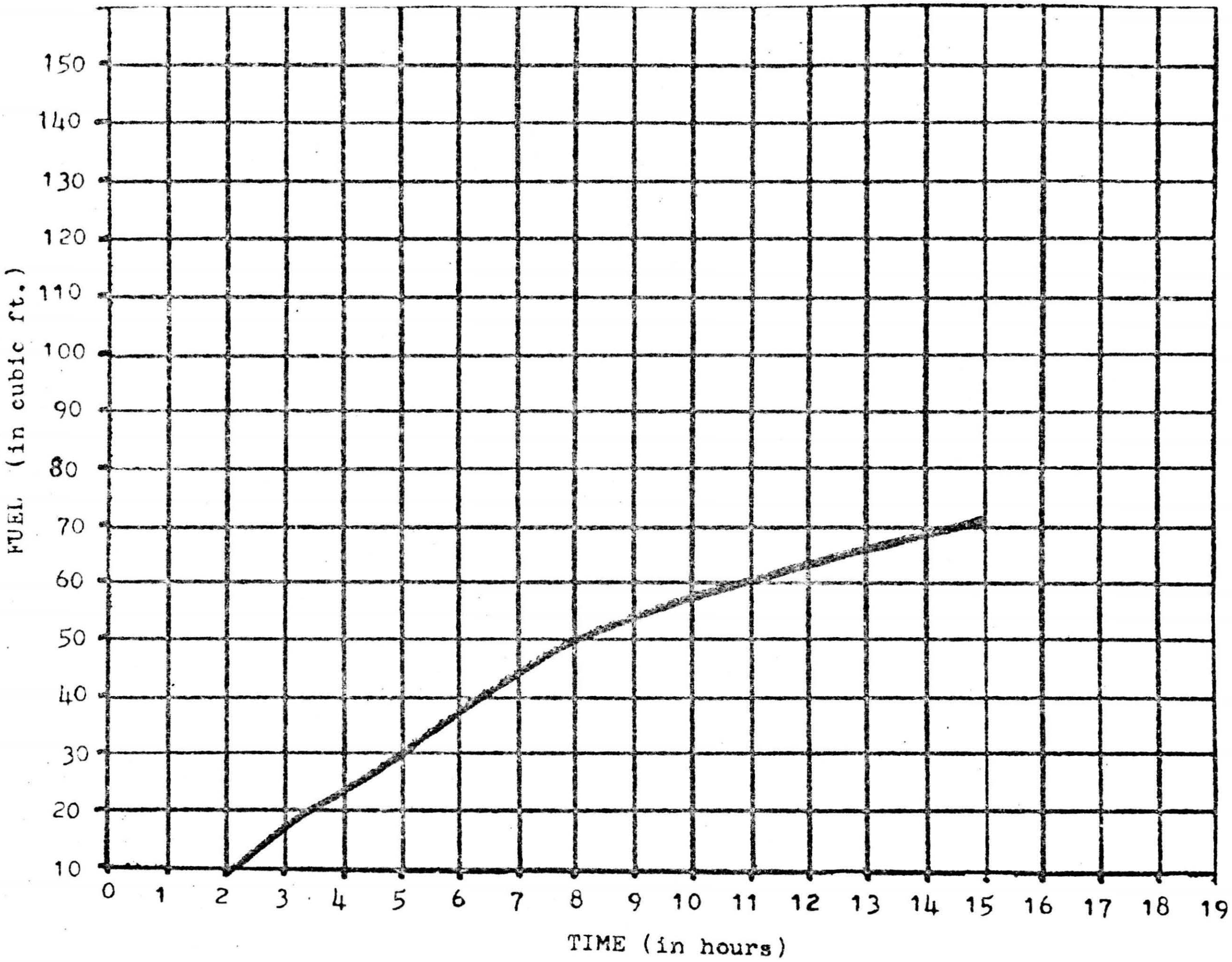
TIME (in hrs.)

FIRING 2


FUEL (in cubic ft.)
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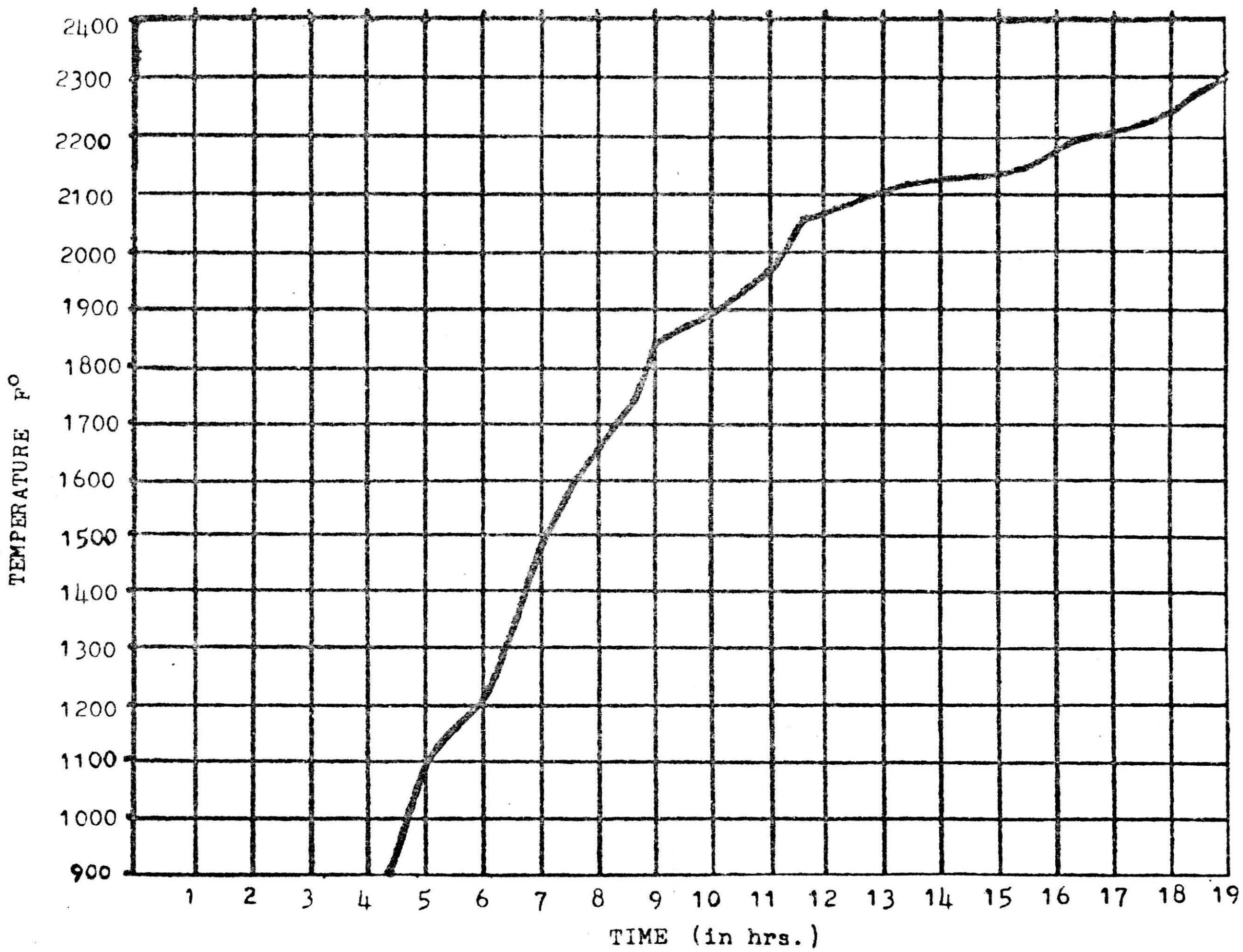
TIME (in hours)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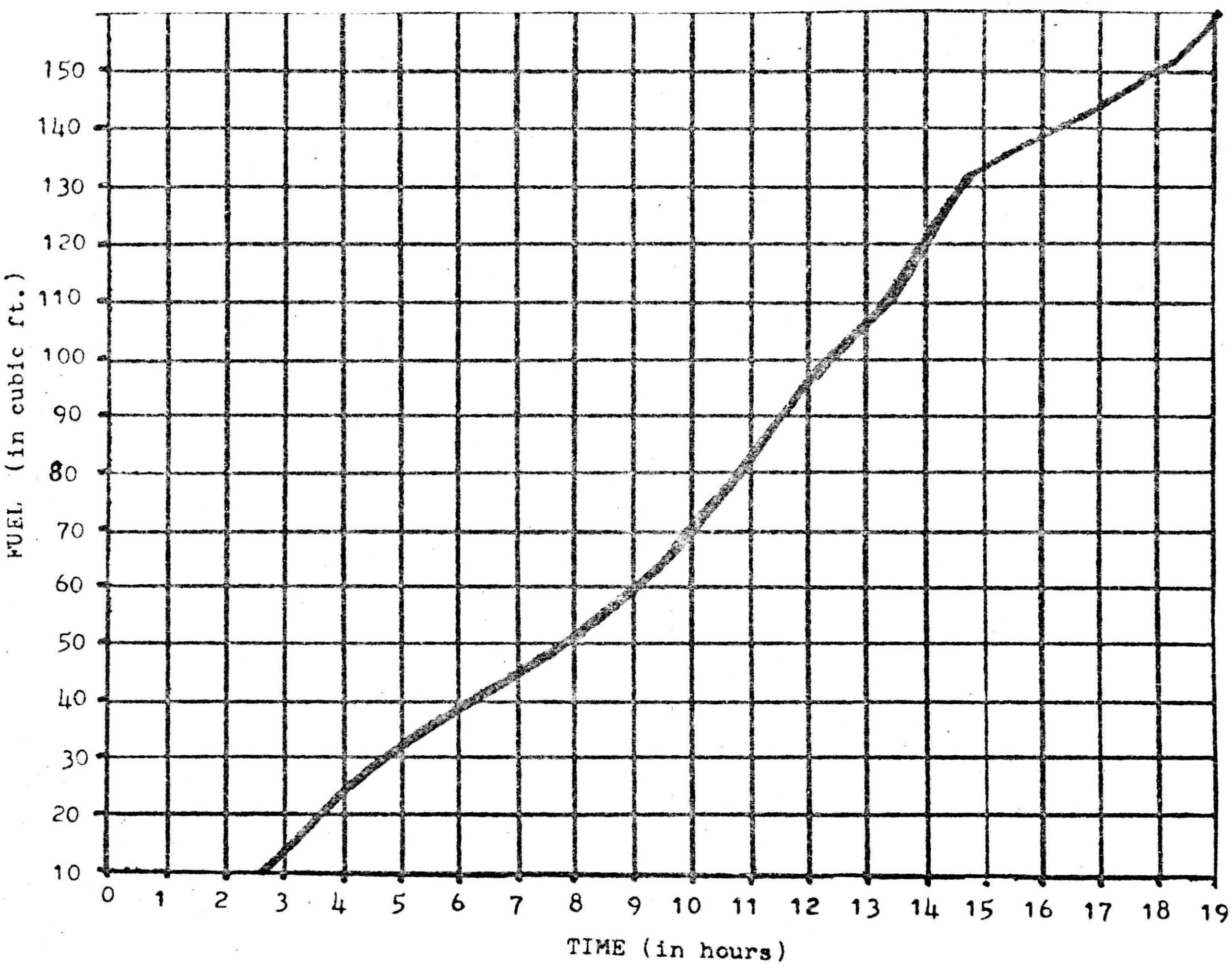
TIME (in hrs.)

FIRING 3

FIRING 3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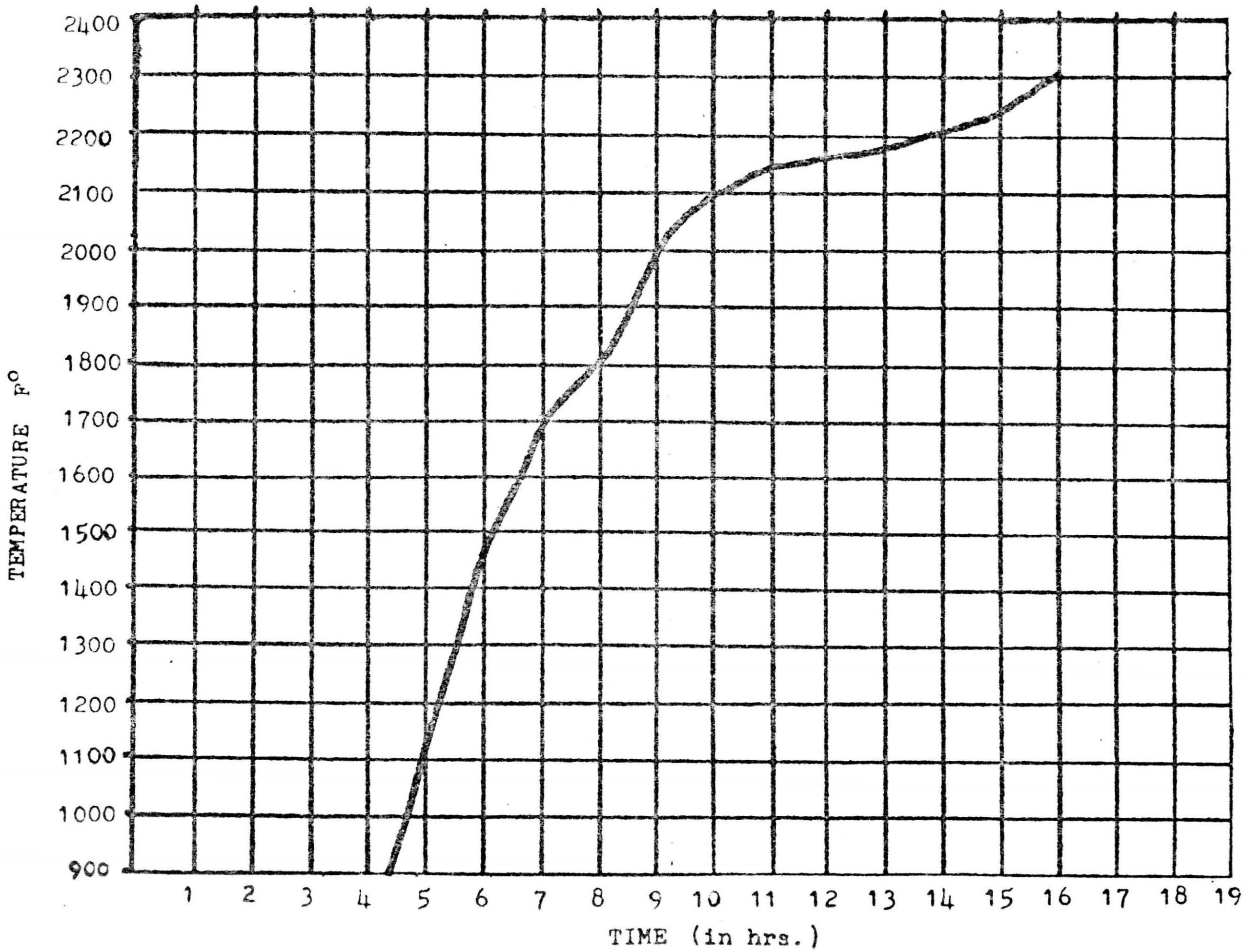

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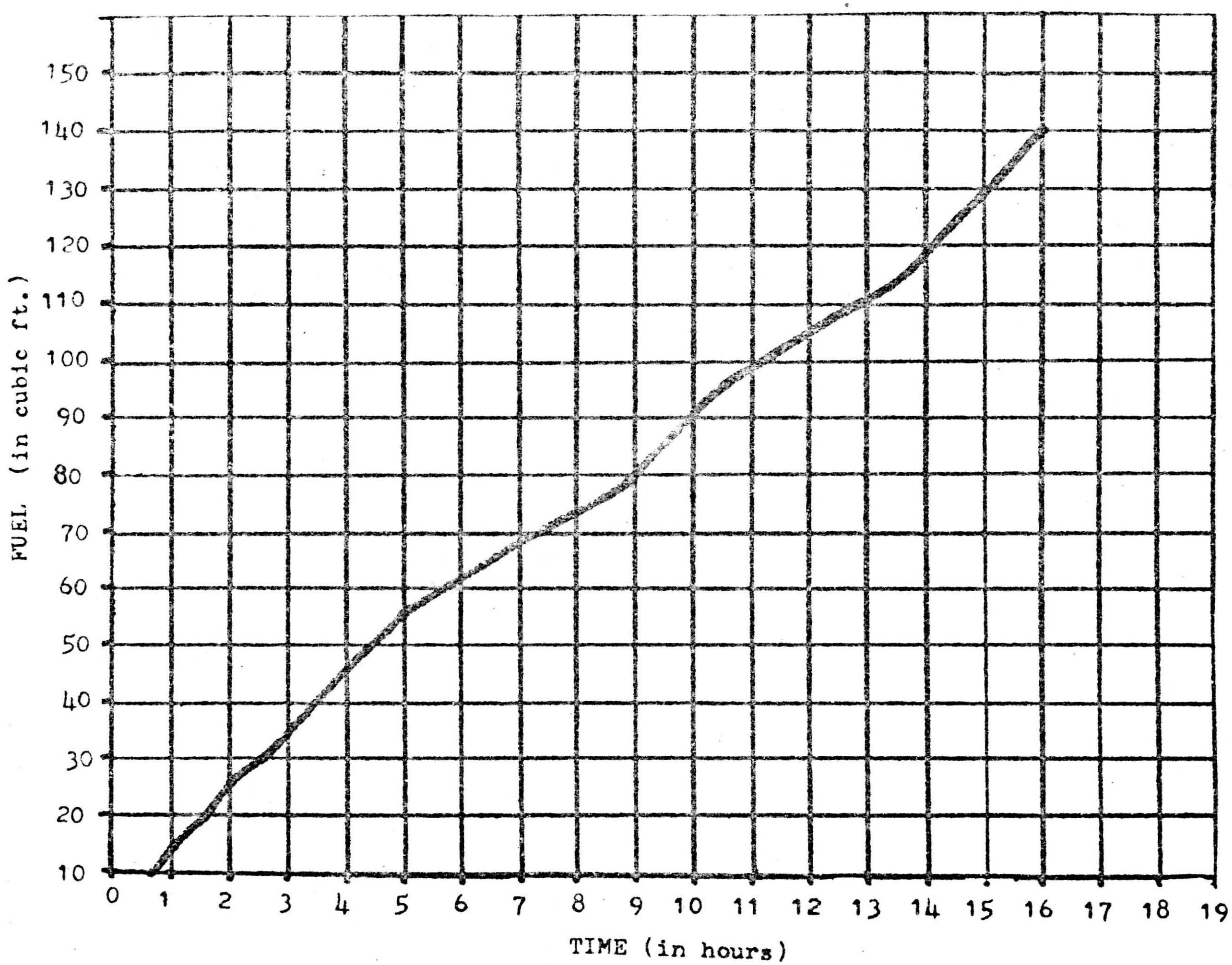
TIME (in hrs.)

FIRING 4

FIRING 4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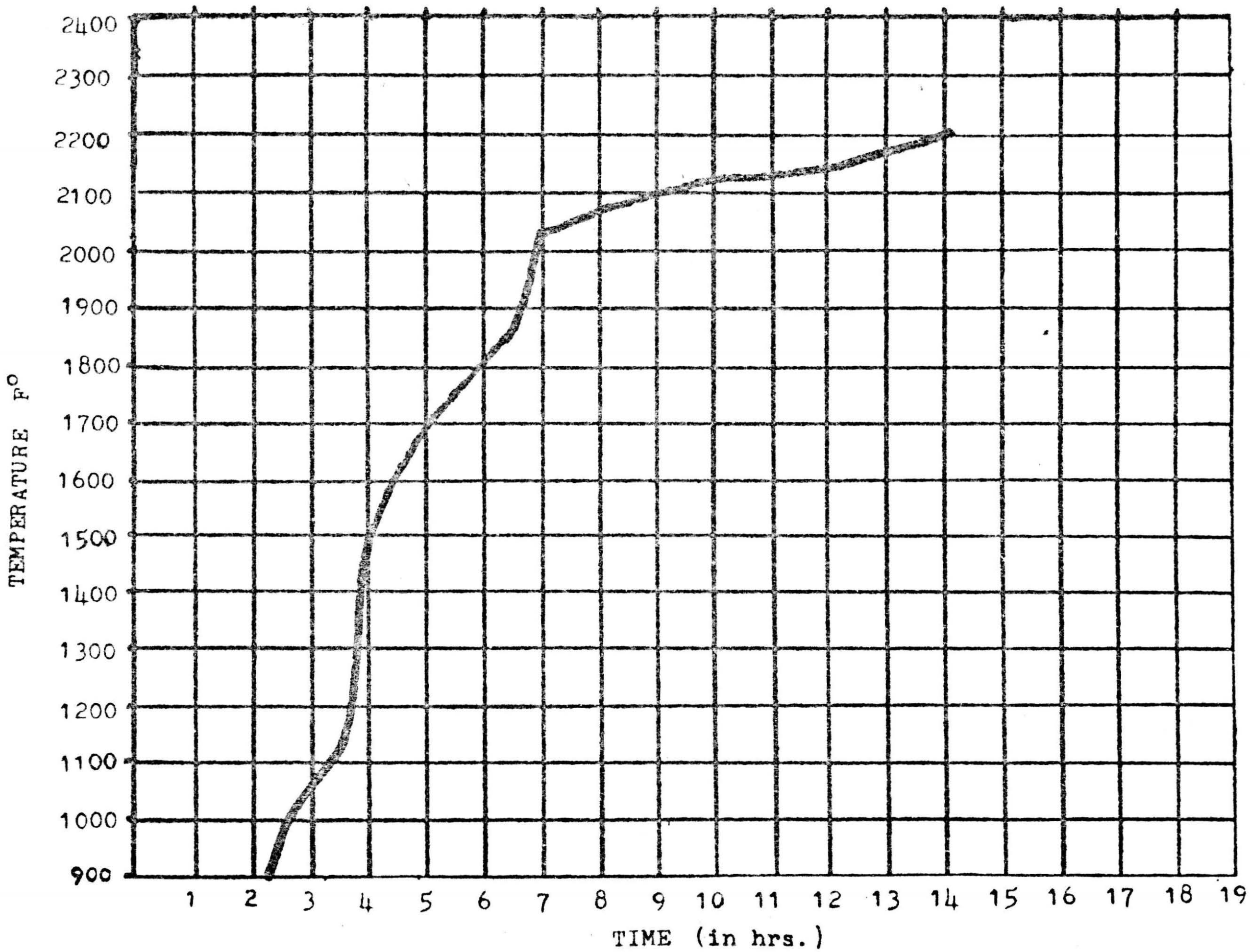
FIRING 5



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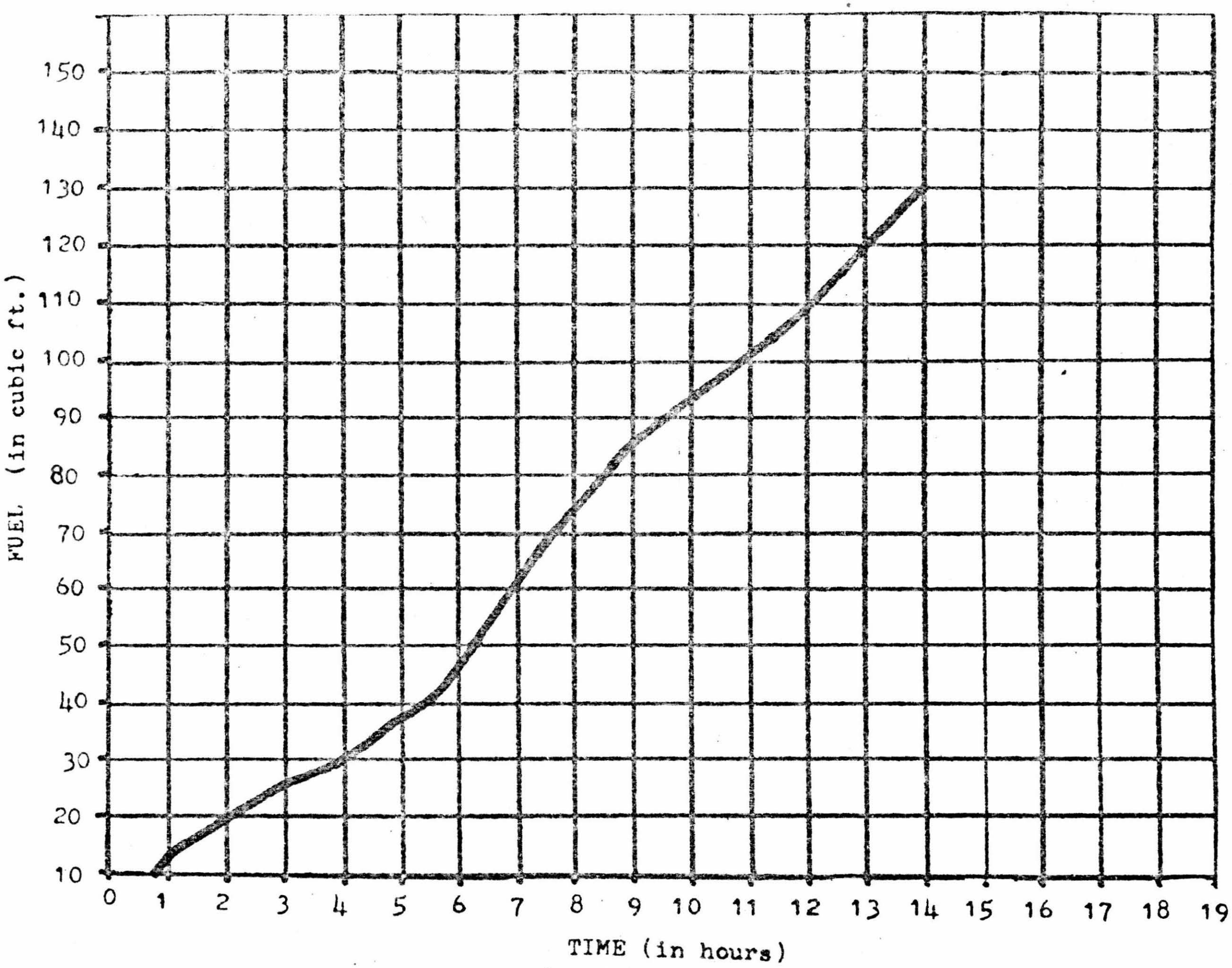
TIME (in hrs.)

FIRING 5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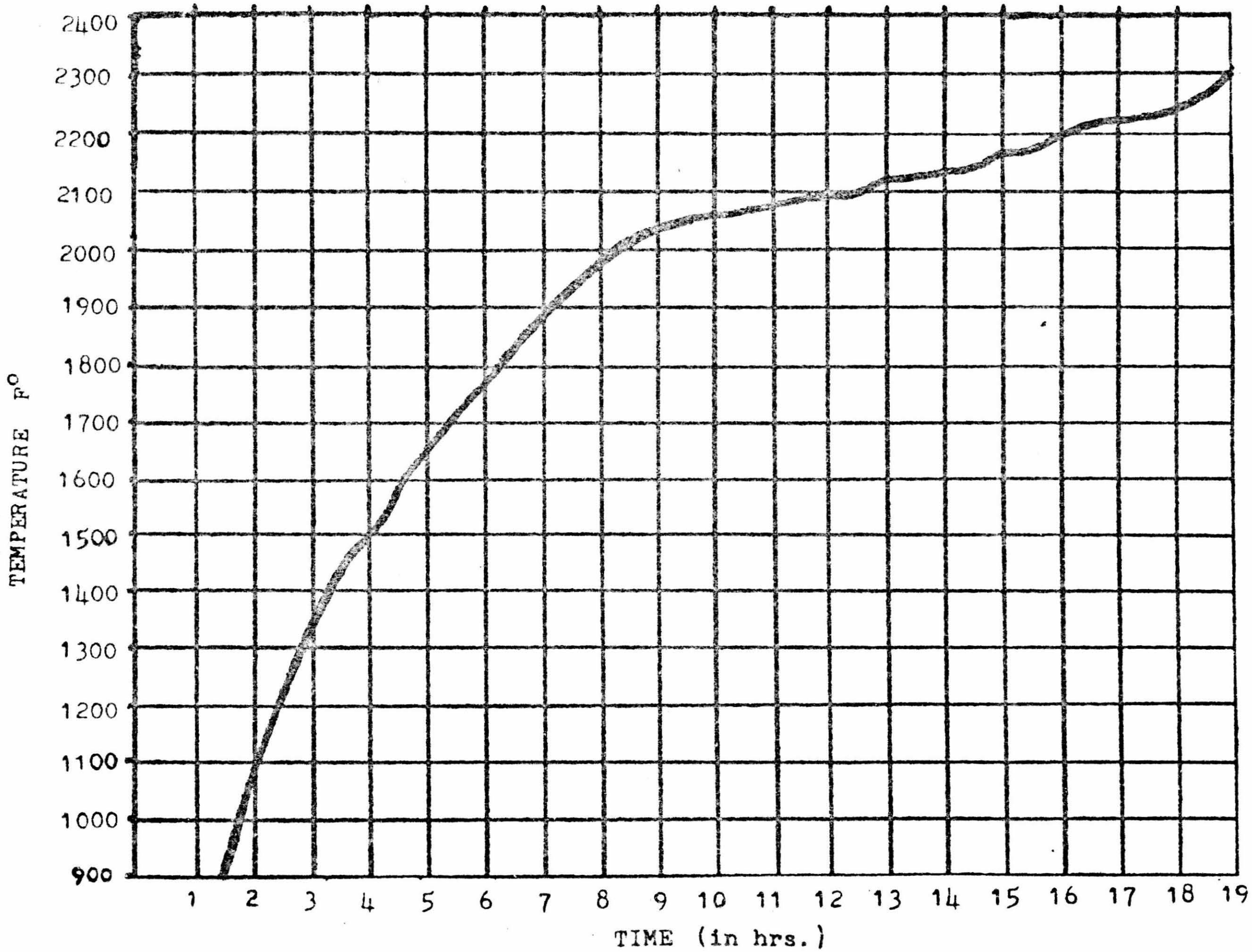
TIME (in hours)

FIRING 6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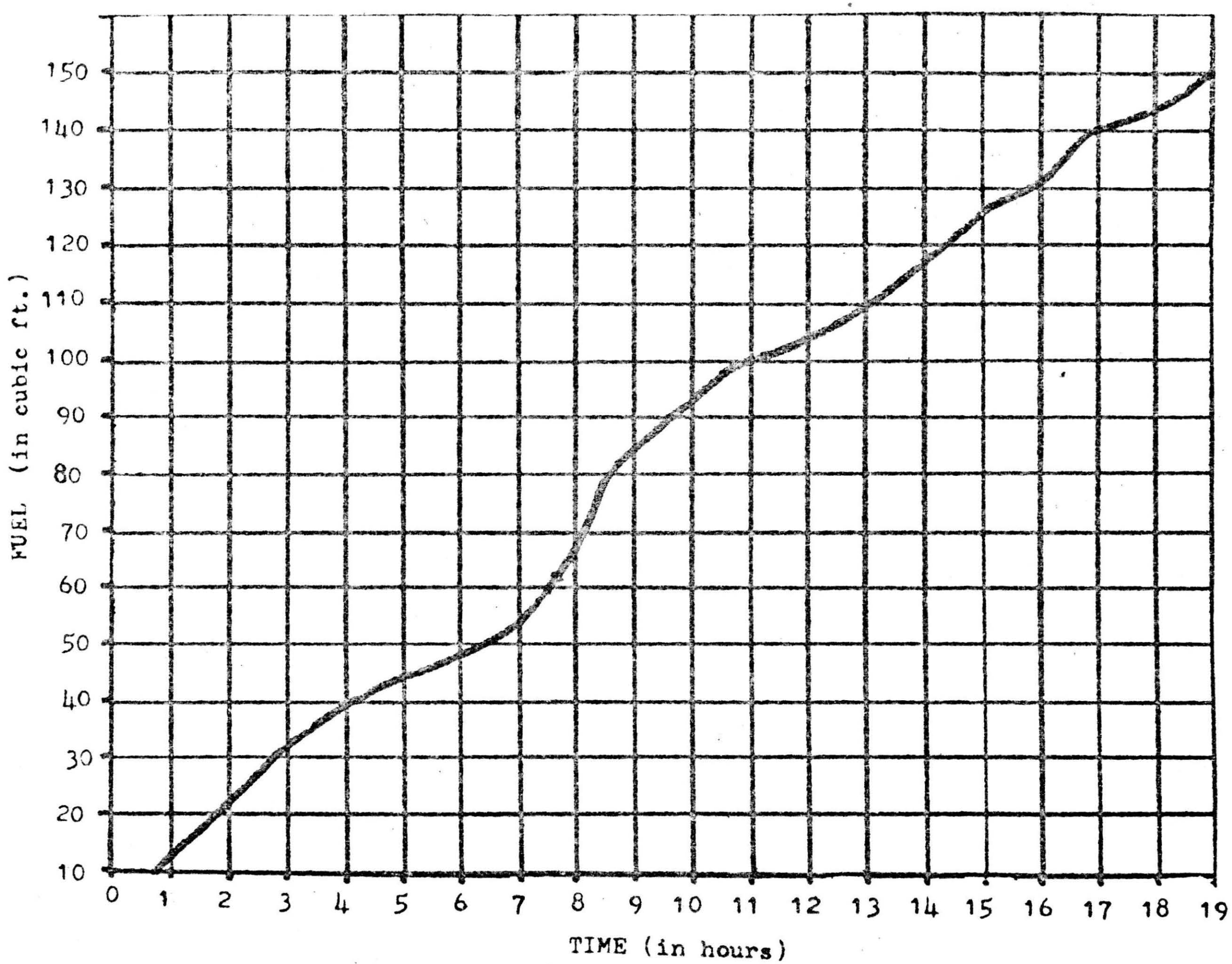
TIME (in hrs.)

FIRING 6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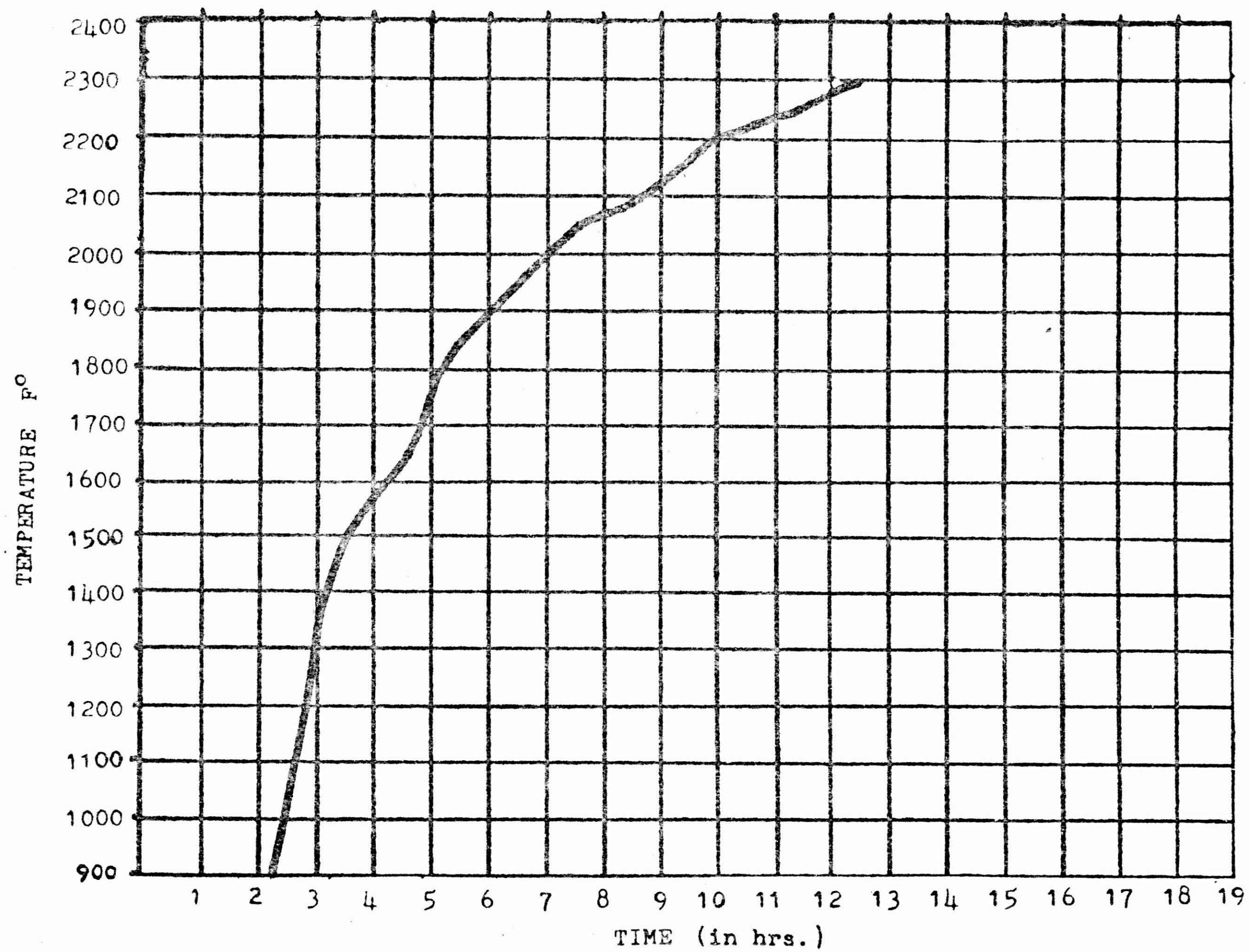
TIME (in hours)

FIRING 7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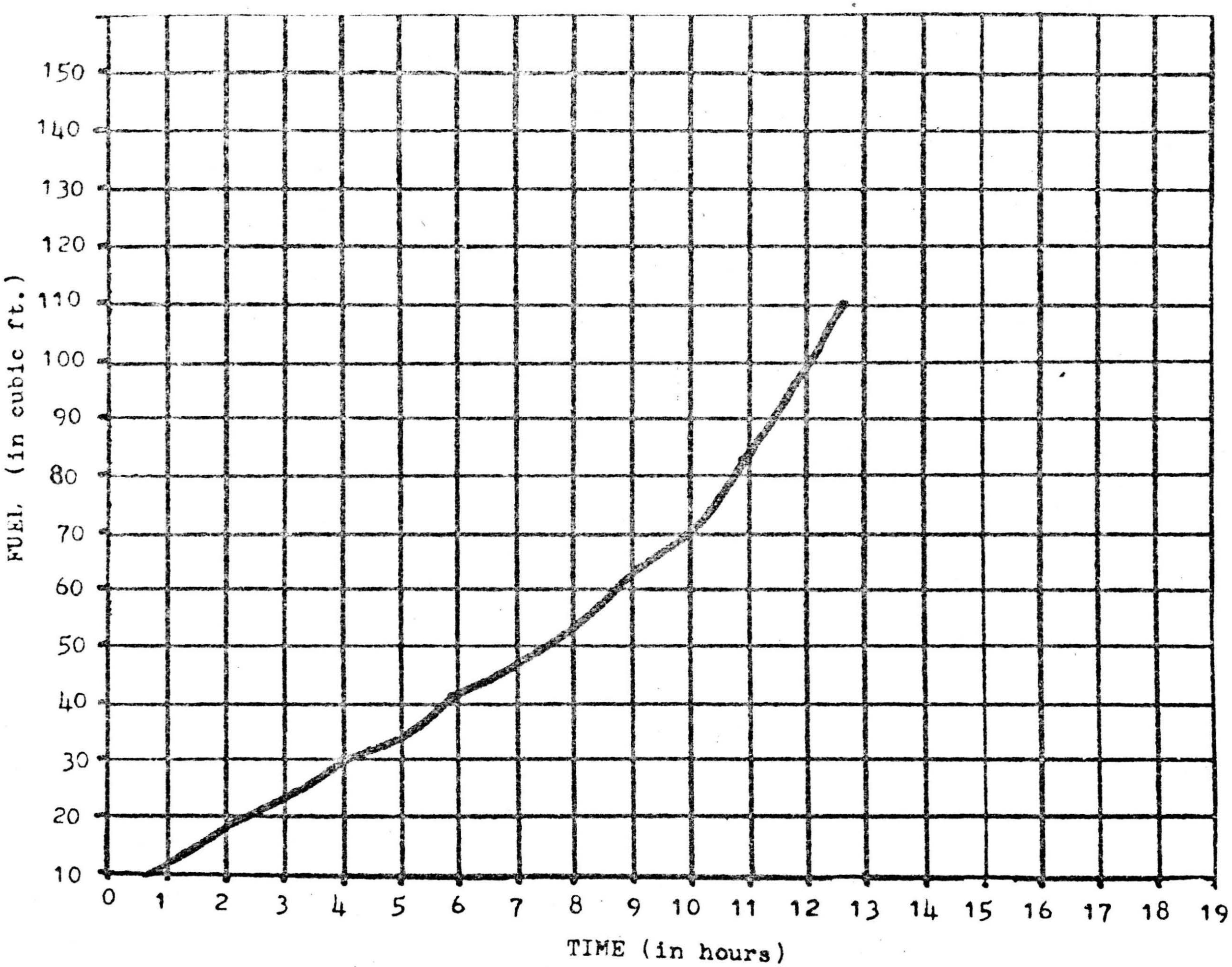
TIME (in hrs.)

FIRING 7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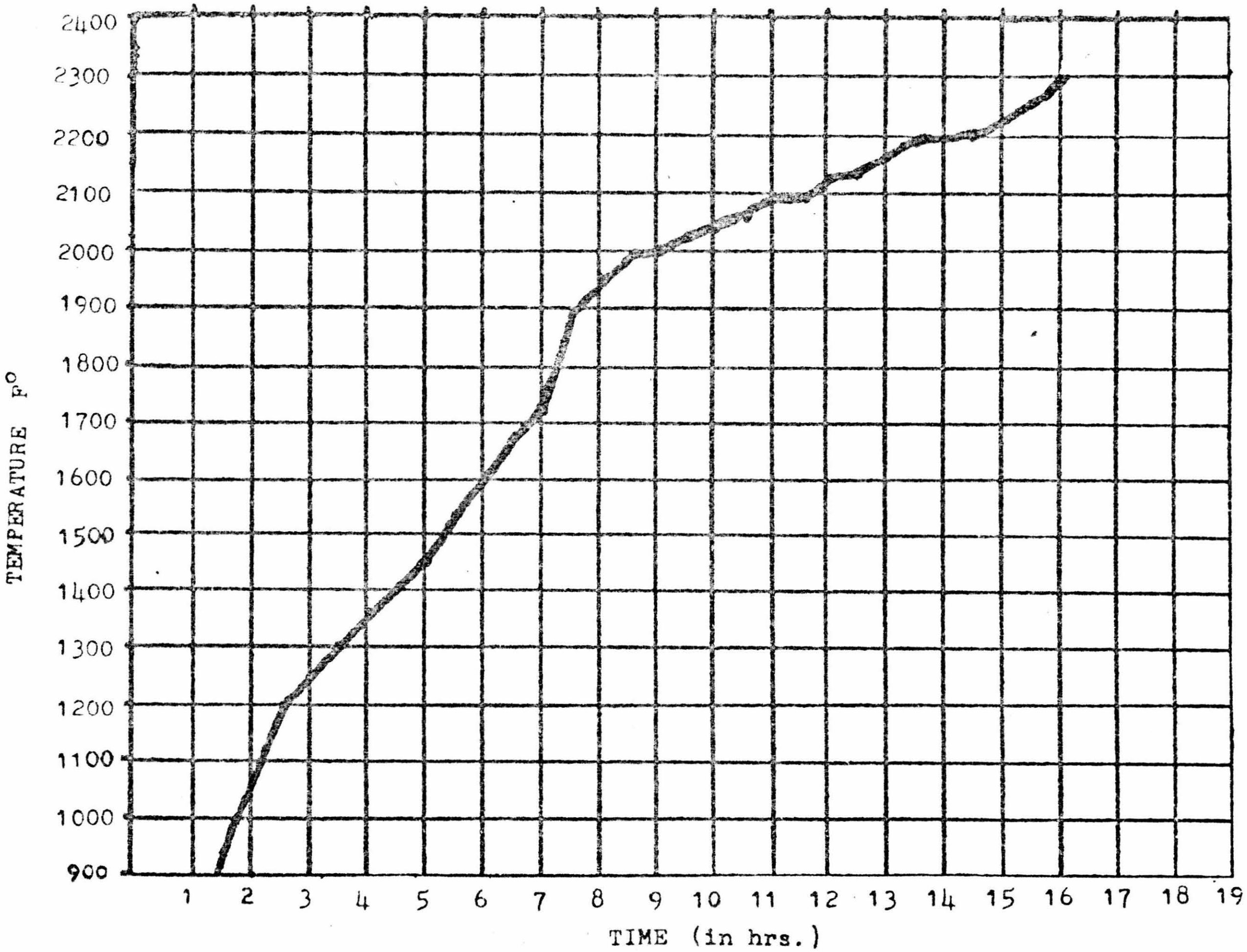
TIME (in hours)

FIRING 8



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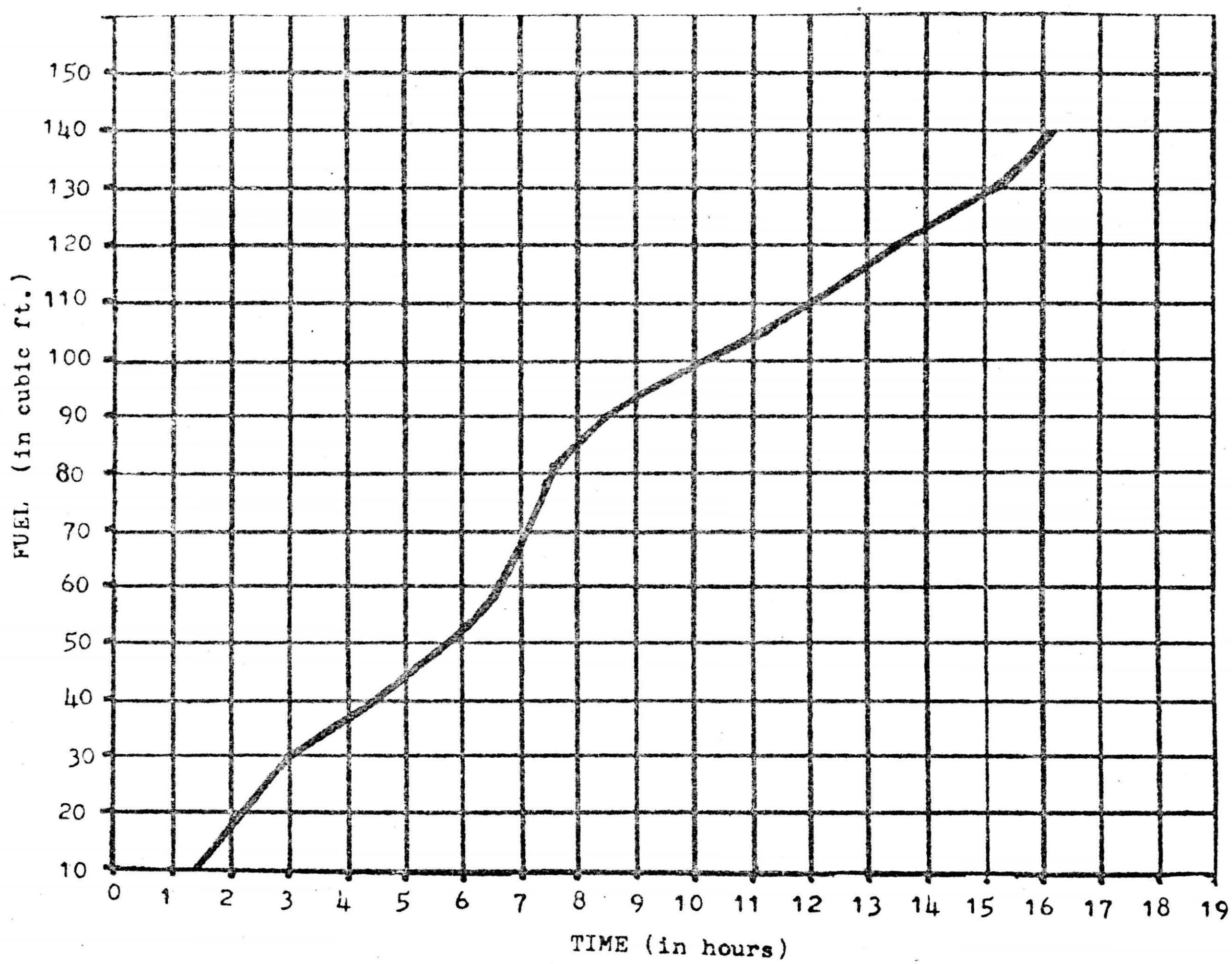
TIME (in hrs.)

FIRING 8



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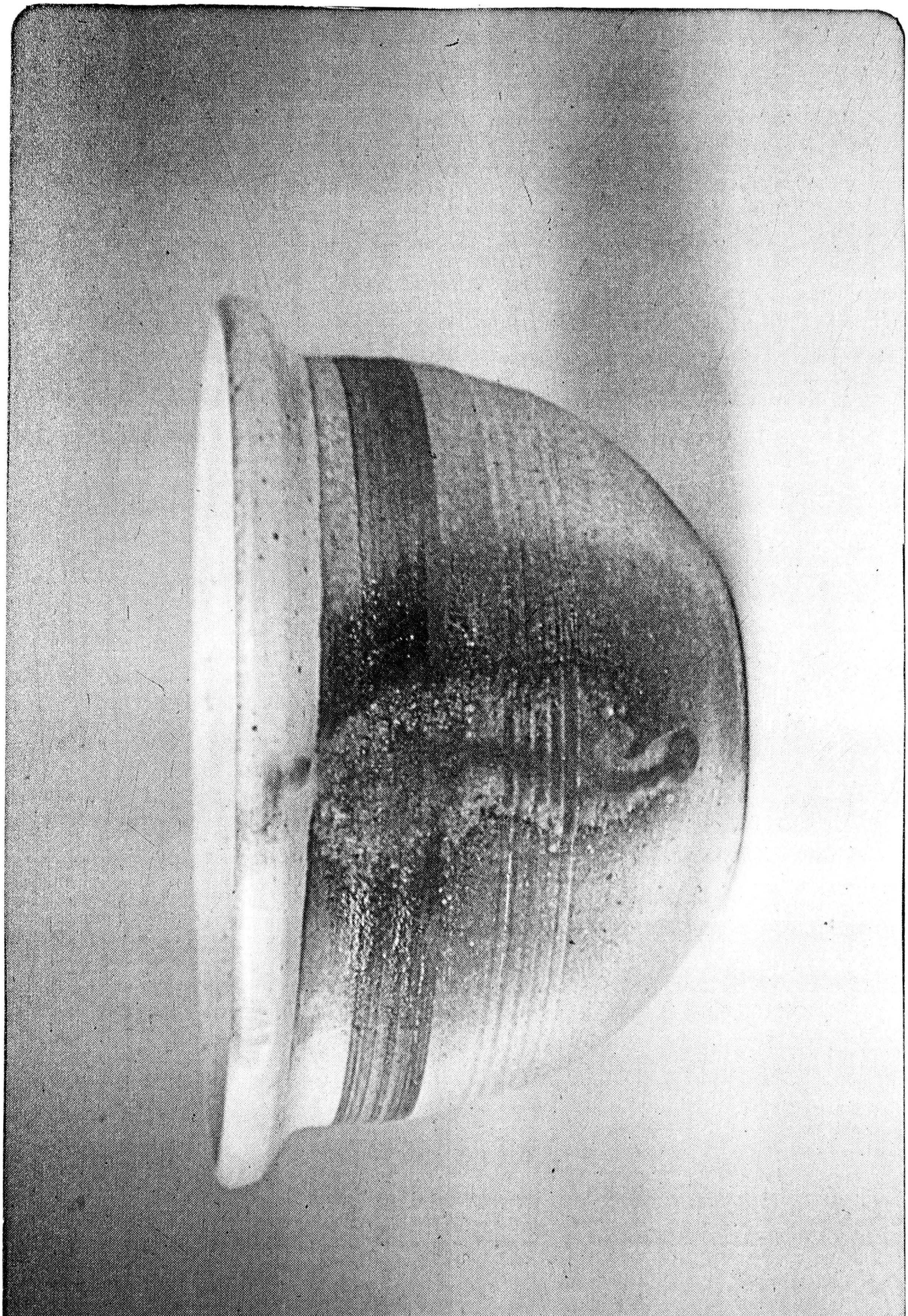
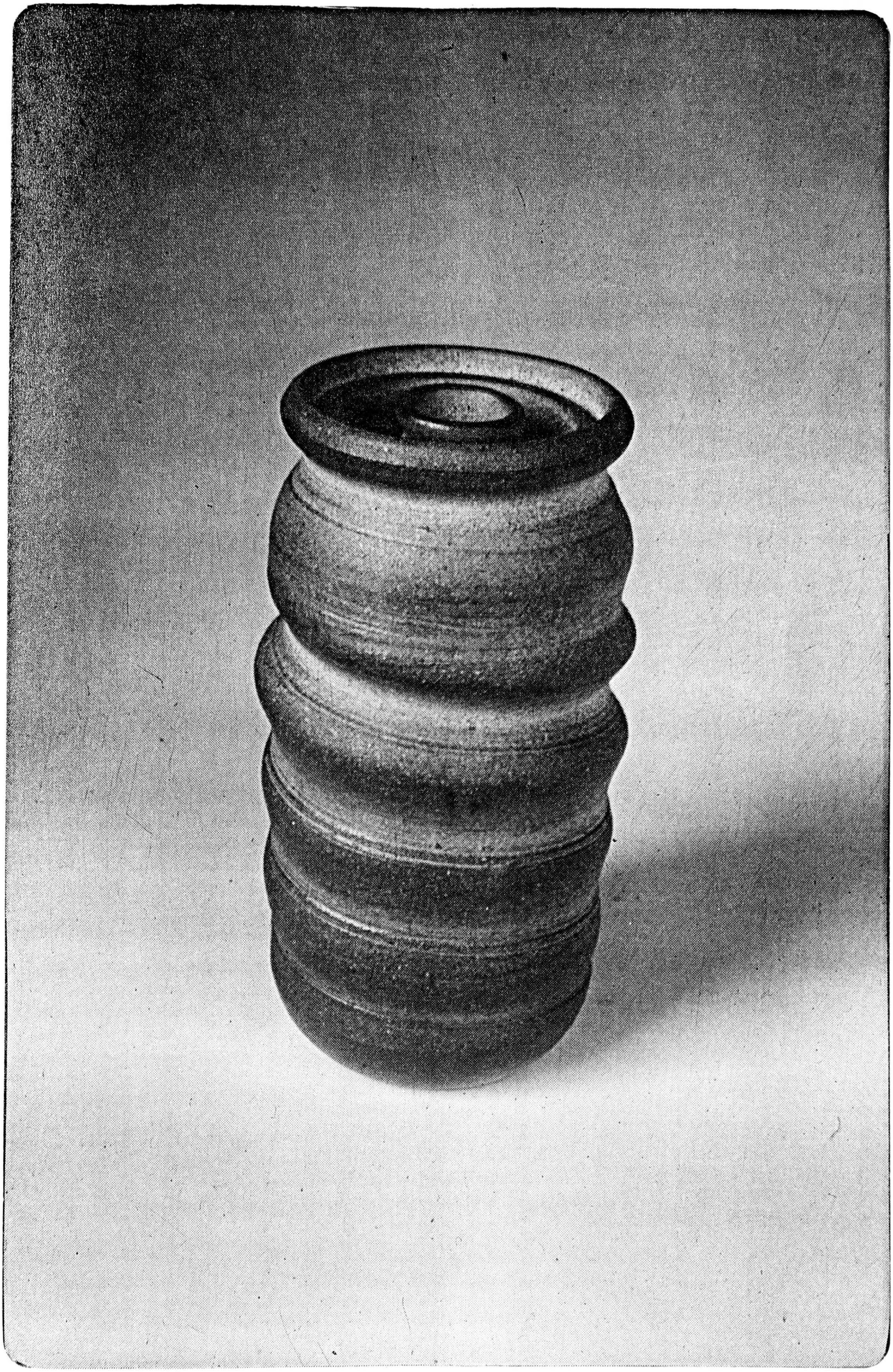
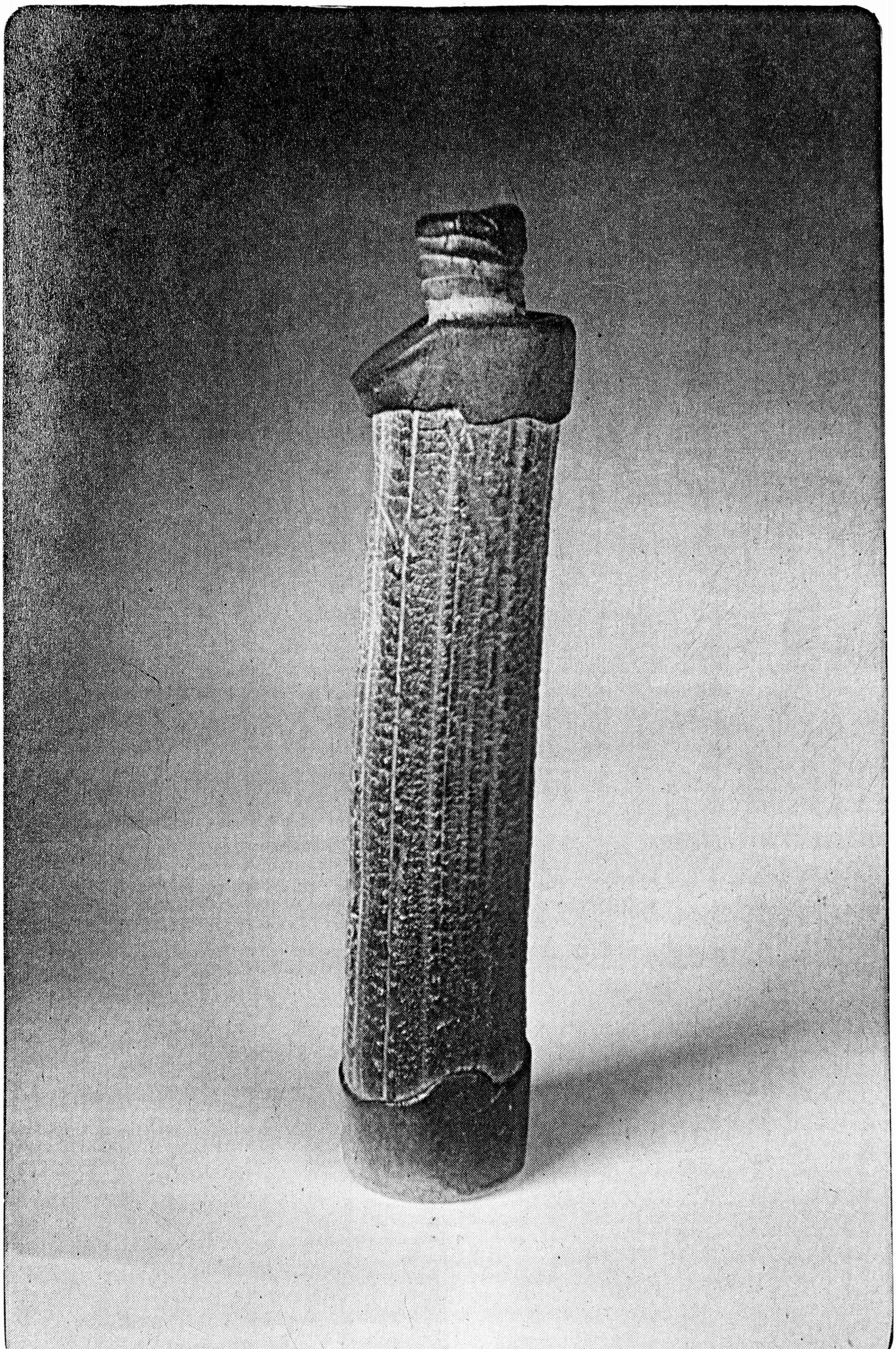
TIME (in hours)

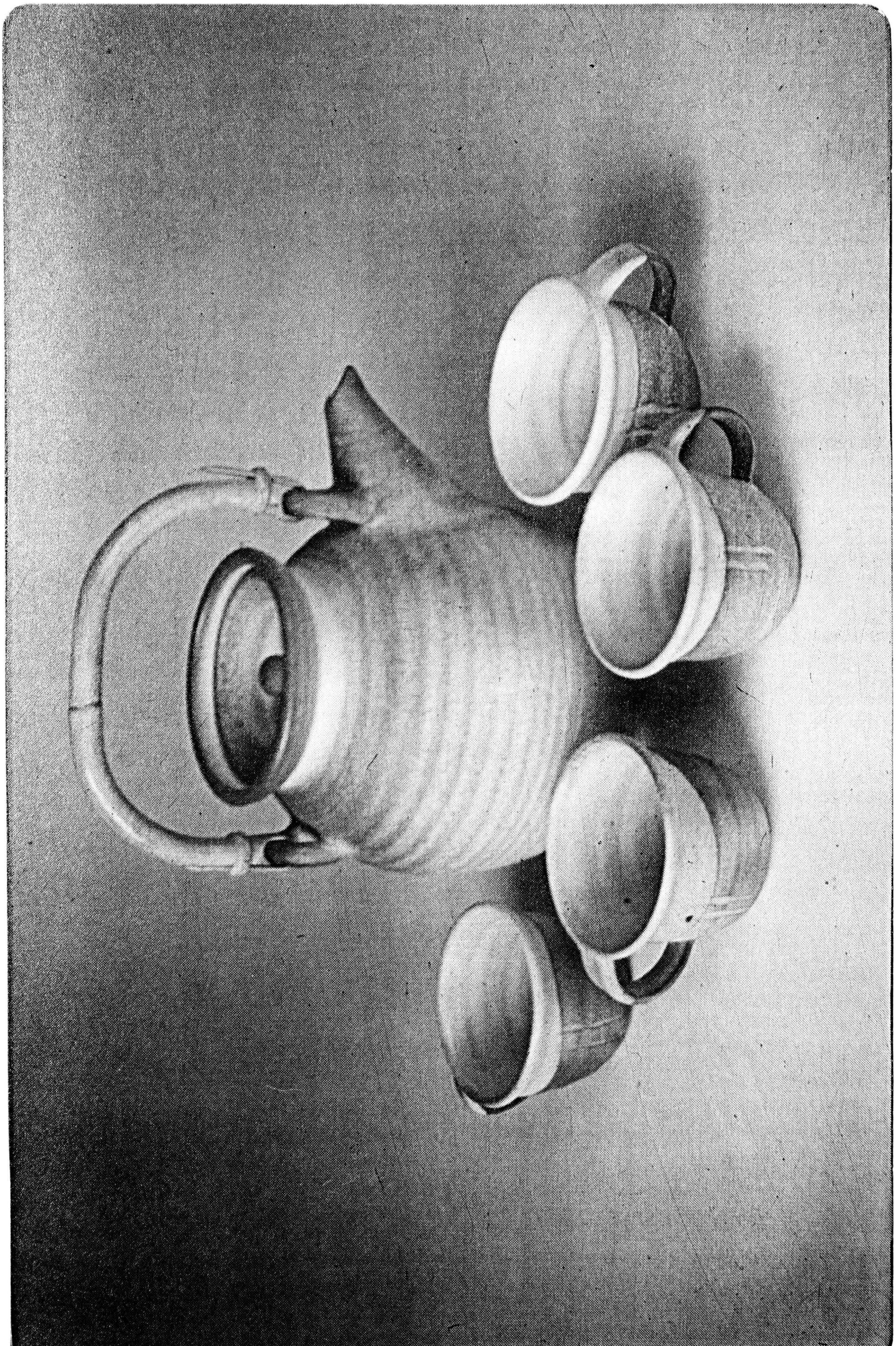
APPENDIX IV

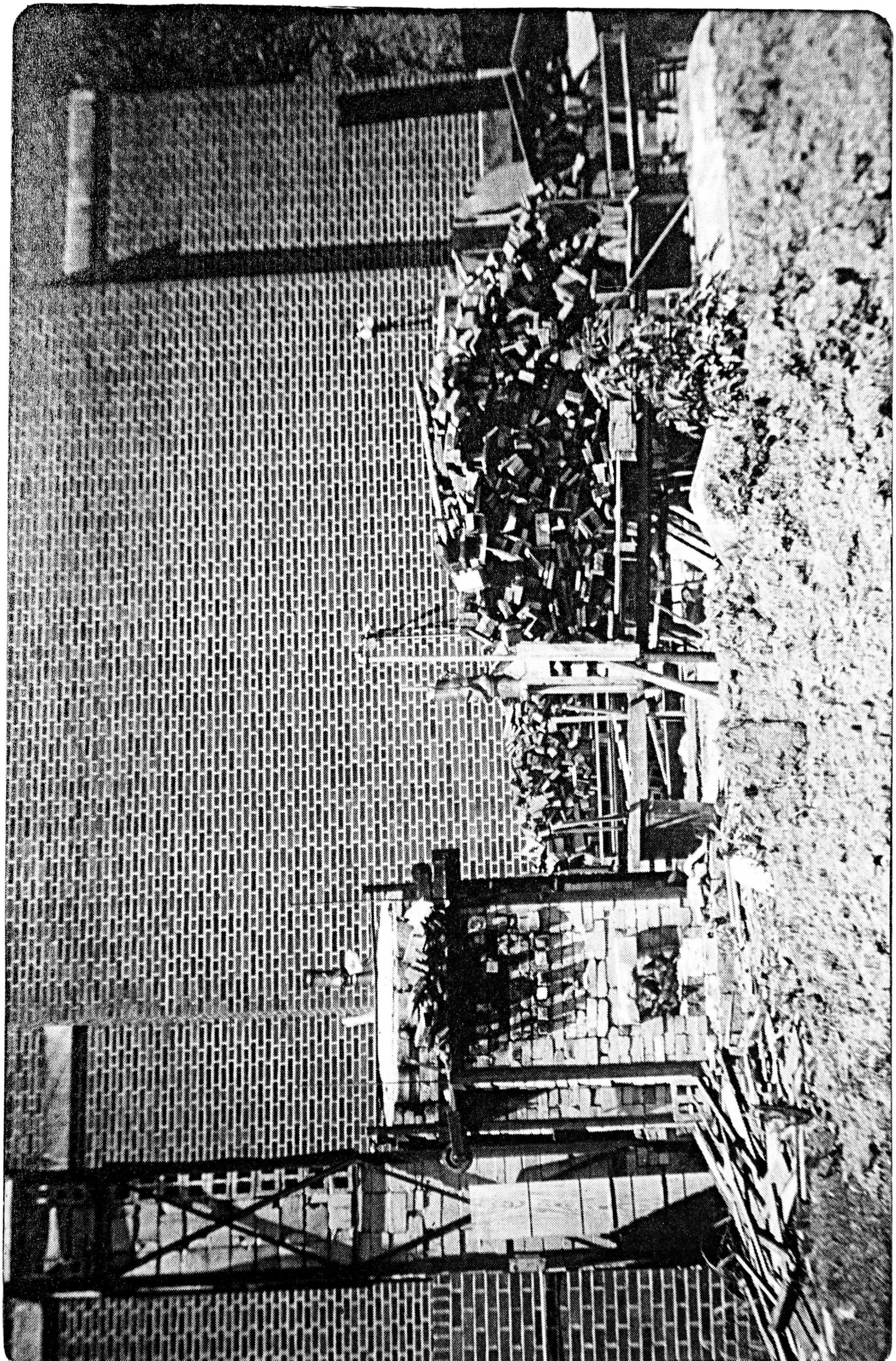
Selected Studio Work











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