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# DEGREE OF VAPORIZATION USING AN AIRBLAST TYPE INJECTOR FOR A PREMIXED - PREVAPORIZED COMBUSTOR

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16. Abstract

The purpose of this report is to present vaporization data that could be useful in designing premixed-prevaporized fuel preparation systems for gas turbine combustors. The effect of the experimental parameters on vaporization was found to be $E = T_{in}\tau^{0.18}(V_{ref} + 38)(P_{in} + 35)/203000$ where $E$ is the degree of vaporization in percent, $T_{in}$ the inlet air temperature in K over the range 450 to 700 K, the residence time in ms over the range 4.3 to 23.8 ms, $V_{ref}$ the reference velocity in m/s over the range 5 to 22 m/s, and $P_{in}$ the inlet pressure in MPa over the range 0.18 to 0.59 MPa. Jet A and Diesel no. 2 fuels were tested for the effect of inlet air temperature and had nearly identical results.

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## APPARATUS

### Test Rig

Figure 1 is a schematic of the test rig. The airflow was measured by a square-edged orifice. The air was heated to temperatures between 450 and 700K in a nonvitiating preheater. The fuel flow rate was measured by two turbine flowmeters in series. The duct was 12 cm in diameter. A temperature and pressure measurement was taken upstream of the injector.

The degree of vaporization was determined with the spillover technique as described in reference 4. This method consists of varying the sample flow through the probe, above and below the isokinetic value. Then from the variation in the fuel-air ratio at the different flows through the probe, the degree of vaporization can be determined. The vaporization measurement was taken in the center of the duct. The vaporization length (see fig. 1) could be varied from 10.2 to 17.8 cm by changing a spool piece. A temperature and pressure measurement was also taken at the plane of the probe.

The fuel-air ratio was determined by passing the mixture sample over a catalyst heated in an oven to 1030K and analyzing the products of combustion for carbon monoxide, carbon dioxide and unburned hydrocarbons. Carbon monoxide and carbon dioxide concentrations were measured on Beckman nondispensive infrared analyzers and unburned hydrocarbon concentrations were measured on a Beckman Flame Ionization Detector. The amount of unburned hydrocarbon and carbon monoxide measured was negligible (less than 100 ppm) because the mixture ratios were lean and nearly complete combustion occurred in the catalyst bed.

Twenty-three centimeters downstream of the probe station was a hydrogen enriched burner section. A drilled plate with 75 percent blockage was used as a flameholder. A water cooled orifice downstream of the burner section was used to control the test section pressure by adding varying amounts of air to the exhaust stream. Water was injected to cool the exhaust products.

### Multiple Conical Tube Fuel Injector

Photographs of this injector are shown in figure 2. Twenty-one conical tubes formed a tube bundle through which the air would flow. Each conical tube had an upstream diameter of 1.3 cm and a downstream diameter of 2.2 cm. The length of the conical tubes was 10.2 cm. Fuel was injected at the upstream end of each conical tube through a 0.5 mm inside diameter open ended fuel tube. Each fuel tube had a length of 25.4 cm.

## RESULTS AND DISCUSSION

Standard conditions for the parametric tests were an inlet air temperature of 600K, pressure of 0.3 MPa, a reference velocity of 10 m/s, a fuel-air ratio of 0.020, and a vaporization length of 17.8 cm. The standard fuel was Jet A. For the parametric tests one of the parameters was varied over a range with the other parameters at the standard conditions. The effect on degree of vaporization of each of the parameters is discussed separately and then a correlation of the collective parameters is presented.

### Inlet Air Temperature - Fuel Type

The degree of vaporization was a linear function of inlet air temperature, see figure 3. At an inlet air temperature of 460K, 66.7 percent of the Jet A and 68 percent of the Diesel no. 2 fuel was vaporized. Nearly complete vaporization of the fuel, 98.5 percent of the Jet A and 96.5 percent with Diesel no. 2, was obtained at an inlet air temperature of 700K.

There was pratically no difference between the Jet A and Diesel no. 2 vaporization data. The result was anticipated since the degree of vaporization would be predicted to be less than 6 percent based on the distillation data presented in Table I, if initial drop sizes are the same for the two fuels. Correlations by Nukiyama and Tanasawa (as given in ref. 6) and Lorenzetto and Lefebvre (ref. 7) confirm that the initial drop sizes are essentially identical (approximately 77 microns).

### Length

Vaporization increased with length to the 0.33 power, see figure 4. Note that the curve has been extrapolated to zero vaporization at zero length. At a vaporization length of 10.2 cm, the vaporization was 73 percent complete and at 17.8 cm about 88 percent complete. If residence time is used instead of length, the vaporization varies with residence time to the 0.18 power. The difference in exponents is due to the specific geometry of this fuel injector in which length and residence time are not directly proportional.

### Reference Velocity

The effect of reference velocity on degree of vaporization is shown in figure 5. Between a reference velocity of 5 and 14.5 m/s, the degree of vaporization decreased slightly from 92 percent to 88 percent. The vaporization then increased to 96.5 percent at a reference velocity of 19 m/s and was complete at a reference velocity of 24.8 and 29.4 m/s.

A change in reference velocity affects vaporization in two ways. First the residence time decreases with increasing velocity which tends to decrease the degree of vaporization. Secondly the drop size decreases with increasing velocity (refs. 6, 7, and 8) which tends to increase the degree of vaporization. The effect of residence time on the degree of vaporization was given in the previous section. Using the correlation given there, the degree of vaporization data presented in figure 5 was adjusted to a constant residence time. These results are plotted in figure 6. This figure shows that the effect of increasing air velocity which decreases drop size, results in a linear increase in degree of vaporization according to the expression, $E = 1.6 (V_{ref} + 38)$.

### Pressure

In general, vaporization increased as the pressure increased from 0.18 to 0.59 MPa, see figure 7. The vaporization increased from 80.2 percent at 0.18

MPa to 93.5 percent at 0.59 MPa. A linear correlation for the effect of pressure on vaporization, $E = 22\ (P_{in} + 3.5)$ predicts the data within 4 percent. However, the effect of pressure may be much more complex, since pressure can affect heat transfer characteristics, drop size, diffusion resistance and the partial pressure necessary for vaporization.

Fuel-Air Ratio

The effect of fuel-air ratio on the degree of vaporization is negligible between fuel-air ratios of 0.005 to 0.020. However, from a fuel-air ratio of 0.020 to 0.034 the degree of vaporization decreased from 90 to 61 percent (although the actual mass of fuel vaporized increased slightly). The degree of vaporization decreased more than what would be expected from the cooling of the airstream by the vaporization process. Factors that could lower the degree of vaporization are an air temperature in the vicinity of the droplet lower than the bulk airstream temperature and a greater diffusion resistance as the fuel-air ratio increases.

At a fuel-air ratio of 0.034 the trend is abruptly reversed and the degree of vaporization increases with fuel-air ratio. The degree of vaporization increases from 61 percent at a 0.034 fuel air ratio to 92 percent at a 0.039 fuel-air ratio and then to 94.5 percent at a 0.0505 fuel-air ratio. The increase in vaporization rate could be attributed to preflame reactions occurring such as observed in reference 8.

No conclusion or correlation is given for the effect of fuel-air on the degree of vaporization. It is felt that the effect may be very dependent on inlet conditions and fuel injector design. Further experimental data is necessary to fully describe the effect.

Correlation of Parameters

The combined effects of inlet air temperature, residence time, reference velocity, and pressure on the degree of vaporization can be expressed as

$$E = T_{in}\,\tau^{0.18}\ (V_{ref} + 38)\ (P_{in} + 3.5)\ /\ 203000.$$

The effect of fuel-air ratio is not included for the reasons discussed in the previous section. The measured degree of vaporization is plotted against that predicted by the above expression in figure 9. The data correlates very well, with the maximum deviation being ± 5 percent. The correlation can then be used in the design of new airblast type fuel injectors since the effects of the variables on the degree of vaporization should be the same.

The correlation is for Jet A fuel, but since Jet A and Diesel no. 2 fuel properties are similar and the vaporization data agreed well when the effect of inlet air temperature was measured, it is expected that the Jet A correlation can also be used with Diesel no. 2.

Summary of Results

Parametric tests of the effect of inlet air temperature, length (residence time), reference velocity, pressure and fuel-air ratio on the degree of vaporization were made. Jet A and Diesel no. 2 fuel were tested. The following results were obtained:

1 The effect of inlet air temperature, residence time, reference velocity and pressure on the degree of vaporization for a constant fuel-air ratio of 0.020 is given by

$$E = T_{in}\,\tau^{0.18}\ (V_{ref} + 38)\ (P + 3.5)\ /\ 20300.$$

The variables were tested over the following ranges; $T_{in}$ from 450 to 700K, from 4.3 to 23.8 ms, $V_{ref}$ from 5 to 29.4 m/s, $P_{in}$ from 0.18 to 0.59 MPa. This correlation predicts the data within ± 5 percent.

2 Results of the effect of inlet air temperature on degree of vaporization using Jet A and Diesel no. 2 were nearly identical.

3 As the fuel-air ratio increased, the degree of vaporization first decreased and then increased. The increased degree of vaporization is felt to be due to an increase in temperature resulting from preflame reactions. Additional testing is required to fully explain the observed effect of fuel-air ratio on degree of vaporization.

Table I - Fuel Properties

| Fuel | Jet A | Diesel no. 2 |
|---|---|---|
| Distillation Data | | |
| Initial boiling point | 458 K | 462 K |
| 5 | 469 | 482 |
| 10 | 472 | 498 |
| 20 | 477 | 511 |
| 30 | 482 | 520 |
| 40 | 487 | 528 |
| 50 | 492 | 538 |
| 60 | 497 | 546 |
| 70 | 503 | 556 |
| 80 | 510 | 569 |
| 90 | 521 | 587 |
| final boiling point | 540 | 592 |
| specific gravity at 289K | 0.8118 | 0.8481 |
| viscosity at 294K, centisokes | 2.13 | 3.75 |
| surface tension, dynes/cm | 30.65 | 31.84 |

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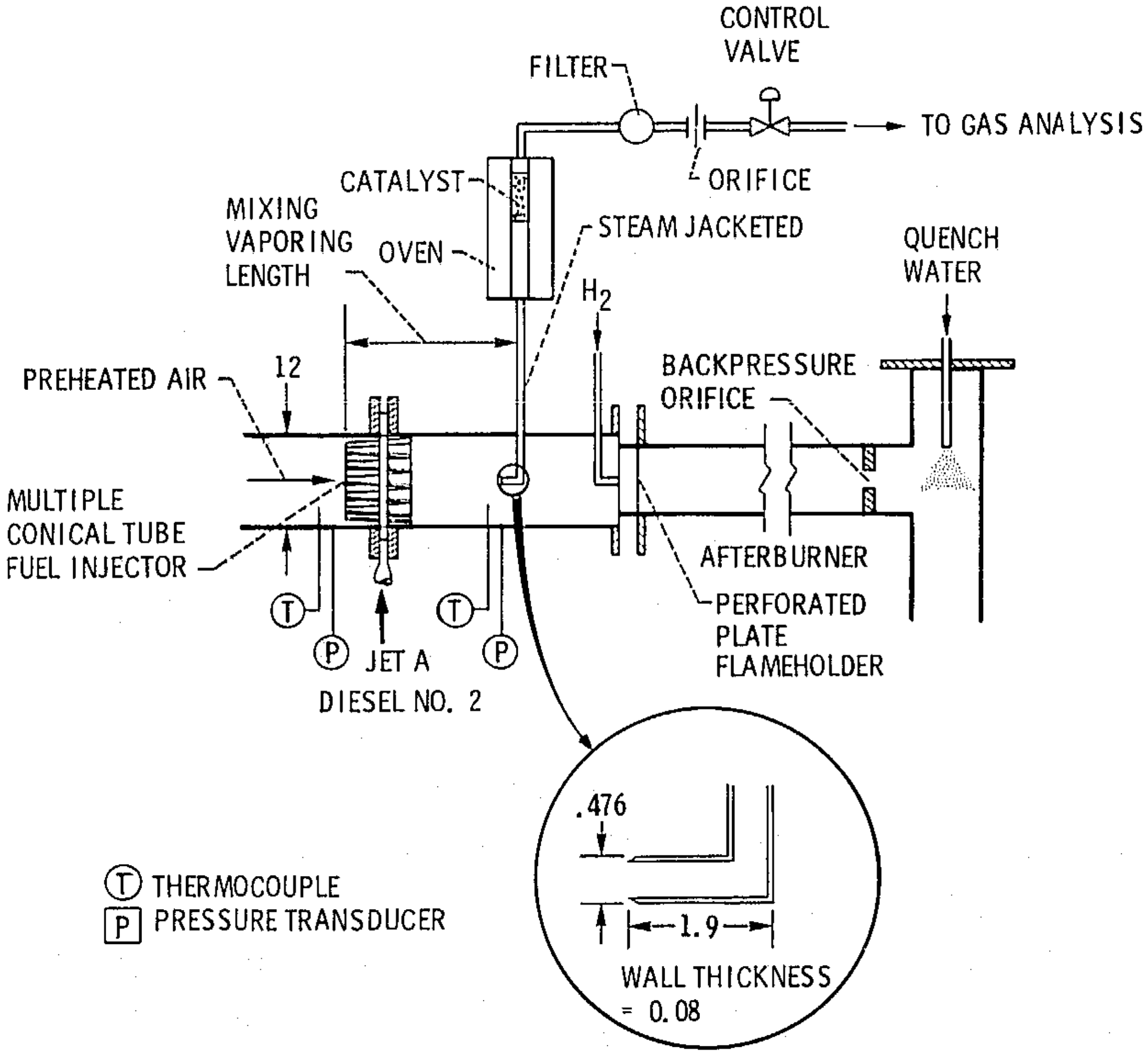
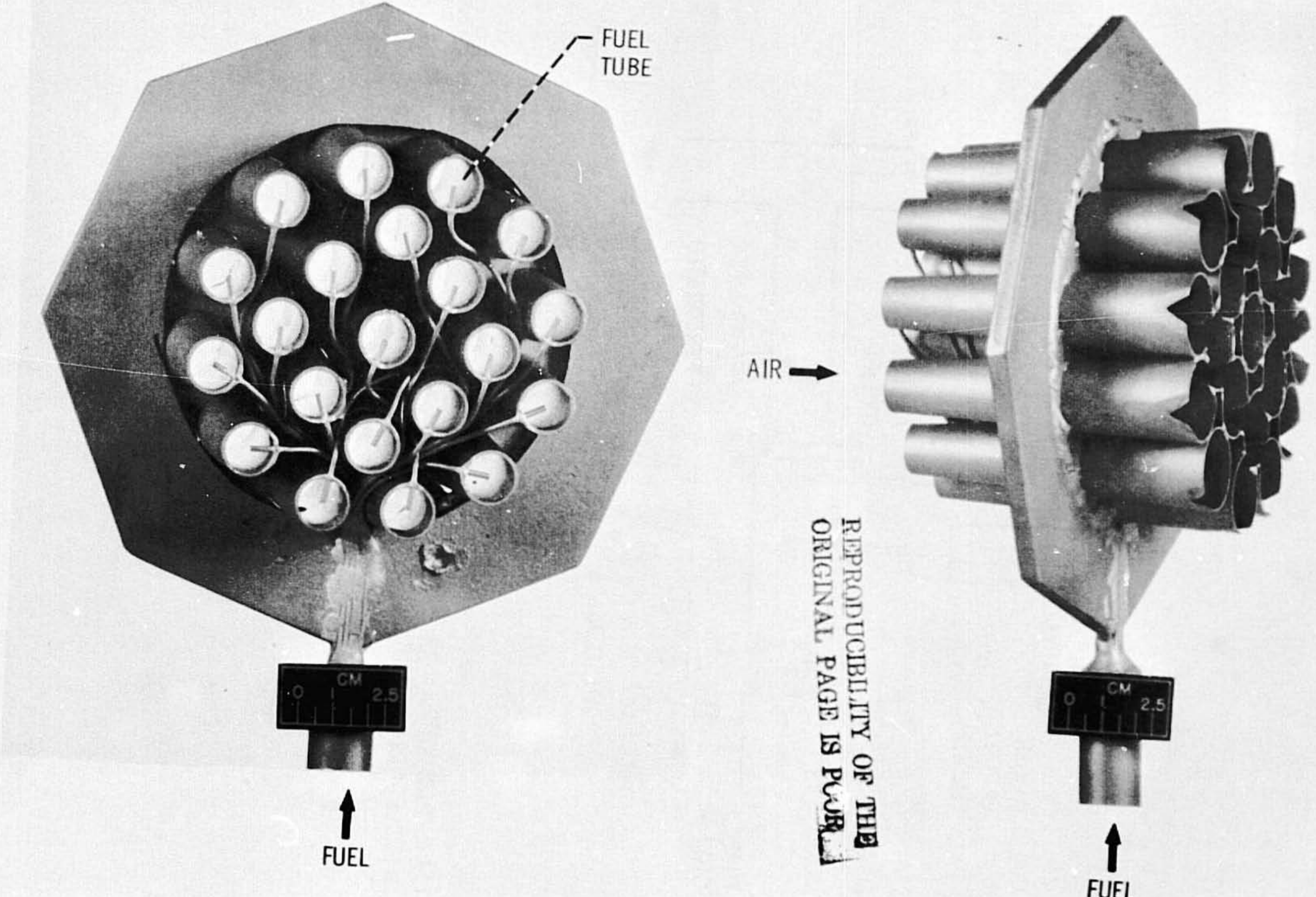


Figure 1. - Rig schematic. (Dimensions in cm.)



(a) UPSTREAM VIEW.

(b) SIDE VIEW.

Figure 2. - Multiple conical tube injector.

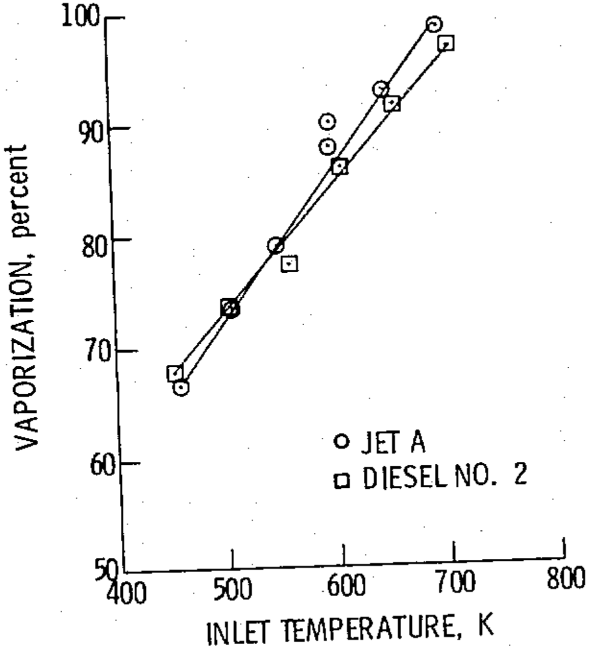


Figure 3. - Effect of inlet air temperature on degree of vaporization, for jet A and diesel no. 2 fuels. $P_{in} = 0.3$ MPa, $V_{ref} =$ 10 m/s, f/a = 0.020, vaporization length = 17.8 cm.

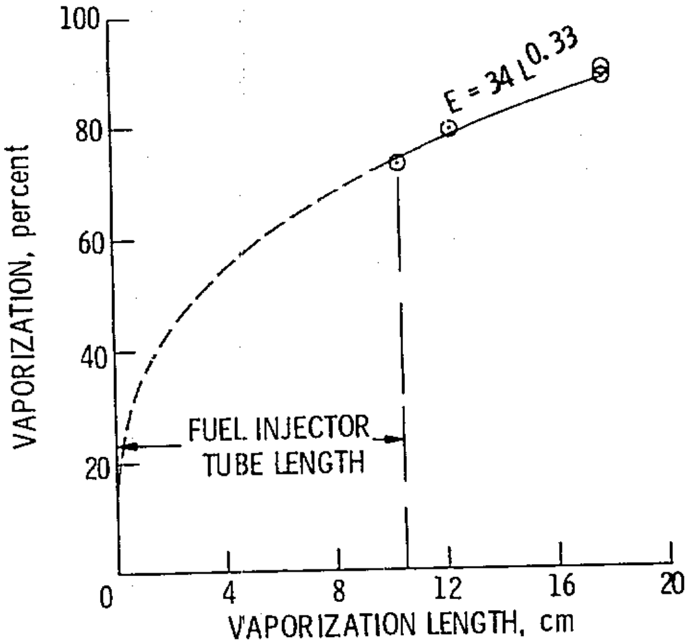


Figure 4. - Effect of vaporization length on degree of vaporization. $T_{in} = 600$ K, $P_{in} = 0.3$ MPa, $V_{ref} = 10$ m/s, f/a = 0.020, jet A fuel.

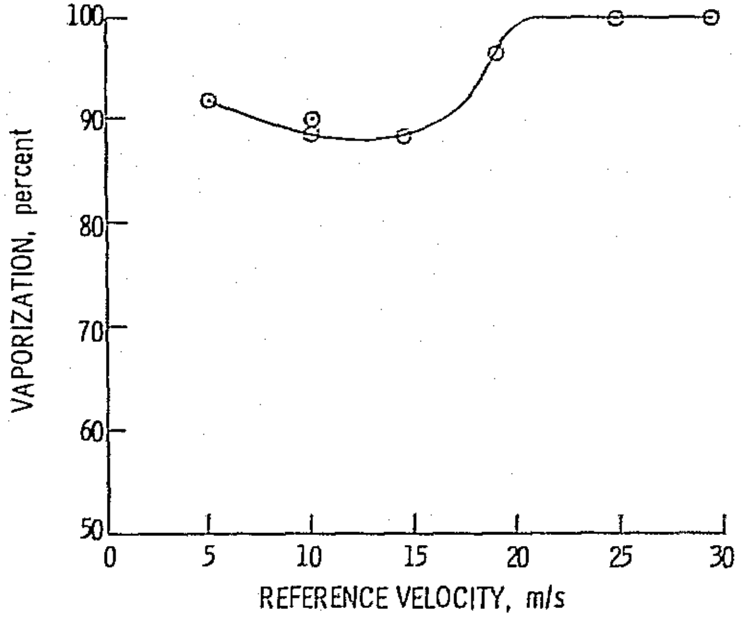


Figure 5. - Effect of reference velocity on degree of vaporization. $T_{in}$ = 600 K, $P_{in}$ = 0.3 MPa, f/a = 0.020, vaporization length = 17.8 cm, jet A fuel.

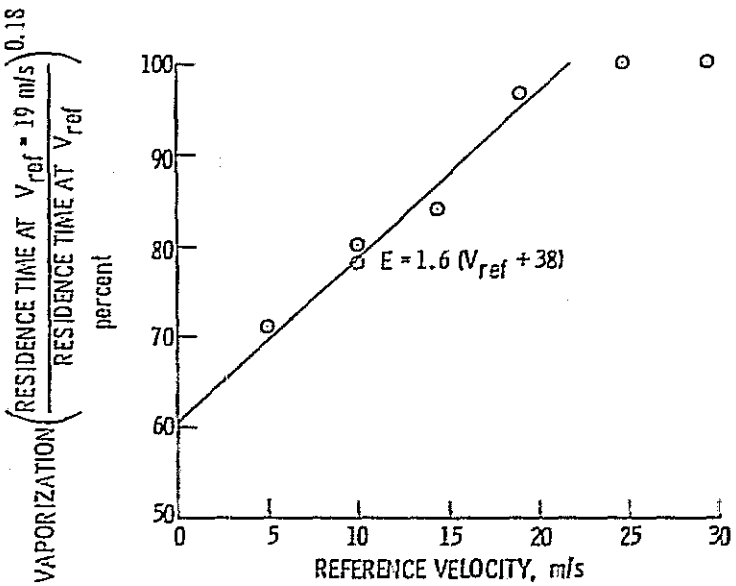


Figure 6. - Degree of vaporization adjusted to a constant residence time as a function of reference velocity. $T_{in}$ = 600 K, $P_{in}$ = 0.3 MPa, f/a = 0.020, vaporization length = 17.8 cm, jet A fuel.

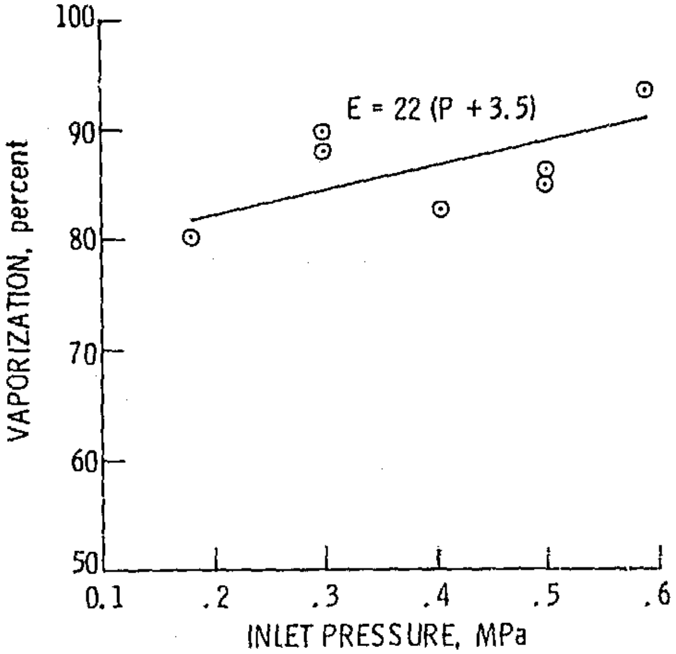


Figure 7. - Effect of inlet pressure on degree of vaporization. $T_{in}$ = 600 K, $V_{ref}$ = 10 m/s, f/a = 0.020, vaporization length = 17.8 cm, jet A fuel.

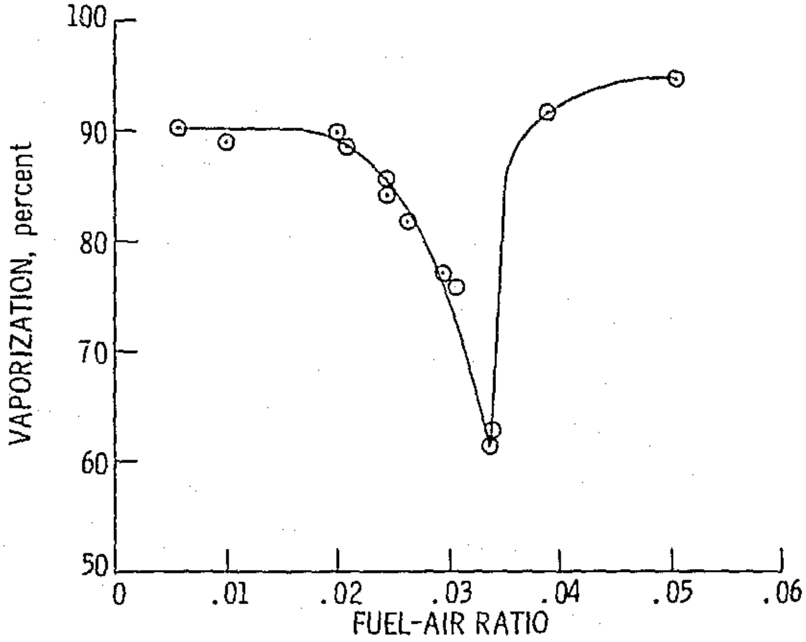


Figure 8. - Effect of fuel-air ratio on degree of vaporization. $T_{in}$ = 600 K, $P_{in}$ = 0.3 MPa, $V_{ref}$ = 10 m/s, vaporization length = 17.8 cm, jet A fuel.

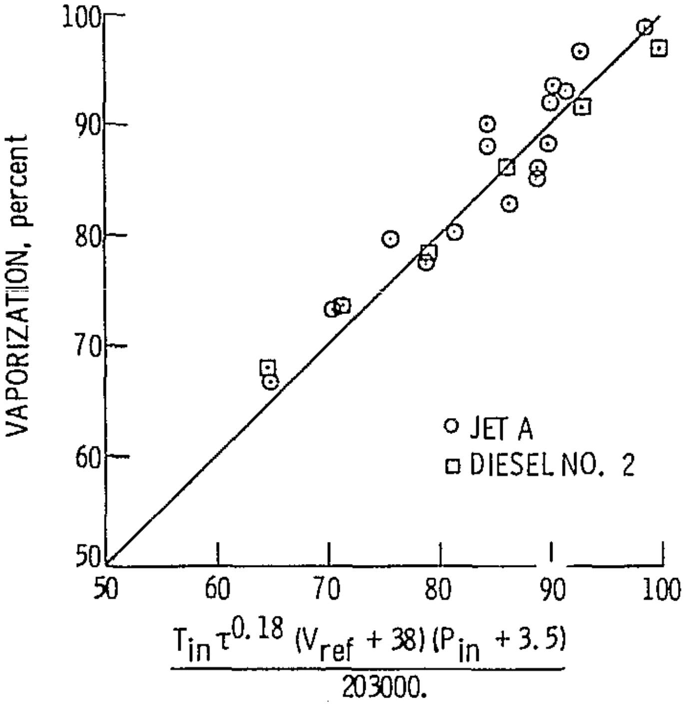


Figure 9. - Correlation of degree of vaporization. $T_{in}$ in K, $\tau$ in ms, $P_{in}$ in m/s, $P_{in}$ in MPa, f/a = 0.020.