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INTEGRAL AIRCRAFT FUEL TANK LEAK CLASSIFICATION

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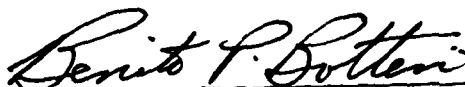
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The dispersing fuel films were found to be very thin (0.05 mm/0.002 in.); i.e., limited liquid volume flow results in extensive surface coverage. Fuels of low volatility such as JP-5 and JP-8 dispersed at a faster rate over the surface and exhibited a greater propensity for dripping than those of high volatility (AvGas and JP-4). Low temperatures, inclined surfaces, and polyurethane latex surface coating enhanced fuel dripping from the test surface.

Fuel flow rates required to support sustained burning at the leakage site were investigated with JP-4, JP-5, JP-8, JP-4/JP-8 mixtures, and AvGas. The measurements were conducted at temperatures ranging from 3.3°C to 98°C (38°F to 209°F). The vapor pressure of the fuel at the test temperature has a very pronounced effect on the propensity of the leaking fuel to sustain burning. The minimum volume flow rates required for sustained burning ranged from 0.2 ml/min. [AvGas at 23°C (73°F)] to 9 ml/min. [JP-5 at 98°C (208°F)].

As a result of this investigation, a revision to Air Force Technical Order 1-1-3 for classifying integral fuel tank external leaks was developed and provided to the AFSC Aeronautical Systems Division (ASD) and AFLC Air Force Acquisition Logistics Division (AFALD) for evaluation and implementation action. The proposed revised criteria provide for a 6 minute leak assessment period and, depending on the specific fuel, a greater tolerable range of fuel leakage. The adoption of the revised criteria will result in a relaxation of integral fuel tank external leak repair requirements while shortening inspection time requirements. This, in turn, should produce significant cost savings without increasing the risk of accidents caused by fuel tank leaks.

FOREWORD

This is an interim Technical Report prepared by Monsanto Research Corporation, Dayton Laboratory. The effort was sponsored by the Air Force Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson AFB, Ohio under Contract No. F33615-78-C-2023 for the period 1 September 1978 to 15 April 1979. The work herein was accomplished under Project 3048, Task 304807, Work Unit No. 30480784, with Mr. R. E. Cretcher, AFAPL/SFH, as Project Engineer. Dr. Leo Parts of Monsanto Research Corp. was technically responsible for the work. Other Monsanto Research Corporation's personnel participating were: Mr. T. J. Bucher, Mr. J. D. Tobias, and Mrs. C. Fritsch.

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INTRODUCTION

Leakage of fuel from integral fuel tanks in aircraft can constitute a potential fire hazard. The Air Force, commercial airline companies, and airframe manufacturers have established their own criteria for integral fuel tank leak classification [1-3]. The criteria established by the different organizations are not uniform (see Table 1). Also, the directives for corrective measures differ. Furthermore, there does not appear to be an experimentally established basis for the corrective measures required.

TABLE 1. AIRCRAFT FUEL LEAK CLASSIFICATIONS

Leak classification	Air Force	Boeing 707	Delta Airlines
	Spot diameter (in.) after 30 min.	Spot diameter (in.) after 15 min.	Spot diameter (in.)
Stain			0.5 to 0.75
Slow seep	<0.75	≤1.5	
Seep	<1.5	≤4	≤1.5
Heavy seep	<3 (no drip)	≤6	≤3.5 to 4
Running leak	Drips or runs from surface.	In excess of heavy seep. Will drip or run from surface.	4 to 5

Unnecessary grounding of aircraft for the repair of leaks that do not constitute a real hazard represents a needless expense. It can also cause delays of operational missions.

Because of these factors, the Fire Protection Branch of the Air Force Aero Propulsion Laboratory (AFAPL) initiated a review of Air Force T.O. 1-1-3 criteria for integral fuel tank leak classification. The purpose of this review was to either validate current criteria or to recommend revised criteria where appropriate. Such revisions were to reduce maintenance time and cost, without compromising personnel and aircraft safety on the ground and in flight. Monsanto Research Corporation (MRC), under contract and in cooperation with AFAPL, was responsible for providing a reliable experimental data basis for the review of leak criteria.

Two aspects of fuel leakage were of major interest in this investigation:

- (1) The rate of fuel dispersion from the leakage site over the external surface of the integral fuel tank.
- (2) The minimum fuel leakage rate at which sustained burning (not just ignition and transitory burning) occurs.

The theoretical basis has not as yet been developed for treating surface-dispersion of complex liquid systems. It is thus not feasible to model a multicomponent system that contains constituents that vaporize during the dispersion [4]. Therefore, it was decided to establish the basis for the review of T.O. 1-3-3 experimentally, by simulating external leakage from integral aircraft fuel tanks with a specially designed test apparatus.

The following fuels were used in this program:

JP-4 (LVP)^a
JP-4 (HVP)^b
JP-5
JP-8
JP-4 (HVP)/JP-8 (10/90 volume % mixture)
JP-4 (HVP)/JP-8 (50/50 volume % mixture)
AvGas

As a broad objective, the physically observable and measurable parameters of fuel leakage and associated fire hazard were to be related to the measured values of fuel flow rates.

An apparatus was designed and fabricated for simulating leakage from an integral fuel tank under controlled conditions. The compositions, and physical and ignitability properties of jet fuels used in this work were determined. Subsequently, the effects of the following variables on the rates of surface-dispersion of fuels were determined:

- (1) Fuel flow rate (1 to 1400 $\mu\text{l}/\text{min.}$; 0.002 to 2.84 fl oz/hr).
- (2) Air flow rate (0 to 20 ft/sec; 0 to 13.6 miles/hr).
- (3) Temperature (3.3°C to 32°C; 38°F to 90°F).
- (4) Angle of inclination of the panel (0°, 5°, 10°, 90°).
- (5) Surface composition of the panel (Alclad, unclad aluminum alloy, and polyurethane latex-coated surface).

The data in parentheses indicate the range within which the experimental parameters were varied.

The environmental and fuel flow conditions under which dripping from the panel surface occurred were determined. The minimum fuel flow rates required to support sustained burning were also determined.

^aLow vapor pressure sample.

^bHigh vapor pressure sample.

EXPERIMENTAL

FUELS AND THEIR PROPERTIES

Fuels

The fuels used in this program were supplied by the Air Force Project Engineer. He obtained the following fuels from the AFAPL's storage facility at Wright-Patterson AFB: JP-4 (LVP), JP-5, JP-8, and AvGas (octane 100/130). The high vapor pressure sample of JP-4 was supplied by the 27th Supply Squadron at Cannon AFB, NM.

Mixtures of JP-4 (HVP) and JP-8 were prepared in the 10/90 and 50/50 volume ratios from the fuels as supplied.

The jet fuels were characterized by determining certain physical properties, and ignition and flammability characteristics. The chemical compositions were also determined. The measurement methods are referenced below. The results are tabulated in the Appendix.

Physical Properties

The results of physical properties measurements, including those of vapor pressures, densities, viscosities and surface tensions, are summarized in Table A-1 and in Figures 15 to 23 in the Appendix.

The vapor pressures of jet fuels were determined with a micro vapor pressure apparatus [6,7] at 0°C, 21.1°C, and 37.8°C (32°F, 70°F, and 100°F).

The densities were measured with a calibrated dilatometer at 0°C, 25°C and 37.8°C (32°F, 77°F, and 100°F).

Flow rate measurement through capillary tubing was used for kinematic viscosity determinations [8] at -17.8°C, 25°C, and 37.8°C (0°F, 77°F, and 100°F).

Surface tensions of the fluids were determined by the capillary rise method at 0°C, 21.1°C, and 37.8°C (32°F, 70°F, and 100°F).

Ignitability and Flammability Characteristics

The flash points and fire points of the fuels were determined by the Pensky-Martens closed cup method [9]. The results are presented in Table A-2 in the Appendix.

Chemical Compositions

A simulated distillation procedure, based upon chromatographic separation of the hydrocarbon components in the jet fuels [10], was used for compositional analysis. The analyses were conducted with a Hewlett-Packard Model 5730A gas chromatograph, equipped with a flame ionization detector. The column packing consisted of 3% OV-1 on Chromosorb W. The temperature rise was programmed at 8°C per minute up to 200°C. The column temperature was maintained at 200°C for eight minutes. Helium served as the carrier gas, at the flow rate of 30 ml/min.

The simulated distillation curves for the four jet fuels are shown in Figure 19 in the Appendix. The compositions of the fuels are presented in Figures 20 to 23 in the Appendix. The compositions are based upon calibration experiments with *n*-paraffins.

APPARATUS AND EXPERIMENTAL PROCEDURES FOR INTEGRAL FUEL TANK LEAK CHARACTERIZATION

Figure 1 is a view of the apparatus designed and fabricated for the characterization of integral fuel tank leaks. There was a small, centrally located orifice in the metal panel; it served as a simulated leakage source. The panel was supported by a 45.7 cm x 61.0 cm x 61.0 cm (18 in. x 24 in. x 24 in.) Unistrut channel frame [2.06 cm (13/16 in.) wide channel]. A syringe pump (see Figure 2) and a metal mirror, mounted under a 45° angle with reference to the panel surface, were also supported by the frame. The metal mirror was used for visually monitoring the surface dispersion of the fluids on the underside of the panel.

The plate was aligned horizontally by means of three adjustable, threaded legs. A bubble-type leveler on the panel surface was used for the initial leveling adjustments. More precise leveling was subsequently achieved by centering the fuel droplet during the flow.

The metal panel could be positioned at an angle with reference to the horizontal plane. A screw mechanism was used for this adjustment. In the experiments conducted, 0°, 5°, 10°, and 90° angles of inclination were used. For the latter measurements, the apparatus was placed on its side.

For measurements at temperatures other than the ambient, a panel with a metal rim was used. It was fabricated from a flat panel by equipping it with 5.1 cm (2 in.) high rim. The rim was sealed to the upper panel surface with high-temperature epoxy adhesive; it was welded in the corners. The desired panel surface temperature was attained and maintained by either cooling or heating water in the pan to the required temperature. The temperature of the panel surface was measured with a Tele-Thermometer, Model 42SC, equipped with sensor No. 409, from Yellow Springs Instrument Company.

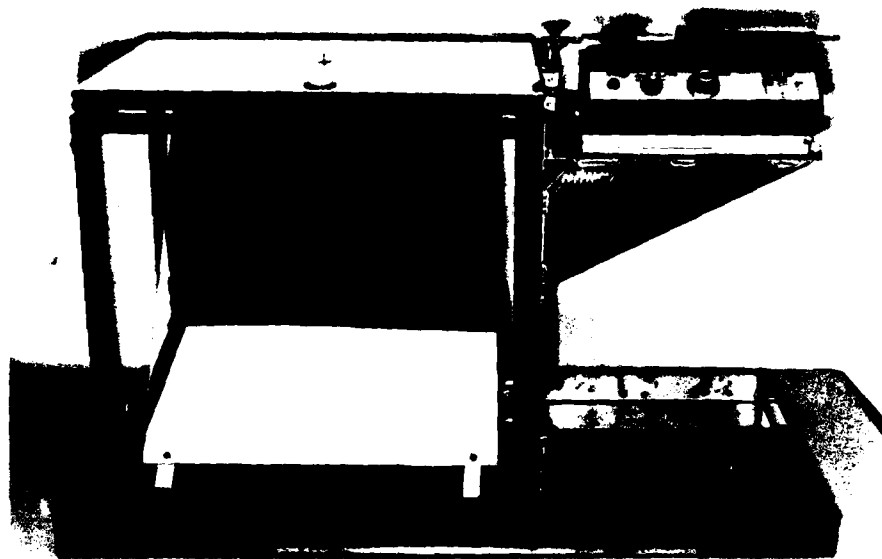


Figure 1. Apparatus for fuel leakage studies.

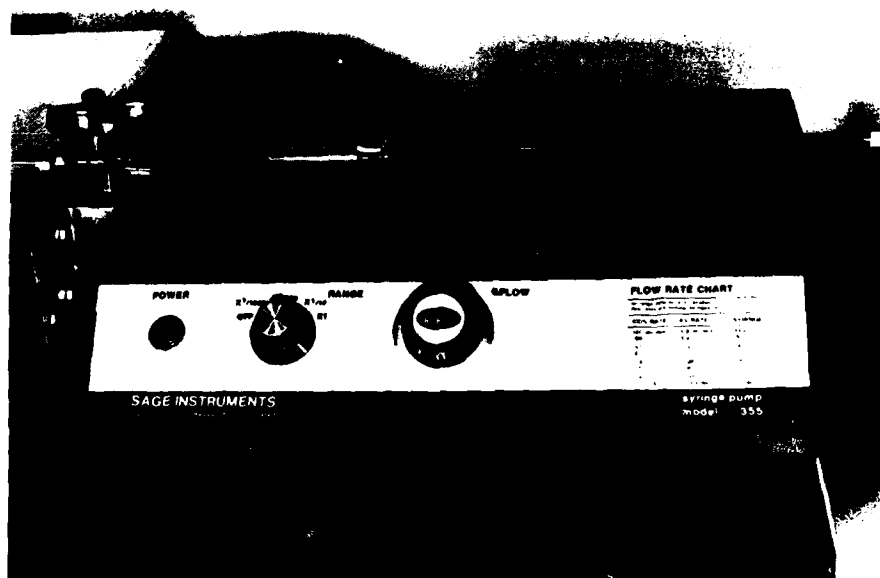


Figure 2. Syringe pump for fuel delivery.

fuel was supplied at a constant rate by means of a syringe pump (Sage Instruments, Model 355; see Figure 2) whose delivery rate could be varied from $<1 \mu\text{l}/\text{min.}$ to $140 \text{ ml}/\text{min.}$ The fuel was pumped through a 1.59 mm (1/16 in.) OD stainless steel tubing of 0.46 mm (0.018 in.) internal diameter. For experiments at room temperature, the transfer tubing was sealed into a small orifice in the center of the 45.7 cm x 61.0 cm x 0.32 cm (18 in. x 24 in. x 1/8 in.) aluminum panel (see Figure 3). For dispersion experiments at other temperatures and for burning experiments, a panel was equipped with a Swagelok fitting for fastening the tubing.

Prior to experiments, the underside of the panel was preconditioned by wiping it with a paper towel moistened with the fuel that was to be used in subsequent experiments. A thin film of low-volatility hydrocarbons was thereby deposited on the panel surface simulating a contaminated fuel tank surface.

During surface-dispersion rate measurements, the spot diameter was measured with a ruler at selected time intervals, without allowing the latter to contact the fuel. The spots were readily visible (see Figure 4 for direct view of spot formed by JP-4, high vapor pressure sample); there was no need to apply dyed talcum [2] onto the surface to enhance spot visibility.

A propane torch with a 7.6 cm (3 in.) long brush flame was used as the ignition source in experiments in which leakage rates for support of sustained burning were determined. The flame was traversed over the central area of the spot at 3-second intervals. If the fuel continued to burn in a stable manner for 30 seconds, the leakage rate was considered to be sufficiently high to support sustained burning.

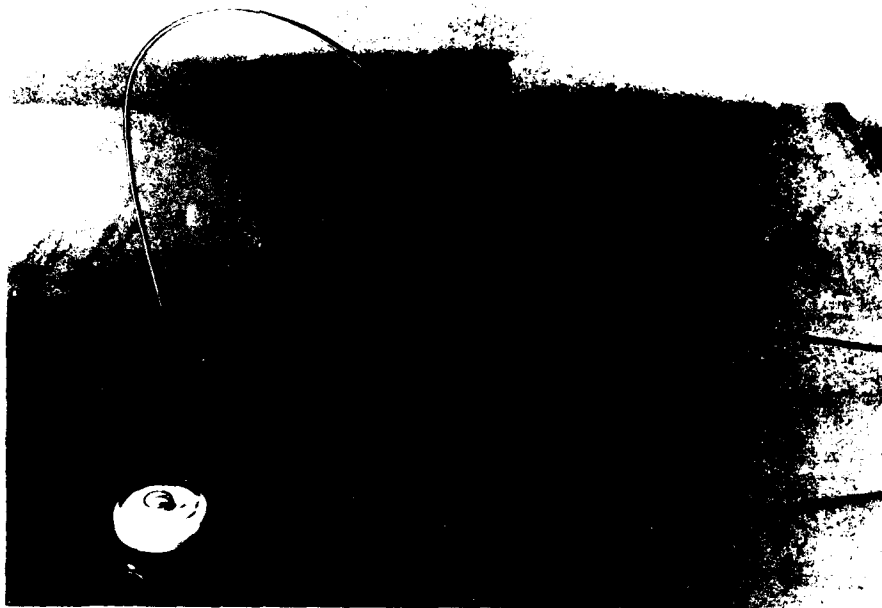


Figure 3. Fuel transfer line, bonded to aluminum surface.



Figure 4. Dispersion of JP-5 on the underside of the aluminum surface.

RESULTS AND DISCUSSION

SURFACE-DISPERSION OF FUELS

The matrix of experiments pertaining to fuel surface-dispersion measurements is presented in Table 2. The results of these parametric experiments are discussed below with the support of illustrative, representative figures. Most of the experimental data are presented in the form of tables and figures in the Appendix. Keys have been devised for these tables and figures to facilitate locating the data.

Fuels and the Effect of Flow Rate

When fuels leak at a slow rate through a small orifice onto the underside of flat, horizontally mounted panels, they disperse in a circular manner (see Figure 4). For fuels of low volatility, the rate of spreading, in terms of surface area coverage, is nearly linear (see the data for JP-5 and JP-8 in Figures 5 and 6), i.e.,

$$dA = kdt \quad (1)$$

In Equation 1, A represents area, t designates time, and k is the rate constant for surface-dispersion. Based on Equation 1, the spot diameter of low-volatility fuels increases proportionally with $t^{1/2}$ (see Figure 7).

It was learned in this work that the spreading fuel film is very thin. Consequently, small quantities of fuel cover large areas. Fuel film thickness was found to increase with the rate of leakage. At sufficiently high fuel flow rates, gravitational force became larger than the interfacial and cohesive forces, and dripping of fuel occurred. We will use the spreading of JP-8 on Alclad surface at 23°C, at an air flow rate of 6.1 m/sec (13.6 miles/hr), to illustrate the latter statements.

At the flow rate of 5 $\mu\text{l}/\text{min.}$, only 0.15 ml of fuel flowed onto the surface in 30 minutes. At that time, the average spot diameter was 12.2 cm (4.8 in.) and the liquid film thickness was ≤ 0.013 mm (0.50 mil). When the fuel flow rate was increased to 25 $\mu\text{l}/\text{min.}$, 0.75 ml of fuel flowed onto the surface in 30 minutes. The average spot diameter was 19.2 cm (7.6 in.) and the film thickness was ≤ 0.026 mm (1.0 mil). Dripping of this fuel was observed when its flow rate was increased to 0.25 ml/min.

The relatively more volatile fuels (i.e., JP-4 and AvGas) spread less rapidly and their rate of spreading, in terms of area coverage was found not to be proportional to time (see Figures 5 and 6). The reduced and nonlinear spreading rates, and the occurrence of dripping only at higher flow rates are attributed to significant partial volatilization of these fuels.

TABLE 2 (continued)^a

Angle (deg)	Panel		Alclad				Unclad aluminum alloy				Polyurethane latex-coated surface			
	Fuel flow rate ($\mu\text{L}/\text{min.}$)	Fluid	JP-4 (LVP) ^b	JP-4 (HVP) ^c	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8
0	1													
0	5													
0	10													
0	25													
0	50													
0	100													
0	250													
0	500													
0	1000													
5	10													
5	100													
5	250													
5	500													
5	10													
5	100													
5	250													
5	500													

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

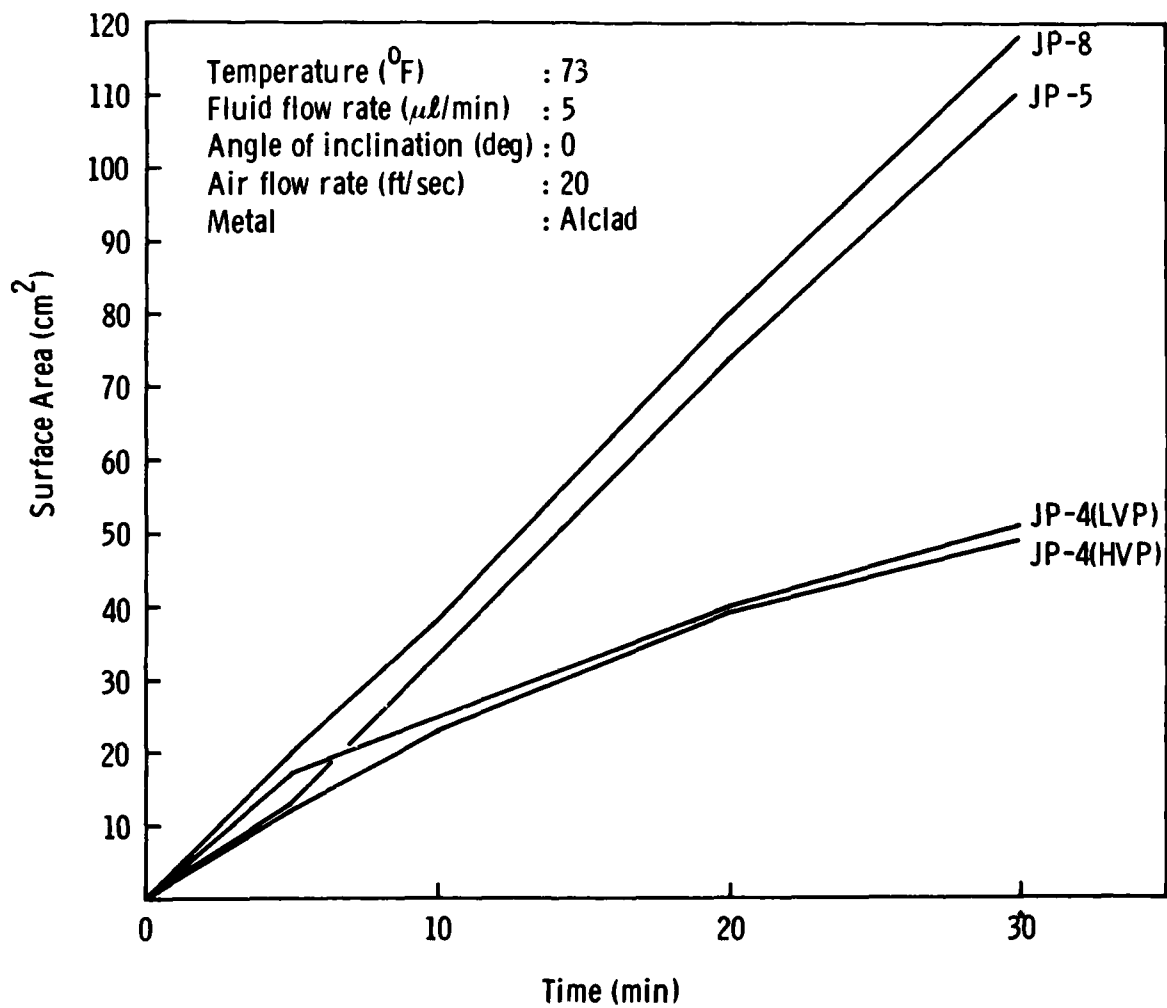


Figure 5. Spot surface areas of jet fuels, at a flow rate of $5 \mu\text{l}/\text{min}.$, as functions of time.

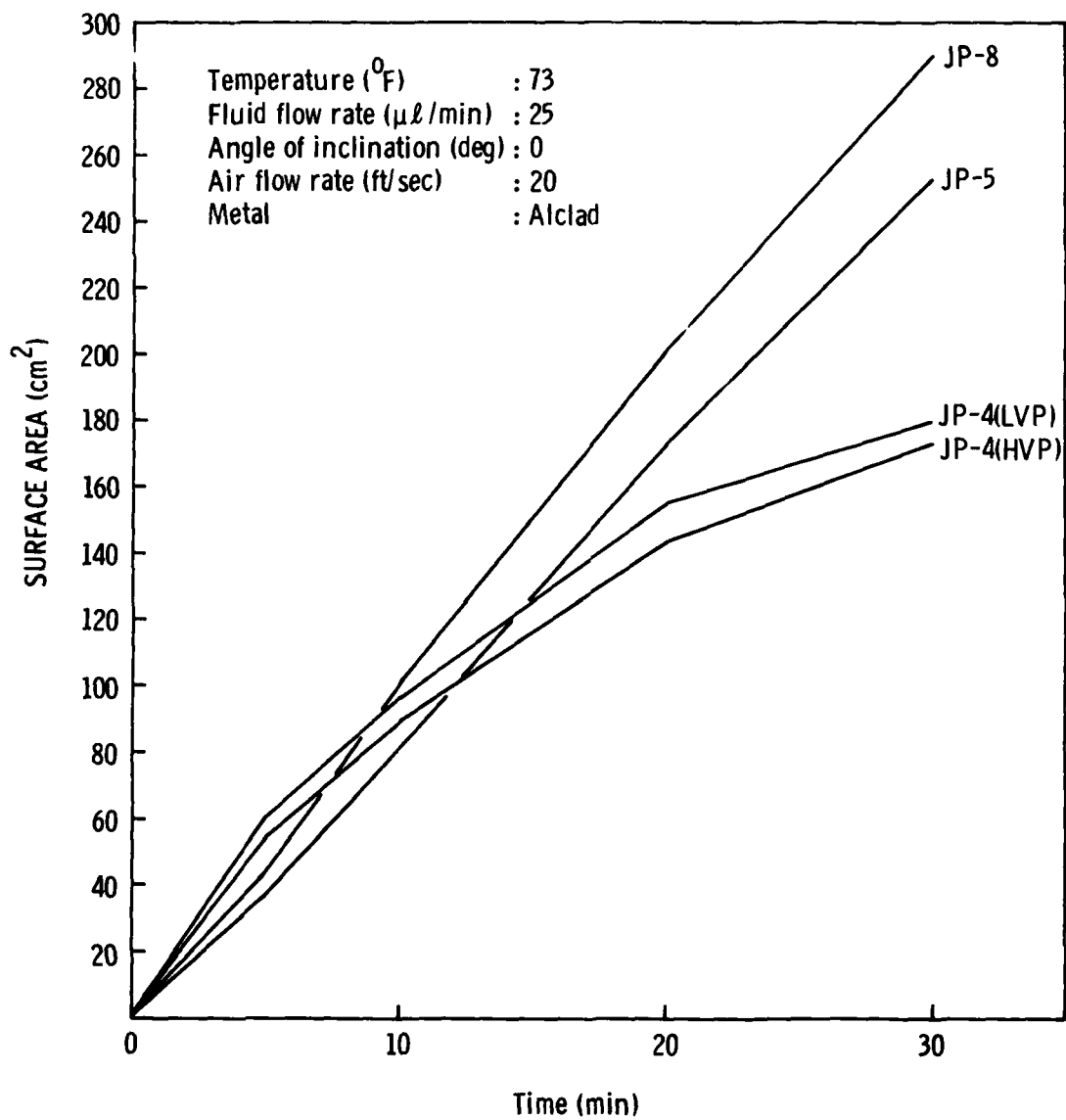


Figure 6. Spot surface areas of jet fuels, at a flow rate of $25 \mu\text{l}/\text{min}.$, as functions of time.

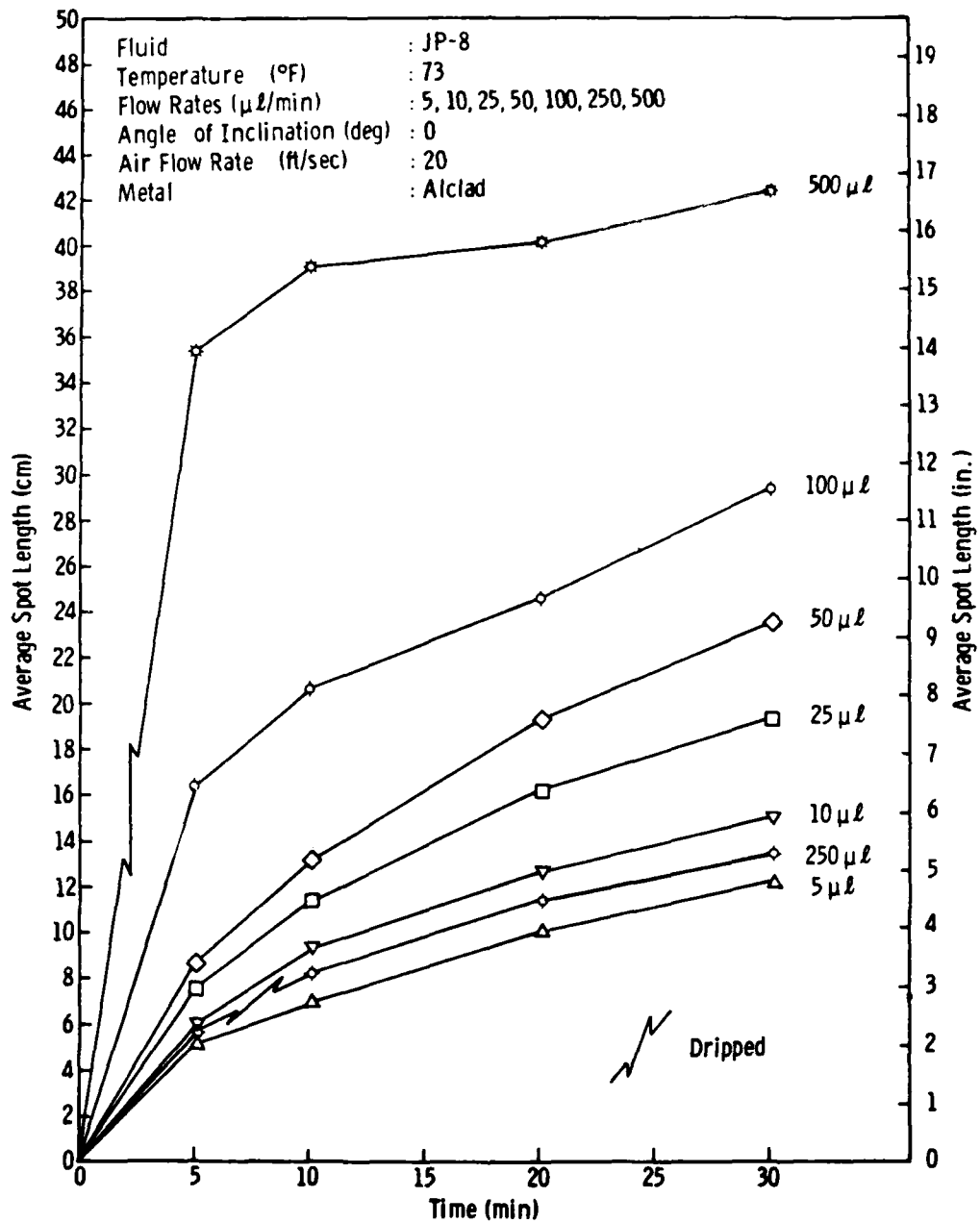


Figure 7. Rates of surface-dispersion of JP-8 at different fluid volume flow rates.

Representative data for the rates of spreading of a fuel [JP-4 (HVP)] at different leakage rates, under a set of selected conditions, are shown in Figure 8.

The spot lengths (or diameters in cases of symmetrical dispersion) for the four jet fuels at the end of 30-minute experiments, as functions of fuel flow rates, are depicted in Figure 9. It should be noted that a spot diameter equal to or greater than 15.2 cm (6 in.) was attained in 30 minutes with all fluids at the volume flow rate of 25 $\mu\text{l}/\text{min}$. (1.5 ml/hr; 0.051 fl oz/hr).

Table A-15 in the Appendix contains the data indicating volume flow rates at which dripping of fuel from the panel surface was observed.

Effect of Temperature

Temperature affects the rate of surface-dispersion of fuels and also the propensity of leaking fuels to drip. Surface-dispersion of fluids is affected by several physical properties (i.e., viscosity, surface tension, and vapor pressure). Therefore, the rate of surface dispersion of different fuels was found to be affected differently by temperature variation.

JP-4(HVP), a fuel of high vapor pressure, dispersed at a slower rate at higher temperature (see Figures 10 and 11). Apparently, vaporization reduced the quantity of dispersing fuel.

In contrast, the rates of dispersion of JP-8 (see Figure 10) and JP-5, fuels of low vapor pressure, increased with temperature. The reductions of viscosity and surface tension with increasing temperature control the rate of surface-dispersion with these fuels in the temperature interval [3.3°C to 32°C (38°F to 90°F)] covered in this study.

The propensity of fuels to drip was found to diminish with increasing temperature (see Table A-15). Whereas JP-8 dripped in quiescent atmosphere at 3.3°C (38°F) at a flow rate of 50 $\mu\text{l}/\text{min}$., at 23°C (73°F) dripping occurred at 100 $\mu\text{l}/\text{min}$., and at 33°C (90°F) no dripping was observed even at the latter flow rate.

Effect of Air Flow Rate

Figures 68 to 82 in the Appendix depict the effect of air flow past the fuel film on the rate of surface-dispersion. At the rates used in this work [0 and 6.1 m/sec.; (0 and 20 ft/sec.; 0 and 13.6 miles/hr)] the air flow had no significant effect on the fuel dispersion.

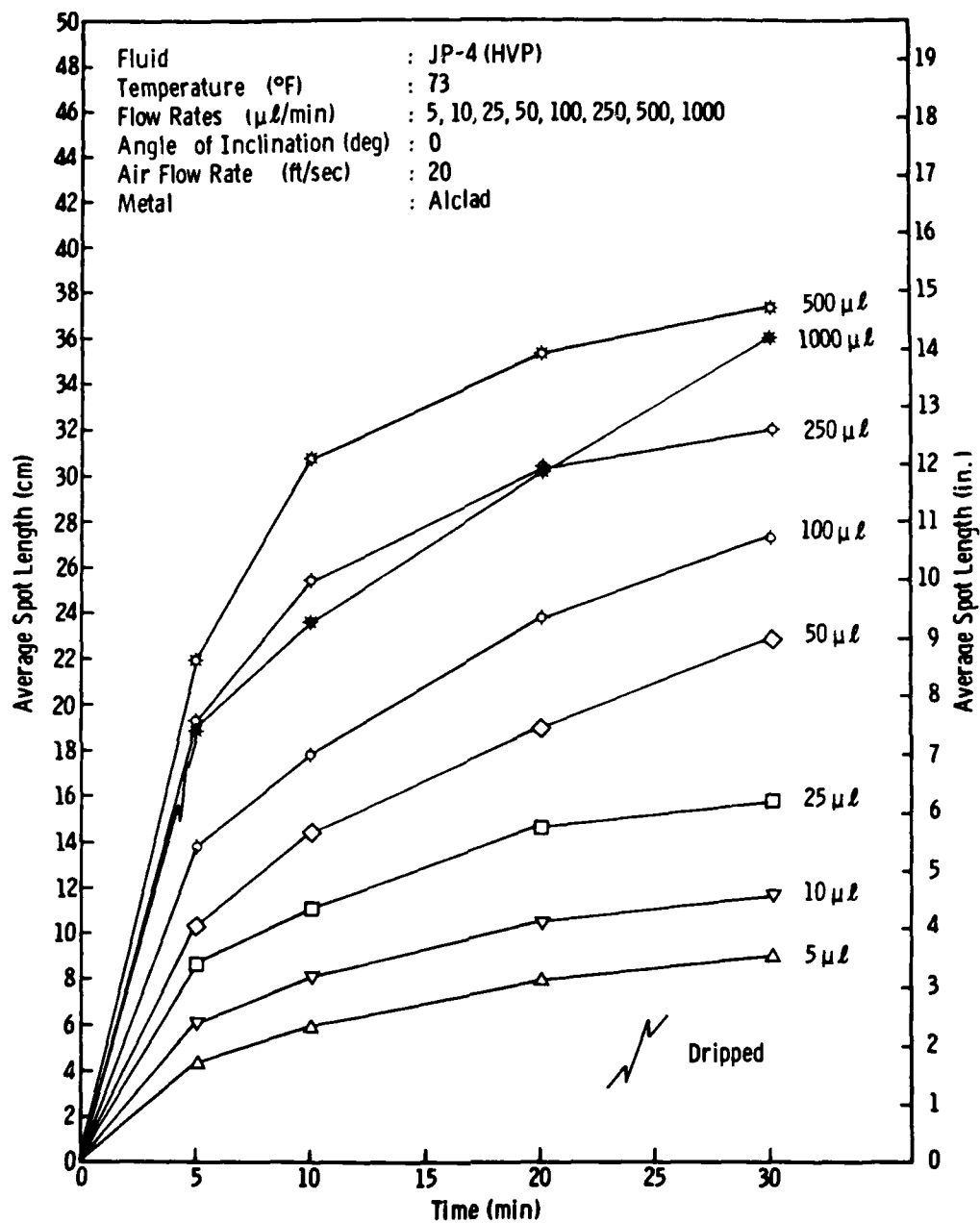


Figure 8. Surface-dispersion of JP-4(HVP) at different fluid volume flow rates.

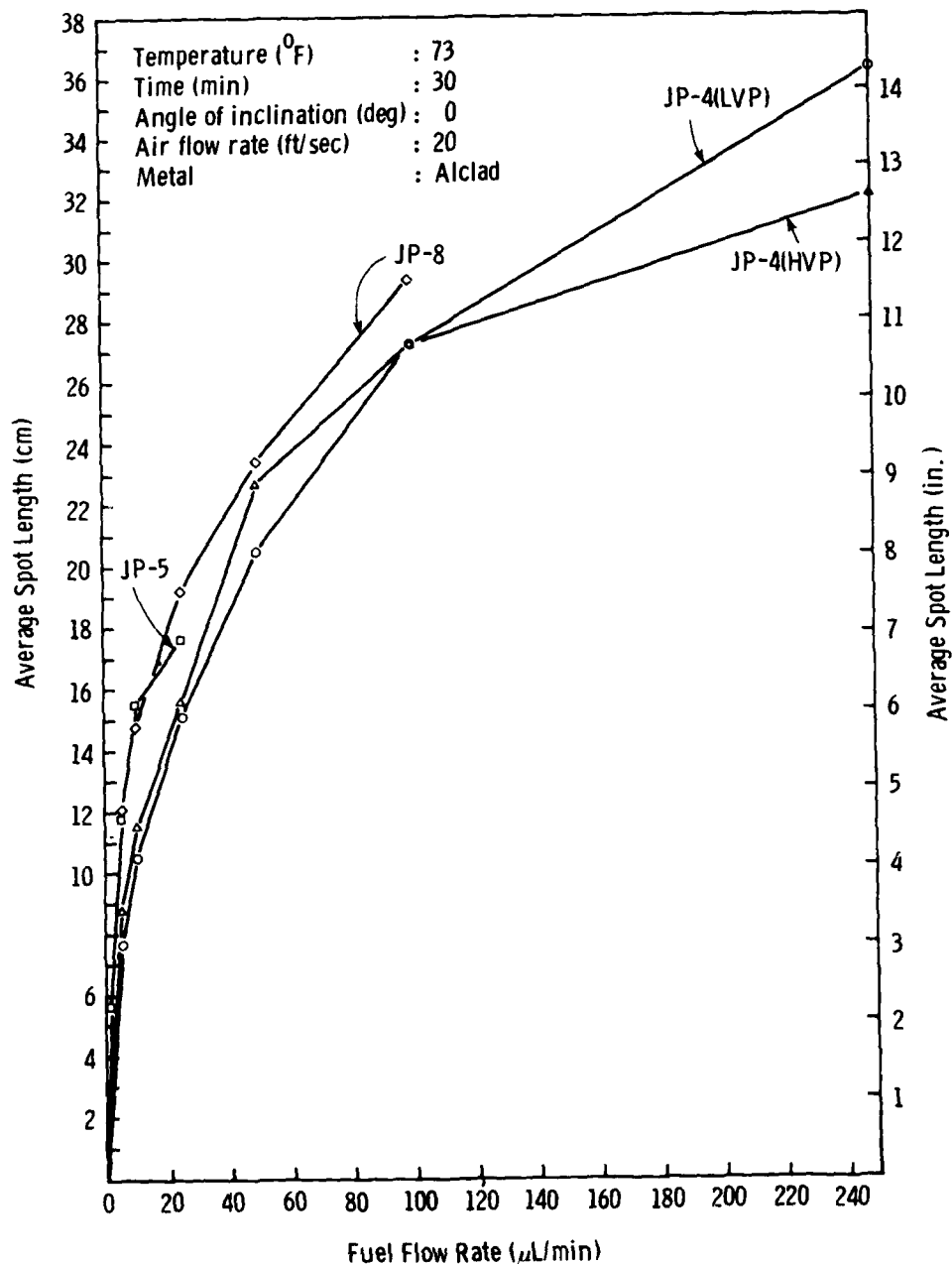


Figure 9. Spot lengths of JP-4(LVP), JP-4(HVP), JP-5 and JP-8 at the end of 30-minute experiments as functions of fuel flow rates.

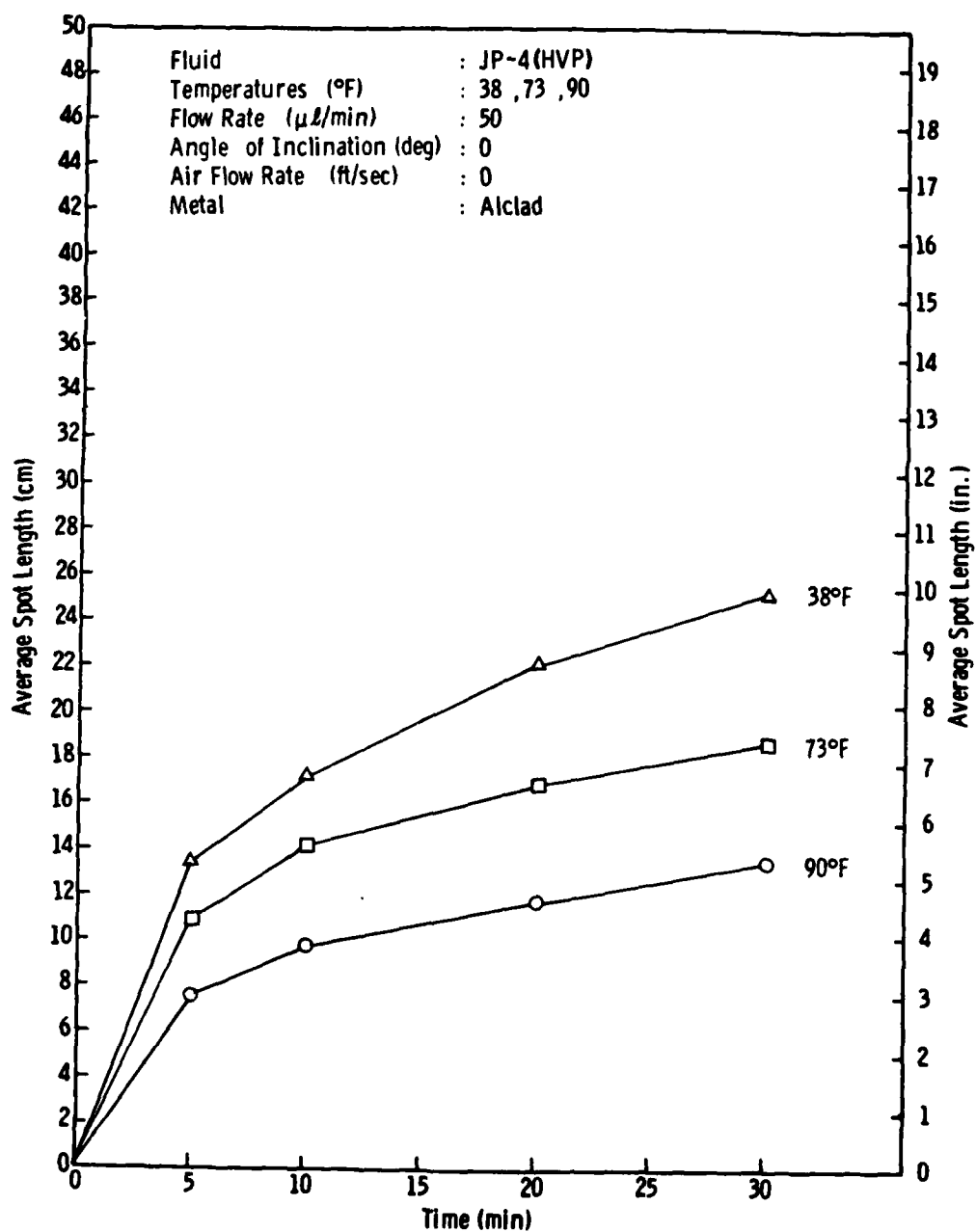


Figure 10. Surface-dispersion of JP-4 (HVP) at different temperatures.

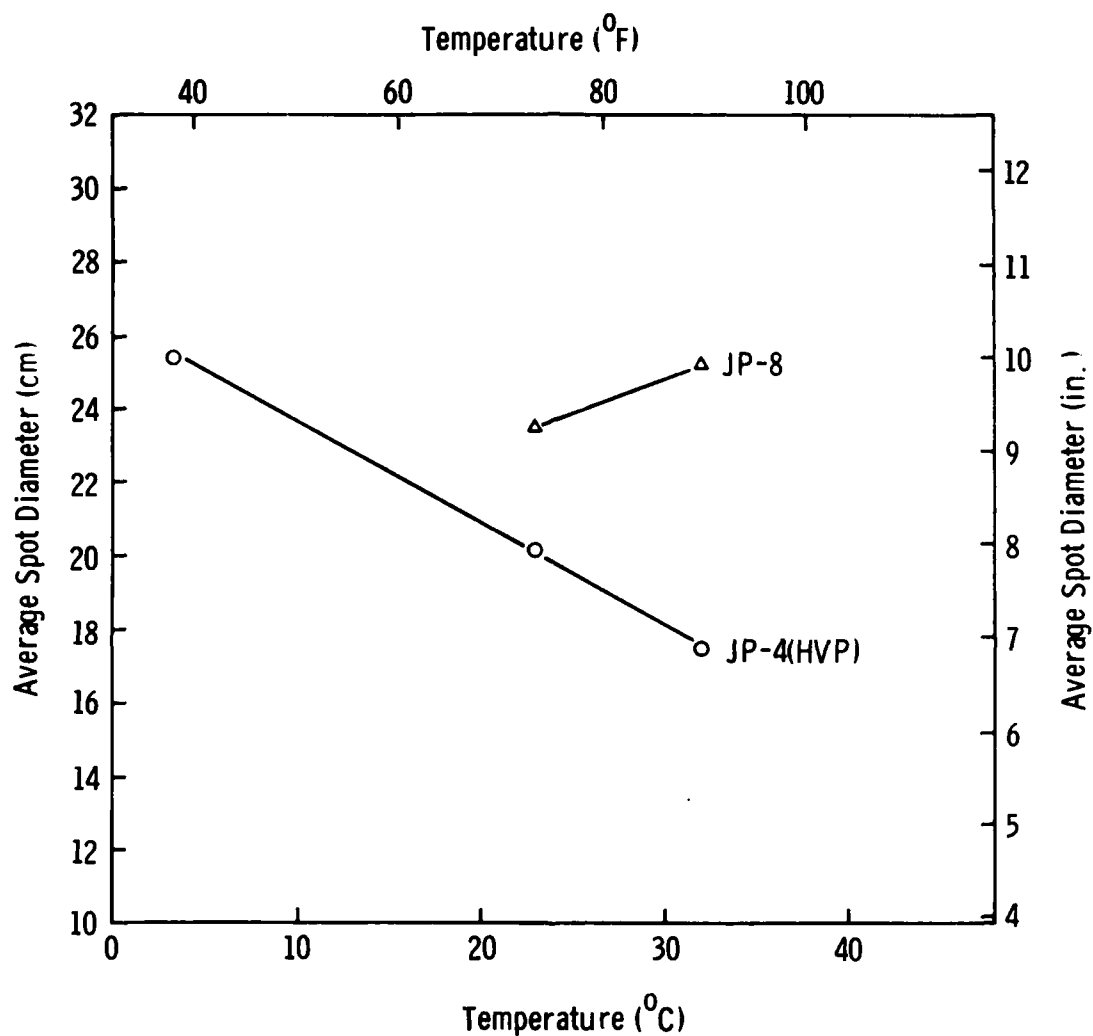


Figure 11. Average spot diameters for JP-4(HVP) and JP-8 as functions of temperature on Alclad surface after 30 minutes in a quiescent atmosphere.

Effect of Panel Angle of Inclination

The direction of fuel dispersion in an inclined plane appears to be affected mainly by the surface tension and volatility. The fuels of low surface tension and high volatility [JP-4(LVP) and JP-4(HVP)] dispersed in a circular pattern on panel surfaces inclined at 5° and 10°, at flow rates ranging up to 500 $\mu\text{l}/\text{min}$. (see Figure 12). At 90° angle of inclination, the surface-dispersion pattern was noncircular when the fuel flow rate was 50 $\mu\text{l}/\text{min}$.

JP-5 and JP-8, fuels of lower volatility and higher surface tension than JP-4, dispersed more readily in noncircular pattern than the latter fuel. The dispersion pattern was distinctly noncircular at the fuel flow rate of 100 $\mu\text{l}/\text{min}$. when the panel angle of inclination was 5° and 10°.

Dripping of fuels from the panel surface occurred more readily (i.e., at lower flow rates) when they dispersed along inclined panel surfaces (see Table A-15 in the Appendix).

Effect of Panel Material

The dispersion of fuels on three different material surfaces commonly used for the aircraft integral fuel tanks was investigated. These materials were unclad aluminum alloy, aluminum-clad aluminum alloy (Alclad), and Alclad coated with polyurethane latex paint.

The rates of dispersion of all jet fuels were not significantly affected by the surface they contacted (see Figure 13). However, dripping occurred more readily from the surface coated with the polyurethane latex paint (see Table A-15 in the Appendix).

MINIMUM FUEL FLOW RATES AT WHICH SUSTAINED BURNING OCCURRED

The leakage of fuel at a rate sufficiently rapid to support sustained burning could be potentially very hazardous. However, for the assessment of hazard associated with leakage, it is essential to know these leakage rates as functions of temperature for the fuels of interest. Experimental measurements were conducted with the following seven fuels and fuel mixtures to determine the flow rates at which they supported sustained burning: AvGas, JP-4(HVP), JP-4(LVP), JP-5, JP-8, JP-4(HVP)/JP-8 (10/90), and JP-4/JP-8 (50/50). The data are summarized in Figure 14, and Table A-17 in the Appendix.

Since the heats of combustion of the fuels used in this work do not differ greatly, the differences of minimum flow rates required for sustained burning are caused mainly by their volatilities. The very volatile fuels [i.e., AvGas and JP-4(HVP)] burned in a sustained manner when leaking at flow rates ranging from 0.2 to 0.7 ml/min . through the orifice. In contrast, the least volatile fuel,

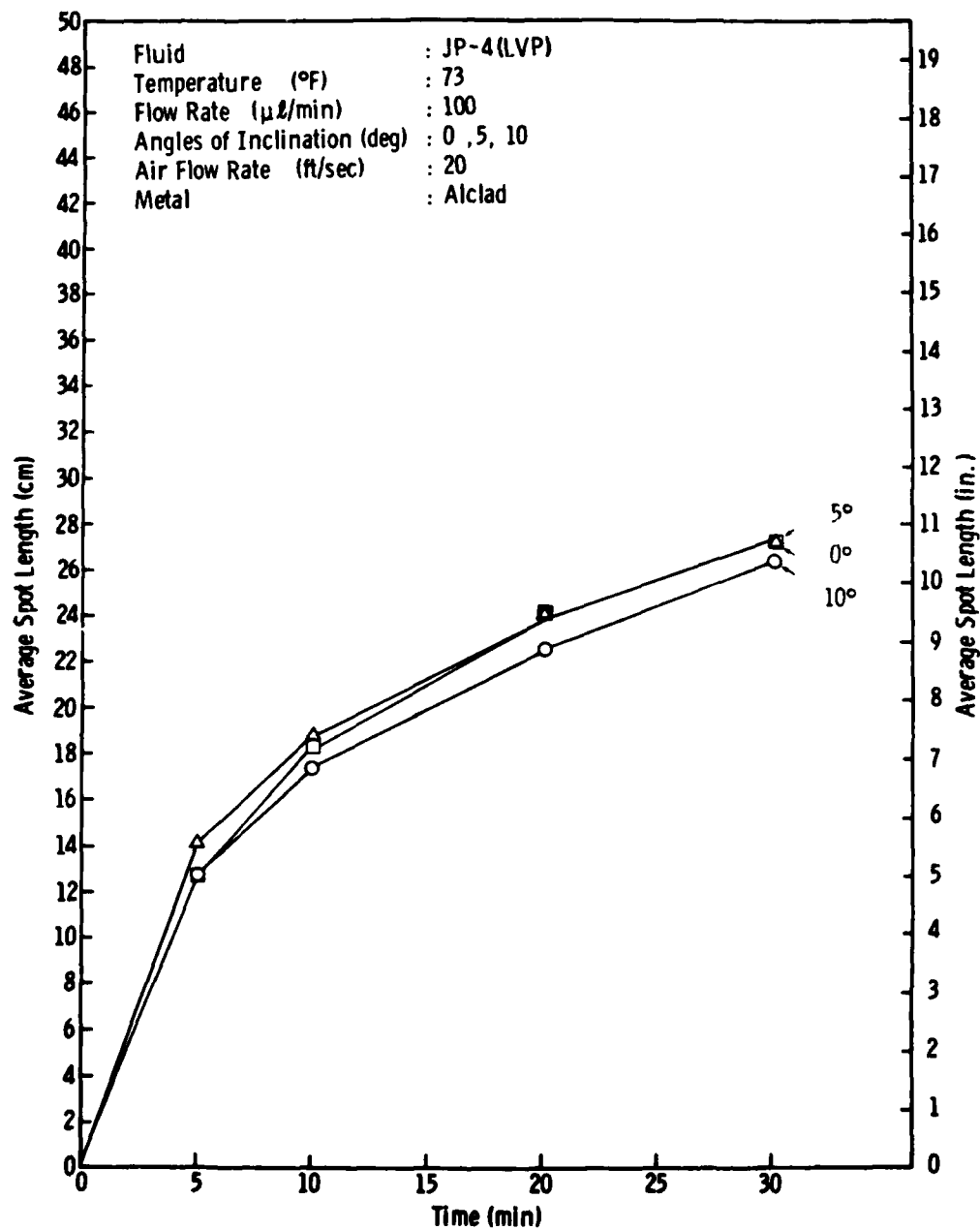


Figure 12. Surface-dispersion of JP-4(LVP) at 0°, 5° and 10° angles of panel inclination.

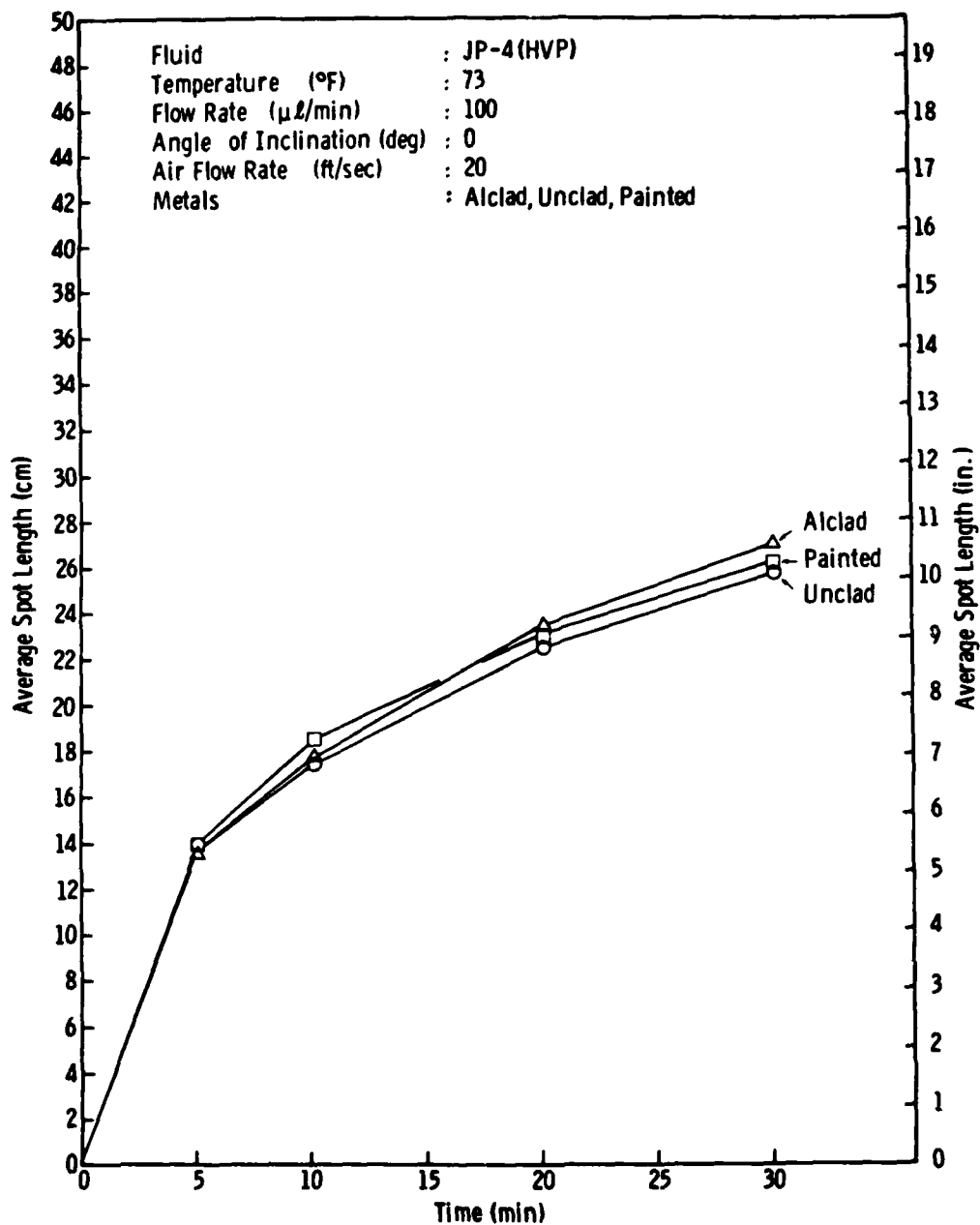


Figure 13. Rates of surface-dispersion of JP-4(HVP) on Alclad, unclad aluminum alloy and polyurethane latex-coated surfaces.

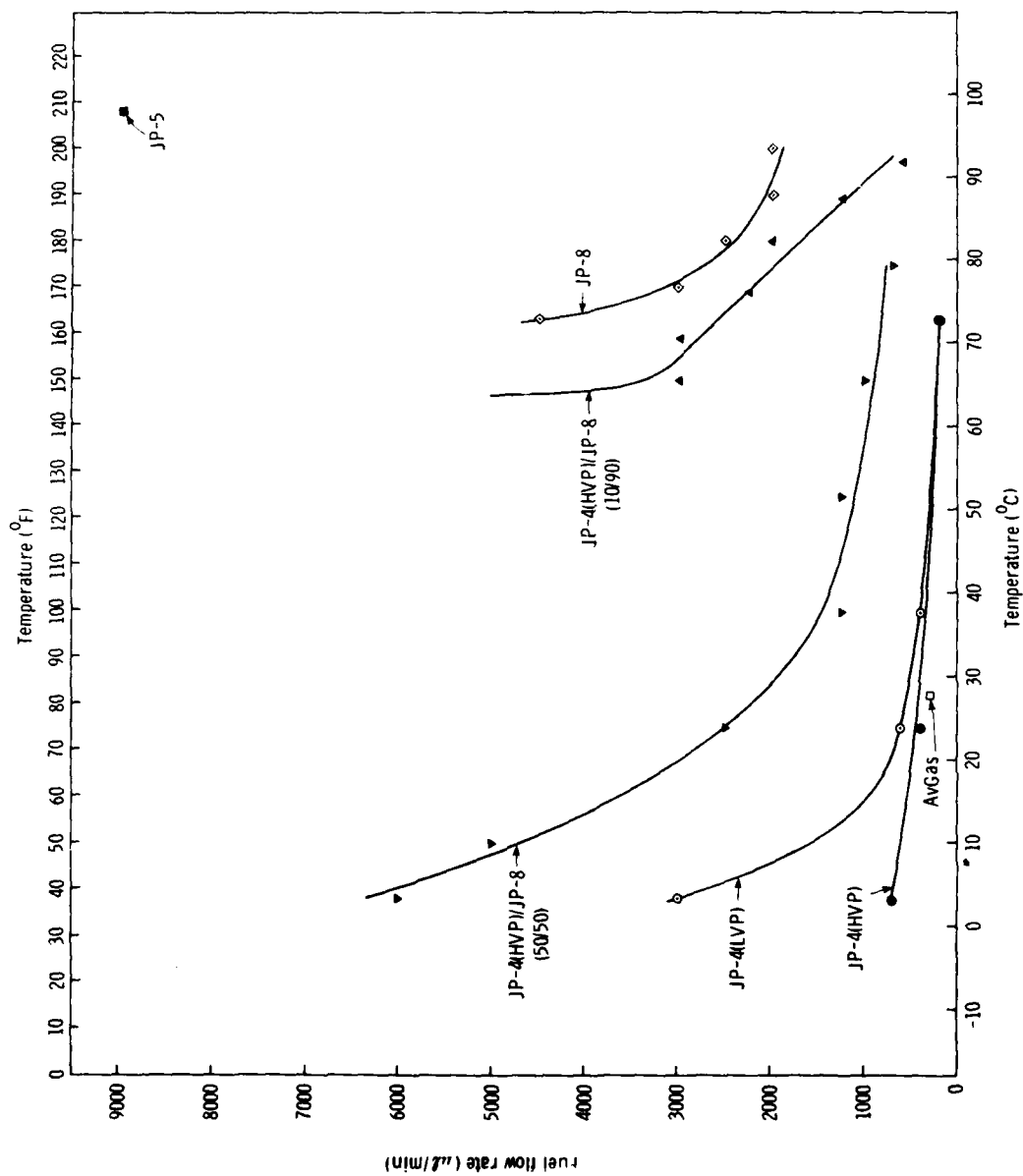


Figure 14. Minimum fuel flow rates at which sustained burning occurred.

JP-5, did not burn in a sustained manner until its flow rate had been increased to the unexpectedly high value of 9 ml/min. To achieve sustained burning even at this flow rate, the fuel and the surface had to be heated to 98°C (208°F).

In the event of integral fuel tank leakage, during normal operation of the aircraft, the conditions are not very conducive for ignition and sustained burning, especially with fuels of low vapor pressure at the ambient temperature. The fuel tank surface functions as a large heat sink, in intimate contact with the dispersing fuel film.

PROPOSED INTEGRAL FUEL TANK EXTERNAL LEAK CLASSIFICATION CRITERIA

Assessment of the fuel leak results and the ignition, flame spread and sustained burning properties of the various aircraft fuels indicates that favorable revision to the Air Force Technical Order 1-1-3 integral fuel tank external leak classification criteria is appropriate without any compromise of operational safety. In view of the differences between the types of fuel with respect to leak pattern versus leak rate manifestations, as well as in the fire threat, it is also apparent that any meaningful fuel leak classification criteria must be formulated on the basis of the specific fuel being utilized.

The revised criteria (see Table 3) that are proposed below classify fuels into three basic categories: the high volatility fuels such as AvGas, the intermediate volatility fuels such as JP-4 and mixtures of JP-4 with lower volatility fuels such as JP-8 and JP-5 (Note: JP-4 for this purpose is equivalent to civil airline Jet B fuel); and the lower volatility fuels such as JP-8 and JP-5 fuels (Note: the civil airline Jet A and Jet A-1 fuel designations for leak hazard purposes are considered equivalent to JP-8).

In arriving at the revised criteria, the following overall facts or trends were given principal consideration:

(1) A relatively small leak rate or overall very small volume of fuel is required to exhibit a leak spot of significant size, length or area. For example, Figure 8 [data for specification, high vapor pressure (HVP), JP-4 fuel] indicates that a leak rate of 25 microliters/minute or 0.025 milliliter/minute (0.025 fluid ounce/per hour) yields a spot length of 6 inches in 30 minutes.

(2) In general, the lower volatility fuels such as JP-8 and JP-5 are much more prone to exhibit dripping, particularly at leak rates in excess of 100 microliters/minute. The tendency to drip becomes more pronounced at lower ambient temperatures. At leak rates below that necessary for dripping to occur, the low volatility fuels such as JP-8 and JP-5 generally exhibit a larger spot length or area than either JP-4 or AvGas.

TABLE 3. PROPOSED AIRCRAFT INTEGRAL FUEL TANK EXTERNAL LEAK CLASSIFICATION CRITERIA

Leak category	Fuel type ^a		
	High volatility (AvGas)	Intermediate volatility (JP-4, JP-4/low volatility fuel mixtures)	Low volatility (JP-8, JP-5)
Class A (stain)	1/4	1/4	1/4
Class B (slow seep)	3/4	3/4	3/4
Class C (weep)	2 1/2 Without dripping	6 Without dripping	8 and/or 4 drops/minute
Class D (running leak)	Greater than 2 1/2 or drips or runs from surface	Greater than 6 or drips or runs from surface	Greater than 8 or 4 drops/ minute

^aAll values represent maximum fuel spot size (length or diameter) in inches or condition after 6 minutes of observation starting with a freshly dried surface.

(3) For leak rates below those required for the onset of dripping, the test data indicate that in general the spot length manifested in 6 minutes will be approximately half that manifested in 30 minutes, regardless of the fuel type.

(4) Figure 14 indicates the fire threat or sustained burning hazard associated with a given leak rate and the type of fuel involved. The data confirm the anticipated fire threat trend or vulnerability as influenced by fuel volatility. In general, the more volatile fuels such as AvGas and JP-4 are more prone to ignition and sustained burning. In addition, depending upon the temperature, a certain minimum fuel leakage rate must be exceeded for each fuel to transition from a flash to sustained fire condition. Even in the latter case, the magnitude of the fire is very small. It should also be noted that the propane flame ignition source utilized in these tests represents a relatively severe ignition threat compared to that which would be encountered in typical ground operations. The latter would more likely be of the static electricity or friction spark type ignition source. In establishing acceptable external leak criteria, the aircraft operational envelope and the effects of fuel migration/interaction with on-board equipment subsystems must also be

considered. In the case of the JP-4 fuel, the leak rates required for sustained burning obtained here are in good qualitative agreement with the fuel liquid regression rates for diffusive burning of gasoline in open pans of various diameters (1 cm to 300 cm diameter range) given in Reference 11. For small pan diameters (1-2 cm), fuel feed rates of approximately 500 $\mu\text{l}/\text{minute}$ or 0.5 ml/minute are indicated as required for sustained burning to occur. In our tests, under different configuration conditions, depending upon environmental temperature, leakage rates of 200 to 700 $\mu\text{l}/\text{minute}$ were required for sustained burning to occur. Accordingly, allowable leak rates for JP-4 should be kept below 200 $\mu\text{l}/\text{minute}$ to minimize the possibility of any localized, sustained fire occurring at the point of leakage.

For lower volatility fuels, such as JP-8 and JP-5, the agreement between our fuel feed rates for sustained burning versus those of Reference 11 is poor. Where our data for JP-8 indicate no ignition at ambient temperatures and 2000 $\mu\text{l}/\text{minute}$ (2 ml/minute) leak rate requirement at elevated temperature (208°F), Reference 11 for the equilibrium diffusive pool burning condition of diesel fuel in the 1-2 cm diameter pan condition indicates a minimal fuel feed rate requirement of 200 to 300 $\mu\text{l}/\text{minute}$. The difference in magnitude is attributable to fuel ignitibility and flame attitude/geometry factors. For maximum safety, it is considered that a leak rate in excess of 200 $\mu\text{l}/\text{minute}$ should not be permitted with the lower volatility (JP-8, JP-5) fuels.

As a consequence of the aforementioned considerations, the suggested revised leak criteria for incorporation into Air Force Technical Order 1-1-3 are delineated in Table 3.

Basically, we have converted all requirements into a common 6 minute inspection interval. The Class A and Class B categories are principally of interest for classifying leaks within dry bays or other partially enclosed areas. Since no effort has yet been conducted to distinguish significant differences between fuels with regards to compartment fire and explosion hazards, the spot length values currently indicated in T. O. 1-1-3 have been maintained, however, on the basis of a six (6) minute rather than a thirty minute inspection period. The Class C and Class D leak categories are principally of interest for classifying external fuel leaks. The criteria are based on the six (6) minute inspection interval and varying depending on the fuel involved. Any external leaks exceeding Class C criteria require immediate repair action. For the high and intermediate volatility fuels the critical leak criteria are those associated with a 100 micro-liters per minute leak rate or approximately one-half the leak rate required for sustained burning of JP-4 at 163°F (see Figure 14). In the case of the lower volatility fuels, such as JP-8, the critical leak patterns are those associated with a 200 micro-liters per minute (4 drops per minute) leak rate or below (see Figure 9). As indicated by the test data, the lower volatility

fuels will exhibit dripping more often than not. As also noted in Figure 14, even at the two microliters per minute leak rate, a large safety factor with respect to the leak rate required for sustained burning still exists. In view of the greater likelihood of low volatility fuels to run and accumulate, any relaxation beyond the 4 drops per minute drip rate is not recommended. The criteria offered are for single leak conditions only. Extension of these criteria to multiple leak scenarios, by allowing for proper distance requirements between leaks, should be defined by AFLC and AFSC/ASD fuel system engineering personnel.

CONCLUSIONS

1. The dispersing fuel films are very thin (<0.05 mm/ 0.002 in. thick). Therefore, fuels leaking at low rates cover significant-sized areas. For example, JP-4 (LVP), leaking at the rate of $25 \mu\text{l}/\text{min}$. (0.051 fl oz/hr) develops a spot of 15 cm (6 in.) diameter in 30 minutes (Ref. Fig. 6).
2. Fuels of low volatility (i.e., JP-5 and JP-8) disperse at faster rates over the surface than those of high volatility (i.e., AvGas and JP-4), at leakage rates at which dripping does not occur (Ref. Fig. 9).
3. Fuels exhibit great differences in their propensity for dripping. Those of low volatility drip much more readily upon leakage than those of high volatility from both horizontal and inclined surfaces.
4. The tendency of fuels to drip becomes greater at lower ambient temperatures.
5. Air flow at the speed of 21.9 km/hr (13.6 miles/hr) has no significant effect on surface-dispersion of fuel.
6. Dripping of leaking fuels occurs more readily from inclined than from horizontal surfaces.
7. The rates of surface-dispersion of fuels are identical on unclad aluminum alloy, Alclad, and polyurethane latex-coated surfaces. However, dripping occurs at lower leakage rates from the latter surface than from the bare metal surfaces.
8. The potential hazards arising from sustained burning are greater with volatile fuels (i.e., AvGas and JP-4) than those of low volatility (i.e., JP-5 and JP-8). Each fuel, at any temperature, must leak at a minimal rate to support sustained burning at the leakage site; only flashing (i.e., transitory burning) occurs at lower leakage rates.
9. Relaxation of the current AF Technical Order 1-1-3 integral fuel tank external leak classification criteria in accordance with the proposed revised criteria indicated in Table 3 is feasible without any compromise of operational safety.

RECOMMENDATIONS

It is recommended that the proposed revised integral fuel tank external leak classification criteria be evaluated by AFSC (ASD), AFLC (AFALD), AFISC/IG and Air Force operating commands for near-term incorporation into Air Force Technical Order 1-1-3. Results of this program should also be furnished to the other Military Services and Civil Aviation authorities for possible United States and International standardization of the leak classification criteria utilized.

APPENDIX I
DATA TABULATIONS

A. Properties of Fuels

TABLE 4. DENSITIES, KINEMATIC VISCOSITIES
AND VAPOR PRESSURES OF JET FUELS

Physical property	Determined value			
	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8
Density (g/cm ³)				
at 0°C (32°F)	0.7693	0.7805	0.8231	0.8169
at 25.0°C (77°F)	0.7489	0.7595	0.8050	0.7982
at 37.8°C (100°F)	0.7387	0.7493	0.7956	0.7888
Kinematic viscosity (centistokes)				
at -17.8°C (0°F)	1.577	1.459	5.913	4.468
at 25°C (77°F)	0.8489	0.8053	2.032	1.715
at 37.8°C (100°F)	0.7369	0.7022	1.636	1.405
Surface tension (dynes/cm)				
at 0°C (32°F)	24.56	24.93	28.22	28.18
at 21.1°C (70°F)	22.66	22.88	26.44	26.17
at 37.8°C (100°F)	21.18	21.26	25.04	24.62
Vapor pressure (torr)				
at 0°C (32°F)	27.0	37.0	4.4	4.7
at 21.1°C (70°F)	63.5	87.5	8.5	10.4
at 37.8°C (100°F)	117.5	158.0	13.4	18.0

TABLE 5. FLASH AND FIRE POINTS OF JET FUELS

Fuel	Flash point		Fire point	
	(°C)	(°F)	(°C)	(°F)
JP-4 (LVP)	-3.5	25.7	1.0	33.8
JP-4 (HVP)	-9.0	15.8	-6.5	20.3
JP-5	56.2	133.2 ^a	62.1	143.8
JP-8	40.7	105.3 ^b	45.3	113.5

^aMr. W. Crawford of the Air Force Aero Propulsion Laboratory reported a flash point of 56.7°C (134°F) for this sample of JP-5 fuel.

^bA flash point of 42.2°C (108°F) was reported by Mr. W. Crawford for this sample of JP-8 fuel.

TABLE 6. SIMULATED DISTILLATION OF JET FUEL SAMPLES

Sample recovered (%)	Temperature							
	(°C)				(°F)			
	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8
0.5	27	23	109	92	81	73	228	198
1	34	25	126	103	93	77	259	217
5	60	56	163	137	140	133	325	279
10	76	70	173	159	169	158	343	318
20	98	93	188	177	208	199	370	351
30	116	111	199	188	241	232	390	370
40	133	126	210	198	271	259	410	388
50	147	143	220	207	297	289	428	405
60	164	161	229	216	327	322	444	421
70	178	179	240	226	352	354	464	439
80	195	204	250	239	383	399	482	462
90	215	229	265	256	419	444	509	493
95	229	245	275	267	444	473	527	513
99	252	264	290	290	486	507	554	554
99.5	266	275	311	298	551	527	592	568

TABLE 7. MOLECULAR DISTRIBUTION IN JET FUELS
ESTABLISHED BY SIMULATED DISTILLATION

Carbon atom number	Weight percent			
	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8
C ₃ - C ₄	<0.1	<0.1		<0.1
C ₄ - C ₅	2.6	4.2		0.1
C ₅ - C ₆	7.7	7.7	0.1	0.2
C ₆ - C ₇	13.6	14.7	0.2	0.9
C ₇ - C ₈	14.7	14.8	0.5	2.5
C ₈ - C ₉	14.2	13.9	1.4	4.5
C ₉ - C ₁₀	12.9	10.9	4.8	7.8
C ₁₀ - C ₁₁	11.9	8.8	14.3	16.6
C ₁₁ - C ₁₂	10.1	7.6	18.3	21.6
C ₁₂ - C ₁₃	7.0	7.0	19.2	18.3
C ₁₃ - C ₁₄	3.3	5.7	15.5	12.3
C ₁₄ - C ₁₅	1.0	3.0	13.9	8.0
C ₁₅ - C ₁₆	0.6	1.0	7.9	4.3
C ₁₆ - C ₁₇	0.1	0.3	3.0	2.2
C ₁₇ - C ₁₈	0.1	0.1	0.6	0.4
C ₁₈ - C ₁₉	0.1	0.1	0.3	0.2

B. Surface Dispersion of Fuels

1. Key to Tables
2. Tables

KEY TO TABLES CONTAINING SURFACE-DISPERSION DATA FOR FUELS^a

Angle (deg)	Temperature		3.3 °C (38 °F)			23 °C (73 °F)					32 °C (90 °F)		
	Fuel	Air flow rate (μl/min.)	JP-4 (HVP)	JP-5	JP-8	(20 ft/sec)	JP-4 (HVP)	JP-5	JP-8	JP-4 ^d JP-8 ^d	JP-4 (HVP)	JP-5	JP-8
0		1				Table A-5							
0		5											
0		10											
0		25											
0		50											
0		100											
0		250											
0		500											
0		1000											
0		1400											
5		10											
5		100											
5		250											
5		500											
10		10											
10		100											
10		250											
10		500											
90		5											
90		10											
90		50											

^a Measurement time was 30 min. for all experiments shown in this table

^b High vapor pressure sample

^c Low vapor pressure sample

^d JP-4/JP-8 in 10/90 volume ratio

^e Single experiments were conducted with AvGas at each flow rate. Triplicate experiments were conducted with the other fluids under all experimental conditions.

KEY TO TABLES CONTAINING SURFACE-DISPERSION DATA FOR FUELS (continued)^a

Angle (deg)	Fuel flow rate (μ l/min.)	Measurement time (min.)	Fluid				Remarks
			JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	
0	10	180		Table A-12	•		Extended measurement time Alclad surface
10	100	30	•			•	Longer flow distance Alclad surface
10	500	30	•			•	Longer flow distance Alclad surface
0	10	30		Table A-13	•	•	^b Painted surface
0	25	30			•	•	^b Painted surface
0	50	30			•	•	^b Painted surface
0	100	30	•	•	•	•	^b Painted surface
0	250	30	•	•			^b Painted surface
0	500	30	•	•			^b Painted surface
0	100	30	•	Table A-14	•	•	Unclad surface

^a All experiments shown in this table were conducted at 23 °C (73 °F),
at an air flow rate of 6.1 m/sec (20 ft/sec)

^b Polyurethane latex coating

TABLE 8. DISPERSION OF LEAKING JET FUELS ON ALCLAD SURFACE
AT 3.3°C (38°F). QUIESCENT ATMOSPHERE. ANGLE
OF INCLINATION 0 DEGREE

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-4 (HVP)	50	5	13.2 ± 2.0	13.2 ± 2.0	138
"	50	10	17.0 ± 1.3	17.1 ± 1.4	228
"	50	20	22.0 ± 0.9	22.2 ± 0.7	383
"	50	30	25.1 ± 1.3	25.7 ± 0.8	505
JP-4 (HVP)	100	5	14.2 ± 0.6	14.4 ± 0.3	160
"	100	10	19.2 ± 1.0	19.0 ± 0.0	286
"	100	20	24.3 ± 0.6	24.8 ± 0.8	475
"	100	30	28.0 ± 0.9	28.7 ± 0.8	631
JP-5	10	5	5.0 ± 0.0	5.3 ± 0.5	21
"	10	10	7.6 ± 0.6	7.6 ± 0.6	45
"	10	20	11.0 ± 1.2	11.0 ± 1.3	95
"	10	30	13.5 ± 1.7	13.8 ± 2.5	147
JP-5	25	5	5.5 ± 0.5	5.5 ± 0.5	24
"	25	10	8.4 ± 0.8	8.5 ± 0.9	56
"	25	20	12.0 ± 1.0	11.3 ± 1.5	107
"	25	30	16.2 ± 1.0	14.7 ± 2.5	186
JP-5	50	5	3.6 ± 0.9	3.6 ± 0.9	10
"	50	10	6.2 ± 0.3	6.6 ± 0.4	32
"	50	20	9.6 ± 0.4	9.7 ± 0.6	73
"	50	30	12.5 ± 0.5	12.7 ± 0.6	125
JP-8	25	5	6.7 ± 0.3	6.7 ± 0.3	35
"	25	10	9.8 ± 0.3	9.8 ± 0.3	76
"	25	20	14.8 ± 1.0	14.8 ± 1.0	172
"	25	30	17.6 ± 0.4	17.9 ± 1.0	247
JP-8	50	5	5.9 ± 0.5	5.7 ± 0.3	26
"	50	10	9.3 ± 0.3	9.0 ± 0.0	66
"	50	20	13.5 ± 0.9	14.0 ± 2.2	149
"	50	30	16.4 ± 1.4	17.0 ± 2.6	219
JP-8	100	5	5.4 ± 0.4	5.4 ± 0.4	23
"	100	10	7.3 ± 1.3	7.3 ± 1.3	42
"	100	20	9.6 ± 2.1	11.0 ± 2.2	83
"	100	30	13.1 ± 2.7	13.3 ± 2.9	137
JP-8	250	5	6.2 ± 0.8	6.2 ± 0.8	30
"	250	10	8.9 ± 1.2	9.1 ± 0.9	63
"	250	20	13.4 ± 1.7	13.5 ± 1.5	142
"	250	30	16.8 ± 2.3	17.5 ± 1.8	231

TABLE 9. DISPERSION OF LEAKING JET FUELS ON ALCLAD SURFACE
AT 23°C (73°F). AIR FLOW RATE 6.1 m/sec.
ANGLE OF INCLINATION 0 DEGREE

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-4 (LVP)	5	5	4.7 ± 0.3	4.8 ± 0.1	17
"	5	10	5.5 ± 0.3	5.8 ± 0.4	25
"	5	20	6.8 ± 0.2	7.5 ± 0.4	40
"	5	30	7.7 ± 0.1	8.3 ± 0.2	51
JP-4 (LVP)	10	5	5.4 ± 1.0	5.7 ± 0.5	24
"	10	10	7.6 ± 0.5	8.0 ± 0.4	48
"	10	20	9.7 ± 0.3	10.3 ± 0.1	78
"	10	30	10.5 ± 0.1	11.0 ± 0.4	91
JP-4 (LVP)	25	5	8.6 ± 0.4	8.9 ± 0.4	60
"	25	10	10.7 ± 0.4	11.4 ± 0.4	96
"	25	20	13.8 ± 0.5	14.3 ± 0.6	155
"	25	30	15.1 ± 0.4	15.2 ± 0.3	180
JP-4 (LVP)	50	5	11.0 ± 0.0	11.2 ± 0.3	97
"	50	10	14.3 ± 0.6	14.6 ± 0.2	164
"	50	20	18.5 ± 0.5	19.0 ± 0.0	276
"	50	30	20.5 ± 0.5	21.7 ± 0.6	349
JP-4 (LVP)	100	5	14.0 ± 0.8	13.7 ± 0.3	151
"	100	10	18.7 ± 0.3	18.9 ± 0.1	278
"	100	20	23.8 ± 0.4	24.0 ± 0.0	449
"	100	30	27.2 ± 0.4	28.2 ± 0.6	603
JP-4 (LVP)	250	5	19.2 ± 0.6	19.6 ± 0.8	295
"	250	10	25.2 ± 0.7	25.3 ± 0.6	663
"	250	20	32.0 ± 0.0	33.5 ± 0.5	842
"	250	30	36.2 ± 0.8	37.7 ± 1.2	1070
JP-4 (LVP)	500	5	22.8 ± 2.3	23.0 ± 2.0	412
"	500	10	30.8 ± 1.3	31.5 ± 1.8	763
"	500	20	40.0 ± 0.0	41.0 ± 0.0	1288
"	500	30	44.7 ± 0.6	44.7 ± 0.6	1567
JP-4 (LVP)	1000	5	18.5 ± 0.9	18.6 ± 0.9	270
"	1000	10	21.7 ± 0.6	22.0 ± 1.0	374
"	1000	20	26.8 ± 0.8	27.5 ± 0.5	580
"	1000	30	30.0 ± 0.9	30.5 ± 0.0	719

TABLE 9 (continued)

Fuel	Fuel flow rate ($\mu\text{L}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-4 (HVP)	5	5	4.3 ± 1.3	3.5 ± 0.9	12
"	5	10	5.9 ± 0.8	5.0 ± 0.5	23
"	5	20	7.9 ± 0.1	6.3 ± 0.6	39
"	5	30	8.8 ± 0.2	7.1 ± 0.6	49
JP-4 (HVP)	10	5	6.0 ± 1.0	5.8 ± 0.8	27
"	10	10	8.0 ± 0.4	7.0 ± 0.5	44
"	10	20	10.4 ± 0.2	9.5 ± 1.0	78
"	10	30	11.5 ± 0.5	9.7 ± 0.6	88
JP-4 (HVP)	25	5	8.6 ± 0.5	8.0 ± 0.5	54
"	25	10	11.0 ± 0.2	10.3 ± 0.3	89
"	25	20	14.5 ± 0.5	12.6 ± 0.4	143
"	25	30	15.6 ± 1.1	14.1 ± 0.5	173
JP-4 (HVP)	50	5	10.3 ± 2.1	10.0 ± 2.0	81
"	50	10	14.3 ± 1.5	12.7 ± 0.8	143
"	50	20	18.9 ± 0.1	17.3 ± 1.0	257
"	50	30	22.7 ± 2.1	19.3 ± 0.6	344
JP-4 (HVP)	100	5	13.7 ± 0.6	13.2 ± 0.6	141
"	100	10	17.8 ± 0.8	16.3 ± 0.6	229
"	100	20	23.7 ± 0.6	22.3 ± 0.3	415
"	100	30	27.2 ± 1.1	25.4 ± 0.4	543
JP-4 (HVP)	250	5	19.2 ± 1.0	18.5 ± 1.5	278
"	250	10	25.3 ± 1.5	24.2 ± 1.0	481
"	250	20	30.3 ± 0.6	28.8 ± 0.8	687
"	250	30	32.0 ± 0.0	31.3 ± 1.2	787
JP-4 (HVP)	500	5	21.8 ± 1.9	22.0 ± 1.0	377
"	500	10	30.7 ± 2.3	31.2 ± 2.4	751
"	500	20	35.3 ± 2.1	38.0 ± 1.7	1054
"	500	30	37.3 ± 1.5	40.3 ± 3.1	1182
JP-4 (HVP)	1000	5	19.0 ± 3.8	21.2 ± 1.3	316
"	1000	10	23.5 ± 2.8	29.0 ± 1.3	535
"	1000	20	30.3 ± 4.7	39.0 ± 2.6	929
"	1000	30	36.0 ± 6.2	43.7 ± 2.3	1235
JP-5	1	5	3.7 ± 0.6	3.7 ± 0.5	11
"	1	10	4.5 ± 0.9	4.8 ± 0.5	17
"	1	20	5.1 ± 1.2	5.9 ± 1.1	24
"	1	30	5.7 ± 0.8	6.5 ± 1.3	29

TABLE 9 (continued)

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-5	5	5	4.0 ± 0.0	4.0 ± 0.0	13
"	5	10	6.5 ± 0.5	6.5 ± 0.5	33
"	5	20	9.7 ± 0.3	9.7 ± 0.3	74
"	5	30	11.8 ± 0.3	11.8 ± 0.3	110
JP-5	10	5	5.8 ± 1.0	5.9 ± 0.8	27
"	10	10	8.7 ± 1.0	8.8 ± 0.8	60
"	10	20	12.5 ± 1.3	13.0 ± 0.9	128
"	10	30	15.5 ± 0.9	15.8 ± 0.3	193
JP-5	25	5	6.8 ± 0.6	6.8 ± 0.8	37
"	25	10	10.2 ± 0.3	10.2 ± 0.3	81
"	25	20	14.7 ± 0.6	15.0 ± 1.0	173
"	25	30	17.6 ± 0.7	18.3 ± 1.1	253
JP-5	50	5	4.5 ± 0.5	4.3 ± 0.5	15
"	50	10	5.7 ± 0.7	5.5 ± 0.8	25
"	50	20	7.3 ± 0.7	7.2 ± 0.7	44
"	50	30	8.7 ± 0.4	8.8 ± 0.8	59
JP-5	100	5	4.3 ± 0.6	4.3 ± 0.6	15
"	100	10	5.8 ± 0.5	5.9 ± 0.3	27
"	100	20	7.3 ± 0.3	7.5 ± 0.1	43
"	100	30	8.5 ± 0.3	8.9 ± 0.2	59
JP-5	250	5	4.0 ± 0.4	3.8 ± 0.4	12
"	250	10	5.9 ± 0.3	5.3 ± 0.2	24
"	250	20	8.1 ± 0.3	7.2 ± 0.3	45
"	250	30	9.3 ± 0.3	8.4 ± 0.4	62
JP-8	5	5	5.0 ± 0.4	5.1 ± 0.2	20
"	5	10	6.8 ± 0.8	7.0 ± 0.9	38
"	5	20	9.9 ± 0.7	10.2 ± 0.4	80
"	5	30	12.0 ± 0.5	12.5 ± 0.1	118
JP-8	10	5	6.0 ± 0.6	6.0 ± 1.0	28
"	10	10	9.2 ± 1.0	9.2 ± 0.8	66
"	10	20	12.5 ± 0.8	12.5 ± 0.3	123
"	10	30	14.8 ± 0.3	14.7 ± 0.5	171

TABLE 9 (continued)

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-8	25	5	7.5 ± 0.5	7.4 ± 0.5	44
"	25	10	11.3 ± 0.3	11.3 ± 0.3	101
"	25	20	16.1 ± 0.4	15.9 ± 0.1	201
"	25	30	19.2 ± 0.3	19.2 ± 0.3	290
JP-8	50	5	8.7 ± 1.4	9.1 ± 1.0	62
"	50	10	13.0 ± 1.3	13.5 ± 1.8	138
"	50	20	19.2 ± 0.3	20.7 ± 1.2	311
"	50	30	23.4 ± 1.0	24.7 ± 1.4	454
JP-8	100	5	16.3 ± 3.8	12.8 ± 5.5	165
"	100	10	20.5 ± 3.3	17.3 ± 2.9	279
"	100	20	24.5 ± 0.5	27.3 ± 1.2	525
"	100	30	29.3 ± 0.8	30.8 ± 1.0	710
JP-8	250	5	5.8 ± 0.3	5.8 ± 0.3	27
"	250	10	8.2 ± 0.8	8.5 ± 0.9	54
"	250	20	11.3 ± 0.6	11.3 ± 0.6	101
"	250	30	13.0 ± 0.6	13.2 ± 0.9	135
JP-8	500	5	35.3 ± 3.1	7.3 ± 1.2	203
"	500	10	39.0 ± 1.0	13.3 ± 1.5	408
"	500	20	40.0 ± 1.0	16.7 ± 1.2	524
"	500	30	42.2 ± 1.3	21.3 ± 3.1	706

TABLE 10. DISPERSION OF LEAKING JET FUELS ON ALCLAD SURFACE
AT 23°C (73°F). AIR FLOW RATE 6.1 m/sec.
ANGLE OF INCLINATION 5 DEGREES

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-4 (LVP)	10	5	5.7 ± 0.5	5.9 ± 0.6	26
"	10	10	7.4 ± 0.3	7.6 ± 0.4	44
"	10	20	9.0 ± 0.0	9.3 ± 0.3	66
"	10	30	10.3 ± 0.3	10.9 ± 0.1	89
JP-4 (LVP)	100	5	12.7 ± 1.2	12.7 ± 1.2	126
"	100	10	17.3 ± 1.0	17.7 ± 0.8	241
"	100	20	22.5 ± 0.9	23.0 ± 1.0	406
"	100	30	26.3 ± 1.3	26.9 ± 1.2	471
JP-4 (LVP)	250	5	20.0 ± 0.9	20.3 ± 1.2	315
"	250	10	25.7 ± 0.8	26.2 ± 0.8	529
"	250	20	33.3 ± 0.6	32.7 ± 0.6	855
"	250	30	38.5 ± 0.5	37.7 ± 0.6	1140
JP-4 (LVP)	500	5	24.8 ± 0.6	23.8 ± 1.8	465
"	500	10	33.7 ± 1.1	31.0 ± 1.0	821
"	500	20	41.4 ± 0.1	37.7 ± 0.6	1226
"	500	30	42.9 ± 0.2	38.0 ± 1.0	1280
JP-4 (HVP)	10	5	6.2 ± 0.7	5.3 ± 0.6	26
"	10	10	8.2 ± 1.0	6.5 ± 0.9	42
"	10	20	10.9 ± 0.1	8.7 ± 1.5	75
"	10	30	12.0 ± 0.0	9.5 ± 1.3	90
JP-4 (HVP)	100	5	12.8 ± 0.8	10.5 ± 0.5	106
"	100	10	16.0 ± 1.0	14.5 ± 0.5	182
"	100	20	22.0 ± 1.0	19.8 ± 1.0	343
"	100	30	25.3 ± 1.5	22.0 ± 0.0	438
JP-4 (HVP)	250	5	17.3 ± 0.6	17.5 ± 0.5	238
"	250	10	21.0 ± 1.0	21.7 ± 1.5	357
"	250	20	29.3 ± 0.6	28.3 ± 0.6	653
"	250	30	33.0 ± 1.0	33.7 ± 2.1	873
JP-4 (HVP)	500	5	20.7 ± 3.8	20.0 ± 3.6	325
"	500	10	28.2 ± 3.3	25.7 ± 4.5	568
"	500	20	38.7 ± 1.2	30.7 ± 2.3	931
"	500	30	40.0 ± 1.7	33.0 ± 0.0	1037

TABLE 10 (continued)

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-5	10	5	4.6 ± 2.3	4.8 ± 2.5	17
"	10	10	6.7 ± 3.1	7.7 ± 4.0	40
"	10	20	11.1 ± 1.2	12.1 ± 2.4	106
"	10	30	14.5 ± 1.5	15.7 ± 2.0	178
JP-5	100	5	19.7 ± 1.5	6.5 ± 1.3	100
"	100	10	32.0 ± 0.0	9.4 ± 0.7	235
"	100	20	32.0 ± 0.0	15.3 ± 0.8	385
"	100	30	32.0 ± 0.0	17.5 ± 0.5	440
JP-8	10	5	5.7 ± 0.6	5.7 ± 0.6	26
"	10	10	8.8 ± 0.8	8.8 ± 0.8	61
"	10	20	12.3 ± 0.8	12.2 ± 0.6	118
"	10	30	15.2 ± 0.7	15.4 ± 0.5	183
JP-8	100	5	14.2 ± 0.8	9.7 ± 1.5	108
"	100	10	24.5 ± 0.5	18.0 ± 3.6	346
"	100	20	34.3 ± 1.2	20.0 ± 1.3	539
"	100	30	36.0 ± 0.0	24.0 ± 0.9	679
JP-8	250	5	31.2 ± 4.4	13.3 ± 3.5	326
"	250	10	35.7 ± 1.2	17.7 ± 1.5	495
"	250	20	36.2 ± 0.8	22.0 ± 3.6	625
"	250	30	36.5 ± 0.5	25.3 ± 0.6	726

TABLE 11. DISPERSION OF LEAKING JET FUELS ON ALCLAD SURFACE
AT 23°C (73°F). AIR FLOW RATE 6.1 m/sec.
ANGLE OF INCLINATION 10 DEGREES

Fuel	Fuel flow rate (μl/min)	Time (min)	Spot dimensions (cm)		Average spot area (cm ²)
			Average length	Average width	
JP-4 (LVP)	10	5	5.0 ± 0.6	5.2 ± 0.8	20
"	10	10	7.4 ± 0.2	7.6 ± 0.2	44
"	10	20	8.6 ± 0.5	9.3 ± 0.2	63
"	10	30	9.7 ± 0.3	10.3 ± 0.3	78
JP-4 (LVP)	100	5	12.7 ± 1.1	13.1 ± 0.9	130
"	100	10	18.2 ± 0.9	18.2 ± 0.5	261
"	100	20	23.8 ± 1.1	23.0 ± 1.0	430
"	100	30	27.1 ± 1.4	26.5 ± 0.9	563
JP-4 (LVP)	250	5	20.0 ± 4.0	19.0 ± 3.5	299
"	250	10	27.1 ± 2.4	24.7 ± 2.3	526
"	250	20	36.1 ± 1.8	32.3 ± 2.1	916
"	250	30	38.1 ± 0.5	35.0 ± 1.0	1047
JP-4 (LVP)	500	5	26.2 ± 1.7	23.3 ± 2.3	481
"	500	10	35.9 ± 0.1	29.7 ± 0.6	837
"	500	20	38.5 ± 0.8	34.7 ± 1.5	1049
"	500	30	40.8 ± 1.0	36.0 ± 1.0	1154
JP-4 (HVP)	10	5	5.4 ± 0.5	5.3 ± 0.8	22
"	10	10	7.1 ± 0.6	7.7 ± 0.6	43
"	10	20	8.5 ± 0.5	9.8 ± 0.3	66
"	10	30	9.4 ± 0.8	10.8 ± 0.3	80
JP-4 (HVP)	100	5	12.3 ± 1.8	12.8 ± 1.1	124
"	100	10	16.3 ± 1.5	17.0 ± 1.0	218
"	100	20	22.0 ± 2.7	23.7 ± 1.2	409
"	100	30	26.2 ± 1.8	28.0 ± 2.7	576
JP-4 (HVP)	250	5	17.3 ± 1.2	17.6 ± 0.5	239
"	250	10	23.7 ± 0.6	23.0 ± 1.0	428
"	250	20	31.0 ± 1.0	31.3 ± 1.2	763
"	250	30	38.0 ± 1.0	35.0 ± 1.7	1045
JP-4 (HVP)	500	5	25.5 ± 4.8	21.7 ± 1.5	434
"	500	10	35.0 ± 0.0	29.0 ± 1.7	797
"	500	20	37.8 ± 0.3	33.3 ± 2.1	988
"	500	30	39.7 ± 0.6	37.7 ± 0.6	1174

TABLE 11 (continued)

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-5	10	5	7.5 ± 0.5	5.7 ± 0.6	33
"	10	10	10.0 ± 1.3	8.5 ± 1.3	67
"	10	20	15.4 ± 1.4	11.5 ± 0.5	139
"	10	30	19.1 ± 0.9	14.7 ± 0.6	220
JP-5	100	5	23.0 ± 1.0	5.3 ± 0.6	90
"	100	10	32.0 ± 0.0	8.9 ± 0.8	223
"	100	20	32.0 ± 0.0	13.8 ± 1.0	348
"	100	30	32.0 ± 0.0	16.0 ± 1.0	402
JP-8	10	5	6.5 ± 0.9	6.5 ± 0.9	33
"	10	10	10.3 ± 0.3	9.3 ± 0.6	76
"	10	20	14.2 ± 0.8	13.3 ± 0.6	148
"	10	30	17.4 ± 0.8	16.8 ± 0.3	230
JP-8	100	5	19.5 ± 1.5	10.7 ± 2.9	163
"	100	10	32.3 ± 1.2	15.7 ± 1.5	398
"	100	20	34.2 ± 0.3	18.8 ± 0.3	505
"	100	30	34.8 ± 1.0	23.3 ± 0.6	638

TABLE 12. DISPERSION OF LEAKING JET FUELS ON ALCLAD SURFACE
AT 23°C (73°F). QUIESCENT ATMOSPHERE. ANGLE
OF INCLINATION 0 DEGREE

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-4 (HVP)	5	5	4.4 ± 0.5	4.4 ± 0.5	15
"	5	10	5.2 ± 0.3	5.4 ± 0.3	22
"	5	20	7.0 ± 0.0	7.5 ± 0.0	41
"	5	30	8.1 ± 0.4	8.8 ± 0.6	56
JP-4 (HVP)	10	5	7.2 ± 0.2	7.2 ± 0.2	41
"	10	10	8.3 ± 0.3	8.2 ± 0.3	54
"	10	20	10.4 ± 0.2	10.6 ± 0.4	86
"	10	30	11.7 ± 0.3	11.9 ± 0.2	109
JP-4 (HVP)	25	5	9.0 ± 0.0	9.0 ± 0.0	64
"	25	10	11.1 ± 0.2	11.2 ± 0.2	98
"	25	20	14.2 ± 0.3	14.2 ± 0.3	158
"	25	30	15.0 ± 1.0	16.2 ± 0.3	191
JP-4 (HVP)	50	5	10.8 ± 0.3	11.0 ± 0.0	94
"	50	10	14.0 ± 0.0	15.0 ± 0.0	165
"	50	20	16.7 ± 1.2	18.3 ± 0.6	240
"	50	30	18.5 ± 1.8	22.0 ± 1.0	320
JP-4 (HVP)	500	5	23.8 ± 0.3	24.5 ± 0.9	459
"	500	10	30.0 ± 1.0	31.3 ± 1.2	738
"	500	20	36.7 ± 0.6	40.3 ± 1.5	1162
"	500	30	42.7 ± 0.6	42.3 ± 1.2	1419
JP-4 (HVP)	1000	5	23.7 ± 0.8	24.3 ± 0.6	452
"	1000	10	29.3 ± 1.3	30.7 ± 0.3	707
"	1000	20	36.3 ± 2.1	39.0 ± 1.0	1113
"	1000	30	41.0 ± 1.7	44.0 ± 1.7	1417
JP-5	10	5	6.0 ± 0.1	6.0 ± 0.1	30
"	10	10	9.0 ± 0.3	9.0 ± 0.3	63
"	10	20	12.8 ± 0.4	12.9 ± 0.6	129
"	10	30	15.4 ± 0.2	15.4 ± 0.2	185
JP-5	25	5	6.1 ± 0.5	6.0 ± 0.7	29
"	25	10	8.9 ± 0.5	12.1 ± 3.4	85
"	25	20	13.6 ± 0.2	22.7 ± 1.2	242
"	25	30	16.8 ± 0.8	26.2 ± 1.3	359

(continued)

TABLE 12 (continued)

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-5	50	5	6.2 ± 0.4	12.7 ± 1.2	62
"	50	10	9.1 ± 0.5	20.2 ± 4.1	144
"	50	20	13.9 ± 1.8	27.2 ± 0.8	297
"	50	30	16.2 ± 0.3	28.7 ± 1.5	366
JP-8	5	5	3.8 ± 1.4	3.0 ± 1.4	12
"	5	10	6.6 ± 1.5	6.7 ± 1.5	34
"	5	20	10.1 ± 0.8	8.1 ± 1.2	65
"	5	30	12.2 ± 0.7	12.3 ± 0.6	118
JP-8	10	5	7.5 ± 0.5	7.5 ± 0.5	44
"	10	10	10.0 ± 0.0	10.0 ± 0.0	79
"	10	20	13.7 ± 0.6	14.0 ± 0.0	150
"	10	30	16.5 ± 0.5	17.0 ± 0.0	220
JP-8	25	5	8.3 ± 0.6	8.3 ± 0.6	54
"	25	10	12.2 ± 0.4	12.2 ± 0.4	117
"	25	20	16.5 ± 0.0	16.5 ± 0.0	214
"	25	30	19.9 ± 0.8	20.1 ± 0.5	314
JP-8	50	5	8.2 ± 1.3	9.2 ± 1.9	59
"	50	10	12.2 ± 1.1	13.3 ± 1.6	128
"	50	20	18.2 ± 1.4	20.4 ± 1.6	292
"	50	30	22.5 ± 1.3	24.5 ± 1.3	433
JP-8	100	5	8.2 ± 0.3	21.3 ± 5.7	137
"	100	10	10.3 ± 2.4	26.8 ± 1.6	218
"	100	20	18.8 ± 0.8	30.3 ± 1.2	449
"	100	30	23.7 ± 0.6	32.0 ± 0.0	595
JP-8	250	5	6.3 ± 0.6	6.8 ± 0.8	34
"	250	10	8.7 ± 0.6	9.0 ± 1.0	61
"	250	20	12.2 ± 1.2	12.7 ± 1.2	121
"	250	30	13.5 ± 0.9	12.7 ± 1.2	135
JP-4 (HVP)/ JP-8 (10/90)	50	5	7.6 ± 3.1	7.7 ± 3.3	46
"	50	10	16.5 ± 4.5	13.7 ± 2.9	177
"	50	20	19.5 ± 3.5	19.2 ± 2.6	294
"	50	30	22.7 ± 5.4	22.7 ± 4.5	404

(continued)

TABLE 12 (continued)

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-4 (HVP)/					
JP-8 (10/90)	100	5	9.3 ± 1.2	10.3 ± 0.3	76
"	100	10	18.5 ± 1.4	12.3 ± 2.5	179
"	100	20	27.7 ± 0.6	20.3 ± 1.0	442
"	100	30	31.0 ± 0.0	23.3 ± 0.6	568
AvGas ^a	100	5	5.2	5.5	22
"	100	10	5.6	6.5	29
"	100	20	5.6	6.6	29
"	100	30	6.0	6.8	32
AvGas	250	5	9.0	9.4	66
"	250	10	9.0	10.0	71
"	250	20	9.5	10.5	78
"	250	30	9.8	10.5	81
AvGas	500	5	13.0	15.0	153
"	500	10	14.0	15.0	165
"	500	20	14.5	16.0	182
"	500	30	14.5	17.0	194
AvGas	1000	5	17.5	19.0	261
"	1000	10	18.0	19.0	269
"	1000	20	19.0	20.5	306
"	1000	30	20.0	22.0	346
AvGas	1400	5	21.5	22.0	371
"	1400	10	23.0	24.0	433
"	1400	20	23.5	26.0	480
"	1400	30	24.0	26.5	499

^aSurface-dispersion data for AvGas are based upon a single experiment under each test condition.

TABLE 13. DISPERSION OF LEAKING JET FUELS ON ALCLAD SURFACE
AT 23°C (73°F). QUIESCENT ATMOSPHERE. ANGLE
OF INCLINATION 90 DEGREES

Fuel	Fuel flow rate ($\mu\ell/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-4 (HVP)	10	5	7.1 ± 0.2	6.3 ± 0.6	36
"	10	10	8.8 ± 0.3	8.3 ± 0.3	57
"	10	20	11.3 ± 0.5	10.2 ± 0.3	90
"	10	30	13.0 ± 0.5	11.0 ± 0.5	112
JP-4 (HVP)	50	5	12.3 ± 0.6	10.7 ± 0.8	103
"	50	10	16.7 ± 0.8	13.9 ± 0.8	182
"	50	20	22.9 ± 1.8	15.7 ± 1.8	283
"	50	30	26.4 ± 0.7	18.2 ± 1.6	378
JP-8	5	5	7.7 ± 0.6	4.6 ± 0.4	28
"	5	10	10.9 ± 1.2	6.1 ± 0.6	53
"	5	10	17.0 ± 0.6	8.1 ± 0.5	108
"	5	30	18.6 ± 1.2	9.5 ± 0.1	139
JP-8	10	5	9.6 ± 1.7	4.7 ± 0.4	35
"	10	10	15.6 ± 1.2	6.6 ± 0.4	81
"	10	20	24.2 ± 0.5	8.7 ± 0.6	166

TABLE 14. DISPERSION OF LEAKING JET FUELS ON ALCLAD SURFACE
AT 32°C (90°F). QUIESCENT ATMOSPHERE. ANGLE
OF INCLINATION 0 DEGREE

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-4 (HVP)	50	5	7.4 ± 1.0	10.5 ± 1.3	61
"	50	10	9.7 ± 0.3	14.8 ± 1.1	112
"	50	20	11.6 ± 0.4	19.1 ± 0.8	174
"	50	30	13.3 ± 1.5	21.8 ± 1.9	227
JP-4 (HVP)	100	5	9.8 ± 0.9	14.3 ± 2.5	111
"	100	10	12.0 ± 1.8	19.4 ± 1.4	183
"	100	20	17.5 ± 1.3	25.4 ± 1.0	349
"	100	30	19.7 ± 0.8	30.0 ± 0.5	464
JP-5	10	5	5.3 ± 0.3	5.7 ± 0.6	24
"	10	10	8.2 ± 0.3	9.0 ± 1.0	58
"	10	20	11.8 ± 0.5	11.8 ± 1.6	105
"	10	30	14.0 ± 0.5	17.2 ± 1.0	189
JP-5	25	5	6.7 ± 0.8	7.2 ± 0.9	38
"	25	10	9.8 ± 1.3	11.1 ± 1.0	86
"	25	20	14.2 ± 1.8	16.2 ± 1.1	180
"	25	30	17.5 ± 0.9	19.1 ± 0.5	262
JP-5	50	5	4.3 ± 0.6	8.7 ± 0.6	30
"	50	10	9.3 ± 1.0	22.8 ± 1.4	167
"	50	20	15.5 ± 1.8	25.0 ± 1.5	304
"	50	30	18.3 ± 0.6	28.5 ± 0.5	413
JP-8	50	5	7.6 ± 2.3	8.5 ± 2.3	51
"	50	10	14.1 ± 1.6	15.0 ± 1.7	167
"	50	20	20.4 ± 0.8	22.0 ± 1.1	353
"	50	30	24.2 ± 0.3	26.3 ± 1.0	500
JP-8	100	5	8.8 ± 0.8	18.5 ± 3.0	128
"	100	10	15.7 ± 1.0	23.7 ± 2.5	292
"	100	20	22.5 ± 1.5	28.8 ± 0.6	509
"	100	30	26.3 ± 1.8	31.0 ± 0.0	641

TABLE 15. DISPERSION OF LEAKING JET FUELS ON ALCLAD SURFACE AT 23°C (73°F). EXTENDED MEASUREMENT TIME AND LONGER FLOW DISTANCE EXPERIMENTS. AIR FLOW RATE 6.1 m/sec. ANGLE OF INCLINATION 10 DEGREES

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-4 (HVP)	500	5	23.0 ± 2.0	22.8 ± 2.3	412
"	500	10	30.5 ± 2.2	27.7 ± 1.3	663
"	500	20	40.7 ± 1.5	33.0 ± 1.0	1054
"	500	30	48.3 ± 1.5	36.3 ± 1.5	1379
JP-5	10	5	4.5 ± 0.4	4.5 ± 0.4	16
"	10	10	7.7 ± 0.4	7.7 ± 0.4	47
"	10	20	11.3 ± 0.4	11.3 ± 0.2	100
"	10	30	14.3 ± 0.4	14.5 ± 0.0	162
"	10	60	20.8 ± 0.4	20.5 ± 0.0	326
"	10	120	31.8 ± 0.4	25.8 ± 2.5	502
"	10	180	31.8 ± 0.4	28.3 ± 3.2	705
JP-8	100	5	17.7 ± 3.5	10.0 ± 3.0	139
"	100	10	29.3 ± 2.1	16.8 ± 3.9	388
"	100	20	39.7 ± 5.9	19.7 ± 2.3	613
"	100	30	50.7 ± 0.6	22.3 ± 1.2	889

TABLE 16. DISPERSION OF LEAKING JET FUELS ON PAINTED ALCLAD SURFACE AT 23°C (73°F). AIR FLOW RATE 6.1 m/sec. ANGLE OF INCLINATION 0 DEGREE

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-4 (LVP)	100	5	15.0 ± 0.0	15.0 ± 0.0	177
"	100	10	19.0 ± 0.0	19.0 ± 0.0	284
"	100	20	23.3 ± 0.6	21.7 ± 0.6	397
"	100	30	25.7 ± 1.5	22.3 ± 0.6	450
JP-4 (LVP)	250	5	18.7 ± 2.3	18.7 ± 2.3	274
"	250	10	25.0 ± 1.0	25.0 ± 1.0	491
"	250	20	32.0 ± 0.0	31.7 ± 0.6	796
"	250	30	36.0 ± 1.0	34.0 ± 1.0	961
JP-4 (LVP)	500	5	23.3 ± 1.2	23.3 ± 1.2	428
"	500	10	29.5 ± 0.9	29.8 ± 0.8	691
"	500	20	38.7 ± 1.2	32.0 ± 1.7	972
"	500	30	42.3 ± 0.6	33.7 ± 1.2	1119
JP-4 (HVP)	100	5	14.0 ± 1.0	14.0 ± 1.0	154
"	100	10	18.6 ± 0.6	18.8 ± 1.0	275
"	100	20	23.3 ± 0.5	23.2 ± 0.4	425
"	100	30	26.3 ± 0.6	26.3 ± 0.6	545
JP-4 (HVP)	250	5	17.4 ± 1.5	17.4 ± 1.5	240
"	250	10	24.0 ± 1.7	24.0 ± 1.7	452
"	250	20	30.7 ± 1.3	30.7 ± 1.3	739
"	250	30	33.7 ± 0.6	33.7 ± 0.6	890
JP-4 (HVP)	500	5	23.8 ± 1.8	23.7 ± 1.6	444
"	500	10	30.5 ± 1.5	30.2 ± 1.0	723
"	500	20	38.3 ± 2.5	35.0 ± 3.5	1054
"	500	30	43.7 ± 1.5	37.7 ± 3.8	1292
JP-5	10	5	6.0 ± 0.0	6.0 ± 0.0	28
"	10	10	9.3 ± 0.9	9.4 ± 0.8	68
"	10	20	13.6 ± 1.4	13.7 ± 1.4	146
"	10	30	16.4 ± 0.5	16.5 ± 0.5	212
JP-5	25	5	6.0 ± 0.0	6.0 ± 0.0	28
"	25	10	8.5 ± 0.9	8.5 ± 0.9	57
"	25	20	9.9 ± 1.0	9.9 ± 1.0	77
"	25	30	11.0 ± 0.9	11.1 ± 0.8	96

TABLE 16 (continued)

Fuel	Fuel flow rate ($\mu\text{l}/\text{min}$)	Time (min)	Spot dimensions (cm)		Average spot area (cm^2)
			Average length	Average width	
JP-5	50	5	5.0 ± 0.4	5.0 ± 0.4	19
"	50	10	6.0 ± 0.0	5.8 ± 0.1	27
"	50	20	8.5 ± 0.5	8.5 ± 0.5	57
"	50	30	9.9 ± 0.3	9.9 ± 0.3	77
JP-5	100	5	4.2 ± 0.3	4.2 ± 0.3	14
"	100	10	6.0 ± 0.0	6.0 ± 0.0	28
"	100	20	8.1 ± 0.2	8.1 ± 0.2	52
"	100	30	9.0 ± 0.1	9.2 ± 0.4	65
JP-8	25	5	9.5 ± 0.5	9.5 ± 0.5	71
"	25	10	12.8 ± 0.8	12.8 ± 0.8	129
"	25	20	17.7 ± 0.8	17.7 ± 0.8	246
"	25	30	21.0 ± 0.9	21.0 ± 0.9	346
JP-8	50	5	8.2 ± 0.8	8.2 ± 0.8	52
"	50	10	12.1 ± 1.4	13.1 ± 3.0	124
"	50	20	16.2 ± 2.0	19.2 ± 4.2	245
"	50	30	19.0 ± 2.0	26.9 ± 2.0	401
JP-8	100	5	6.5 ± 0.5	6.6 ± 0.4	34
"	100	10	8.8 ± 0.3	8.8 ± 0.3	61
"	100	20	11.7 ± 0.3	11.7 ± 0.3	107
"	100	30	13.8 ± 0.3	13.8 ± 0.3	150

TABLE 17. DISPERSION OF LEAKING JET FUELS ON UNCLAD ALUMINUM
ALLOY SURFACE AT 23°C (73°F). AIR FLOW RATE
6.1 m/sec. ANGLE OF INCLINATION 0 DEGREE

Fuel	Fuel flow rate (μl/min)	Time (min)	Spot dimensions (cm)		Average spot area (cm ²)
			Average length	Average width	
JP-4 (LVP)	100	5	14.8 ± 0.6	15.2 ± 0.6	177
"	100	10	18.7 ± 0.6	19.0 ± 0.9	279
"	100	20	22.7 ± 0.6	23.7 ± 0.6	421
"	100	30	24.8 ± 0.5	26.5 ± 0.5	516
JP-4 (HVP)	100	5	13.8 ± 0.8	14.1 ± 0.6	153
"	100	10	17.7 ± 0.3	18.7 ± 0.6	259
"	100	20	22.6 ± 0.5	23.2 ± 0.3	411
"	100	30	25.8 ± 0.3	26.3 ± 0.3	534
JP-5	100	5	4.8 ± 0.3	5.0 ± 0.5	19
"	100	10	6.0 ± 0.5	6.5 ± 0.5	31
"	100	20	7.5 ± 0.5	7.9 ± 0.7	47
"	100	30	8.7 ± 0.6	8.8 ± 0.7	60
JP-8	100	5	10.2 ± 0.4	14.7 ± 0.6	117
"	100	10	15.5 ± 2.2	20.3 ± 1.2	247
"	100	20	20.2 ± 0.3	23.2 ± 2.8	367
"	100	30	23.7 ± 0.6	27.5 ± 2.3	511

C. Leakage Conditions That Caused Dripping of Fuels

TABLE 18. LEAKAGE CONDITIONS THAT CAUSED DRIPPING OF FUELS^{a, b}

Angle (deg)	Temperature		3.3°C (38°F)				23°C (73°F)								32°C (90°F)			
	Fuel	Air flow rate ($\mu\text{l}/\text{min.}$)	None				6.1 ml/sec (20 ft/sec)								None			
			JP-4 (HVP)	JP-5	JP-8	Fluid	JP-4 (HVP)	JP-4 (HVP)	JP-5	JP-8	JP-8 (HVP)	JP-8 (HVP)	JP-5	JP-5	JP-5	JP-5	JP-5	JP-8
0		1																
0		5																
0		10																
0		25																
0		50																
0		100																
0		250																
0		500																
0		1000																
0		1400																
5		10																
5		100																
5		250																
5		500																
10		10																
10		100																
10		250																
10		500																
90		5																
90		10																
90		50																

- ^a Experiments during which dripping of the fluids occurred are encircled
^b Measurement time was 30 minutes for all experiments shown in this table
^c High vapor pressure sample
^d Low vapor pressure sample
^e JP-4/JP-8 in 10/90 volume ratio
^f Single experiments were conducted with AvGas at each flow rate. Triplicate experiments were conducted with the other fluids under all experimental conditions.

TABLE 18 (continued) a, b

Angle (deg)	Panel		Alclad				Unclad aluminum alloy				Polyurethane latex-coated surface			
	Fuel flow rate ($\mu\text{L}/\text{min.}$)	Fluid	JP-4 (LVP) c	JP-4 d (HVP)	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8
0	1													
0	5													
0	10													
0	25													
0	50													
0	100													
0	250													
0	500													
0	1000													
5	10													
5	100													
5	250													
5	500													
5	10													
5	100													
5	250													
5	500													

a. Experiments during which dripping of the fluids occurred are encircled.

b. Measurement time was 30 minutes for all experiments shown in this table.

c. Low vapor pressure sample.

d. High vapor pressure sample.

D. Sustained Burning of Leaking Fuels

TABLE 19. RESULTS OF TESTS FOR SUSTAINED BURNING AT TEMPERATURES FROM 3.3°C TO 98°C (38°F TO 208°F). QUIESCENT ATMOSPHERE. ANGLE OF INCLINATION 0 DEGREE

Temperature		Fuel flow rate (μl/min)	Fuel burning characteristics						Avg. Gas
(°C)	(°F)		JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)/ JP-8 (10/90)	JP-4 (HVP) / JP-8 (50/50)	
3.3	38	500	E ^a	E	E	E			
		600		E					
		700		SB ^b					
		800		SB					
		900		SB					
		1000	F	SB	E	E			
		1500	E		E	E			
		2000	E		E	E			
		2500	E		E	E			
		3000	SB		E	E			
		3500	SB		E	E			
		4000	SB		E	E			
		4500	SB		E	E			
		5000	SB		E	E			
		5500		E	E			E	
		6000			E	E		SB	
		6500			E	E			
		7000			E	E			
		7500			E	E			
		8000			E	E			
10	50	4500						E	
		5000						SB	
24	75	100		E					
		200		E					
		300		E					
		400		SB					
		500	E	SB	E	E			
		600	SB	SB					
		700		SB					
		1000	SB		E	E			
		1500			E	E			
		2000	SB		E	E		E	
		2500	SB		E	E		SB	
		3000			E	E		SB	
		3500	SB		E	E			
		4000			E	E			
		4500			E	E			
		5000	SB		E	E			
		5500			E	E			
		6000			E	E			
		6500			E	E			
		7000			E	E			
		7500			E	E			
		8000			E	E			

(continued)

^aExtinguished upon removal of the ignition source.

^bSustained burning.

TABLE 19 (continued)

Temperature (°C) (°F)		Fuel flow rate (μl/min)	Fuel burning characteristics						Avsa
			JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)/ JP-8 (10/90)	JP-4 (HVP)/ JP-8 (50/50)	
28	82	200							E
		300							SE
		400							SB
38	100	300	E	E					
		400	SB	SB					
		500	SB						
		600	SB						
		1000						E	
		1250						SB	
		1500						JB	
		1750						SB	
		2000						SB	
		2500						SB	
		3000						SB	
		8000			E	E			
49	120	9000				E			
52	125	1000						E	
		1250						SB	
		1500						SB	
		1750						SB	
		2000						SB	
		2500						SB	
60	140	3000						SB	
		2000					E		
		2500					E		
		3000					E		
		3500					E		
59	139	4000					E		
		4500					E		
		5000					E		
		5500					E		
		6000					E		
		6500					E		
		7000					E		
62	144	9000				E	E		
		2000					E		
		2500					E		
		3000					E		
		3500					E		
		4000					E		

continued

TABLE 19 (continued)

Temperature (°C)	Temperature (°F)	Fuel flow rate (μl/min)	Fuel burning characteristics					JP-8 (50/50)	JP-8
			JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)/ JP-8 (10/90)		
62	144	4500						E	
		5000						E	
		5500						F	
		6000						E	
		6500						E	
		7000						E	
		7500						E	
		8000						E	
		8500						E	
		9000						E	
66	150	900							E
		1000			E				SB
		1250							SB
		1500							SB
		1750							SB
		2000							SB
		2500					E		SB
		3000					SB		SB
		8000			E	E			
69	156	9000			E				
71	159	2500					E		
		3000					SB		
72	162	9000			E	E			
73	163	100	E	E					
		200	SB	SB					
		300	SB	SB					
		400	SB	SB					
		1500				E			
		2000				E			
		2500				E			
		3000				E			
		3500				E			
		4000				E			
76	169	4500				SB			
		8000				SB			
		1500					E		
		2000					E		
		2500					SB		
		9000			E				

TABLE 19 (continued)

Temperature (°C) (°F)		Fuel flow rate (μl/min)	Fuel burning characteristics						AvGas
			JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)/ JP-8 (10/90)	JP-4 (HVP)/ JP-8 (50/50)	
77	170	2000				E			
		3000				SB			
		4000				SB			
78	172	9000			E				
79	175	600						E	
		700						SB	
		800						SB	
		900						SB	
		1000						SB	
		1250						SB	
		1500						SB	
		1750						SB	
		2000						SB	
82	180	1500					E		
		2000				E	SB		
		2500				SB			
		3000				SB			
83	181	9000			E				
86	187	9000			E				
88	190	700					E		
		1000					E		
		1500				E	SB		
		2000				SB			
		2500				SB	SB		
92	197	500					E		
		600					SB		
		700					SB		
		800					SB		
		900					SB		
		1000					SB		

(continued)

TABLE 19 (continued)

Temperature (°C) (°F)		Fuel flow rate (μl/min)	Fuel burning characteristics						AvGas
			JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)/ JP-8 (10/90)	JP-4 (HVP)/ JP-8 (50/50)	
93	200	1500				E			
		2000				SB			
		2500				SB			
		3000				SB			
98	208	500					E		
		700					E		
		800					SB		
		1000					SB		
		8000			E				
		8500			E				
		9000			SB				

TABLE 20. MINIMUM FLOW RATES FOR SUSTAINED BURNING AT TEMPERATURES FROM 33°C TO 98°C (38°F TO 208°F). QUIESCENT ATMOSPHERE. ANGLE OF INCLINATION 0 DEGREE

Temperature (°C) (°F)		Flow rate (μl/min)						AvGas
		JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)/ JP-8 (10/90)	JP-4 (HVP)/ JP-8 (50/50)	
3.3	38	3000	700				6000	
10	50						5000	
24	75	600	400				2500	
28	82							300
38	100	400	400				1250	
52	125						1250	
66	150					3000	1000	
71	159					3000		
73	163	200	200		4500			
76	169					2500		
77	170				3000			
79	175						700	
82	180				2500	2000		
88	190				2000	1500		
92	197					600		
93	200				2000			
98	208			9000				

TABLE 21. IGNITABILITY OF DISPERSED FUELS, FLOWING
AT SELECTED RATES, ON ALCLAD SURFACE^a

Fuel	Fuel flow rate (μl/min)	Temperature		Fuel flow time (min) ^b	Spot dimensions (cm)		Remarks
		°C	°F		Length	Width	
JP-4 (LVP)	500	23	73	5	25.0	25.0	Flames flashed over the surface. No sustained burning.
	600	23	73	5	27.5	27.5	Flames initially flashed over the surface. Sustained burning.
JP-4 (HVP)	100	23	73	5	14.0	14.0	No sustained burning. The torch flame dried the surface.
	200	23	73	5	18.0	18.0	No sustained burning. The torch flame dried the surface.
	300	23	73	5	21.0	21.0	No sustained burning. The torch flame dried the surface.
	400	23	73	5	23.0	23.0	Sustained burning with a small flame.
	500	23	73	5	25.0	25.0	Sustained burning with a small flame.
JP-4 (HVP)	100	23	73	10	19.0	19.0	No sustained burning. The torch flame dried the surface.
	200	23	73	10	23.5	23.5	No sustained burning. The torch flame dried the surface.
	300	23	73	10	26.5	26.5	Sustained burning with a small flame.
	400	23	73	10	30.5	30.5	Sustained burning with a small flame.
JP-8	2750	82	180	1	9	23	Ignition and transitory burning; no sustained burning.
	2750	82	180	3	17	24	Ignition and transitory burning; no sustained burning.
	3000	82	180	1	16	22	Sustained burning with a small flame.
	3000	82	180	3	17	24	Sustained burning with a small flame.

^aSingle experiments were conducted under each combination of selected conditions, with the panel mounted at 0° angle of inclination.

^bFlow time prior to exposure of the dispersing fuel to the flame of a propane torch.

APPENDIX II

GRAPHICAL PRESENTATION OF RESULTS

A. Properties of Fuels

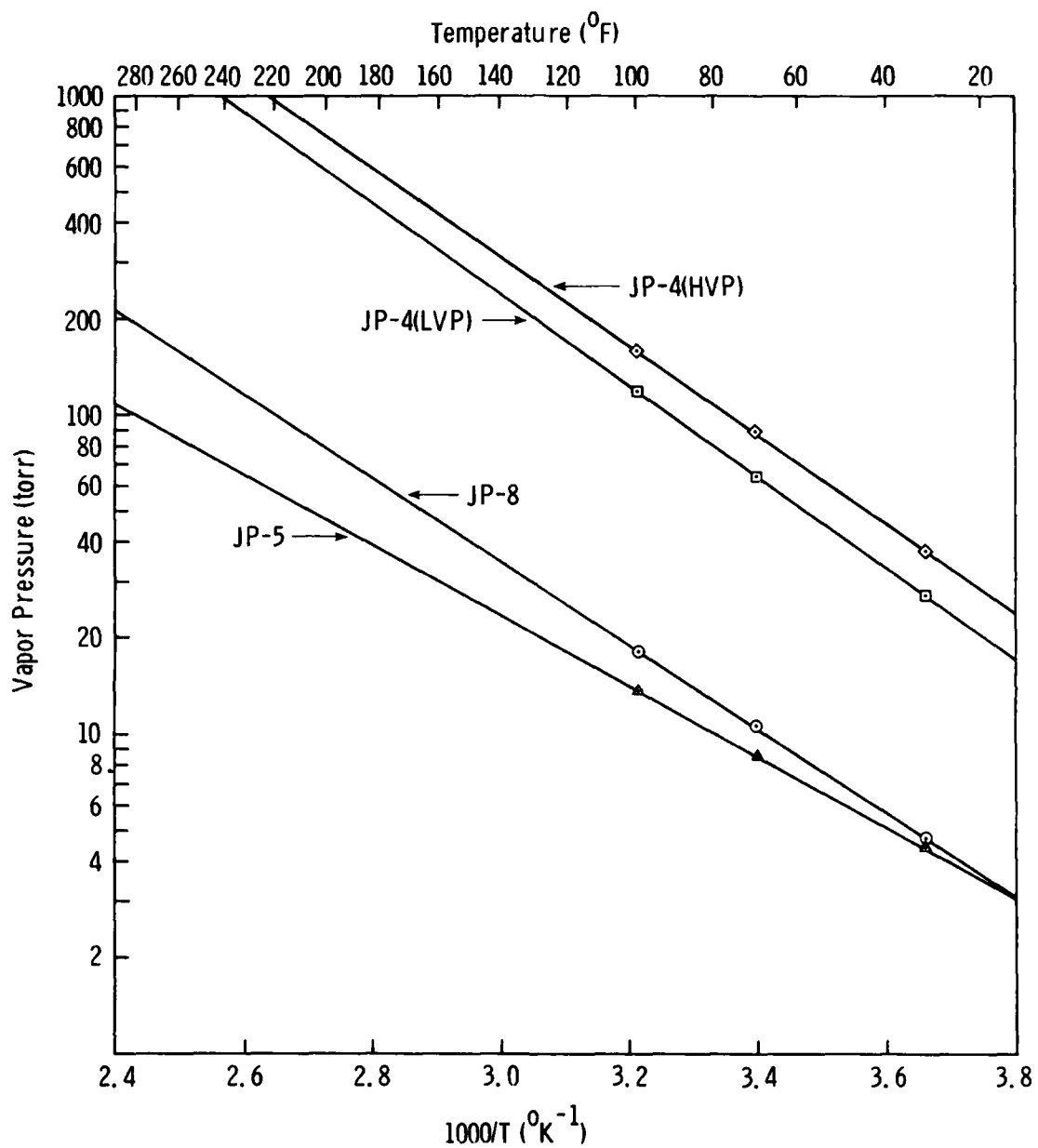


Figure 15. Vapor pressures of jet fuels.

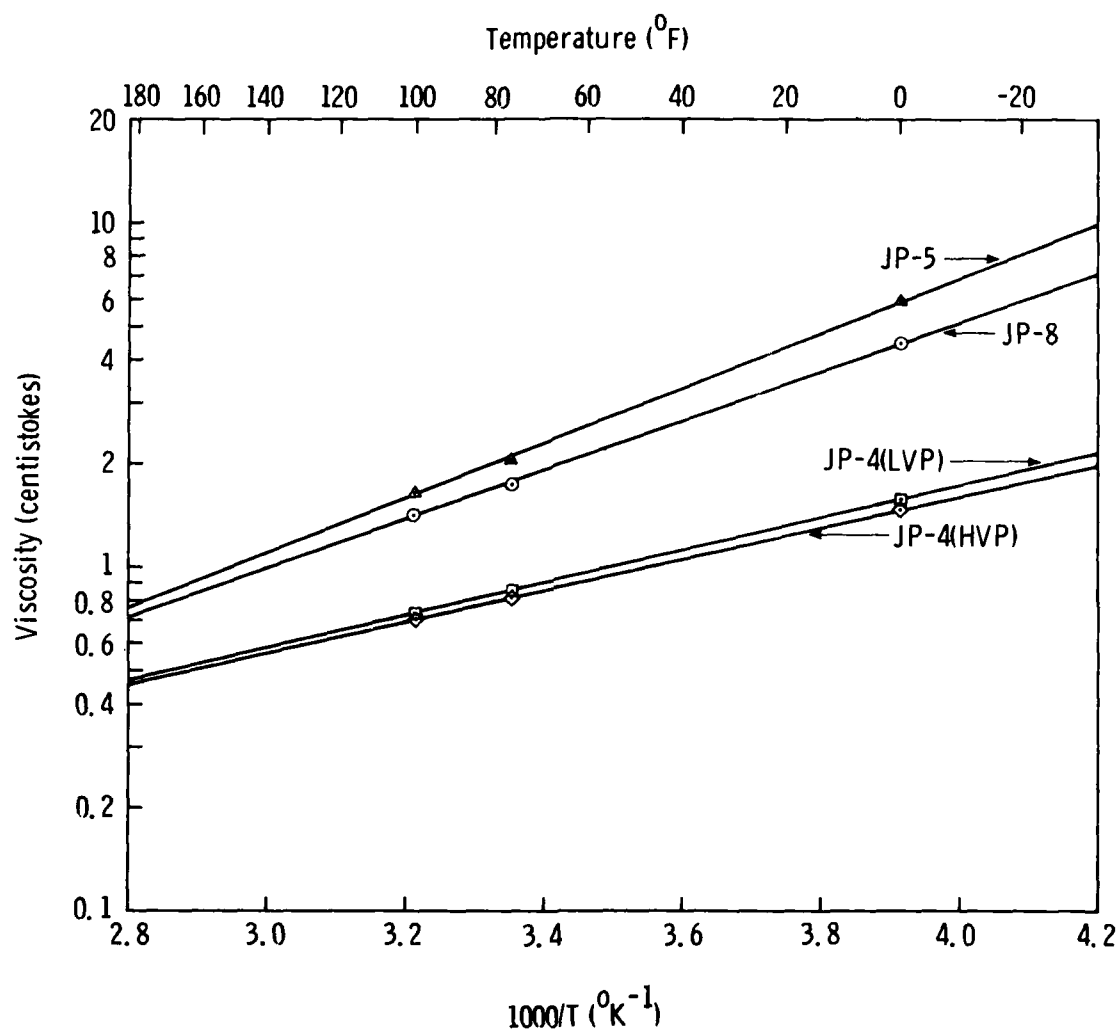


Figure 16. Viscosities of jet fuels.

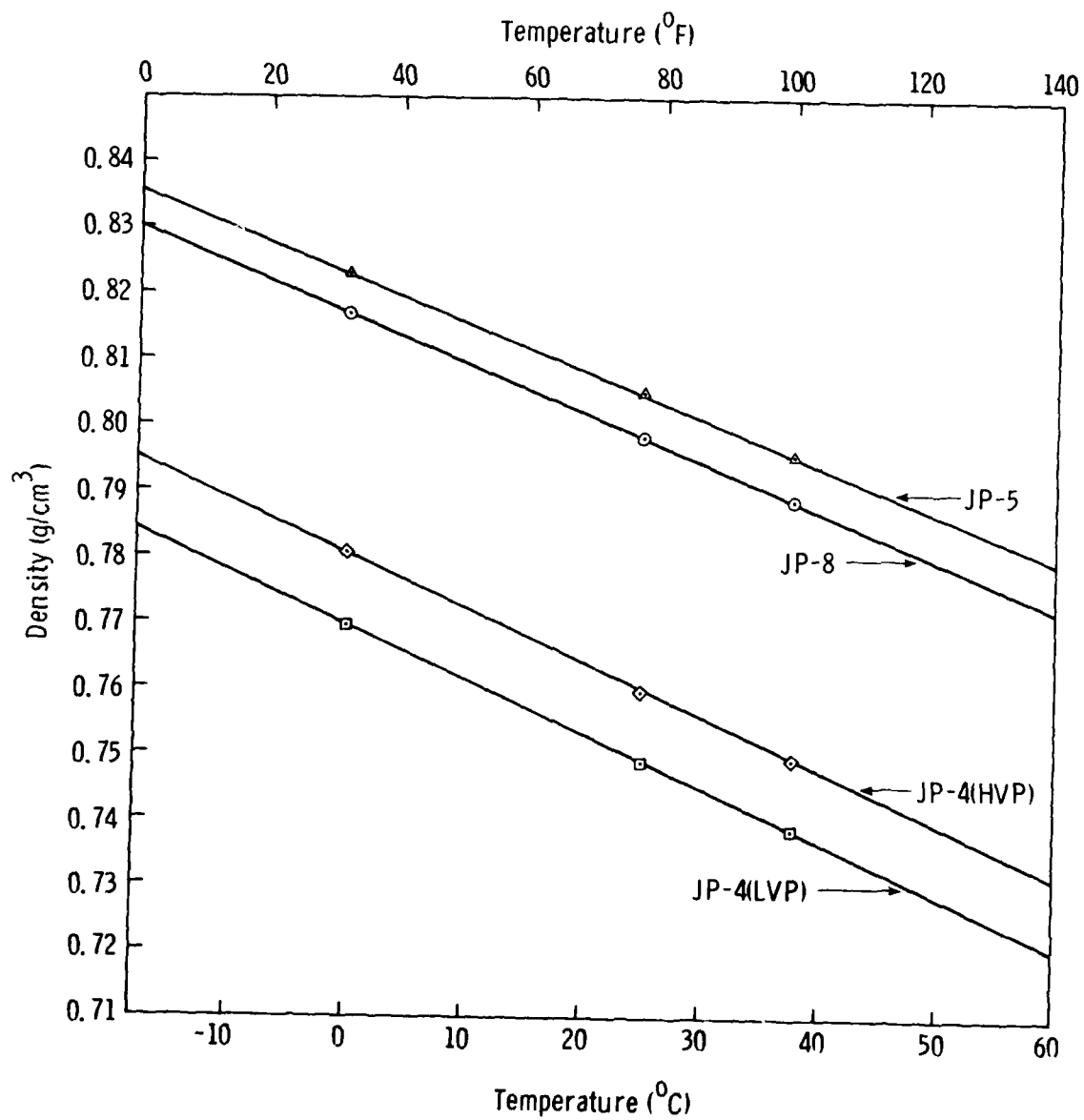


Figure 17. Densities of jet fuels.

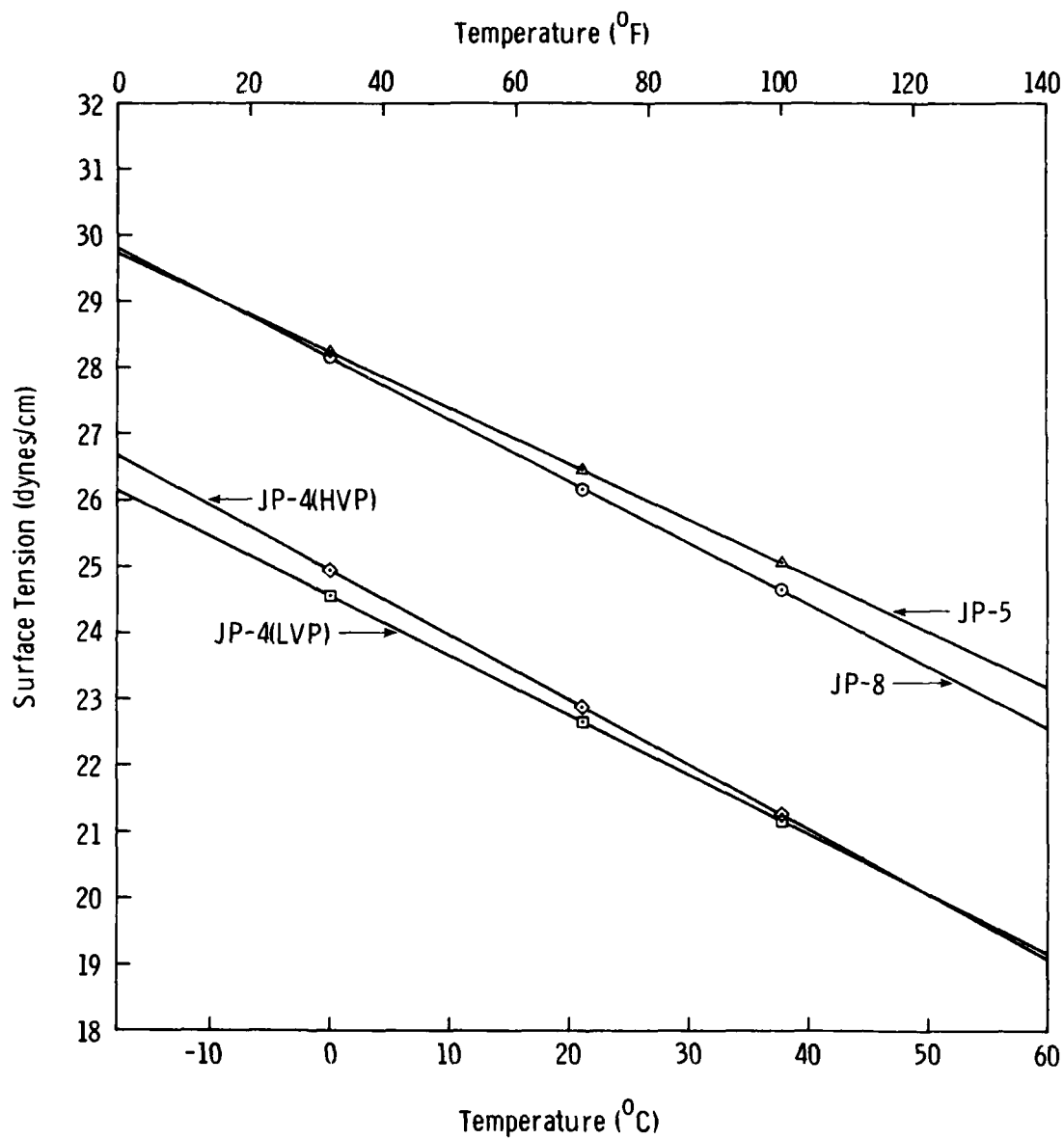


Figure 18. Surface tensions of jet fuels.

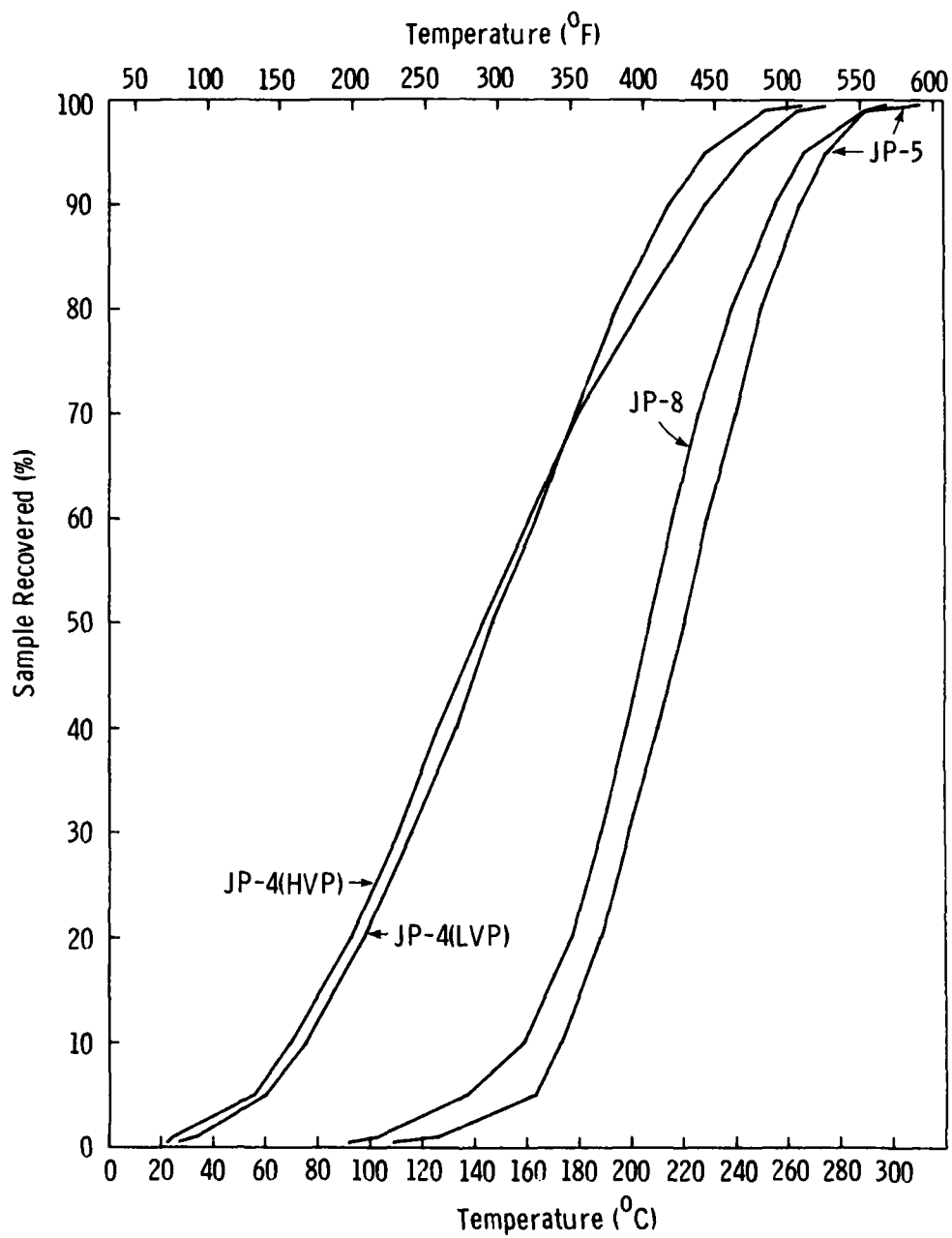


Figure 19. Simulated distillation curves of jet fuels.

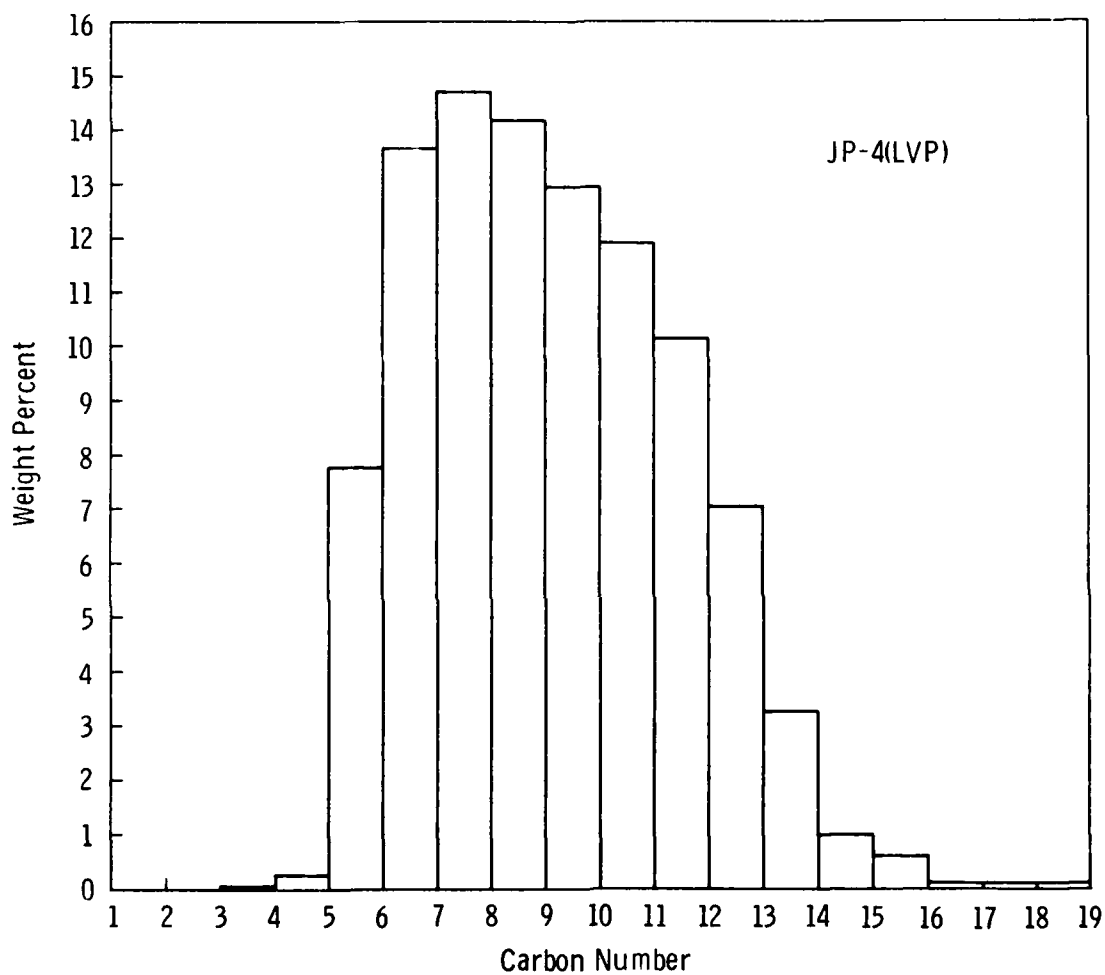


Figure 20. Distribution of hydrocarbons in JP-4(LVP), determined by simulated distillation.

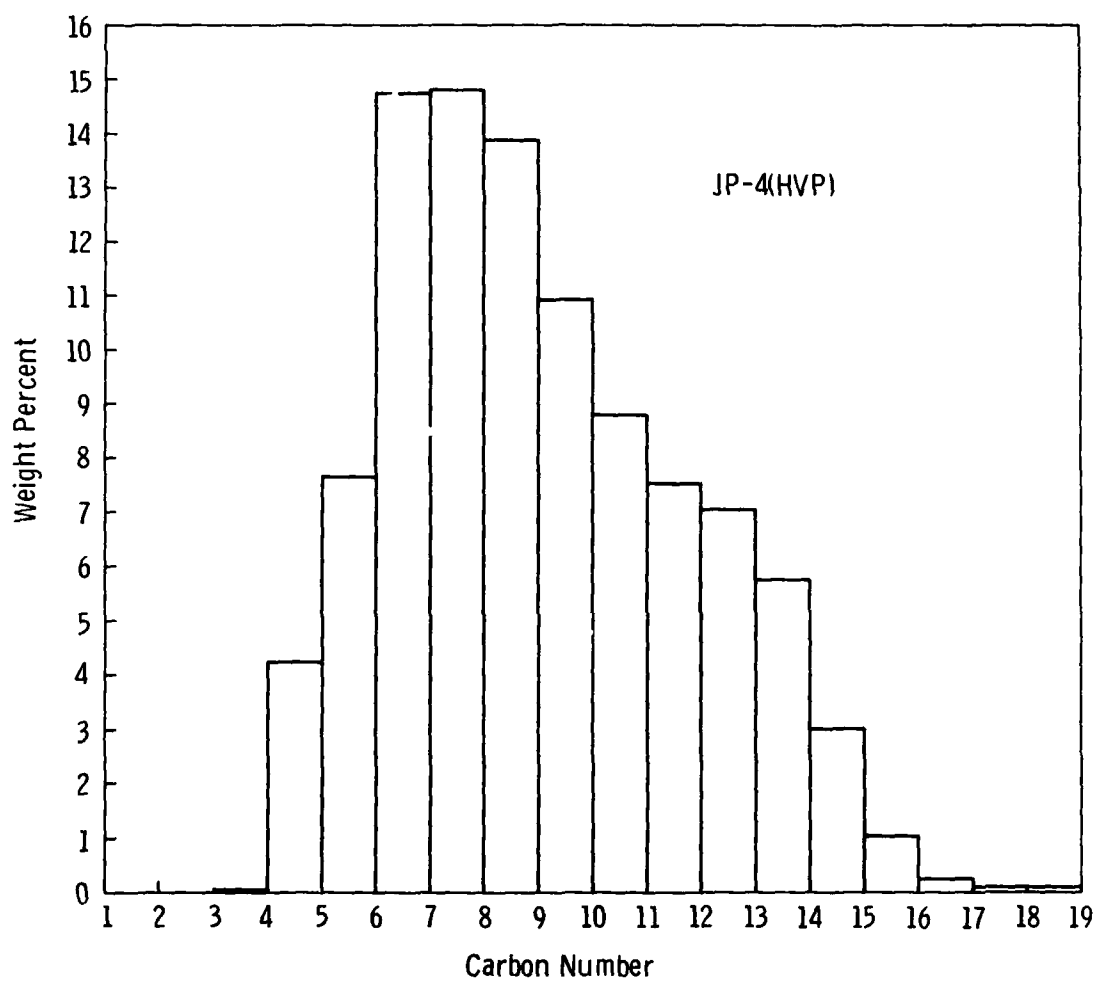


Figure 21. Distribution of hydrocarbons in JP-4(HVP), determined by simulated distillation.

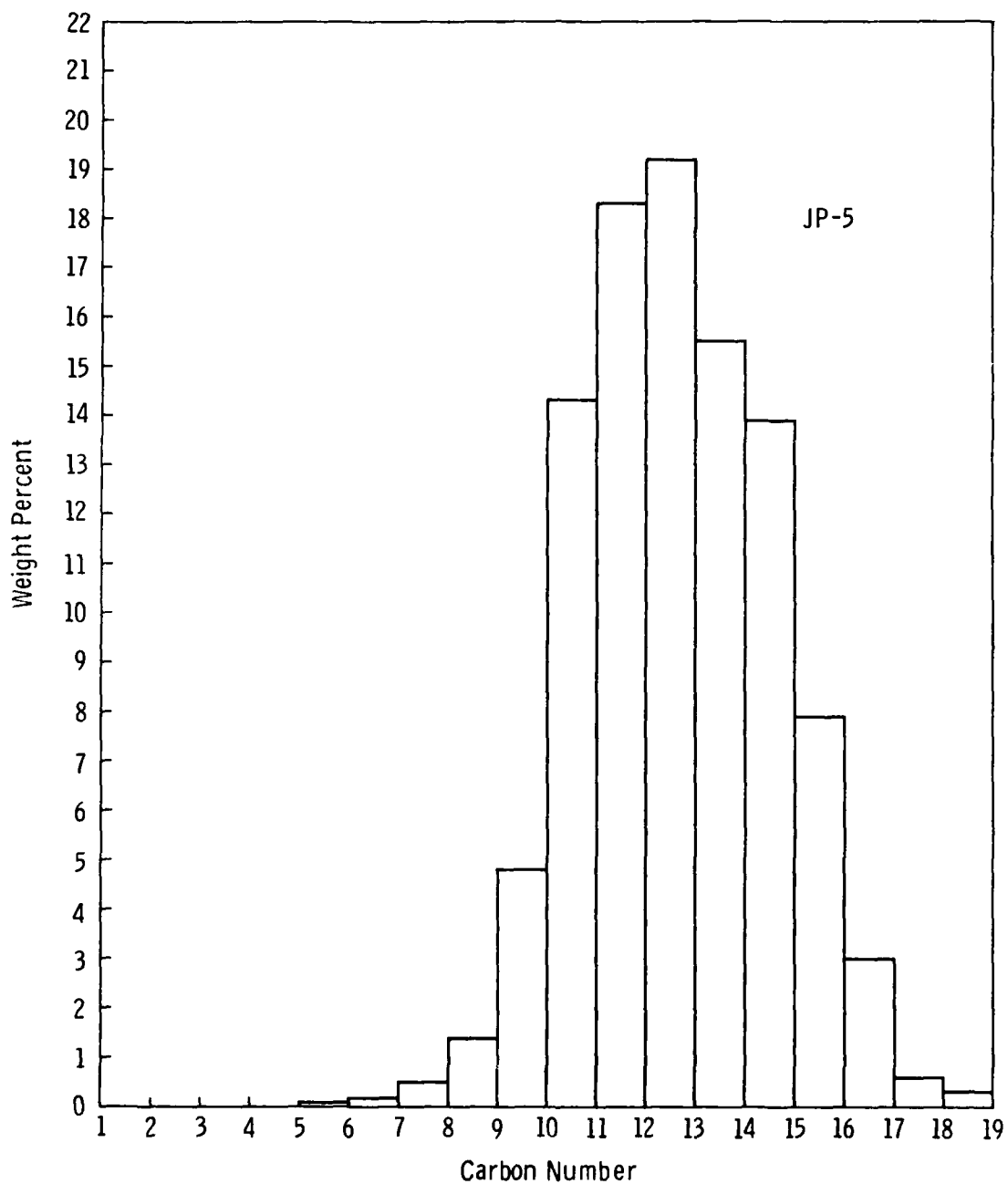


Figure 22. Distribution of hydrocarbons in JP-5, determined by simulated distillation.

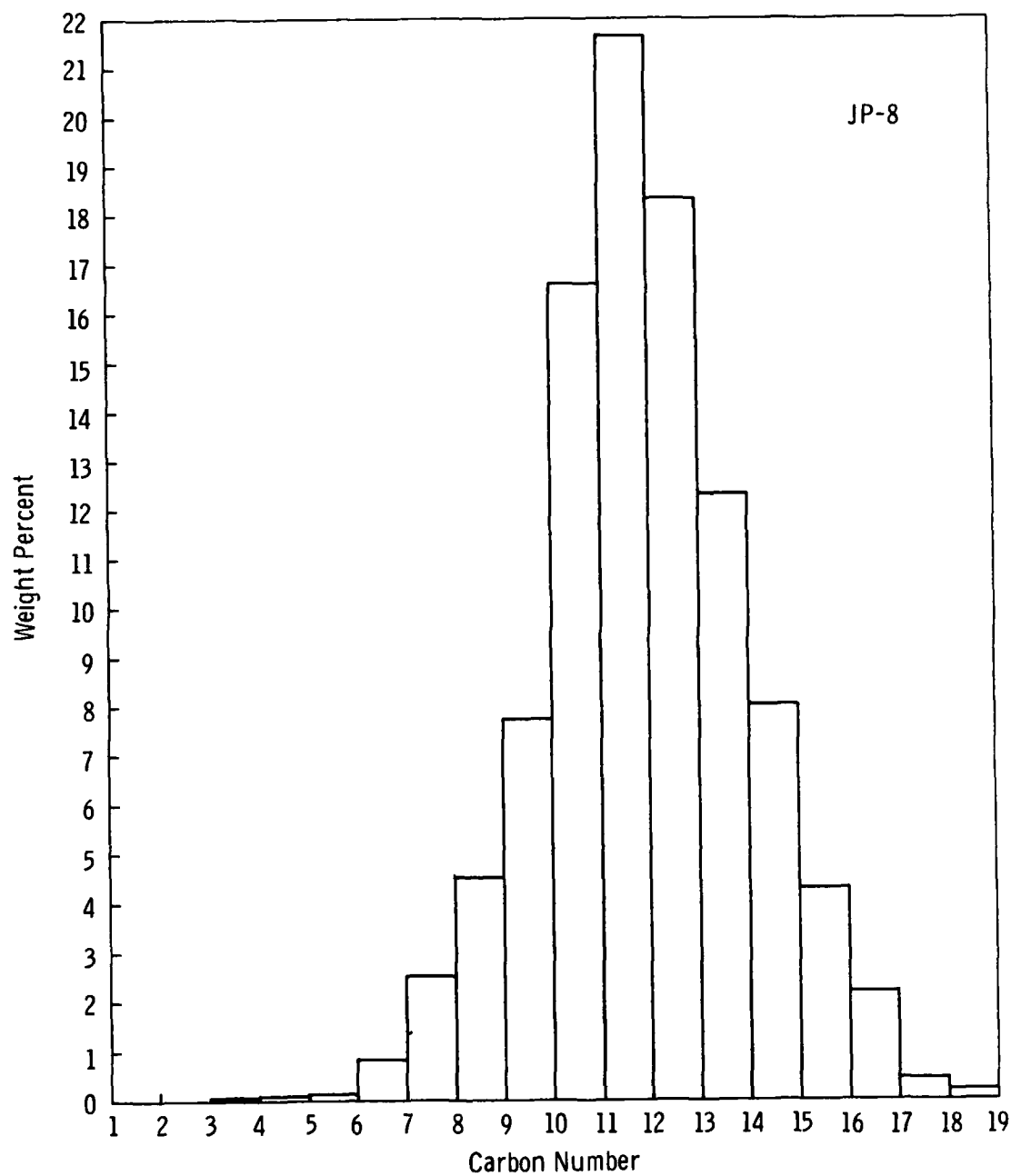


Figure 23. Distribution of hydrocarbons in JP-8, determined by simulated distillation.

B. Surface-Dispersion of Fuels

1. Key to Figures
2. Figures

Key 1. Effect of Fuel Flow Rate (1 to 1000 $\mu\text{l}/\text{min.}$) at Fixed Angles of Panel Inclination (0° , 5° , 10° and 90°).^a

Angle (deg)	Temperature		3.3°C (38°F)						23°C (73°F)						32°C (90°F)					
	Fuel flow rate ($\mu\text{l}/\text{min.}$)	Air flow rate ($\mu\text{l}/\text{min.}$)	None			6.1 ml/sec (20 ft/sec)			None			None			None			None		
			JP-4 (HVP) ^b	JP-5	JP-8	JP-4 (HVP) ^b	JP-5	JP-8	JP-4 (HVP) ^b	JP-5	JP-8	JP-4 (HVP) ^b	JP-5	JP-8	JP-4 (HVP) ^b	JP-5	JP-8	JP-4 (HVP) ^b	JP-5	JP-8
0	1																			
0	5																			
0	10																			
0	25																			
0	50																			
0	100																			
0	250																			
0	500																			
0	1000																			
0	1400																			
5	10																			
5	100																			
5	250																			
5	500																			
10	10																			
10	100																			
10	250																			
10	500																			
90	5																			
90	10																			
90	50																			

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

^d JP-4/JP-8 in 1000 volume ratio.

^e Single experiments were conducted with AvGas at each flow rate. Triplicate experiments were conducted with the other fluids under all experimental conditions.

Key 2. Comparison of the Dispersion of Different Fuels on Alclad Surface at Fixed Flow Rates (5, 10, 25, 50, 100 and 250 $\mu\text{l}/\text{min.}$) and Angles of Inclination (0° , 5° and 10°). ^a

Angle (deg)	Temperature		3.3°C (38°F)			23°C (73°F)						32°C (90°F)			
	Fuel flow rate (μl/min.)	Air flow rate	None			6.1 ml/sec (20 fl/sec)			None			None			
		JP-4 (UNP) ¹	JP-5	JP-8	JP-4 (UNP)	JP-5	JP-8	JP-4 (UNP)	JP-5	JP-8	JP-4 (UNP)	JP-5	JP-8		
0	1	Fluid													
0	5														
0	10														
0	25														
0	50														
0	100														
0	250														
0	500														
0	1000														
0	1400														
5	10														
5	100														
5	250														
5	500														
10	10														
10	100														
10	250														
10	500														
90	5														
90	10														
90	50														

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

^d JP-4/JP-8 in 10/90 volume ratio.

^e Single experiments were conducted with AVGAS at each flow rate. Triplicate experiments were conducted with the other fluids under all experimental conditions.

Key 3. Effect of Temperature on the Rates of Surface-Dispersion of JP-4 (HVP) and JP-5 at Fixed Fuel Flow Rates (10, 25 and 50 $\mu\text{L}/\text{min.}$).

Angle (deg)	Temperature		3.3°C (38°F)					23°C (73°F)					32°C (90°F)					
	Fuel flow rate (μl/min.)	Air flow rate	None			6.1 ml/sec (20 ft/sec)					None							
			JP 4 (HVP) ^a	JP-5	JP-8	JP 4 (LVP) ^c	JP 4 (HVP)	JP-5	JP-8	JP 4 (HVP)	JP-5	JP-8	JP 4 (HVP)	JP-5	JP-8	JP 4 (HVP)	JP-5	JP-8
0	1	Fluid																
0	5																	
0	10																	
0	25																	
0	50																	
0	100																	
0	250																	
0	500																	
0	1000																	
0	1400																	
5	10																	
5	100																	
5	250																	
5	500																	
10	10																	
10	100																	
10	250																	
10	500																	
90	5																	
90	10																	
90	50																	

^a Measurement time was 30 - n. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

^d JP-4/JP-8 in 1000:1 volume ratio.

^e Single experiments were conducted with AvGas at each flow rate.

Triplicate experiments were conducted with the other fluids under all experimental conditions.

Key 4. Effect of Temperature on the Rate of Surface-Dispersion of JP-8 at Fixed Fuel Flow Rates (50 and 100 $\mu\text{l}/\text{min.}$).^a

Angle (deg)	Fuel flow rate ($\mu\text{l}/\text{min.}$)	3.3°C (38°F)				23°C (73°F)								32°C (90°F)			
		None				None								None			
		JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-4 (HVP)	JP-5	JP-8	JP-8
0	1																
0	5																
0	10																
0	25																
0	50																
0	100																
0	250																
0	500																
0	1000																
0	1400																
5	10																
5	100																
5	250																
5	500																
10	10																
10	100																
10	250																
10	500																
90	5																
90	10																
90	50																

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

^d JP-4/JP-8 in 1000 volume ratio.

^e Single experiments were conducted with AvGas at each flow rate. Triplicate experiments were conducted with the other fluids under all experimental conditions.

Key 5. Effect of Air Flow Rate (6.1 m/sec and none) on the Rate of Surface-Dispersion of JP-4 (HVP).^a

Angle (deg)	Temperature		3.3°C (38°F)					23°C (73°F)					32°C (90°F)				
	Fuel flow rate (μl/min.)	Air flow rate (μl/min.)	None					6.1 m/sec (20 ft/sec)					None				
			JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-5	JP-8
0	1																
0	5																
0	10																
0	25																
0	50																
0	100																
0	250																
0	500																
0	1000																
0	1400																
5	10																
5	100																
5	250																
5	500																
10	10																
10	100																
10	250																
10	500																
90	5																
90	10																
90	50																

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

^d JP-4/JP-8 in 1000 volume ratio.

^e Single experiments were conducted with AvGas at each flow rate. Triplicate experiments were conducted with the other fluids under all experimental conditions.

Key 6. Effect of Air Flow Rate (6.1 m/sec and none) on the Rate of Surface-Dispersion of JP-5.^a

Angle (deg)	Temperature		3.3°C (38°F)				23°C (73°F)						32°C (90°F)			
	Fuel flow rate (μl/min.)	Air flow rate	None				None						None			
			JP-4 (LVP) ^c	JP-4 (HVP) ^b	JP-5	JP-8	JP-4 (LVP) ^c	JP-4 (HVP) ^b	JP-5	JP-8	JP-4 (HVP) ^b	JP-8	JP-4 (HVP) ^b	JP-5	JP-8	JP-8
0	1															
0	5															
0	10															
0	25															
0	50															
0	100															
0	250															
0	500															
0	1000															
0	1400															
5	10															
5	100															
5	250															
5	500															
10	10															
10	100															
10	250															
10	500															
90	5															
90	10															
90	50															

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

^d JP-4/JP-8 in 1000 volume ratio.

^e Single experiments were conducted with AuGas at each flow rate. Triple experiments were conducted with the other fluids under all experimental conditions.

Key 7. Effect of Air Flow Rate (6.1 m/sec and none)
on the Rate of Surface-Dispersion of JP-8.^a

Angle (deg)	Temperature		3.3°C (38°F)				23°C (73°F)				32°C (90°F)			
	Fuel flow rate (μl/min.)	Air flow rate (μl/min.)	None		JP-8	JP-5	None		JP-8	JP-5	JP-8	JP-5	JP-8	JP-5
			JP-8 AVGAS ^b	JP-5 AVGAS ^b			JP-8 AVGAS ^b	JP-5 AVGAS ^b						
			JP-8 AVGAS ^b	JP-5 AVGAS ^b	JP-8 AVGAS ^b	JP-5 AVGAS ^b	JP-8 AVGAS ^b	JP-5 AVGAS ^b	JP-8 AVGAS ^b	JP-5 AVGAS ^b	JP-8 AVGAS ^b	JP-5 AVGAS ^b	JP-8 AVGAS ^b	JP-5 AVGAS ^b
0	1													
0	5													
0	10													
0	25													
0	50													
0	100													
0	250													
0	500													
0	1000													
0	1400													
5	10													
5	100													
5	250													
5	500													
10	10													
10	100													
10	250													
10	500													
90	5													
90	10													
90	50													

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

^d JP-8/JP-5 in 1000 volume ratio.

^e Single experiments were conducted with AVGAS at each flow rate. Tripartite experiments were conducted with the other fluids under all experimental conditions.

Key 8. Effect of the Panel Angle of Inclination on the Rates of Surface-Dispersion of Jet Fuels at the Fixed Fluid Flow Rate of 10 $\mu\text{l}/\text{min}$.

Angle (deg)	Temperature		33°C (90°F)				23°C (73°F)								32°C (90°F)			
	Fuel	Air flow rate ($\mu\text{l}/\text{min}$)	None				6.1 ml/sec (20 ft/sec)								None			
			JP-4 (HVP) ^b	JP-5	JP-8	Fluid	JP-4 (HVP) ^b	JP-5	JP-8	JP-4 (HVP) ^b	JP-5	JP-8	JP-4 (HVP) ^b	JP-5	JP-8	JP-4 (HVP) ^b	JP-5	JP-8
0	1	1																
0	5	5																
0	10	10																
0	25	25																
0	50	50																
0	100	100																
0	250	250																
0	500	500																
0	1000	1000																
0	1400	1400																
5	10	10																
5	100	100																
5	250	250																
5	500	500																
10	10	10																
10	100	100																
10	250	250																
10	500	500																
90	5	5																
90	10	10																
90	50	50																

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

^d JP-4/JP-8 in 10/90 volume ratio.

^e Single experiments were conducted with AvGas at each flow rate. Triplicate experiments were conducted with the other fluids under all experimental conditions.

Key 9. Effect of the Panel Angle of Inclination on the Rates of Surface-Dispersion of Jet Fuels at the Fixed Fluid Flow Rate of 100 $\mu\text{l}/\text{min.}$ ^a

Angle (deg)	Temperature		3.3°C (38°F)				23°C (73°F)				32°C (90°F)			
	Fuel flow rate ($\mu\text{l}/\text{min.}$)	Air flow rate ($\mu\text{l}/\text{min.}$)	None		JP-5		JP-8		JP-5		JP-8		JP-5	
			JP-8	JP-5	JP-8	JP-5	JP-8	JP-5	JP-8	JP-5	JP-8	JP-5	JP-8	JP-5
0	1													
0	5													
0	10													
0	25													
0	50													
0	100													
0	250													
0	500													
0	1000													
0	1400													
5	10													
5	100													
5	250													
5	500													
10	10													
10	100													
10	250													
10	500													
90	5													
90	10													
90	50													

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

^d JP-8 in 1000 volume ratio.

^e Single experiments were conducted with AVGas at each flow rate. Triplicate experiments were conducted with the other fluids under all experimental conditions.

Key 10. Effect of the Panel Angle of Inclination on the Rates of Surface-Dispersion of JP-4 (LVP) and JP-4 (HVP) at the Fixed Fluid Flow Rate of 250 $\mu\text{l}/\text{min}$.^a

Angle (deg)	Temperature		3.3°C (38°F)					23°C (73°F)					32°C (90°F)				
	Fuel flow rate ($\mu\text{l}/\text{min}$)	Air flow rate ($\mu\text{l}/\text{min}$)	None					None					None				
			JP-4 (HVP) ^b	JP-5	JP-8	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-5	JP-8
0	1																
0	5																
0	10																
0	25																
0	50																
0	100																
0	250																
0	500																
0	1000																
0	1400																
5	10																
5	100																
5	250																
5	500																
10	10																
10	100																
10	250																
10	500																
90	5																
90	10																
90	50																

^a Measurement time was 30 min. for all experiments shown in this table.
^b High vapor pressure sample.
^c Low vapor pressure sample.
^d JP-4/JP-8 in 1000 volume ratio.
^e Single experiments were conducted with Aviax at each flow rate. Triplicate experiments were conducted with the other fluids under all experimental conditions.

Key 11. Effect of the Panel Angle of Inclination on the Rates of Surface-Dispersion of JP-4 (LVP) and JP-4 (HVP) at the Fixed Fluid Flow Rate of 500 $\mu\text{l}/\text{min}$.^a

Angle (deg)	Temperature		3.3°C (38°F)						23°C (73°F)						32°C (90°F)					
	Fuel flow rate (μl/min.)	Air flow rate	None			6.1 ml/sec (20 W/sec)			None			None			None					
			JP-4 (HVP)	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-5	JP-8	JP-4 (HVP)	JP-5	JP-8		
0	1																			
0	5																			
0	10																			
0	25																			
0	50																			
0	100																			
0	250																			
0	500																			
0	1000																			
0	1400																			
5	10																			
5	100																			
5	250																			
5	500																			
10	10																			
10	100																			
10	250																			
10	500																			
90	5																			
90	10																			
90	50																			

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

^d JP-4 (JP-8 in 1000 volume ratio).

^e Single experiments were conducted with AvGas at each flow rate. Triplicate experiments were conducted with the other fluids under all experimental conditions.

Key 12. Effects of Fuel Flow Rate (10 to 500 $\mu\text{l}/\text{min.}$) on the Rates of Surface-Dispersion of Jet Fuels on a Horizontally Mounted, Polyurethane Latex-Coated Panel.^a

Angle (deg)	Panel		Alclad			Unclad aluminum alloy			Polyurethane latex-coated surface			
	Fuel flow rate ($\mu\text{l}/\text{min.}$)	Fluid	JP-4 (LVP) ^b	JP-4 (HVP) ^c	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8
0	1											
0	5											
0	10											
0	25											
0	50											
0	100											
0	250											
0	500											
0	1000											
5	10											
5	100											
5	250											
5	500											
5	10											
5	100											
5	250											
5	500											
5	10											
5	100											
5	250											
5	500											

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

Key 13. Comparison of the Dispersion of Different Fuels on Unclad Aluminum Alloy and on Polyurethane Latex-Coated Surface.^a

Angle (deg)	Fuel flow rate (μl/min.)	Panel		Alclad				Unclad aluminum alloy				Polyurethane latex-coated surface			
		Fuel flow rate (μl/min.)	Fluid	JP-4 (LVP) ^b	JP-4 (HVP) ^c	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8
0	1														
0	5														
0	10														
0	25														
0	50														
0	100														
0	250														
0	500														
0	1000														
5	10														
5	100														
5	250														
5	500														
5	10														
5	100														
5	250														
5	500														

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

Key 14. Effect of Panel Surface Composition (Alclad vs. Polyurethane Latex Coating) on the Rates of Surface-Dispersion of JP-5 at the Fixed Fluid Flow Rates of 10 and 25 $\mu\text{l}/\text{min.}$ ^a

Angle (deg)	Fuel flow rate ($\mu\text{l}/\text{min.}$)	Panel		Alclad			Unclad aluminum alloy			Polyurethane latex-coated surface			
		Fluid		JP-4 (LVP) ^b	JP-4 (HVP) ^c	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)
0	1												
0	5												
0	10												
0	25												
0	50												
0	100												
0	250												
0	500												
0	1000												
5	10												
5	100												
5	250												
5	500												
5	10												
5	100												
5	250												
5	500												

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

Key 15. Effect of Panel Surface Composition (Alclad vs. Polyurethane Latex Coating) on the Rates of Surface-Dispersion of JP-8 at the Fixed Fluid Flow Rates of 25 and 50 $\mu\text{L}/\text{min}$.^a

Angle (deg)	Fuel flow rate ($\mu\text{L}/\text{min}$)	Panel		Alclad			Unclad aluminum alloy			Polyurethane latex-coated surface				
		Fluid	JP-4 (LVP) ^b	JP-4 (HVP) ^c	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-8
0	1													
0	5													
0	10													
0	25									107				
0	50													
0	100													
0	250													
0	500													
0	1000													
5	10													
5	100													
5	250													
5	500													
5	10													
5	100													
5	250													
5	500													

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

Key 16. Effect of Panel Surface Composition (Alclad, Unclad Aluminum Alloy and Polyurethane Latex Coating) on the Rates of Surface-Dispersion of JP-4 (LVP) and JP-4 (HVP) at the Fixed Fluid Flow Rate of 100 $\mu\text{l}/\text{min}$.^a

Angle (deg)	Fuel flow rate ($\mu\text{l}/\text{min}$)	Panel		Alclad			Unclad aluminum alloy			Polyurethane latex-coated surface			
		Fuel flow rate ($\mu\text{l}/\text{min}$)	Fluid	JP-4 (LVP) ^b	JP-4 (HVP) ^c	JP-5	JP-8	JP-4 (LVP)	JP-4 (HVP)	JP-5	JP-4 (LVP)	JP-4 (HVP)	JP-8
0	1												
0	5												
0	10												
0	25												
0	50												
0	100												
0	250												
0	500												
0	1000												
5	10												
5	100												
5	250												
5	500												
5	10												
5	100												
5	250												
5	500												

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

Key 17. Effect of Panel Surface Composition (Alclad, Unclad Aluminum Alloy and Polyurethane Latex Coating) on the Rates of Surface-Dispersion of JP-5 and JP-8 at the Fixed Fluid Flow Rate of 100 $\mu\text{l}/\text{min.}$ ^a

Angle (deg)	Fuel flow rate ($\mu\text{L}/\text{min.}$)	Panel		Alclad			Unclad aluminum alloy			Polyurethane latex-coated surface				
		Fluid	JP-4 (LVPI) ^b	JP-4 (HVP) ^c	JP-5	JP-8	JP-4 (LVPI)	JP-4 (HVP)	JP-5	JP-8	JP-4 (LVPI)	JP-4 (HVP)	JP-5	JP-8
0	1													
0	5		•	•	•	•	•	•	•	•	•	•	•	•
0	10		•	•	•	•	•	•	•	•	•	•	•	•
0	25		•	•	•	•	•	•	•	•	•	•	•	•
0	50		•	•	•	•	•	•	•	•	•	•	•	•
0	100		•	•	•	•	•	•	•	•	•	•	•	•
0	250		•	•	•	•	•	•	•	•	•	•	•	•
0	500		•	•	•	•	•	•	•	•	•	•	•	•
0	1000		•	•	•	•	•	•	•	•	•	•	•	•
5	10		•	•	•	•	•	•	•	•	•	•	•	•
5	100		•	•	•	•	•	•	•	•	•	•	•	•
5	250		•	•	•	•	•	•	•	•	•	•	•	•
5	500		•	•	•	•	•	•	•	•	•	•	•	•
5	10		•	•	•	•	•	•	•	•	•	•	•	•
5	100		•	•	•	•	•	•	•	•	•	•	•	•
5	250		•	•	•	•	•	•	•	•	•	•	•	•
5	500		•	•	•	•	•	•	•	•	•	•	•	•

^a Measurement time was 30 min. for all experiments shown in this table.

^b High vapor pressure sample.

^c Low vapor pressure sample.

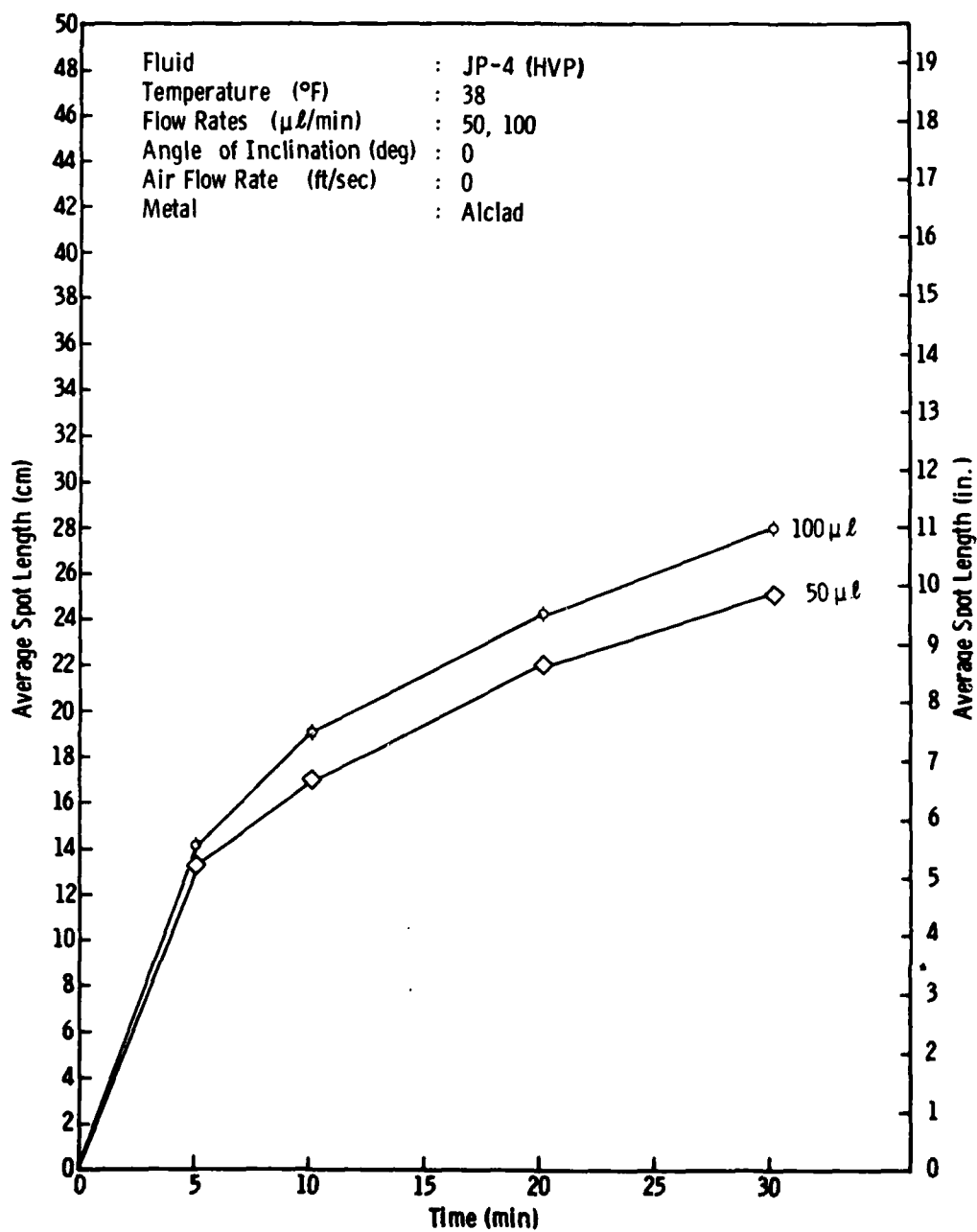


Figure 24.

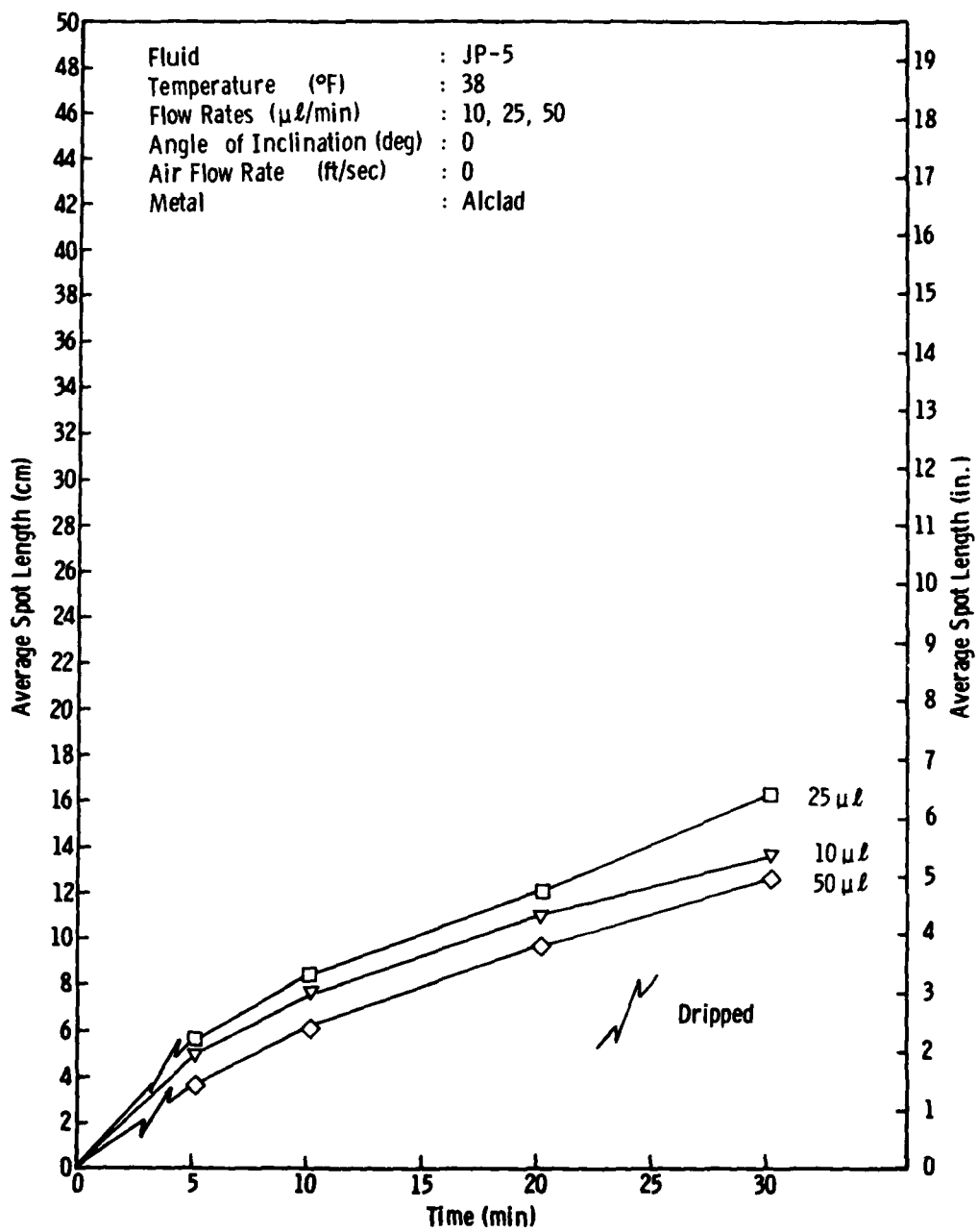


Figure 25.

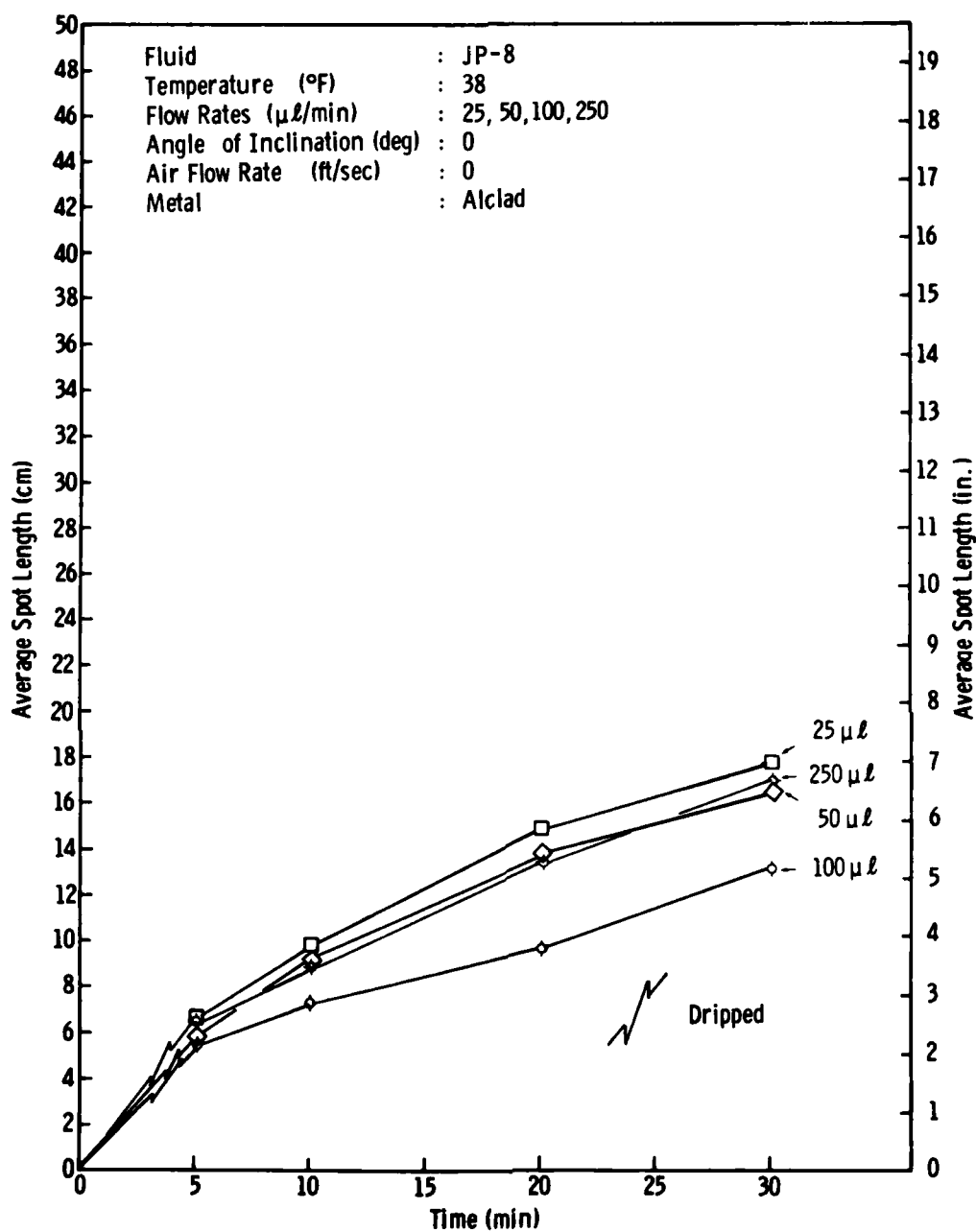


Figure 26.

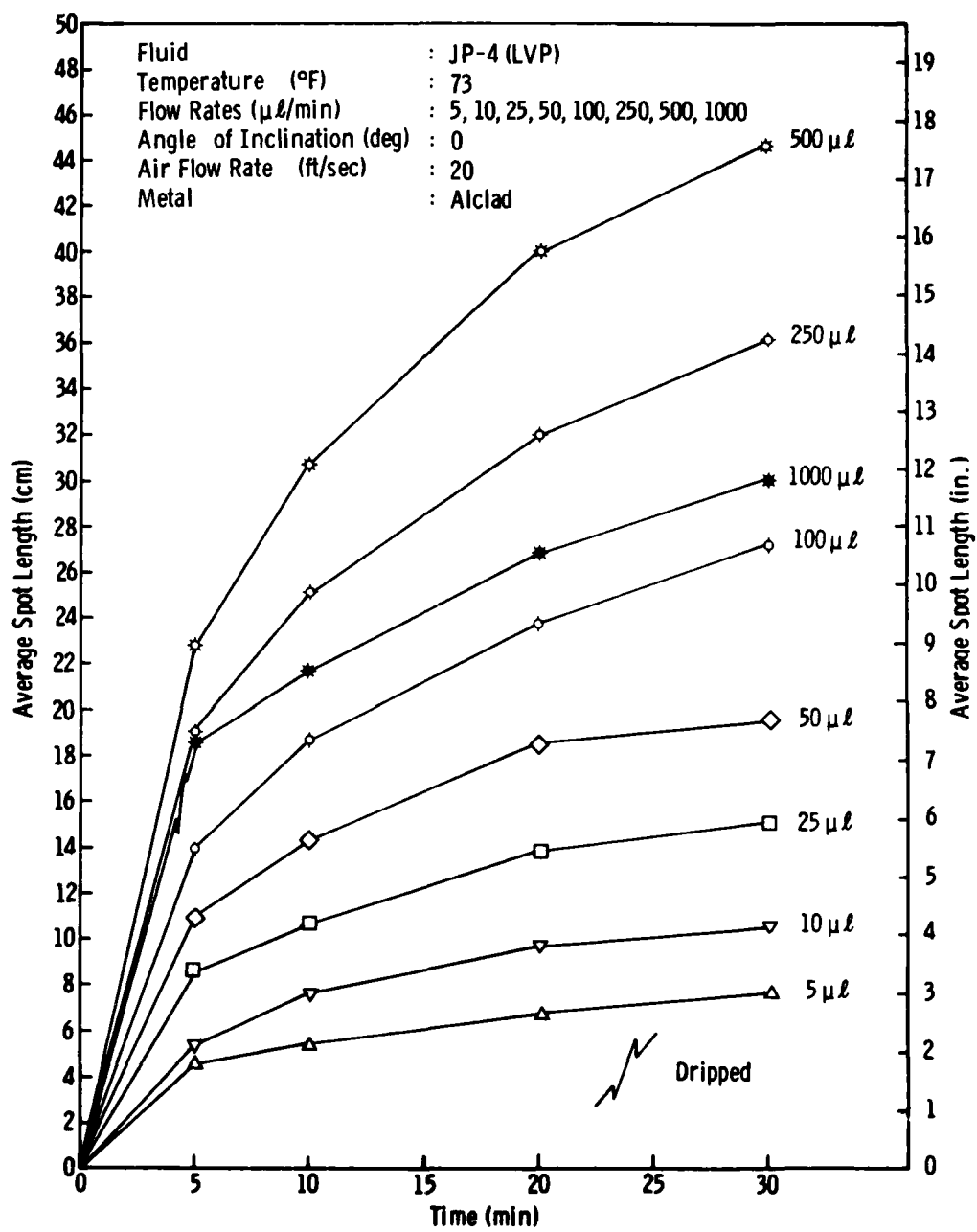


Figure 27.

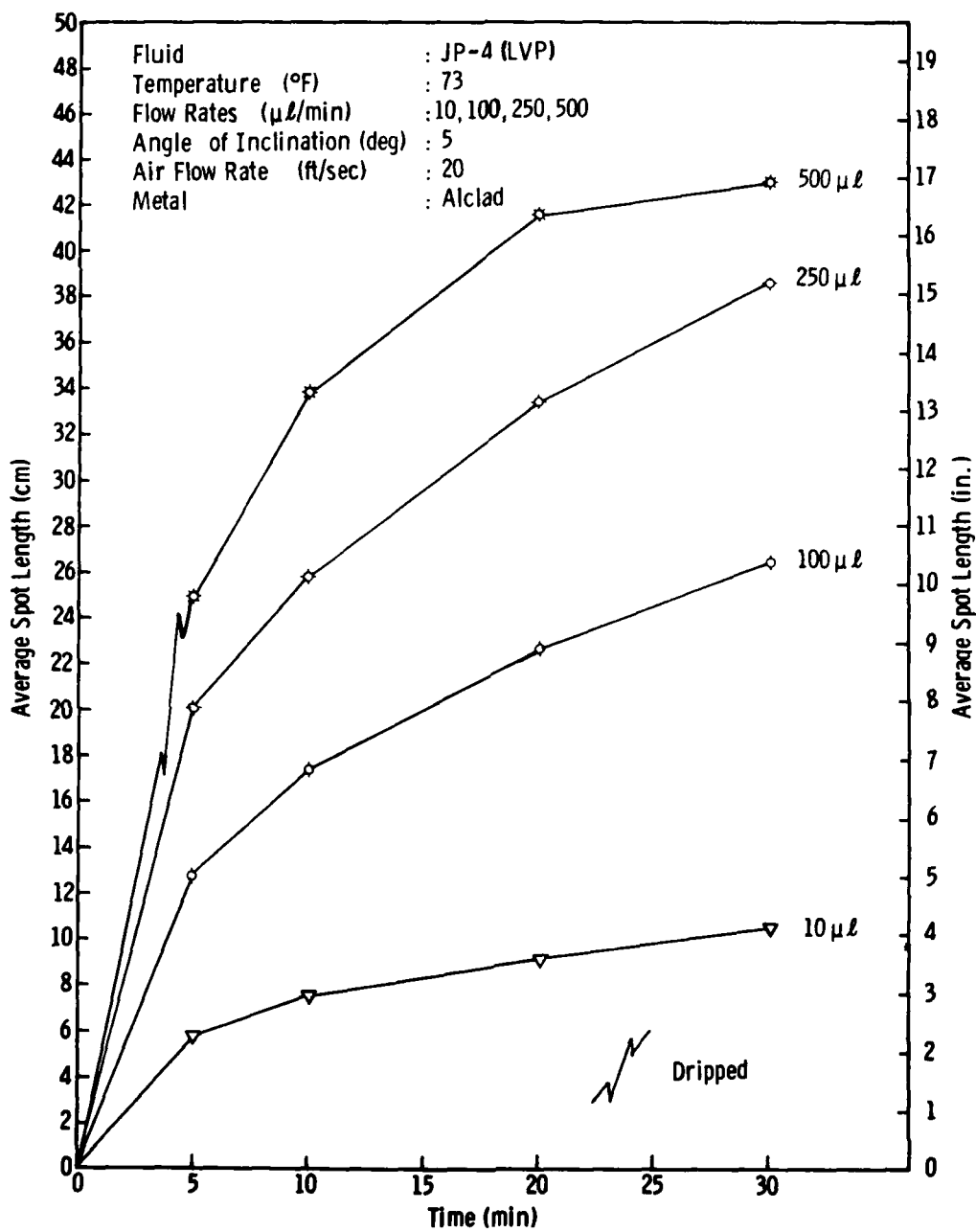


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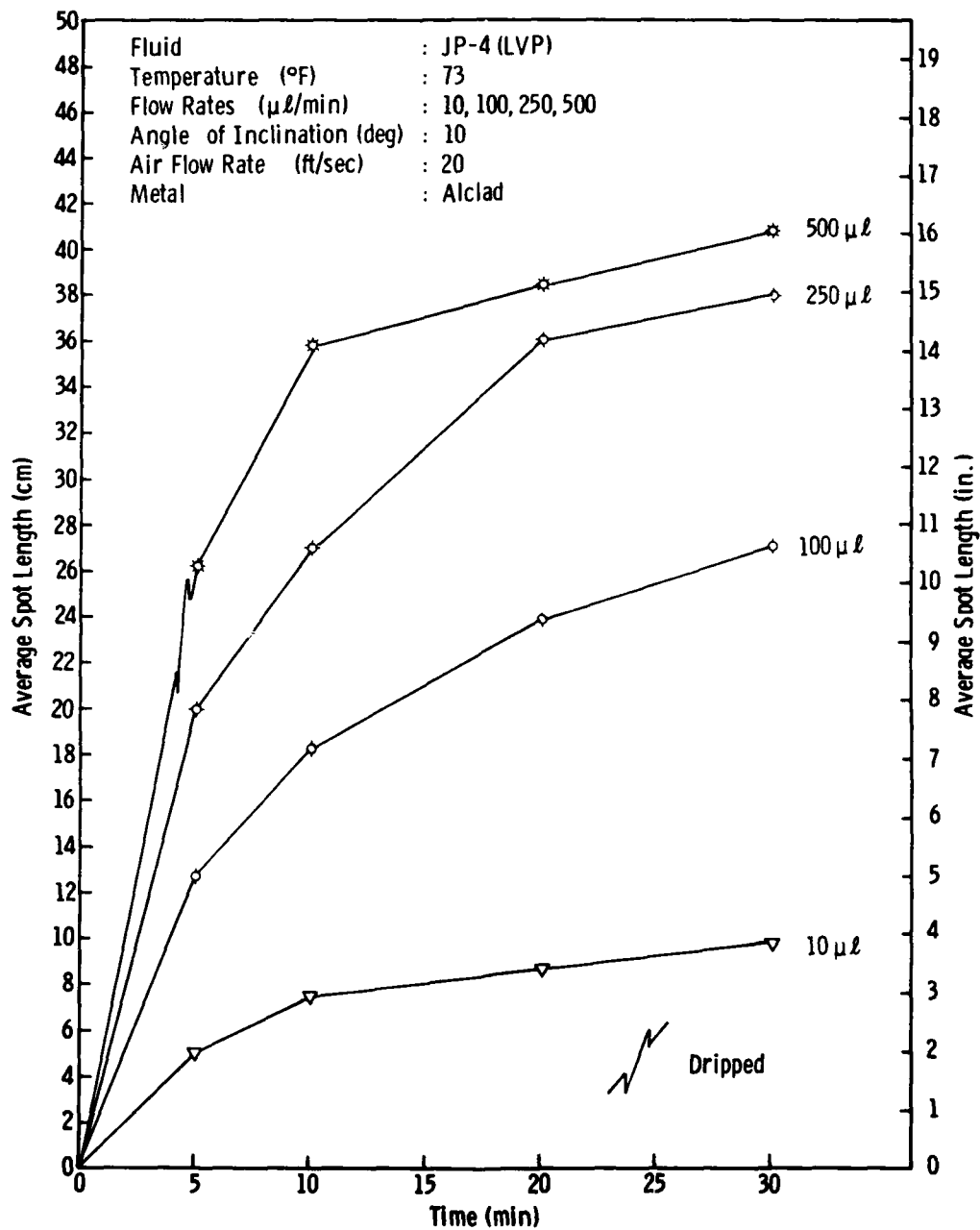


Figure 29.

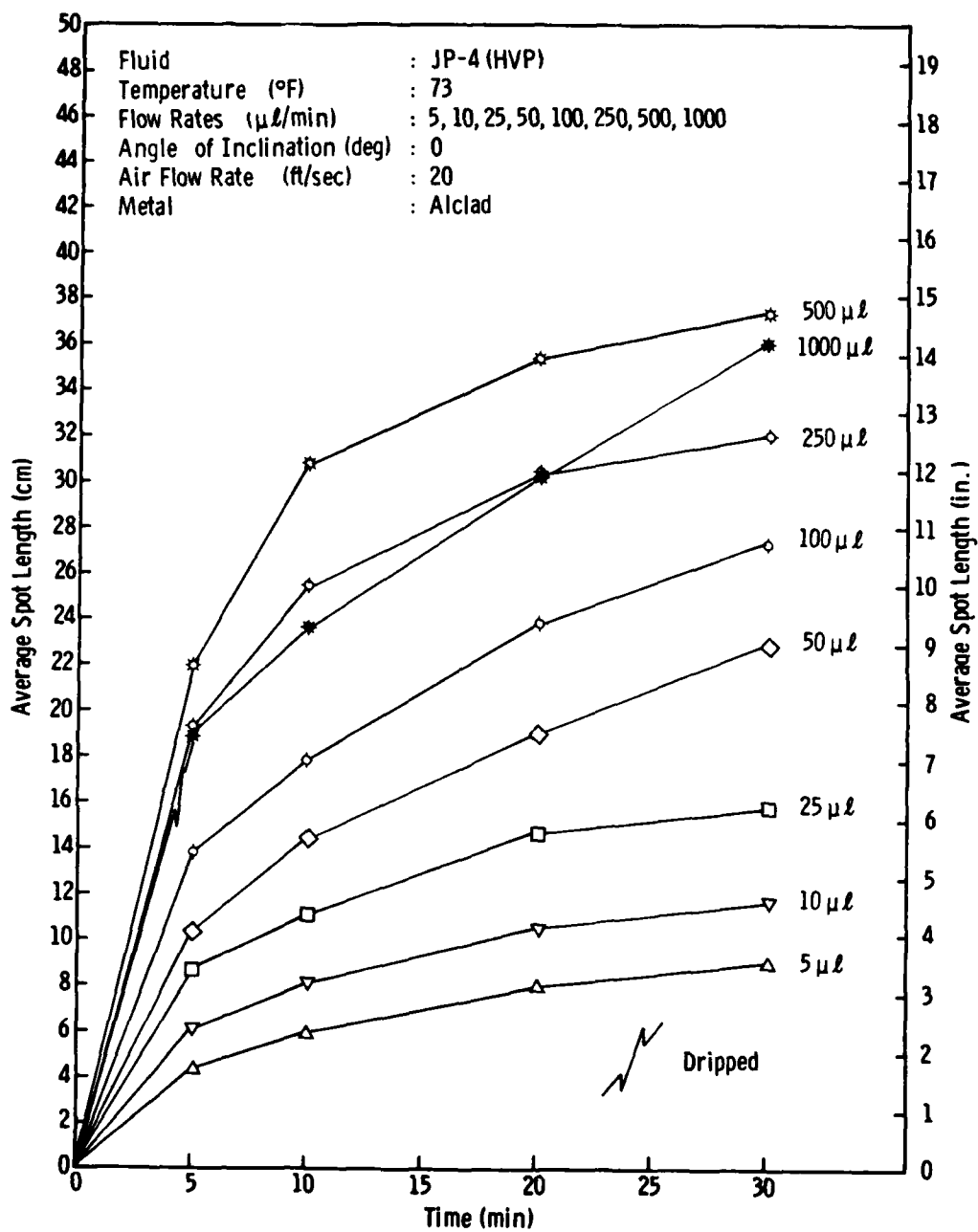


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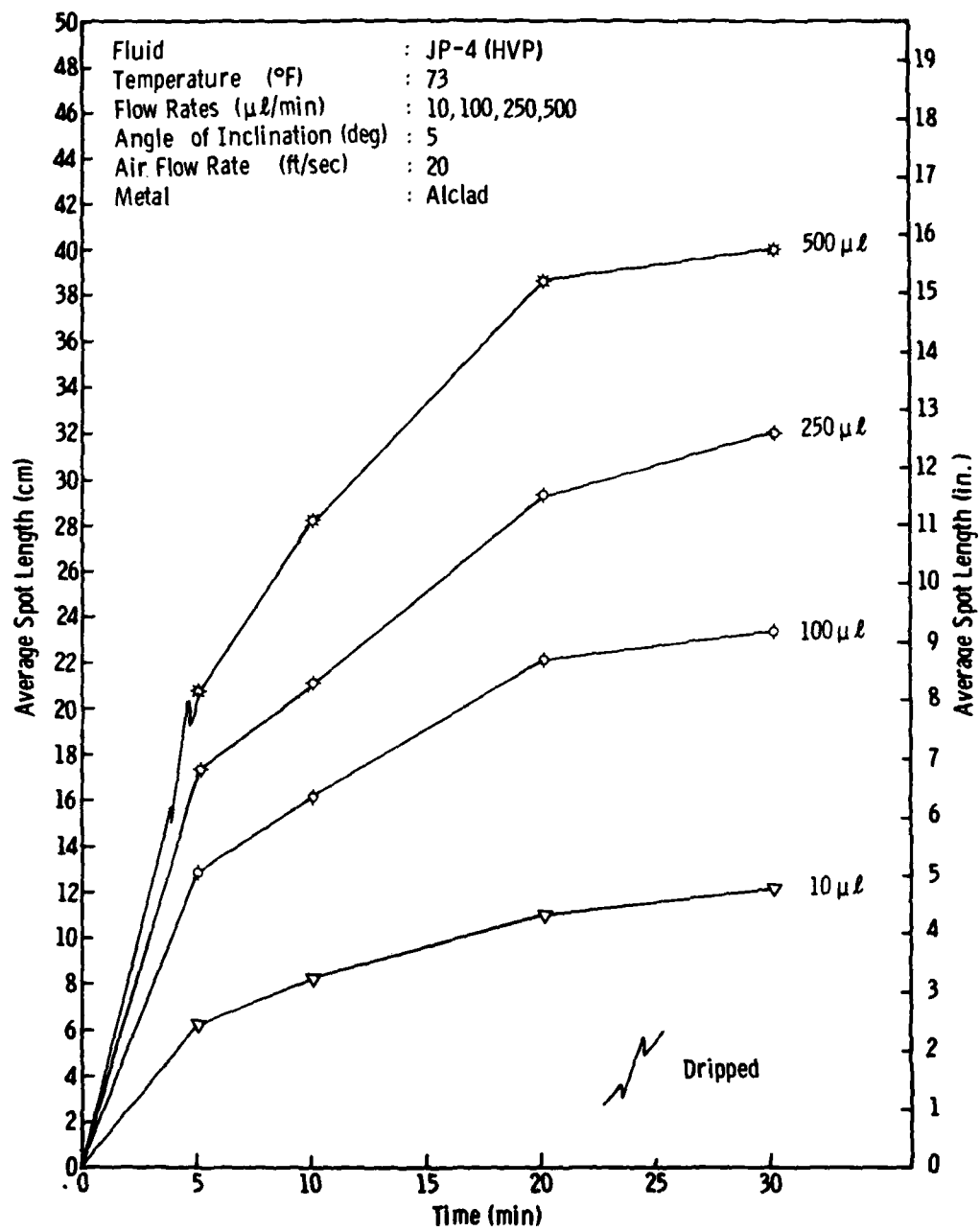


Figure 31.

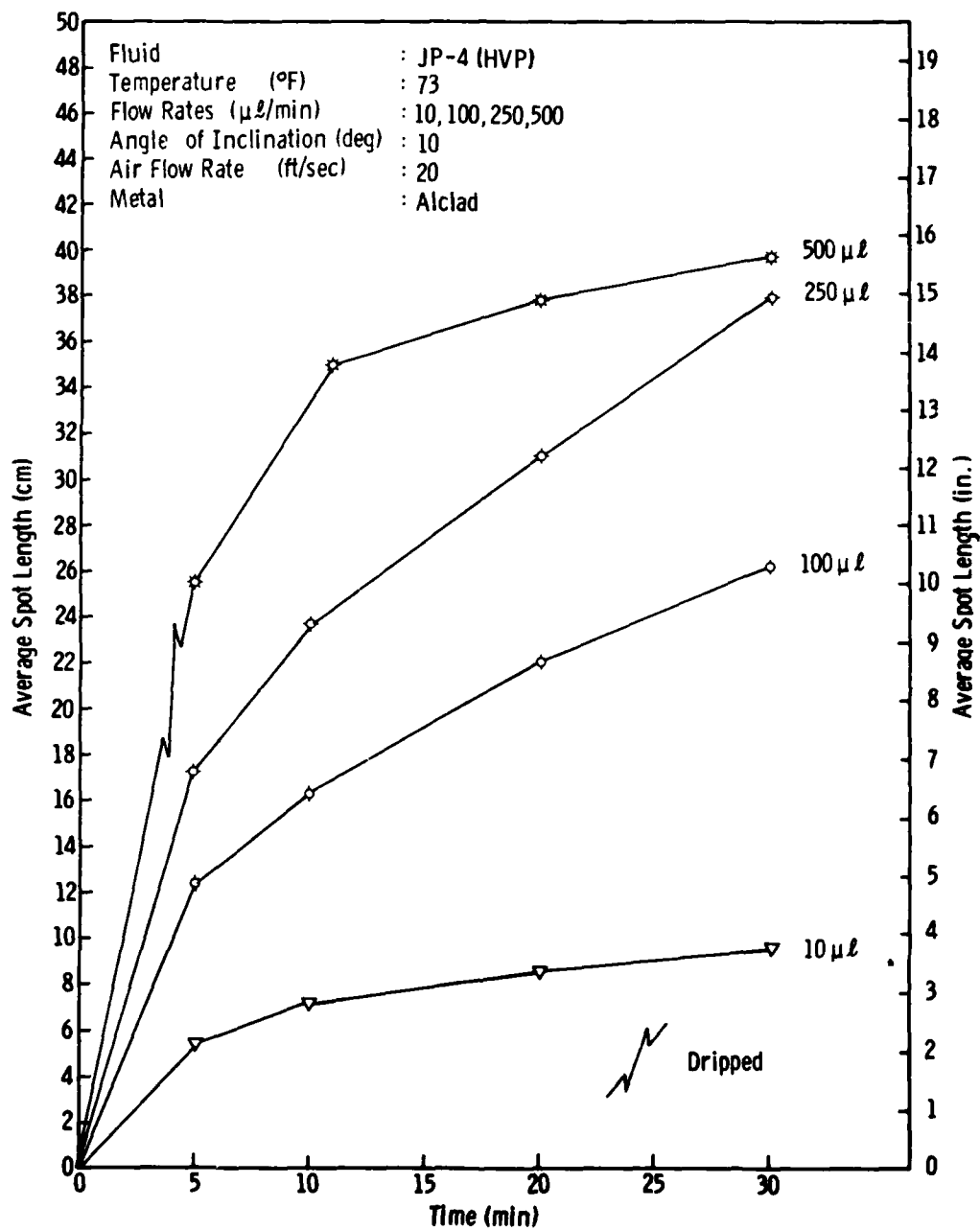


Figure 32.

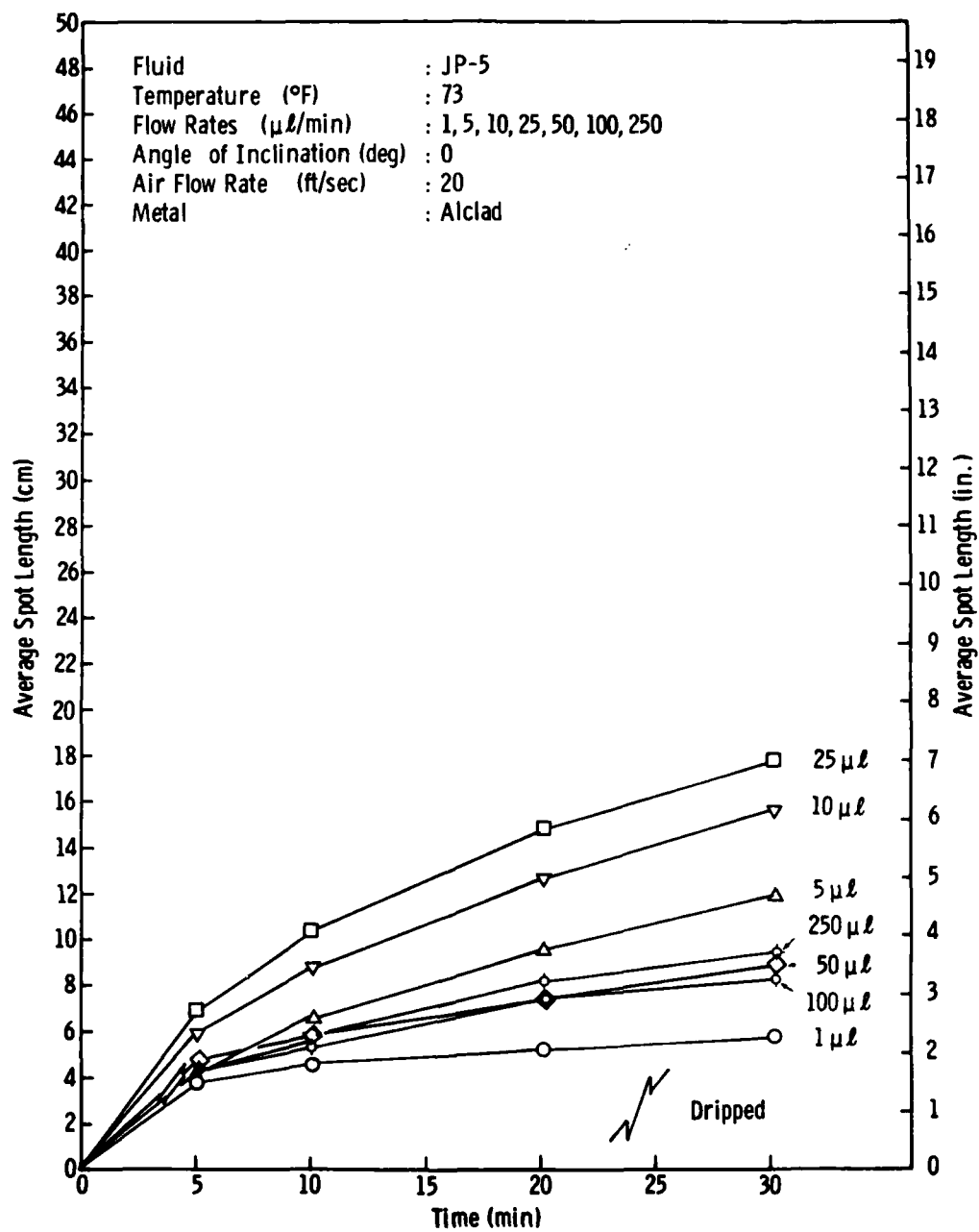


Figure 33.

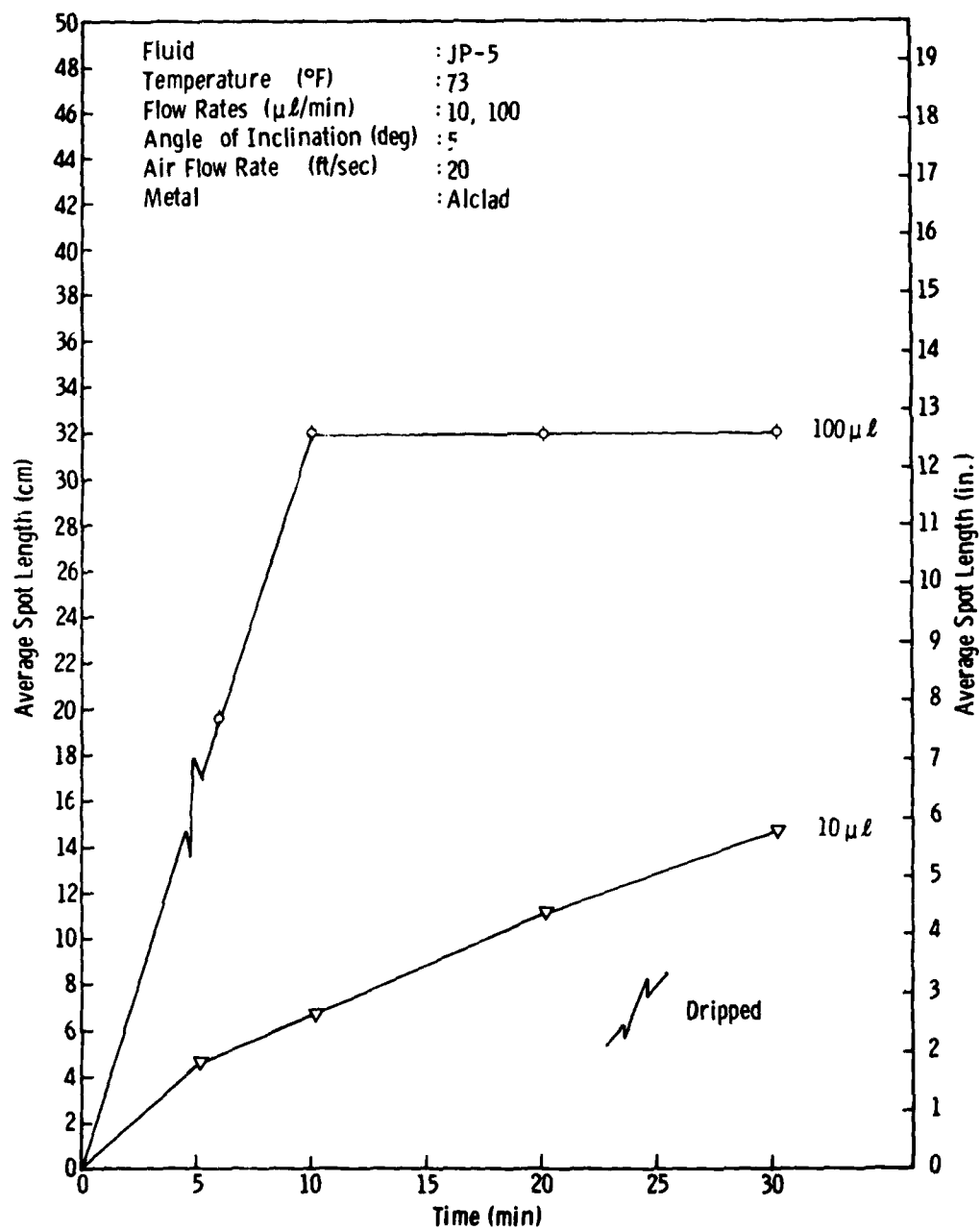


Figure 34.

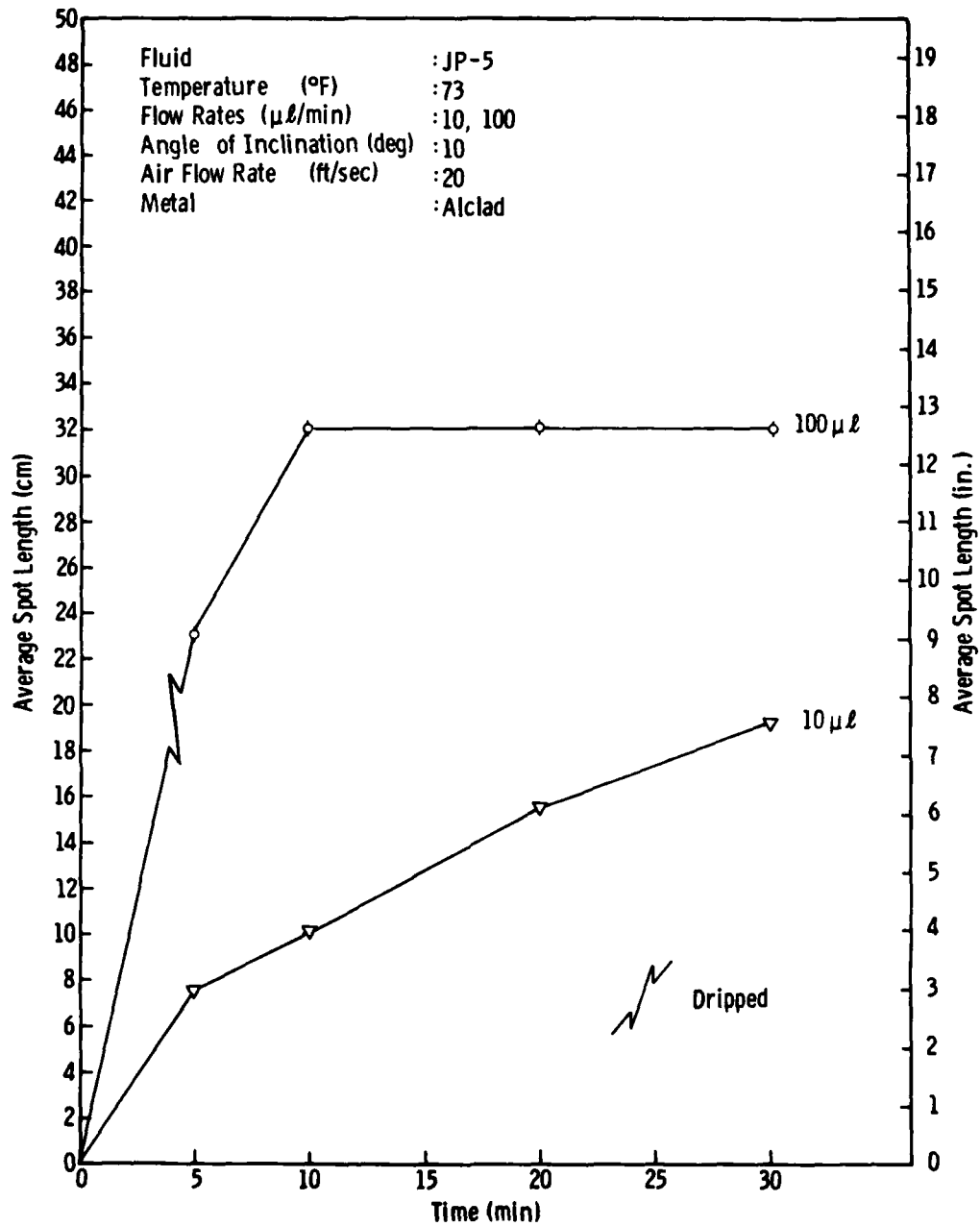


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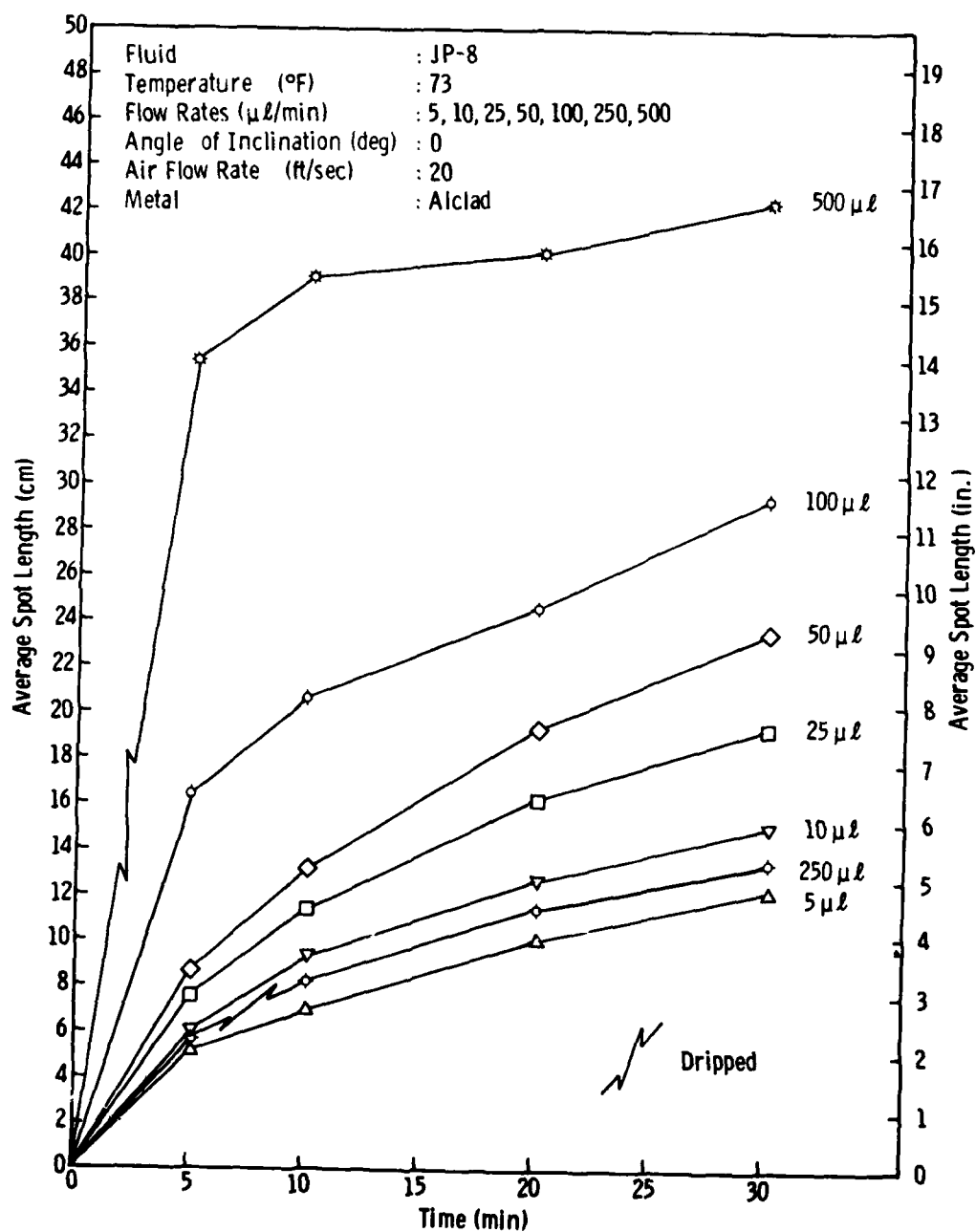


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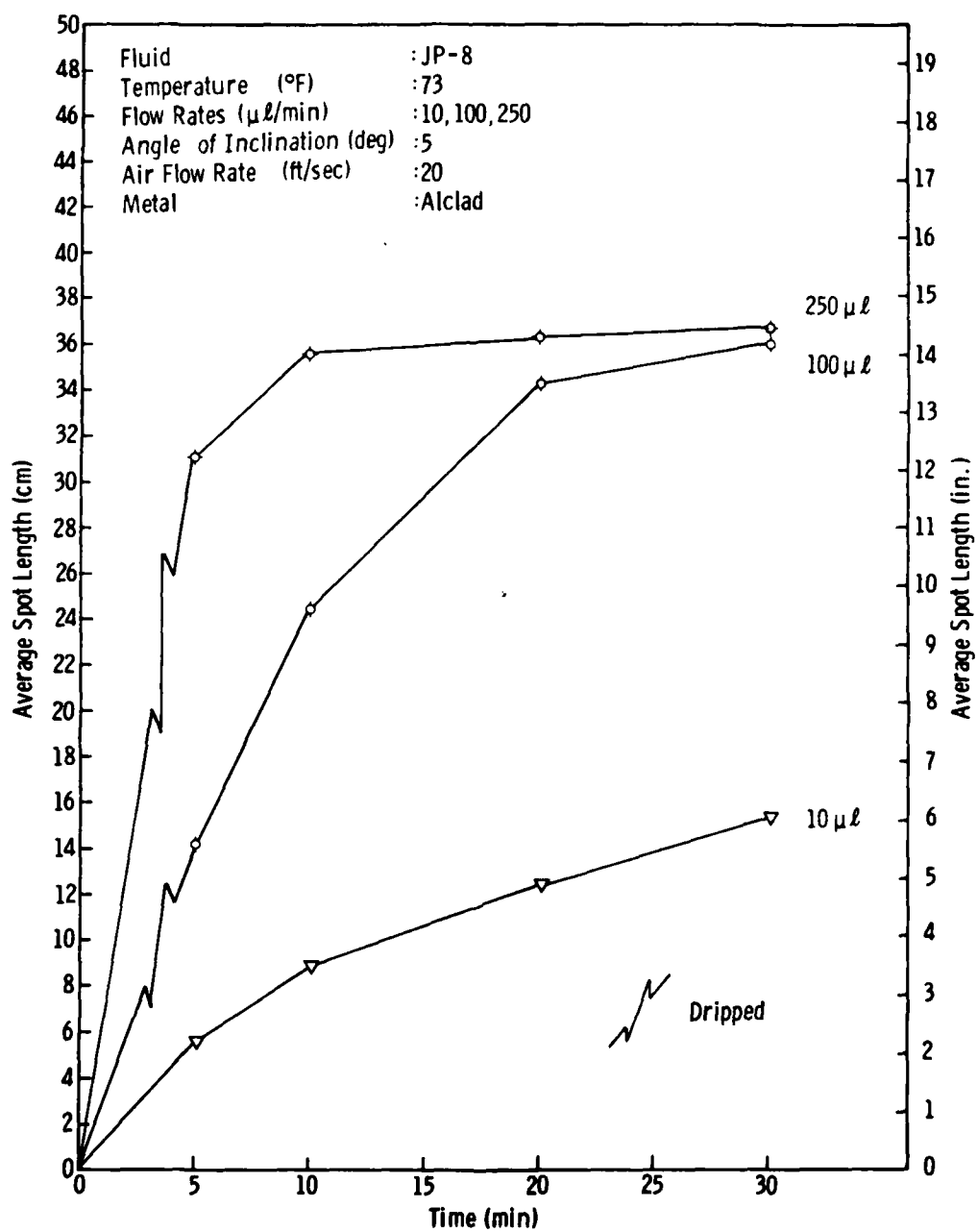


Figure 37.

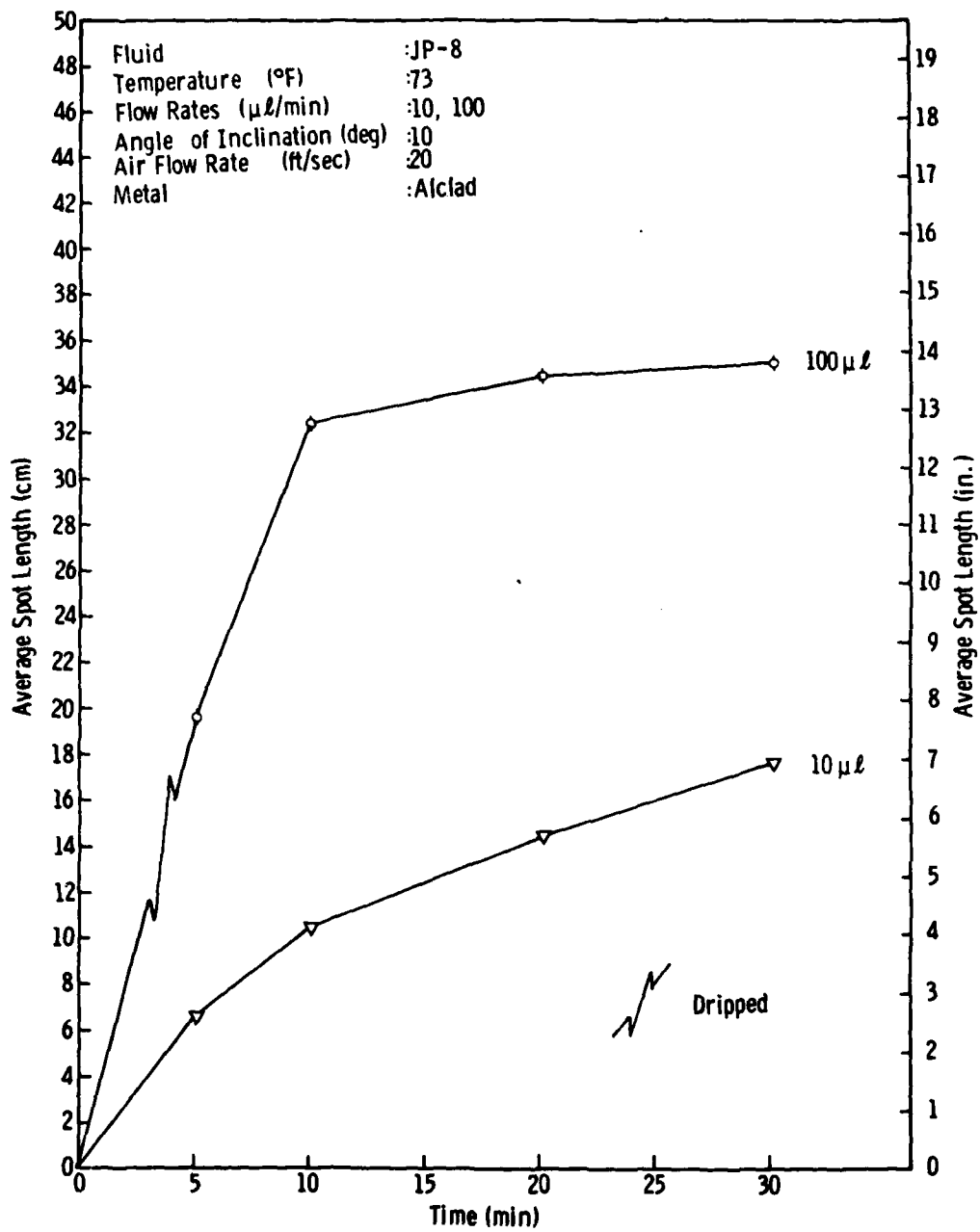


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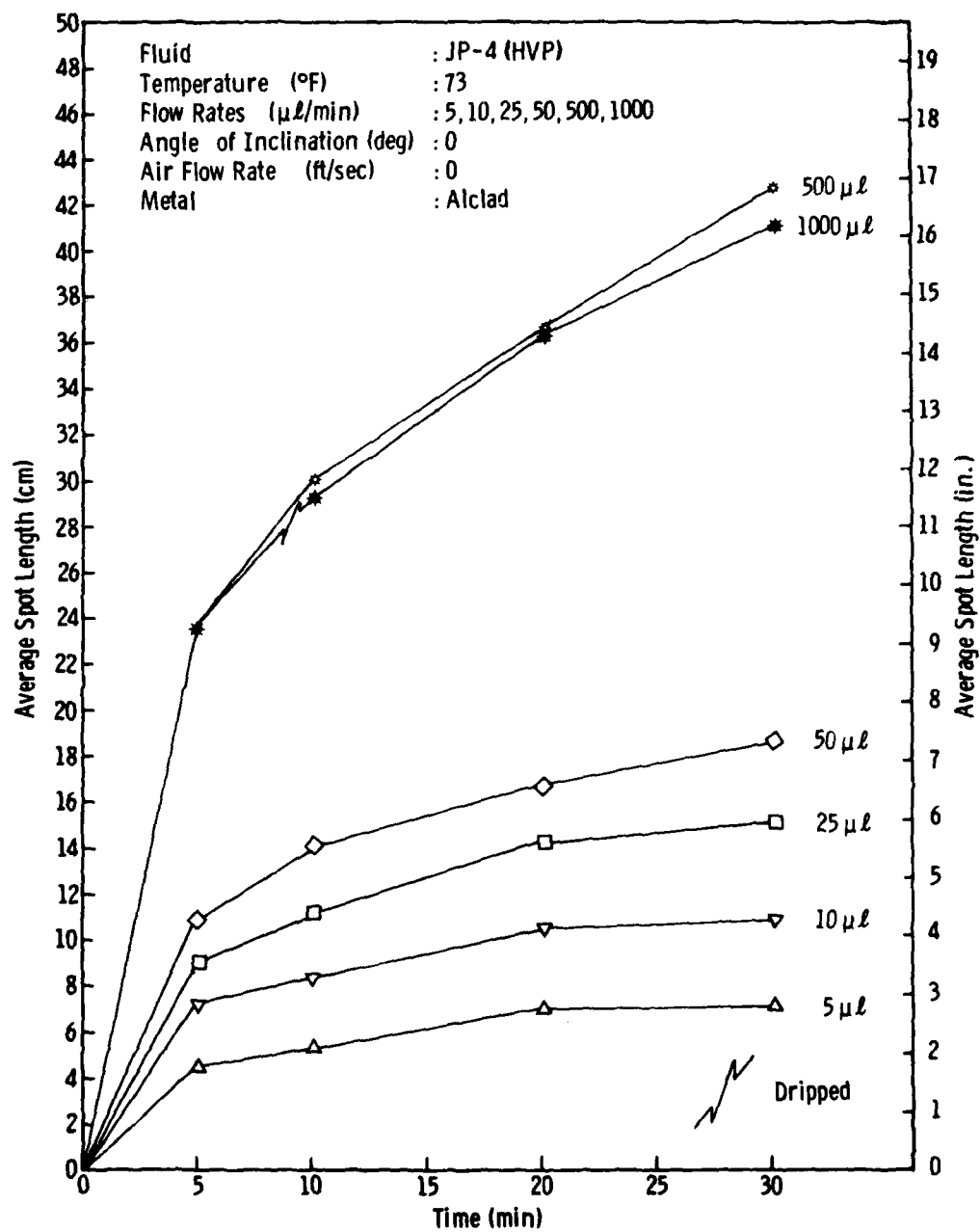


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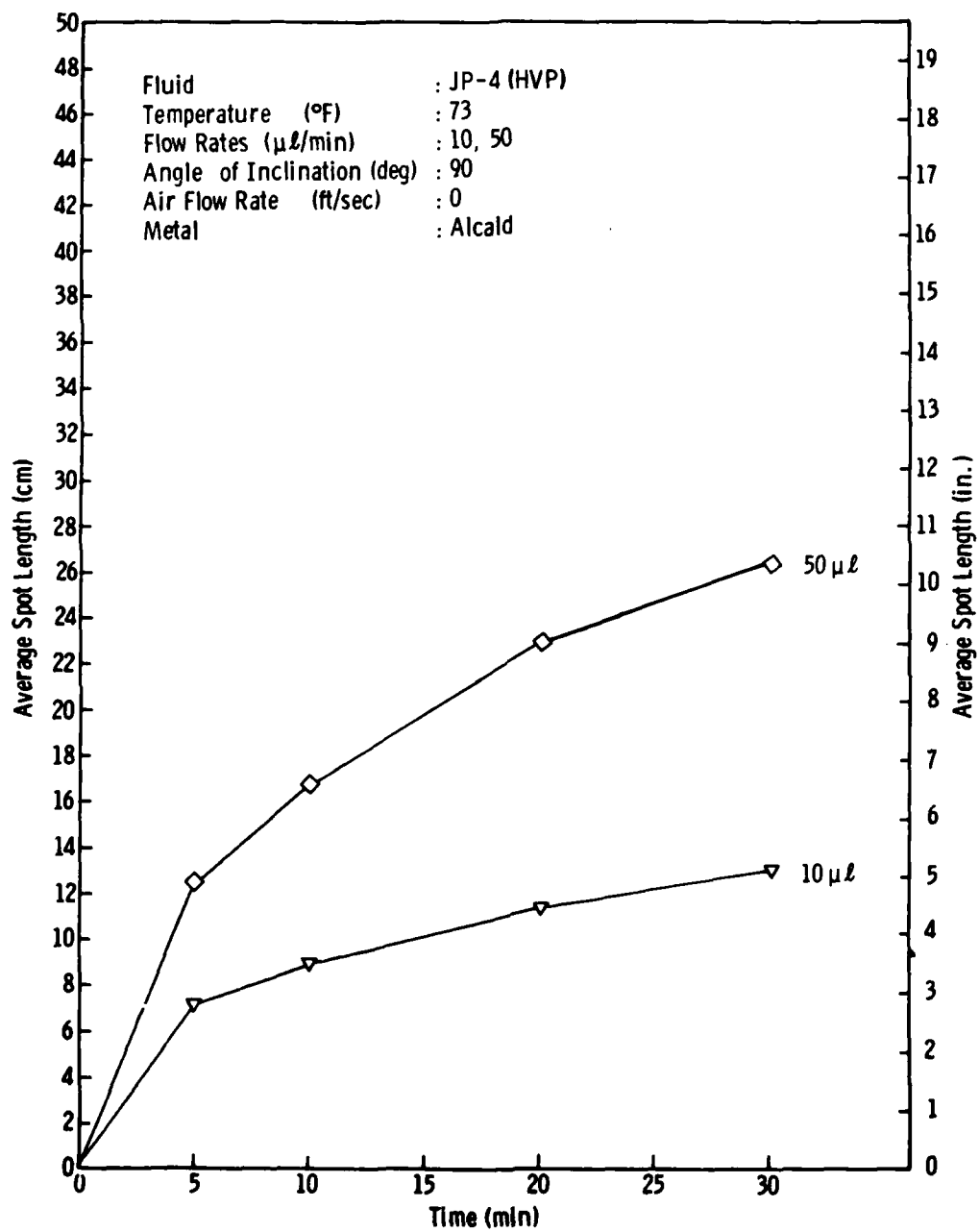


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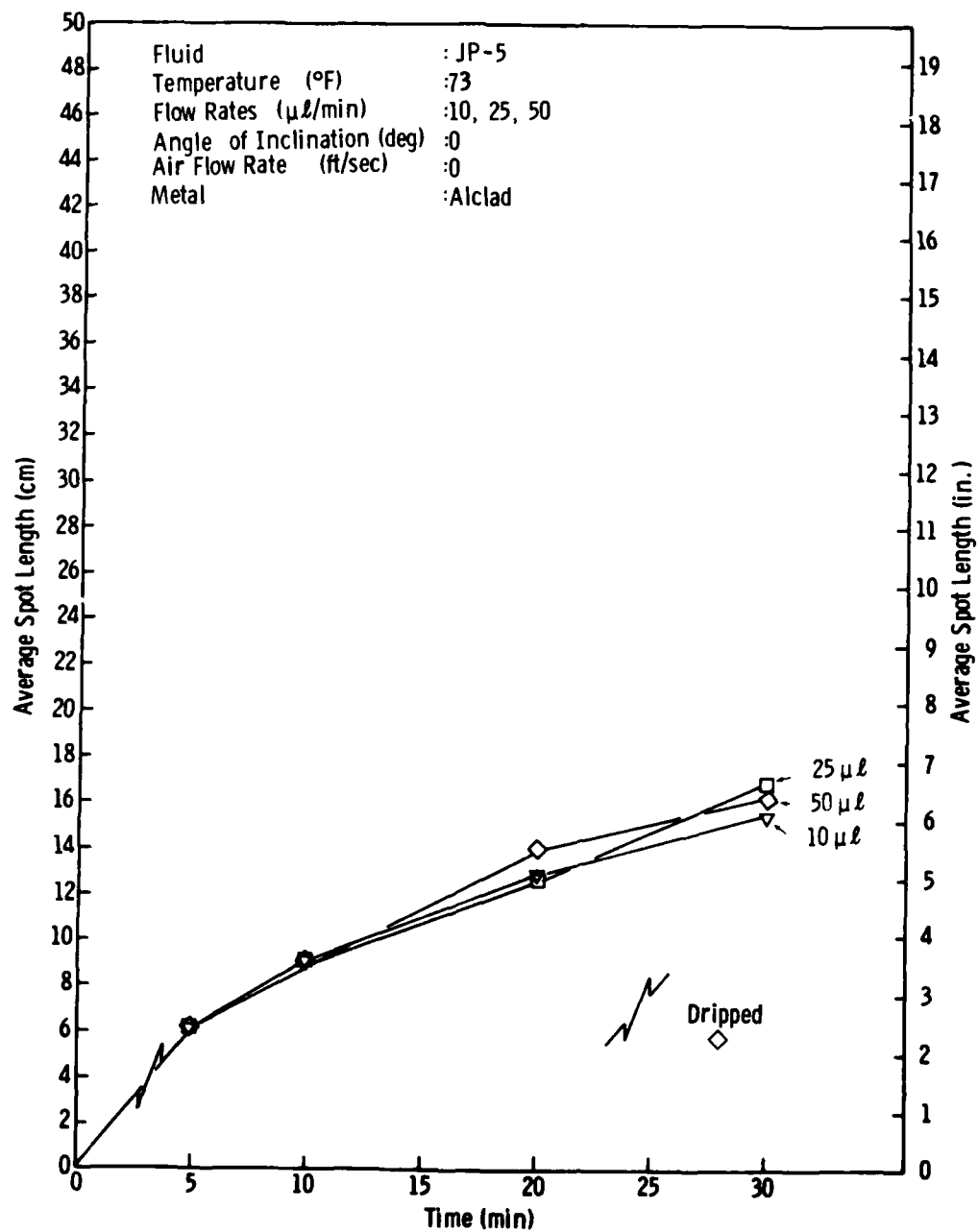


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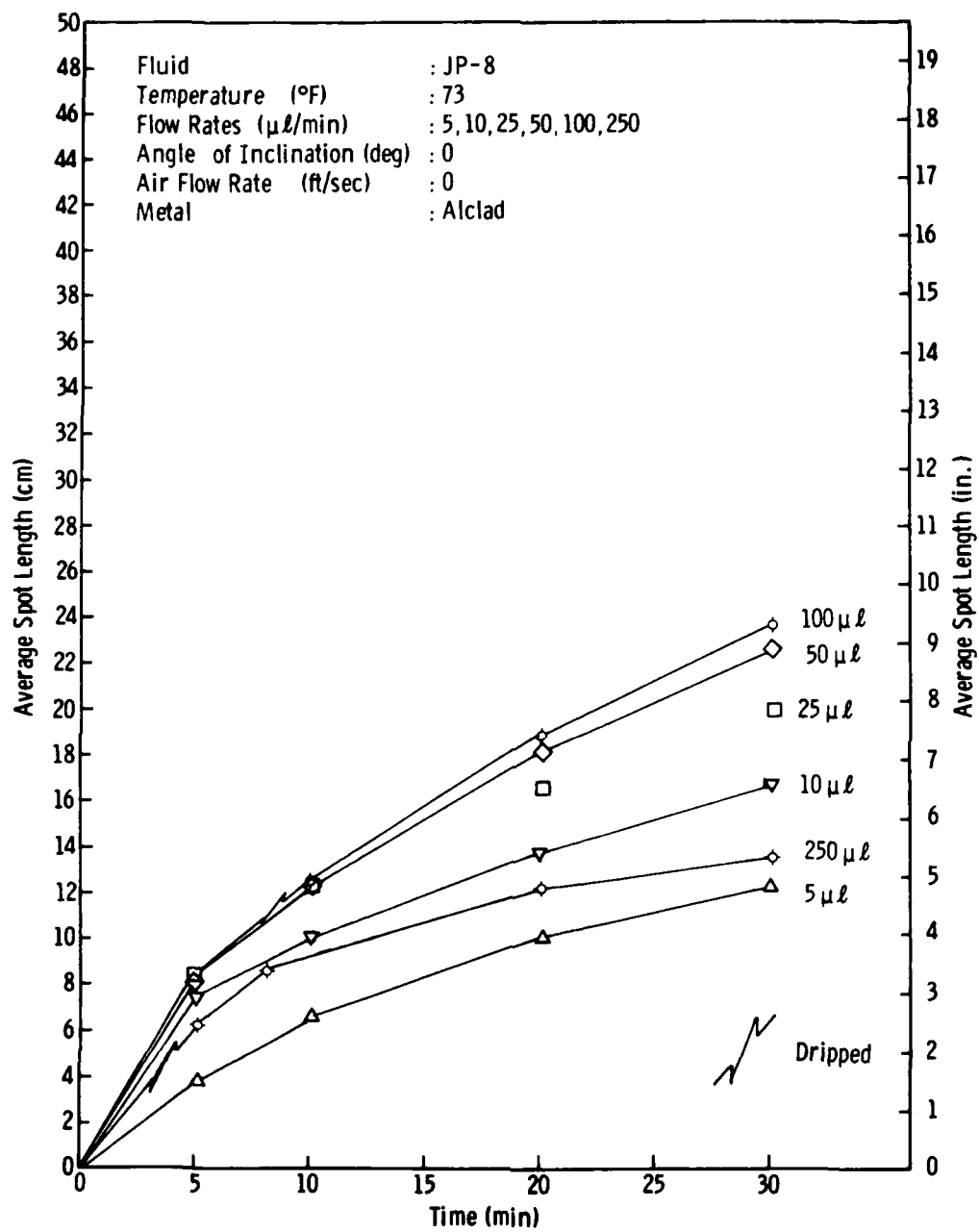


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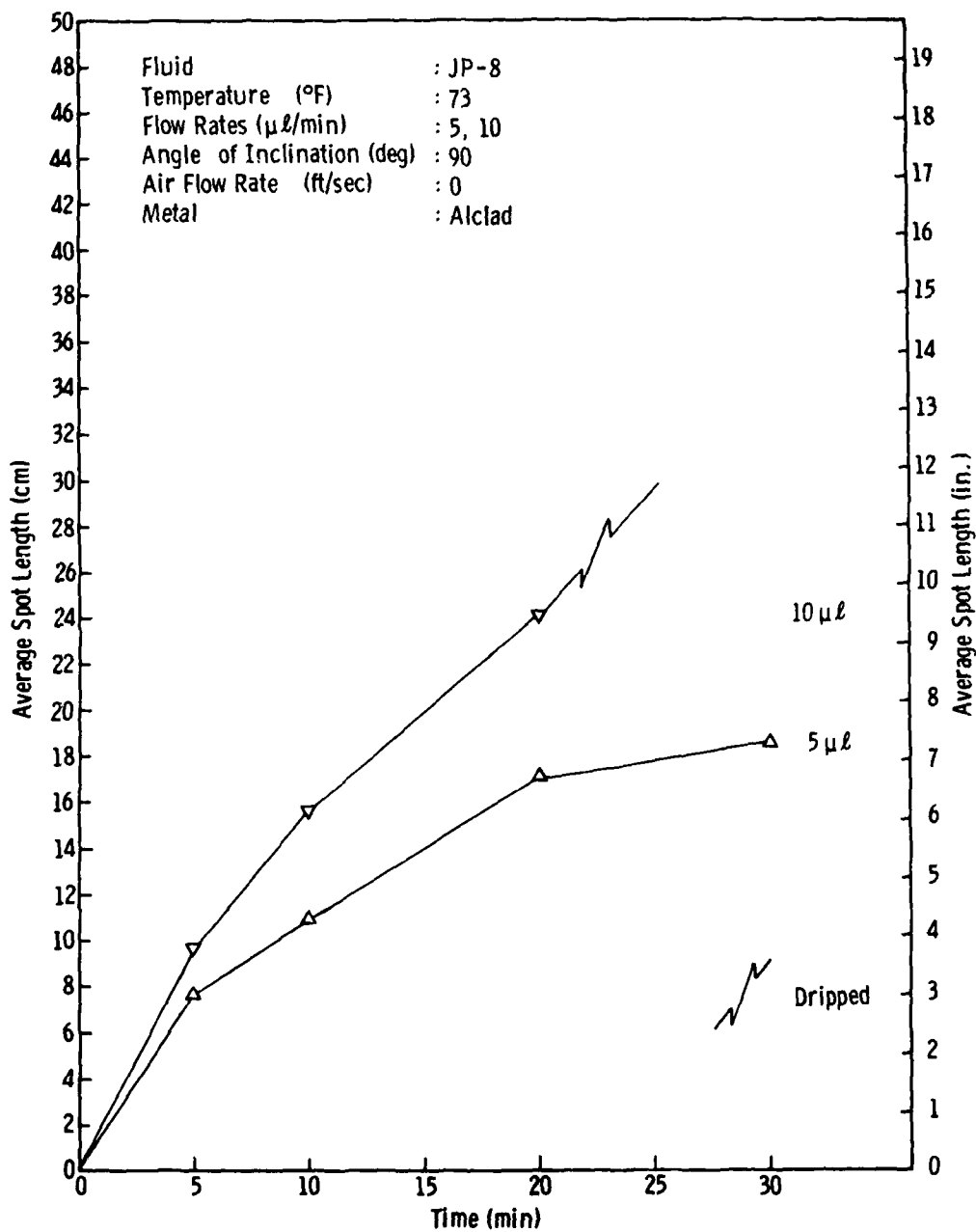


Figure 43.

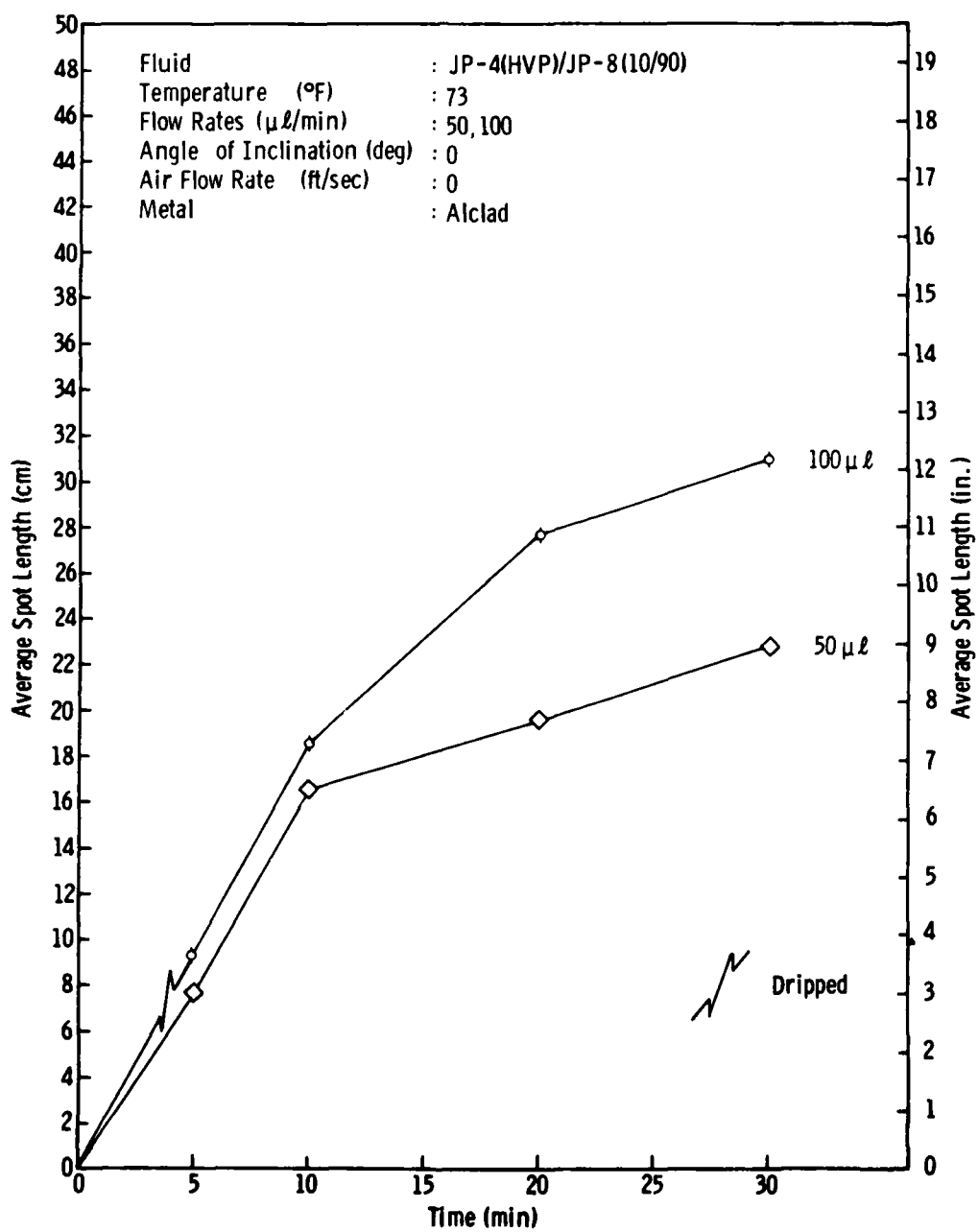


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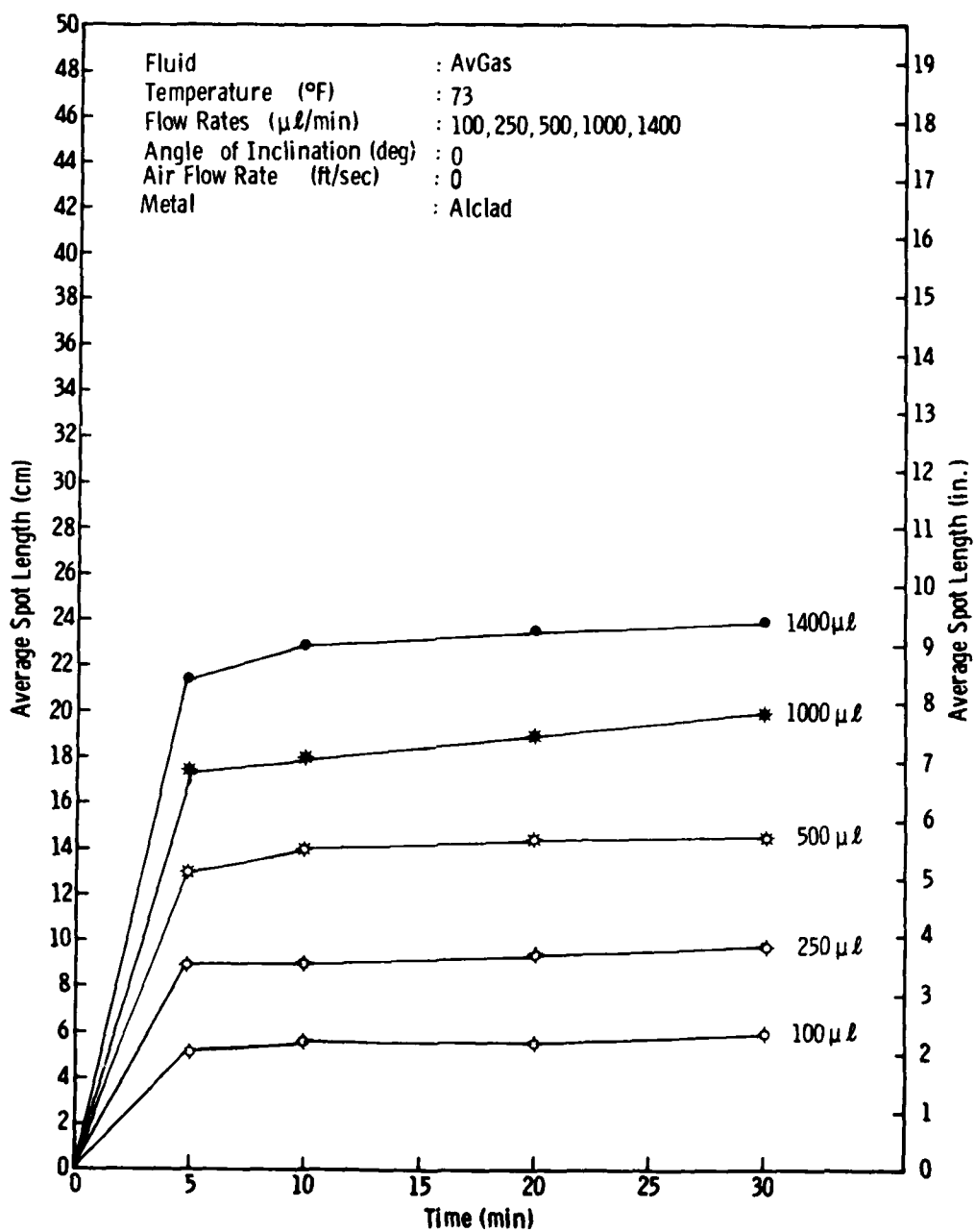


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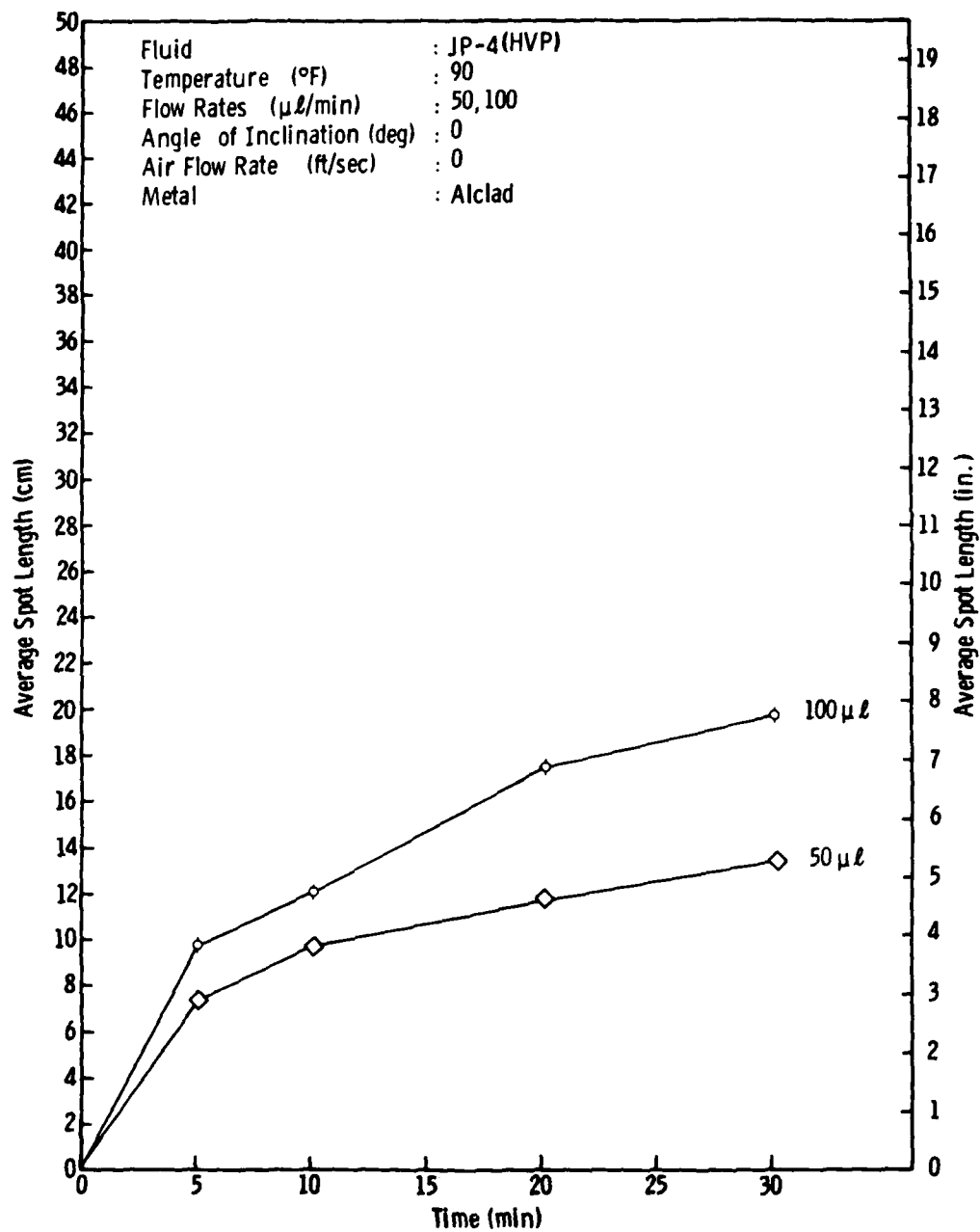


Figure 46.

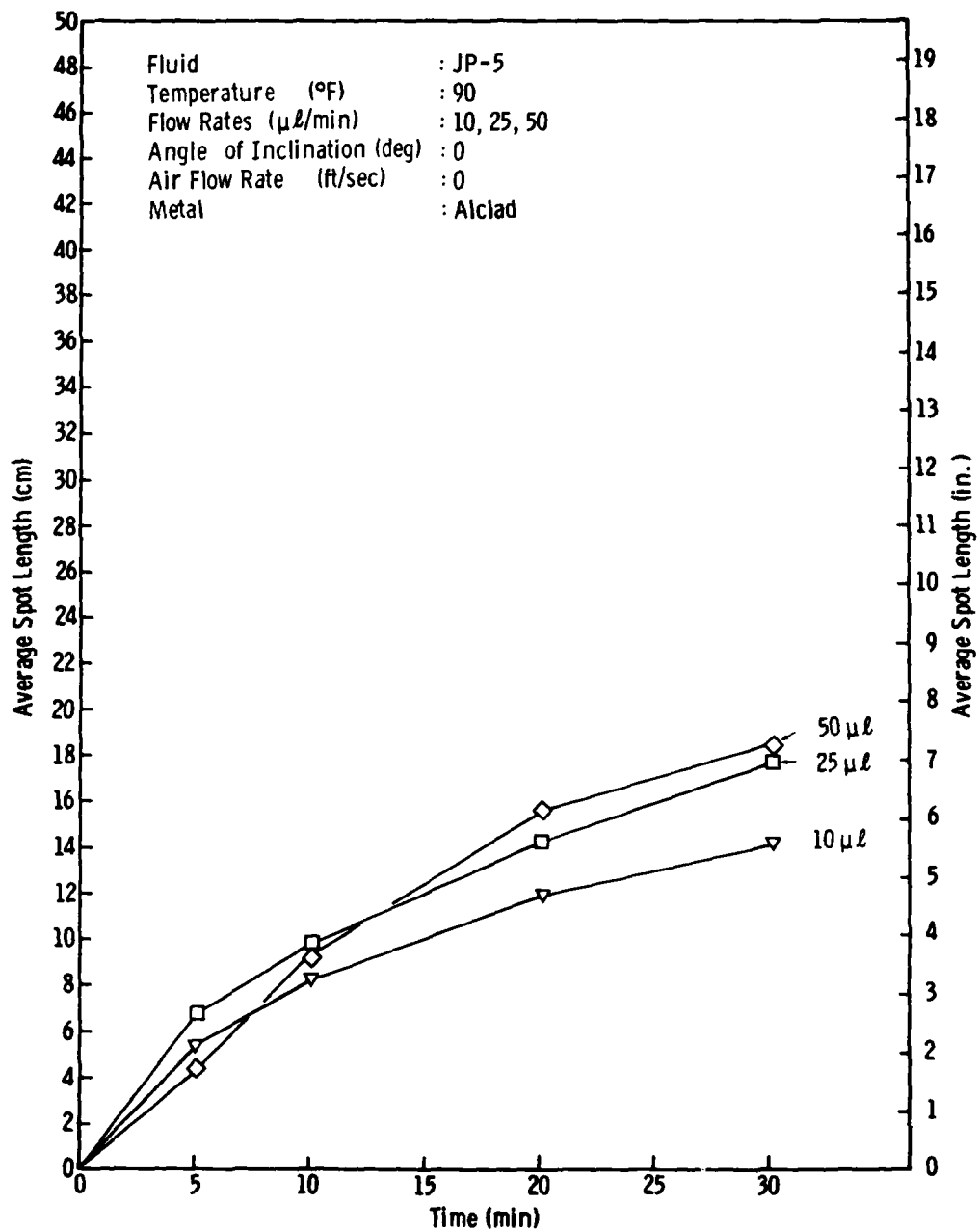


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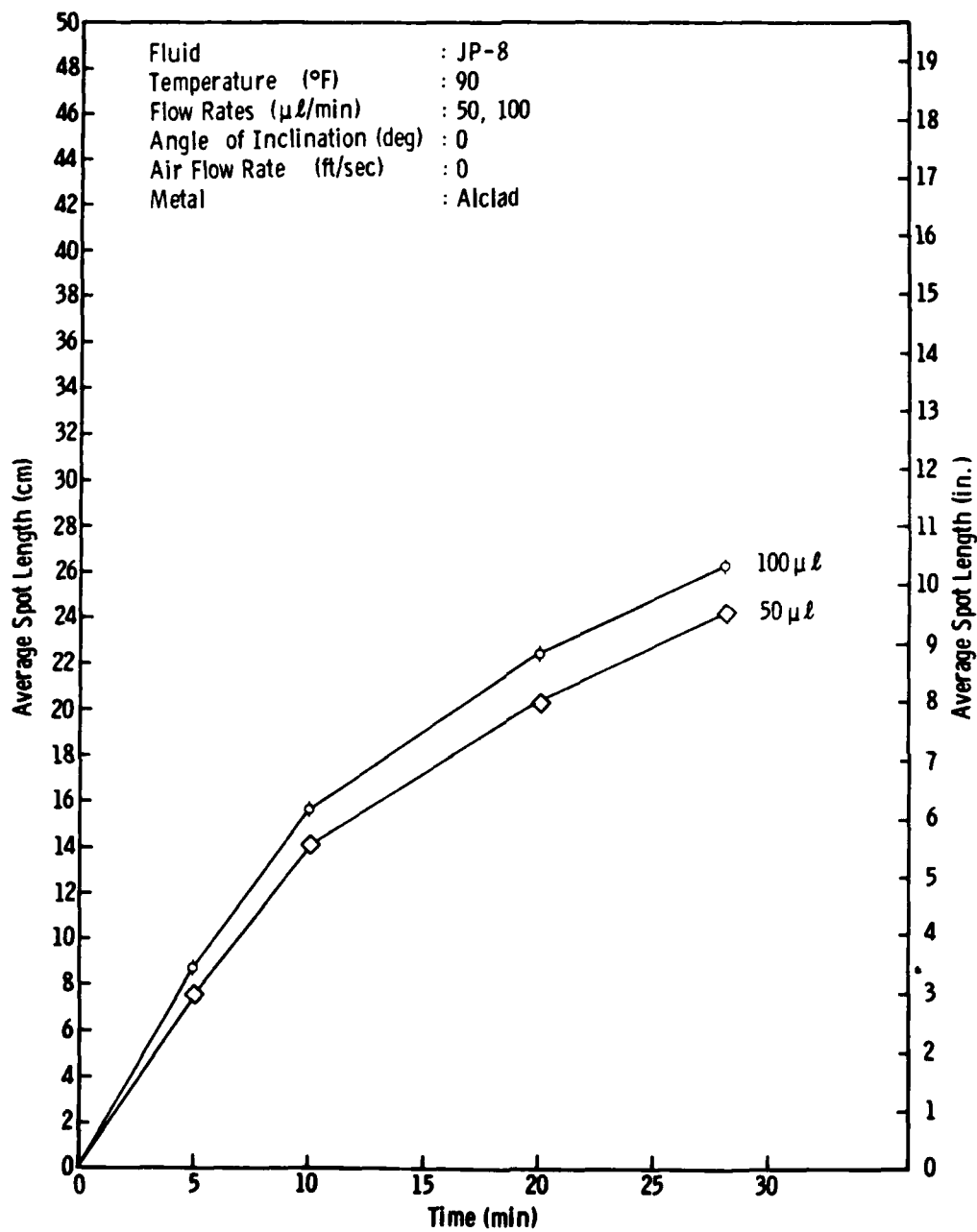


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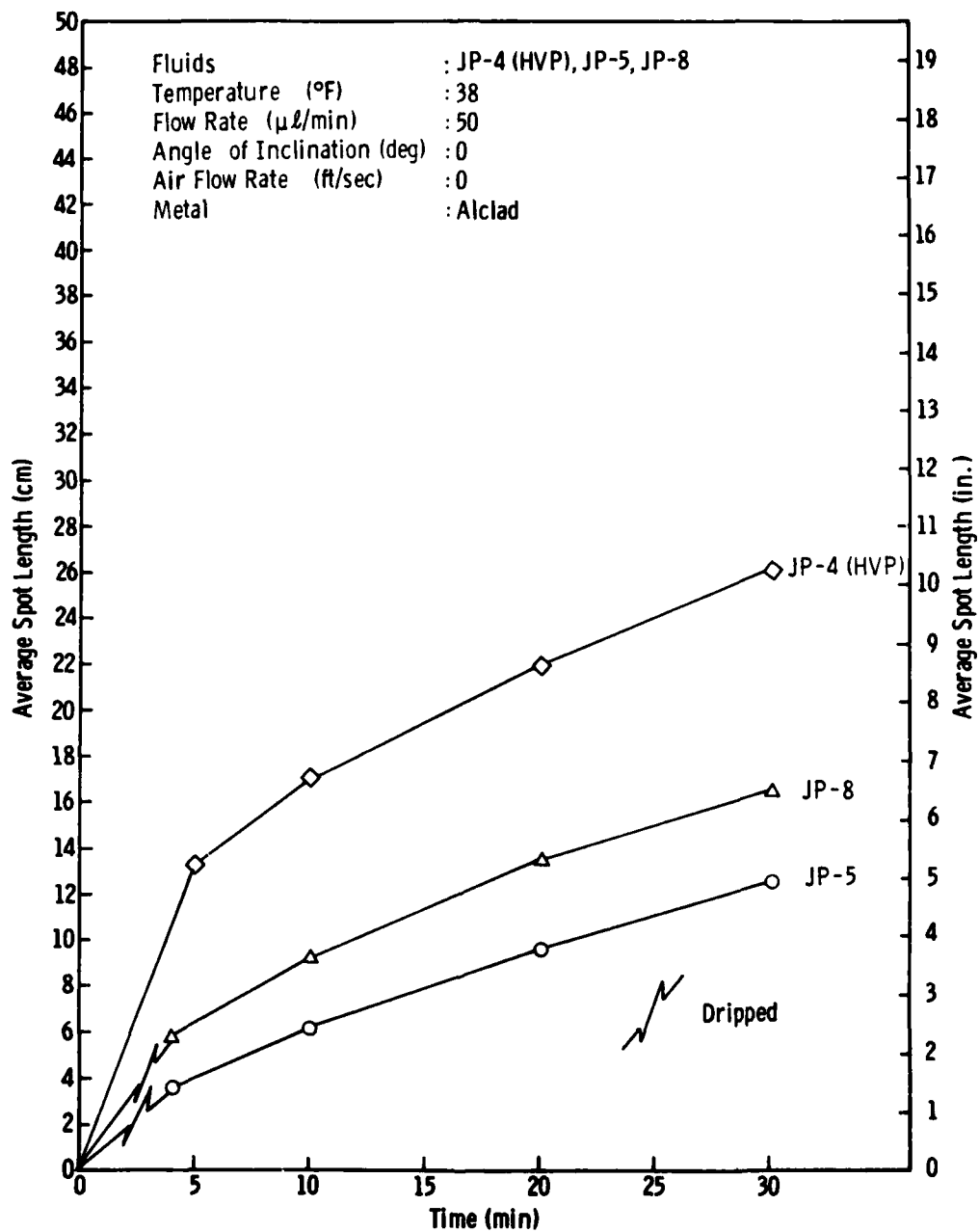


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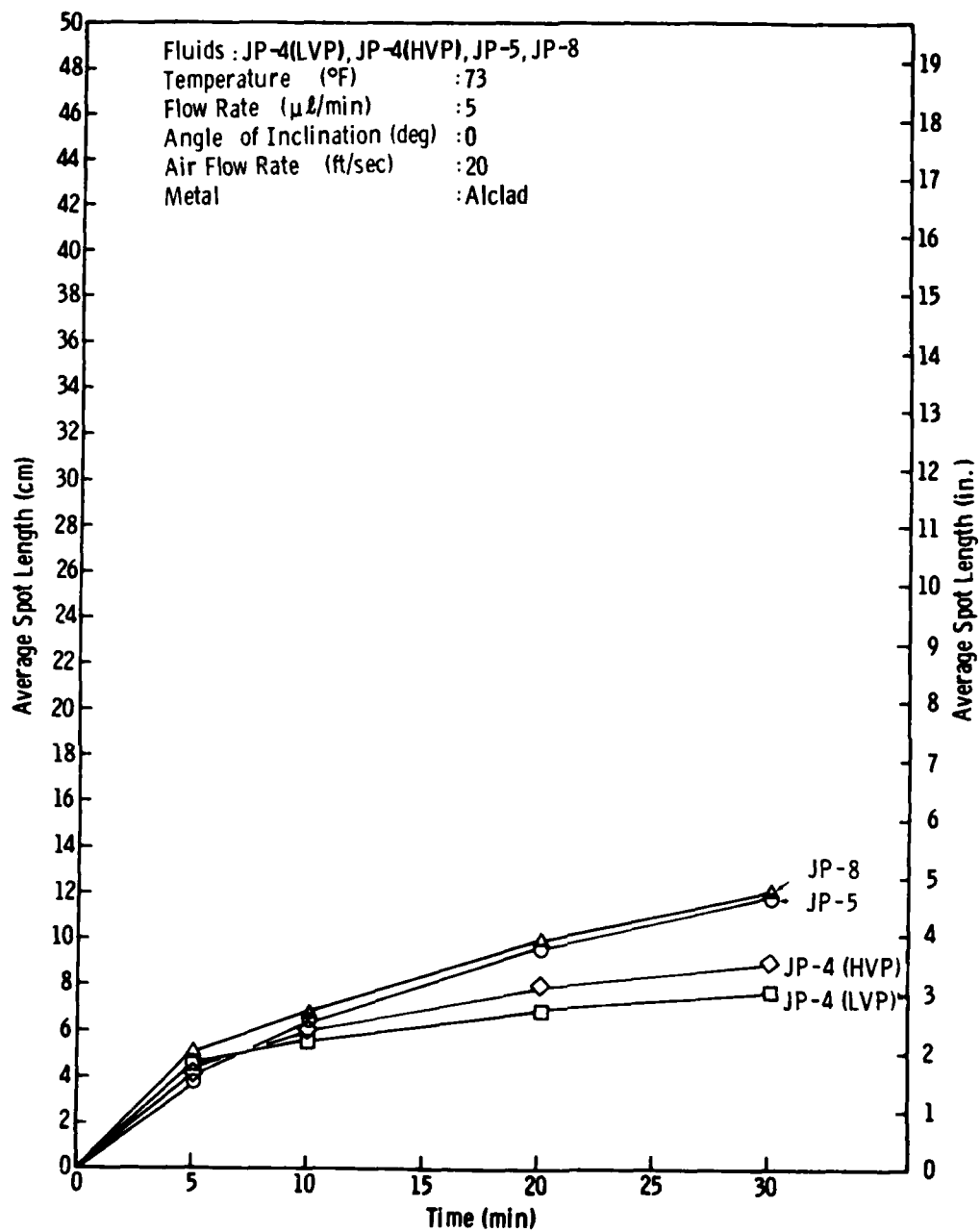


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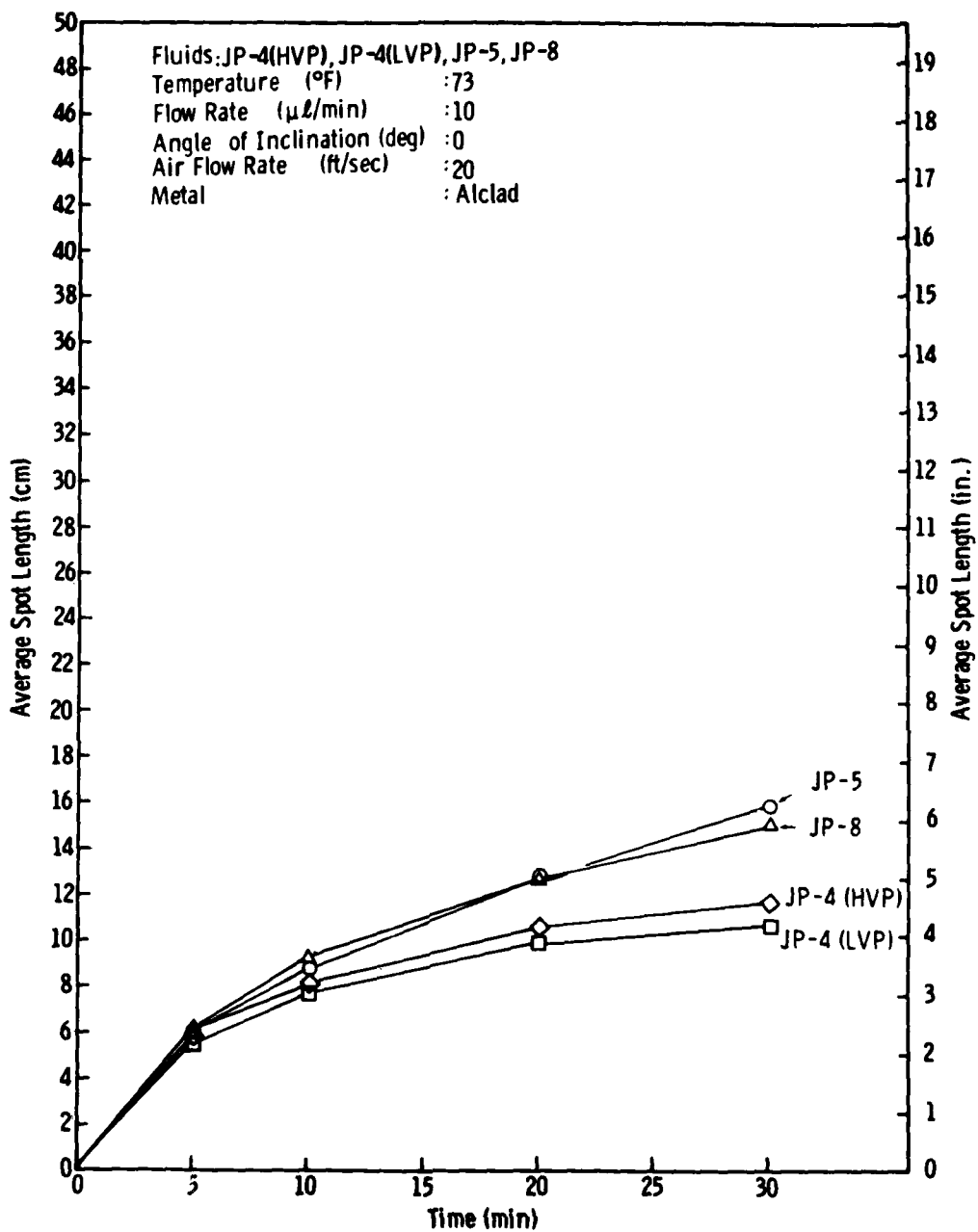


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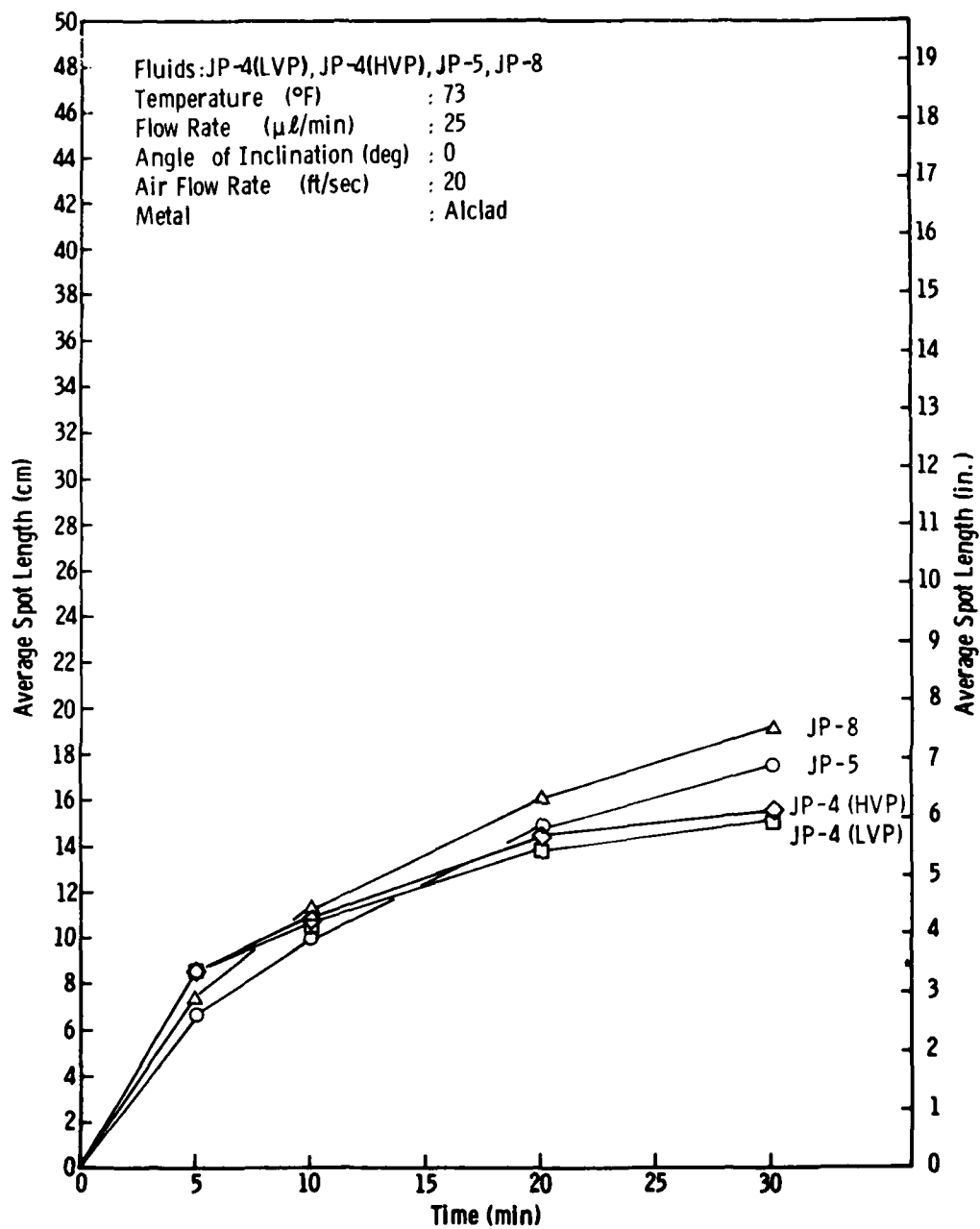


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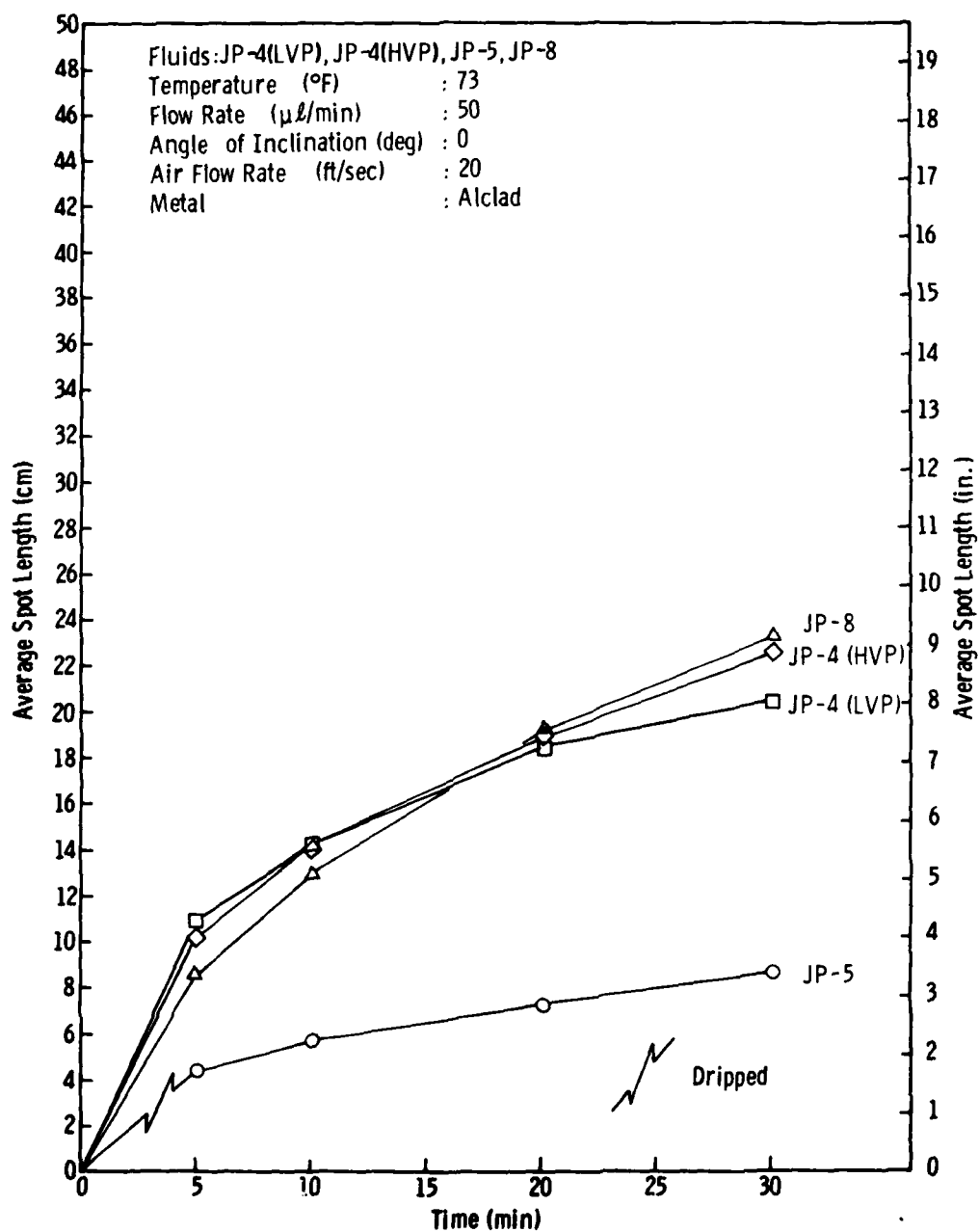


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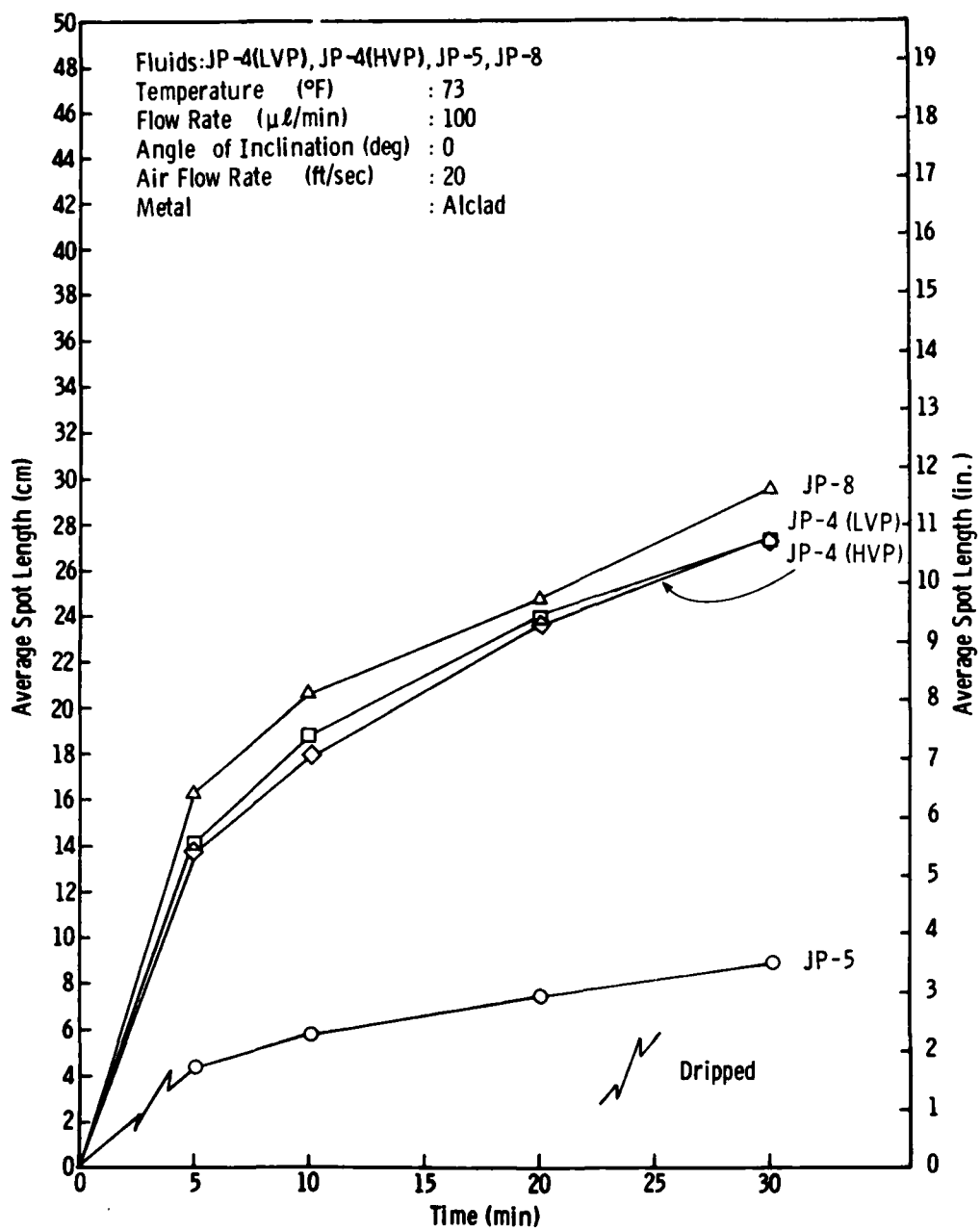


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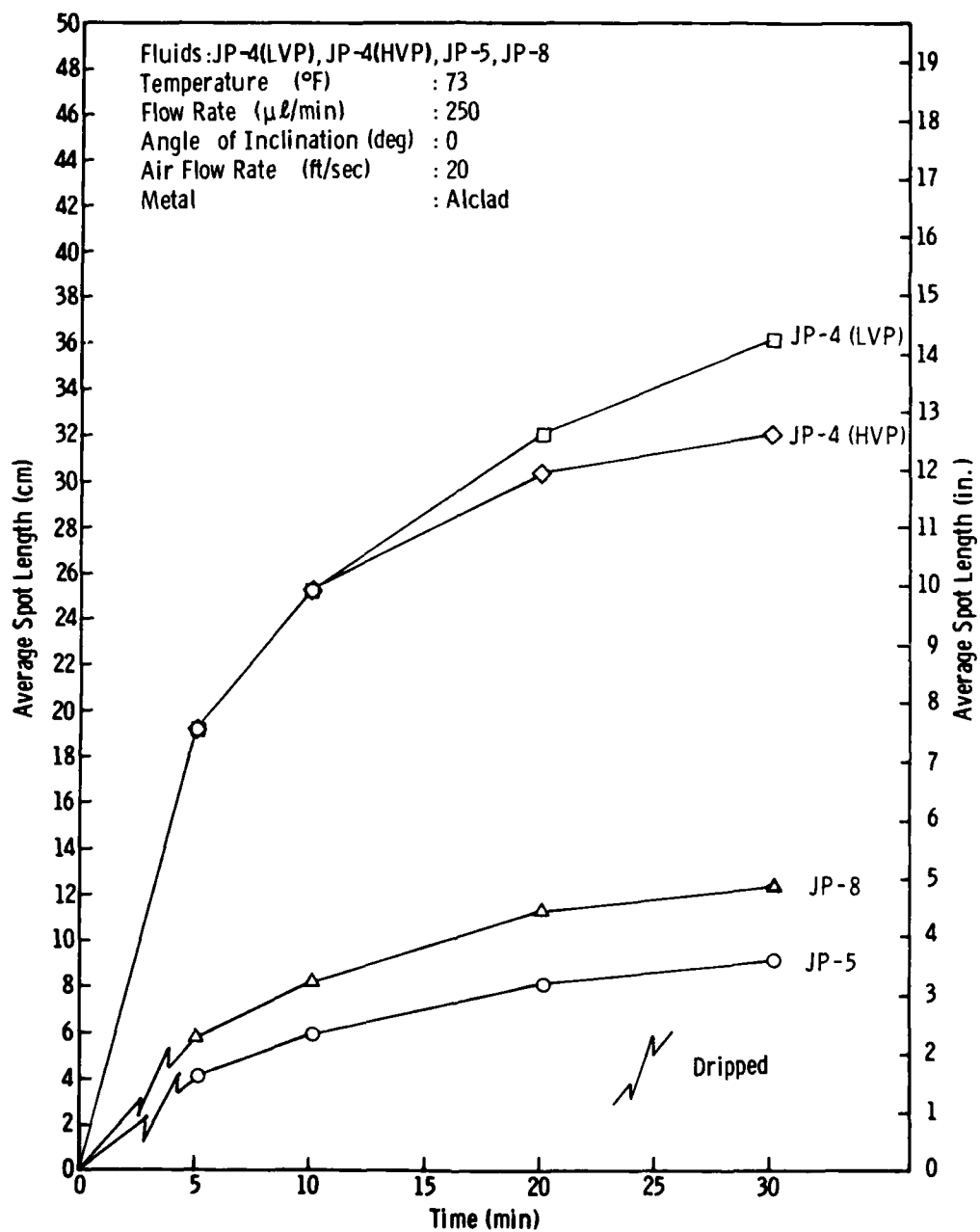


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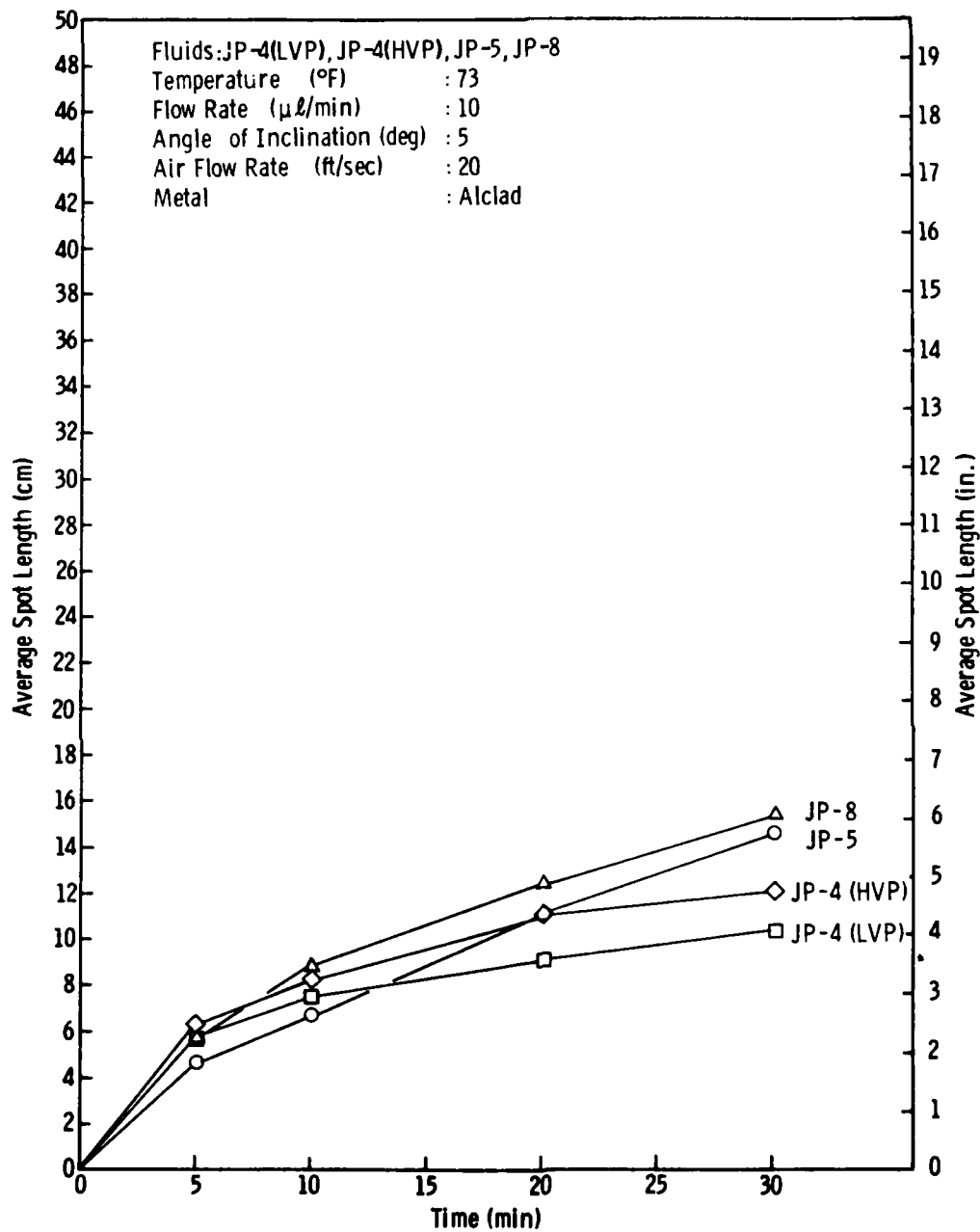


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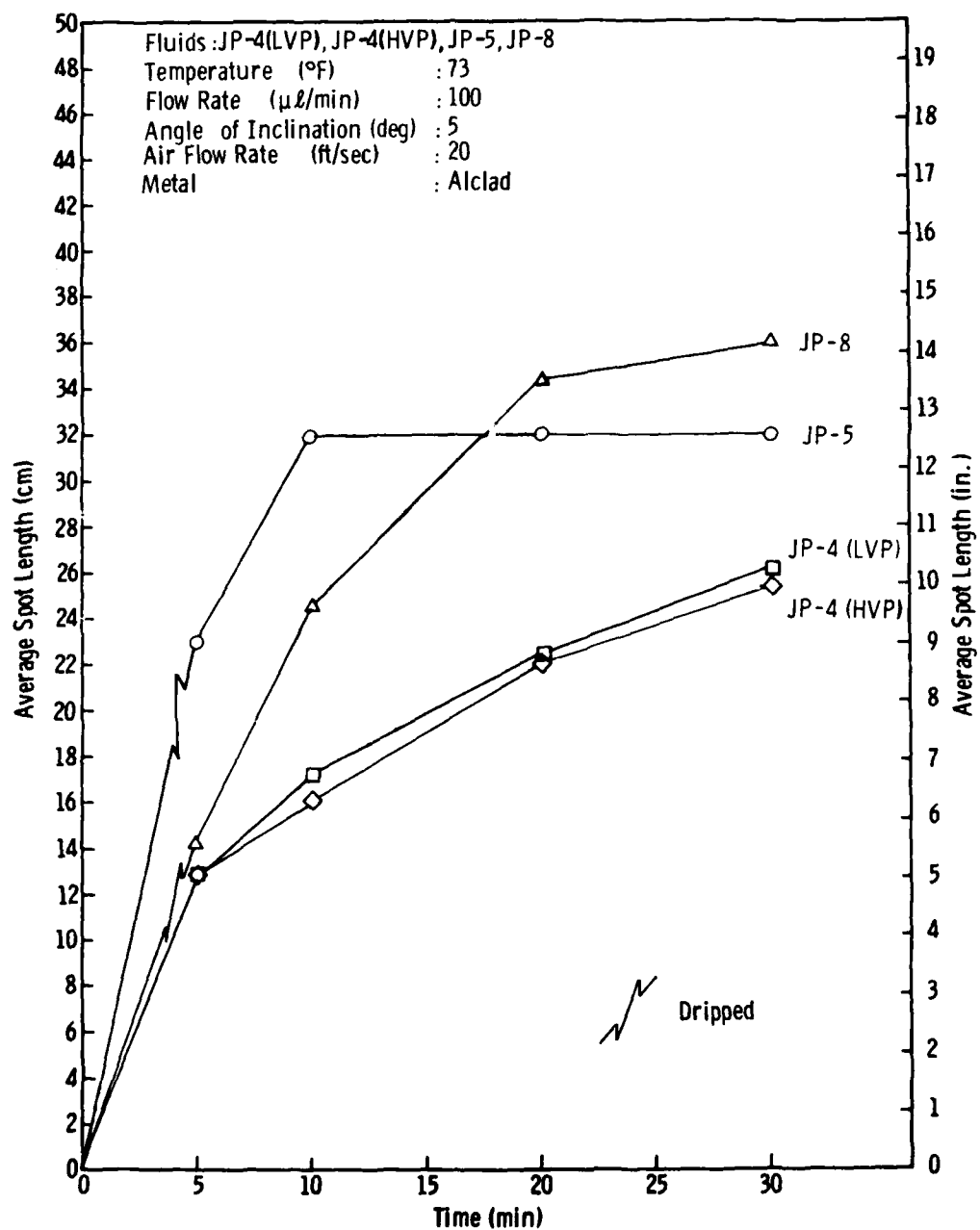


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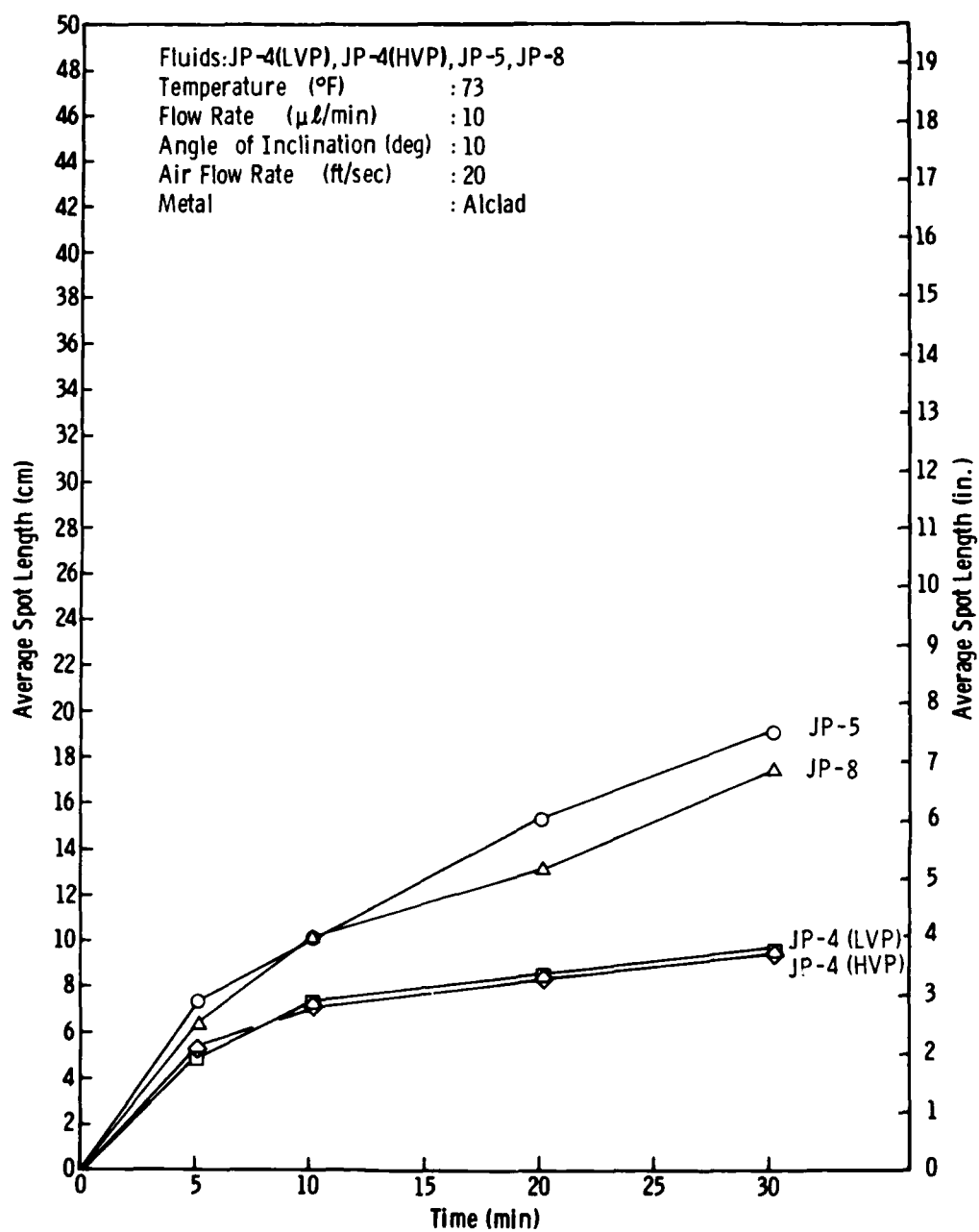


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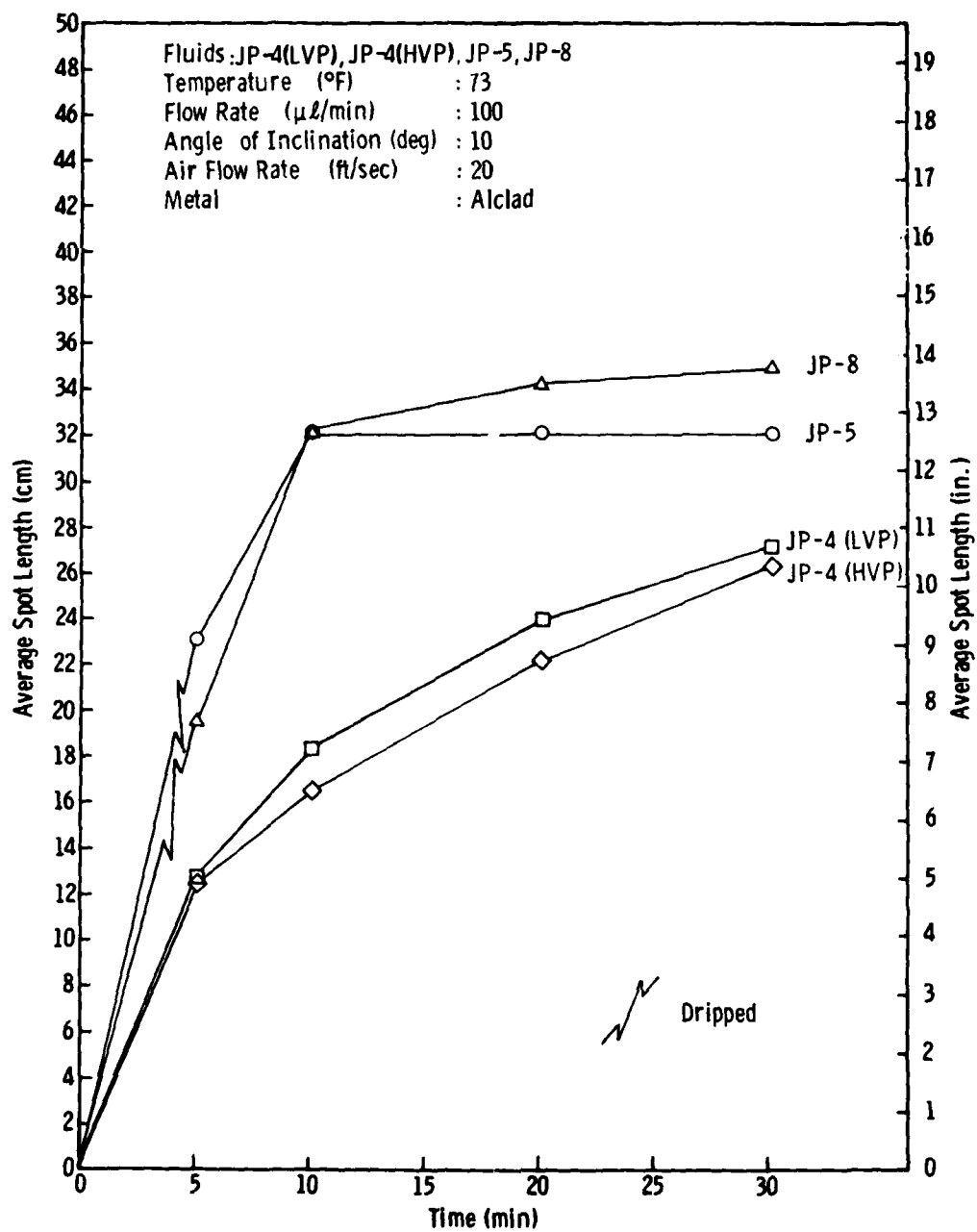


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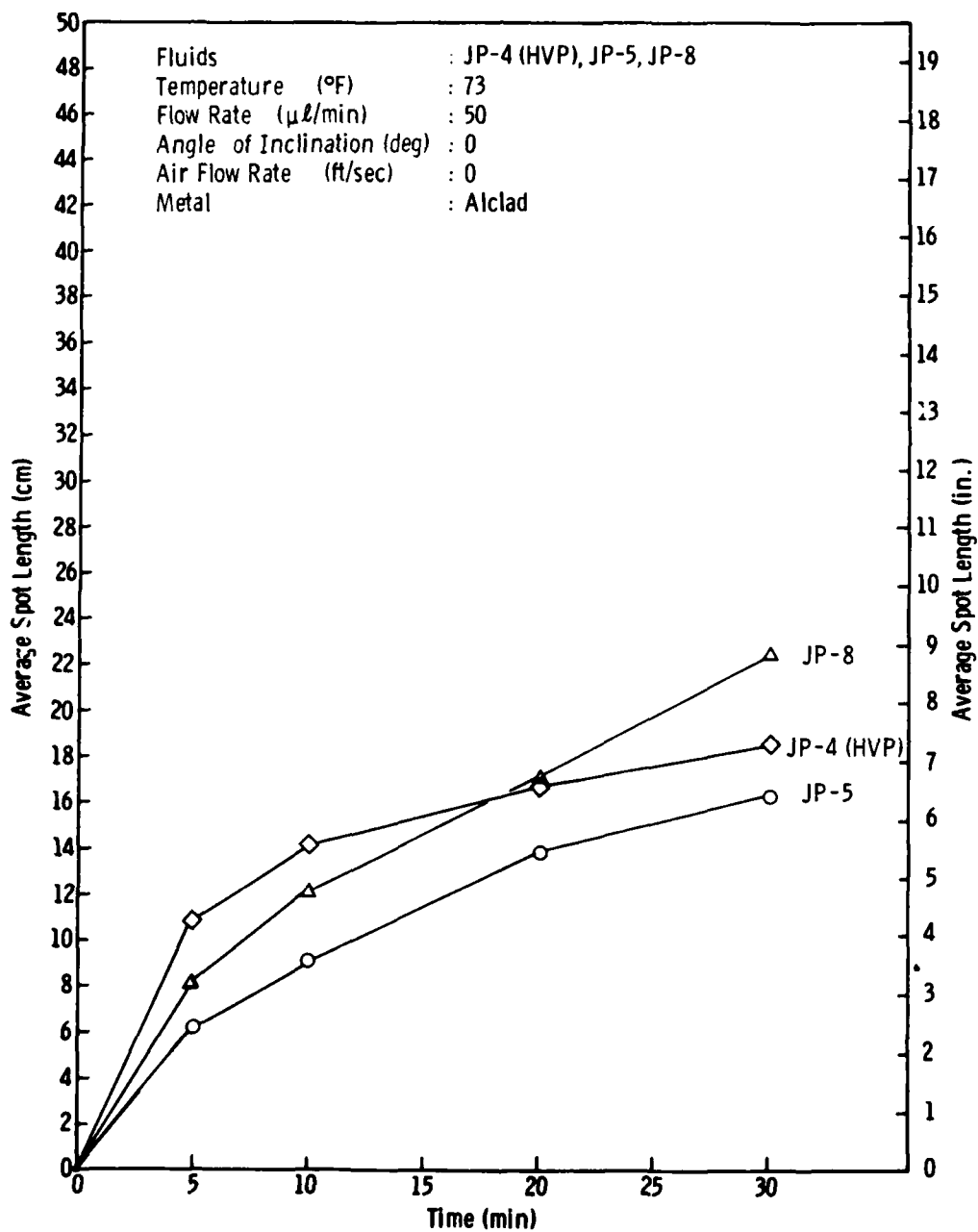


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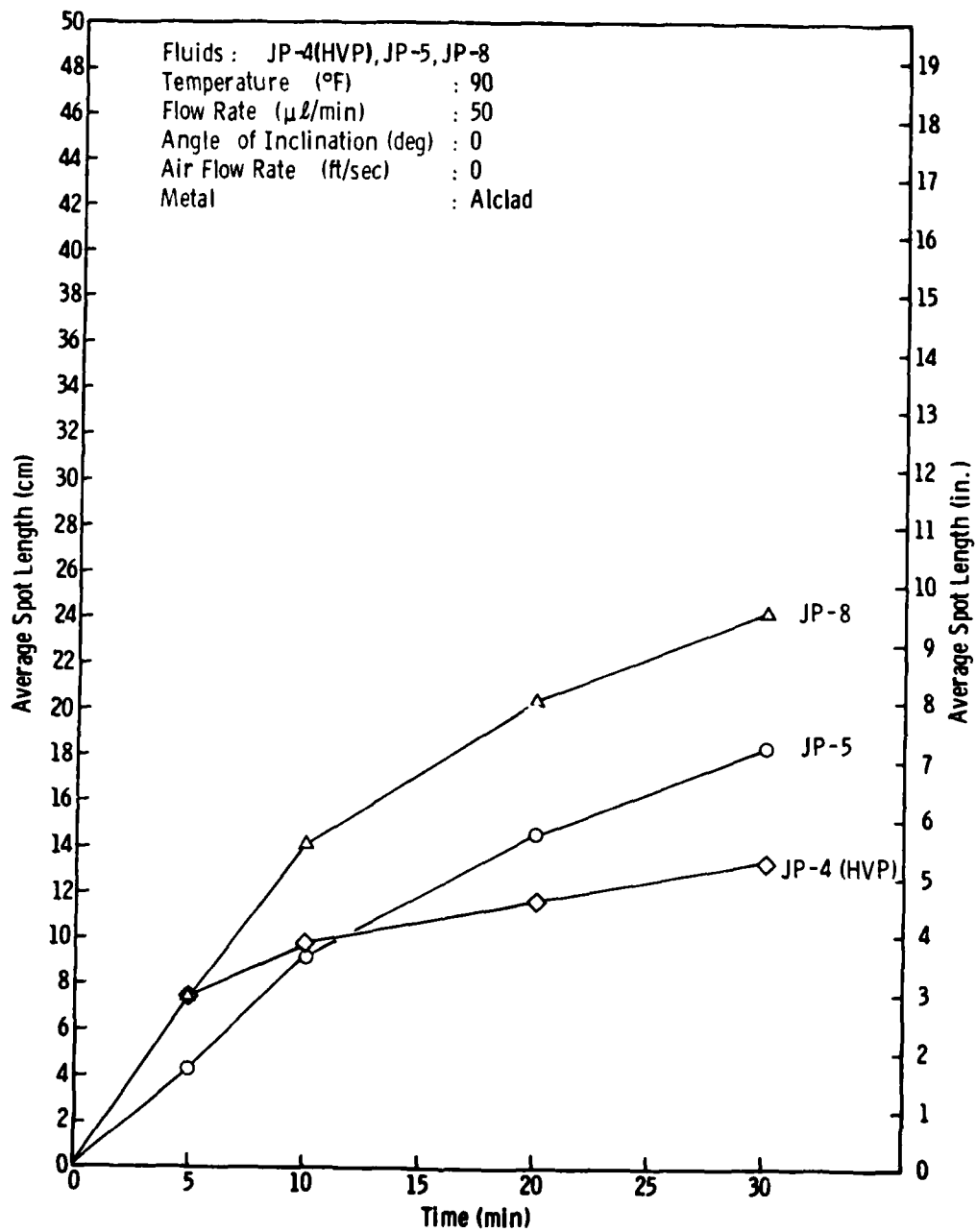


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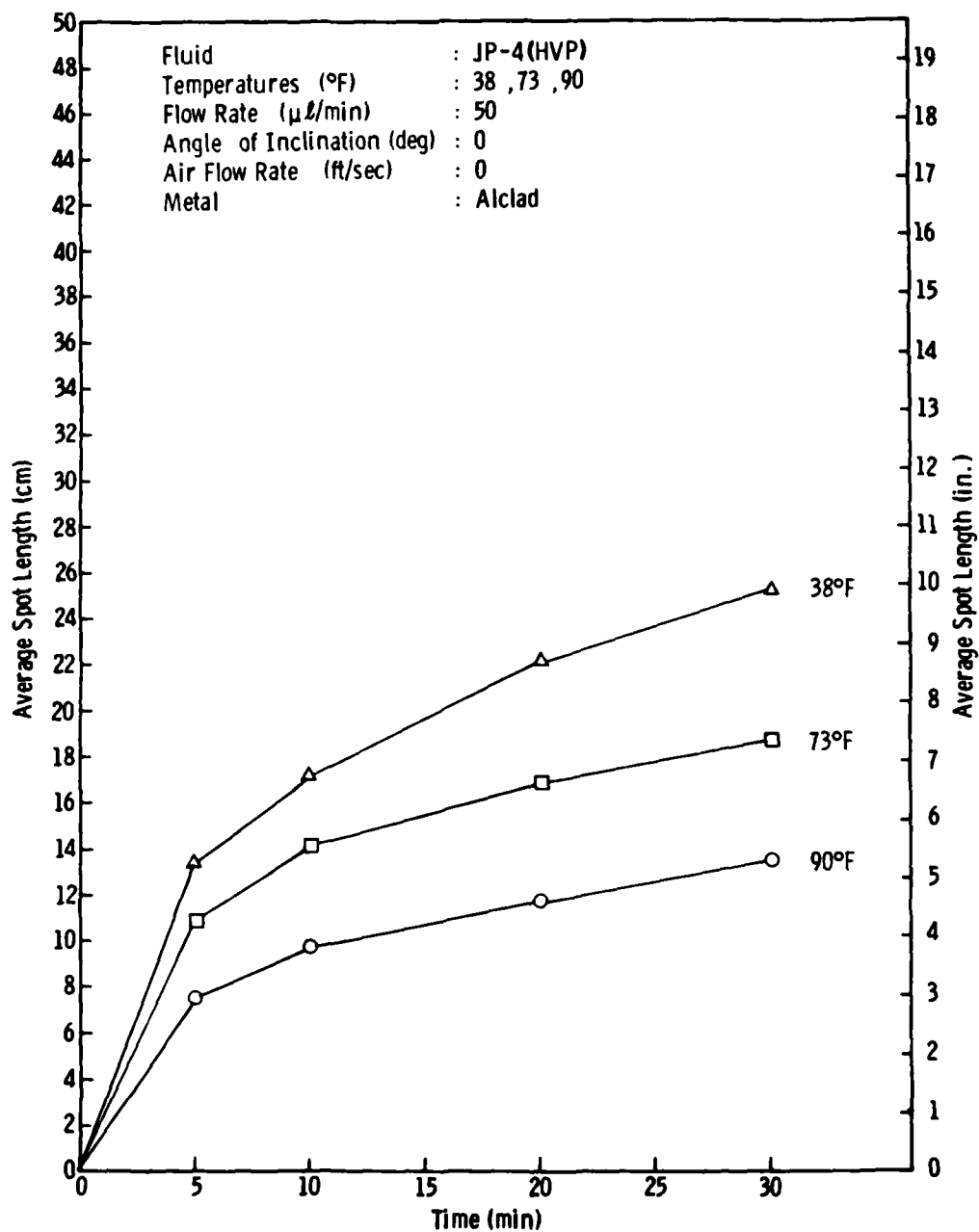


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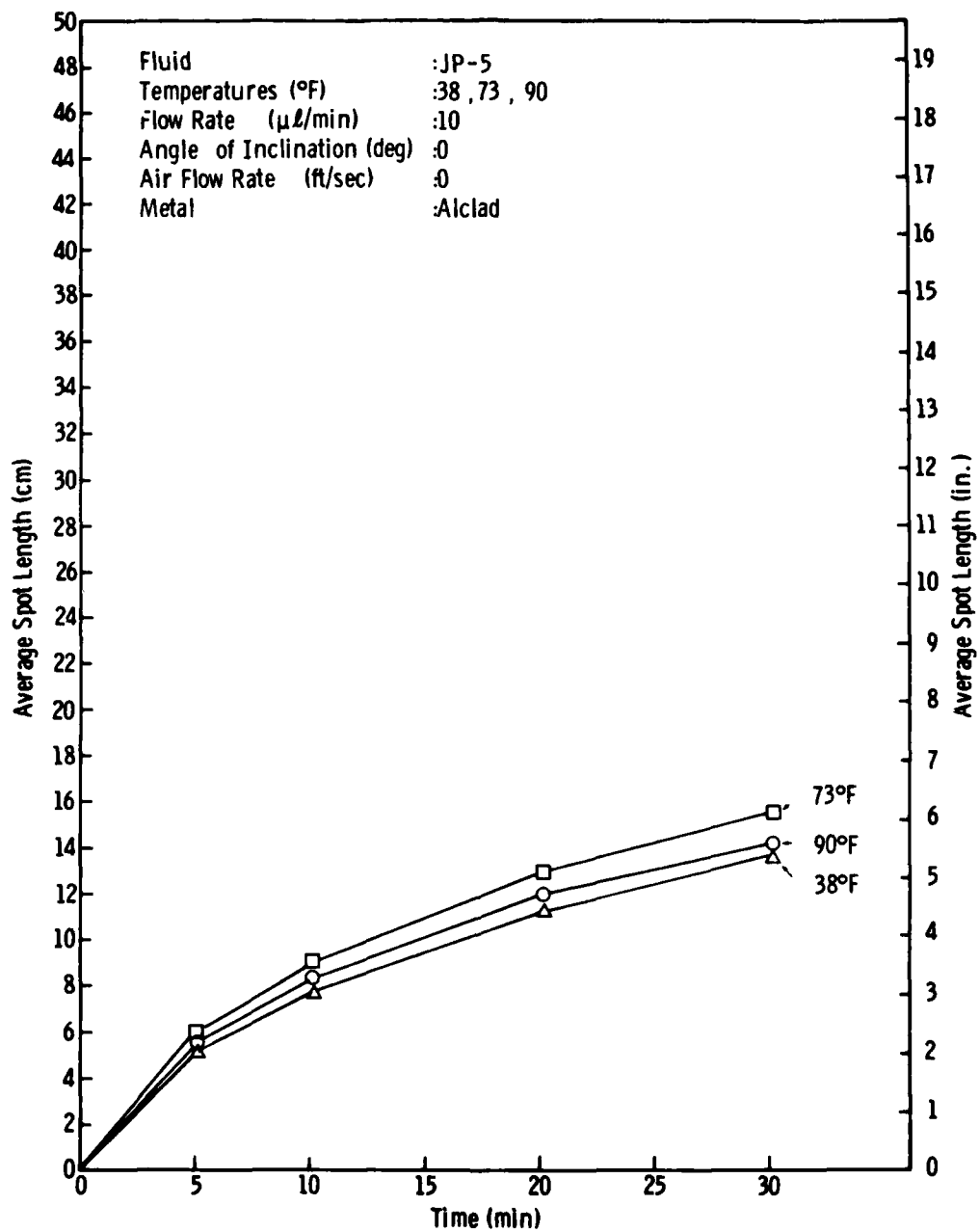


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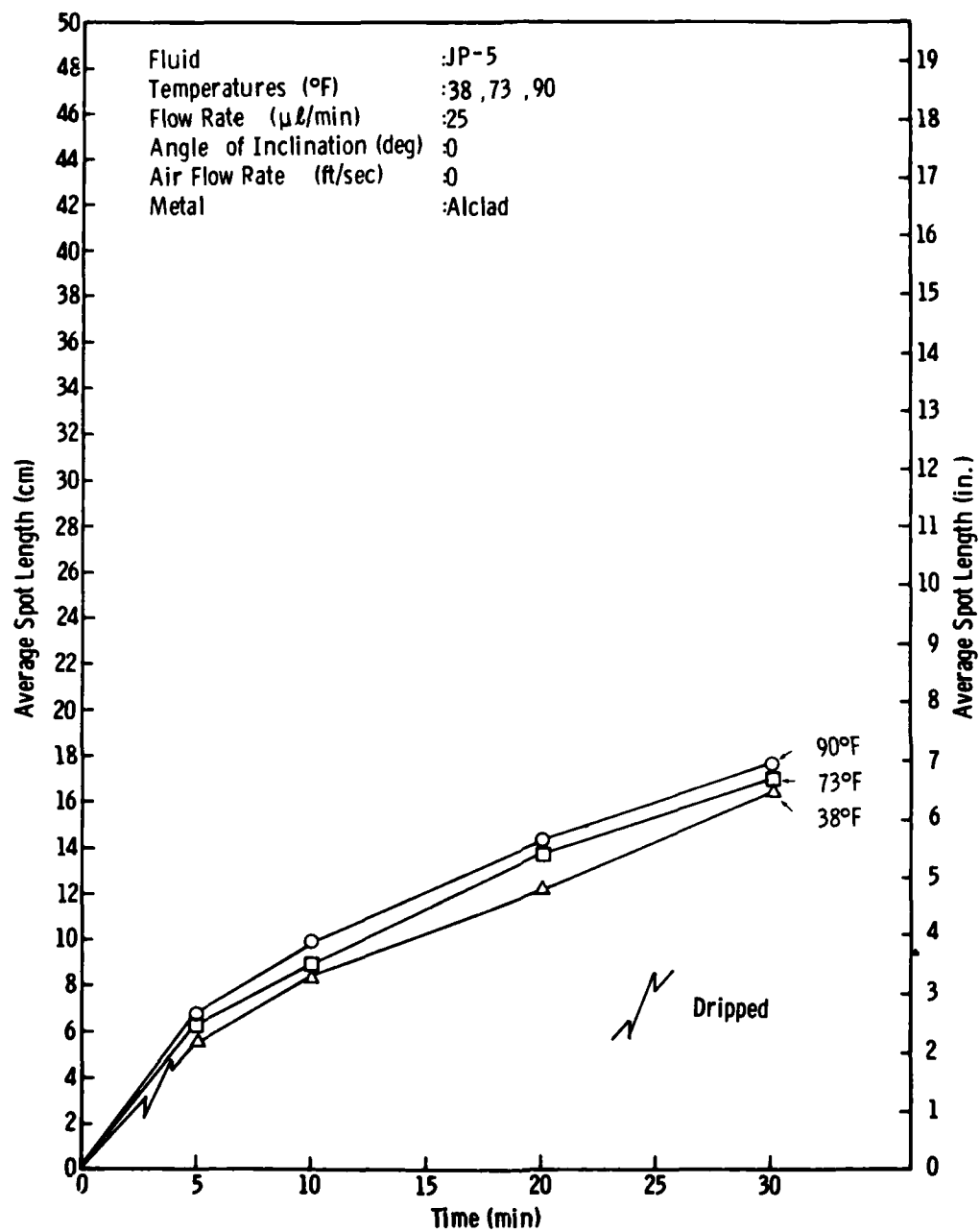


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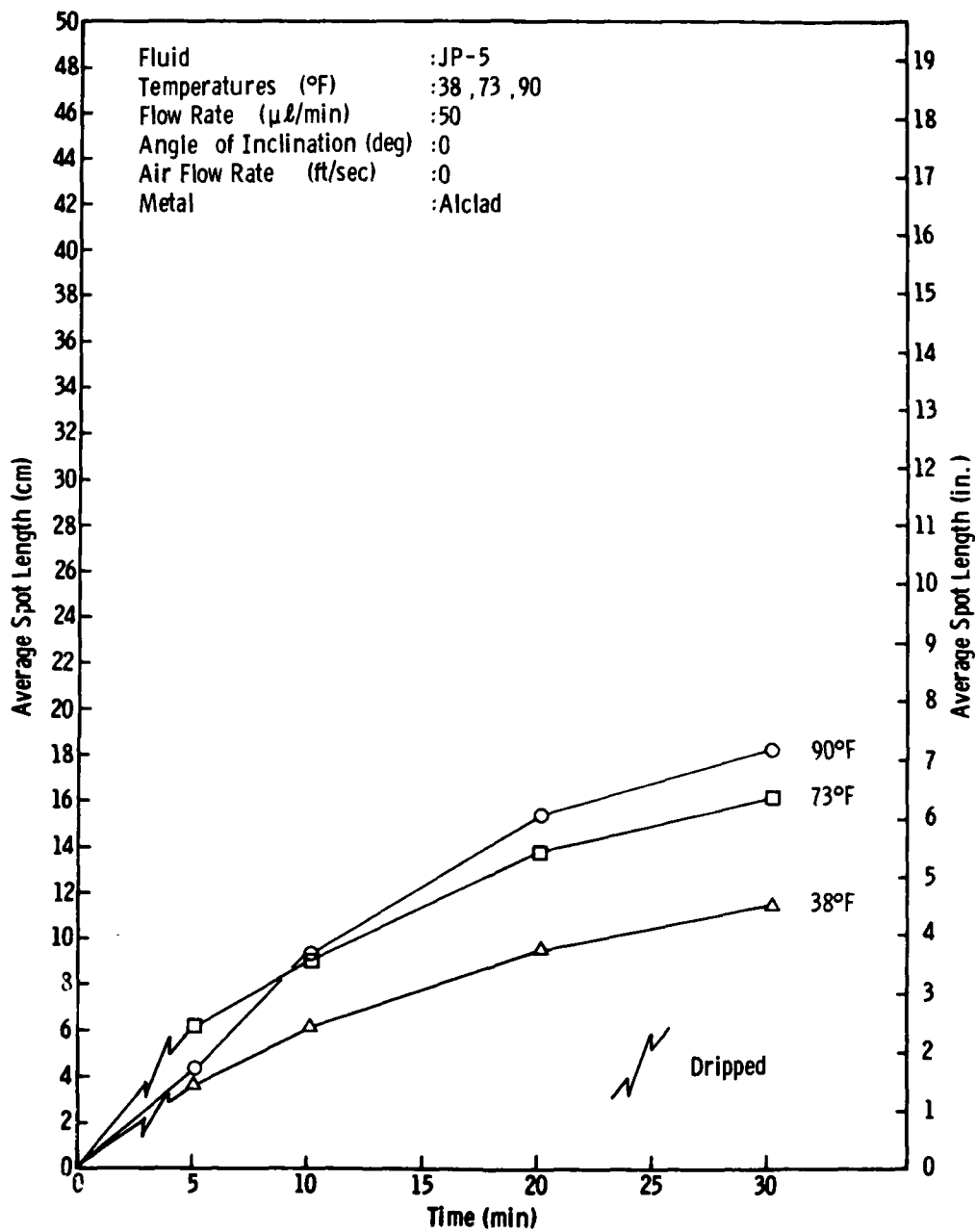


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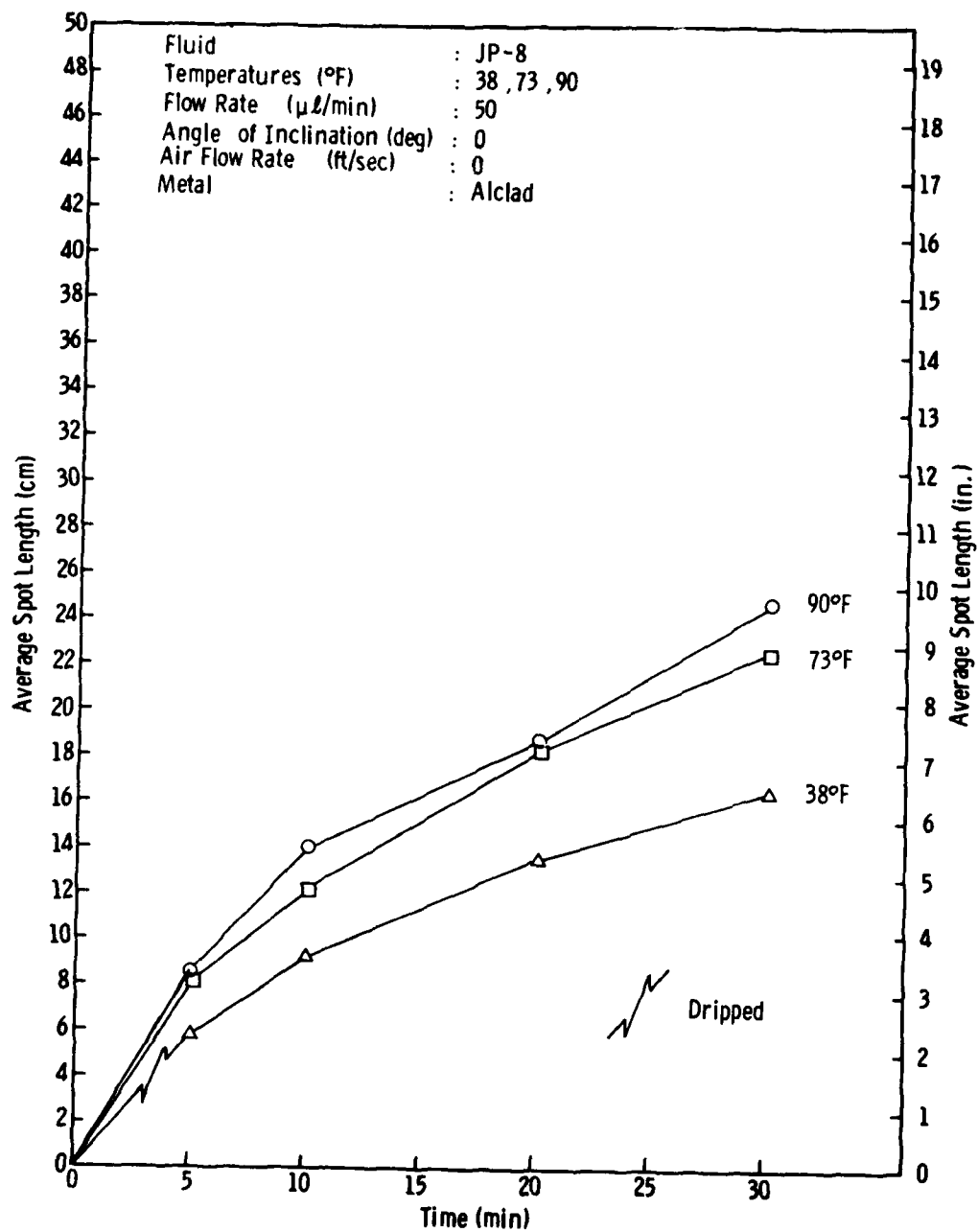


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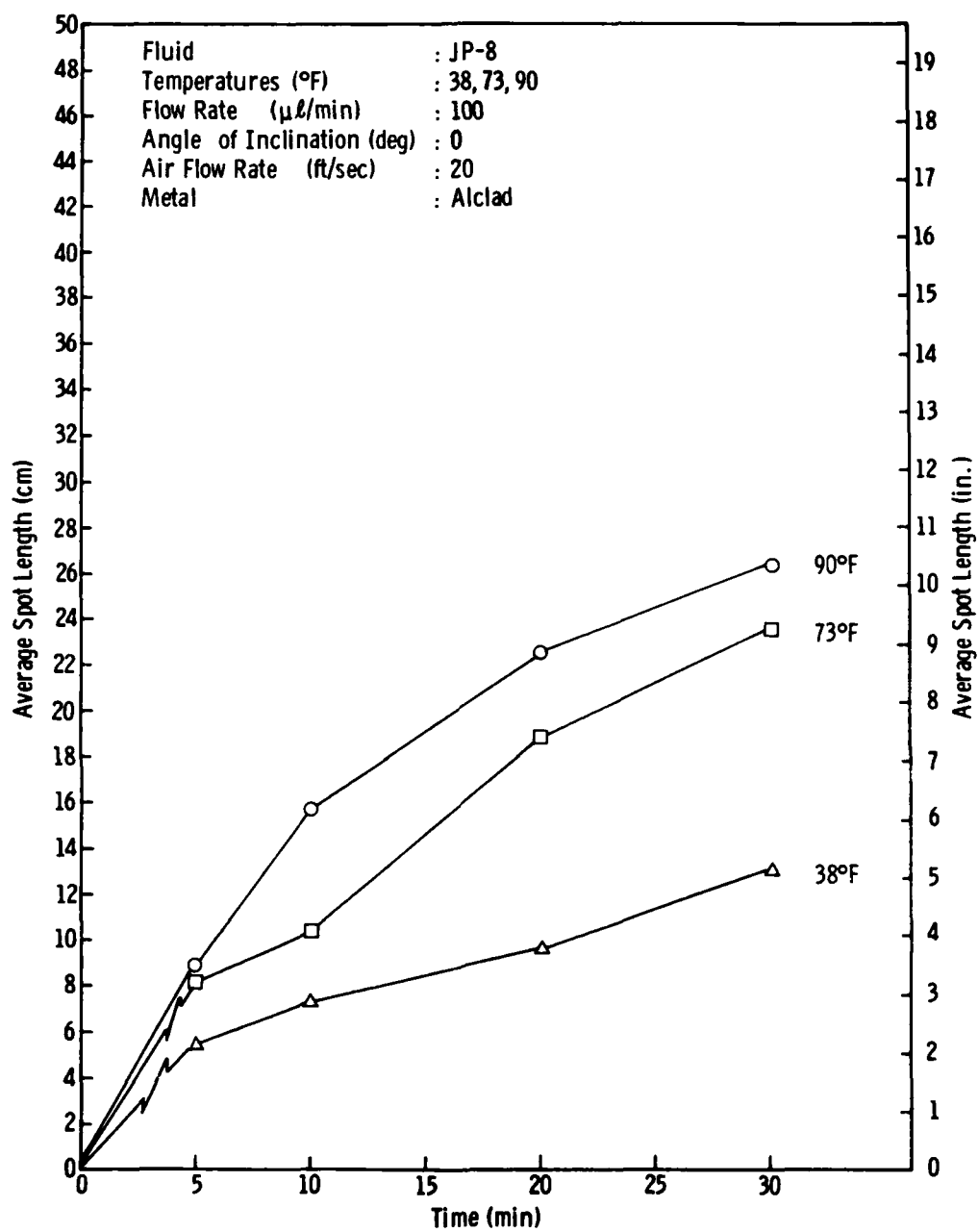


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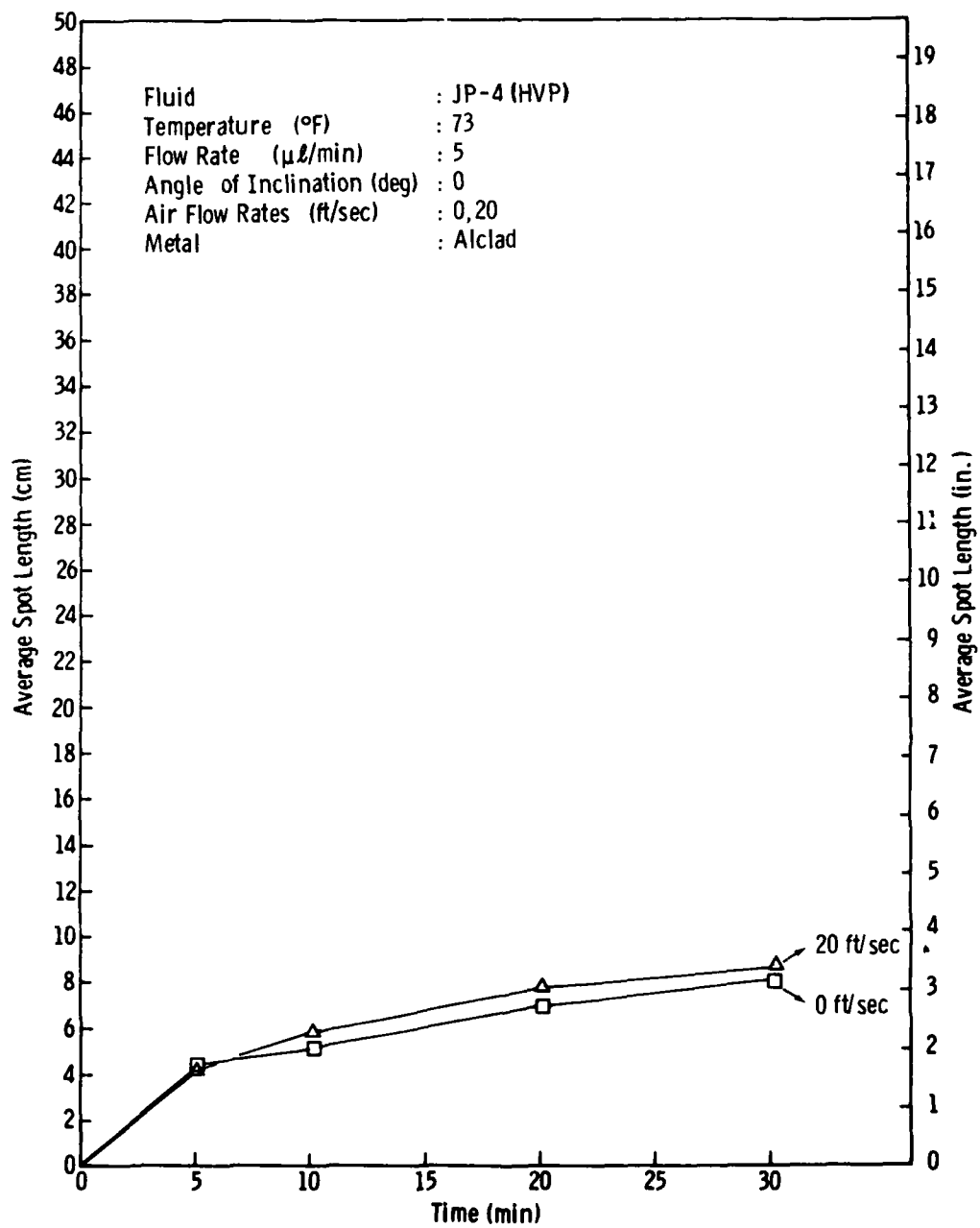


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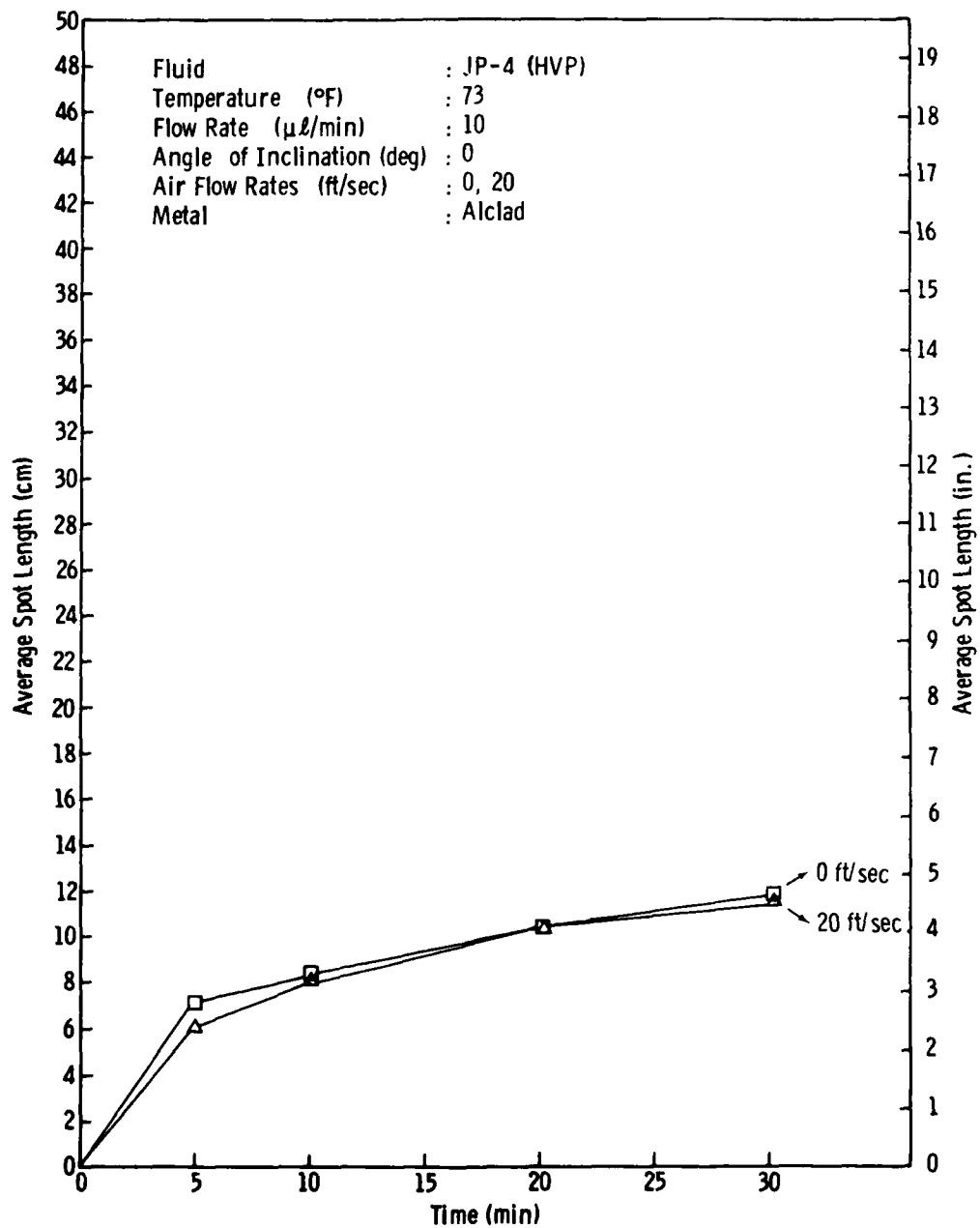


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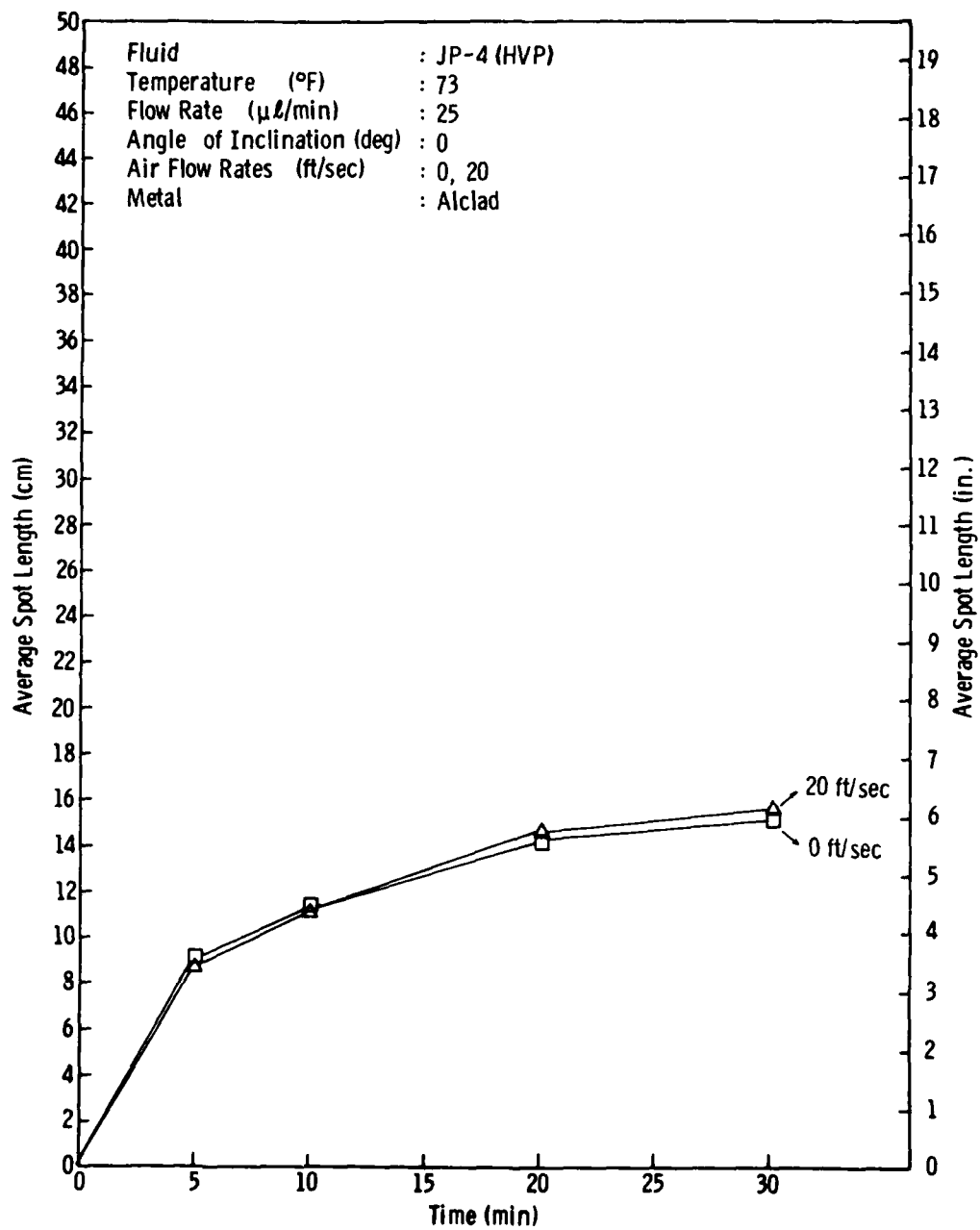


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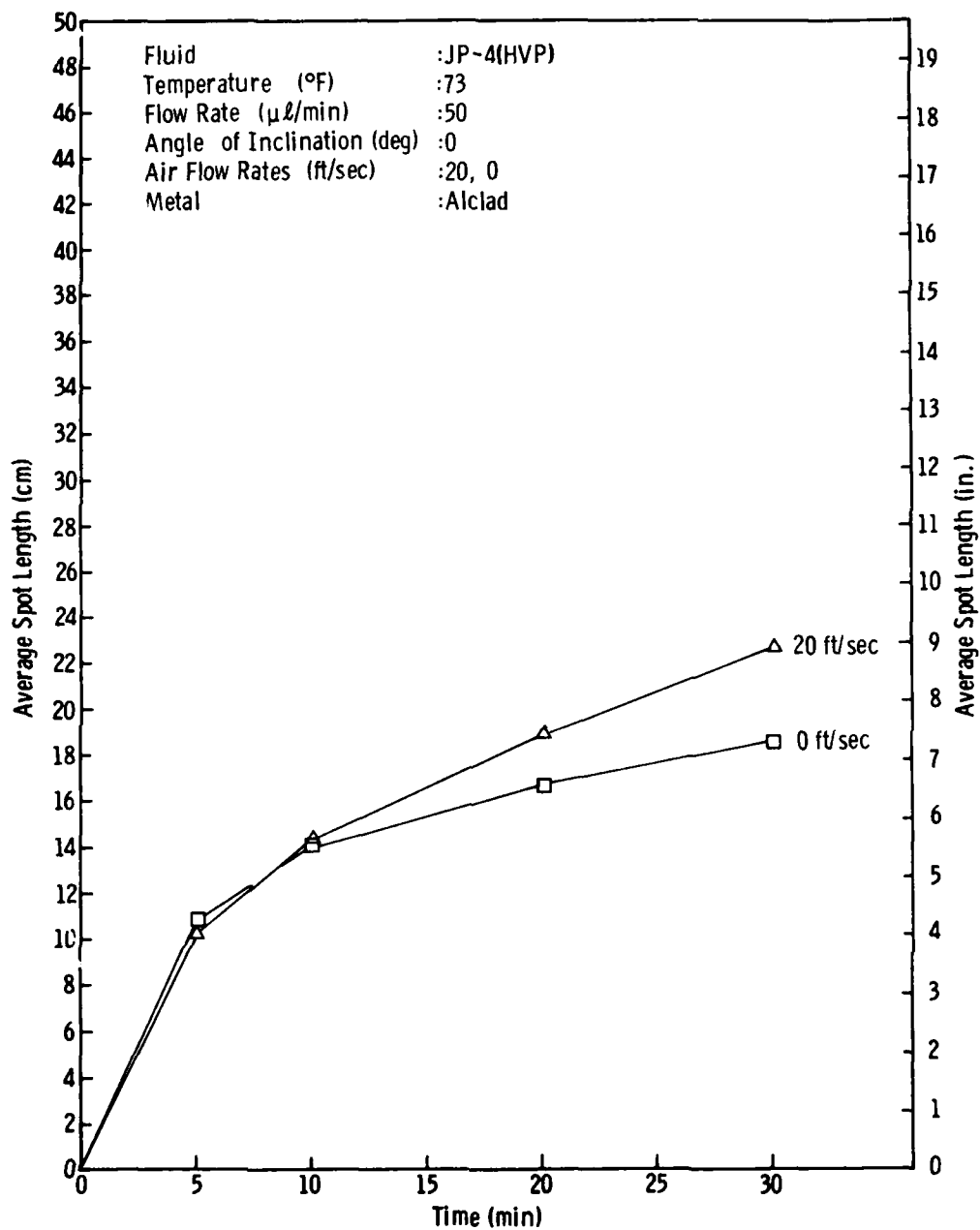


Figure 71.

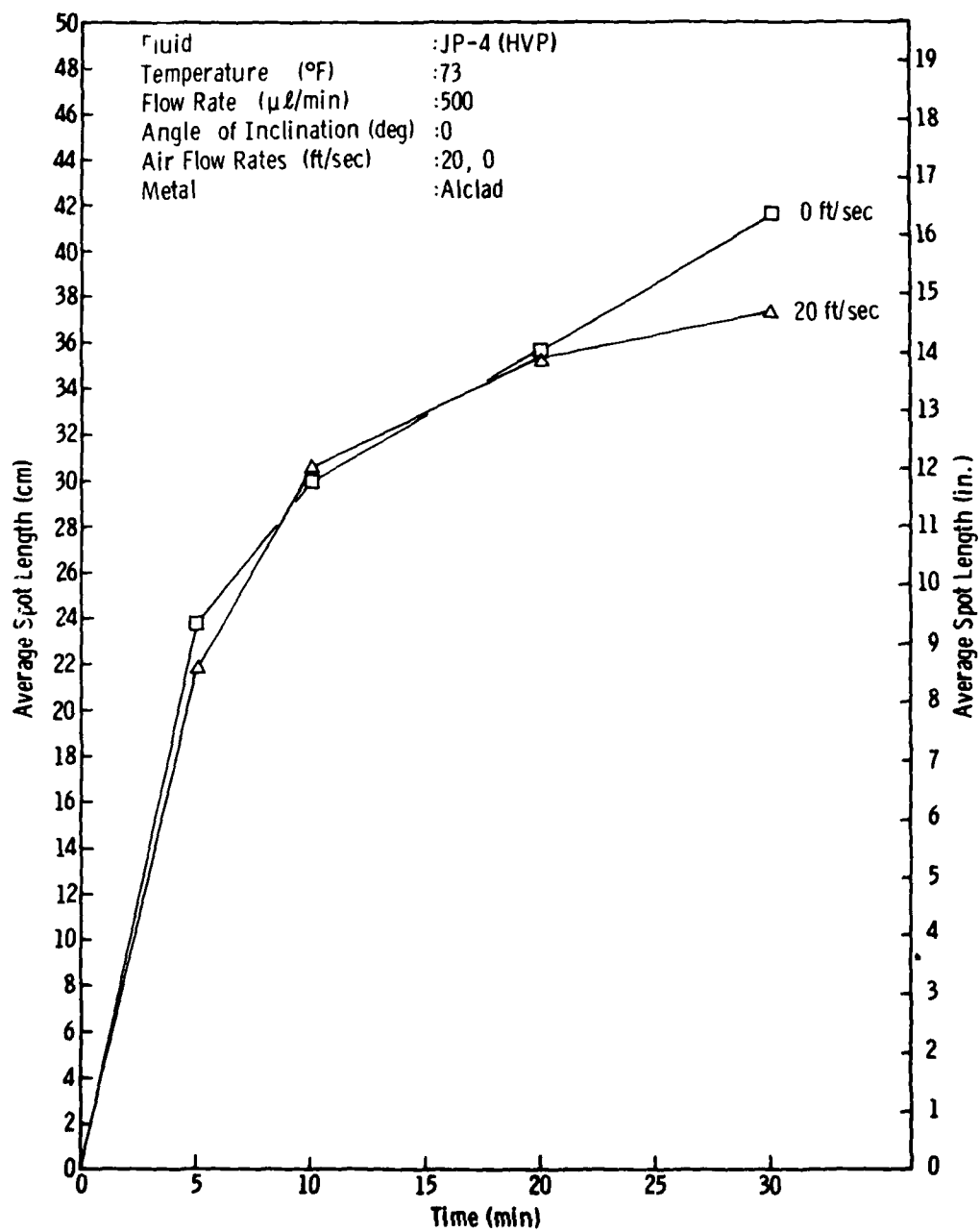


Figure 72.

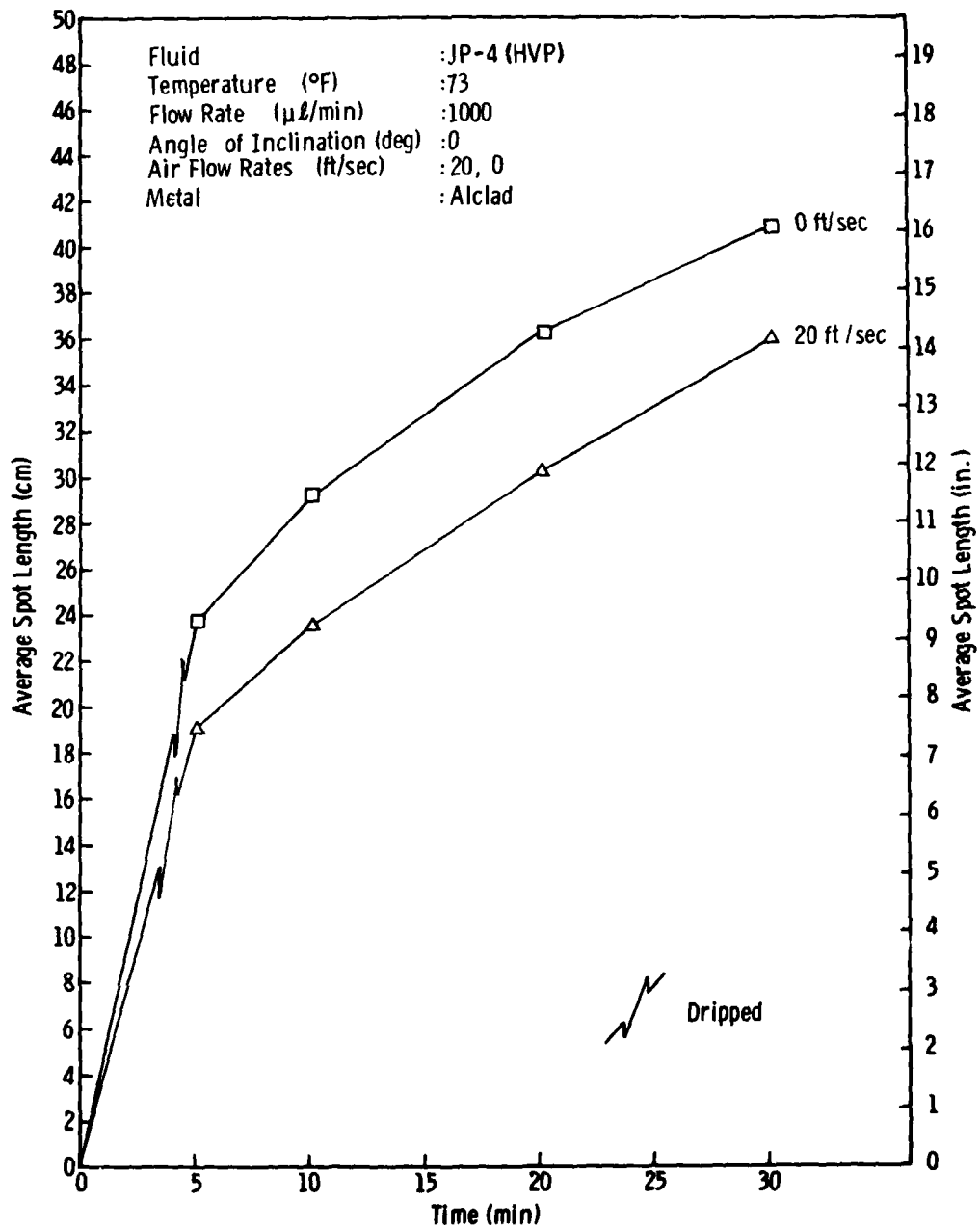


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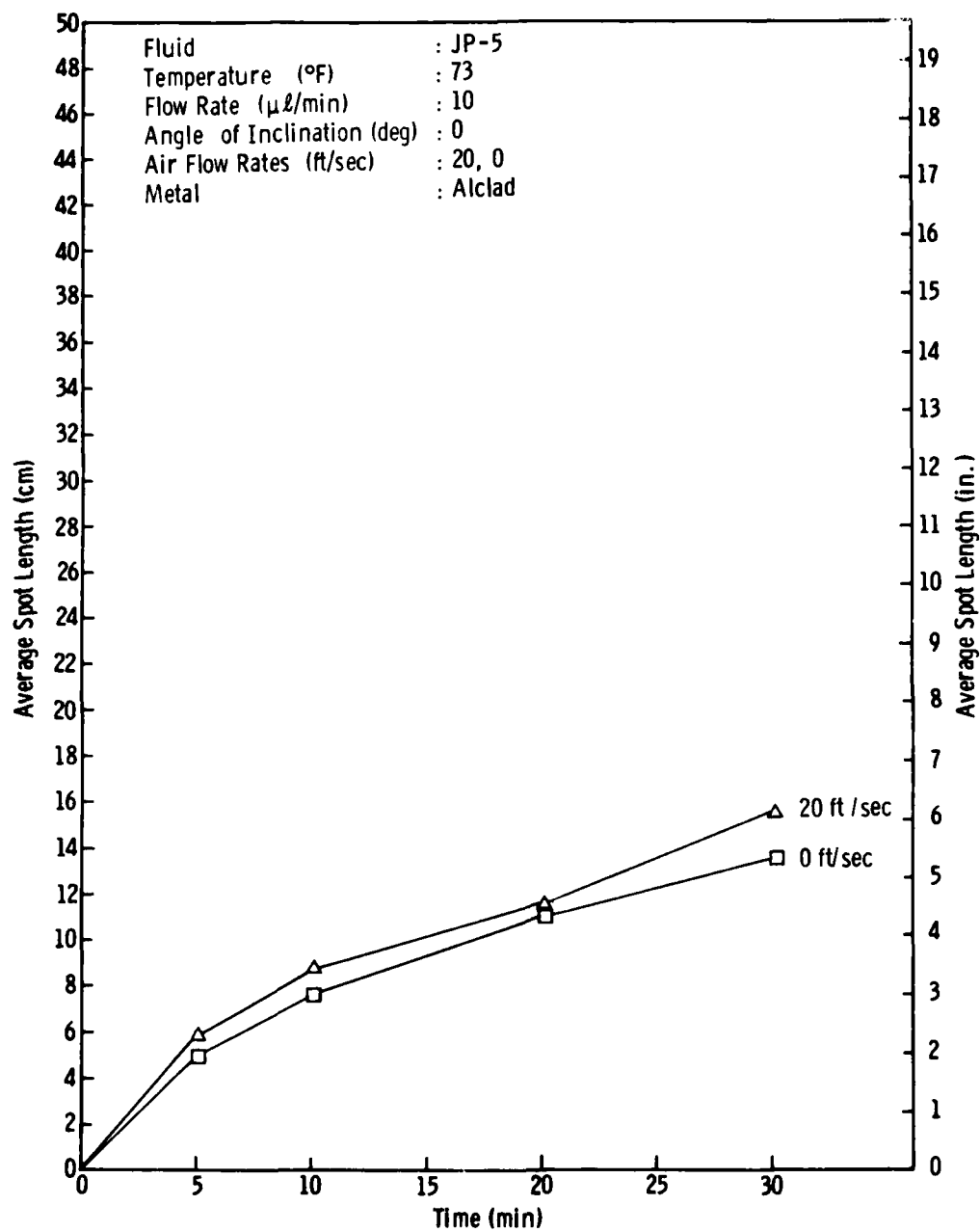


Figure 74.

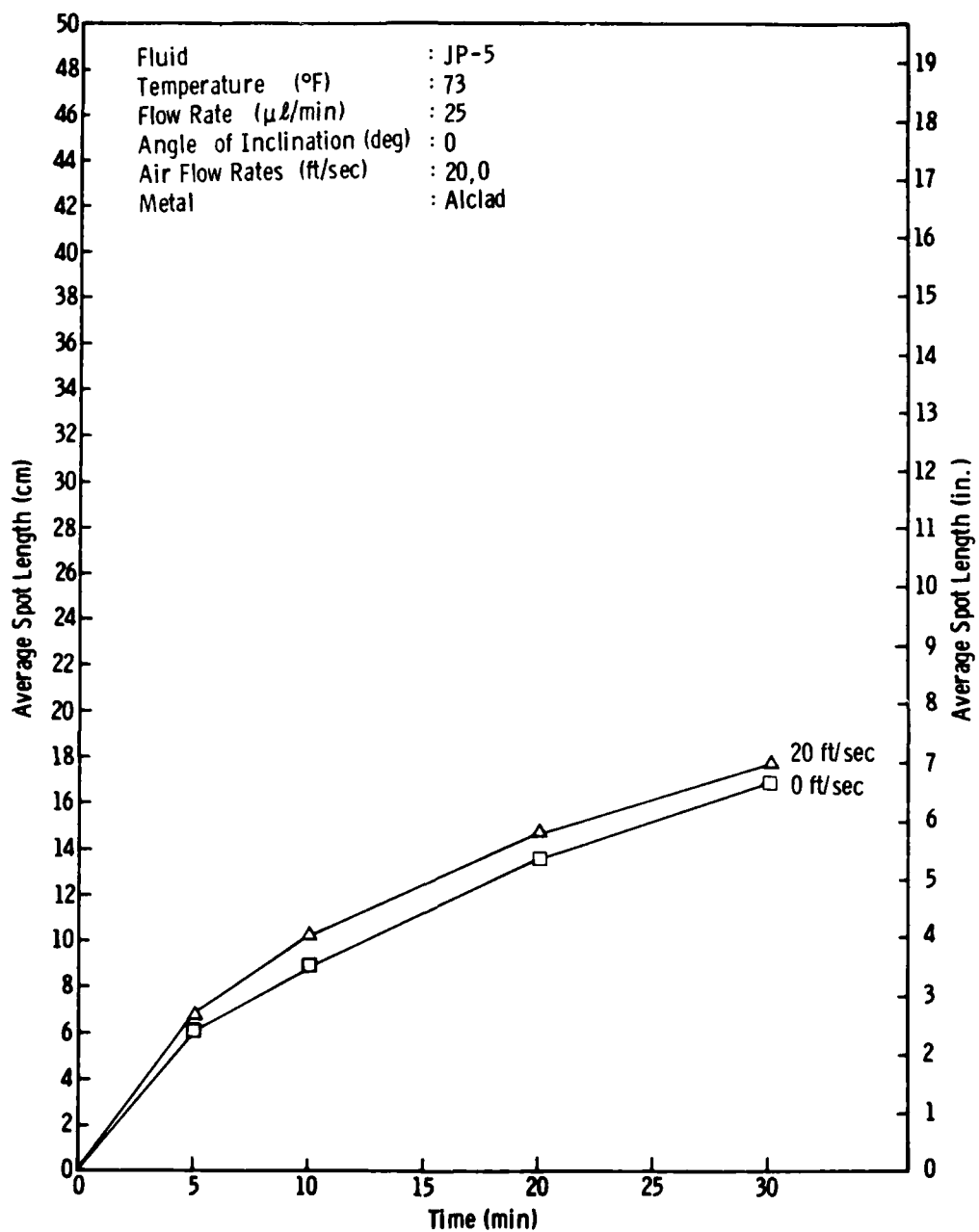


Figure 75.

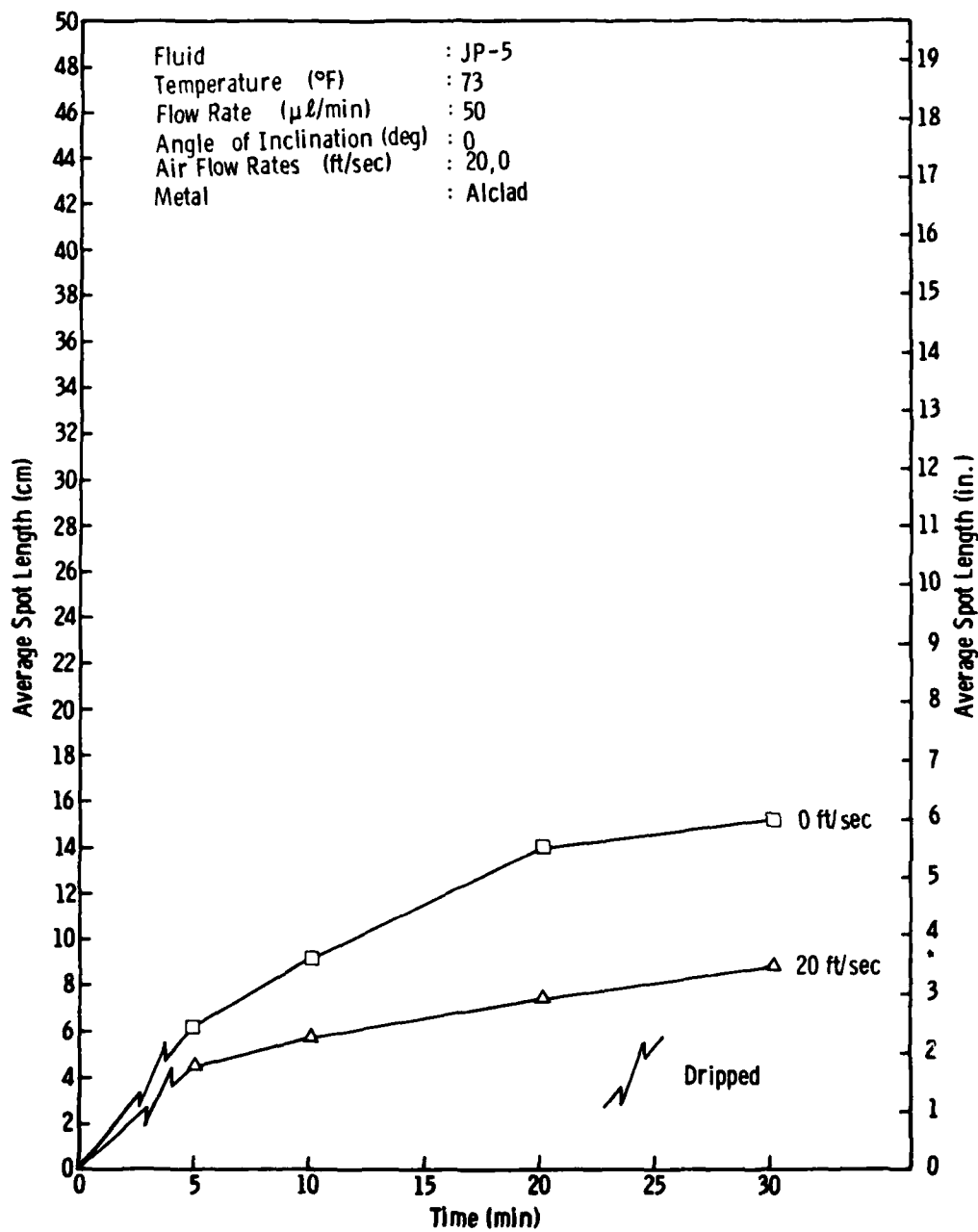


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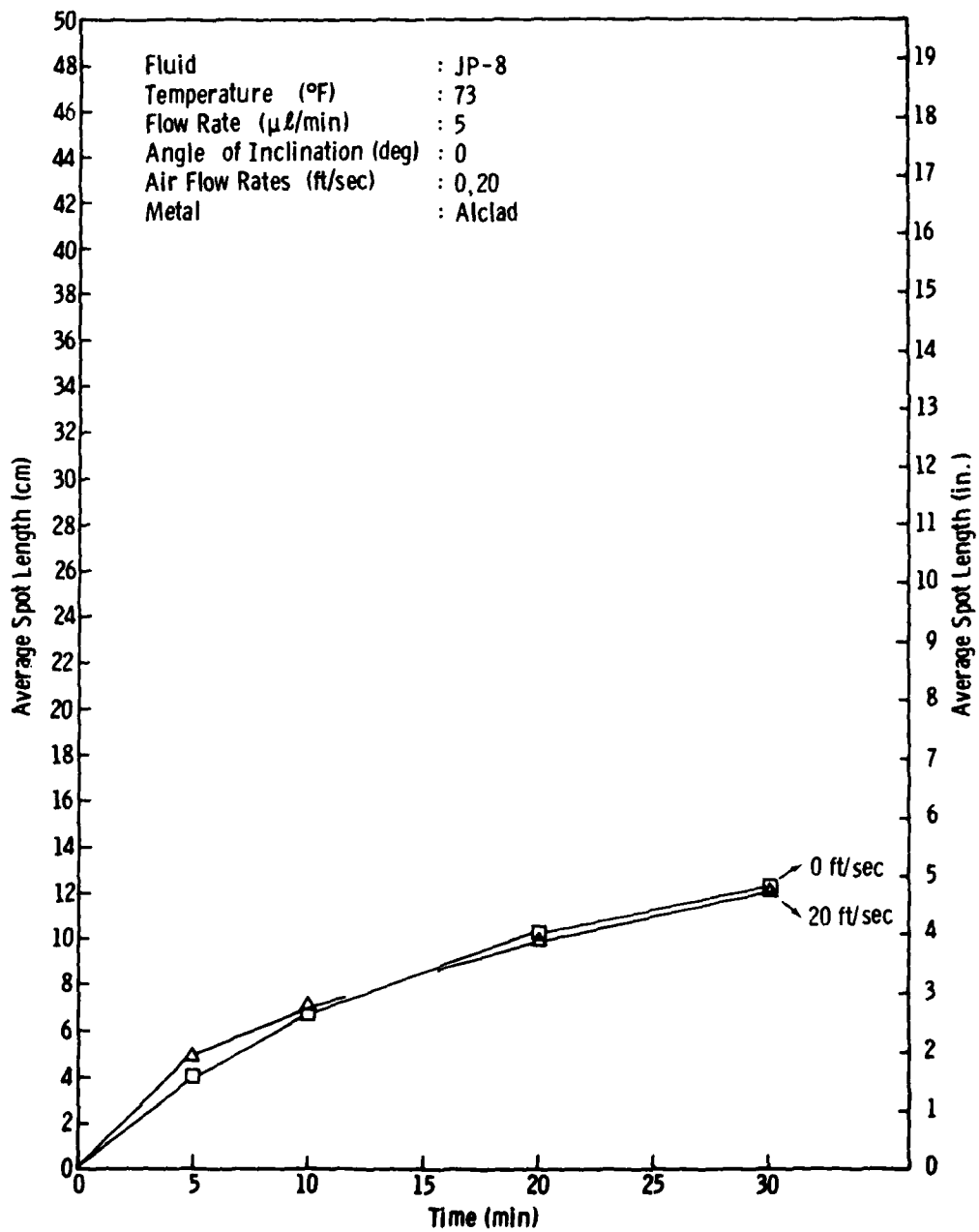


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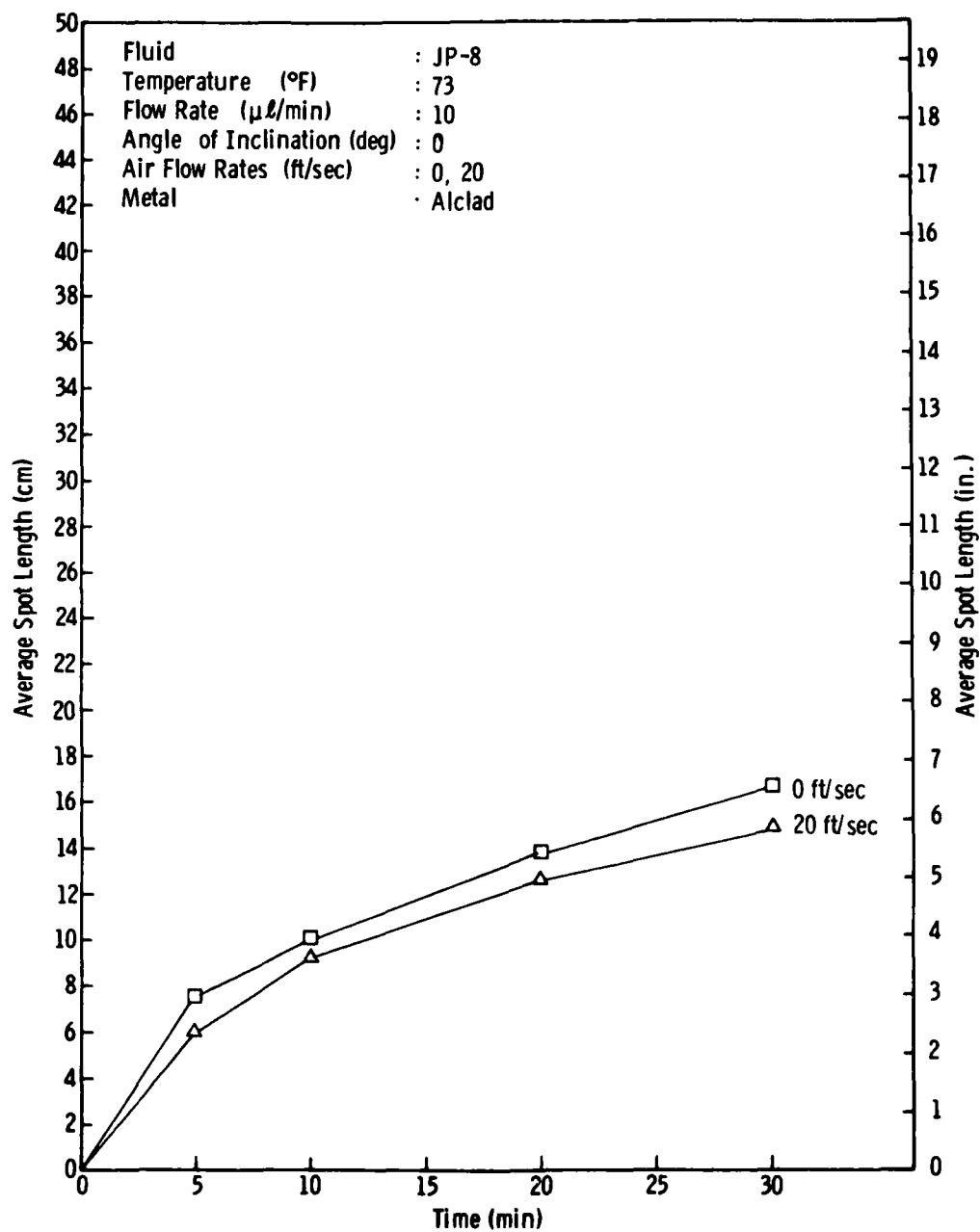


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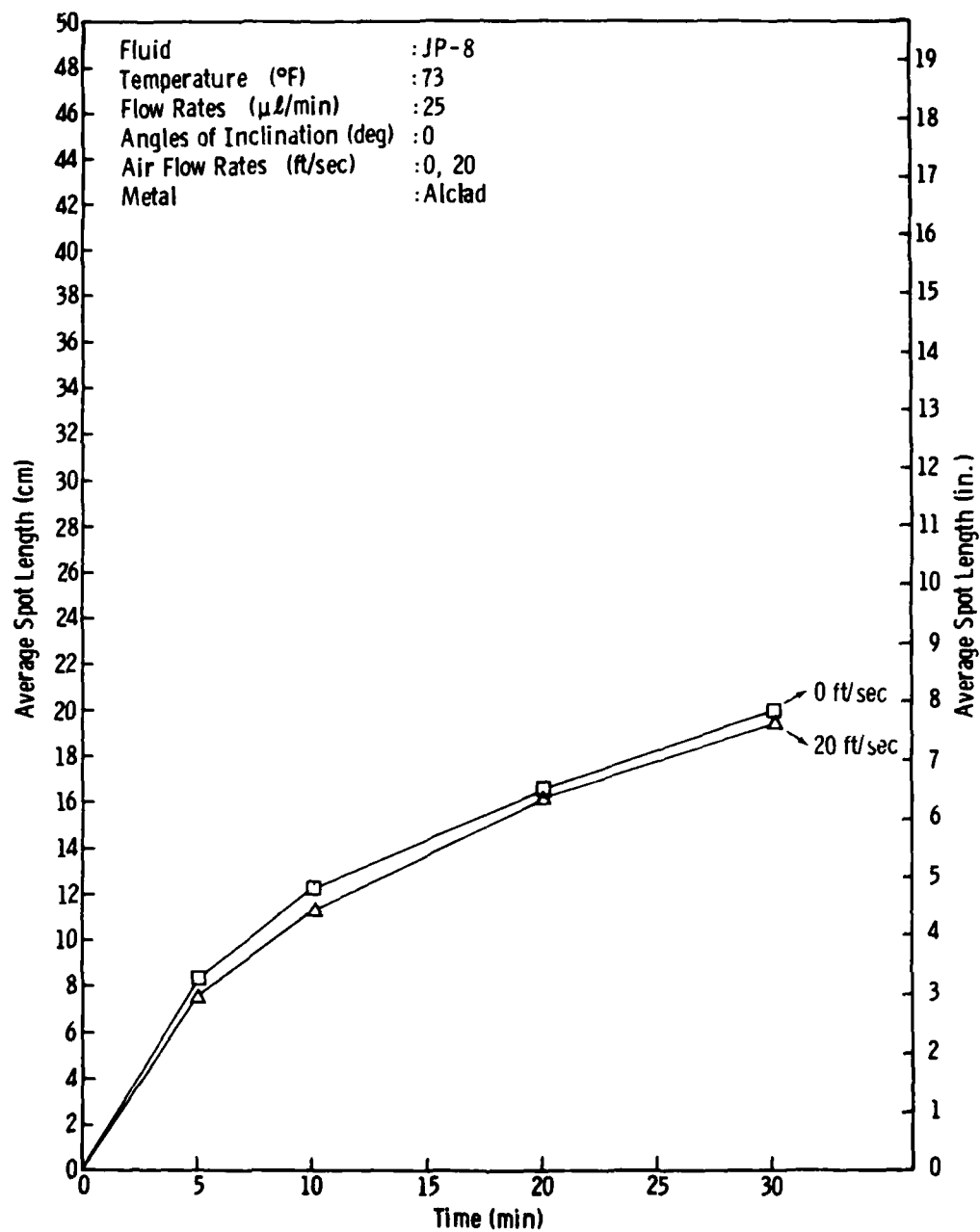


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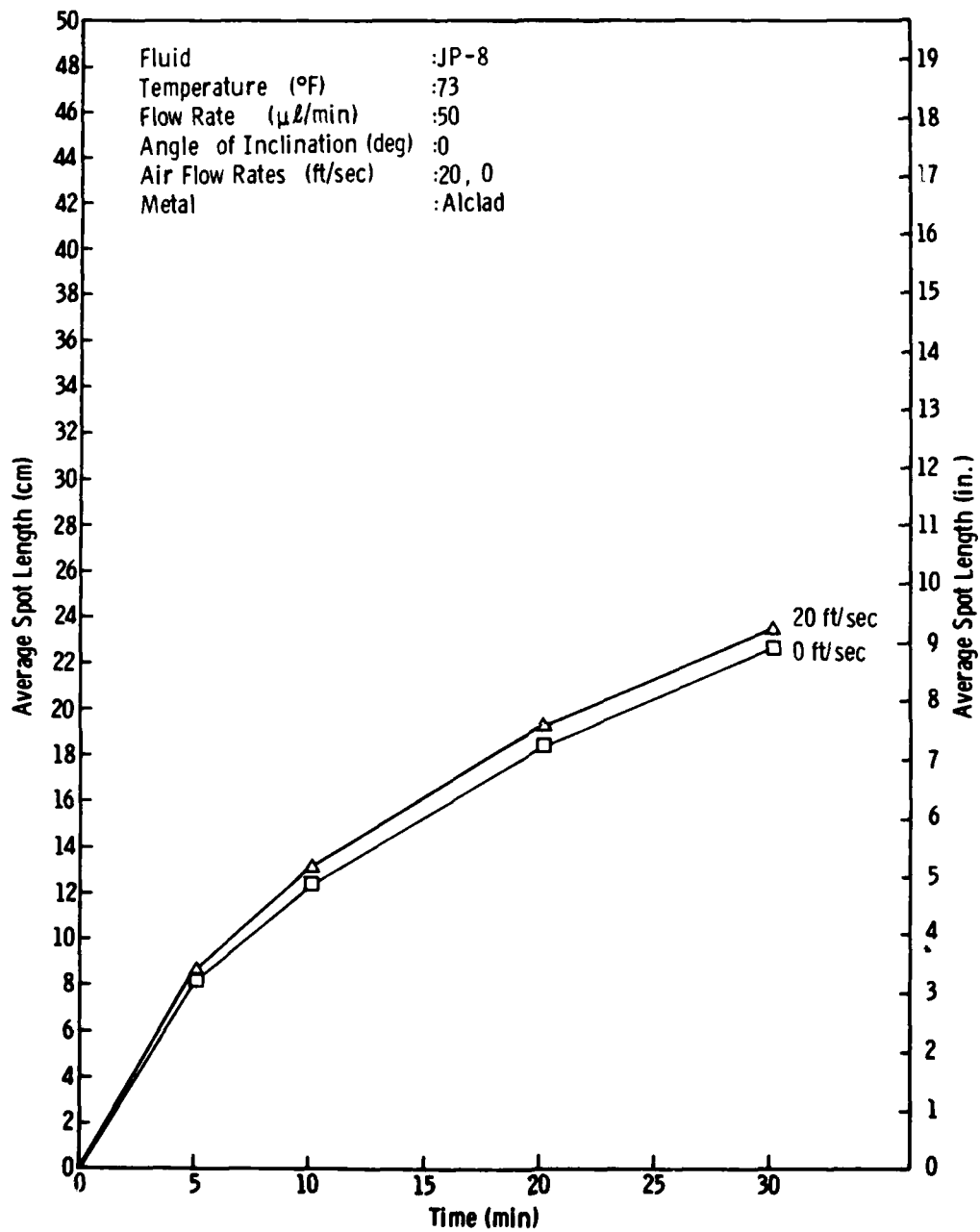


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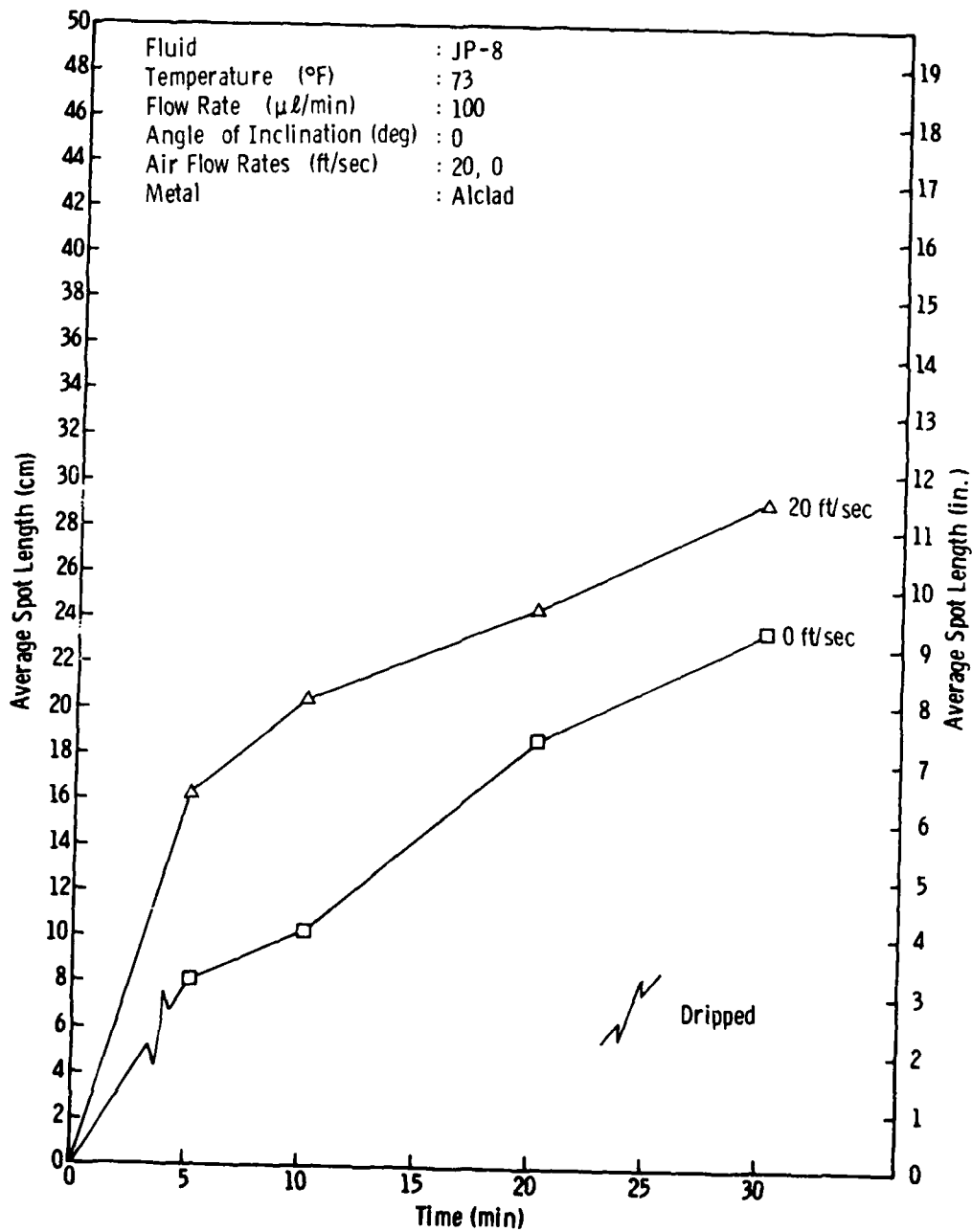


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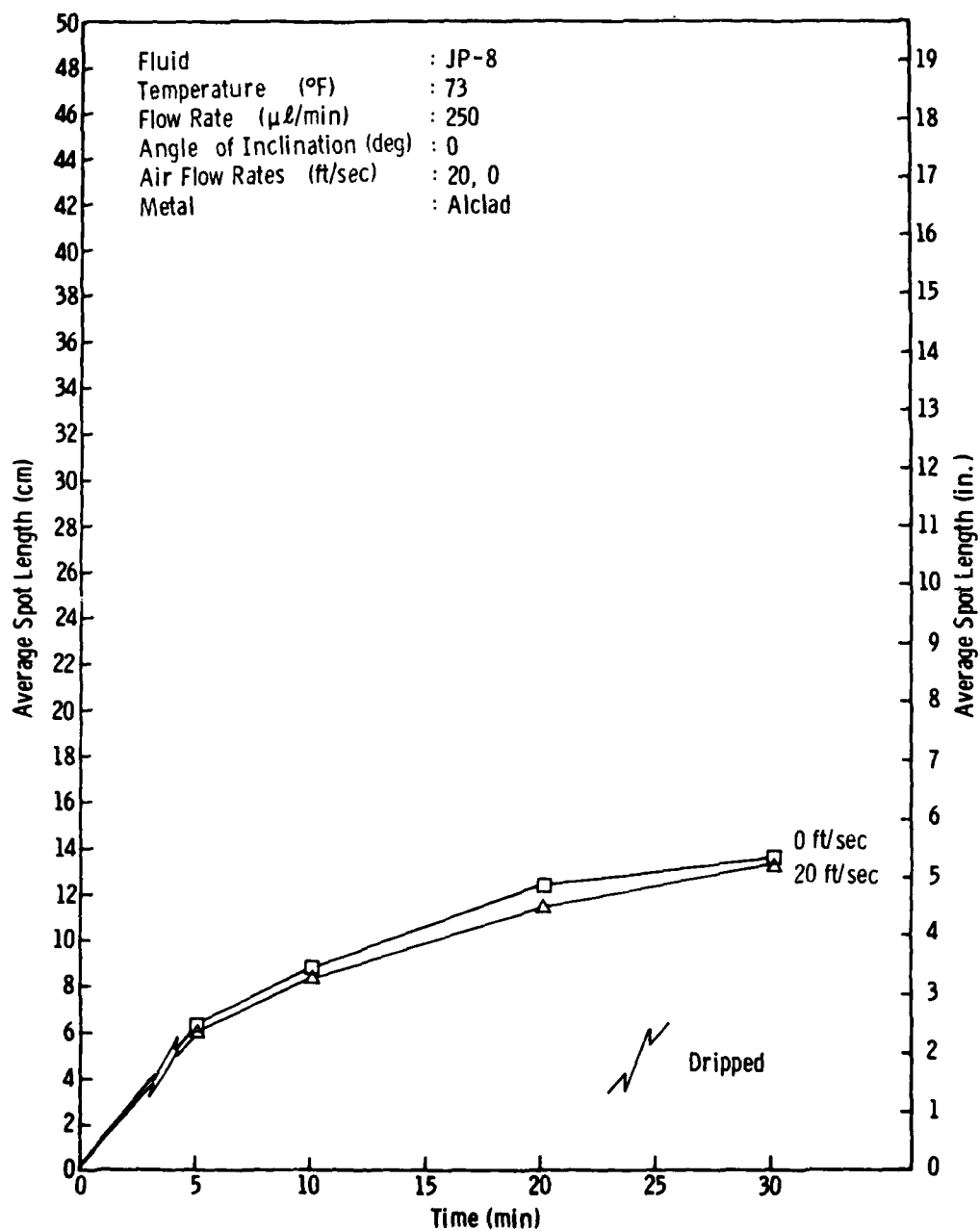


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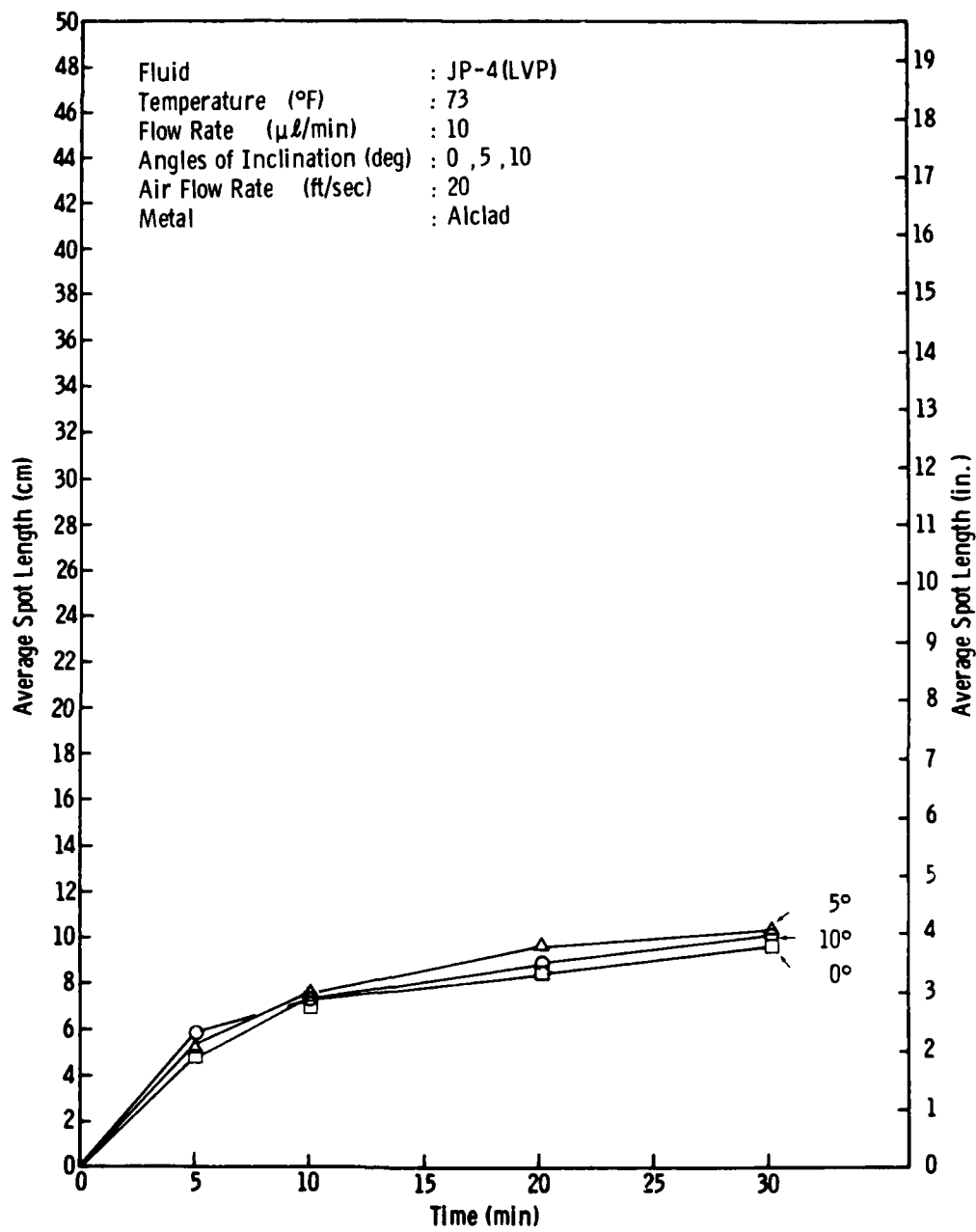


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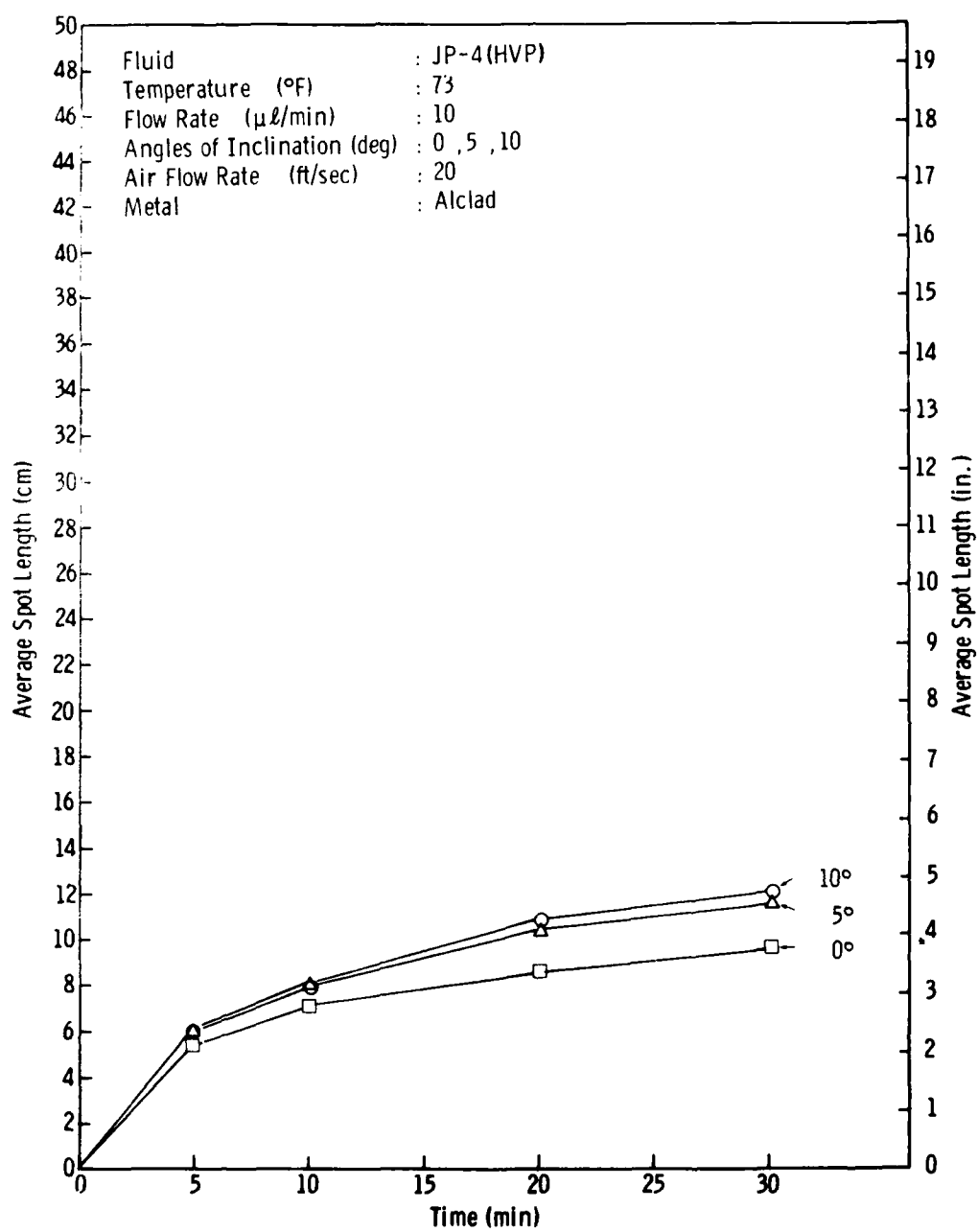


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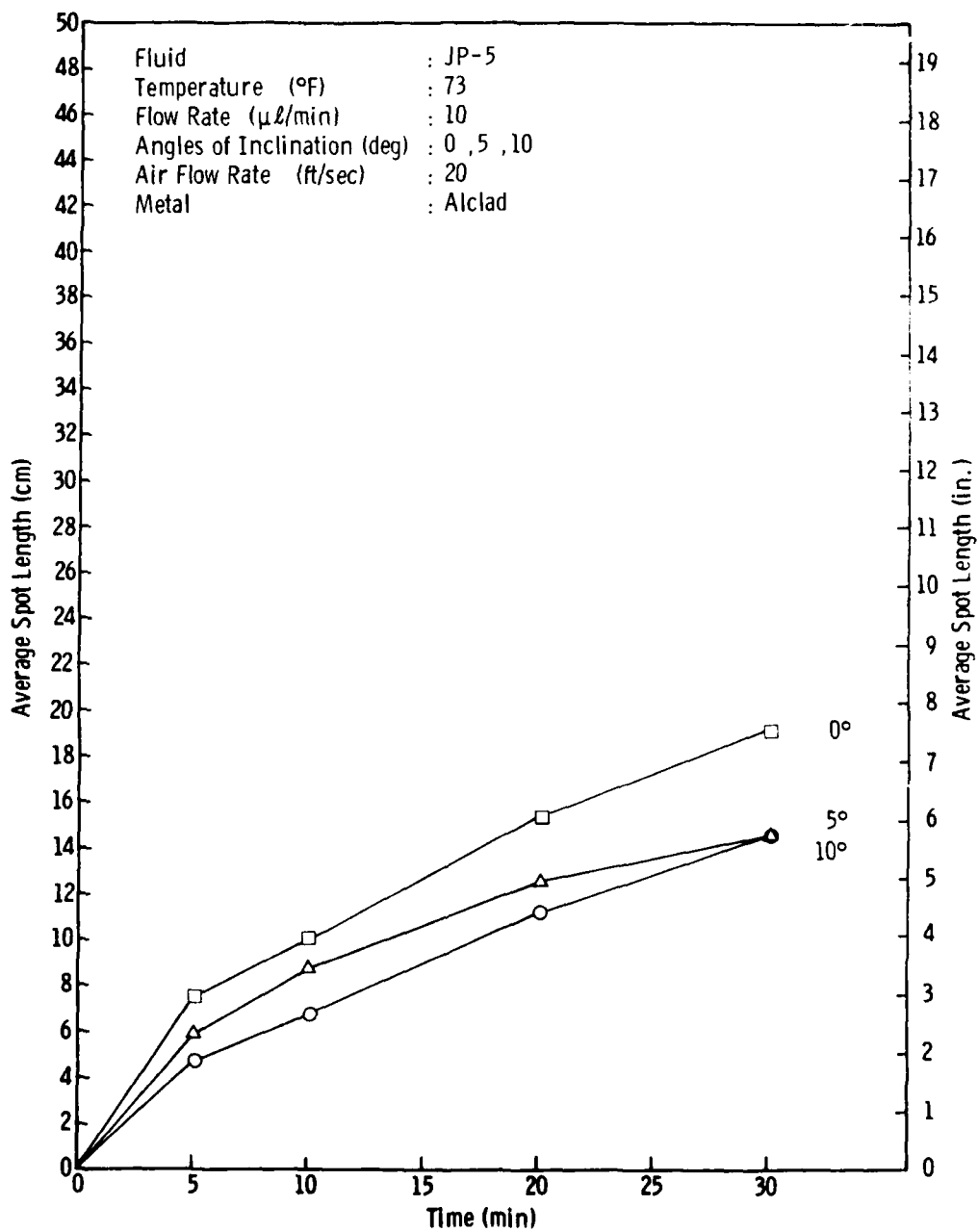


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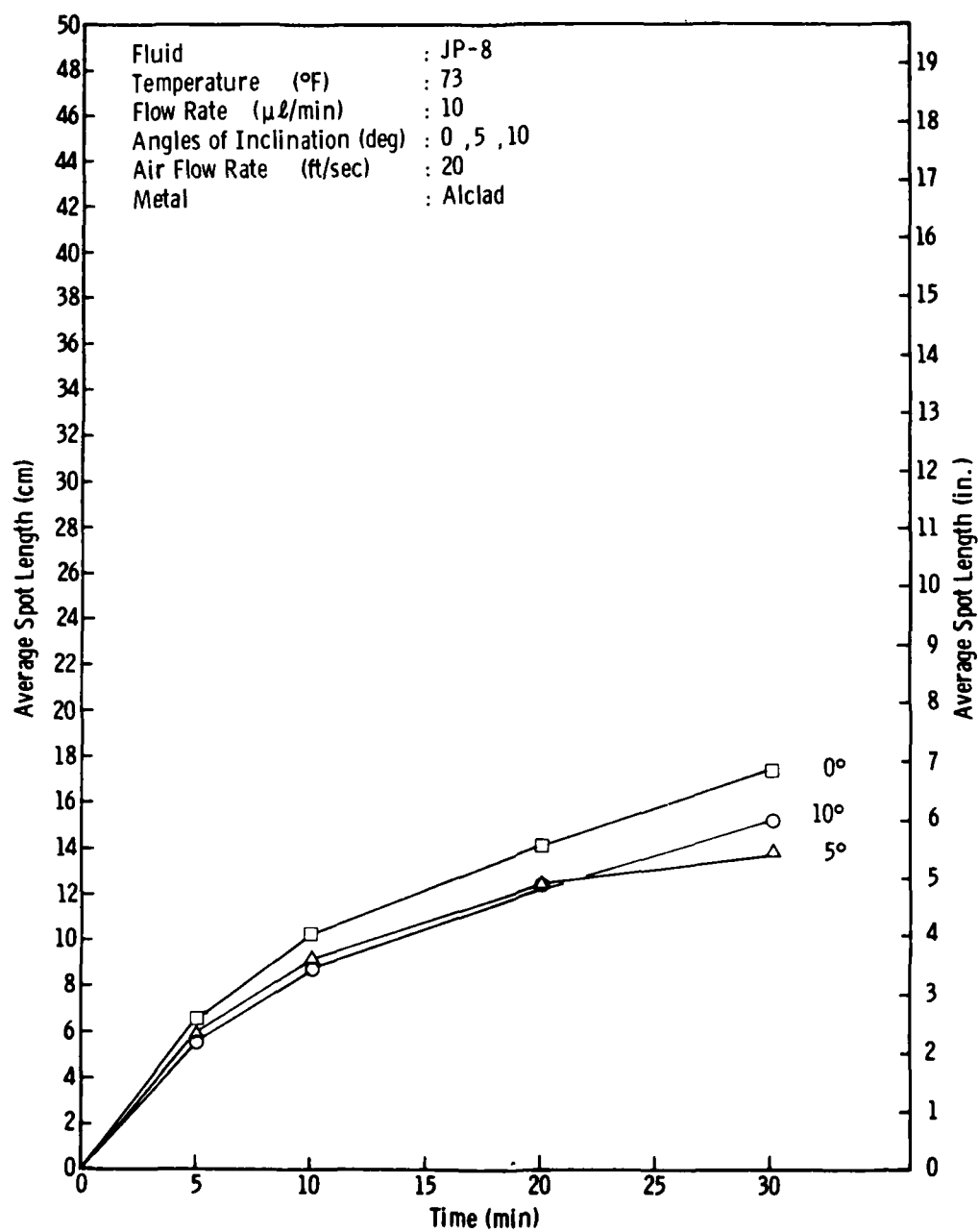


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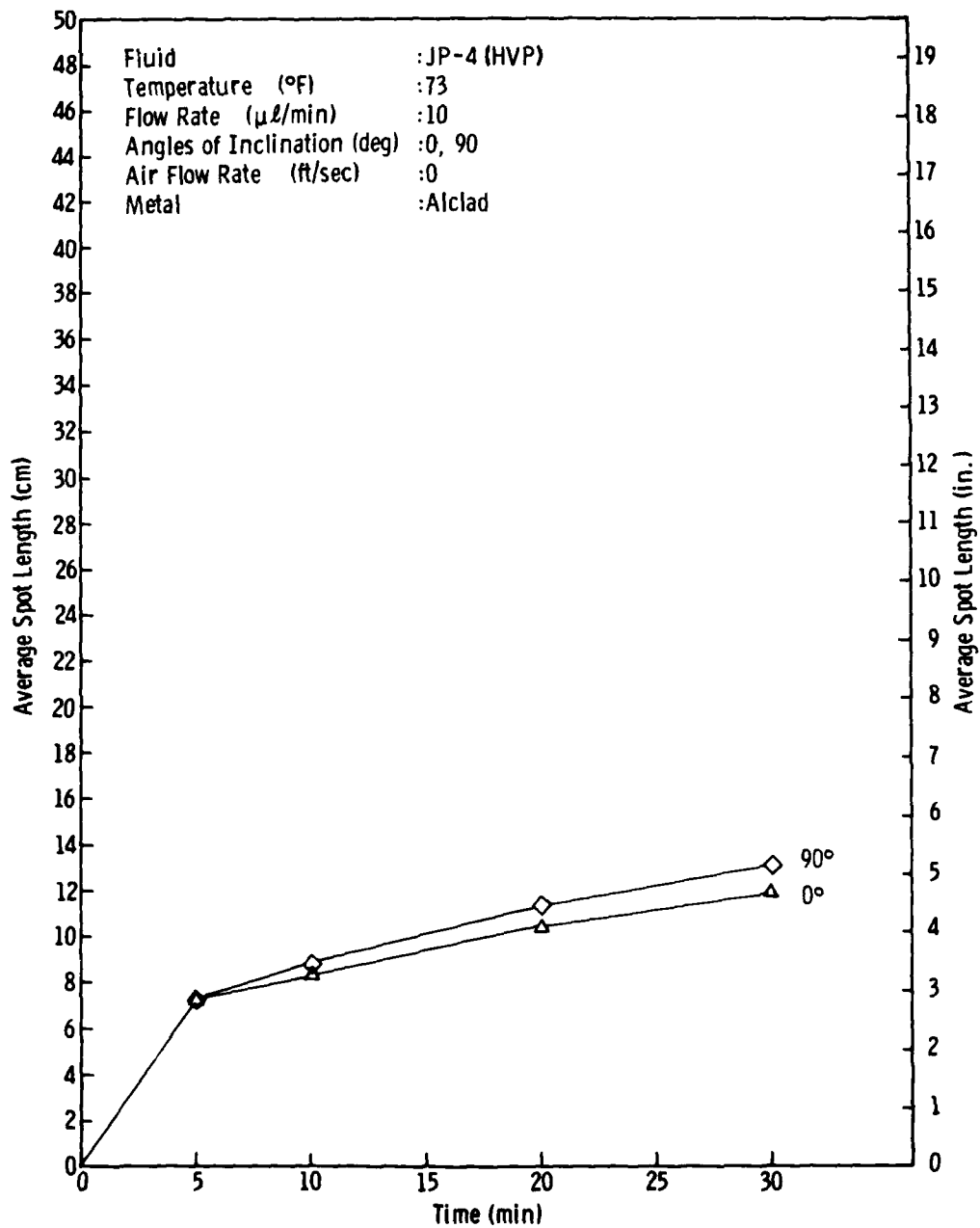


Figure 87.

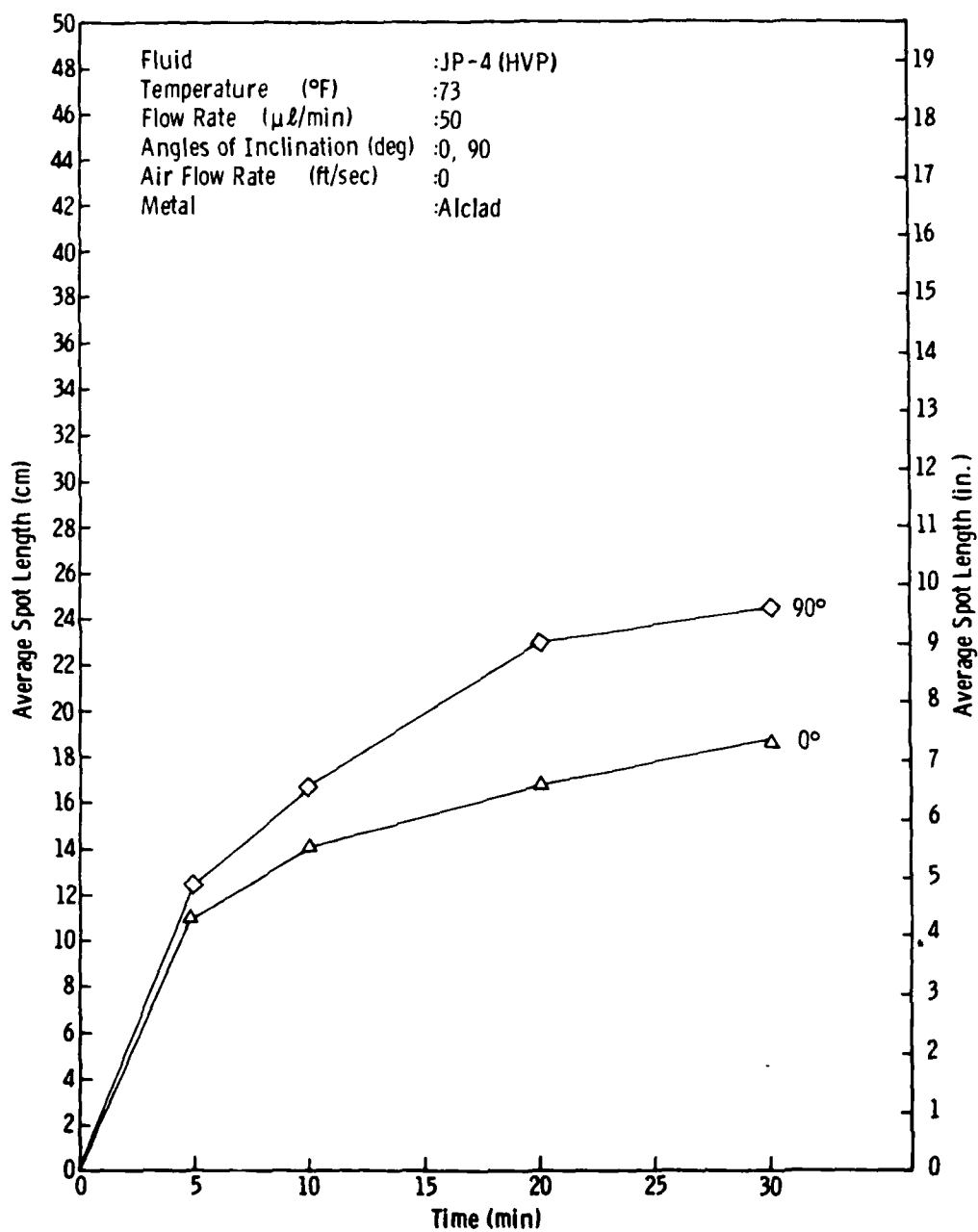


Figure 88.

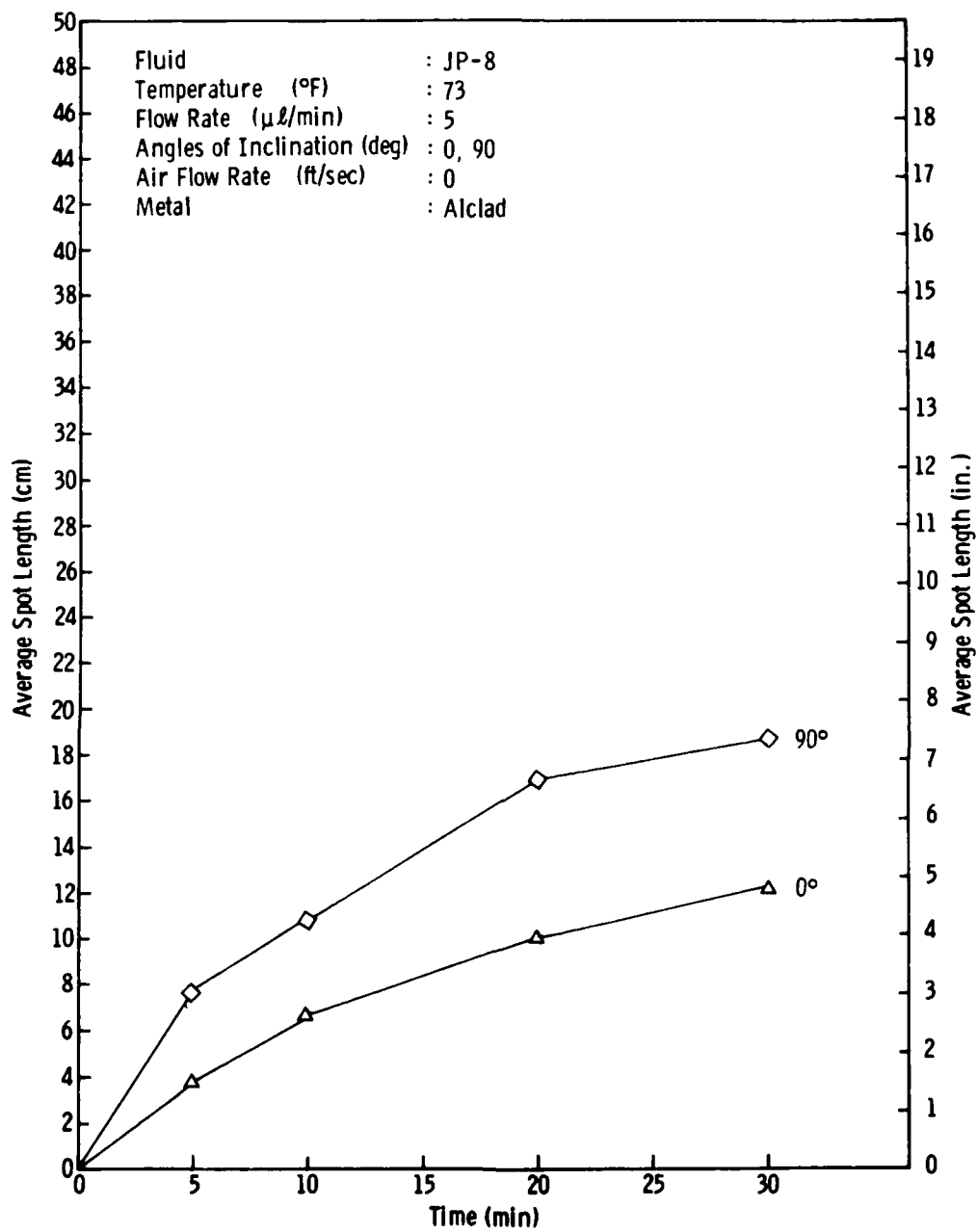


Figure 89.

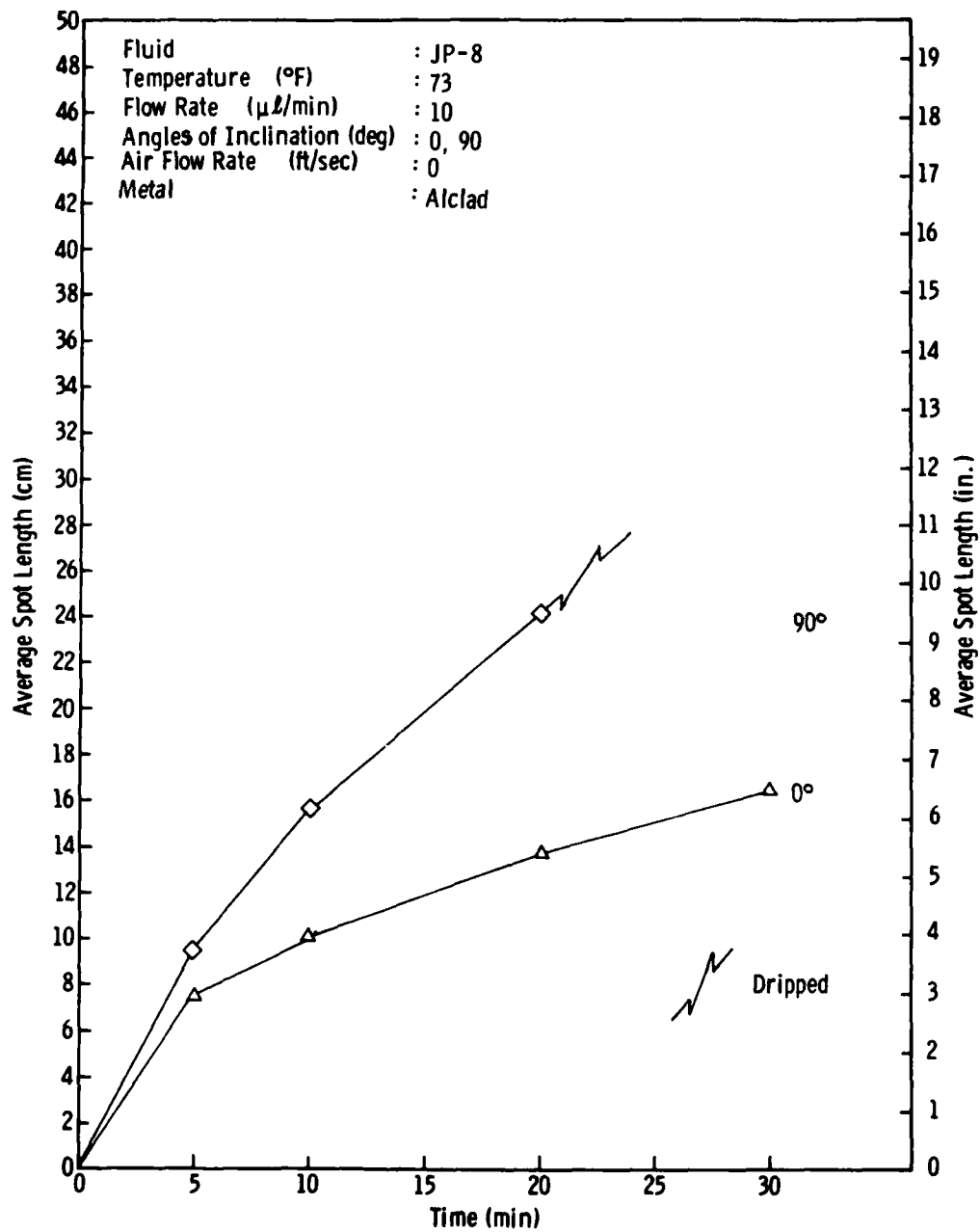


Figure 90.

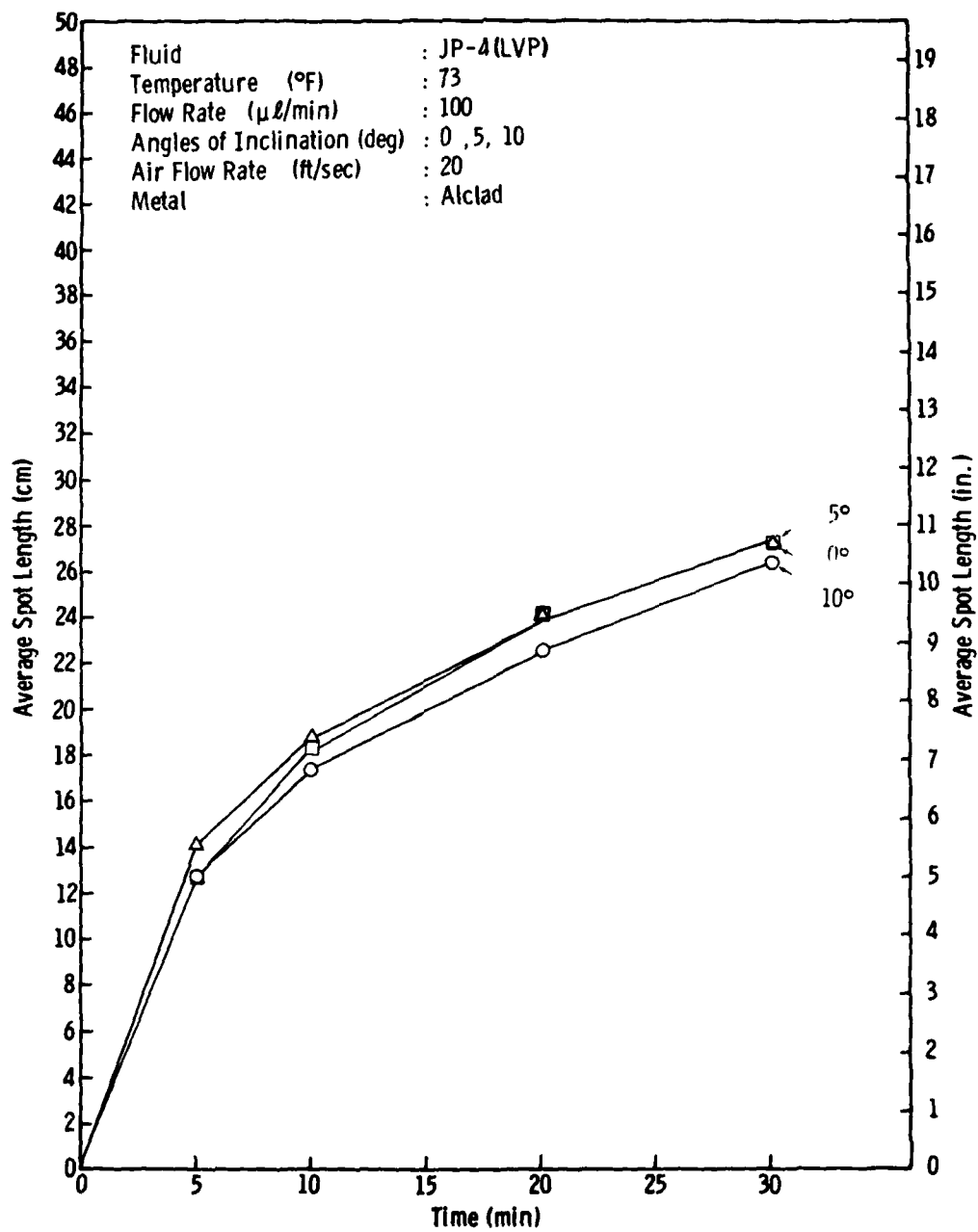


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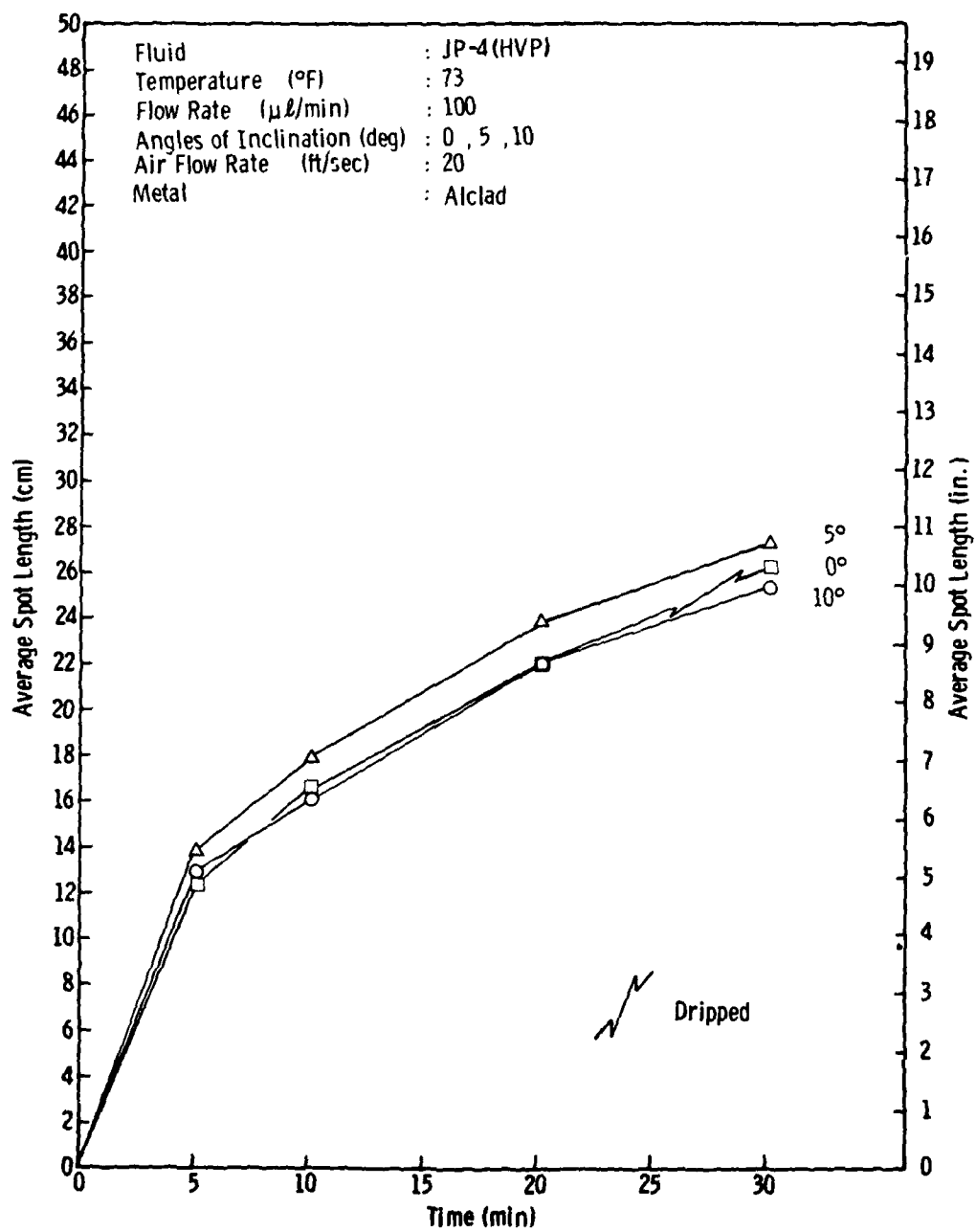


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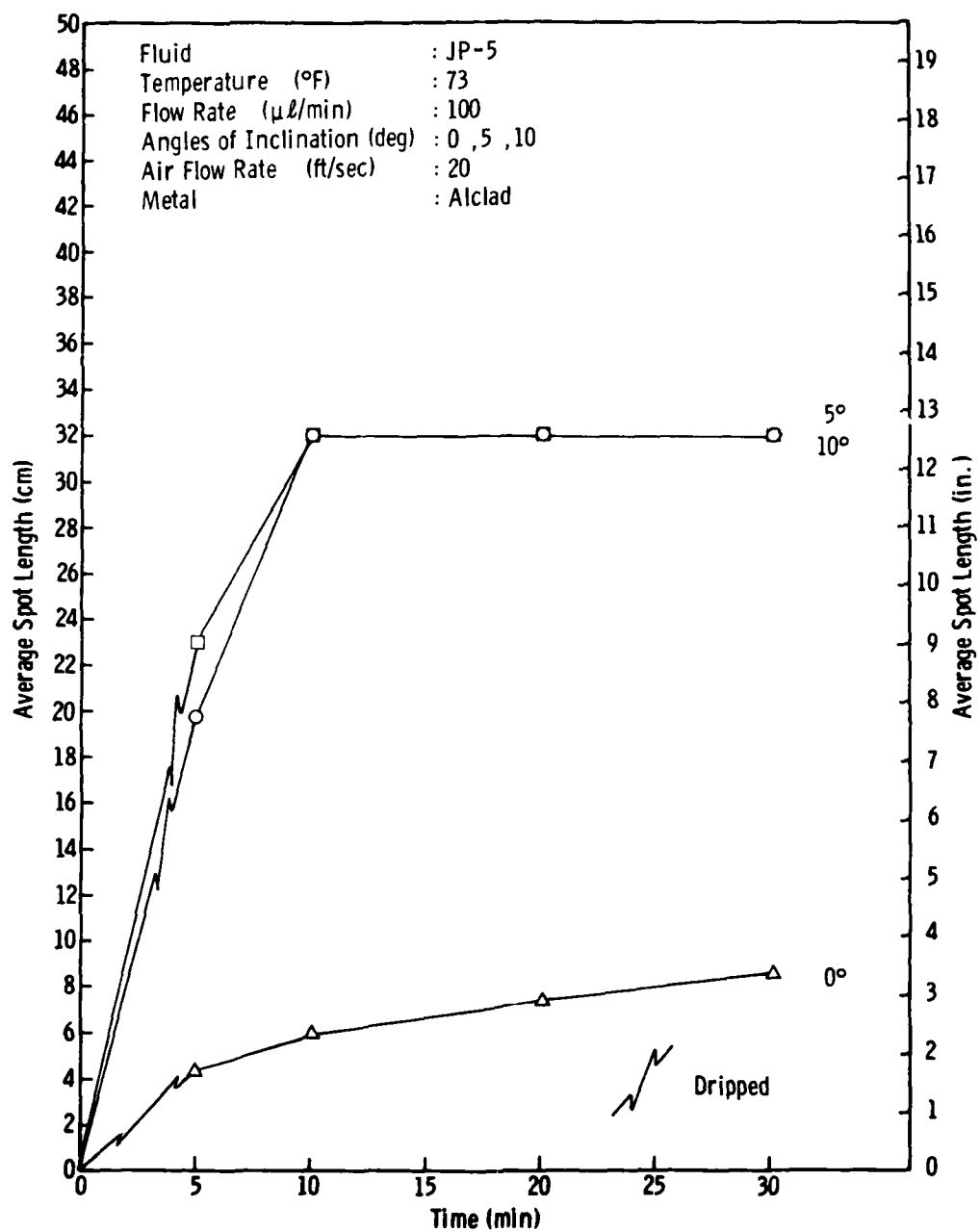


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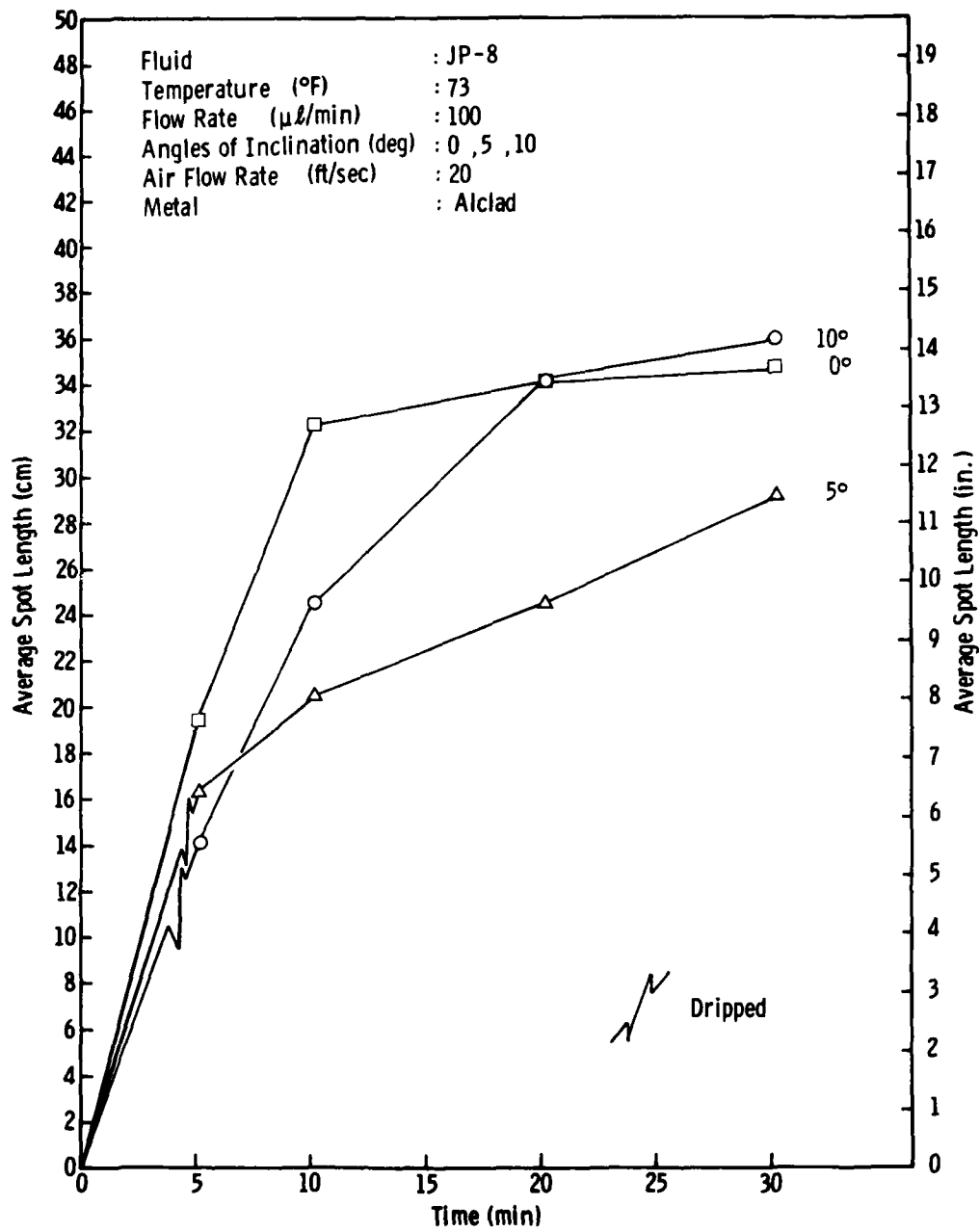


Figure 94.

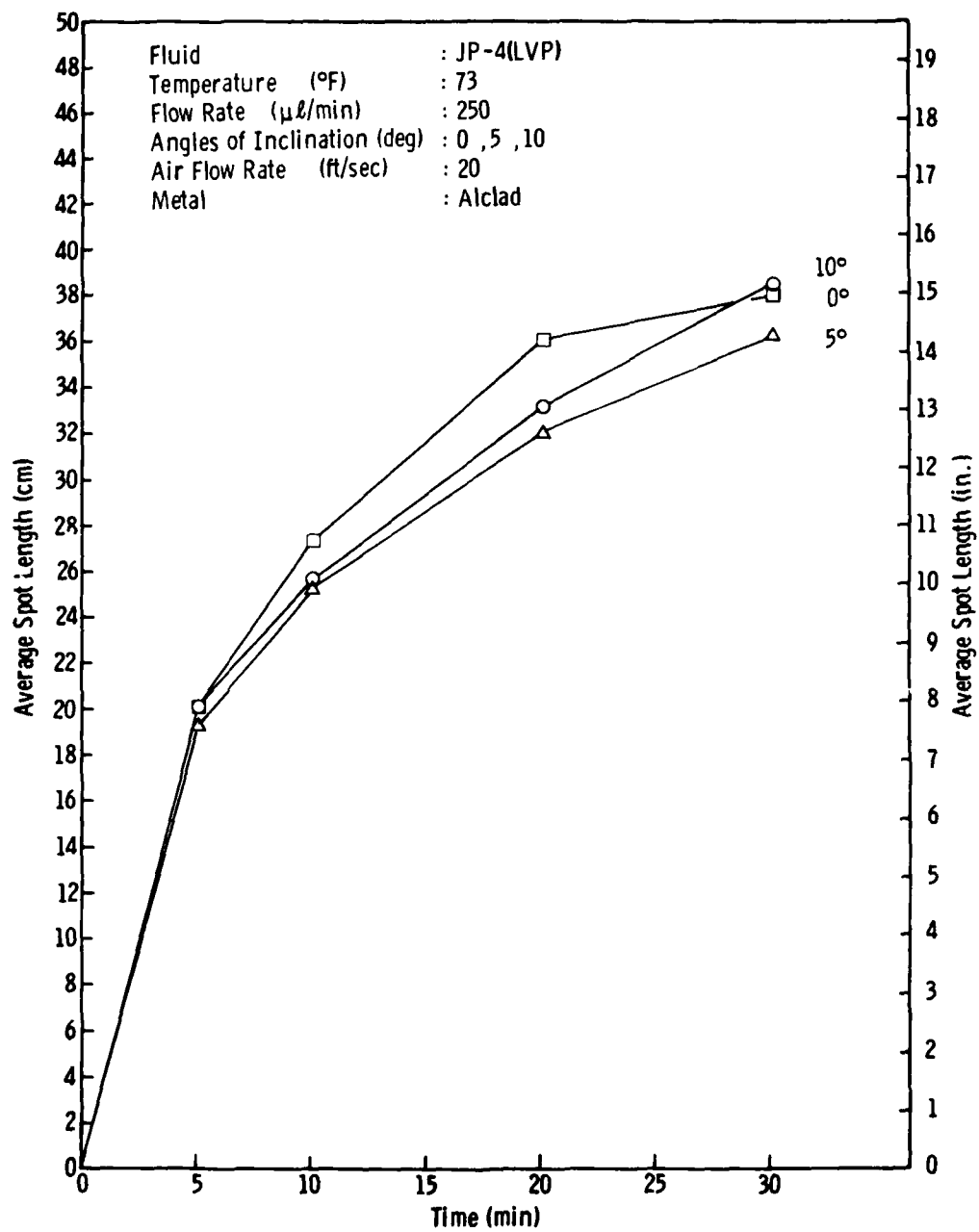


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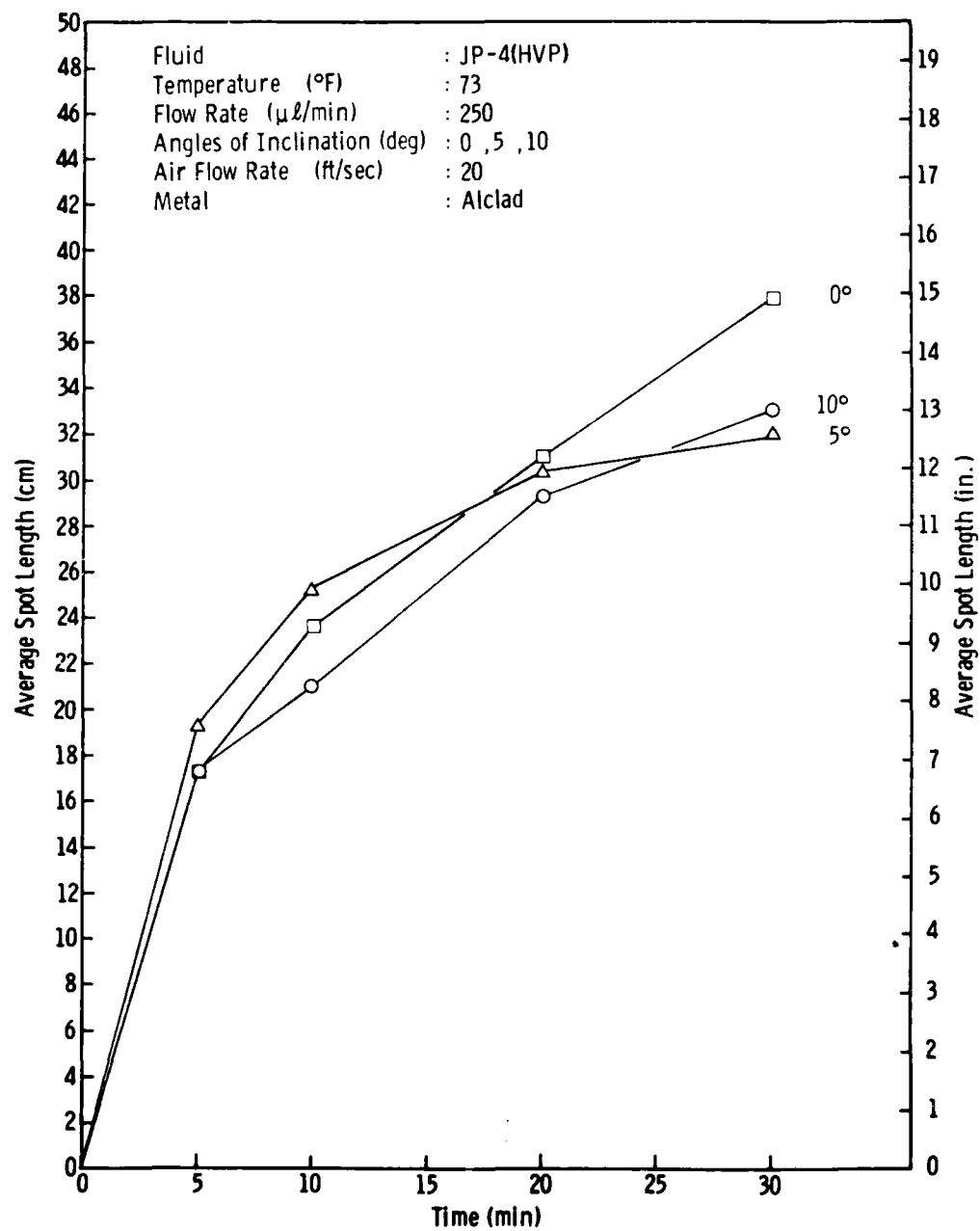


Figure 96.

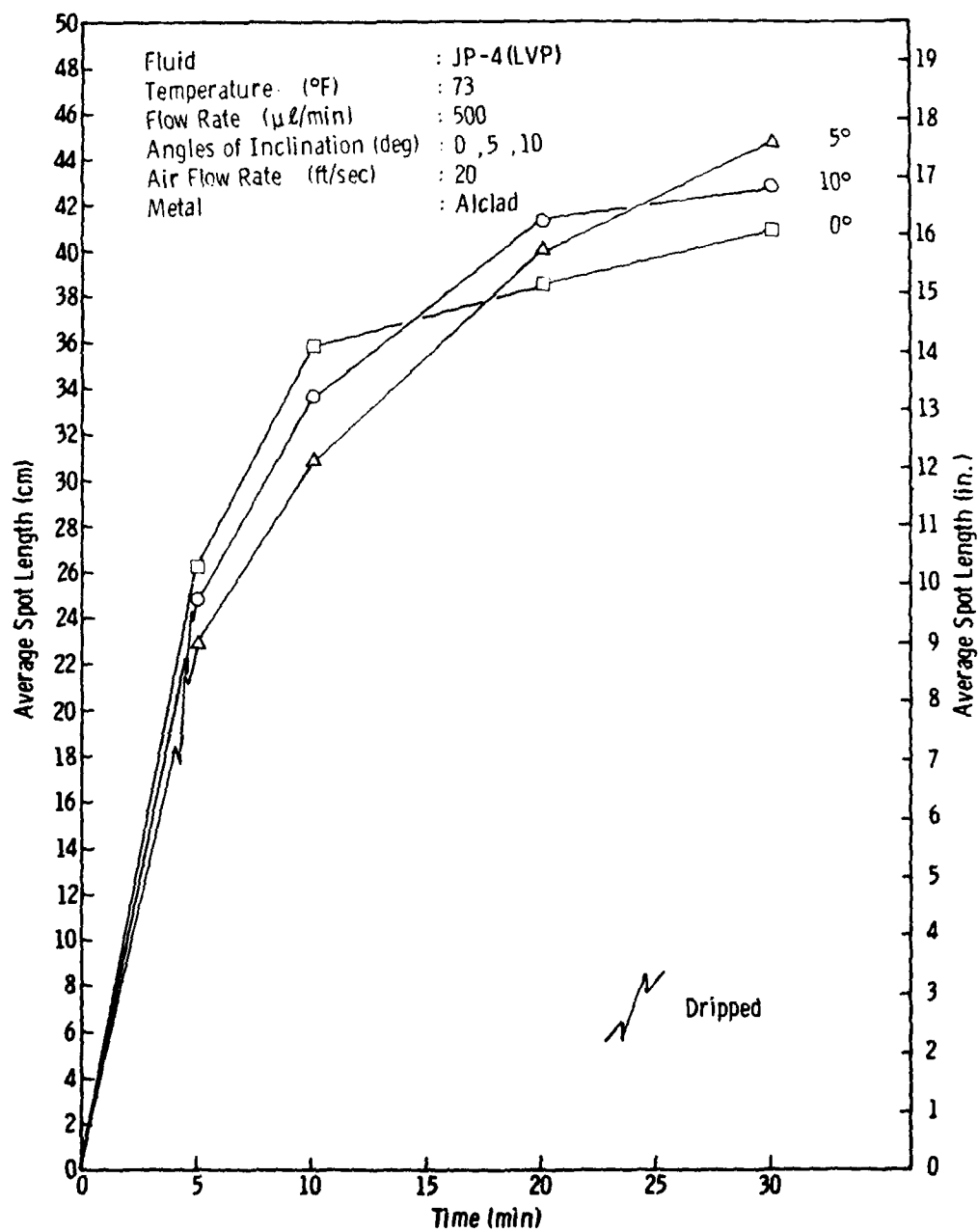


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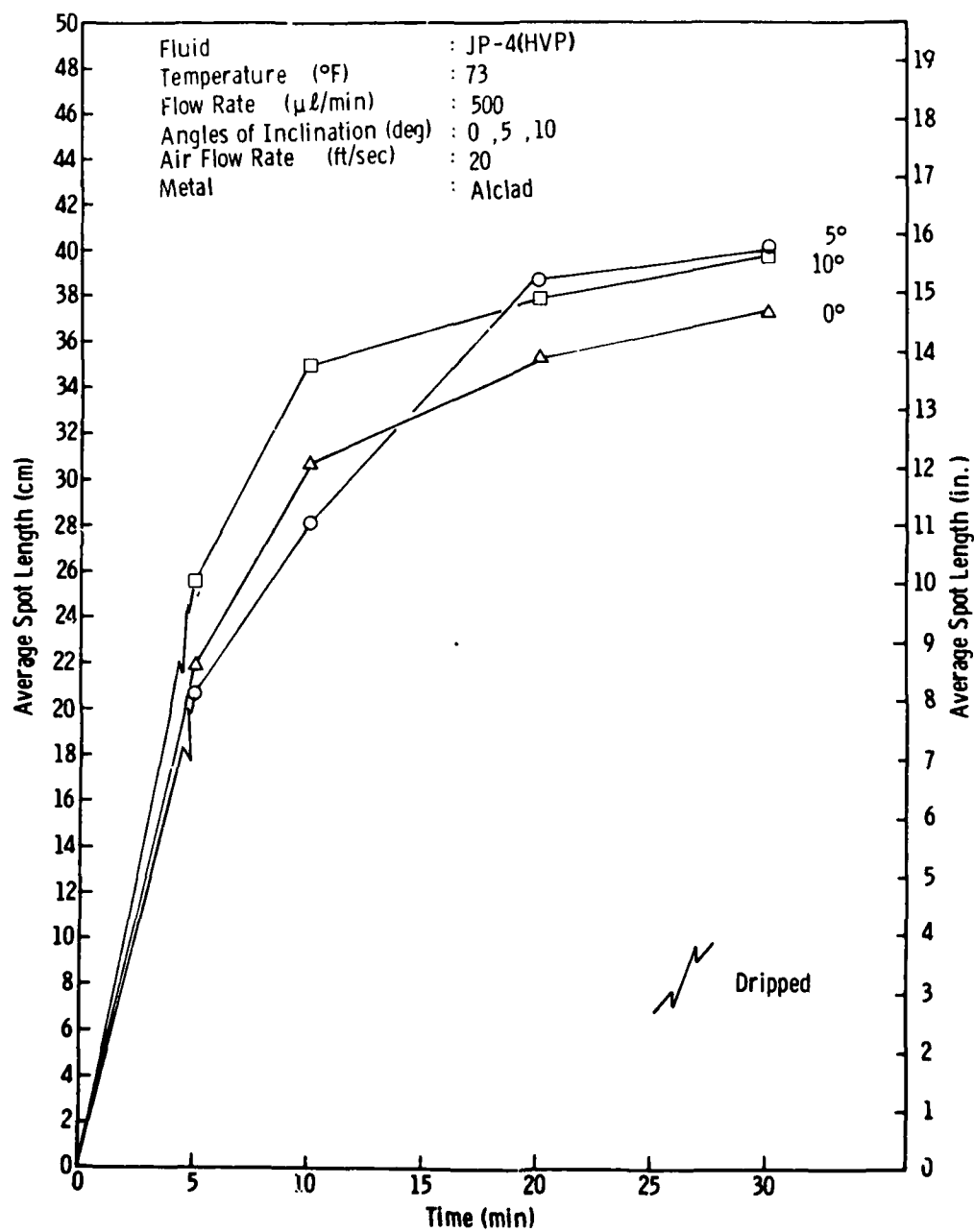


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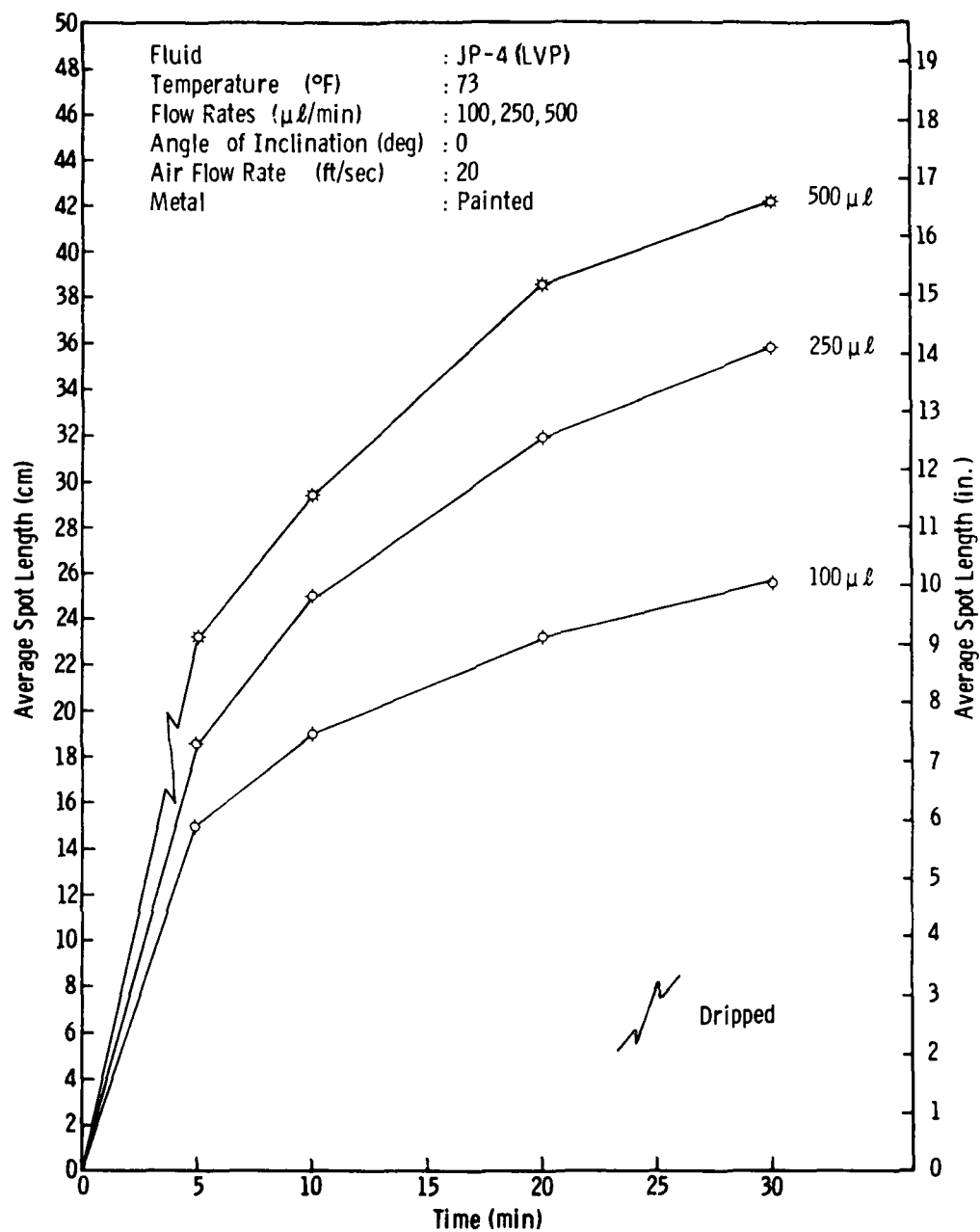


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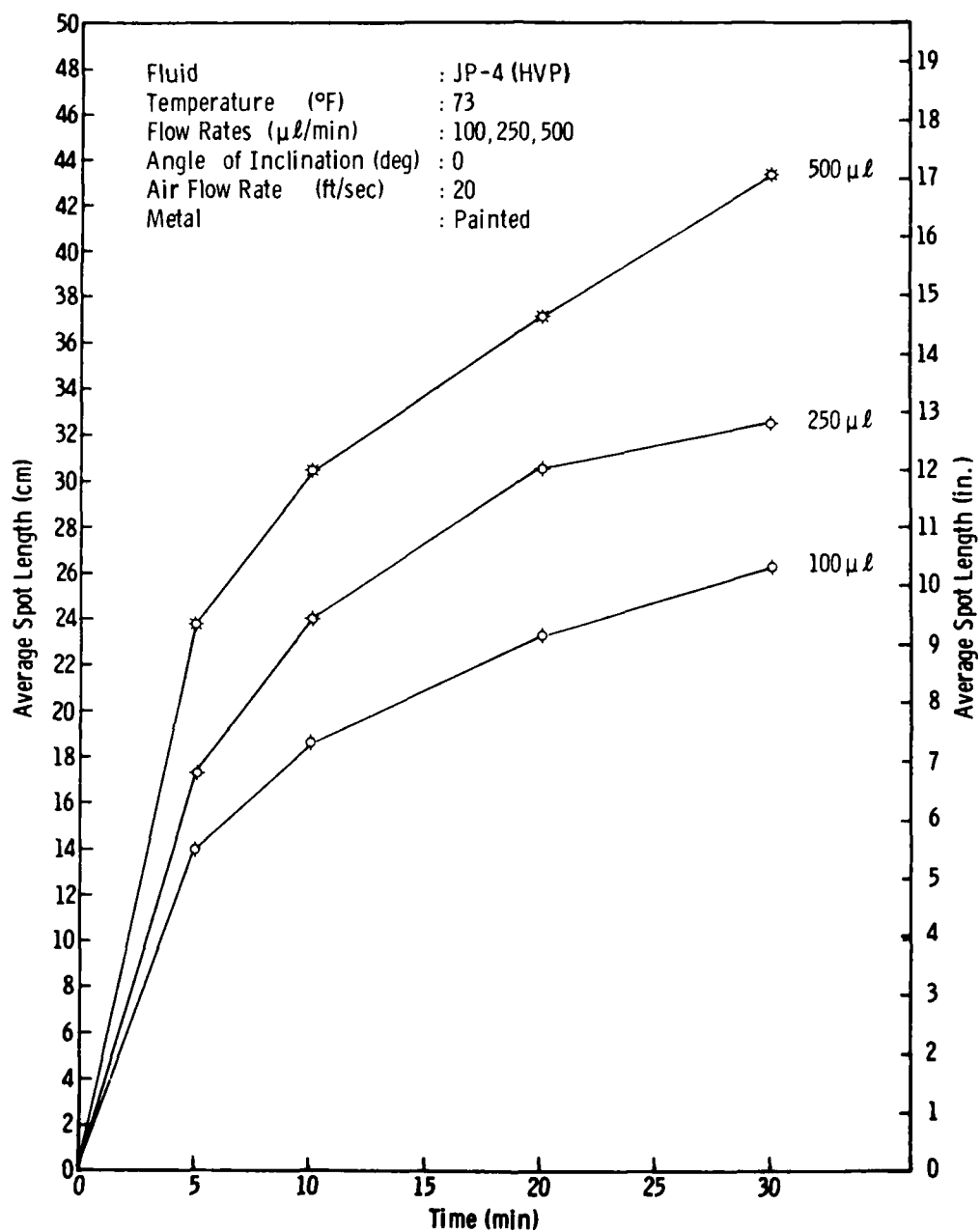


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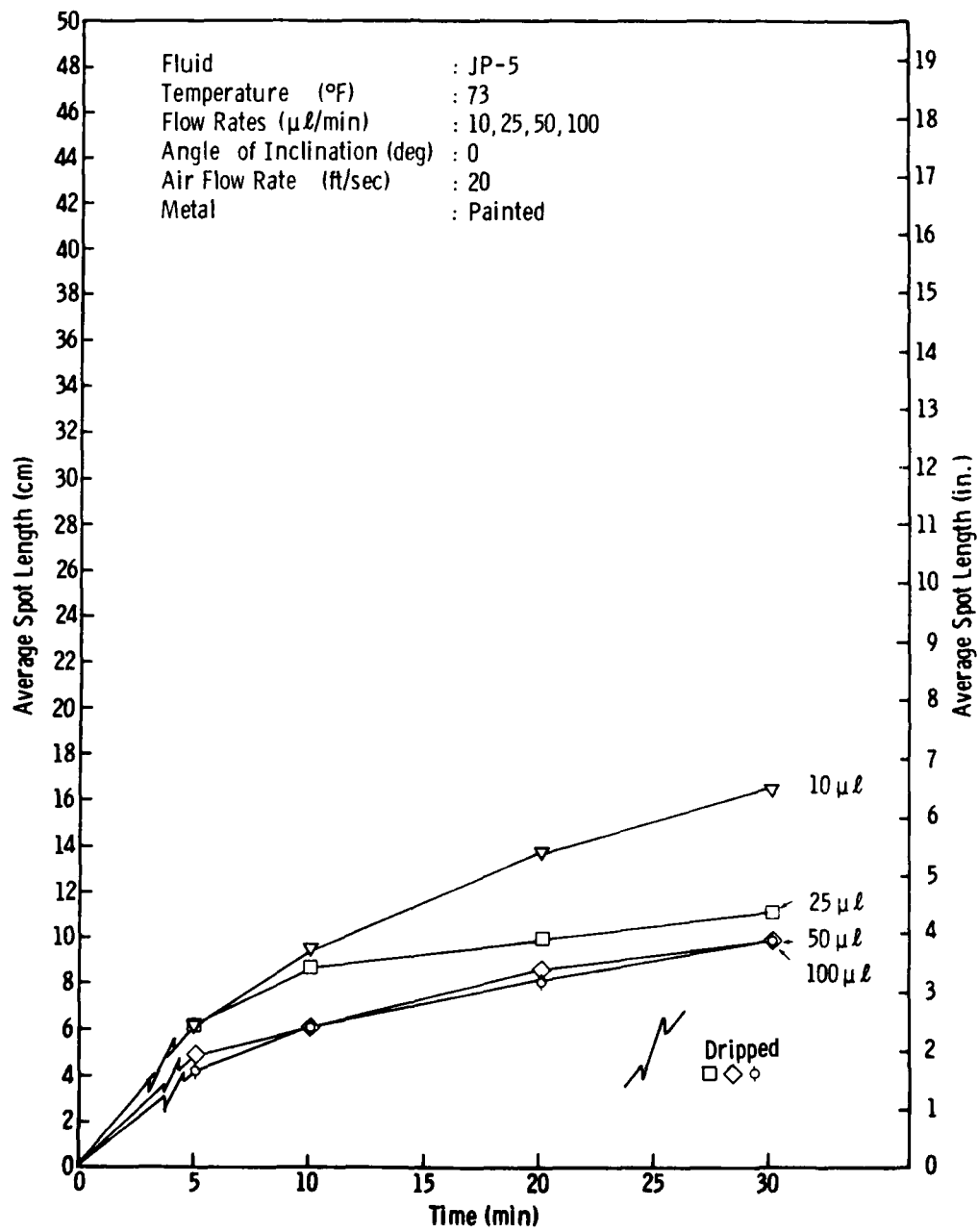


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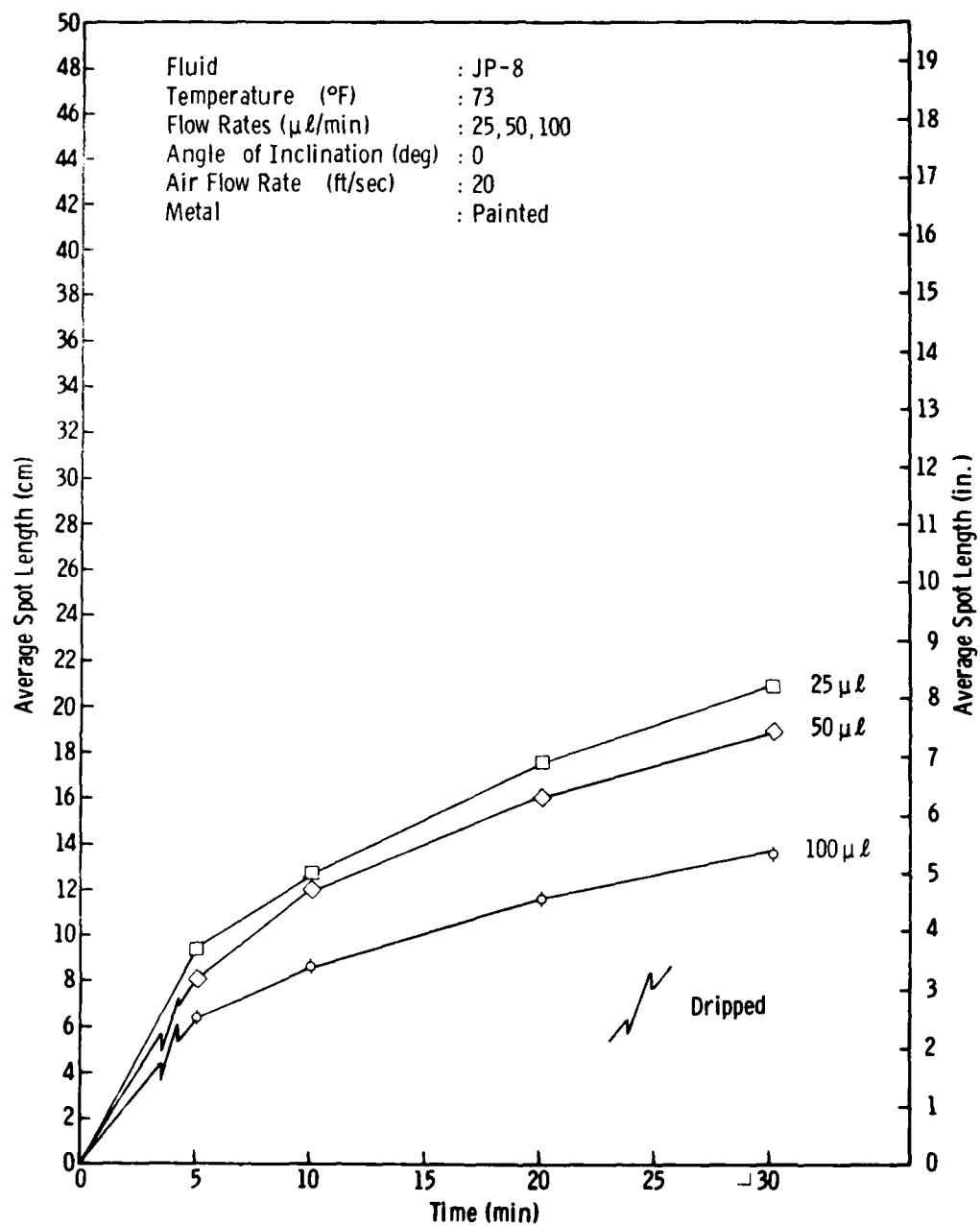


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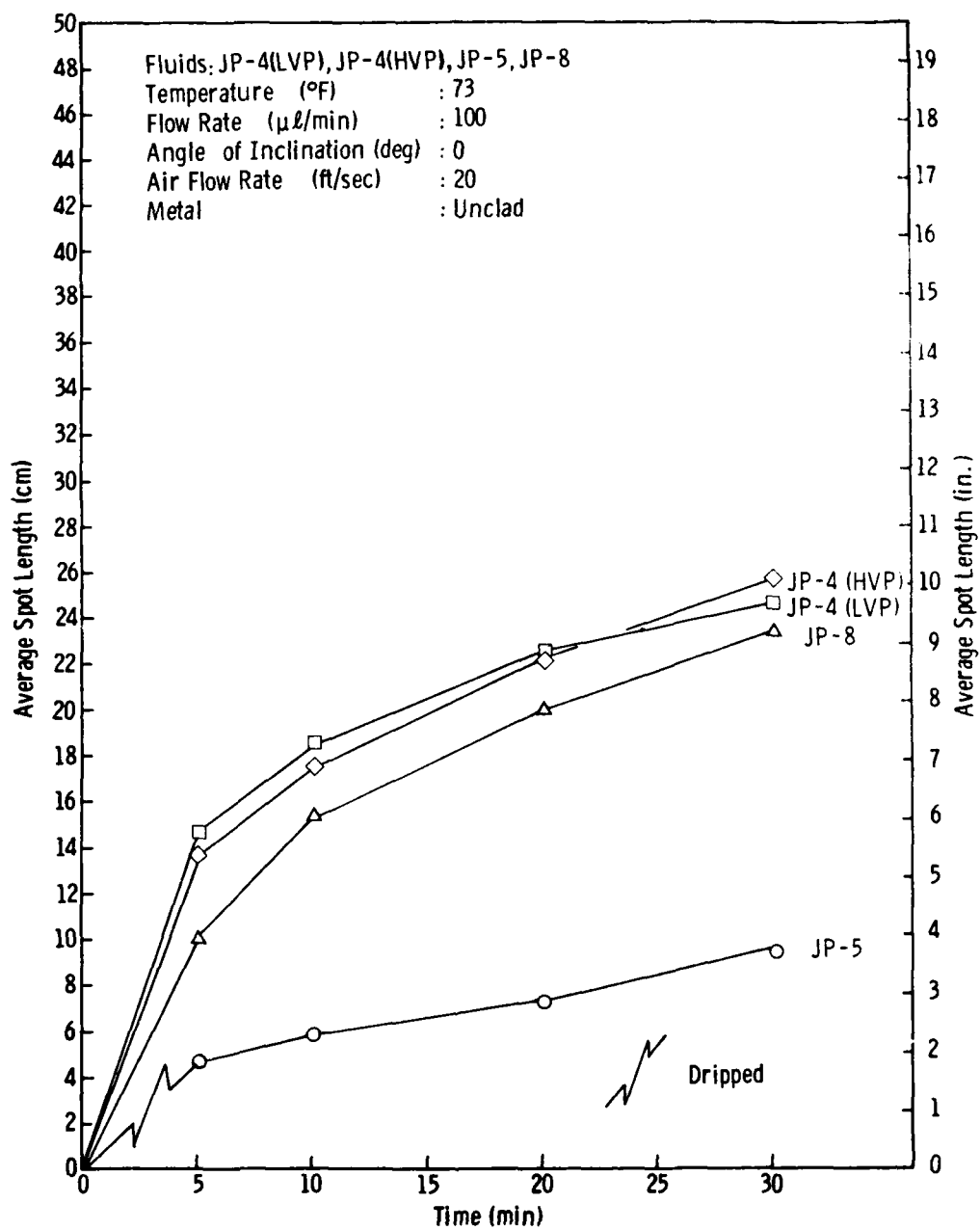


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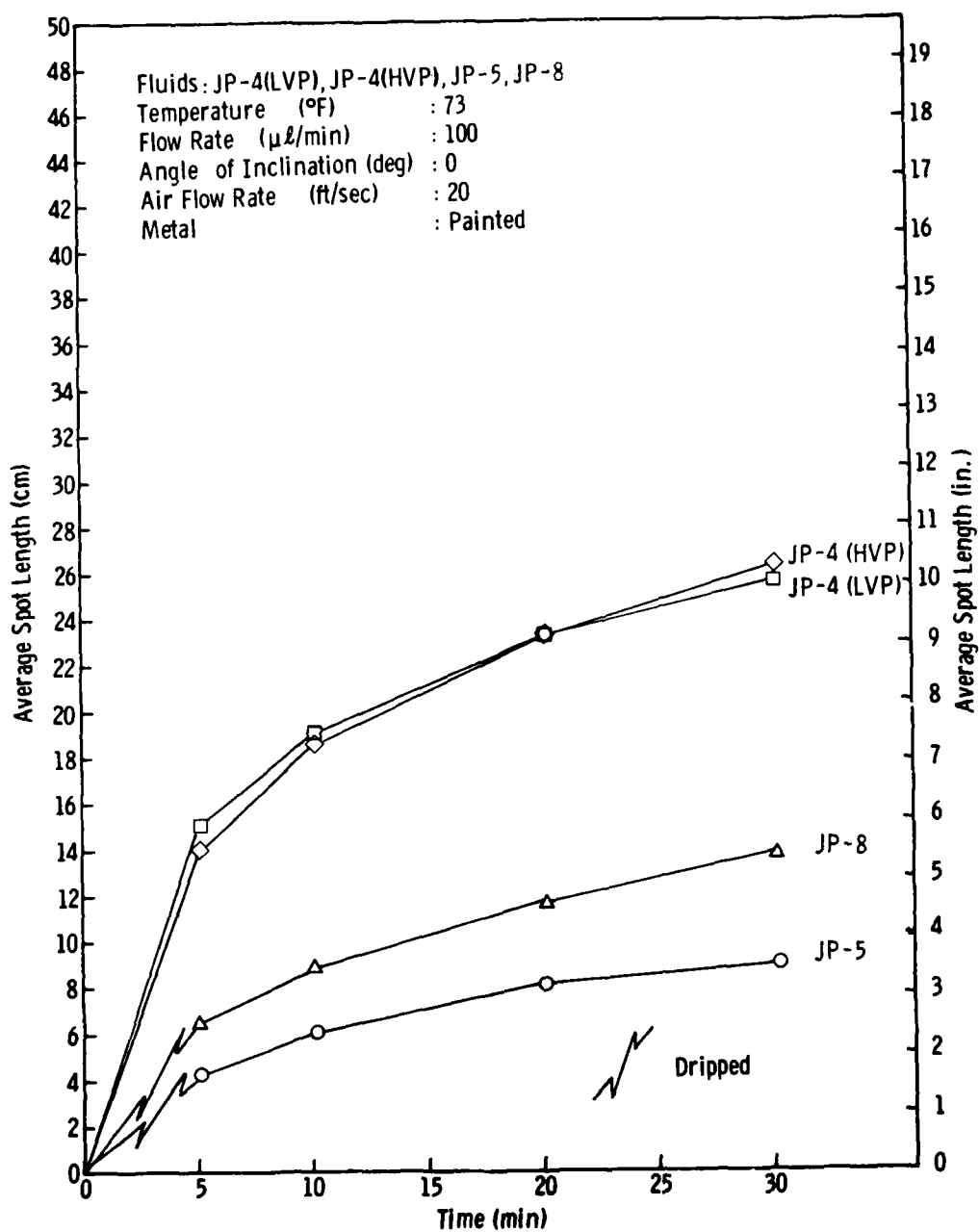


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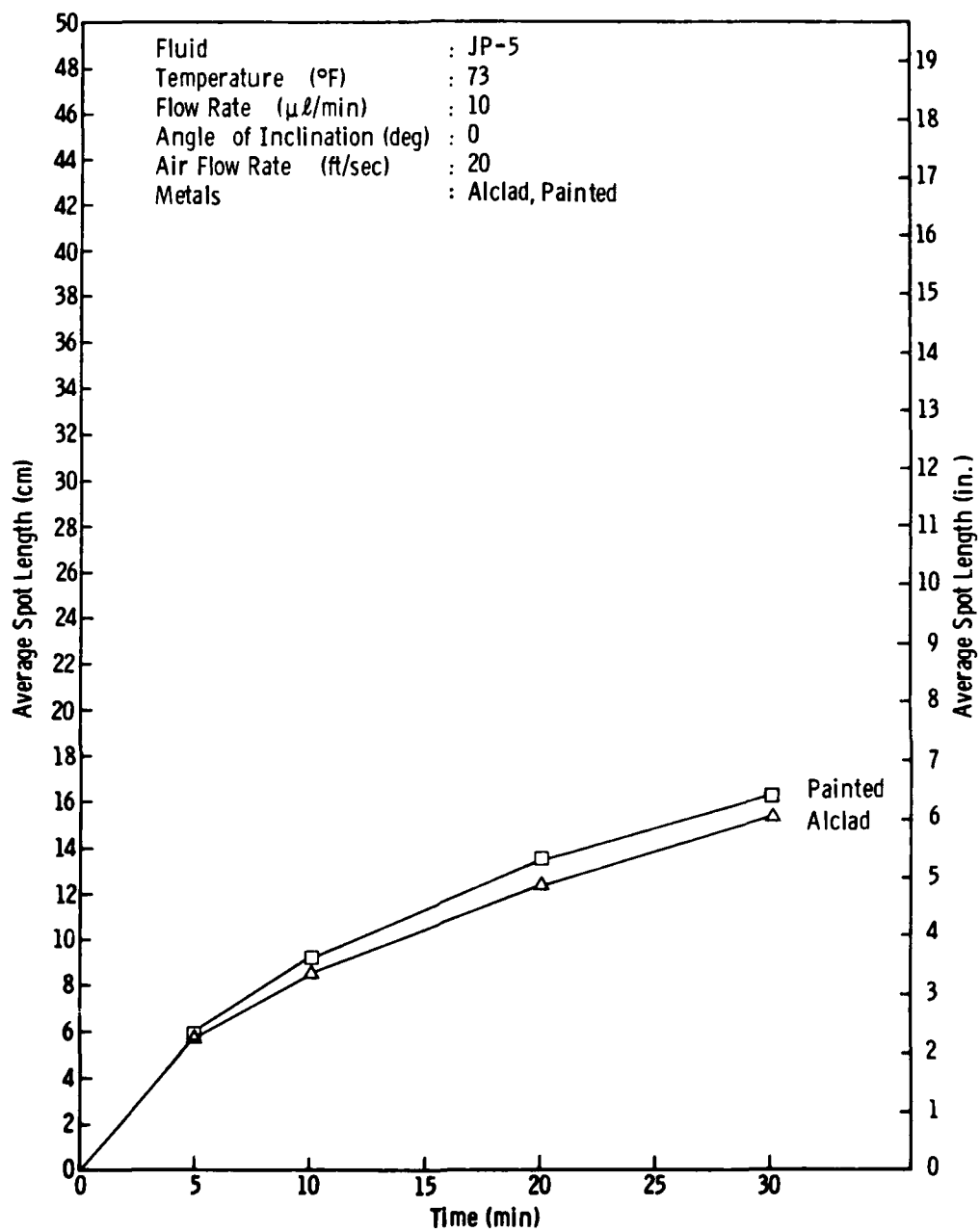


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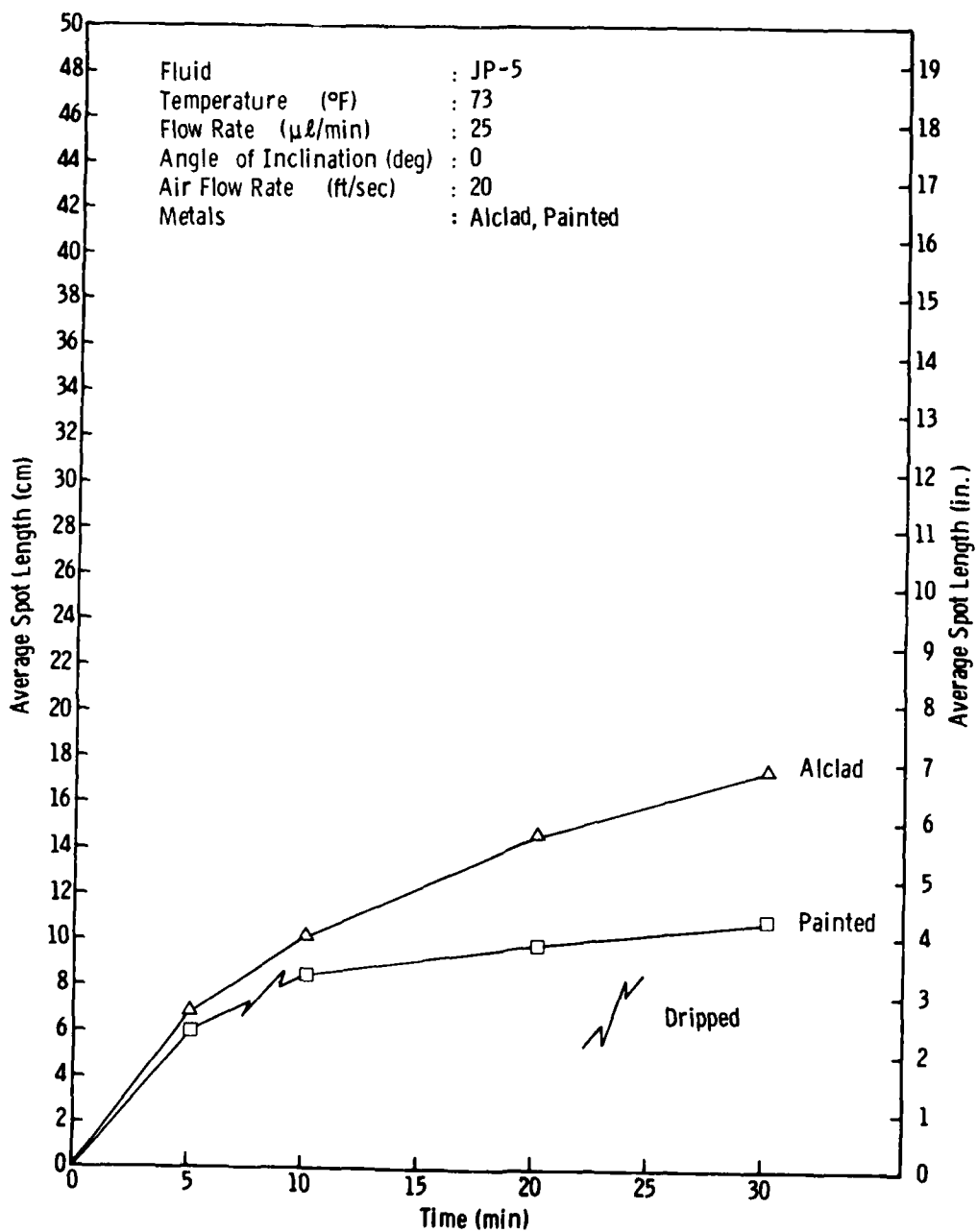


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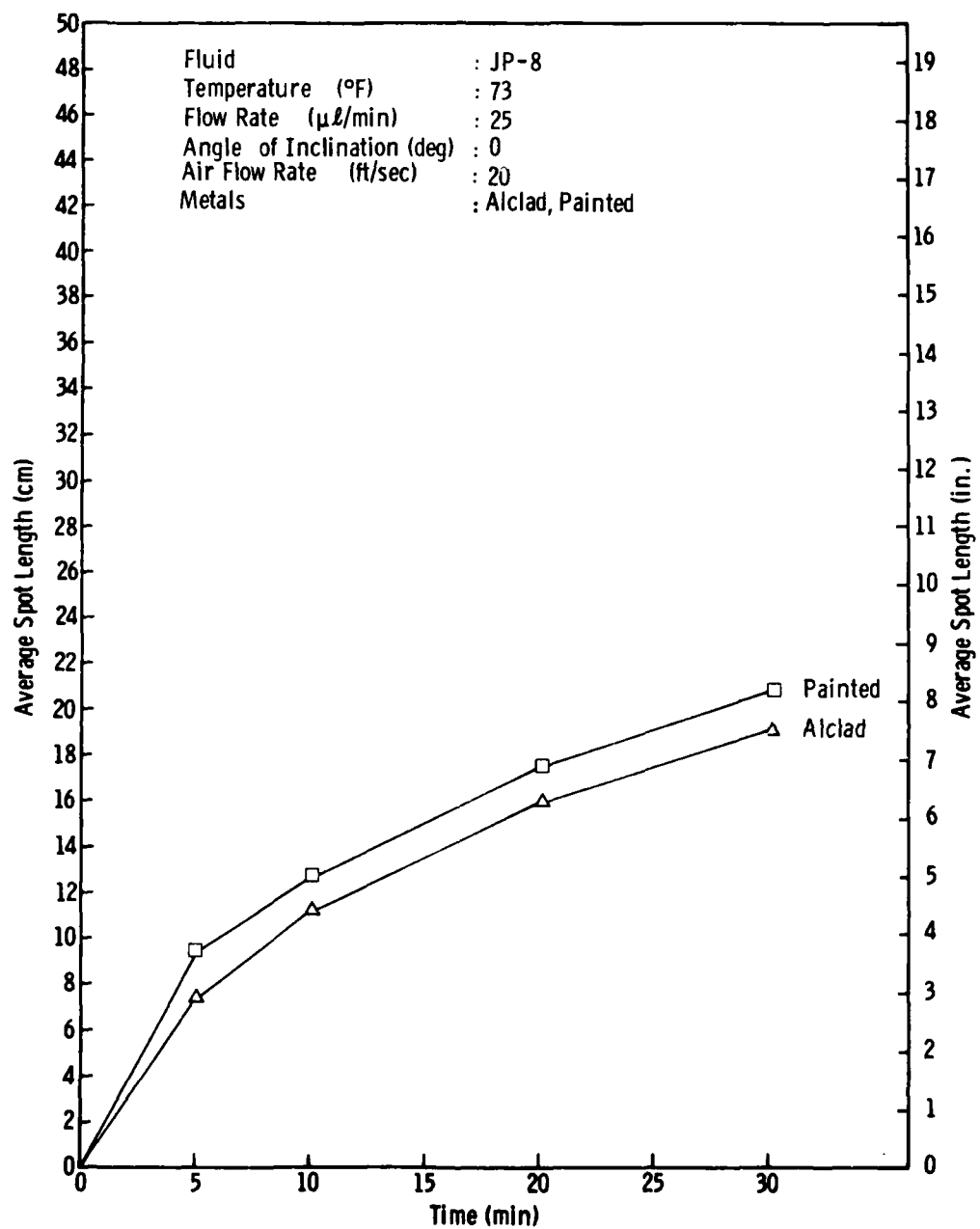


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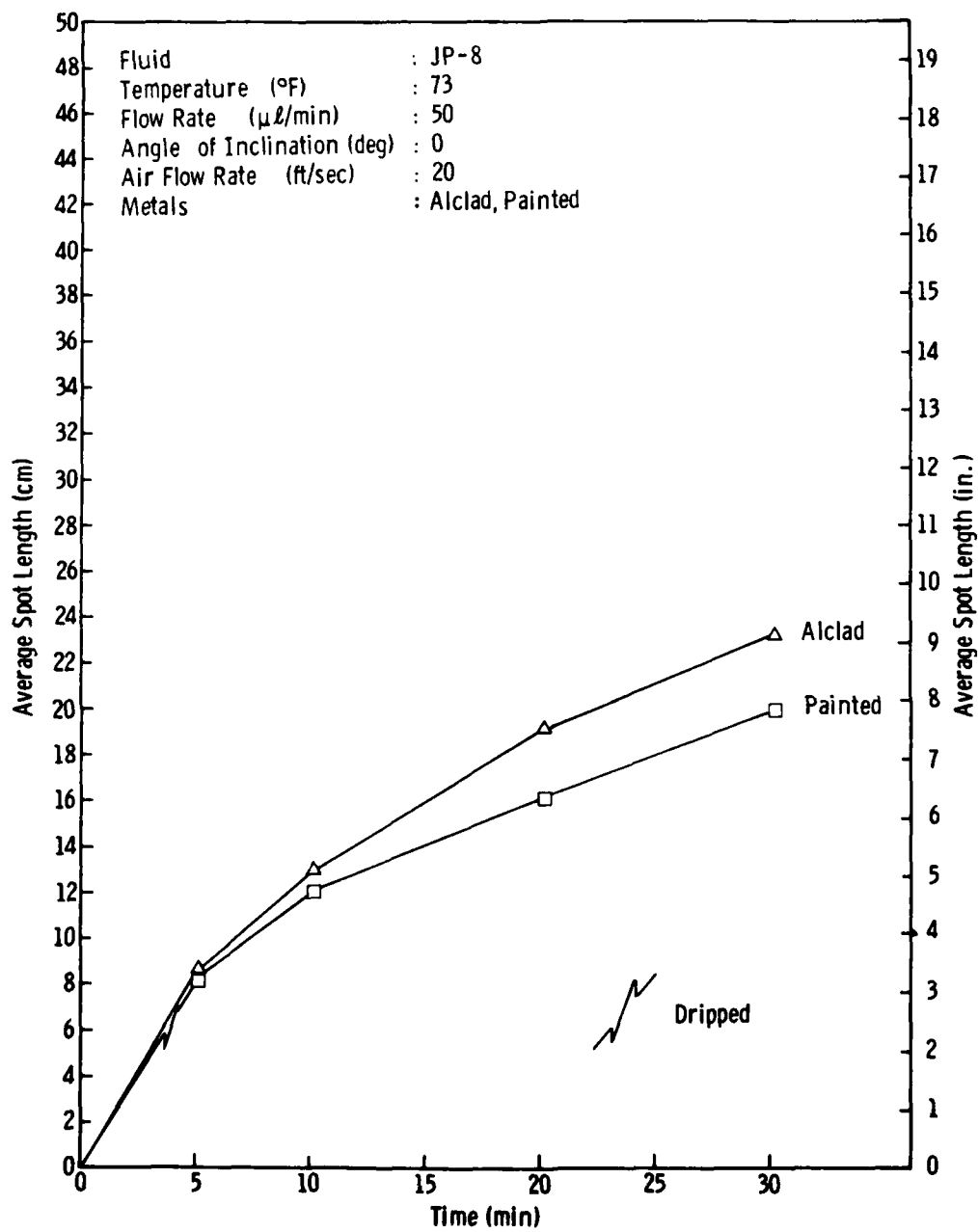


Figure 108.

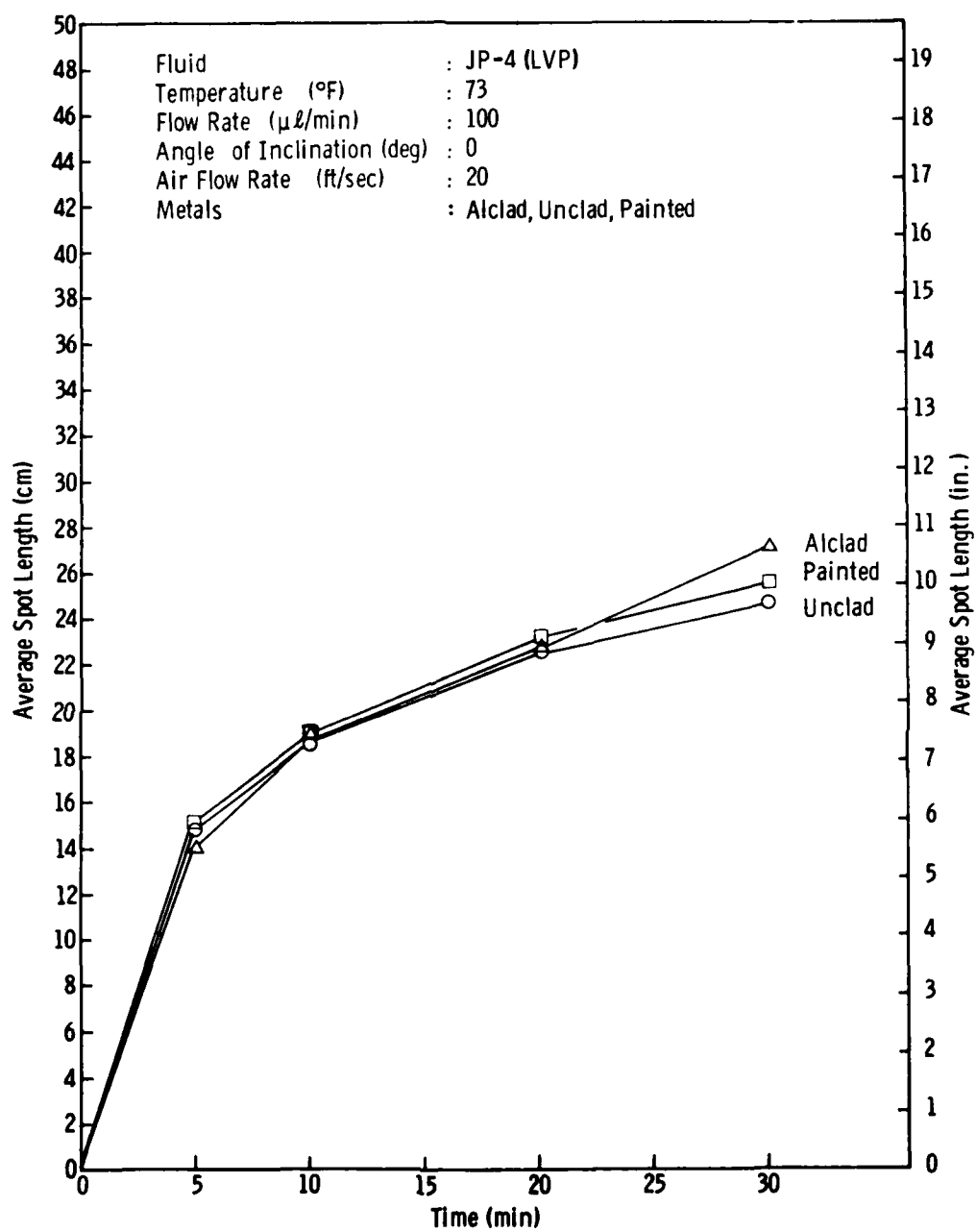


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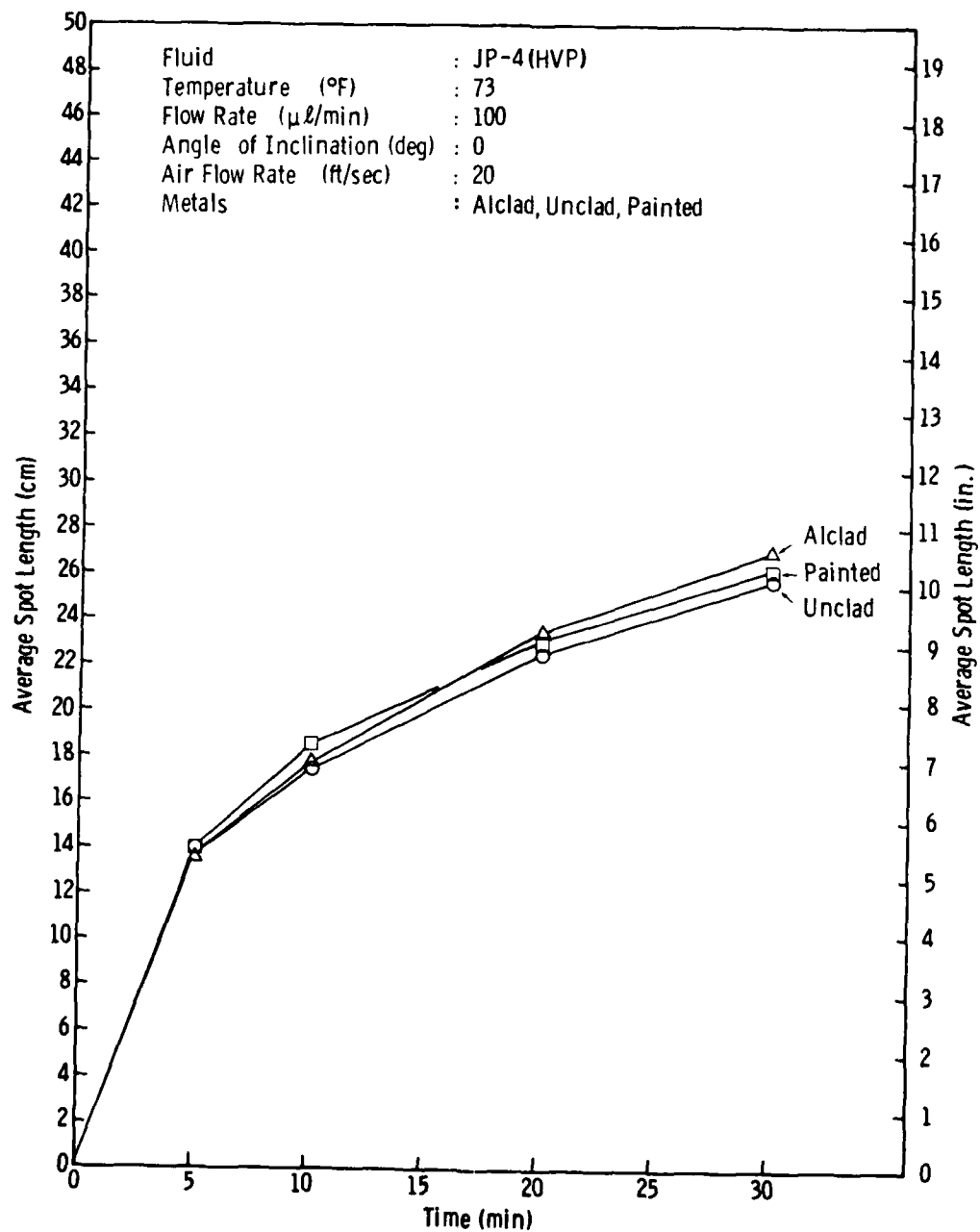


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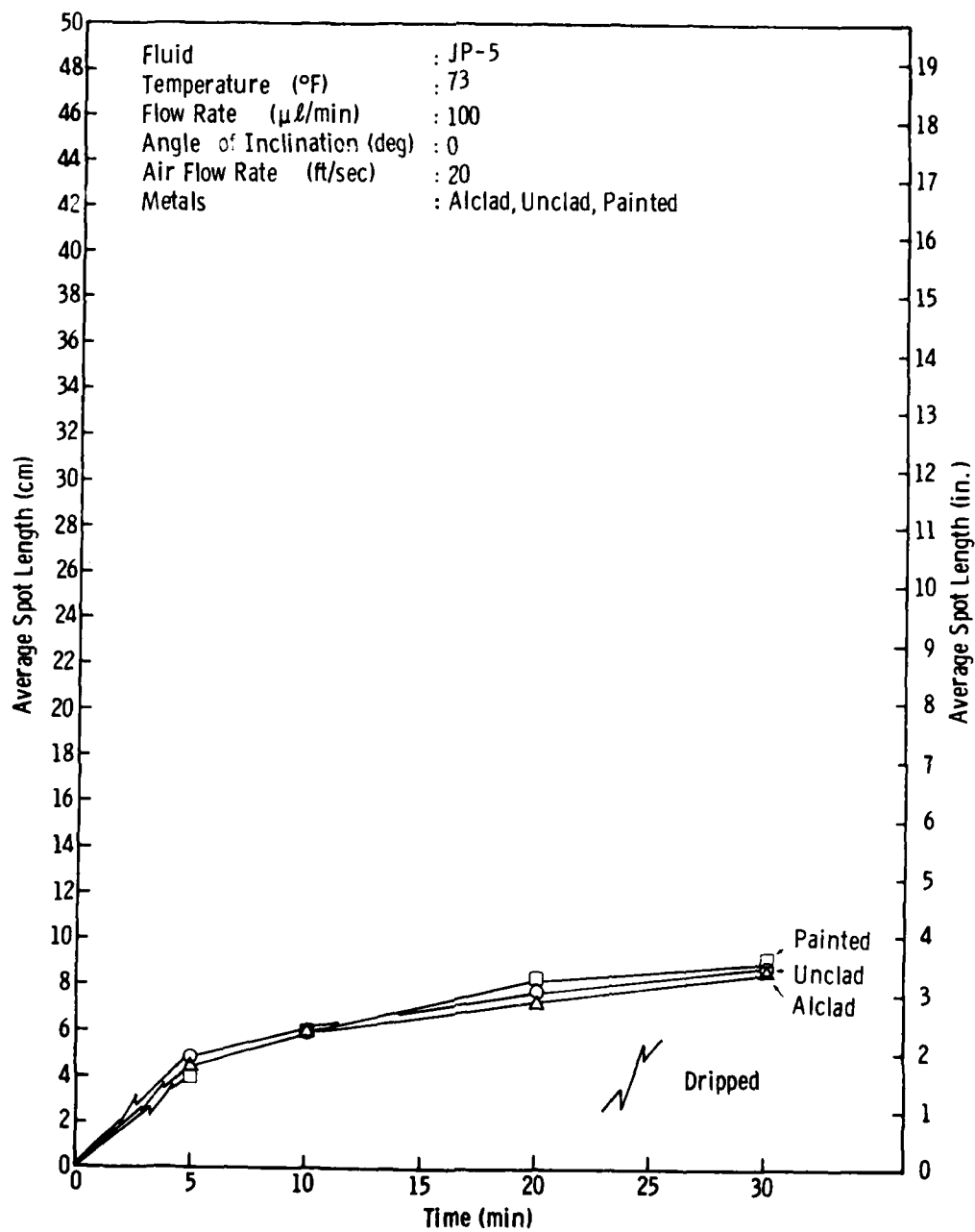


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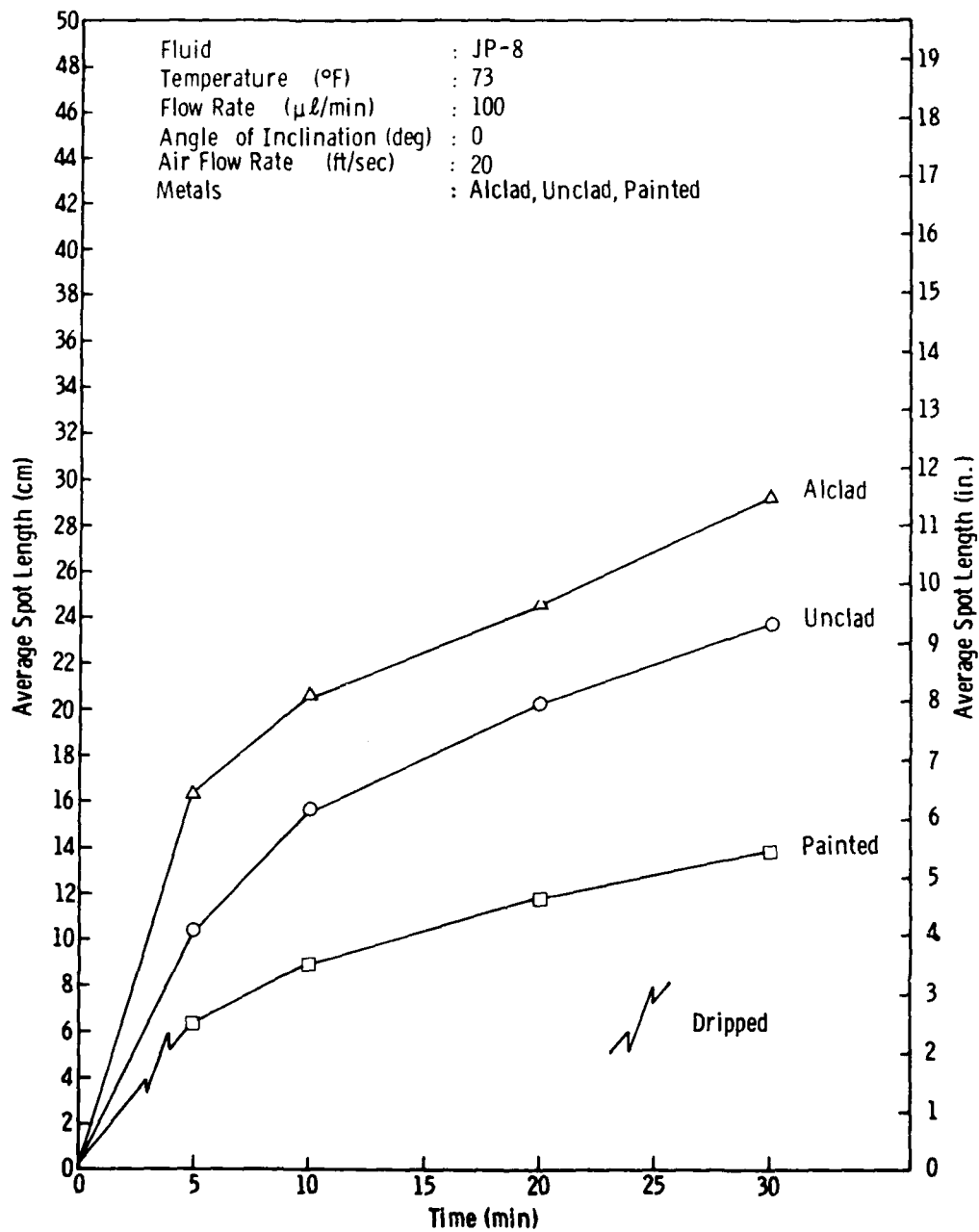


Figure 112.

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