

DIMENSIONAL EFFECTS ON ATOMIZATION
PATTERNS IN LIQUID FUEL INJECTION
SYSTEMS

Thesis for the Degree of M. S.
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Curtis Edward Behrens
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This is to certify that the

thesis entitled

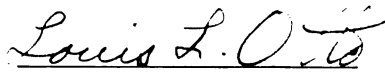
Dimensional Effects on Automization
Patterns in Liquid Fuel Injection
Systems

presented by

Curtis Edward Behrens

has been accepted towards fulfillment
of the requirements for

M.S. degree in M.E.

A handwritten signature in cursive script, reading "Louis L. Otto". The signature is written in dark ink and is positioned above the printed name and title.

Major professor

Date May 13, 1955

DIMENSIONAL EFFECTS ON ATOMIZATION PATTERNS
IN LIQUID FUEL INJECTION SYSTEMS

By

Curtis Edward Behrens

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Mechanical Engineering

Year 1955

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AN ABSTRACT

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ABSTRACT

This investigation involved research into the problems connected with liquid-fuel injection systems. A chamber was constructed to enclose and study the spray patterns of fuel-injection nozzles. The variables involved were the speed of the injection pump, the length, size, and material used in the injector tubing, and the nozzle opening pressure of the nozzle. The spray characteristics were visually studied and correlated with the variables involved.

It was found that the largest source of difficulty in proper injection of the fuel was the metal tubing used to connect the high pressure oil pump with the injection nozzle. It was found that the process of dribble, which is the issuance of coarse particles of oil from the nozzle after the injection process should have been completed, was present regardless of the type of tubing used. It was also found that the type of tubing influenced the appearance of trailing phases, which tend to increase the duration of the injection process.

The experiments indicated that the injection nozzle used had very little effect on the characteristics of the spray other than to alter its shape and general profile. The changing of the pressure at which the nozzle opens to release the oil had no effect other than to cause the appearance of coarse

particles in the spray.

The speed variable, combined with the type of tubing used affected the most important subject of the studies, the injection delay or lag. The delay is the late beginning or lag of the beginning of the injection process, the most significant characteristic requiring adjustment to the operating requirements of the individual engine.

The conclusions drawn from the experiments were that the lines connecting the high pressure pump with the injection nozzle should be kept as short as possible to minimize the effects of line length variation on the length of the delay period and the duration of the injection process. The lines of a multi-cylinder engine should all be of the same length to assure uniform timing of injection to the cylinders.

It was suggested that investigation be made of an injection system utilizing a low pressure hydraulic system to transmit the force necessary for injection. The use of low pressure oil is expected to reduce the effects of the resiliency of the tubing encountered with the high pressure systems.

TABLE OF CONTENTS

Acknowledgements.	.Page 2
Vita.	.Page 3
Abstract.	.Page 4
Table of Illustrations.	.Page 8
Introduction.	.Page 9
Discussion.	.Page 12
Summary and Conclusions	.Page 27
Appendix I: Description of Test Apparatus	.Page 30
Appendix II: Graphs and Charts	.Page 33
Appendix III: Photographs of Test Apparatus	.Page 37
Appendix IV: Photographs of Spray Patterns	.Page 41
Appendix V: Original Data	.Page 51

TABLE OF ILLUSTRATIONS

Fuel Flow Rate versus Throttle Rack Opening.	Page 33
Injection Delay versus Pump Speed.	Page 34
Appearance of the Second Phase	Page 35
Chart of Injection Delay versus Pump Speed	Page 36
Side View of Test Stand.	Page 37
Near End View of Test Stand.	Page 38
A Detailed View of the Pump.	Page 39
A Side view of the Motor	Page 40
Photographs of Spray Patterns.	Pages 41 - 50

INTRODUCTION

This experiment was a visual study of the characteristics of the process of liquid-fuel injection. A spray test chamber was built to confine the spray of a diesel engine fuel-injection nozzle of the standard type, an American Bosch system being used for these experiments. A stroboscopic light was employed to visually stop the action of the spray at various points in the injection process.

The problems of liquid-fuel injection that were studied fell into three main categories. The first was the phenomenon of injection-delay period. Injection delay, probably the most significant problem connected with fuel-injection, is the delay of the beginning of the injection process with reference to the beginning of the pumping action by the fuel-injection pump. The injection delay is cited in terms of the number of degrees of injection pump shaft rotation from the point where the fuel inlet port of the pump is closed and the displacement begins to the point where oil begins to discharge from the injection nozzle. This lag in the beginning of the injection process will change with different operating characteristics of an engine. The variables affecting the delay period are the speed of the injection pump, the delivery valve used in the pump, and the type and length of metal tubing used to connect the injection pump with the

nozzle. The effect of injection delay on the diesel engine is not definite, since the delay characteristics of an injection system must be experimentally adapted to the operating requirements of each individual engine.

The second problem of liquid-fuel injection is an appearance of coarse particles or droplets in the spray and a 'dribble' of coarse droplets from the injection nozzle after the bulk of the oil has been injected and the injection process should have been completed. The coarse droplets, apparently affected by the length and type of tubing used, and by the nozzle valve opening pressure would affect the engine by lengthening the process of combustion with a resulting reduction in efficiency.

The third trouble encountered in liquid-fuel injection is the breakup of the injection spray into separate phases and the lengthening of the injection process. The results of results of the increase in the duration of the injection process are the same as the other problems, namely, a possible reduction in combustion efficiency due to improper injection of the fuel.

The factors affecting these variables were studied in relation to the visual characteristics of the spray patterns in order to determine the steps necessary to insure an approach toward ideal injection with respect to the engine. The problem reduces itself to one of causing injection to take place in the desired length of time with little after-spray

or dribble, with optimum atomization of the fuel, and with injection beginning at the proper time.

DISCUSSION

The first experiments made produced data on the basic test nozzle used, an American Bosch model AKC 45 SD 51. This was a narrow pintle type nozzle with an opening pressure for these experiments of seventeen hundred pounds per square inch. The data was recorded, without varying the nozzle-opening pressure, for one-eighth inch increments of throttle rack opening, a speed range of one hundred to two thousand revolutions per minute of pump speed, and using three different types of injector tubing.

Upon completion of these experiments, a fuel-flow rate determination was recorded. The nozzle pressure was not changed, and rates were recorded near a speed of one thousand revolutions per minute for one-eighth inch increments of throttle rack opening.

The next series of experiments involved changing the nozzle-opening pressure of the basic test nozzle used, the American Bosch AKC 45 SD 51. Increments of approximately five hundred pounds per square inch were chosen between the limits of one thousand to twenty-four hundred pounds per square inch. The data was recorded for three different throttle settings; one-quarter, one-half, and three-quarters of an inch throttle rack opening, using the two standard steel injector lines.

In order to compare the general orientation of the spray pattern, two other pintle type nozzles were visually studied, the American Bosch model AKB 35 SD 173 and the American Bosch model AKB 25 R 75.

The variables involved were the length and type of injector tubing and the nozzle-opening pressure used, since these factors undesireably affect the spray characteristics and can be altered within limits in engine installations. Other variables were present and are taken into consideration.

The eleven inch length of standard extruded steel tubing, one-quarter of an inch outside diameter, was accepted as the control in these experiments, as it would represent a typical short line as installed on an engine. A forty-four inch length of standard extruded steel tubing was employed to represent a typical long line as used on engines. These two lines differed only in length. These lines are generally used on engines, and have heavy walls to resist the internal pressure without undue elastic yield. The small inside diameter assures a small internal volume of oil under compression during injection. The oil in the tubing was compressed significantly by the pressures encountered, two thousand pounds per square inch being a typical value. The yielding of the tubing to the high pressures would be determined by the modulus of elasticity of the metal used, the wall thickness, and the length of the tubing.

In order to exaggerate the variables imposed by the injector tubing a forty-one inch long, five-sixteenths inch outside diameter thin wall copper tubing was fabricated. Copper was chosen for its low stiffness, and the thin walled tubing used had a very high internal volume under compression.

The nozzle-opening pressure represents the pressure that must build up in the injector tubing and nozzle before the valve in the nozzle opens and releases the oil. The pressure is allowed to build up high enough to overcome the pressure encountered in the cylinder of an engine, and enough additional pressure allowed to assure complete atomization of the fuel for proper combustion. The valve in its closed position prevents the products of combustion from entering the nozzle and clogging the mechanism. Attached to the valve in the nozzles used in these tests was a pintle, a conical shaped device that assures proper radial dispersion and breakup of the spray. The actual pressure available for atomization of the fuel would be the pressure in the nozzle during injection minus the pressure inside the cylinder of an engine. The pressure settings in practice will range from sixteen hundred to twenty-two hundred pounds per square inch on Bosch injection systems. The pressure inside the cylinder at the time of injection would be approximately five hundred pounds per square inch. The nozzle opening pressure of the model AKC 45 SD 51 nozzle was adjusted by placing shims consisting of small steel washers behind the valve spring.

The three different nozzles used differed primarily only in the shape of the pintle used to disperse the spray. The basic test nozzle used, the model AKC 45 SD 51, was equipped with a narrow type pintle giving little radial dispersion of the spray. The model AKB 35 SD 173 nozzle could be classified as a medium pintle type, giving slightly more radial dispersion of the spray. The model AKB 25 R 75 nozzle was a large diameter wide angle pintle nozzle, giving a relatively wide angle radial dispersion to the spray. It was felt that the setting of the nozzle valve and the injector tubing used determined the characteristics of the spray, consequently the last two nozzles were only visually and photographically studied.

The rack or throttle opening on the fuel pump determines the amount of fuel injected by each pumping stroke. Since the total rack movement was exactly one inch, increments of one-eighth inch were chosen for these experiments. A micrometer barrel was employed to accurately determine the amount of rack movement.

An important variable in these experiments was the speed at which the pump was driven. A speed range of one hundred to two thousand revolutions per minute of pump speed was chosen to represent the range of speeds that would be encountered in operation of both two-stroke cycle and four-stroke cycle engines. Difficulty was encountered in selecting speeds in the low speed end of operation, consequently data was recorded

for speeds near one hundred, two hundred and sixty, and four hundred and eighty revolutions per minute, with increments of two hundred revolutions per minute at speeds from six hundred to two thousand revolutions per minute inclusive.

The nozzle would not discharge with the throttle rack set at one-eighth inch open when operating at low speeds, even with the eleven inch long line installed. It was assumed that the surges of oil in the line caused by the pumping action were not of great enough magnitude to open the nozzle valve at low speeds when pumping the very small quantity of oil, and the pulsations were absorbed by the elasticity of the line. A slight leakage of oil past the plunger in the injection pump would also prevent discharge of oil at low speeds and small throttle openings. When the speed was increased sufficiently to cause discharge from the nozzle, a fine dribble was observed, usually over a relatively long period of time.

The number of degrees of pump shaft rotation represented the time element involved at any given speed. All references to the spray were made in terms of degrees of pump shaft rotation, with the zero point being the point of port closure of the pump, the theoretical beginning of the pumping process. The intervals of time could have been computed, but the pump rotation was more easily correlated to operating conditions in an engine. It was observed that the injection process would increase in duration as the speed was increased at a given throttle rack setting, but would not double as the speed was doubled. The pump is cam operated and will pump for a

certain number of degrees of shaft rotation, but at high pump speeds the velocity of the oil in the lines reaches a value sufficient to impart enough kinetic energy to the oil to change the valve closing characteristics. The bleed-off of pressure after the pumping stroke was completed was apparently a time function, as the trailing phases and the dribble were extended over a greater number of degrees as the speed was increased.

The first characteristic of the spray to be discussed is the determination of the injection delay period, made by adjusting the timing of the Strobolux to observe the beginning of injection, or the point at which the oil just began to emerge from the nozzle. The number of degrees of pump shaft rotation from the point of port closure was recorded, as the amount of delay of the beginning of injection.

The injection delay was definitely held to a minimum by the short steel line. With no exceptions a maximum of seven degrees delay was observed with this line, and considering the three to five degrees delay necessary to open the nozzle valve, this represents two to five degrees of actual delay. The amount of injection delay was not significantly affected by the throttle opening, although it varies slightly with different throttle settings. Reference is made to the enclosed chart which illustrates the insignificant effect of throttle opening on delay for the three lines tested.

The forty-four inch length of standard steel tubing gave

results involving the largest amount of injection delay, generally reaching a value of fifteen degrees and more in the higher speed ranges. Again considering the number of degrees necessary to open the nozzle valve, this represents ten or more degrees of actual delay. It is interesting to note that the large internal-volume, low-stiffness copper tubing used to exaggerate the conditions affecting delay gave less injection delay than the long standard steel tubing of the type used on engines.

It must be remembered when speaking of delay referred to in the number of degrees, that this was degrees of pump shaft rotation. This is important in that ten degrees of pump shaft rotation represents twenty degrees of crankshaft rotation in a four-stroke cycle engine. The American Bosch injection pump and system used in these experiments is most widely used on four-stroke cycle diesels and not two-stroke cycle engines. The important implications of fifteen degrees of injection delay can be more readily realized when it is remembered that this signifies injection would be thirty degrees of crankshaft rotation late in a four-stroke cycle engine.

An interesting phenomenon was observed in reference to the injection-delay period. A series of points in the speed range would appear between four and eight hundred revolutions per minute where the delay period would become unusually short. Injection would start between five and seven degrees after pump port closure at very low speeds, and in this critical

speed range would drop to a value as low as two and one-half degrees followed by an increase after reaching this minimum. The low point in the curve did not appear at the same speeds for the three different lines used, but appeared about three hundred revolutions per minute higher for the short steel tubing than the two long lines used. The amount of dip in the curve was the greatest for the forty-one inch copper tubing used. It was hypothesized that one of the factors causing this phenomenon was the frequency of the injection pulses, which would be some multiple of the natural frequency of the spring and mass combination formed by the injector nozzle valve and related parts of the system that could be set into vibration.

Another factor affecting the delay period is the type of discharge valve used in the injection pump. The valve used for these experiments was a simple poppet valve, with a short movement necessary to open and close the oil passage. This valve allows a pressure to remain in the line, the amount determined by the closing pressure of the valve in the nozzle. Another type of poppet valve with a relatively long movement before oil flow can occur, (not tested) will relieve the pressure in the line after the pumping action is completed. The large movement of the valve necessary, and the buildup of the pressure in the line before the next pumping cycle can occur results in an increase in the delay period before oil is discharged from the nozzle.

The second characteristic of the spray that was observed was the breakup of the spray into separate and distinct phases, or individual discharges of oil from the nozzle. These phases would fall into three general categories, where (1) a second phase would appear near the beginning of injection, where (2) individual phases would appear after the bulk of the oil had been injected, and (3) the breakup of the whole spray into separate phases caused by valve bounce or nozzle squeak.

The pintle nozzle is designed to limit the amount of oil that is injected for the first few degrees in order to assure the starting of the combustion process without introduction of a large quantity of fuel into the cylinder at a time where combustion knock would occur. The separate and distinct phase that would occur under certain conditions at the beginning of injection was caused by the opening and closing of the nozzle valve, due to a release of the built-up pressure in the line. The pressure dropped to a low enough value to allow the nozzle valve to close before the pressure built up again sufficiently to hold the nozzle valve open to allow discharge of the bulk of the oil.

The phases appearing at the end of the injection process, after the bulk of the oil was injected, were caused by the same nozzle-valve bounce. The nozzle-valve action under these circumstances was often caused by harmonic surges in the line, and occasionally by the bouncing of the nozzle valve at its natural frequency assisted by the oil held under pressure in the line at a pressure near the nozzle-valve opening and

closing pressure by the resiliency of the line. The large diameter copper tubing would often allow several trailing phases to appear due to its ability to hold a large quantity of oil under pressure after the pumping process was completed.

The breakup of the whole quantity of oil into separate phases was accompanied by a squeak from the nozzle. The nozzle valve would vibrate at its natural frequency at low speeds due to the slow discharge of oil from the pump and the pressure and oil-flow conditions at the nozzle valve. The squeak would generally disappear with an increase in speed, when the flow rate of oil through the nozzle valve was sufficient to hold the valve open.

Similar to the breakup into phases was the breakup of the spray into nodes. The breakup was not separate and distinct as when the nozzle valve was opening and closing, but seemed to indicate that the valve was vibrating, but not completely closing. The nodes of the spray were most noticeable using the short steel tubing, where little resiliency was present and the oil would be delivered to the nozzle with small fluctuations in the pressure at the nozzle. The nodes were also affected by the throttle opening, suggesting the flow of oil through the nozzle valve at small throttle settings was not sufficient to hold the valve open.

The forty-one inch long large diameter copper tubing allowed the nozzle to squeak through a wide speed range. The high resiliency of this line and the corresponding ability to

store and release the pressure would allow the nozzle valve to vibrate under many conditions of operation.

The trailing phases that appeared particularly when using the long injector lines were also observed to be subject to what might be termed a form of delay. If a consistent second phase would appear near the end of the injection process and remain present over a wide speed range, the point of appearance (with an increase in speed) would be delayed a larger number of degrees than would the beginning of injection. The varying time of appearance of the trailing phases of injection was one of the large factors contributing to the lengthening of the injection process over a large number of degrees as the speed was increased with a given throttle opening. In the high speed ranges it was often observed that a large number of degrees would separate the end of the injection of the bulk of the spray from the trailing second or third phase. The point of beginning of the trailing phases was affected also by the pump speed, the trailing phase beginning at a later time (larger number of degrees) as the speed was increased. As the speed is increased, the velocity of the oil in the line and its associated kinetic energy is a factor contributing to the holding open of the nozzle valve and the lengthening of the duration of the spray. Another factor is the pressure bleed-off from the line due to line resilience. The enclosed graph of the appearance of the second phase using the forty-four inch long standard steel tubing illustrates the trailing phase sensitivity to throttle-rack opening and pump

speed. The regular increase in the second phase appearance with incremental increase in throttle rack opening can be seen from this graph. The portion of the fuel oil injected well after the bulk of the spray represents wasted fuel in an engine, since the combustion process is substantially completed. This wasted fuel will appear as a smoky exhaust from the engine. The duration of the injection process is necessarily longer with increases in throttle-rack opening, as the construction of the injection pump requires a larger number of degrees of pump rotation to pump larger quantities of fuel.

The third characteristic of the injection spray was the 'after-spray' or dribble. This condition was always present to some degree under the conditions of these experiments, and consisted of an appearance of well-separated coarse particles of oil issuing from the nozzle after the bulk of the oil had been injected and the injection process would be considered complete. Certain conditions caused an increase in the amount of dribble appearing, occurring sometimes for many degrees after the injection process. The dribble process was considered to be caused by the leakage of oil from the nozzle due to the residual pressure in the line after the pressure had dropped sufficiently to cause the valve spring to close the nozzle valve. The large diameter copper tube, which gave the largest quantity of dribble, would be able to hold a relatively large volume of oil under pressure after the nozzle valve had closed, explaining the appearance of the large volume of dribble

using this line. The number of degrees of the dribble duration was dependent on the speed of pump rotation, suggesting that the dribble process of leakage past the nozzle valve requires approximately the same interval of time regardless of the pump speed. The observance of the dribble from the nozzle was not possible at high pump speeds and large throttle rack openings since the chamber had to be relatively free of mist to observe the small, widely separated particles of oil. It was not possible to photograph the dribble droplets.

A different type of pump discharge valve, mentioned previously, uses a relatively long closing stroke to relieve the trapped pressure in the injection line between injections. This type valve would probably greatly reduce the amount of dribble, but it was not tested.

A series of fuel-rate tests were recorded to determine the rate of flow of fuel from the nozzle at the throttle rack settings used. The choice of one thousand revolutions per minute pump speed was determined by the fact the nozzle would not discharge at low speeds with a one-eighth inch throttle rack opening, and the chosen speed represents approximately the middle of the operating range. No attempt was made to regulate the speed during the long fuel-rate timed runs, but a close observation was made on the speed with a mental average over the test interval. The speed would vary slightly with changes in the line voltage supplied to the motor, but it was estimated that the speed was accurate to within plus

or minus five revolutions per minute, an error of one-half percent. Care was taken to keep error to a minimum in these tests, as it was known there was much source of error present. The overall error was estimated to be within plus or minus three percent.

The tabulated data is enclosed as well as a graph of the amount of fuel discharged with respect to the throttle rack opening. It is interesting to note that when allowance is made for experimental error, if a curve is plotted through the distribution of points, a straight line relationship seems apparent between the rack opening and the amount of fuel discharged from the nozzle. This discharge rate to rack position relationship is determined by the curvature of the helix cut in the pump plunger, and any desired relationship can be obtained by changing the helix. This data was recorded only to establish this relationship and is not thought to have any direct relationship to the spray patterns.

The series of photographs enclosed pictorially illustrates the spray patterns seen in the spray chamber. The pictures were taken using the Strobolux gas discharge light, fired once for each picture by a manually operated contactor in conjunction with the timer-contactor device mounted on the pump shaft. The first series of seven pictures show the steps in the injection process for the Bosch AKC 45 SD 51 nozzle, with a comparison of the effect of low nozzle-valve opening pressure. These photographs illustrate the effect of the

pintle limiting the amount of fuel injected for the first few degrees of injection. The next two pictures show the breakup of the spray at the beginning of the injection process. The following four pictures show the later stages of the spray, with coarse particles caused by the low nozzle-opening pressure, and the orientation of the spray breakup in the last stages and after the injection process. An excellent picture is included of the breakup of the spray into seven phases caused by the nozzle squeak at low speeds.

The next four photographs show the stages of the spray pattern using the Bosch AKB 35 SD 173 nozzle. It can be seen that the pintle of this nozzle does not alter the shape of the spray materially. The last four pictures are the stages of the spray for the AKB 25 R 75 wide pintle nozzle, showing the large radial dispersion of this pintle and the lack of the restrained beginning of the spray to control engine knock. These pictures give a visual account of the differences in the overall pattern produced by this nozzle with the pattern produced by the other two types of pintle nozzles.

The original data enclosed represents a complete log of the experiments performed. Individual details of the steps of the tests may be compared to the generalizations and the summaries presented in this text.

SUMMARY

The studies detailed in this thesis warrant certain design recommendations intended to reduce the undesirable effects of the problems encountered in liquid-fuel injection systems. It was apparent from the spray patterns and knowledge already available that the injector lines must be kept as short as possible on engines to reduce the effects of line resilience, the trailing phases and dribble. In order to insure that individual cylinders of a multi-cylinder engine operate under the same conditions, an injection system layout should be chosen with the injector lines all the same length. One system employed today combines the features of short lines and lines the same length by the use of separate injection pumps for each cylinder mounted close to the individual injector nozzles.

The indications of the nozzle-opening pressure experiments point to the use of higher nozzle-opening pressures to increase the atomization and reduce the presence of coarse particles in the spray. The nozzle-opening pressure apparently had no effect on the delay period or the appearance of trailing phases in the injection process. The process of dribble after the completion of the injection process can be controlled by the use of the large-travel pump-discharge valve.

In an effort to reduce the effects of the injector tubing

on the spray characteristics of nozzles, the unit injector was developed and is in wide use today. The unit injector has the high pressure oil pump and the discharge nozzle built integrally so that the oil passage between the pump and the nozzle is extremely short, not subject to the compressibility and resiliency effects of the injector line. The unit-injector pump is actuated by a positive rocker arm mechanism, and will have injection pressures as high as thirty thousand pounds per square inch. This system is not without its own limitations, and is not the whole answer to liquid-fuel injection problems. The American Bosch system and other similar systems with the high-pressure fuel pump separate from the nozzle are still the popular injection systems from the standpoint of the number of engine manufacturers.

These studies seem to indicate that the undesirable effects of delay and dribble cannot be completely eliminated when the system used employs a length of tubing under high oil pressure to connect the supply of high pressure fuel with the injection nozzle. It is suggested that perhaps investigation of a different method of delivery of the fuel to the injectors might yield significant results. A system is visualized using a high volume low pressure hydraulic system to deliver the force necessary for injection. The hydraulic fluid used would be diesel fuel, so that the low pressure system would also supply the oil to be injected. This change in the method of transmission of the force might eliminate

some of the line resilience problems causing delay and lengthening of the duration of the spray. The injector nozzle would consist of a double piston, to step the hydraulic pressure to a sufficient value for injection into the cylinder. This method would also allow higher injection pressures for more complete atomization of the fuel, since the connecting line pressure would not be a limiting factor.

APPENDIX I

DESCRIPTION OF TEST APPARATUS

The experiments were performed with the nozzle mounted in a closed test chamber, three feet on a side in dimensions. The chamber had two glass windows approximately thirty-four inches square fitted in opposite sides of the chamber for observation of the spray. A Strobolux gas-discharge stroboscopic light was mounted in the top of the chamber to illuminate the spray. Inlet and outlet air plenum chambers and diffusers were fitted to each end. Removal of the oil mist and vapor created by the spray was accomplished by a stove pipe outlet from the rear plenum chamber connected to a large sheet metal box filled with ten pounds of fine steel wool. The filtered air was removed from the steel wool by a centrifugal air blower and returned to the spray chamber by the inlet plenum chamber and diffuser. The joints of the chamber and filter box were soldered, gasketed and sealed, in an attempt to make a closed system. It was found that a pressure was developed inside the test chamber during operation, and that oil mist was forced out the gasketed joints.

A standard American Bosch two-cylinder fuel pump was used, using only one cylinder to supply the injector nozzle. The pump was driven by a three-horsepower direct current

motor, using a dynamometer panel for armature current supply. The motor drove a short, large diameter shaft by vee-belt which was mounted on ball bearing pillow blocks. A one hundred and fifty pound flywheel was used to reduce angular jerk caused by the pump. The shaft was connected to the pump by a sheet metal coupling, constructed so no angular motion could take place between the flywheel and the pump.

A timing device was fitted to the flywheel shaft to fire the Strobotac, a neon discharge light used to determine pump speed and timing of the Strobolux light. The flywheel was marked in degrees of pump shaft rotation, with zero degrees being the point at which the inlet port of the pump was closed. The Strobotac, fired by the timing device, was arranged to illuminate the flywheel and pointer to determine the relative position of the firing of the lights.

The fuel system consisted of a five gallon can containing diesel-engine fuel oil with a pair of standard diesel fuel filters to filter the oil. The oil passed from the filters to the low-pressure fuel pump, mounted on the side of the injector pump. The low-pressure pump kept a constant supply of oil in the high-pressure injection pumps, with an overflow system used to dispose of the surplus. The bottom of the spray chamber drained into the filter box, and the box was periodically drained from a petcock and the oil reused.

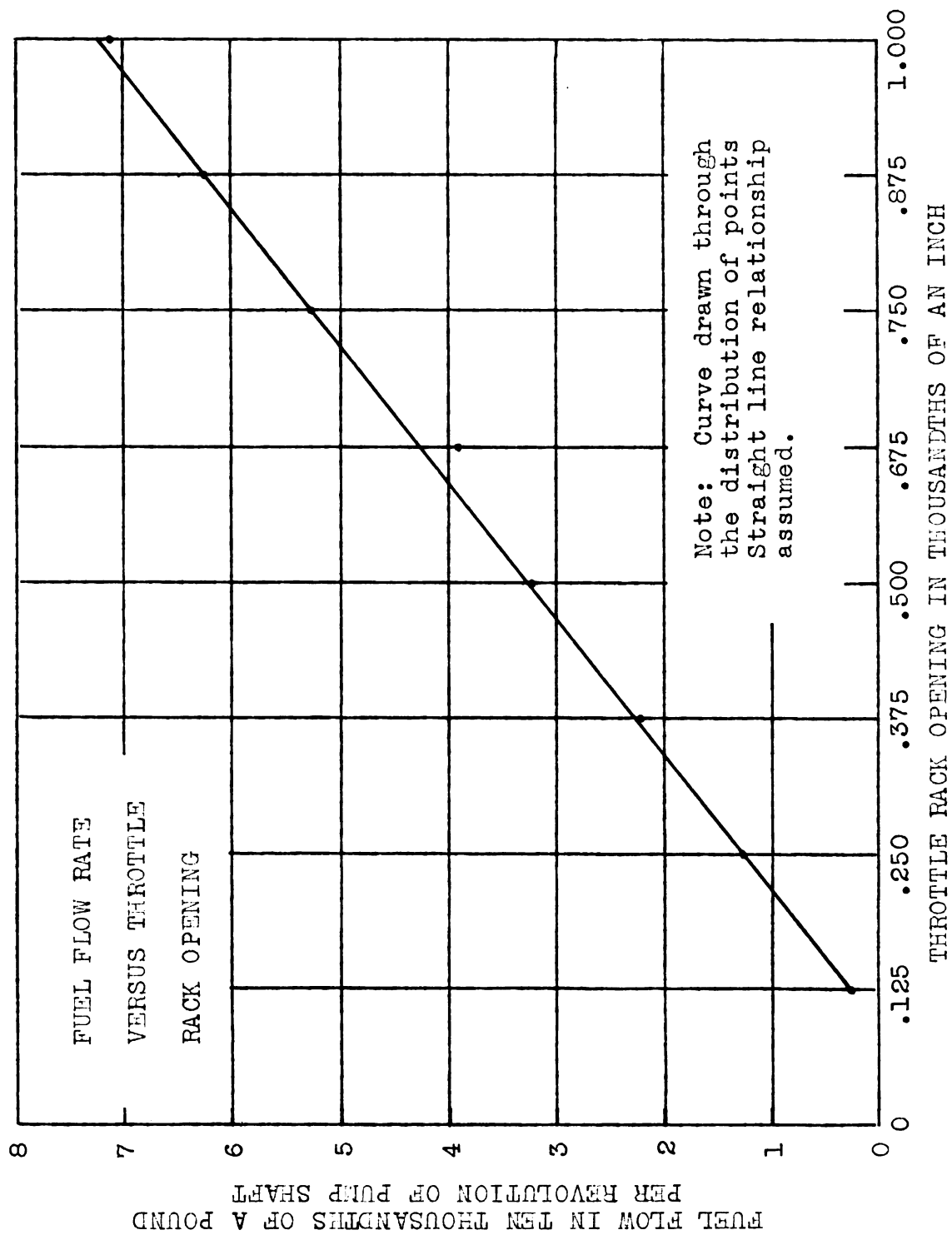
A micrometer barrel (permanently mounted on the test rig) was used to accurately determine the rack positions during

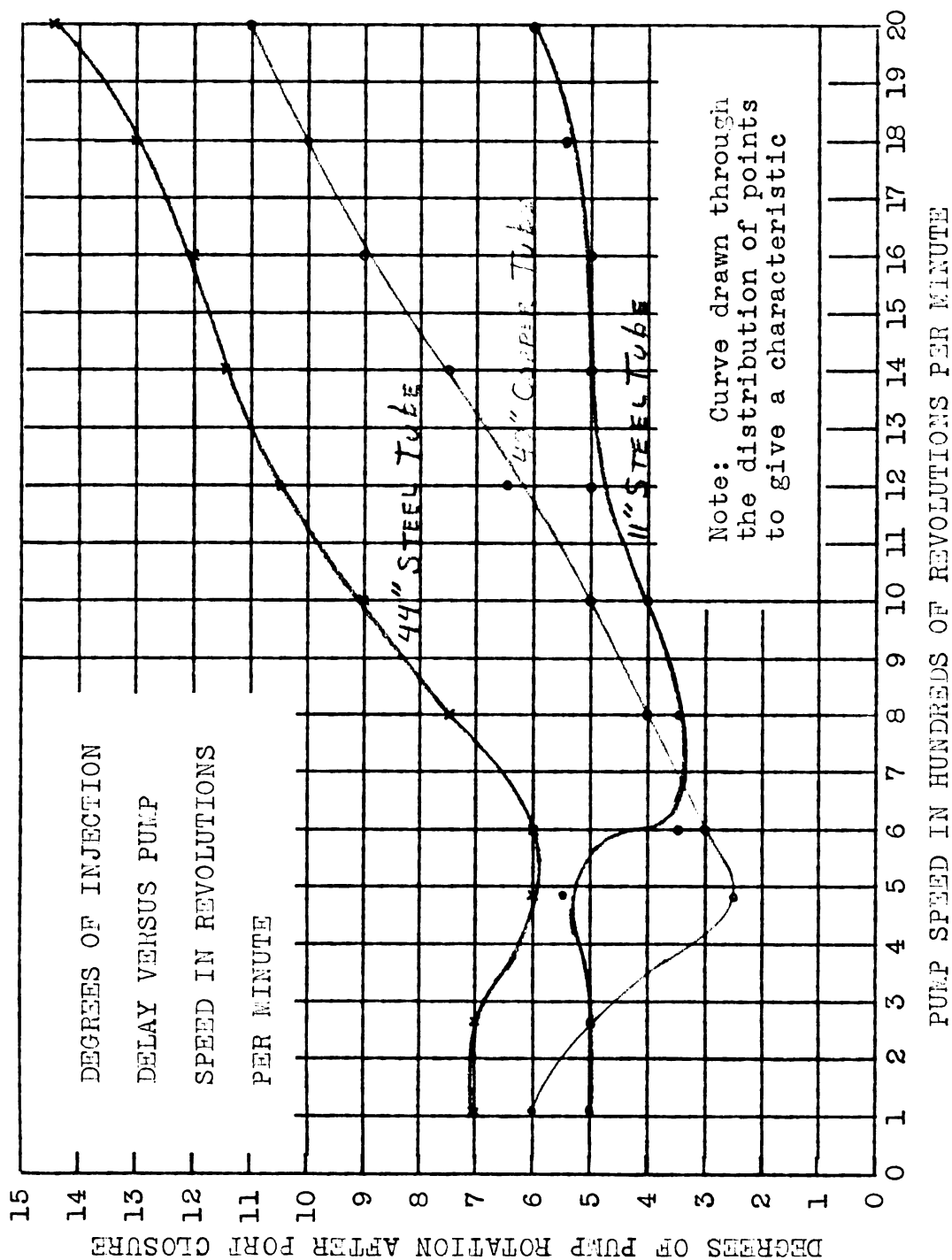
the tests.

A stovepipe butterfly valve was installed in the inlet air pipe to regulate the amount of air passing through the spray chamber, but it was found necessary to leave the valve open to insure sufficient air circulation through the chamber to carry away the mist. Air circulation at high velocity had no apparent effect on the spray patterns of the nozzles used in these tests.

The whole test stand was six feet high, three feet wide, and five and one-half feet long, with the dimensions of the spray chamber three feet on a side.

The fuel-flow rate was measured from the nozzle by submerging the injector nozzle in diesel oil held in an overflow can, running the pump at approximately one thousand revolutions per minute, and weighing the oil discharged over a period of time.





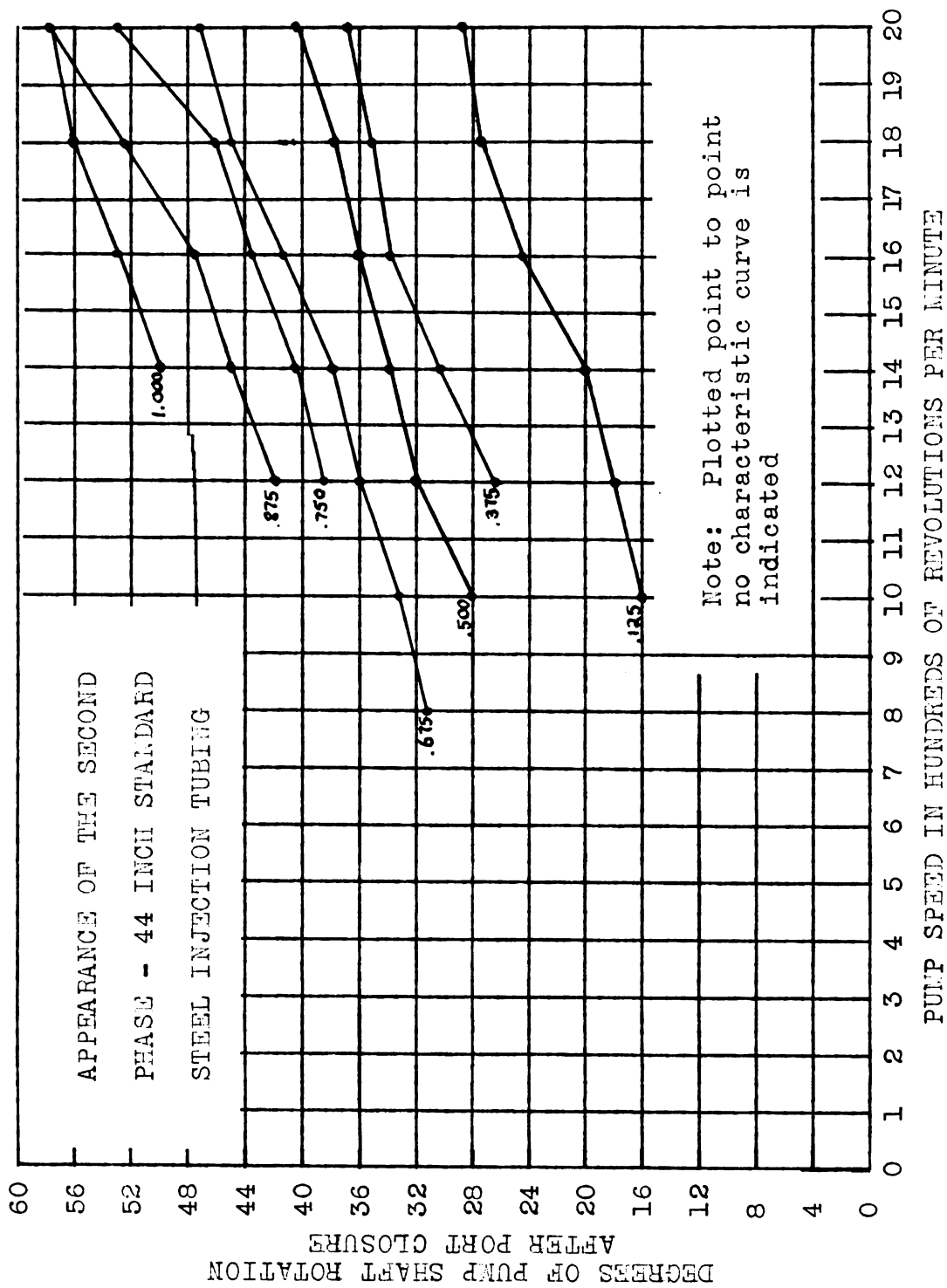


CHART OF INJECTION DELAY VERSUS PUMP SPEED

Speed in revolutions per minute of pump shaft - Injection delay in degrees		110	260	480	600	800	1000	1200	1400	1600	1800	2000
41" Copper Tubing	5 1/2	6 1/2	3 1/2	3	4	5 1/2	7	7	8	9	10	11
	6	5	3	3	4 1/2	5 1/2	7	7 1/2	8	9	10	11
	6	4	2 1/2	3	4	5	6 1/2	7	7 1/2	9	10	11
	8	4 1/2	2 1/2	3	4	5 1/2	7	7	7 1/2	9	10 1/2	10 1/2
	6	4	2 1/2	3	4	5 1/2	6	6	7 1/2	9	10	10 1/2
	6	4 1/2	2 1/2	3	4	5	6	6 1/2	8	8 1/2	9 1/2	11
	6	6	2 1/2	3	4	5	6 1/2	8	8	8 1/2	9 1/2	10 1/2
Ave. 6		5	2 1/2	3	4	5	6 1/2	7 1/2	9	10	11	11
11" Steel Tubing	4 1/2	5	5 1/2	3	3	3	4 1/2	4 1/2	5	5 1/2	5 1/2	5 1/2
	5	4 1/2	4 1/2	3	3 1/2	3 1/2	4 1/2	4 1/2	5	5 1/2	6	6
	5	4 1/2	5	3 1/2	3 1/2	3 1/2	5	5	5	5	5 1/2	6
	5 1/2	5	5 1/2	3 1/2	3 1/2	3 1/2	4 1/2	4 1/2	5	5	5 1/2	6
	5	5	5 1/2	4	4	5	5	5	5	5	5 1/2	6
	5 1/2	5	5 1/2	5	4	4	5	5	5 1/2	5 1/2	5 1/2	6
	5 1/2	5	5 1/2	5	3 1/2	3 1/2	5	5	5 1/2	5 1/2	5 1/2	6
Ave. 5		5	5 1/2	3 1/2	4	5	5	5	5 1/2	5 1/2	5 1/2	6
44" Steel Tubing	6 1/2	7	5 1/2	5 1/2	7	7	10 1/2	10 1/2	11 1/2	12 1/2	14	15
	7	7	5 1/2	5 1/2	7	7	11	11	11 1/2	13	13 1/2	15
	7	8	6	6	7	7	11	11	11 1/2	12	13	15
	7	6 1/2	6	7	8	8	10	10	11 1/2	11 1/2	13	14
	7	7	6	6 1/2	8 1/2	8 1/2	9 1/2	9 1/2	10	12	12 1/2	14
	7	7	6	6	8	8	10	10	11	11	12	13
	6	7	6	6	7 1/2	7 1/2	10	10	11	11 1/2	12	13
Ave. 7		7	6	6	7 1/2	7 1/2	10 1/2	11 1/2	12	13	14 1/2	15

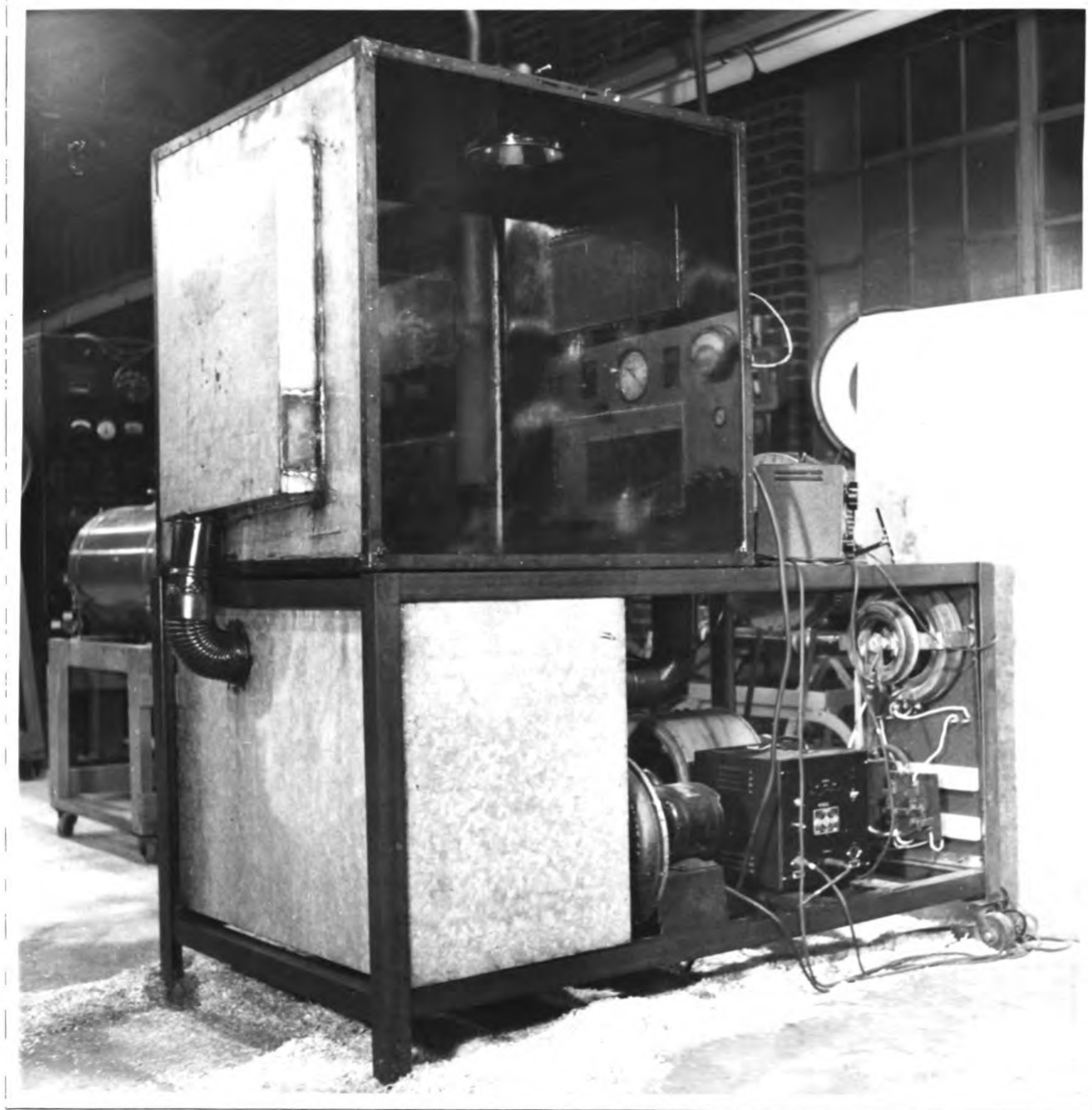


PLATE 1: Side view of test stand showing spray chamber, Strobolux light, rear plenum chamber, filter box and connecting tubing. The meters seen are reflections in the glass. The Strobolux power supply, the Strobotac, part of the centrifugal blower, and the field control rheostats can also be seen.

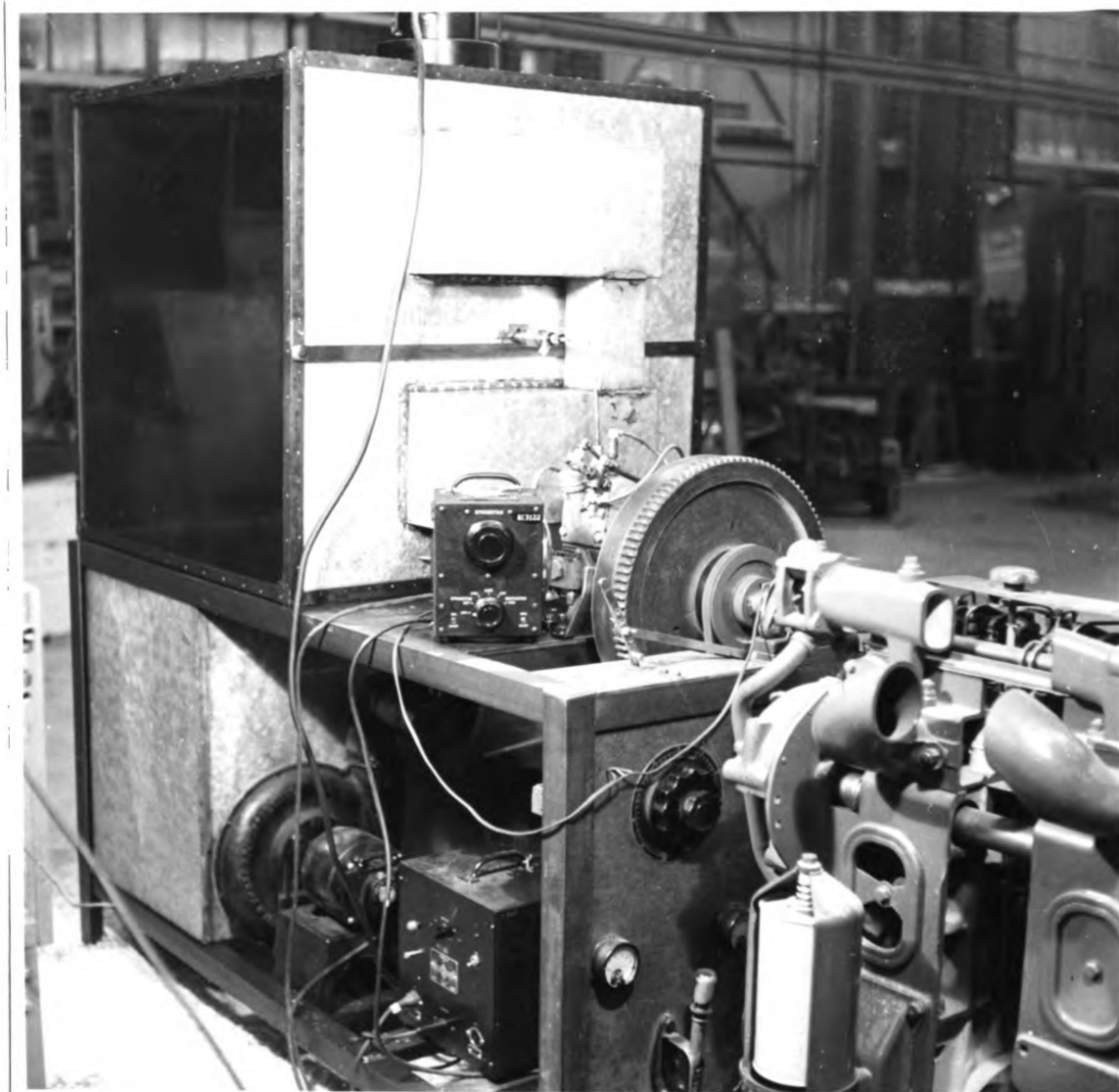


PLATE 2: Near end view of the test stand showing inlet plenum chambers, Strobolux light, and nozzle mounting bracket. The Strobotac, flywheel, and motor field controls can also be seen in addition to the centrifugal blower and Strobolux power supply.

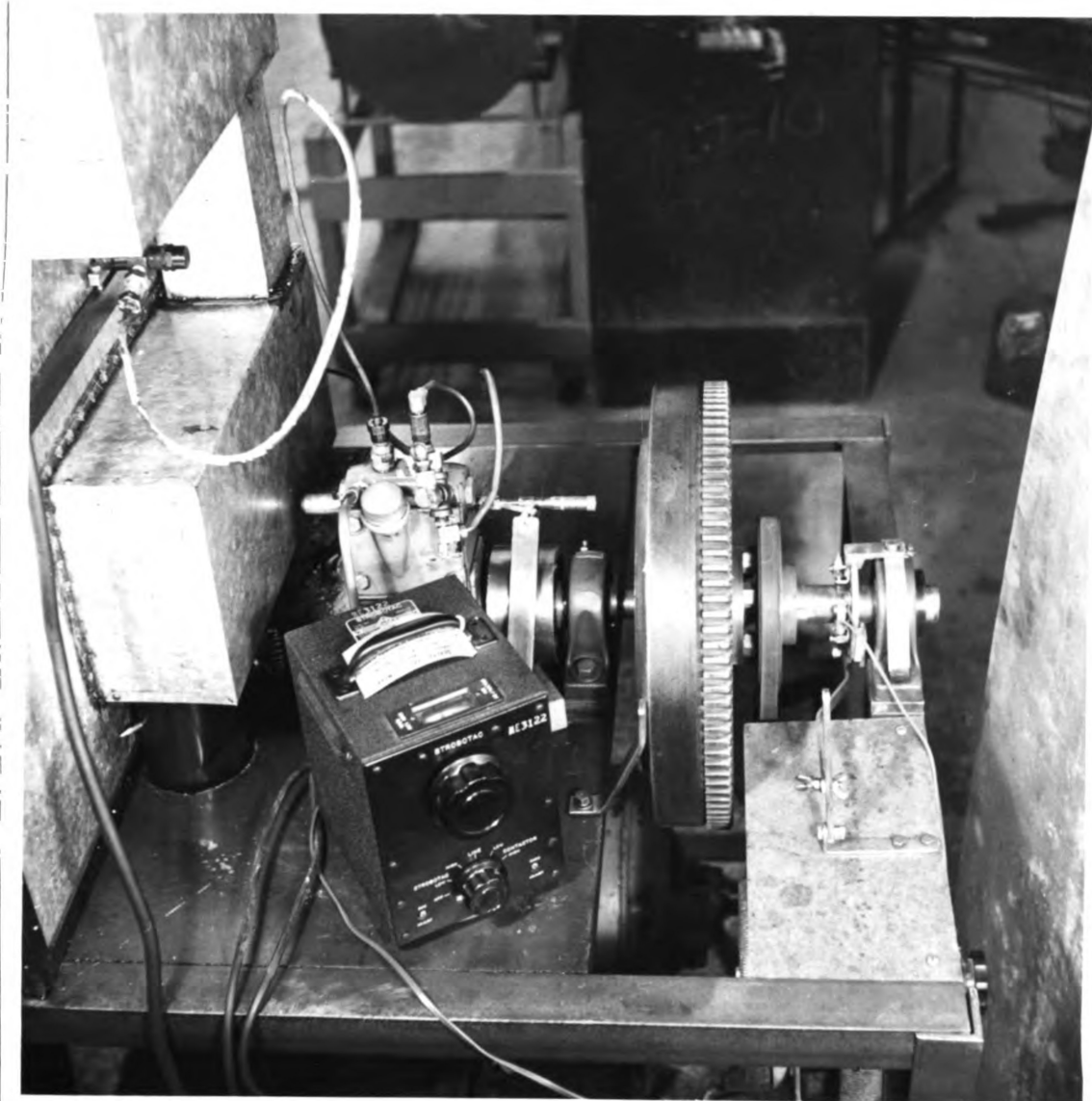


PLATE 3: A detailed view of the pump, flywheel and the Strobotac. The timer and control, flywheel bearings, micro-meter throttle adjustment, and flywheel pointer can also be seen. This illustration also shows the nozzle mounted in the end of the spray chamber, and the pipe to the inlet plenum chamber.

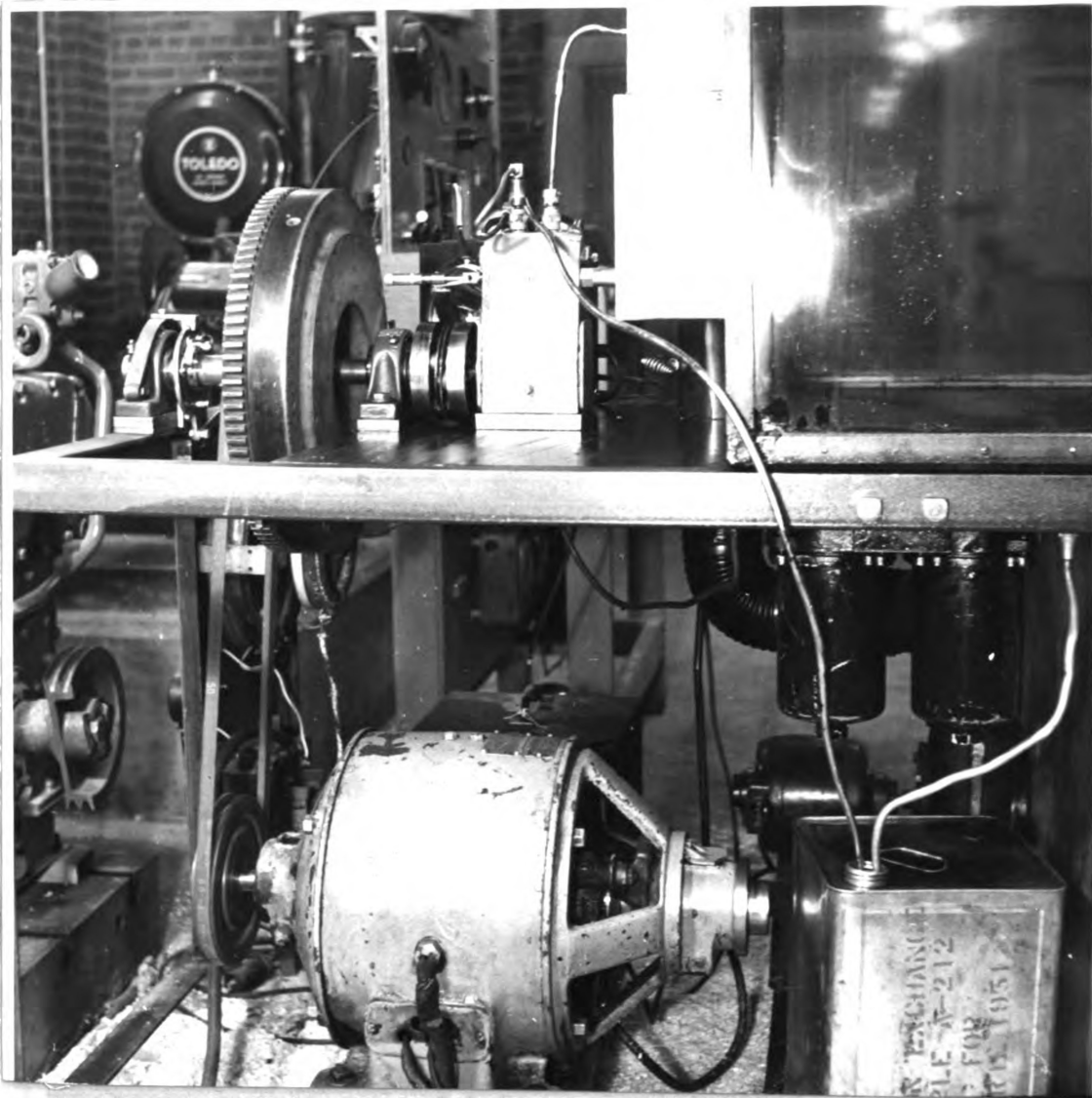


PLATE 4: This side view shows the details of the mounting of the motor, the vee belt drive, and the coupling connecting the flywheel shaft and the pump. The details of the fuel system can also be seen, with the five gallon reservoir, the fuel filters, and the overflow and supply tubing.

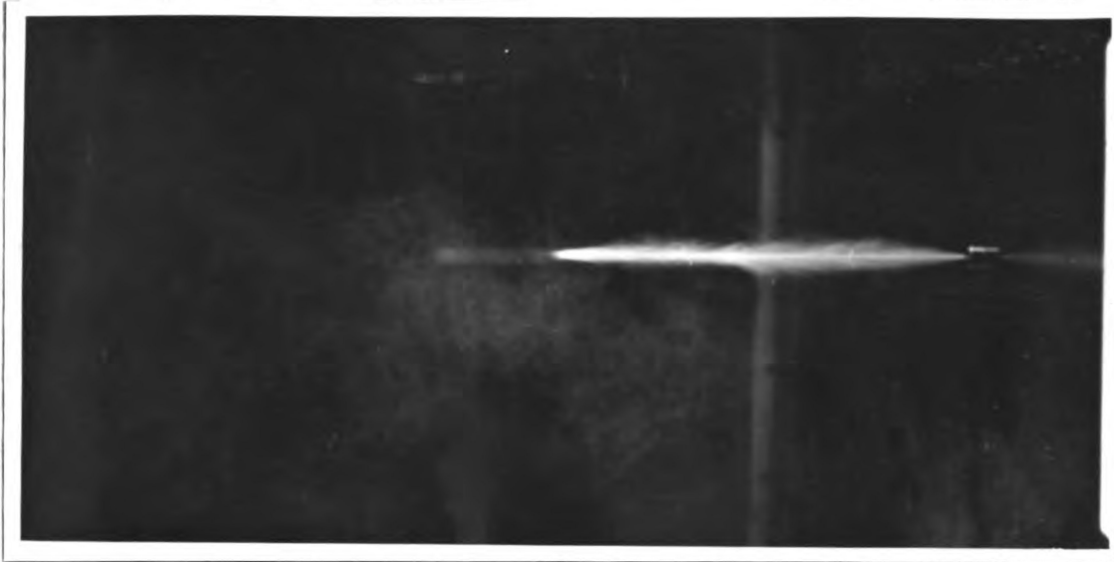


PLATE 5: Injection begins at 5° , photo at 9° , 250 rpm., .500 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 11 inch long steel tube, 1000 psi. nozzle opening pressure. An "ideal" injection. A small cloud from the previous spray is shown.

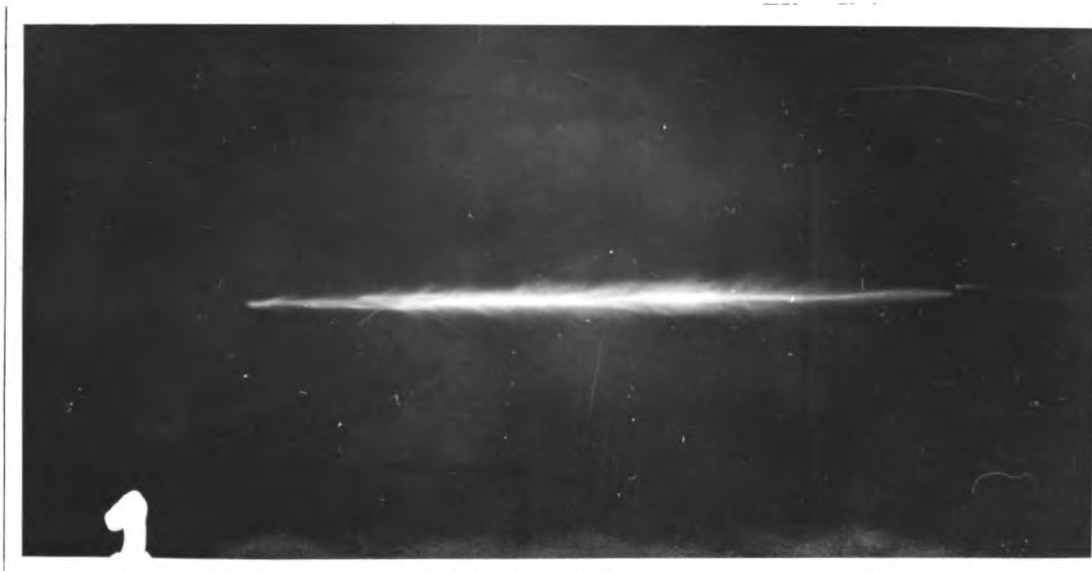


PLATE 6: Injection begins at $4\frac{1}{2}^{\circ}$, photo at 11° , 260 rpm., .375 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 1675 psi. nozzle opening pressure, 11 inch long steel tube. Injection is single phase.

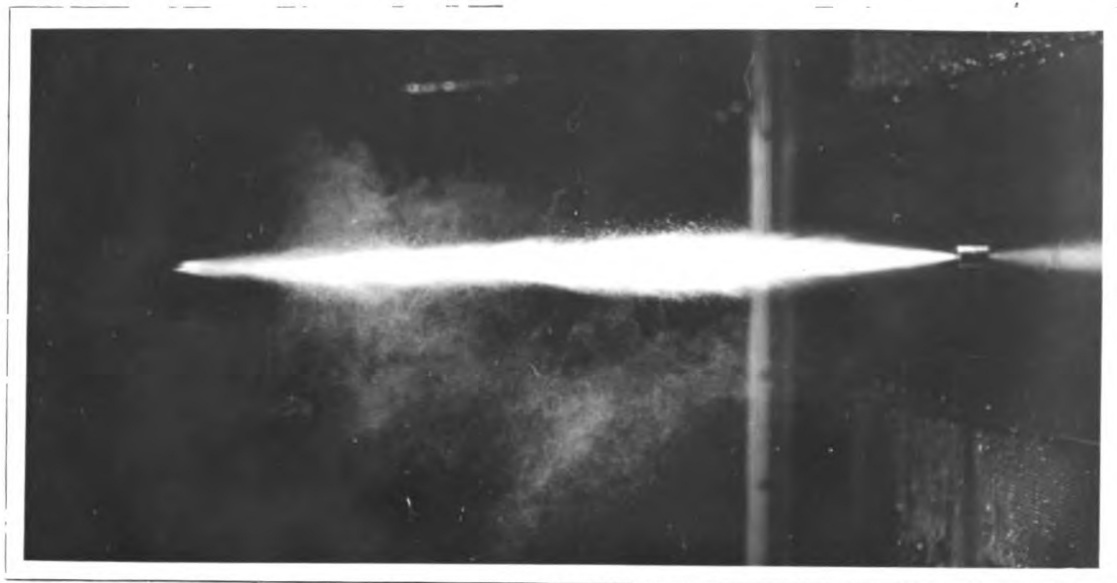


PLATE 7: Injection begins at 5° , photo at 15° , 250 rpm., .500 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 11 inch long steel tube, 1000 psi. nozzle opening pressure. The middle of an "ideal" injection.



PLATE 8: Injection begins at $4\frac{1}{2}^{\circ}$, photo at 15° , end of injection at 15° , 260 rpm., .375 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 1675 psi. nozzle opening pressure, 11 inch long steel tube.



PLATE 9: Injection begins at 5° , photo at 19° , 250 rpm., .500 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 11 inch long steel tube, 1000 psi. nozzle opening pressure.



PLATE 10: Injection begins at 5° , photo at 24° , injection ends at 23° , 250 rpm., .500 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 11 inch long steel tube.



PLATE 11: Injection begins at 5° , photo at 11° , second phase starts at 8° , 420 rpm., .250 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 1675 psi. nozzle opening pressure, 41 inch long copper tube. The breakup of the spray at the beginning of injection.

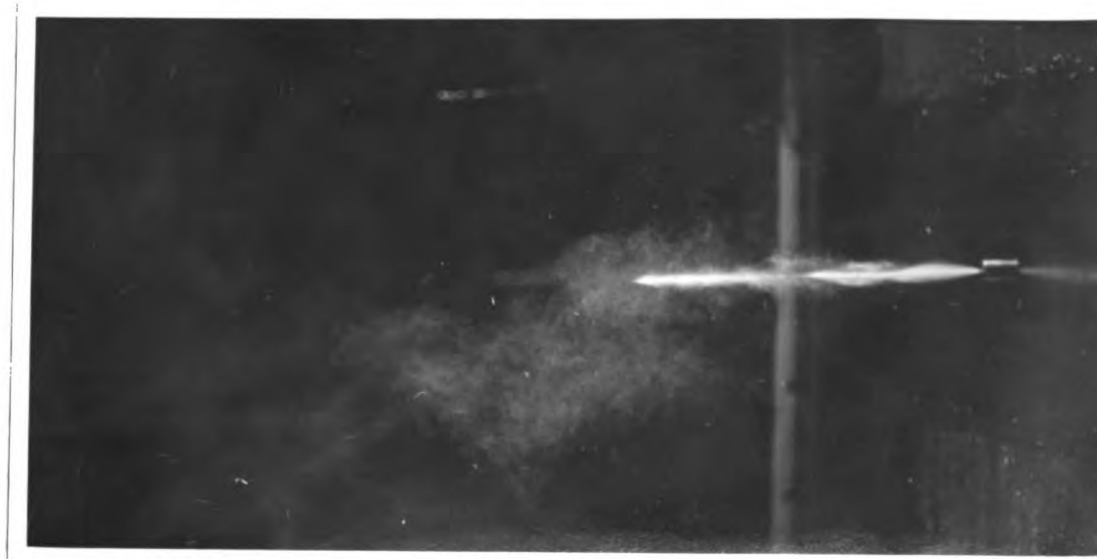


PLATE 12: Injection begins at 5° , photo at 9° , 250 rpm., .375 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 41 inch long copper tube, 1000 psi. nozzle opening pressure. Two phase.



PLATE 13: Injection begins at 5° , photo at 17° , second phase begins at 16° , injection ends at 20° , 260 rpm., .375 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 1675 psi. nozzle opening pressure, 41 inch long copper tube. An illustration of the breakup of the spray near the end of injection.



PLATE 14: Injection begins at 5° , photo at 25° , 250 rpm., .500 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 1000 psi. nozzle opening pressure, 41 inch long copper tube. Coarse particles are shown.

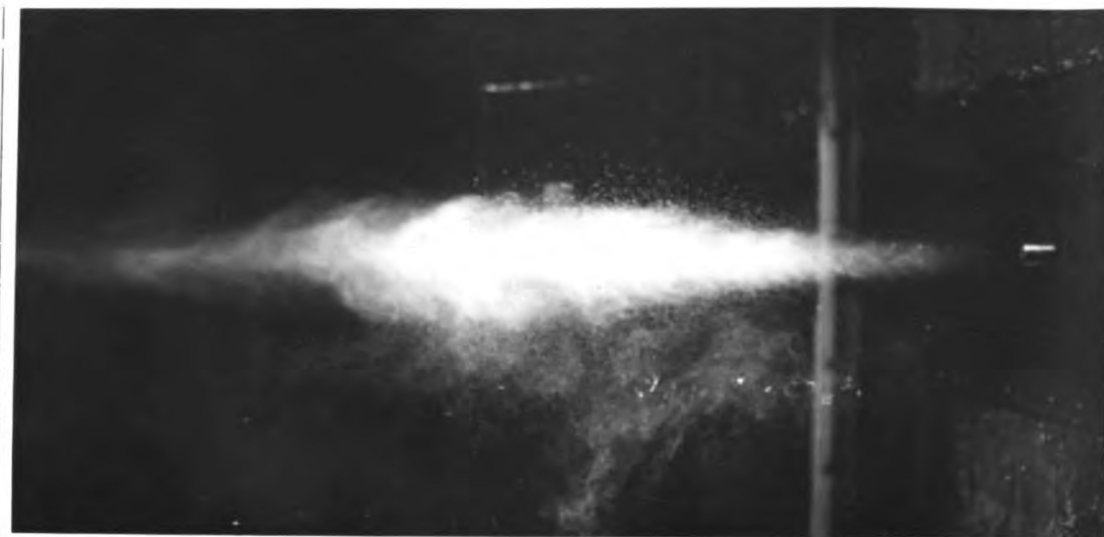


PLATE 15: Injection begins at 5° , photo at 35° , 250 rpm., .500 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 1000 psi. nozzle opening pressure, 41 inch long copper tube. This shows coarse particles appearing after injection.

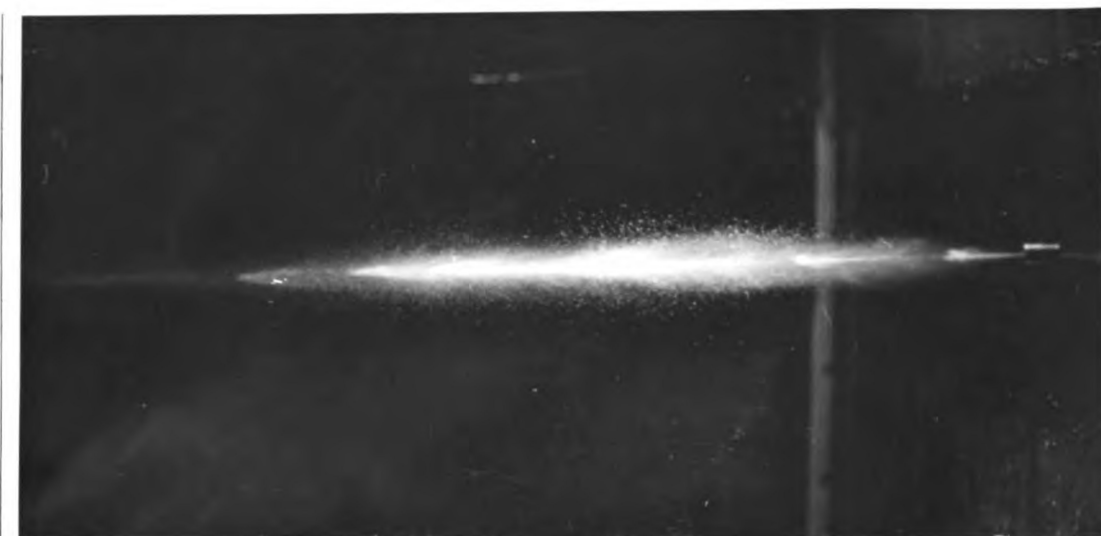


PLATE 16: Injection begins at 4° , photo at 14° , 105 rpm., .625 inch rack opening, AKC 45 SD 51 narrow pintle nozzle, 1000 psi. nozzle opening pressure, 41 inch long copper tube. A breakup into seven distinct phases is shown caused by nozzle squeak at low speeds.



PLATE 17: Injection begins at $3\frac{1}{2}^{\circ}$, photo at 7° , 250 rpm., .375 inch rack opening, AKB 35 SD 173 medium pintle nozzle, 2000 psi. nozzle opening pressure, 44 inch long steel tube. The first stage of injection of this nozzle.

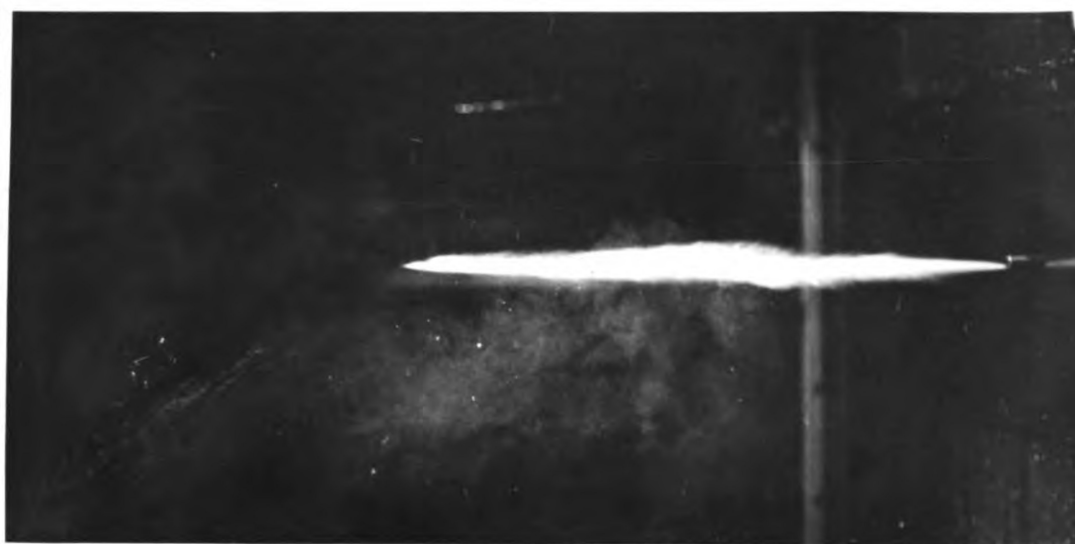


PLATE 18: Injection begins at $3\frac{1}{2}^{\circ}$, photo at 12° , 250 rpm., .375 inch rack opening, AKB 35 SD 173 medium pintle nozzle, 2000 psi. nozzle opening pressure, 44 inch long steel tube. The second stage of injection of the nozzle.



PLATE 19: Injection begins at $3\frac{1}{2}^{\circ}$, photo at $16\frac{1}{2}^{\circ}$, 250 rpm., .375 inch rack opening, AKB 35 SD 173 medium pintle nozzle, 2000 psi. nozzle opening pressure, 44 inch long steel tube. The end of the first phase.



PLATE 20: Injection begins at $3\frac{1}{2}^{\circ}$, photo at 25° , 250 rpm., .375 inch rack opening, AKB 35 SD 173 medium pintle nozzle, 2000 psi. nozzle opening pressure, 44 inch long steel tube. This shows the appearance of the second phase.

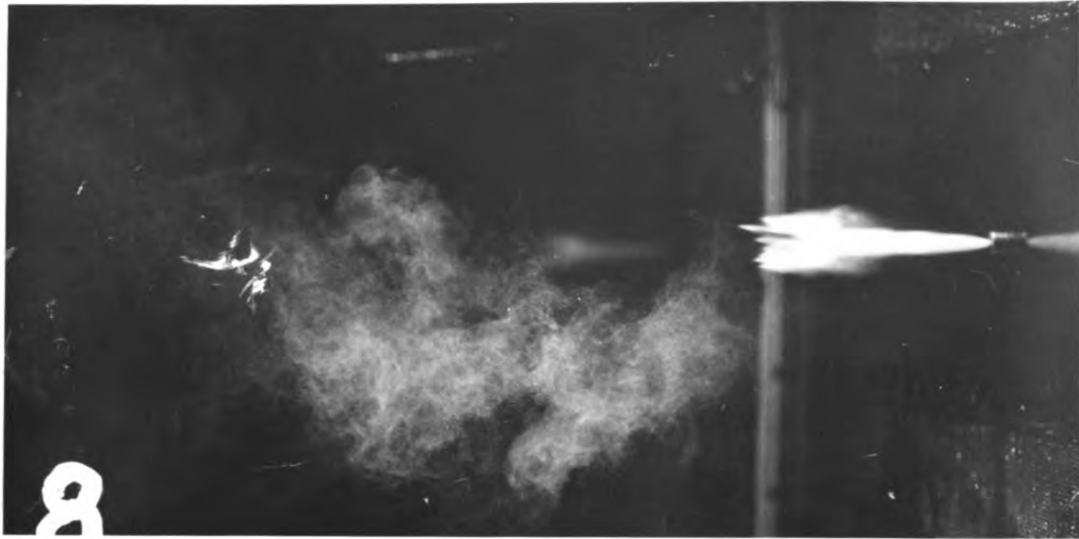


PLATE 21: Injection begins at 9° , photo at 12° , 250 rpm., .375 inch rack opening, AKB 25 R 75 wide pintle nozzle, 2000 psi. nozzle opening pressure, 44 inch long steel tube.



PLATE 22: Injection begins at 9° , photo at 15° , 250 rpm., .375 inch rack opening, AKB 25 R 75 wide pintle nozzle, 2000 psi. nozzle opening pressure, 44 inch long steel tube. The end of injection.



PLATE 23: Injection begins at 9° , photo at 18° , 250 rpm., .500 inch rack opening, AKB 25 R 75 wide pintle nozzle, 2000 psi. nozzle opening pressure, 44 inch long steel tube. The end of the injection.



PLATE 24: Injection begins at 7° , photo at 30° , 465 rpm., .375 inch rack opening, AKB 25 R 75 wide pintle nozzle, 2000 psi. nozzle opening pressure, 44 inch steel tube. The breakup of the spray after injection.

APPENDIX V
ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .125 inch throttle rack opening, AKC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 41 inch long copper tube			
106			No spray
262			No spray
480			No spray
600			No spray
800			Tiny trickle
1000	$6\frac{1}{2}$	$17\frac{1}{2}$	Bulk of spray after second phase
1200	7	20	
1400	$7\frac{1}{2}$	23, $38\frac{1}{2}$	Third phase very small
1600	9	26, 44	Third phase small
1800	10	30, 51	Two-three phase
2000	$11\frac{1}{2}$	34, 36	2nd and 3rd blend together

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .250 inch throttle rack opening, AKC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 41 inch long copper tube			
106	$5\frac{1}{2}$		Inconsistent - nozzle squeak - many phases
255	$6\frac{1}{2}$	11	Consistent
477	$3\frac{1}{2}$	$6\frac{1}{2}$, $13\frac{1}{2}$	1st phase very small
600	3	6, 15, 22	1st & 4th phase small
800	4	18	
1000	5	20	
1200	7	$22\frac{1}{2}$, 36, 49	4th phase very small
1400	7	$24\frac{1}{2}$, 34 40, 55	3rd & 5th small
1600	9	$27\frac{1}{2}$, 44, 51, 64	4th & 5th small
1800	10	30, 49, 56, 67	4th & 5th small
2000	11	34, 63	3rd phase small

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .375 inch throttle rack opening, AKC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 41 inch long copper tube			
112	6		Inconsistent - nozzle squeak - many phases
268	5	15, 20	2nd & 3rd irregular and small -
498	3	18, 23, $28\frac{1}{2}$	3rd & 4th small
600	3	$18\frac{1}{2}$, 25, 27, 31	4th & 5th very small
800	$4\frac{1}{2}$	21, 30, 38	4th phase small
1000	$5\frac{1}{2}$	24, 34, 41, 45	4th & 5th phase small
1200	7	26, $37\frac{1}{2}$, 41	4th phase small
1400	8	27, 43	
1600	9	29, 45	
1800	10,	31, 49	
2000	11	$33\frac{1}{2}$, 51	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .500 inch throttle rack opening, AKC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 41 inch long copper tube			
96	5		Inconsistent - nozzle squeak - many phases
260	4	$18\frac{1}{2}$	
470	$2\frac{1}{2}$	21, 26	
600	3	22, 29, 33, 40	4th & 5th phase small
800	4	24, $32\frac{1}{2}$, 34, 35, 37, 41, 45	4th, 5th, 6th, 7th, and 8th phase small but clear
1000	5	$26\frac{1}{2}$, 37, $38\frac{1}{2}$, 42	3rd & 4th blend together
1200	$6\frac{1}{2}$	29, $37\frac{1}{2}$, $40\frac{1}{2}$, 43, $48\frac{1}{2}$	4th & 5th phase small
1400	$7\frac{1}{2}$	31, 43, 45, $47\frac{1}{2}$, 49	4th, 5th, & 6th blend together
1600	9	33, 48	
1800	10	34, 51, 53	
2000	11	35, $54\frac{1}{2}$	After 55° many more phases blending together

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .675 inch throttle rack opening, AKC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 41 inch long copper tube

98	8	11, 15, 18	Phases fairly consistent
273	$4\frac{1}{2}$	23, $26\frac{1}{2}$	consistent
465	$2\frac{1}{2}$	26, 31, $40\frac{1}{2}$	4th phase weak
600	3	34, 39, 46	3rd & 4th phase small
800	4	$28\frac{1}{2}$, 37, 41 $43\frac{1}{2}$, 51, 62	3rd, 4th, & 5th blend together - 7th small
1000	$5\frac{1}{2}$	$31\frac{1}{2}$, 40, 44, 46, 53, 58, 61, 66	4th, 5th, 6th, 7th, 8th & 9th small - 5th unsteady
1200	7	35, 44, 50, 56, 66	4th, 5th, & 6th small
1400	$7\frac{1}{2}$	35, 49, 59, 63, 66	4th, 5th, & 6th small
1600	9	38, 52, 54, 57, $64\frac{1}{2}$, 67	Last 5 phases small
1800	$10\frac{1}{2}$	39, $55\frac{1}{2}$	
2000	$10\frac{1}{2}$	40, 60	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .750 inch throttle rack opening, AKC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 41 inch long copper tube

100	6	10, 14, 17, 21	2nd phase inconsistent
284	4	25	Dribble
475	$2\frac{1}{2}$	27, 33, $37\frac{1}{2}$	4th phase small
600	3	$28\frac{1}{2}$, 36, 41	
800	4	31, 39, $44\frac{1}{2}$, 43, 51	
1000	$5\frac{1}{2}$	34, 44, 49	
1200	6	36, 47	
1400	$7\frac{1}{2}$	37, 50	
1600	9	$39\frac{1}{2}$, 56, 67	
1800	10	$39\frac{1}{2}$, 56	
2000	$10\frac{1}{2}$	$42\frac{1}{2}$, $61\frac{1}{2}$	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .375 inch throttle rack opening, AKC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 41 inch long copper tube

104	6		Inconsistent - many phases - nozzle squeak
260	$4\frac{1}{2}$	30	
488	$2\frac{1}{2}$	$33\frac{1}{2}$, 38	
600	3	$34\frac{1}{2}$, 40, 45	
800	4	36, 44, 48	
1000	5	$38\frac{1}{2}$, 48, 51, 53	
1200	6	40, 52	
1400	8	40, $52\frac{1}{2}$	
1600	$8\frac{1}{2}$	42, 56, 69	
1800	$9\frac{1}{2}$	43, 60, 62	
2000	11	45, 64	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: 1.000 inch throttle rack opening, AKC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 41 inch long copper tube

100	6		Inconsistent - many phases - nozzle squeak
242	6		Single phase to 33°
468	2 $\frac{1}{2}$	38	Dribble
600	3	50	
800	4	44 $\frac{1}{2}$, 53	
1000	5	47	Dribble
1200	6 $\frac{1}{2}$	49, 61, 68	
1400	8	50,	Injection continues past 73°
1600	8 $\frac{1}{2}$	52, 69	Past 73°
1800	9 $\frac{1}{2}$	56	Continuous past 73°
2000	10 $\frac{1}{2}$		Continuous & single phase past 73°

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .125 inch throttle rack opening, AKC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 11 inch long steel tube			
110			No spray
274			No spray
492			No spray
600			Very small trace of spray
800	4		Dribble to 11°
1000	4		Thin stream to 16°
1200	5		Very fine stream to 38° Single phase with nodes
1400	5		Fine spray to 35°
1600	5½		Fine to 45° - nodes
1800	7		Fine to 43° - nodes
2000	6½		Fine to 67° - nodes

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .250 inch throttle rack opening, AKC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 11 inch long steel tube			
114	$4\frac{1}{2}$		Nodes or phases plus dribble to 12°
272	5		Fine spray to 16°
498	$5\frac{1}{2}$		Very fine dribble to 30°
600	3		Node - fine dribble
800	3		Node - fine dribble
1000	4	14	Fine dribble
1200	5		Single phase
1400	5		Single phase
1600	$5\frac{1}{2}$		
1800	$5\frac{1}{2}$		
2000	$5\frac{1}{2}$	24	Second phase small

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .375 inch throttle rack opening, AKC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 11 inch long steel tube

108	5	$6\frac{1}{2}$, $7\frac{1}{2}$, $8\frac{1}{2}$	3rd inconsistent - fine spray to 16°
272	$4\frac{1}{2}$		Single phase to 14° with dribble
480	$4\frac{1}{2}$		Single phase to 22° with dribble
600	3	5	Main injection begins at 5° - ends at 10° fine spray after 10°
800	$3\frac{1}{2}$	17	Nodes - 2nd very small
1000	4	19	
1200	$4\frac{1}{2}$	20	2nd phase small
1400	5	21	
1600	6	24	
1800	6	26	
2000	6	29	2nd very small

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .500 inch throttle rack opening, AKC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 11 inch long steel tube			
114	5	$6\frac{1}{2}$, 9, 10 12, 14	Inconsistent
266	$4\frac{1}{2}$		Single phase with small dribble to 19°
492	5	13	Second phase small
600	$3\frac{1}{2}$	$5\frac{1}{2}$,	Two phase (?)
800	$3\frac{1}{2}$	21	2nd phase small
1000	4	22	2nd phase very small
1200	5	$23\frac{1}{2}$	2nd phase extremely small
1400	5	$26\frac{1}{2}$	2nd phase small
1600	5	28, $42\frac{1}{2}$	
1800	$5\frac{1}{2}$	40	
2000	6	40	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .675 inch throttle rack opening, AFC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 11 inch long steel tube			
102	$5\frac{1}{2}$		Inconsistent - nozzle squeak - many phases
244	5		Single phase to 22°
475	$5\frac{1}{2}$		Single phase to 26°
600	3	$5\frac{1}{2}$	Main body of spray at $5\frac{1}{2}$ ends at 27°
800	$3\frac{1}{2}$		Single phase to $27\frac{1}{2}$
1000	4	28	Dribble - 2nd phase small
1200	$4\frac{1}{2}$	30	
1400	5	44	
1600	5	44, $46\frac{1}{2}$	
1800	$5\frac{1}{2}$	$43\frac{1}{2}$, 46, 51	
2000	5	43	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .750 inch throttle rack opening, AKC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 11 inch long steel tube

108	5		Inconsistent - nozzle squeak - many phases
270	5		Single phase to 25° no perceptible dribble
490	5½		Single phase to 30°
600	3½	5½	Main stream at 5½° - ends at 30°
800	3½	29	
1000	4	30	
1200	5	32½	
1400	4½	45	
1600	5	46, 49½	
1800	5½	45, 48	
2000	6	42, 45	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .875 inch throttle rack opening, AHC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 11 inch long steel tube

102	$5\frac{1}{2}$		Inconsistent - nozzle squeak - many phases
250	5		Single phase to $29\frac{1}{2}^{\circ}$
470	$5\frac{1}{2}$		Single phase to 32°
600	4	$5\frac{1}{2}$	Ends at 32°
800	4		Single phase to $33\frac{1}{2}^{\circ}$
1000	5		Single phase to 37°
1200	5	37	2nd phase small
1400	5	40	
1600	5	41	
1800	$5\frac{1}{2}$	50	
2000	$5\frac{1}{2}$	45, 48	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: 1.000 inch throttle rack opening, AKC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 11 inch long steel tube

104	$5\frac{1}{2}$		Inconsistent - many phases - nozzle squeak
268	5	33, 35	Slightly irregular - Dribble to about 40°
485	$5\frac{1}{2}$		Single phase with nodes to about 45°
600	5		Single phase to 40° No apparent dribble
800	$3\frac{1}{2}$		Single phase to 42° No apparent dribble
1000	4		Single phase to 45°
1200	5		Single phase to 45°
1400	$5\frac{1}{2}$	45	2nd phase small
1600	$5\frac{1}{2}$	47	2nd phase small
1800	$5\frac{1}{2}$	50	2nd phase small
2000	6	52, $64\frac{1}{2}$	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .125 inch throttle rack opening, AFC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 44 inch long steel tube			
118			No spray
268			No spray
500	6		Small spray with trace dribble to about 35°
600	7		Dribble to about 21°
800	8		End at 15° - Good pattern
1000	10	16	2nd phase small - end 40°
1200	10½	18	2nd phase small - end indeterminate
1400	12	20	
1600	13½	24½	2nd phase small
1800	14½	27	
2000	15½	29	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .250 inch throttle rack opening, AKC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 44 inch long steel tube			
117	$6\frac{1}{2}$	9	2nd phase small - end 12° Inconsistent
270	7		Single phase to 13°
505	$5\frac{1}{2}$		Single phase to 17°
600	$5\frac{1}{2}$		Single phase to 18° no apparent dribble
800	7		Single phase to 23°
1000	9		Single phase to 24°
1200	$10\frac{1}{2}$		Single phase to 30°
1400	$11\frac{1}{2}$		
1600	$12\frac{1}{2}$		Apparently single phase
1800	14		
2000	16	39	2nd phase jerky

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .375 inch throttle rack opening, AKC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 44 inch long steel tube			
110	7	10, 11	Inconsistent - no nozzle squeak heard - dribble to about 30°
268	7		Single phase to 17°
500	5½		Single phase to 22°
600	5½		Single phase to 27°
800	7		Single phase to 27°
1000	9½		Single phase to 30°
1200	11	26½	
1400	11½	30½	
1600	13	34	Second phase jerky and intermittent
1800	13½		
2000	15	37	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .500 inch throttle rack opening, AKC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 44 inch long steel tube

114	7		Several inconsistent phases to 30°
274	8		Inconsistent - single phase to 20°
502	6		Single phase & dribble to 27°
600	6		Single phase & dribble to 27°
800	7		Single phase & dribble to 30°
1000	9 $\frac{1}{2}$	28	
1200	11	32	
1400	11 $\frac{1}{2}$	34	
1600	12	36	
1800	13	37 $\frac{1}{2}$	
2000	15	40 $\frac{1}{2}$	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .675 inch throttle rack opening, AHC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 44 inch long steel tube

110	7		Inconsistent - nozzle squeak - many phases
260	$6\frac{1}{2}$		Single phase to 35°
492	6		Single phase & dribble to 35°
600	7		Single phase to 30°
800	8	31	
1000	9	$33\frac{1}{2}$	
1200	10	36	
1400	$11\frac{1}{2}$	$41\frac{1}{2}$	
1600	$11\frac{1}{2}$	$41\frac{1}{2}$	
1800	13	45	
2000	14	47	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .750 inch throttle rack opening, AKC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 44 inch long steel tube

105	7		Inconsistent - nozzle squeak - many phases
260	7		Single phase & dribble to 29°
494	6		Single phase to 32°
600	6 $\frac{1}{2}$		Single phase to 33°
800	8 $\frac{1}{2}$	32 $\frac{1}{2}$	
1000	9		Single phase to 40°
1200	9 $\frac{1}{2}$	38 $\frac{1}{2}$	
1400	10 $\frac{1}{2}$	40 $\frac{1}{2}$	
1600	12	43	
1800	12 $\frac{1}{2}$	46	
2000	14	49	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .875 inch throttle rack opening, AKC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 44 inch long steel tube

102	7		Inconsistent - nozzle squeak - many phases
260	7		Single phase to 32°
485	6		Single phase to 36°
600	6 $\frac{1}{2}$	34	
800	8		Single phase to 40°
1000	9 $\frac{1}{2}$		Single phase to 40°
1200	10	42	
1400	10	45	
1600	11	47	
1800	12	53	
2000	13	58	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: 1.000 inch throttle rack opening, AKC 45 SD 51 nozzle,
1675 psi. nozzle opening pressure, 44 inch long steel tube

100	6		Inconsistent - nozzle squeak - many phases
258	7	34	End at 38°
485	6	38	2nd phase inconsistent
600	6		Single phase to 44°
800	7 $\frac{1}{2}$		Single phase to 45°
1000	9		Single phase to 50°
1200	10		Single phase to 55°
1400	11	50	2nd phase small
1600	11 $\frac{1}{2}$	53	2nd phase small
1800	12	56	
2000	13	58	

ORIGINAL DATA

Speed in rpm.	Throttle rack opening	Gross pounds & oz.	Minutes	Net Pounds	Pounds per revolution	Can tare oz.
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FUEL FLOW RATE: ALC 45 SD 51 nozzle, 1675 psi. nozzle opening pressure, 44 inch long steel tube used

1050	.125	1 $\frac{1}{4}$ 11 3/4	30	.907	.0000288	13 $\frac{1}{2}$ oz.
1048	.250	2 $\frac{1}{4}$ 2 3/4	10	1.344	.0001282	13 $\frac{1}{2}$ oz.
1044	.375	3 $\frac{1}{4}$ 2 $\frac{1}{2}$	10	2.33	.000223	13 $\frac{1}{2}$ oz.
1035	.500	2 $\frac{1}{4}$ 8 oz.	5	1.67	.0003225	13 $\frac{1}{2}$ oz.
1035	.500	2 $\frac{1}{4}$ 8 $\frac{1}{4}$	5			13 $\frac{1}{2}$ oz.
1035	.500	2 $\frac{1}{4}$ 7 3/4	5			13 $\frac{1}{2}$ oz.
1037	.625	2 $\frac{1}{4}$ 13 3/4	5	2.03	.000392	13 $\frac{1}{2}$ oz.
980	.750	3 $\frac{1}{4}$ 14 3/4	6	3.00	.000527	13 $\frac{1}{2}$ oz.
975	.875	3 $\frac{1}{4}$ 14 $\frac{1}{2}$	5	3.06	.000623	13 $\frac{1}{2}$ oz.
973	1.000	4 $\frac{1}{4}$ 4 $\frac{1}{2}$	5	3.45	.00071	13 $\frac{1}{2}$ oz.

Note: Strobotac adjusted for correct speed, periodic speed readings with mental average, weight accuracy to less than plus or minus $\frac{1}{4}$ oz., timer checked with electric clock for accuracy, speed average estimated accurate to within plus or minus 5 rpm.

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .250 inch throttle rack opening, AKC 45 SD 51 nozzle,
1050 psi. nozzle opening pressure, 11 inch long steel tube

110	5		Inconsistent - nozzle squeak - many phases
257	5		Single phase & dribble to about 17°
487	3 $\frac{1}{2}$		Single phase to 19°
600	3 $\frac{1}{2}$	13	2nd phase small
800	4		Single phase to 20°
1000	5	16 $\frac{1}{2}$, 18 $\frac{1}{2}$	
1200	5 $\frac{1}{2}$	18 $\frac{1}{2}$	
1400	6	22, 24	
1600	5		
1800	6 $\frac{1}{2}$		
2000	7		

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .500 inch throttle rack opening, AKC 45 SD 51 nozzle,
1050 psi. nozzle opening pressure, 11 inch long steel tube

112	5		Inconsistent - nozzle squeak - many phases
272	$4\frac{1}{2}$		Single phase to 23°
497	$3\frac{1}{2}$	21	
600	$3\frac{1}{2}$		Single phase to 22°
800	4		Single phase to 26°
1000	$4\frac{1}{2}$	25	
1200	5	27	
1400	5	29	
1600	5	45, 43	
1800	$5\frac{1}{2}$	45	
2000	$5\frac{1}{2}$	43	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .750 inch throttle rack opening, AKC 45 SD 51 nozzle, 1050 psi. nozzle opening pressure, 11 inch long steel tube			
108	5		Inconsistent - nozzle squeak - many phases
250	$4\frac{1}{2}$		Single phase to 27°
430	$3\frac{1}{2}$		Single phase to $28\frac{1}{2}^{\circ}$
600	4	30	
800	$4\frac{1}{2}$		Single phase to 31°
1000	5	33	
1200	5	$34\frac{1}{2}$	
1400	5	36, 52	3rd phase inconsistent
1600	$4\frac{1}{2}$	47	
1800	5	47	
2000	5	48	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .250 inch throttle rack opening, AKC 45 SD 51 nozzle, 1450 psi. nozzle opening pressure, 11 inch long steel tube			
104	$5\frac{1}{2}$		Nozzle squeak
250	5		Single phase and much dribble to 27°
415	$5\frac{1}{2}$		Single phase & dribble to 16°
600	$3\frac{1}{2}$		Single phase & dribble to 21°
800	4		Single phase & dribble to 18°
1000	5	$15\frac{1}{2}$, 17	End at 26°
1200	$5\frac{1}{2}$	18	2nd phase small
1400	$6\frac{1}{2}$	$20\frac{1}{2}$	2nd phase small
1600	$6\frac{1}{2}$	22	2nd phase small
1800	7	$23\frac{1}{2}$	2nd phase small
2000	$7\frac{1}{2}$	26	2nd phase small

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .500 inch throttle rack opening, AKC 45 SD 51 nozzle, 1450 psi. nozzle opening pressure, 11 inch long steel tube			
108	$5\frac{1}{2}$		Nozzle squeak
260	5		Single phase & dribble to 20°
435	4		Single phase & dribble to 23°
600	4		Single phase & dribble to 27°
800	$4\frac{1}{2}$		Single phase & dribble to 26°
1000	$5\frac{1}{2}$	25	2nd phase small
1200	6	27	2nd phase small
1400	6	29	2nd phase small
1600	$5\frac{1}{2}$		
1800	$5\frac{1}{2}$	$46\frac{1}{2}$	2nd phase shaky
2000	6	$41\frac{1}{2}$	2nd phase shaky

1

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .750 inch throttle rack opening, AKC 45 SD 51 nozzle, 1450 psi. nozzle opening pressure, 11 inch long steel tube			
105	$5\frac{1}{2}$		Nozzle squeak
260	$5\frac{1}{2}$		Single phase & dribble to 27°
413	$5\frac{1}{2}$		Single phase & dribble to 32°
600	4		Single phase & dribble to 35°
800	$4\frac{1}{2}$		Single phase & dribble to 35° (?)
1000	5		Single phase & dribble to 36°
1200	$5\frac{1}{2}$	34	2nd phase small
1400	5	36, 53	
1600	5	47, 51	
1800	5	$47\frac{1}{2}$, 65	
2000	6	43	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .250 inch throttle rack opening, AKC 45 SD 51 nozzle,
2000 psi. nozzle opening pressure, 11 inch long steel tube

106	6		Nozzle squeak
249	$5\frac{1}{2}$		Single phase & dribble to 15°
470	$5\frac{1}{2}$		Single phase & dribble to 15°
600	$6\frac{1}{2}$		Single phase & dribble to 24°
800	$4\frac{1}{2}$		Single phase & dribble to 13°
1000	5	16	
1200	6	18	
1400	$6\frac{1}{2}$		
1600	7		
1800	$7\frac{1}{2}$		
2000	$7\frac{1}{2}$	26	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .500 inch throttle rack opening, AEC 45 SD 51 nozzle, 2000 psi. nozzle opening pressure, 11 inch long steel tube			
108	6		Inconsistent - nozzle squeak - many phases
260	5½		Single phase to 20°
482	6		Single phase to 22°
600	6½		Single phase to 22°
800	4		Single phase to 23°
1000	5		Single phase to 26°
1200	5½		Single phase to 30°
1400	5½	27	
1600	6	29	
1800	6	41, 46	
2000	6	40	2nd phase inconsistent

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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D ATA: .750 inch throttle rack opening, AKC 45 SD 51 nozzle,
2000 psi. nozzle opening pressure, 11 inch long steel tube

106			Inconsistent - nozzle squeak - many phases
256	$5\frac{1}{2}$		Single phase to 27°
480	$5\frac{1}{2}$	23	
600	$6\frac{1}{2}$		Single phase with nodes to 30°
800	4		Single phase & dribble to 35°
1000	5	31	2nd phase small
1200	$5\frac{1}{2}$	33	2nd phase small
1400	5	35, 48	
1600	$5\frac{1}{2}$	48, 51	
1800	6	43	
2000	$6\frac{1}{2}$	45, 49	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .250 inch throttle rack opening, A1C 45 SD 51 nozzle,
2400 psi. nozzle opening pressure, 11 inch long steel tube

104	$6\frac{1}{2}$		Inconsistent - nozzle squeak - many phases
269	7		Single phase to 14°
500	6		Single phase & dribble to 19°
600	$6\frac{1}{2}$		Single phase & dribble to 18°
800	7		Single phase & dribble to 18°
1000	$5\frac{1}{2}$	16	2nd phase small
1200	6	$17\frac{1}{2}$	2nd phase small
1400	$6\frac{1}{2}$		Single phase to 19°
1600	7		Single phase to 22°
1800	7		Single phase to 24°
2000	8		Single phase to 25°

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .500 inch throttle rack opening, AKC 45 SD 51 nozzle,
2400 psi. nozzle opening pressure, 11 inch long steel tube

108	7		Inconsistent - nozzle squeak - many phases
265	$6\frac{1}{2}$		Single phase to $18\frac{1}{2}^{\circ}$
505	$6\frac{1}{2}$		Single phase to 22°
600	$6\frac{1}{2}$		Single phase to 22°
800	6	22	
1000	$6\frac{1}{2}$		Single phase to 27°
1200	$5\frac{1}{2}$		Single phase to 28°
1400	6	27	
1600	$6\frac{1}{2}$	28	
1800	7	40, 45	
2000	7	39, $43\frac{1}{2}$	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
---------------------	---	---	----------

DATA: .750 inch throttle rack opening, AKC 45 SD 51 nozzle,
2400 psi. nozzle opening pressure, 11 inch long steel tube.

102	7		Nozzle squeak
265	$6\frac{1}{2}$		Single phase to 25°
495	6		Single phase to 28°
600	$6\frac{1}{2}$		Single phase to 29°
800	$7\frac{1}{2}$	29	
1000	$5\frac{1}{2}$		Single phase to 33°
1200	6	33	
1400	6	35	
1600	$6\frac{1}{2}$	50	
1800	7	46, $48\frac{1}{2}$	
2000	$6\frac{1}{2}$	47, 54	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .250 inch throttle rack opening, AEC 45 SD 51 nozzle,
1000 psi. nozzle opening pressure, 44 inch steel tubing

106	$5\frac{1}{2}$		No nozzle squeak - phases and dribble to 16°
252	5	$7\frac{1}{2}$	End at 17°
430	$5\frac{1}{2}$		Single phase & dribble to 22°
600	$5\frac{1}{2}$		Single phase & dribble to 23°
800	$8\frac{1}{2}$		Single phase & dribble to 42°
1000	$10\frac{1}{2}$		Single phase & dribble to 37°
1200	12		Single phase & dribble to 42°
1400	12		Single phase & dribble to 44°
1600	14	33	
1800	16	34	
2000	17	38	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
---------------------	---	---	----------

DATA: .500 inch throttle rack opening, AKC 45 SD 51 nozzle,
1000 psi. nozzle opening pressure, 44 inch long steel tube

104	7		Inconsistent - nozzle squeak - many phases
245	5	7	Dribble to 21°
465	6		Single phase & dribble to 35°
600	7	24	End at 35°
800	9		Single phase to 29°
1000	10 $\frac{1}{2}$		Single phase to 33°
1200	11 $\frac{1}{2}$		Single phase to 45°
1400	12		
1600	12 $\frac{1}{2}$	40	
1800	13 $\frac{1}{2}$	41 $\frac{1}{2}$	
2000	15	47	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .750 inch throttle rack opening, AKC 45 SD 51 nozzle,
1000 psi. nozzle opening pressure, 44 inch long steel tube

106	6		Nozzle squeak
258	5	7	Dribble to 30°
462	6	30	End at 47°
600	7		Single phase to 35°
800	9		Single phase to 39°
1000	9 $\frac{1}{2}$	37	
1200	10	40	
1400	10 $\frac{1}{2}$	41	
1600	10 $\frac{1}{2}$	44 $\frac{1}{2}$	
1800	12	47	
2000	13 $\frac{1}{2}$	50	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .250 inch throttle rack opening, AKC 45 SD 51 nozzle, 1450 psi. nozzle opening pressure, 44 inch long steel tube			
112	7		Single phase & dribble to $12\frac{1}{2}^{\circ}$
272	7		Single phase & dribble to $17\frac{1}{2}^{\circ}$
505	$5\frac{1}{2}$		Single phase & dribble to 19°
600	6		Single phase & dribble to 23°
800	$7\frac{1}{2}$	$17\frac{1}{2}$	2nd phase small
1000	$9\frac{1}{2}$		
1200	11	27	2nd phase small
1400	12		
1600	13		
1800	$14\frac{1}{2}$	34	
2000	$16\frac{1}{2}$	35	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .500 inch throttle rack opening, AKC 45 SD 51 nozzle,
1450 psi. nozzle opening pressure, 44 inch long steel tube

114	7		Nozzle squeak
265	7		Single phase & dribble to 21°
498	6		Single phase & dribble to 27°
600	6 $\frac{1}{2}$		Single phase & dribble to 30°
800	8		Single phase & dribble to 31°
1000	10	29	
1200	11 $\frac{1}{2}$	33	
1400	12	35	
1600	12 $\frac{1}{2}$	37	
1800	13 $\frac{1}{2}$	38 $\frac{1}{2}$	
2000	14 $\frac{1}{2}$	42	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .750 inch throttle rack opening, AKC 45 SD 51 nozzle,
1450 psi. nozzle opening pressure, 44 inch long steel tube

108	$6\frac{1}{2}$		Nozzle squeak
262	7		Single phase & dribble to 27°
495	6		Single phase & dribble to 31°
600	$6\frac{1}{2}$	30	2nd phase small - End at 37°
800	$8\frac{1}{2}$		Single phase to 38°
1000	10	36	
1200	$10\frac{1}{2}$	39	
1400	11	$40\frac{1}{2}$	
1600	$11\frac{1}{2}$	43	
1800	$12\frac{1}{2}$	46	
2000	$13\frac{1}{2}$	$49\frac{1}{2}$	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .250 inch throttle rack opening, AKC 45 SD 51 nozzle, 2000 psi. nozzle opening pressure, 44 inch long steel tube			
114	7		No nozzle squeak Single phase & dribble to 11°
268	7½		Single phase & dribble to 13°
495	6		Single phase & dribble to 19°
600	6½		End at 19°
800	7		End at 29°
1000	9		End at 25°
1200	10½		End at 31°
1400	12		End at 34°
1600	13		End at 42°
1800	14	30	2nd phase shaky
2000	15½	33	2nd phase shaky

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .500 inch throttle rack opening, AKC 45 SD 51 nozzle,
2000 psi. nozzle opening pressure, 44 inch long steel tube

102	7		Nozzle squeak
244	$7\frac{1}{2}$		Single phase & dribble to 25°
465	7	10	Ends at 24°
600	7		Single phase to 31°
800	$7\frac{1}{2}$	26	
1000	9	28	
1200	11	31	2nd phase small
1400	$11\frac{1}{2}$	34	2nd phase small
1600	$12\frac{1}{2}$	35	
1800	$13\frac{1}{2}$	$37\frac{1}{2}$	
2000	$14\frac{1}{2}$	$40\frac{1}{2}$, 43	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .750 inch throttle rack opening, AHC 45 SD 51 nozzle,
2000 psi. nozzle opening pressure, 44 inch long steel tube

110	7		Nozzle squeak
260	$7\frac{1}{2}$		Single phase to 21°
482	7	10	Ends at 23°
600	7		Single phase & dribble to 27°
800	8	26	2nd phase small - ends at 30°
1000	9	$28\frac{1}{2}$	2nd phase small - ends at 33°
1200	11	31	2nd phase small - ends at 38°
1400	12	34	2nd phase small
1600	$12\frac{1}{2}$	35	
1800	$13\frac{1}{2}$	38	
2000	$14\frac{1}{2}$	$40\frac{1}{2}$	

ORIGINAL DATA

Speed in Injection rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .250 inch throttle rack opening, AKC 45 SD 51 nozzle,
2400 psi. nozzle opening pressure, 44 inch long steel tube

112	$7\frac{1}{2}$		Nozzle squeak
262	$7\frac{1}{2}$		Inconsistent - dribble to 25°
495	7		Single phase to 16°
600	7		Single phase & dribble to 22°
800	8	17	2nd phase small - ends at 30°
1000	9		Single phase & dribble to 30°
1200	$10\frac{1}{2}$	23	2nd phase small
1400	12		Single phase to 30°
1600	13	$27\frac{1}{2}$	2nd phase small
1800	14	30	2nd phase small
2000	$15\frac{1}{2}$	32	2nd phase small

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
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DATA: .500 inch throttle rack opening, AKC 45 SD 51 nozzle,
2400 psi. nozzle opening pressure, 44 inch long steel tube.

108	$7\frac{1}{2}$		Nozzle squeak
260	8		Single phase to 21°
467	8	10, 22	End at 27°
600	8	$11\frac{1}{2}$	2nd phase inconsistent - end at 27°
800	8	26	2nd phase small
1000	9	28	2nd phase small
1200	11	31	2nd phase small
1400	12	33	
1600	13	35	
1800	14	37	
2000	15	40	

ORIGINAL DATA

Speed in rpm.	Injection begins- degrees after port closure	Appearance of later phases- degrees after port closure	Comments
DATA: .750 inch throttle rack opening, AKC 45 SD 51 nozzle, 2400 psi. nozzle opening pressure, 44 inch long steel tube			
100	$7\frac{1}{2}$		Nozzle squeak
255	8		Single phase & dribble to 29°
435	7		Single phase & dribble to 33°
600	$7\frac{1}{2}$	29	2nd phase small
800	9	32	2nd phase small
1000	10	31	2nd phase small
1200	11	37	2nd phase small
1400	$11\frac{1}{2}$	40	2nd phase small
1600	$12\frac{1}{2}$	42	2nd phase small
1800	$13\frac{1}{2}$	45	2nd phase small
2000	$14\frac{1}{2}$	48	2nd phase small

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