NASA SP-3035

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THERMODYNAMIC, TRANSPORT, AND FLOW PROPERTIES FOR THE PRODUCTS OF METHANE BURNED IN OXYGEN-ENRICHED AIR

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OFFICE OF TECHNOLOGY UTILIZATION 1966
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

SUMMARY

Results of calculations to determine the composition and the thermodynamic, transport, and flow properties (including normal-shock properties) of gas mixtures are presented. These properties are computed for methane burned in air enriched with oxygen so as to maintain approximately 20 percent oxygen in the combustion products. Results are presented for equivalence ratios of 0.315, 0.370, 0.425, 0.480, and 0.525, for pressures varying from 0.0001 to 1000 atmospheres and for temperatures from 100° R (56° K) to 6000° R (3300° K).

INTRODUCTION

In recent years, applications for materials capable of withstanding extremely high-temperature oxidizing environments and for airbreathing propulsion systems suitable for operation at hypersonic velocities have become increasingly more evident. Consequently, large-scale hypersonic test facilities capable of simulating flight environments have become necessary in the development of these advanced materials and propulsion systems. One method of providing the high stagnation temperature and pressure needed for flight simulation in a facility is through combustion heating of a high-pressure airstream. However, combustion of fuel in the airstream requires consumption of some or all of the oxygen in the stream. In some test situations where it is desired to maintain burning in the test gas or to determine the effect of oxidation on materials in the test gas, combustion-product oxygen percentages approaching those in air (approximately 20 percent by volume) are required. Therefore, the necessity for knowledge of the properties of a combustion-heated, oxygen-enriched test medium becomes evident.

In the present paper the results of a study to determine the properties of the products of methane burned with oxygen-enriched air are presented. This study parallels that of reference 1, which was concerned with determining the properties of the products of methane burned with pure air. It should be noted that the results of the present study are generally applicable to all situations in which corresponding gas mixtures of methane, air, and oxygen are present.

The general equations and the analytical approach used are presented. Because of the preponderance of data, summarized results of the study are given in tables and figures. These results are presented as functions of temperature, pressure, and equivalence ratio, for a temperature range from 100° R (56° K) to 6000° R (3300° K), a pressure range from 0.0001 to 1000 atmospheres (1 atm = 1×10^5 N/m^2), and an equivalence-ratio range from 0.315 to 0.525. The results include analytically determined values of gas constituency, molecular weight, isentropic exponent, specific heat, viscosity, thermal conductivity, and Prandtl number. Also presented are thermodynamic property diagrams for each of the selected equivalence ratios. Additional data giving the appropriate ratios of properties in front of, across, and behind a normal shock in the isentropically expanded combustion products are presented in the tables.

SYMBOLS

The units used for the physical quantities defined in this paper are given both in U.S. Customary Units and in the International System of Units (SI) (ref. 2). Appendix A presents factors relating these two systems of units.

A	number of formula weights of equivalent reactant; also, cross-sectional area, ft^2 (m^2)
a	velocity of sound, ft/sec (m/s)
a,b,c,d,e	number of gram atoms of the elements H, O, N, Ar, C
C_nH_m	hydrocarbon fuel containing n atoms of carbon and m atoms of hydrogen
c_p^o	molar specific heat at constant pressure, Btu/mole-°R (J/mole-°K)
c_p	specific heat at constant pressure, Btu/lbm-°R (J/kg-°K)
F	free energy per formula weight of material, Btu/mole (J/mole)
H	enthalpy, Btu/lbm (J/kg)
K	thermal conductivity, Btu/ft-sec-°R (W/m-°K)
k	Boltzmann's constant
L	ratio of mass of oxygen in air to mass of air

M	molecular weight
N_{Ma}	Mach number
m	mass, lbm (kg); also, gram atoms of hydrogen
$m(O_2)^+$	mass of excess oxygen available in combustion products, lbm (kg)
$(m_f/m_x)_s$	ratio of mass of fuel to mass of oxidant at stoichiometric conditions
N_{Pr}	Prandtl number
n	number of moles; also, gram atoms of carbon
$n(O_2)^+$	number of moles of excess oxygen available in combustion products
p	pressure, atmospheres
q	dynamic pressure, lbf/ft^2 (N/m^2)
R	universal gas constant, 1.98588 Btu/mole-^oR (8.31432 J/mole-^oK)
R_{eq}	equivalence ratio, $(m_f/m_x)/(m_f/m_x)_s$
R_{sp}	specific gas constant, Btu/lbm-^oR (J/kg-^oK)
S	entropy per mole, Btu/mole-^oR (J/mole-^oK)
s	entropy per unit mass, Btu/lbm-^oR (J/kg-^oK)
T	temperature, ^oR (^oK)
V	velocity, ft/sec (m/s); also, volume, ft^3 (m^3)
X	mole fraction

$\alpha = (\partial \ln M/\partial \ln T)_p$

$\beta = (\partial \ln M/\partial \ln p)_T$

γ	isentropic exponent, $(\partial \ln p/\partial \ln \rho)_S$
δ	variation of $\Delta F/RT$ from equilibrium
ϵ	Lennard-Jones force constant
θ	ratio of total moles of oxygen to moles of oxygen in air
θ_1	factor defined by equation (B18)
μ	viscosity, slugs/ft-sec $(N\text{-}s/m^2)$
ρ	mass density, slugs/ft^3 (kg/m^3)
σ	collision diameter of molecule, angstroms (m)
ϕ	factor in viscosity formula, defined by equation (27)
Ω	collision integral

Subscripts:

a	air
c	combustion chamber
EF	equivalent formula
e	exit of nozzle
f	fuel
i	ith product of reaction
l	postcombustion specie or dummy index
m	atoms of hydrogen
n	atoms of carbon

o assigned value

p constant pressure

r equivalent reactant

s constant entropy

T at temperature T; also, constant temperature

t stagnation condition

tot total

x oxidant

0 absolute zero of temperature

1 free-stream or preceding shock

2 following shock

Superscripts:

o thermodynamic standard state

* throat

ANALYTICAL APPROACH AND RESULTS

The general equations for computing the combustion gas properties make use of the following assumptions: (1) The process is adiabatic; (2) the precombustion and postcombustion pressures are equal; (3) combustion occurs in a zero-velocity environment; (4) the gas is in chemical equilibrium; (5) the ideal gas equation of state is valid; and (6) only gas phases are considered. The equations are presented in the following sections of this paper to outline the general approach taken for calculating the combustion gas properties. The results presented in the tables and figures are for a 20-percent-oxygen combustion gas. The equivalence ratios chosen for the study correspond to the equilibrium flame temperatures indicated in figure 1. These temperatures are typical of those needed for simulating the energy levels of lower hypersonic flight. The relative amounts of methane, air, and oxygen required to achieve the flame temperatures shown in figure 1 are obtained as discussed in appendix B.

The International System of Units (ref. 2) is used in the equations presented in the text. However, the primary system of units used in the figures is the U.S. Customary System since it was believed that this system is the one most commonly used to present the applicable parameters.

Gas Composition and Thermodynamic Properties

Gas composition.- In the computation of the combustion gas composition, the general equation for the reaction is written such that the fuel and oxidant are expressed by an equivalent formula (that is, in the form of a single large molecule). The number of atoms of each element in this large molecule is the sum of the numbers of atoms of each element in the fuel and oxidant molecules. The chemical equilibrium equations for reaction products are written under the assumption that the products are formed from their constituent gaseous atoms.

The equations required in the composition calculations are those describing the conservation of mass, chemical equilibrium, Dalton's law of partial pressures, and the conservation of enthalpy and entropy. The equations, as outlined in the following paragraphs, are developed in detail in references 3 and 4.

Combustion at constant pressure: The elements involved in the reaction may be represented by an equivalent formula written as

$$H_{a_o}O_{b_o}N_{c_o}Ar_{d_o}C_{e_o}$$

where a_o, b_o, c_o, d_o, and e_o are proportional to the total number of gram atoms of the elements hydrogen H, oxygen O, nitrogen N, argon Ar, and carbon C, respectively. For example, the equivalent formula for $2CH_4 + C_2H_4$ is written as C_4H_{12}.

The equivalent formula representation of the equilibrium reaction may be expressed as

$$A\left(H_{a_o}O_{b_o}N_{c_o}Ar_{d_o}C_{e_o}\right) \rightarrow \sum n_i\left(H_{a_i}O_{b_i}N_{c_i}Ar_{d_i}C_{e_i}\right) \tag{1}$$

or

$$H_{a_o}O_{b_o}N_{c_o}Ar_{d_o}C_{e_o} \rightarrow \frac{1}{A} \sum n_i\left(H_{a_i}O_{b_i}N_{c_i}Ar_{d_i}C_{e_i}\right) \tag{2}$$

where A is the number of formula weights of the equivalent reactant and n_i is the number of moles of the ith atom or molecule. The products of reaction are considered to be contained by a volume V which is numerically equal to RT, where R is the gas constant and T is the absolute temperature, so that $p_i = n_i$.

The equations describing the relative amounts of each element in the combustion products can be written as:

$$\left.\begin{aligned} a &= \frac{1}{A}\sum_i a_i n_i \\ b &= \frac{1}{A}\sum_i b_i n_i \\ c &= \frac{1}{A}\sum_i c_i n_i \\ . &= . \; . \; . \end{aligned}\right\} \tag{3}$$

where $a, b, c, \ldots$ are the gram atoms of the elements H, O, N, . . . in each equivalent formula from which the reaction products are formed. For equation (2), the conservation of mass is defined by the relations

$$\left.\begin{aligned} a &= a_o \\ b &= b_o \\ c &= c_o \\ . &= . \; . \; . \end{aligned}\right\} \tag{4}$$

Each reaction product can be considered as being formed from the gaseous atoms and can be written as

$$a_iH + b_iO + c_iN + d_iAr + e_iC = H_{a_i}O_{b_i}N_{c_i}Ar_{d_i}C_{e_i} \tag{5}$$

If ΔF is defined as the change in free energy and $\Delta F/RT$ is represented by the symbol δ, the change in free energy for each specie can be written as

$$\delta_i = \left(\frac{\Delta F^o}{RT}\right)_i + \ln p_i - (a_i \ln p_H + b_i \ln p_O + c_i \ln p_N + d_i \ln p_{Ar} + e_i \ln p_C) = 0 \tag{6}$$

where $(\Delta F^{o})_i$ is the standard-state free-energy change across the reaction. The standard state of the reaction products is taken as 1 atmosphere. For constant temperature and pressure, δ_i must equal zero for the reaction to be in equilibrium.

The equation for Dalton's law of partial pressures is written as

$$p = \sum_i p_i \tag{7}$$

If a pressure p_o is assigned, then

$$p = p_o \tag{8}$$

The reaction is assumed to occur in a zero-velocity environment and therefore, the static pressure is equal to the stagnation pressure.

The mole fraction X_i for each species in the products may be obtained from

$$X_i = \frac{n_i}{\sum_i n_i} \tag{9}$$

Species considered for the combustion products are listed in table I. Curves showing mole fractions as a function of temperature for each species present are given in figures 2, 3, 4, 5, and 6 for pressures of 0.01, 1.0, and 100 atmospheres. These pressures were selected to represent typical test-section, test-section recovery, and free-stream stagnation pressures, respectively, for a hypersonic test facility.

The principle of conservation of energy states that if the chemical energy is included in the enthalpy of each element or species, the enthalpy of the products of reaction is equal to the enthalpy of the reactants. The molar enthalpy of a species of reaction is defined as

$$\left(H_T^o\right)_i = \int_0^T \left(c_p^o\right)_i \, dT + \left(H_0^o\right)_i \tag{10}$$

where $\left(c_p^o\right)_i$ represents the molar specific heat at constant pressure, and $\left(H_0^o\right)_i$ represents the assigned reference enthalpy at 0^o K for the ith specie. An assigned reference is used since only differences in enthalpy are to be utilized. The enthalpy of the reactants per mole of equivalent formula is

$$H_T^o = \sum_i n_{f_i}\left(H_T^o\right)_{f_i} + \sum_i n_{x_i}\left(H_T^o\right)_{x_i} \tag{11}$$

where n_{f_i} and n_{x_i} are the moles of the ith fuel and ith oxidant corresponding to the equivalent formula of the fuel and oxidant, respectively; and $\left(H_T^o\right)_{f_i}$ and $\left(H_T^o\right)_{x_i}$ are the molar enthalpies of the ith fuel and ith oxidant, respectively. The enthalpy of the combustion products per mole of reactants is written as

$$\left(H_T^o\right)_c = \frac{1}{A}\sum_i \left(H_T^o\right)_i n_i \tag{12}$$

Then, assuming consistent assignment of reference enthalpies, the requirement for adiabatic combustion at zero velocity is that

$$\left(H_T^o\right)_c = H_T^o \tag{13}$$

Isentropic expansion to an assigned pressure: The entropy of the reaction products per mole of reactant is represented by the equation

$$S = \frac{1}{A}\sum_i (S_T)_i n_i \tag{14}$$

where

$$(S_T)_i = (S_T^o)_i - R \ln p_i \tag{15}$$

and $\left(S_T^o\right)_i$ is the absolute molar entropy of the ith product species at temperature T in the standard state. Then, for isentropic expansion to an assigned pressure, the entropy at any point during the expansion S_e must be equal to the entropy preceding the expansion S_c. The entropy following combustion S_o may also be assigned. Therefore,

$$S_e = S_c = S_o \tag{16}$$

Appendix B presents an example of the equivalent formula approach used to obtain the gas composition and the procedure used for determining the computer program input data for this study.

Thermodynamic properties.- With the composition known, other thermodynamic properties can be calculated.

The mean molecular weight of the products is defined as

$$M = \frac{\sum_i n_i M_i}{\sum_i p_i} = \frac{AM_{EF}}{p} \tag{17}$$

where M_{EF} is the equivalent formula molecular weight. Figure 7 presents curves of molecular weight plotted as a function of temperature for lines of constant pressure for the selected equivalence ratios.

The equation of state is then written as

$$p = \frac{\rho RT}{M} \tag{18}$$

Presented in figure 8 are thermodynamic property diagrams of enthalpy in the form $H - H_0$ as a function of pressure for lines of constant temperature and entropy for the selected equivalence ratios. For convenience the entropy is nondimensionalized as $s/R_{sp,r}$. Applicable values of the equivalent reactant specific gas constant $R_{sp,r}$ are indicated in the figures. Further discussion on the method for obtaining $R_{sp,r}$ is included in appendix B.

In this study, three key thermodynamic first partial derivatives are selected as a basis upon which the other partial derivatives can be written: $(\partial H/\partial T)_p$, $(\partial \ln M/\partial \ln T)_p$, and $(\partial \ln M/\partial \ln p)_T$. A summary of some of the other derivatives is presented in the following discussion. Further details and derivations may be found in reference 4.

Taking the logarithms of equation (17) and differentiating gives the following partial derivative of molecular weight with respect to temperature at constant pressure:

$$\alpha = \left(\frac{\partial \ln M}{\partial \ln T}\right)_p = \left(\frac{\partial \ln A}{\partial \ln T}\right)_p$$

The partial derivative of molecular weight with respect to pressure at constant temperature can be written as

$$\beta = \left(\frac{\partial \ln M}{\partial \ln p}\right)_T = \frac{p}{\sum p_i\left(\frac{\partial \ln p_i}{\partial \ln A}\right)_T} - 1 \tag{19}$$

The specific heat at constant pressure per mole of reaction products is defined as

$$c_p^o = \frac{A}{n}\left(\frac{\partial H}{\partial T}\right)_p \tag{20}$$

which can then be rewritten as

$$c_p^o = \frac{1}{nT}\left[\sum_i \left(H_T^o\right)_i p_i\left(\frac{\partial \ln p_i}{\partial \ln T}\right)_p + T\sum_i \left(c_p^o\right)_i n_i - \sum_i \left(H_T^o\right)_i n_i\left(\frac{\partial \ln A}{\partial \ln T}\right)_p\right] \tag{21}$$

The specific heat at constant pressure for the subject products of combustion is plotted in figure 9 as a function of temperature for lines of constant pressure. The plots are presented for the selected equivalence ratios.

The isentropic exponent γ is represented as

$$\gamma = \frac{c_p^o/R}{\left(\frac{c_p^o}{R}\right)(1 + \beta) - (1 - \alpha)^2} \tag{22}$$

Plots showing the isentropic exponent as a function of temperature are presented in figure 10 again for the selected equivalence ratios.

Transport Properties

Viscosity.- From references 1 and 5, the absolute viscosity for all species except H_2O may be computed from

$$\mu_i = \frac{2.6693\sqrt{M_i T}}{\sigma^2 \Omega} \times 10^{-6} \tag{23}$$

where σ is the collision diameter of the molecule in angstroms and Ω is the collision integral. Table II lists the values of Ω obtained from reference 6 where Ω is tabulated as a function of kT/ϵ. The symbol k represents the Boltzmann's constant and ϵ represents the Lennard-Jones force constant. Values of σ and ϵ/k for the species were obtained from references 5 and 6 and are reproduced in table I. Values of σ and ϵ/k for the species CH, NH, N, and C (gas) were not available. However, these species represent a small percentage of the product gas and therefore should have little effect on the transport properties.

The viscosity of the species H_2O can be written as (see ref. 1)

$$\mu(H_2O) = \frac{2.5639\sqrt{T}}{1 + \frac{1371}{T} \times 10^{-37.4/T}} \times 10^{-6} \qquad (T \leqq 1300^o \text{ K}) \tag{24}$$

$$\mu(H_2O) = \frac{1.4980\sqrt{T}}{1 + \frac{24.51 \times 10^4}{T^2}} \times 10^{-6} \qquad (T > 1300^o \text{ K}) \tag{25}$$

and the viscosity of the gas mixture can be represented by the equation

$$\mu = \sum_i \frac{\mu_i}{\sum \frac{X_l}{X_i} \phi_{i,l}} \tag{26}$$

where

$$\phi_{i,l} = \frac{\left[1 + \left(\frac{\mu_i}{\mu_l}\right)^{1/2}\left(\frac{M_i}{M_l}\right)^{1/4}\right]^2}{2\sqrt{2}\left(1 + \frac{M_i}{M_l}\right)^{1/2}} \tag{27}$$

Thermal conductivity.- From reference 1, an approximate relation for thermal conductivity K of gaseous mixtures is the Eucken equation

$$K = \left(c_p + \frac{5}{4}R_{sp}\right)\mu \tag{28}$$

where R_{sp} is the specific gas constant and is represented by

$$R_{sp} = \frac{R}{M} \tag{29}$$

Prandtl number.- The equation for Prandtl number is

$$N_{Pr} = \frac{c_p\mu}{K} \tag{30}$$

Curves of viscosity, thermal conductivity, and Prandtl number are presented in figures 11, 12, and 13, respectively. They are plotted as a function of temperature for lines of constant pressure and the plots are shown for the selected equivalence ratios. As can be noted in figure 11, viscosity is relatively insensitive to pressure over the pressure range from 0.0001 to 1000 atmospheres.

Flow Properties

In order to make the properties of the oxygen-enriched combustion products useful for test-facility or other applications, the properties of the gas along the nozzle and at the nozzle exit or test-section entrance must be determined. The equations describing one-dimensional flow properties, including normal-shock properties, are summarized in the following paragraphs. They are derived from the basic conservation of mass, momentum, and energy relations and are based on the assumptions of isentropic expansion and chemical equilibrium during expansion, and the premise that dissociation during expansion is a function of temperature only, that is, $\beta = 0$. In the thermodynamic property diagrams (fig. 8), the condition that $\beta = 0$ is restricted to the regions in which the constant-temperature lines are approximately parallel to the ordinate. The solution of these equations requires tables of R_{sp}, c_p, and γ as functions of T. The values of these parameters may be chosen at any pressure compatible with the assumption that $\beta = 0$.

Free-stream properties.- The general equations for the free-stream gas properties are the same as those given in reference 1. They are repeated herein for convenient reference and are as follows:

$$\frac{p}{p_t} = \exp \int_{T_t}^{T} \left[\frac{c_p \gamma}{R_{sp}(\gamma - 1)}\right]^{1/2} \frac{dT}{T} \tag{31}$$

$$\frac{\rho}{\rho_t} = \exp \int_{T_t}^{T} \left[\frac{c_p}{R_{sp}\gamma(\gamma - 1)}\right]^{1/2} \frac{dT}{T} \tag{32}$$

$$a = (\gamma R_{sp} T)^{1/2} \tag{33}$$

$$V = \left[2\int_{T}^{T_t} \left(\frac{c_p R_{sp} \gamma}{\gamma - 1}\right)^{1/2} dT\right]^{1/2} \tag{34}$$

$$N_{Ma} = \left[\frac{2\int_{T}^{T_t} \left(\frac{c_p R_{sp} \gamma}{\gamma - 1}\right)^{1/2} dT}{\gamma R_{sp} T}\right]^{1/2} \tag{35}$$

$$\frac{q}{p_t} = \frac{1}{R_{sp} T} \frac{p}{p_t} \int_{T}^{T_t} \left(\frac{c_p R_{sp} \gamma}{\gamma - 1}\right)^{1/2} dT \tag{36}$$

$$T^* = \frac{2}{\gamma^* R_{sp}^*} \int_{T^*}^{T_t} \left(\frac{c_p R_{sp} \gamma}{\gamma - 1}\right)^{1/2} dT \tag{37}$$

$$\frac{A}{A^*} = \frac{1}{N_{Ma}} \left(\frac{\gamma^* R_{sp} T}{\gamma R_{sp}^* T^*}\right)^{1/2} \exp \int_{T}^{T^*} \left[\frac{c_p \gamma}{R_{sp}(\gamma - 1)}\right]^{1/2} \frac{dT}{T} \tag{38}$$

As noted in reference 1, T^* in equation (37) is not an explicit function since the integral contains T^* as the lower limit. Since the equation is also not amenable to solution by the process of direct iteration, the procedure used is to assume a value of T^* known to be greater than the actual value of T^*, and to decrease this assumed value by

5° K decrements until the difference between the assumed value and the calculated value changes sign. This procedure gives a value of T^* within 5° K of the actual value.

Properties following a normal shock.- Once the free-stream properties along the nozzle are known, the properties following a normal shock can be computed. The procedure used in this study is outlined in the following paragraphs.

The conservation of mass, momentum, and energy are expressed by the equations

$$\rho_1 V_1 = \rho_2 V_2 \tag{39}$$

$$p_1 + \rho_1 V_1^2 = p_2 + \rho_2 V_2^2 = p_2 + \rho_1 V_1 V_2 \tag{40}$$

$$H_1^o + \frac{V_1^2}{2} = H_2^o + \frac{V_2^2}{2} = H_{t,1}^o \tag{41}$$

In addition, the relation $\rho = \rho(p,H^o)$, which is obtained from the composition program, must be utilized.

In solving this system of equations, a value of V_2 is assumed so that values of ρ_2, p_2, and H_2^o can be calculated. The quantities p_2 and H_2^o are then entered into the previously described composition program. The output from the composition program is obtained and the density, designated ρ', is compared with the previously computed value of ρ_2. If the difference between these densities satisfies an error criterion, the computed values are accepted as being the true solution. If the error criterion is not satisfied, another value of V_2 is chosen and the process is repeated until a solution is obtained.

Once the solution is obtained, the output available from the composition program includes values for the parameters p_i, p_2, T_2, ρ_2, H_2^o, $(s^o/R)_2$, $N_{Ma,2}$, α_2, β_2, $\left(c_p^o\right)_2$, γ_2, and a_2. The Mach number is then computed from

$$N_{Ma,2} = \frac{V_2}{a_2} \tag{42}$$

and the ratios p_2/p_1, ρ_2/ρ_1, and T_2/T_1 are obtained.

The following scheme was used to determine the ratios involving $p_{t,2}$: Since the previously described free-stream properties program computed the subsonic as well as the supersonic properties of the gas along a constant entropy line, the subsonic properties can be stored in a table and later used in this program. Therefore, the values of $N_{Ma,1}$ and $p_1/p_{t,1}$ are stored as $N'_{Ma,2}$ and $(p_2/p_{t,2})'$. When $N_{Ma,2}$ is computed from the normal-shock relations, the corresponding value of $N_{Ma,2}$ is found in the table just described and an interpolation is accomplished to determine $p_2/p_{t,2}$. Then the computation

$$\frac{p_{t,2}}{p_{t,1}} = \frac{p_1}{p_{t,1}} \frac{p_2}{p_1} \frac{p_{t,2}}{p_2} \tag{43}$$

is made and the ratio

$$\frac{p_1}{p_{t,2}} = \frac{p_1}{p_{t,1}} \frac{p_{t,1}}{p_{t,2}} \tag{44}$$

is obtained. It should be noted that the method used in obtaining $p_{t,2}$ made use of the inherent assumption that $\beta = 0$.

The subject combustion-gas flow properties, both in front of and behind the normal shock, are tabulated for the selected equivalence ratios in table III as a function of the free-stream Mach number.

COMPUTATIONAL PROCEDURE

The equations described on the preceding pages have been programed on the IBM 7094 electronic data processing system. The information in tables I and II was stored as input in the computer program. In addition, the thermodynamic properties were stored in the program in the form of the equations

$$\frac{c_p^o}{R} = A + BT + CT^2 + DT^3$$

$$\frac{H_T^o}{RT} = A + \frac{1}{2}BT + \frac{1}{3}CT^2 + \frac{1}{4}DT^3 + \frac{E}{T}$$

$$\frac{S_T^o}{R} = A \ln T + BT + \frac{1}{2}CT^2 + \frac{1}{3}DT^3 + F$$

where T is in degrees Kelvin. The coefficients A, B, C, D, E, and F, obtained from reference 4, were also stored in the computer program.

The values used in plotting the curves shown in the figures were computed at the selected equivalence ratios of 0.315, 0.370, 0.425, 0.480, and 0.525. Results were acquired at temperature increments to 100° R (56° K) over the range from 100° R (56° K) to 6000° R (3300° K). Results were also obtained in increments of 0.2 of the ratio $s/R_{sp,r}$ over the range from 17 to 56. Pressures used in the computations were 1000, 500, 100, 50, 10, 5, 1, 0.5, 0.1, 0.05, 0.01, 0.005, 0.001, 0.0005, and 0.0001 atmospheres.

CONCLUDING REMARKS

Results of calculations to determine the composition and the thermodynamic, transport, and flow properties for the products of methane burned in oxygen-enriched air such that 20 percent oxygen is maintained in the products are presented. These results are exhibited in the form of tables and figures for equivalence ratios of 0.315, 0.370, 0.425, 0.480, and 0.525. The pressure ranges from 0.0001 to 1000 atmospheres and the temperature from 100° R (56° K) to 6000° R (3300° K). Flow properties both in front of and behind a normal shock in an isentropically expanded stream are listed in the tables.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 3, 1966.

APPENDIX A

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

The International System of Units (SI) was adopted by the Eleventh General Conference on Weights and Measures, held in Paris, October 1960 in Resolution No. 12 (ref. 2). Conversion factors for the units used herein are given in the following table:

Physical quantity	U.S. Customary Unit	Conversion factor (*)	SI Unit
Enthalpy.	Btu/lbm	2324.4444	joules/kilogram (J/kg)
Entropy	Btu/lbm-^{o}R	4184	joules/kilogram-degree Kelvin (J/kg-^{o}K)
Specific heat . .	Btu/lbm-^{o}R	4184	joules/kilogram-degree Kelvin (J/kg-^{o}K)
Temperature . .	^{o}R	5/9	degrees Kelvin (^{o}K)
Thermal conductivity. .	Btu/ft-sec-^{o}R	6226.4778	watts/meter-degree Kelvin (W/m-^{o}K)
Universal gas constant. . . .	Btu/mole-^{o}R	4.186718	joules/mole-degree Kelvin (J/mole-^{o}K)
Viscosity	slugs/ft-sec	47.880258	newton-second/meter^2 (N-s/m^2)

*Multiply value given in U.S. Customary Unit by conversion factor to obtain equivalent value in SI unit.

APPENDIX B

EXAMPLE OF EQUIVALENT FORMULA APPROACH AND PROCEDURE FOR OBTAINING INPUT DATA

This appendix is intended to clarify the equivalent formula approach for determining the properties of combustion product gases and to outline the procedure used in determining the required computer program input data.

Example of Equivalent Formula Approach

The composition program used for this study was set up to handle 17 species containing the elements H, O, N, Ar, and C. As was stated in the text, the equivalent formula is defined as being one large molecule of fuel or oxidant whose elements contain the same number of atoms as are available in the total fuel or total oxidant. It is noted that the mass of the equivalent formula is numerically equal to the molecular weight of the equivalent formula. The gram atoms of each element per gram of equivalent formula is then the atoms of each element divided by the molecular weight of the equivalent formula. This approach reduces the formula weights to unit masses.

In the composition program, the general equivalent formula is written as

$$H_aO_bN_cAr_dC_e \tag{B1}$$

where a, b, c, d, and e are to be found. If the fuel and oxidant are designated by the subscripts f and x, respectively, the total number of atoms of each element in the reaction is

$$\left.\begin{aligned} a_o &= \frac{a_x + R_{eq}(m_f/m_x)_s a_f}{1 + R_{eq}(m_f/m_x)_s} \\ \ldots &= \ldots \end{aligned}\right\} \tag{B2}$$

where R_{eq} is the equivalence ratio and $(m_f/m_x)_s$ is the mass ratio of fuel to oxidant at stoichiometric conditions and must be determined from the chemical equation.

Similarly, the enthalpy of the reactants is

$$H_T^o = \frac{H_x^o + R_{eq}(m_f/m_x)_s H_f^o}{1 + R_{eq}(m_f/m_x)_s} \tag{B3}$$

The enthalpies in equation (B3) contain the chemical enthalpies and must be determined separately for the fuel and oxidant. The enthalpies are in joules per kilogram and the gases are considered to be at 300° K when mixed. A similar equation is used to compute the entropy (J/kg-°K) if the entropy is used as an input to the composition program.

Procedure for Obtaining Composition Program Input Required to Maintain Approximately 20 Percent Oxygen in the Combustion Products

The following procedure was used in this study to insure that the combustion products contained approximately 20 percent oxygen (by volume). However, the procedure is of such generality that it can be used to determine the input quantities for any percentage of oxygen in the products.

It is defined that

$$\theta = \frac{\text{Total moles of } O_2}{\text{Moles of } O_2 \text{ in air}} = \frac{\text{Total mass of } O_2}{\text{Mass of } O_2 \text{ in air}}$$

$$L = \frac{\text{Mass of } O_2 \text{ in air}}{\text{Mass of air}} = 0.231441$$

Then

$$\frac{m_{tot}(O_2)}{m_a} = \theta L \tag{B4}$$

where $m_{tot}(O_2)$ is the total mass of O_2 and m_a is the mass of air. Also

$$\frac{m}{m_a} = (\theta - 1)L \tag{B5}$$

where m is the mass of O_2 in excess of that in air. The assumed composition of one mole of air is

$$0.780900N_2 + 0.209500O_2 + 0.009300Ar + 0.000299CO_2 + 0.000001H_2 \tag{B6}$$

The assumed composition of one mole of air plus additional O_2 is

$$0.780900N_2 + 0.209500\theta O_2 + 0.009300Ar + 0.000299CO_2 + 0.000001H_2 \tag{B7}$$

Then the equivalent formula for the oxygen-enriched air becomes

$$H_{0.000002}O_{0.419000\theta+0.000598}N_{1.561800}Ar_{0.009300}C_{0.000299} \tag{B8}$$

The molecular weight of the oxygen-enriched-air equivalent formula $M_{x,EF}$ is

$$M_{x,EF} = (0.4190\theta + 0.000598)(16) + (1.5618)(14.008) + (0.0093)(39.44) + (0.000299)(12.010) + (0.000002)(1.008) \tag{B9}$$

$$M_{x,EF} = 22.262303 + 6.704000\theta \tag{B10}$$

The gram atoms per gram of equivalent formula for the enriched air oxidant is

$$\left.\begin{aligned} a_x &= \frac{0.000002}{M_{x,EF}} \\ b_x &= \frac{0.4190\theta + 0.0006}{M_{x,EF}} \\ c_x &= \frac{1.5618}{M_{x,EF}} \\ d_x &= \frac{0.0093}{M_{x,EF}} \\ e_x &= \frac{0.000299}{M_{x,EF}} \end{aligned}\right\} \tag{B11}$$

The enthalpy of the oxidant (J/kg) is

$$H_x^o = \frac{nMH^o(N_2) + nMH^o(O_2) + nMH^o(Ar) + nMH^o(CO_2)}{nM(N_2) + nM(O_2) + nM(Ar) + nM(CO_2)} \tag{B12}$$

and using values of H^o obtained from reference 3 referenced to 300° K yields

$$H_x^o = \left(\frac{2969.6965 + 863.9358\theta}{22.262303 + 6.7040\theta}\right)4184 \tag{B13}$$

For the fuels, the definitions relating to the equivalent formula are approached in the same way. The equation for the equivalent formula of a general hydrocarbon fuel is written as

$$C_nH_m \tag{B14}$$

Thus, the molecular weight of the fuel equivalent formula $M_{f,EF}$ is

$$M_{f,EF} = 12.010n + 1.008m \tag{B15}$$

and the gram atoms per gram of the fuel equivalent formula are

$$\left.\begin{aligned} a_f &= \frac{m}{M_{f,EF}} \\ b_f &= c_f = d_f = 0 \\ e_f &= \frac{n}{M_{f,EF}} \end{aligned}\right\} \tag{B16}$$

The enthalpy of CH_4 (J/kg) (referenced to 300° K) used in this study is

$$H_f^o = 1311.9748(4184) \tag{B17}$$

Stoichiometric conditions are defined as those conditions for which just enough oxygen is available to consume fully one mole of fuel. For the general fuel C_nH_m there must be 2n atoms of oxygen to combine with the carbon to form CO_2 and $m/2$ atoms of oxygen to combine with the hydrogen to form H_2O. Therefore, the total oxygen atoms required for a stoichiometric reaction are $(2n + m/2)$. Since in the equivalent formula for oxygen-enriched air the available number of oxygen atoms is 0.4190θ (the 0.000598 oxygen atoms in the CO_2 are already in combination), the number of atoms of each element in the enriched-air equivalent formula must be increased by a factor

$$\theta_1 = \frac{2n + m/2}{0.4190\theta} \tag{B18}$$

in order to balance the chemical equation for stoichiometric burning. The ratio of fuel mass to oxidant mass at stoichiometric conditions is

$$\left(\frac{m_f}{m_x}\right)_s = \frac{M_{f,EF}}{M_{x,EF}\theta_1} \tag{B19}$$

The following procedure is employed to find the excess of oxygen when an equivalence ratio of less than 1 is used. By definition

$$\frac{m_f}{m_x} = R_{eq}\left(\frac{m_f}{m_x}\right)_s \tag{B20}$$

Since the reaction is always considered to proceed from 1 mole of fuel and the necessary oxidant,

$$m_f = (m_f)_s \tag{B21}$$

Therefore,

$$m_x = \frac{(m_x)_s}{R_{eq}} \tag{B22}$$

But

$$(m_x)_s = M_{x,EF}\theta_1 \tag{B23}$$

Finally

$$m_x = \frac{M_{x,EF}\theta_1}{R_{eq}} \tag{B24}$$

where m_x is the total mass of the oxidant. The additional oxidant mass for $R_{eq} < 1$ over that for $R_{eq} = 1$ is

$$\Delta m = m_x - (m_x)_s = \frac{M_{x,EF}\theta_1(1 - R_{eq})}{R_{eq}} \tag{B25}$$

This Δm, however, still includes mass from components in the enriched air other than oxygen. The mass ratio of oxygen in enriched air to the enriched air (obtained from eqs. (B4) and (B5)) is

$$\frac{m_{tot}(O_2)}{m_a + m} = \frac{\left[m_{tot}(O_2)/m_a\right]}{1 + m/m_a} = \frac{\theta L}{1 + (\theta - 1)L} \tag{B26}$$

Therefore, the mass of excess oxygen available for further combustion is

$$m(O_2)^+ = \frac{\Delta m \theta L}{1 + (\theta - 1)L} \tag{B27}$$

The number of moles of excess oxygen available is

$$n(O_2)^+ = \frac{\Delta m \theta L}{M(O_2)\left[1 + (\theta - 1)L\right]} \tag{B28}$$

where $M(O_2)$ is the molecular weight of oxygen.

The total number of moles after reaction for the nondissociated gas is

$$n_{tot} = \left(n + \frac{m}{2}\right) + \left(\frac{2n + \frac{m}{2}}{0.4190\theta} - \frac{2n + \frac{m}{2}}{2\theta}\right)\frac{1}{R_{eq}} + n(O_2)^+ \tag{B29}$$

where $(n + m/2)$ is the number of moles of CO_2 and H_2O; $(2n + m/2)/(0.4190\theta R_{eq})$ is the number of moles of air; $(2n + m/2)/(2\theta R_{eq})$ is the number of moles of oxygen in air; and $n(O_2)^+$ is the number of moles of excess oxygen. The percentage by volume of excess oxygen in the nondissociated product gas is

$$\text{Percent excess } O_2 = \frac{n(O_2)^+}{n_{tot}} \tag{B30}$$

Figure 14 shows the variation of this parameter as a function of R_{eq} for several values of θ. Figure 15 gives the flame temperatures corresponding to several combinations of R_{eq} and θ. The cross plotting of figures 14 and 15 for the case of 20 percent excess oxygen gives figure 1, from which can be obtained the proper combinations of θ and R_{eq} for the temperature desired, while still maintaining approximately 20 percent oxygen in the gas. Figure 16 presents a plot of the value of θ required to maintain 20 percent oxygen in the products as a function of R_{eq}. This figure is presented as a convenience to the reader desiring to determine the relative amounts of methane, air, and oxygen used in the reaction.

The molecular weight of the equivalent reactant can now be determined by defining that

$$m_{tot} = m_x + m_f = \frac{M_{x,EF}\theta_1}{R_{eq}} + M_{f,EF} \tag{B31}$$

where m_{tot} is the total mass of the reactants. (It must be remembered that the reaction proceeds from 1 mole of fuel and therefore the mass of the fuel is numerically equal to the molecular weight of the fuel.) Then, the molecular weight of the equivalent reactant can be written as

$$M_r = \frac{m_{tot}}{n_{tot}} \tag{B32}$$

These relationships can be used to write the equivalent reactant specific gas constant:

$$R_{sp,r} = \frac{R}{M_r} \tag{B33}$$

where R is the universal gas constant.

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TABLE I.- COLLISION DIAMETERS AND LENNARD-JONES FORCE CONSTANTS

Specie	σ, angstroms (a)	ϵ/k, ^{o}K	Specie	σ, angstroms (a)	ϵ/k, ^{o}K
H_2O	-----	-----	O_2	3.433	113.0
CH_4	3.822	136.5	OH	3.110	93.8
CH	-----	-----	H_2	2.968	33.3
CO_2	3.996	190.0	H	2.497	99.8
CO	3.590	110.0	O	3.068	102.2
NH_3	3.474	312.3	N	-----	-----
NH	-----	-----	Ar	3.418	124.0
N_2	3.681	91.5	C(gas)	-----	-----
NO	3.470	119.0			

(a) 1 angstrom equals 1×10^{-10} m.

TABLE II.- VALUES OF kT/ϵ and Ω

kT/ϵ	Ω	kT/ϵ	Ω	kT/ϵ	Ω	kT/ϵ	Ω	kT/ϵ	Ω
0.30	2.785	1.15	1.482	1.95	1.186	3.5	0.9999	6.0	0.8963
.35	2.628	1.20	1.452	2.0	1.175	3.6	.9932	7.0	.8727
.40	2.492	1.25	1.424	2.1	1.156	3.7	.9870	8.0	.8538
.45	2.368	1.30	1.399	2.2	1.138	3.8	.9811	9.0	.8379
.50	2.257	1.35	1.375	2.3	1.122	3.9	.9755	10.0	.8242
.55	2.156	1.40	1.353	2.4	1.107	4.0	.9700	20.0	.7432
.60	2.065	1.45	1.333	2.5	1.093	4.1	.9649	30.0	.7005
.65	1.982	1.50	1.314	2.6	1.081	4.2	.9600	40.0	.6718
.70	1.908	1.55	1.296	2.7	1.069	4.3	.9553	50.0	.6504
.75	1.841	1.60	1.279	2.8	1.058	4.4	.9507	60.0	.6335
.80	1.780	1.65	1.264	2.9	1.048	4.5	.9464	70.0	.6194
.85	1.725	1.70	1.248	3.0	1.039	4.6	.9422	80.0	.6076
.90	1.675	1.75	1.234	3.1	1.030	4.7	.9382	90.0	.5973
.95	1.629	1.80	1.221	3.2	1.022	4.8	.9343	100.0	.5882
1.00	1.587	1.85	1.209	3.3	1.014	4.9	.9305	200.0	.5320
1.05	1.549	1.90	1.197	3.4	1.007	5.0	.9269	400.0	.4811
1.10	1.514								

TABLE III.- NONDIMENSIONAL FLOW PROPERTIES FOR ISENTROPICALLY EXPANDED COMBUSTION PRODUCTS INCLUDING NORMAL-SHOCK PROPERTIES FOR SELECTED EQUIVALENCE RATIOS

(a) $R_{eq} = 0.315$

N_{Ma}	p/p_t	ρ/ρ_t	T/T_t	V/a_t	q/p_t	A/A^*	$N_{Ma,2}$	p_2/p_1	ρ_2/ρ_1	T_2/T_1	$p_{t,2}/p_{t,1}$	$p_1/p_{t,2}$
0.	1.0000	1.0000	1.00000	0.	0.	0.						
0.3350	0.9309	0.9458	0.98425	0.3325	0.067158	1.869						
0.4934	0.8573	0.8871	0.96636	0.4855	0.134311	1.364						
0.6155	0.7885	0.8313	0.94846	0.6004	0.192444	1.177						
0.7202	0.7243	0.7783	0.93057	0.6962	0.242271	1.085						
0.8143	0.6644	0.7280	0.91267	0.7800	0.284468	1.035						
0.9014	0.6087	0.6803	0.89477	0.8554	0.319678	1.010						
0.9834	0.5568	0.6350	0.87688	0.9244	0.348500	1.001						
1.0618	0.5087	0.5922	0.85898	0.9884	0.371496	1.004	0.9345	1.155	1.119	1.032	0.999936	0.508684
1.1373	0.4639	0.5516	0.84109	1.0482	0.389194	1.017	0.8777	1.341	1.254	1.069	0.996897	0.465356
1.2107	0.4224	0.5132	0.82319	1.1046	0.402095	1.037	0.8287	1.536	1.392	1.104	0.990421	0.426516
1.2825	0.3840	0.4769	0.80530	1.1580	0.410671	1.064	0.7870	1.740	1.529	1.139	0.980174	0.391782
1.3531	0.3485	0.4426	0.78740	1.2089	0.415360	1.098	0.7509	1.953	1.665	1.173	0.965816	0.360817
1.4228	0.3157	0.4102	0.76951	1.2575	0.416579	1.139	0.7195	2.175	1.801	1.208	0.947419	0.333187
1.4920	0.2854	0.3797	0.75161	1.3041	0.414713	1.187	0.6918	2.407	1.936	1.243	0.926053	0.308193
1.5609	0.2575	0.3510	0.73372	1.3489	0.410128	1.241	0.6671	2.649	2.071	1.280	0.901223	0.285761
1.6297	0.2319	0.3240	0.71582	1.3920	0.403162	1.303	0.6449	2.901	2.204	1.317	0.873389	0.265530
1.6986	0.2084	0.2986	0.69792	1.4337	0.394129	1.373	0.6249	3.166	2.337	1.355	0.843012	0.247193
1.7679	0.1868	0.2747	0.68003	1.4740	0.383318	1.451	0.6067	3.444	2.469	1.395	0.810970	0.230369
1.8377	0.1671	0.2524	0.66213	1.5130	0.371002	1.539	0.5901	3.736	2.601	1.437	0.777553	0.214894
1.9083	0.1491	0.2314	0.64424	1.5509	0.357429	1.638	0.5749	4.042	2.731	1.480	0.742667	0.200722
1.9797	0.1326	0.2118	0.62634	1.5877	0.342833	1.748	0.5608	4.365	2.860	1.526	0.706690	0.187693
2.0521	0.1177	0.1934	0.60845	1.6235	0.327428	1.871	0.5477	4.706	2.989	1.574	0.669972	0.175673
2.1259	0.1041	0.1763	0.59055	1.6583	0.311410	2.010	0.5356	5.065	3.116	1.625	0.632835	0.164545
2.2010	0.9184 -1	0.1604	0.57266	1.6923	0.294962	2.165	0.5243	5.446	3.242	1.678	0.595570	0.154212
2.2778	0.8074 -1	0.1455	0.55476	1.7253	0.278248	2.340	0.5137	5.850	3.367	1.735	0.558443	0.144589
2.3567	0.7074 -1	0.1318	0.53686	1.7576	0.261411	2.538	0.5038	6.279	3.491	1.795	0.521684	0.135600
2.4375	0.6174 -1	0.1190	0.51897	1.7891	0.244579	2.761	0.4945	6.736	3.614	1.859	0.485498	0.127178
2.5203	0.5369 -1	0.1071	0.50107	1.8199	0.227894	3.014	0.4857	7.223	3.736	1.928	0.450471	0.119178
2.6056	0.4649 -1	0.9623 -1	0.48318	1.8499	0.211484	3.302	0.4773	7.744	3.856	2.001	0.416389	0.111662
2.6946	0.4009 -1	0.8616 -1	0.46528	1.8793	0.195409	3.630	0.4695	8.303	3.975	2.080	0.383302	0.104582
2.7881	0.3439 -1	0.7686 -1	0.44739	1.9081	0.179712	4.007	0.4622	8.905	4.092	2.166	0.351273	0.097894
2.8847	0.2934 -1	0.6831 -1	0.42949	1.9363	0.164467	4.443	0.4554	9.556	4.208	2.258	0.320409	0.091564
2.9853	0.2489 -1	0.6046 -1	0.41160	1.9639	0.149764	4.949	0.4488	10.260	4.323	2.358	0.290816	0.085576
3.0910	0.2098 -1	0.5329 -1	0.39370	1.9910	0.135660	5.539	0.4424	11.026	4.437	2.467	0.262595	0.079898
3.2024	0.1757 -1	0.4675 -1	0.37581	2.0175	0.122191	6.232	0.4364	11.863	4.548	2.586	0.235807	0.074499
3.3202	0.1460 -1	0.4079 -1	0.35791	2.0435	0.109391	7.051	0.4308	12.780	4.659	2.717	0.210490	0.069358
3.3446	0.1405 -1	0.3967 -1	0.35433	2.0487	0.106914	7.232	0.4294	12.974	4.680	2.745	0.205582	0.068366
3.3693	0.1353 -1	0.3856 -1	0.35075	2.0538	0.104465	7.420	0.4284	13.173	4.702	2.773	0.200759	0.067376
3.3943	0.1301 -1	0.3748 -1	0.34717	2.0589	0.102044	7.615	0.4273	13.375	4.724	2.802	0.195996	0.066396
3.4196	0.1252 -1	0.3642 -1	0.34359	2.0640	0.099652	7.817	0.4262	13.581	4.746	2.832	0.191294	0.065424
3.4453	0.1203 -1	0.3539 -1	0.34001	2.0691	0.097288	8.027	0.4251	13.791	4.767	2.862	0.186652	0.064461
3.4722	0.1156 -1	0.3437 -1	0.33644	2.0741	0.094950	8.245	0.4241	14.006	4.789	2.893	0.182067	0.063507
3.4984	0.1111 -1	0.3337 -1	0.33286	2.0792	0.092639	8.471	0.4232	14.226	4.810	2.924	0.177548	0.062558
3.5250	0.1067 -1	0.3239 -1	0.32928	2.0842	0.090358	8.706	0.4221	14.450	4.832	2.956	0.173081	0.061621
3.5519	0.1024 -1	0.3143 -1	0.32570	2.0892	0.088107	8.950	0.4211	14.679	4.853	2.989	0.168676	0.060693
3.5791	0.9823 -2	0.3049 -1	0.32212	2.0942	0.085886	9.203	0.4201	14.913	4.875	3.023	0.164333	0.059774
3.6066	0.9421 -2	0.2958 -1	0.31854	2.0991	0.083696	9.466	0.4190	15.151	4.896	3.057	0.160054	0.058863
3.6345	0.9032 -2	0.2868 -1	0.31496	2.1041	0.081536	9.740	0.4180	15.396	4.917	3.092	0.155839	0.057960
3.6627	0.8656 -2	0.2780 -1	0.31138	2.1090	0.079408	10.024	0.4170	15.645	4.938	3.128	0.151687	0.057066
3.6912	0.8292 -2	0.2694 -1	0.30780	2.1139	0.077311	10.320	0.4160	15.901	4.959	3.164	0.147601	0.056179

TABLE III.- NONDIMENSIONAL FLOW PROPERTIES FOR ISENTROPICALLY EXPANDED COMBUSTION PRODUCTS INCLUDING NORMAL-SHOCK PROPERTIES FOR SELECTED EQUIVALENCE RATIOS – Continued

(a) Concluded

N_{Ma}	p/p_t	ρ/ρ_t	T/T_t	V/a_t	q/p_t	A/A^*	$N_{Ma,2}$	p_2/p_1	ρ_2/ρ_1	T_2/T_1	$p_{t,2}/p_{t,1}$	$p_1/p_{t,2}$
3.7201	0.7940 -2	0.2610 -1	0.30422	2.1188	0.075746	10.628	0.4149	16.162	4.980	3.202	0.143579	0.055301
3.7493	0.7600 -2	0.2528 -1	0.30064	2.1237	0.073213	10.948	0.4139	16.429	5.001	3.240	0.139622	0.054430
3.7768	0.7271 -2	0.2448 -1	0.29707	2.1285	0.071215	11.281	0.4129	16.702	5.021	3.280	0.135736	0.053568
3.8069	0.6954 -2	0.2370 -1	0.29349	2.1333	0.069254	11.626	0.4117	16.982	5.042	3.320	0.131910	0.052720
3.8375	0.6648 -2	0.2293 -1	0.28991	2.1381	0.067325	11.986	0.4107	17.268	5.062	3.361	0.128165	0.051872
3.8688	0.6353 -2	0.2219 -1	0.28633	2.1429	0.065426	12.362	0.4098	17.561	5.083	3.404	0.124483	0.051032
3.9006	0.6067 -2	0.2146 -1	0.28275	2.1476	0.063558	12.753	0.4088	17.861	5.103	3.447	0.120865	0.050198
3.9330	0.5792 -2	0.2075 -1	0.27917	2.1523	0.061719	13.162	0.4079	18.169	5.123	3.492	0.117308	0.049371
3.9661	0.5526 -2	0.2005 -1	0.27559	2.1571	0.059911	13.589	0.4070	18.485	5.143	3.537	0.113812	0.048550
3.9998	0.5269 -2	0.1937 -1	0.27201	2.1618	0.058132	14.035	0.4061	18.809	5.163	3.584	0.110376	0.047736
4.0341	0.5021 -2	0.1871 -1	0.26843	2.1664	0.056382	14.502	0.4052	19.142	5.183	3.632	0.107000	0.046928
4.0692	0.4782 -2	0.1806 -1	0.26485	2.1711	0.054661	14.992	0.4044	19.483	5.203	3.682	0.103683	0.046126
4.1050	0.4552 -2	0.1742 -1	0.26127	2.1757	0.052969	15.504	0.4036	19.833	5.223	3.732	0.100474	0.045330
4.1428	0.4330 -2	0.1680 -1	0.25770	2.1804	0.051304	16.041	0.4027	20.193	5.243	3.785	0.097220	0.044541
4.1801	0.4116 -2	0.1620 -1	0.25412	2.1850	0.049664	16.605	0.4021	20.554	5.262	3.838	0.094074	0.043754
4.2181	0.3910 -2	0.1561 -1	0.25054	2.1896	0.048052	17.199	0.4013	20.945	5.282	3.893	0.090979	0.042977
4.2568	0.3712 -2	0.1503 -1	0.24696	2.1942	0.046469	17.822	0.4005	21.336	5.302	3.950	0.087941	0.042205
4.2964	0.3521 -2	0.1447 -1	0.24338	2.1988	0.044914	18.478	0.3997	21.739	5.321	4.009	0.084959	0.041439
4.3367	0.3337 -2	0.1392 -1	0.23980	2.2034	0.043388	19.167	0.3989	22.154	5.341	4.069	0.082034	0.040679
4.3779	0.3161 -2	0.1338 -1	0.23622	2.2080	0.041890	19.894	0.3981	22.582	5.360	4.131	0.079165	0.039924
4.4199	0.2991 -2	0.1286 -1	0.23264	2.2125	0.040420	20.660	0.3974	23.022	5.379	4.195	0.076353	0.039176
4.4628	0.2828 -2	0.1235 -1	0.22906	2.2170	0.038978	21.467	0.3966	23.477	5.398	4.260	0.073596	0.038433
4.5067	0.2672 -2	0.1185 -1	0.22548	2.2216	0.037565	22.320	0.3959	23.945	5.418	4.328	0.070896	0.037695
4.5516	0.2523 -2	0.1137 -1	0.22190	2.2261	0.036180	23.223	0.3952	24.429	5.437	4.398	0.068251	0.036963
4.5974	0.2379 -2	0.1090 -1	0.21832	2.2306	0.034823	24.177	0.3944	24.928	5.456	4.471	0.065662	0.036236
4.6443	0.2242 -2	0.1044 -1	0.21475	2.2351	0.033494	25.186	0.3937	25.444	5.474	4.546	0.063129	0.035515
4.6924	0.2111 -2	0.9995 -2	0.21117	2.2396	0.032193	26.257	0.3937	25.444	5.474	4.546	0.063129	0.035515
4.7415	0.1985 -2	0.9561 -2	0.20759	2.2440	0.030920	27.391	0.3923	26.528	5.512	4.703	0.058227	0.034088
4.7918	0.1865 -2	0.9140 -2	0.20401	2.2485	0.029676	28.597	0.3916	27.099	5.531	4.786	0.055859	0.033382
4.8434	0.1750 -2	0.8731 -2	0.20043	2.2529	0.028459	29.878	0.3909	27.690	5.549	4.872	0.053546	0.032681
4.8963	0.1640 -2	0.8333 -2	0.19685	2.2573	0.027270	31.242	0.3903	28.302	5.568	4.961	0.051287	0.031985
4.9506	0.1536 -2	0.7948 -2	0.19327	2.2618	0.026109	32.696	0.3896	28.936	5.586	5.053	0.049083	0.031294
5.0062	0.1437 -2	0.7573 -2	0.18969	2.2662	0.024976	34.245	0.3889	29.595	5.605	5.149	0.046933	0.030608
5.0634	0.1342 -2	0.7210 -2	0.18611	2.2706	0.023871	35.901	0.3883	30.279	5.623	5.248	0.044837	0.029927
5.1222	0.1252 -2	0.6858 -2	0.18253	2.2750	0.022793	37.671	0.3876	30.989	5.641	5.351	0.042794	0.029251
5.1825	0.1166 -2	0.6517 -2	0.17895	2.2793	0.021743	39.567	0.3870	31.728	5.659	5.458	0.040806	0.028579
5.2447	0.1085 -2	0.6186 -2	0.17538	2.2837	0.020720	41.599	0.3863	32.497	5.677	5.570	0.038870	0.027912
5.3086	0.1008 -2	0.5867 -2	0.17180	2.2881	0.019725	43.781	0.3857	33.297	5.695	5.687	0.036987	0.027250
5.3745	0.9349 -3	0.5558 -2	0.16822	2.2924	0.018757	46.130	0.3851	34.132	5.713	5.808	0.035157	0.026592
5.4423	0.8658 -3	0.5259 -2	0.16464	2.2967	0.017816	48.657	0.3845	35.003	5.731	5.934	0.033380	0.025939
5.5123	0.8005 -3	0.4971 -2	0.16106	2.3011	0.016902	51.386	0.3839	35.912	5.748	6.067	0.031655	0.025290
5.5845	0.7389 -3	0.4692 -2	0.15748	2.3054	0.016015	54.332	0.3833	36.862	5.766	6.205	0.029981	0.024646
5.6591	0.6808 -3	0.4423 -2	0.15390	2.3097	0.015154	57.524	0.3827	37.857	5.783	6.350	0.028359	0.024005
5.7362	0.6260 -3	0.4165 -2	0.15032	2.3140	0.014321	60.986	0.3821	38.898	5.800	6.501	0.026789	0.023370
5.8160	0.5746 -3	0.3915 -2	0.14674	2.3183	0.013514	64.748	0.3815	39.991	5.818	6.660	0.025269	0.022738
5.8986	0.5262 -3	0.3676 -2	0.14316	2.3225	0.012733	68.844	0.3809	41.137	5.835	6.827	0.023800	0.022111
5.9842	0.4809 -3	0.3445 -2	0.13958	2.3268	0.011979	73.313	0.3804	42.343	5.852	7.002	0.022380	0.021488

TABLE III.- NONDIMENSIONAL FLOW PROPERTIES FOR ISENTROPICALLY EXPANDED COMBUSTION PRODUCTS INCLUDING NORMAL-SHOCK PROPERTIES FOR SELECTED EQUIVALENCE RATIOS – Continued

(b) $R_{eq} = 0.370$

N_{Ma}	p/p_t	ρ/ρ_t	T/T_t	V/a_t	q/p_t	A/A^*	$N_{Ma,2}$	p_2/p_1	ρ_2/ρ_1	T_2/T_1	$p_{t,2}/p_{t,1}$	$p_1/p_{t,2}$
0.	1.0000	1.0000	1.00000	0.	0.	0.						
0.0951	0.9943	0.9955	0.99879	0.0950	0.005702	6.263						
0.3536	0.9243	0.9397	0.98366	0.3509	0.073343	1.793						
0.4926	0.8593	0.8872	0.96852	0.4853	0.132460	1.375						
0.5927	0.8041	0.8435	0.95339	0.5796	0.179673	1.211						
0.6686	0.7595	0.8095	0.93826	0.6490	0.216183	1.128						
0.7412	0.7150	0.7745	0.92312	0.7140	0.250370	1.071						
0.8216	0.6639	0.7312	0.90799	0.7854	0.285963	1.031						
0.9001	0.6136	0.6872	0.89286	0.8537	0.317542	1.010						
0.9735	0.5671	0.6461	0.87772	0.9158	0.343609	1.001						
1.0434	0.5237	0.6071	0.86259	0.9737	0.364941	1.002						
1.1108	0.4831	0.5701	0.84746	1.0281	0.381993	1.011	0.9789	1.160	1.112	1.042	0.993908	0.486048
1.1763	0.4451	0.5348	0.83232	1.0795	0.395135	1.026	0.8838	1.387	1.279	1.085	0.989653	0.449780
1.2403	0.4097	0.5013	0.81719	1.1284	0.404715	1.047	0.8328	1.575	1.410	1.117	0.982634	0.416906
1.3030	0.3766	0.4695	0.80206	1.1751	0.411059	1.074	0.7924	1.763	1.536	1.148	0.972695	0.387140
1.3648	0.3457	0.4393	0.78692	1.2198	0.414472	1.105	0.7583	1.954	1.660	1.178	0.959528	0.360288
1.4259	0.3170	0.4107	0.77179	1.2628	0.415242	1.142	0.7288	2.151	1.782	1.207	0.943566	0.335911
1.4865	0.2902	0.3835	0.75666	1.3042	0.413640	1.184	0.7027	2.354	1.903	1.237	0.925049	0.313707
1.5467	0.2653	0.3578	0.74153	1.3442	0.409917	1.232	0.6795	2.565	2.024	1.268	0.903800	0.293552
1.6067	0.2422	0.3334	0.72639	1.3829	0.404313	1.285	0.6585	2.782	2.143	1.299	0.880422	0.275103
1.6666	0.2208	0.3104	0.71126	1.4204	0.397053	1.343	0.6395	3.008	2.261	1.331	0.855182	0.258168
1.7266	0.2009	0.2886	0.69613	1.4567	0.388347	1.409	0.6221	3.243	2.379	1.363	0.828106	0.242641
1.7868	0.1826	0.2681	0.68099	1.4920	0.378385	1.481	0.6062	3.487	2.496	1.397	0.799493	0.228352
1.8473	0.1656	0.2487	0.66586	1.5263	0.367348	1.560	0.5915	3.741	2.612	1.432	0.769681	0.215145
1.9083	0.1499	0.2304	0.65073	1.5598	0.355406	1.648	0.5778	4.006	2.728	1.469	0.739308	0.202797
1.9698	0.1355	0.2132	0.63559	1.5923	0.342715	1.745	0.5651	4.282	2.842	1.506	0.708128	0.191341
2.0320	0.1222	0.1970	0.62046	1.6241	0.329419	1.852	0.5533	4.571	2.956	1.546	0.676386	0.180682
2.0949	0.1100	0.1817	0.60533	1.6551	0.315652	1.969	0.5422	4.873	3.069	1.587	0.644298	0.170738
2.1588	0.9881 -1	0.1674	0.59019	1.6854	0.301534	2.099	0.5318	5.189	3.181	1.630	0.612067	0.161433
2.2238	0.8855 -1	0.1540	0.57506	1.7150	0.287171	2.243	0.5221	5.521	3.293	1.675	0.579867	0.152705
2.2899	0.7917 -1	0.1414	0.55993	1.7440	0.272672	2.402	0.5129	5.869	3.403	1.722	0.547857	0.144505
2.3572	0.7061 -1	0.1296	0.54479	1.7724	0.258134	2.579	0.5041	6.235	3.513	1.772	0.516198	0.136783
2.4260	0.6281 -1	0.1186	0.52966	1.8001	0.243643	2.775	0.4959	6.621	3.622	1.825	0.485030	0.129497
2.4963	0.5572 -1	0.1083	0.51453	1.8273	0.229275	2.993	0.4881	7.028	3.729	1.880	0.454665	0.122556
2.5684	0.4929 -1	0.9871 -1	0.49939	1.8539	0.215099	3.237	0.4806	7.459	3.836	1.939	0.425103	0.115952
2.6423	0.4347 -1	0.8977 -1	0.48426	1.8800	0.201177	3.510	0.4736	7.914	3.942	2.001	0.396289	0.109697
2.7184	0.3822 -1	0.8146 -1	0.46913	1.9056	0.187565	3.816	0.4668	8.397	4.047	2.067	0.368311	0.103761
2.7970	0.3348 -1	0.7375 -1	0.45400	1.9307	0.174307	4.160	0.4604	8.911	4.151	2.138	0.341238	0.098118
2.8781	0.2923 -1	0.6660 -1	0.43886	1.9553	0.161441	4.549	0.4543	9.458	4.253	2.213	0.315127	0.092745
2.9622	0.2541 -1	0.5998 -1	0.42373	1.9795	0.149005	4.989	0.4484	10.042	4.355	2.294	0.290029	0.087621
3.0493	0.2201 -1	0.5386 -1	0.40860	2.0032	0.137030	5.490	0.4428	10.668	4.455	2.380	0.265988	0.082730
3.1401	0.1897 -1	0.4821 -1	0.39346	2.0265	0.125538	6.062	0.4374	11.340	4.555	2.473	0.243035	0.078052
3.2349	0.1627 -1	0.4302 -1	0.37833	2.0494	0.114550	6.719	0.4323	12.063	4.653	2.573	0.221190	0.073573
3.3340	0.1389 -1	0.3824 -1	0.36320	2.0719	0.104078	7.476	0.4273	12.844	4.750	2.682	0.200467	0.069278
3.4381	0.1179 -1	0.3386 -1	0.34806	2.0940	0.094137	8.354	0.4226	13.690	4.845	2.800	0.180877	0.065156
3.5478	0.9939 -2	0.2985 -1	0.33293	2.1157	0.084732	9.377	0.4181	14.611	4.940	2.928	0.162420	0.061195
3.6638	0.8326 -2	0.2620 -1	0.31780	2.1371	0.075866	10.579	0.4137	15.617	5.033	3.069	0.145090	0.057383
3.7870	0.6922 -2	0.2287 -1	0.30266	2.1581	0.067540	12.000	0.4095	16.721	5.125	3.224	0.128876	0.053711
3.8126	0.6665 -2	0.2224 -1	0.29964	2.1623	0.065939	12.315	0.4085	16.955	5.144	3.257	0.125753	0.052999
3.8385	0.6415 -2	0.2163 -1	0.29661	2.1665	0.064360	12.642	0.4077	17.194	5.162	3.290	0.122687	0.052285
3.8648	0.6172 -2	0.2102 -1	0.29358	2.1706	0.062802	12.980	0.4069	17.437	5.180	3.324	0.119666	0.051577
3.8914	0.5936 -2	0.2043 -1	0.29056	2.1747	0.061265	13.331	0.4061	17.686	5.198	3.359	0.116688	0.050874
3.9184	0.5708 -2	0.1985 -1	0.28753	2.1788	0.059751	13.695	0.4053	17.939	5.216	3.395	0.113753	0.050176
3.9455	0.5491 -2	0.1930 -1	0.28450	2.1828	0.058312	14.061	0.4046	18.196	5.234	3.431	0.110967	0.049487
3.9728	0.5287 -2	0.1878 -1	0.28148	2.1867	0.056945	14.428	0.4038	18.456	5.251	3.468	0.108317	0.048809
4.0006	0.5087 -2	0.1827 -1	0.27845	2.1906	0.055585	14.806	0.4031	18.722	5.267	3.506	0.105684	0.048134
4.0289	0.4891 -2	0.1776 -1	0.27542	2.1945	0.054226	15.198	0.4024	18.994	5.284	3.545	0.103056	0.047461
4.0576	0.4699 -2	0.1725 -1	0.27240	2.1985	0.052862	15.612	0.4016	19.273	5.302	3.585	0.100422	0.046791
4.0869	0.4510 -2	0.1674 -1	0.26937	2.2024	0.051489	16.059	0.4009	19.560	5.319	3.625	0.097771	0.046123
4.1168	0.4323 -2	0.1623 -1	0.26634	2.2065	0.050101	16.542	0.4002	19.854	5.337	3.667	0.095097	0.045457
4.1472	0.4138 -2	0.1572 -1	0.26332	2.2106	0.048696	17.051	0.3994	20.158	5.355	3.709	0.092392	0.044791

TABLE III.- NONDIMENSIONAL FLOW PROPERTIES FOR ISENTROPICALLY EXPANDED COMBUSTION PRODUCTS INCLUDING NORMAL-SHOCK PROPERTIES FOR SELECTED EQUIVALENCE RATIOS – Continued

(b) Concluded

N_{Ma}	p/p_t	ρ/ρ_t	T/T_t	V/a_t	q/p_t	A/A^*	$N_{Ma,2}$	p_2/p_1	ρ_2/ρ_1	T_2/T_1	$p_{t,2}/p_{t,1}$	$p_1/p_{t,2}$
4.1784	0.3956 -2	0.1520 -1	0.26029	2.2148	0.047270	17.604	0.3986	20.470	5.374	3.753	0.089650	0.044126
4.2102	0.3775 -2	0.1468 -1	0.25726	2.2191	0.045821	18.189	0.3978	20.791	5.393	3.797	0.086869	0.043461
4.2427	0.3597 -2	0.1415 -1	0.25424	2.2235	0.044349	18.832	0.3970	21.123	5.413	3.842	0.084045	0.042796
4.2763	0.3414 -2	0.1359 -1	0.25121	2.2282	0.042776	19.554	0.3961	21.469	5.434	3.889	0.081034	0.042125
4.3112	0.3222 -2	0.1298 -1	0.24818	2.2333	0.041056	20.398	0.3952	21.834	5.457	3.937	0.077749	0.041442
4.3470	0.3036 -2	0.1239 -1	0.24516	2.2385	0.039349	21.369	0.3942	22.209	5.481	3.986	0.074491	0.040762
4.3834	0.2857 -2	0.1180 -1	0.24213	2.2437	0.037665	22.357	0.3933	22.595	5.505	4.036	0.071279	0.040085
4.4205	0.2685 -2	0.1123 -1	0.23910	2.2489	0.036014	23.427	0.3923	22.992	5.529	4.087	0.068132	0.039413
4.4583	0.2521 -2	0.1068 -1	0.23608	2.2542	0.034406	24.626	0.3913	23.400	5.553	4.140	0.065068	0.038746
4.4968	0.2365 -2	0.1015 -1	0.23305	2.2594	0.032846	25.837	0.3904	23.818	5.577	4.194	0.062098	0.038084
4.5359	0.2217 -2	0.9639 -2	0.23002	2.2646	0.031342	27.149	0.3895	24.246	5.600	4.250	0.059235	0.037429
4.5756	0.2078 -2	0.9153 -2	0.22700	2.2698	0.029898	28.481	0.3886	24.685	5.624	4.307	0.056488	0.036781
4.6159	0.1947 -2	0.8692 -2	0.22397	2.2749	0.028520	29.968	0.3877	25.135	5.647	4.365	0.053866	0.036140
4.6569	0.1824 -2	0.8257 -2	0.22094	2.2799	0.027210	31.444	0.3868	25.594	5.670	4.425	0.051376	0.035507
4.6981	0.1712 -2	0.7858 -2	0.21792	2.2847	0.026007	32.951	0.3860	26.061	5.692	4.487	0.049088	0.034885
4.7392	0.1617 -2	0.7525 -2	0.21489	2.2890	0.024997	34.454	0.3853	26.527	5.711	4.551	0.047164	0.034285
4.7808	0.1528 -2	0.7213 -2	0.21186	2.2931	0.024046	35.777	0.3846	27.004	5.729	4.616	0.045354	0.033692
4.8230	0.1445 -2	0.6919 -2	0.20884	2.2972	0.023150	37.284	0.3839	27.491	5.747	4.683	0.043647	0.033105
4.8658	0.1367 -2	0.6643 -2	0.20581	2.3011	0.022301	38.756	0.3833	27.990	5.764	4.752	0.042031	0.032526
4.9094	0.1294 -2	0.6381 -2	0.20278	2.3049	0.021496	40.248	0.3827	28.501	5.781	4.823	0.040498	0.031953
4.9538	0.1225 -2	0.6134 -2	0.19976	2.3087	0.020728	41.892	0.3821	29.025	5.797	4.897	0.039038	0.031385
4.9989	0.1160 -2	0.5897 -2	0.19673	2.3124	0.019993	43.451	0.3815	29.564	5.813	4.972	0.037640	0.030822
5.0450	0.1099 -2	0.5671 -2	0.19370	2.3160	0.019287	45.050	0.3810	30.118	5.828	5.050	0.036298	0.030264
5.0920	0.1040 -2	0.5454 -2	0.19068	2.3196	0.018606	46.698	0.3804	30.688	5.844	5.131	0.035002	0.029710
5.1400	0.9840 -3	0.5244 -2	0.18765	2.3232	0.017944	48.653	0.3799	31.275	5.859	5.214	0.033744	0.029160
5.1891	0.9301 -3	0.5038 -2	0.18462	2.3267	0.017293	50.590	0.3794	31.882	5.874	5.299	0.032507	0.028613
5.2398	0.8760 -3	0.4824 -2	0.18160	2.3304	0.016611	52.670	0.3788	32.515	5.890	5.388	0.031216	0.028064
5.2917	0.8243 -3	0.4616 -2	0.17857	2.3341	0.015946	54.926	0.3783	33.169	5.906	5.479	0.029955	0.027519
5.3448	0.7749 -3	0.4414 -2	0.17554	2.3378	0.015296	57.387	0.3777	33.845	5.922	5.574	0.028724	0.026976
5.3992	0.7276 -3	0.4218 -2	0.17252	2.3415	0.014662	59.980	0.3772	34.545	5.938	5.672	0.027523	0.026437
5.4551	0.6826 -3	0.4027 -2	0.16949	2.3452	0.014043	62.649	0.3767	35.270	5.954	5.774	0.026353	0.025901
5.5123	0.6396 -3	0.3842 -2	0.16646	2.3489	0.013440	65.623	0.3761	36.021	5.969	5.879	0.025212	0.025368
5.5711	0.5986 -3	0.3663 -2	0.16344	2.3525	0.012852	68.725	0.3756	36.799	5.985	5.988	0.024100	0.024838
5.6314	0.5596 -3	0.3488 -2	0.16041	2.3562	0.012279	72.045	0.3751	37.607	6.001	6.101	0.023017	0.024311
5.6934	0.5224 -3	0.3320 -2	0.15738	2.3598	0.011721	75.665	0.3746	38.446	6.016	6.219	0.021964	0.023786
5.7570	0.4872 -3	0.3156 -2	0.15436	2.3635	0.011178	79.337	0.3740	39.318	6.032	6.341	0.020939	0.023265
5.8225	0.4536 -3	0.2998 -2	0.15133	2.3671	0.010650	83.389	0.3735	40.224	6.047	6.468	0.019943	0.022747
5.8900	0.4219 -3	0.2845 -2	0.14831	2.3707	0.010137	87.803	0.3730	41.168	6.062	6.600	0.018976	0.022231
5.9594	0.3917 -3	0.2696 -2	0.14528	2.3743	0.009638	92.394	0.3725	42.150	6.078	6.738	0.018036	0.021719
6.0309	0.3632 -3	0.2553 -2	0.14225	2.3780	0.009154	97.495	0.3720	43.174	6.093	6.882	0.017124	0.021209
6.1046	0.3362 -3	0.2415 -2	0.13923	2.3816	0.008684	102.998	0.3716	44.242	6.108	7.031	0.016240	0.020702
6.1807	0.3107 -3	0.2281 -2	0.13620	2.3852	0.008229	108.899	0.3711	45.358	6.123	7.188	0.015383	0.020198
6.2592	0.2867 -3	0.2153 -2	0.13317	2.3887	0.007787	115.261	0.3706	46.524	6.138	7.351	0.014554	0.019696
6.3404	0.2640 -3	0.2028 -2	0.13015	2.3923	0.007360	122.070	0.3701	47.745	6.153	7.523	0.013751	0.019197
6.4243	0.2426 -3	0.1909 -2	0.12712	2.3959	0.006947	129.512	0.3697	49.023	6.168	7.702	0.012975	0.018701
6.5111	0.2226 -3	0.1794 -2	0.12409	2.3994	0.006548	137.604	0.3692	50.364	6.182	7.890	0.012225	0.018208
6.6011	0.2038 -3	0.1683 -2	0.12107	2.4030	0.006162	146.367	0.3687	51.771	6.197	8.087	0.011501	0.017717
6.6944	0.1861 -3	0.1577 -2	0.11804	2.4066	0.005790	156.268	0.3683	53.251	6.212	8.295	0.010804	0.017229

TABLE III.- NONDIMENSIONAL FLOW PROPERTIES FOR ISENTROPICALLY EXPANDED COMBUSTION PRODUCTS INCLUDING NORMAL-SHOCK PROPERTIES FOR SELECTED EQUIVALENCE RATIOS – Continued

(c) $R_{eq} = 0.425$

N_{Ma}	p/p_t	ρ/ρ_t	T/T_t	V/a_t	q/p_t	A/A^*	$N_{Ma,2}$	p_2/p_1	ρ_2/ρ_1	T_2/T_1	$p_{t,2}/p_{t,1}$	$p_1/p_{t,2}$
0.	1.0000	1.0000	1.00000	0.	0.	0.						
0.3063	0.9435	0.9544	0.98855	0.3044	0.055193	2.033						
0.4481	0.8830	0.9051	0.97555	0.4439	0.111269	1.470						
0.5501	0.8271	0.8594	0.96254	0.5464	0.160060	1.258						
0.6384	0.7753	0.8166	0.94953	0.6306	0.202601	1.147						
0.7244	0.7258	0.7751	0.93652	0.7052	0.240507	1.081						
0.8035	0.6777	0.7339	0.92352	0.7743	0.274514	1.040						
0.8764	0.6320	0.6942	0.91051	0.8379	0.304123	1.016						
0.9426	0.5891	0.6564	0.89750	0.8966	0.329297	1.004						
1.0071	0.5487	0.6204	0.88450	0.9515	0.350491	1.001						
1.0692	0.5107	0.5861	0.87149	1.0032	0.368019	1.005	0.9633	1.126	1.096	1.027	0.998862	0.511275
1.1293	0.4749	0.5533	0.85848	1.0522	0.382176	1.015	0.8980	1.294	1.224	1.058	0.994743	0.477443
1.1878	0.4413	0.5220	0.84547	1.0988	0.393237	1.030	0.8522	1.452	1.340	1.084	0.990298	0.445634
1.2449	0.4097	0.4922	0.83247	1.1433	0.401463	1.050	0.8142	1.612	1.453	1.109	0.983986	0.416387
1.3009	0.3801	0.4639	0.81946	1.1860	0.407098	1.074	0.7813	1.774	1.565	1.134	0.975531	0.389588
1.3561	0.3522	0.4368	0.80645	1.2271	0.410375	1.102	0.7523	1.941	1.676	1.158	0.964519	0.365179
1.4105	0.3261	0.4111	0.79344	1.2666	0.411509	1.135	0.7265	2.112	1.787	1.182	0.950838	0.342983
1.4644	0.3017	0.3866	0.78044	1.3049	0.410704	1.171	0.7034	2.289	1.897	1.207	0.935588	0.322432
1.5178	0.2788	0.3633	0.76743	1.3419	0.408153	1.212	0.6824	2.470	2.006	1.232	0.918053	0.303645
1.5709	0.2573	0.3411	0.75442	1.3777	0.404034	1.257	0.6632	2.657	2.115	1.257	0.898405	0.286432
1.6238	0.2373	0.3201	0.74142	1.4125	0.398516	1.306	0.6457	2.850	2.223	1.282	0.876900	0.270608
1.6765	0.2186	0.3001	0.72841	1.4464	0.391756	1.361	0.6295	3.048	2.331	1.308	0.853672	0.256046
1.7293	0.2011	0.2812	0.71540	1.4793	0.383903	1.420	0.6145	3.254	2.438	1.335	0.829010	0.242590
1.7821	0.1848	0.2632	0.70239	1.5114	0.375092	1.485	0.6006	3.466	2.544	1.362	0.803221	0.230092
1.8351	0.1696	0.2461	0.68939	1.5427	0.365451	1.556	0.5877	3.685	2.650	1.391	0.776504	0.218454
1.8883	0.1555	0.2299	0.67638	1.5733	0.355097	1.633	0.5756	3.912	2.755	1.420	0.749045	0.207589
1.9418	0.1423	0.2146	0.66337	1.6031	0.344141	1.717	0.5643	4.147	2.860	1.450	0.721022	0.197420
1.9957	0.1301	0.2001	0.65036	1.6323	0.332688	1.808	0.5536	4.391	2.964	1.481	0.692594	0.187881
2.0501	0.1188	0.1864	0.63736	1.6609	0.320830	1.908	0.5436	4.644	3.068	1.513	0.664117	0.178859
2.1049	0.1083	0.1734	0.62435	1.6889	0.308662	2.017	0.5341	4.907	3.171	1.547	0.635591	0.170343
2.1602	0.9853 -1	0.1612	0.61134	1.7163	0.296268	2.135	0.5251	5.180	3.273	1.581	0.607044	0.162317
2.2163	0.8953 -1	0.1497	0.59834	1.7431	0.283724	2.264	0.5166	5.464	3.375	1.617	0.578606	0.154737
2.2732	0.8122 -1	0.1388	0.58533	1.7694	0.271096	2.406	0.5085	5.760	3.476	1.655	0.550379	0.147564
2.3308	0.7354 -1	0.1285	0.57232	1.7952	0.258448	2.560	0.5008	6.068	3.576	1.694	0.522463	0.140765
2.3894	0.6648 -1	0.1189	0.55931	1.8206	0.245840	2.730	0.4935	6.389	3.676	1.735	0.494947	0.134312
2.4489	0.5998 -1	0.1098	0.54631	1.8454	0.233325	2.915	0.4865	6.725	3.775	1.778	0.467915	0.128178
2.5095	0.5400 -1	0.1013	0.53330	1.8699	0.220951	3.119	0.4798	7.076	3.873	1.822	0.441439	0.122338
2.5714	0.4853 -1	0.9329 -1	0.52029	1.8938	0.208762	3.344	0.4734	7.443	3.970	1.869	0.415584	0.116772
2.6345	0.4351 -1	0.8579 -1	0.50728	1.9174	0.196794	3.591	0.4673	7.828	4.067	1.918	0.390404	0.111457
2.6992	0.3893 -1	0.7877 -1	0.49428	1.9406	0.185076	3.865	0.4615	8.232	4.163	1.970	0.365939	0.106374
2.7653	0.3474 -1	0.7220 -1	0.48127	1.9634	0.173643	4.168	0.4559	8.656	4.259	2.024	0.342231	0.101512
2.8330	0.3093 -1	0.6606 -1	0.46826	1.9858	0.162525	4.503	0.4505	9.103	4.353	2.082	0.319322	0.096855
2.9025	0.2746 -1	0.6033 -1	0.45525	2.0078	0.151746	4.877	0.4453	9.574	4.447	2.142	0.297361	0.092352
2.9740	0.2432 -1	0.5499 -1	0.44225	2.0294	0.141323	5.293	0.4403	10.071	4.540	2.206	0.276317	0.088005
3.0475	0.2147 -1	0.5003 -1	0.42924	2.0507	0.131273	5.758	0.4354	10.597	4.632	2.274	0.256109	0.083834
3.1233	0.1890 -1	0.4541 -1	0.41623	2.0717	0.121611	6.279	0.4308	11.154	4.723	2.346	0.236755	0.079826
3.2017	0.1658 -1	0.4113 -1	0.40323	2.0923	0.112347	6.864	0.4263	11.745	4.813	2.423	0.218266	0.075973
3.2829	0.1450 -1	0.3716 -1	0.39022	2.1126	0.103487	7.524	0.4220	12.374	4.902	2.505	0.200646	0.072262
3.3671	0.1263 -1	0.3349 -1	0.37721	2.1326	0.095035	8.271	0.4178	13.044	4.991	2.592	0.183894	0.068686
3.4546	0.1096 -1	0.3010 -1	0.36420	2.1523	0.086993	9.119	0.4137	13.760	5.078	2.686	0.168009	0.065237
3.5458	0.9471 -2	0.2697 -1	0.35120	2.1716	0.079365	10.085	0.4098	14.527	5.164	2.786	0.152986	0.061906
3.6410	0.8147 -2	0.2409 -1	0.33819	2.1907	0.072147	11.192	0.4060	15.351	5.250	2.894	0.138815	0.058691
3.7407	0.6974 -2	0.2145 -1	0.32518	2.2095	0.065336	12.464	0.4024	16.238	5.334	3.011	0.125483	0.055579
3.8454	0.5939 -2	0.1903 -1	0.31217	2.2279	0.058929	13.935	0.3989	17.197	5.417	3.137	0.112976	0.052568
3.9555	0.5028 -2	0.1681 -1	0.29917	2.2462	0.052919	15.645	0.3954	18.237	5.500	3.274	0.101277	0.049650
4.0720	0.4231 -2	0.1479 -1	0.28616	2.2641	0.047300	17.643	0.3921	19.369	5.581	3.424	0.090368	0.046822
4.1955	0.3536 -2	0.1295 -1	0.27315	2.2818	0.042062	19.995	0.3889	20.606	5.661	3.587	0.082226	0.044078
4.3269	0.2933 -2	0.1128 -1	0.26015	2.2992	0.037196	22.784	0.3858	21.964	5.740	3.767	0.070828	0.041413
4.3543	0.2823 -2	0.1096 -1	0.25754	2.3027	0.036267	23.403	0.3850	22.252	5.756	3.806	0.069028	0.040893
4.3820	0.2716 -2	0.1065 -1	0.25494	2.3061	0.035352	24.045	0.3844	22.545	5.772	3.845	0.067265	0.040372
4.4101	0.2612 -2	0.1035 -1	0.25234	2.3096	0.034451	24.710	0.3838	22.844	5.787	3.884	0.065529	0.039854

TABLE III.- NONDIMENSIONAL FLOW PROPERTIES FOR ISENTROPICALLY EXPANDED COMBUSTION PRODUCTS

INCLUDING NORMAL-SHOCK PROPERTIES FOR SELECTED EQUIVALENCE RATIOS – Continued

(c) Concluded

N_{Ma}	p/p_t	ρ/ρ_t	T/T_t	V/a_t	q/p_t	A/A^*	$N_{Ma,2}$	p_2/p_1	ρ_2/ρ_1	T_2/T_1	$p_{t,2}/p_{t,1}$	$p_1/p_{t,2}$
4.4386	0.2511 -2	0.1005 -1	0.24974	2.3130	0.033564	25.401	0.3832	23.150	5.803	3.925	0.063822	0.039339
4.4675	0.2413 -2	0.9764 -2	0.24714	2.3164	0.032691	26.117	0.3826	23.462	5.819	3.966	0.062143	0.038827
4.4967	0.2318 -2	0.9480 -2	0.24454	2.3198	0.031833	26.861	0.3820	23.780	5.834	4.009	0.060492	0.038317
4.5265	0.2226 -2	0.9202 -2	0.24194	2.3232	0.030988	27.633	0.3814	24.105	5.850	4.052	0.058868	0.037811
4.5566	0.2137 -2	0.8929 -2	0.23933	2.3266	0.030158	28.436	0.3808	24.438	5.865	4.096	0.057272	0.037307
4.5872	0.2050 -2	0.8662 -2	0.23673	2.3300	0.029341	29.270	0.3803	24.777	5.880	4.141	0.055703	0.036806
4.6183	0.1966 -2	0.8400 -2	0.23413	2.3334	0.028538	30.138	0.3797	25.124	5.896	4.187	0.054161	0.036308
4.6498	0.1885 -2	0.8144 -2	0.23153	2.3368	0.027748	31.040	0.3791	25.478	5.911	4.234	0.052646	0.035812
4.6819	0.1807 -2	0.7894 -2	0.22893	2.3401	0.026972	31.979	0.3786	25.840	5.926	4.283	0.051158	0.035320
4.7144	0.1731 -2	0.7649 -2	0.22633	2.3435	0.026209	32.957	0.3780	26.211	5.941	4.332	0.049695	0.034829
4.7475	0.1657 -2	0.7409 -2	0.22373	2.3468	0.025460	33.975	0.3774	26.590	5.957	4.382	0.048260	0.034342
4.7810	0.1586 -2	0.7174 -2	0.22112	2.3501	0.024723	35.037	0.3769	26.978	5.972	4.434	0.046859	0.033857
4.8152	0.1517 -2	0.6945 -2	0.21852	2.3534	0.024000	36.143	0.3764	27.375	5.987	4.487	0.045466	0.033374
4.8498	0.1451 -2	0.6720 -2	0.21592	2.3568	0.023290	37.297	0.3758	27.781	6.002	4.541	0.044107	0.032894
4.8851	0.1387 -2	0.6501 -2	0.21332	2.3601	0.022593	38.502	0.3753	28.197	6.017	4.597	0.042774	0.032417
4.9210	0.1325 -2	0.6287 -2	0.21072	2.3634	0.021909	39.759	0.3747	28.624	6.032	4.654	0.041466	0.031942
4.9575	0.1265 -2	0.6077 -2	0.20812	2.3666	0.021238	41.073	0.3742	29.061	6.047	4.712	0.040184	0.031470
4.9946	0.1207 -2	0.5872 -2	0.20552	2.3699	0.020579	42.447	0.3737	29.508	6.062	4.772	0.038926	0.031000
5.0325	0.1151 -2	0.5672 -2	0.20291	2.3732	0.019933	43.883	0.3731	29.968	6.077	4.833	0.037692	0.030532
5.0710	0.1097 -2	0.5477 -2	0.20031	2.3764	0.019300	45.386	0.3726	30.439	6.091	4.896	0.036483	0.030067
5.1102	0.1045 -2	0.5286 -2	0.19771	2.3797	0.018678	46.960	0.3721	30.922	6.106	4.960	0.035298	0.029604
5.1501	0.9949 -3	0.5100 -2	0.19511	2.3829	0.018069	48.609	0.3716	31.418	6.121	5.026	0.034137	0.029144
5.1909	0.9466 -3	0.4918 -2	0.19251	2.3862	0.017472	50.337	0.3711	31.927	6.136	5.094	0.033000	0.028686
5.2324	0.9001 -3	0.4741 -2	0.18991	2.3894	0.016888	52.151	0.3706	32.451	6.150	5.164	0.031886	0.028230
5.2747	0.8554 -3	0.4568 -2	0.18730	2.3926	0.016315	54.054	0.3701	32.988	6.165	5.236	0.030796	0.027776
5.3178	0.8123 -3	0.4399 -2	0.18470	2.3959	0.015754	56.054	0.3696	33.541	6.180	5.310	0.029729	0.027325
5.3618	0.7709 -3	0.4234 -2	0.18210	2.3991	0.015205	58.156	0.3691	34.109	6.194	5.386	0.028685	0.026876
5.4068	0.7311 -3	0.4074 -2	0.17950	2.4023	0.014668	60.366	0.3686	34.694	6.209	5.464	0.027663	0.026429
5.4526	0.6928 -3	0.3917 -2	0.17690	2.4055	0.014142	62.694	0.3681	35.295	6.223	5.544	0.026664	0.025984
5.4994	0.6561 -3	0.3765 -2	0.17430	2.4086	0.013628	65.145	0.3676	35.915	6.237	5.627	0.025687	0.025542
5.5473	0.6208 -3	0.3616 -2	0.17170	2.4118	0.013125	67.730	0.3672	36.553	6.252	5.712	0.024733	0.025101
5.5961	0.5870 -3	0.3472 -2	0.16909	2.4150	0.012634	70.457	0.3667	37.211	6.266	5.800	0.023800	0.024663
5.6461	0.5545 -3	0.3331 -2	0.16649	2.4182	0.012154	73.336	0.3662	37.889	6.280	5.891	0.022889	0.024227
5.6972	0.5234 -3	0.3194 -2	0.16389	2.4213	0.011685	76.379	0.3658	38.589	6.295	5.984	0.021999	0.023793
5.7495	0.4936 -3	0.3061 -2	0.16129	2.4245	0.011227	79.599	0.3653	39.311	6.309	6.081	0.021131	0.023361
5.8030	0.4651 -3	0.2932 -2	0.15869	2.4276	0.010780	83.007	0.3648	40.056	6.323	6.181	0.020284	0.022931
5.8578	0.4379 -3	0.2806 -2	0.15609	2.4307	0.010343	86.619	0.3644	40.827	6.337	6.284	0.019458	0.022503
5.9138	0.4118 -3	0.2683 -2	0.15349	2.4339	0.009918	90.451	0.3639	41.623	6.351	6.390	0.018653	0.022077
5.9713	0.3869 -3	0.2565 -2	0.15088	2.4370	0.009503	94.520	0.3635	42.447	6.366	6.500	0.017868	0.021653
6.0302	0.3631 -3	0.2449 -2	0.14828	2.4401	0.009099	98.844	0.3630	43.299	6.380	6.614	0.017103	0.021231
6.0906	0.3405 -3	0.2337 -2	0.14568	2.4432	0.008705	103.446	0.3626	44.182	6.394	6.732	0.016359	0.020811
6.1526	0.3188 -3	0.2229 -2	0.14308	2.4463	0.008322	108.347	0.3621	45.097	6.408	6.855	0.015635	0.020393
6.2162	0.2983 -3	0.2123 -2	0.14048	2.4494	0.007949	113.574	0.3617	46.045	6.422	6.981	0.014930	0.019977
6.2815	0.2787 -3	0.2021 -2	0.13788	2.4525	0.007586	119.155	0.3613	47.029	6.435	7.113	0.014245	0.019563
6.3487	0.2601 -3	0.1923 -2	0.13528	2.4556	0.007234	125.122	0.3608	48.051	6.449	7.250	0.013579	0.019151
6.4177	0.2424 -3	0.1827 -2	0.13267	2.4587	0.006891	131.508	0.3604	49.113	6.463	7.392	0.012932	0.018741
6.4887	0.2256 -3	0.1734 -2	0.13007	2.4617	0.006558	138.353	0.3600	50.217	6.477	7.539	0.012305	0.018332
6.5617	0.2097 -3	0.1645 -2	0.12747	2.4648	0.006235	145.699	0.3596	51.366	6.491	7.693	0.011696	0.017926
6.6370	0.1946 -3	0.1558 -2	0.12487	2.4679	0.005922	153.595	0.3591	52.563	6.504	7.853	0.011105	0.017521
6.7146	0.1803 -3	0.1475 -2	0.12227	2.4709	0.005619	162.095	0.3587	53.810	6.518	8.020	0.010533	0.017118
6.7946	0.1668 -3	0.1394 -2	0.11967	2.4740	0.005325	171.259	0.3583	55.112	6.532	8.194	0.009979	0.016717
6.8772	0.1541 -3	0.1316 -2	0.11707	2.4770	0.005040	181.154	0.3579	56.472	6.545	8.376	0.009443	0.016318
6.9625	0.1421 -3	0.1242 -2	0.11446	2.4800	0.004764	191.859	0.3575	57.893	6.559	8.566	0.008925	0.015920
7.0507	0.1308 -3	0.1169 -2	0.11186	2.4831	0.004498	203.460	0.3571	59.380	6.573	8.765	0.008424	0.015524
7.1419	0.1201 -3	0.1100 -2	0.10926	2.4861	0.004241	216.055	0.3567	60.938	6.586	8.973	0.007941	0.015130
7.2363	0.1102 -3	0.1033 -2	0.10666	2.4891	0.003993	229.756	0.3563	62.571	6.600	9.192	0.007474	0.014738
7.3341	0.1008 -3	0.9687 -3	0.10406	2.4921	0.003754	244.691	0.3559	64.286	6.613	9.421	0.007025	0.014347
7.4356	0.9202 -4	0.9071 -3	0.10146	2.4951	0.003524	261.006	0.3555	66.089	6.627	9.662	0.006592	0.013959

TABLE III.- NONDIMENSIONAL FLOW PROPERTIES FOR ISENTROPICALLY EXPANDED COMBUSTION PRODUCTS INCLUDING NORMAL-SHOCK PROPERTIES FOR SELECTED EQUIVALENCE RATIOS – Continued

(d) $R_{eq} = 0.480$

N_{Ma}	p/p_t	ρ/ρ_t	T/T_t	V/a_t	q/p_t	A/A^*	$N_{Ma,2}$	p_2/p_1	ρ_2/ρ_1	T_2/T_1	$p_{t,2}/p_{t,1}$	$p_1/p_{t,2}$
0.	1.0000	1.0000	1.00000	0.	0.	0.						
0.2546	0.9612	0.9682	0.99278	0.2538	0.038196	2.413						
0.4090	0.9033	0.9204	0.98150	0.4056	0.092765	1.588						
0.5209	0.8485	0.8748	0.97022	0.5138	0.141507	1.319						
0.6141	0.7968	0.8312	0.95894	0.6025	0.184856	1.184						
0.6961	0.7480	0.7895	0.94765	0.6793	0.223214	1.105						
0.7706	0.7018	0.7497	0.93637	0.7479	0.256951	1.057						
0.8396	0.6582	0.7118	0.92509	0.8104	0.286415	1.028						
0.9045	0.6170	0.6755	0.91381	0.8682	0.311935	1.011						
0.9661	0.5781	0.6409	0.90253	0.9221	0.333812	1.003						
1.0251	0.5414	0.6078	0.89125	0.9727	0.352327	1.000	0.9748	1.058	1.047	1.011	1.000434	0.541165
1.0820	0.5068	0.5762	0.87996	1.0207	0.367746	1.008	0.9233	1.193	1.153	1.034	0.998864	0.507329
1.1370	0.4741	0.5460	0.86868	1.0662	0.380317	1.018	0.8796	1.330	1.258	1.057	0.996214	0.475866
1.1905	0.4432	0.5173	0.85740	1.1097	0.390271	1.033	0.8418	1.470	1.363	1.078	0.991733	0.446933
1.2428	0.4142	0.4898	0.84612	1.1514	0.397827	1.051	0.8086	1.612	1.467	1.099	0.985316	0.420347
1.2940	0.3868	0.4636	0.83484	1.1915	0.403187	1.073	0.7791	1.759	1.571	1.119	0.976696	0.396012
1.3444	0.3610	0.4386	0.82356	1.2300	0.406543	1.099	0.7527	1.908	1.674	1.139	0.966178	0.373611
1.3939	0.3367	0.4147	0.81227	1.2673	0.408072	1.128	0.7290	2.061	1.777	1.160	0.953645	0.353035
1.4429	0.3138	0.3920	0.80099	1.3033	0.407941	1.160	0.7074	2.218	1.879	1.180	0.939113	0.334136
1.4913	0.2923	0.3703	0.78971	1.3382	0.406306	1.196	0.6877	2.378	1.981	1.200	0.923010	0.316643
1.5393	0.2720	0.3497	0.77843	1.3721	0.403312	1.235	0.6696	2.542	2.082	1.221	0.905524	0.300396
1.5870	0.2530	0.3300	0.76715	1.4050	0.399096	1.278	0.6529	2.711	2.183	1.242	0.886504	0.285369
1.6345	0.2351	0.3112	0.75587	1.4370	0.393783	1.325	0.6375	2.884	2.283	1.263	0.866133	0.271427
1.6818	0.2183	0.2934	0.74458	1.4683	0.387492	1.376	0.6231	3.062	2.383	1.285	0.844585	0.258460
1.7291	0.2025	0.2764	0.73330	1.4987	0.380333	1.431	0.6098	3.245	2.482	1.307	0.822206	0.246314
1.7762	0.1877	0.2602	0.72202	1.5285	0.372410	1.490	0.5972	3.432	2.581	1.329	0.799293	0.234865
1.8233	0.1739	0.2448	0.71074	1.5575	0.363822	1.555	0.5855	3.625	2.679	1.353	0.775607	0.224157
1.8706	0.1609	0.2302	0.69946	1.5850	0.354551	1.624	0.5745	3.824	2.777	1.376	0.751300	0.214117
1.9179	0.1487	0.2162	0.68818	1.6138	0.345009	1.699	0.5640	4.029	2.874	1.401	0.726511	0.204683
1.9654	0.1373	0.2030	0.67590	1.6410	0.334945	1.779	0.5542	4.239	2.971	1.426	0.701365	0.195799
2.0132	0.1267	0.1905	0.66561	1.6677	0.324541	1.866	0.5449	4.456	3.068	1.451	0.675978	0.187420
2.0612	0.1168	0.1786	0.65433	1.6938	0.313866	1.960	0.5361	4.680	3.164	1.478	0.650458	0.179500
2.1095	0.1075	0.1673	0.64305	1.7195	0.302982	2.061	0.5277	4.911	3.259	1.505	0.624903	0.172003
2.1582	0.9884 -1	0.1556	0.63177	1.7446	0.291948	2.170	0.5197	5.150	3.354	1.533	0.599463	0.164879
2.2074	0.9078 -1	0.1464	0.62049	1.7693	0.280816	2.288	0.5121	5.397	3.448	1.562	0.574446	0.158036
2.2571	0.8328 -1	0.1368	0.60921	1.7936	0.269636	2.416	0.5049	5.652	3.542	1.593	0.549599	0.151534
2.3073	0.7631 -1	0.1277	0.59792	1.8174	0.258449	2.554	0.4979	5.915	3.636	1.624	0.524991	0.145349
2.3581	0.6982 -1	0.1191	0.58664	1.8409	0.247298	2.703	0.4913	6.189	3.729	1.656	0.500686	0.139456
2.4096	0.6380 -1	0.1110	0.57536	1.8639	0.236219	2.865	0.4849	6.472	3.821	1.690	0.476744	0.133834
2.4618	0.5822 -1	0.1033	0.56408	1.8865	0.225247	3.042	0.4789	6.765	3.913	1.724	0.453218	0.128464
2.5148	0.5305 -1	0.9604 -1	0.55280	1.9090	0.214412	3.233	0.4730	7.070	4.004	1.760	0.430154	0.123328
2.5685	0.4826 -1	0.8919 -1	0.54152	1.9309	0.203745	3.442	0.4674	7.387	4.095	1.798	0.407597	0.118413
2.6230	0.4384 -1	0.8275 -1	0.53023	1.9525	0.193275	3.669	0.4619	7.716	4.185	1.837	0.385590	0.113704
2.6785	0.3976 -1	0.7658 -1	0.51895	1.9738	0.183023	3.916	0.4567	8.059	4.275	1.878	0.364170	0.109187
2.7351	0.3600 -1	0.7097 -1	0.50767	1.9948	0.173008	4.187	0.4517	8.416	4.364	1.920	0.343359	0.104849
2.7928	0.3254 -1	0.6550 -1	0.49639	2.0155	0.163246	4.483	0.4468	8.788	4.453	1.965	0.323182	0.100678
2.8515	0.2935 -1	0.6055 -1	0.48511	2.0358	0.153755	4.808	0.4421	9.177	4.541	2.011	0.303657	0.096667
2.9117	0.2643 -1	0.5582 -1	0.47383	2.0558	0.144547	5.165	0.4376	9.582	4.628	2.060	0.284802	0.092804
2.9730	0.2375 -1	0.5139 -1	0.46255	2.0756	0.135634	5.557	0.4332	10.007	4.715	2.110	0.266631	0.089082
3.0359	0.2130 -1	0.4724 -1	0.45126	2.0951	0.127025	5.989	0.4290	10.451	4.801	2.164	0.249152	0.085492
3.1004	0.1906 -1	0.4335 -1	0.43998	2.1143	0.118724	6.467	0.4249	10.918	4.886	2.220	0.232369	0.082025
3.1667	0.1702 -1	0.3972 -1	0.42870	2.1332	0.110735	6.996	0.4209	11.407	4.971	2.279	0.216279	0.078675
3.2347	0.1515 -1	0.3633 -1	0.41742	2.1518	0.103065	7.582	0.4170	11.922	5.055	2.341	0.200885	0.075437
3.3045	0.1346 -1	0.3317 -1	0.40614	2.1702	0.095717	8.234	0.4133	12.464	5.139	2.406	0.186188	0.072304
3.3764	0.1193 -1	0.3023 -1	0.39486	2.1884	0.088694	8.960	0.4096	13.035	5.222	2.475	0.172188	0.069272
3.4505	0.1054 -1	0.2750 -1	0.38357	2.2062	0.081995	9.771	0.4061	13.639	5.304	2.549	0.158935	0.066309
3.5271	0.9284 -2	0.2496 -1	0.37229	2.2239	0.075619	10.680	0.4026	14.277	5.386	2.626	0.146363	0.063434
3.6062	0.8154 -2	0.2260 -1	0.36101	2.2413	0.069563	11.700	0.3993	14.954	5.466	2.708	0.134450	0.060648
3.6882	0.7138 -2	0.2043 -1	0.34973	2.2584	0.063825	12.850	0.3960	15.672	5.546	2.796	0.123185	0.057946
3.7734	0.6227 -2	0.1841 -1	0.33845	2.2753	0.058398	14.149	0.3928	16.437	5.626	2.889	0.112556	0.055323
3.8620	0.5412 -2	0.1655 -1	0.32717	2.2920	0.053277	15.623	0.3897	17.252	5.704	2.989	0.102545	0.052776
3.9544	0.4685 -2	0.1484 -1	0.31588	2.3084	0.048455	17.300	0.3867	18.124	5.782	3.096	0.093140	0.050300
4.0507	0.4038 -2	0.1327 -1	0.30460	2.3246	0.043926	19.218	0.3837	19.058	5.859	3.210	0.084323	0.047892
4.1517	0.3465 -2	0.1182 -1	0.29332	2.3406	0.039682	21.420	0.3809	20.062	5.936	3.334	0.076077	0.045549
4.2576	0.2959 -2	0.1050 -1	0.28204	2.3564	0.035716	23.959	0.3781	21.144	6.012	3.467	0.068384	0.043268
4.3690	0.2513 -2	0.9289 -2	0.27076	2.3720	0.032018	26.903	0.3753	22.314	6.087	3.611	0.061227	0.041046
4.4864	0.2122 -2	0.8185 -2	0.25948	2.3873	0.028581	30.334	0.3726	23.583	6.161	3.767	0.054585	0.038880
4.6108	0.1781 -2	0.7181 -2	0.24819	2.4025	0.025395	34.355	0.3700	24.965	6.234	3.938	0.048441	0.036768
4.7429	0.1484 -2	0.6271 -2	0.23691	2.4174	0.022451	39.102	0.3675	26.475	6.307	4.125	0.042773	0.034706
4.8838	0.1228 -2	0.5446 -2	0.22563	2.4322	0.019739	44.746	0.3650	28.135	6.380	4.330	0.037561	0.032693
4.9132	0.1181 -2	0.5291 -2	0.22338	2.4351	0.019223	46.001	0.3643	28.486	6.394	4.373	0.036569	0.032298

TABLE III.- NONDIMENSIONAL FLOW PROPERTIES FOR ISENTROPICALLY EXPANDED COMBUSTION PRODUCTS INCLUDING NORMAL-SHOCK PROPERTIES FOR SELECTED EQUIVALENCE RATIOS – Continued

(d) Concluded

N_{Ma}	p/p_t	ρ/ρ_t	T/T_t	V/a_t	q/p_t	A/A^*	$N_{Ma,2}$	p_2/p_1	ρ_2/ρ_1	T_2/T_1	$p_{t,2}/p_{t,1}$	$p_1/p_{t,2}$
4.9429	0.1136 -2	0.5140 -2	0.22112	2.4380	0.018717	47.303	0.3638	28.845	6.408	4.418	0.035597	0.031903
4.9731	0.1092 -2	0.4991 -2	0.21886	2.4409	0.018219	48.654	0.3633	29.211	6.423	4.463	0.034641	0.031509
5.0037	0.1049 -2	0.4845 -2	0.21661	2.4439	0.017729	50.056	0.3628	29.584	6.437	4.509	0.033703	0.031118
5.0347	0.1007 -2	0.4703 -2	0.21435	2.4458	0.017249	51.512	0.3623	29.966	6.451	4.556	0.032782	0.030728
5.0662	0.9671 -3	0.4553 -2	0.21209	2.4496	0.016777	53.024	0.3618	30.355	6.466	4.505	0.031877	0.030340
5.0982	0.9282 -3	0.4427 -2	0.20984	2.4525	0.016313	54.596	0.3614	30.752	6.480	4.654	0.030989	0.029953
5.1305	0.8905 -3	0.4293 -2	0.20758	2.4554	0.015858	56.230	0.3609	31.158	6.494	4.704	0.030117	0.029569
5.1636	0.8540 -3	0.4162 -2	0.20532	2.4583	0.015410	57.929	0.3604	31.573	6.508	4.755	0.029261	0.029186
5.1970	0.8187 -3	0.4034 -2	0.20307	2.4611	0.014971	59.697	0.3600	31.997	6.523	4.808	0.028421	0.028805
5.2309	0.7844 -3	0.3909 -2	0.20081	2.4540	0.014541	61.536	0.3595	32.431	6.537	4.862	0.027597	0.028425
5.2654	0.7513 -3	0.3787 -2	0.19856	2.4658	0.014118	63.452	0.3590	32.874	6.551	4.916	0.026788	0.028047
5.3005	0.7193 -3	0.3667 -2	0.19630	2.4597	0.013703	65.448	0.3586	33.327	6.565	4.973	0.025995	0.027671
5.3361	0.6884 -3	0.3550 -2	0.19404	2.4725	0.013296	67.528	0.3581	33.791	6.579	5.030	0.025218	0.027297
5.3723	0.6584 -3	0.3436 -2	0.19179	2.4753	0.012897	69.697	0.3576	34.265	6.593	5.089	0.024456	0.026924
5.4091	0.6295 -3	0.3324 -2	0.18953	2.4782	0.012506	71.960	0.3572	34.751	6.608	5.149	0.023708	0.026552
5.4463	0.6016 -3	0.3215 -2	0.18727	2.4810	0.012122	74.321	0.3567	35.248	6.622	5.210	0.022976	0.026183
5.4844	0.5746 -3	0.3108 -2	0.18502	2.4838	0.011746	76.786	0.3563	35.757	6.636	5.274	0.022258	0.025815
5.5231	0.5485 -3	0.3004 -2	0.18276	2.4856	0.011378	79.362	0.3558	36.279	6.650	5.338	0.021556	0.025448
5.5625	0.5234 -3	0.2902 -2	0.18051	2.4894	0.011017	82.054	0.3554	36.813	6.664	5.404	0.020867	0.025083
5.6026	0.4992 -3	0.2802 -2	0.17825	2.4922	0.010663	84.870	0.3549	37.361	6.678	5.472	0.020193	0.024720
5.6434	0.4758 -3	0.2705 -2	0.17599	2.4949	0.010317	87.817	0.3545	37.923	6.692	5.542	0.019533	0.024358
5.6850	0.4532 -3	0.2611 -2	0.17374	2.4977	0.009978	90.902	0.3540	38.500	6.706	5.513	0.018887	0.023997
5.7274	0.4315 -3	0.2518 -2	0.17148	2.5005	0.009646	94.134	0.3536	39.091	6.720	5.686	0.018255	0.023638
5.7705	0.4106 -3	0.2428 -2	0.16922	2.5032	0.009321	97.522	0.3531	39.699	6.734	5.762	0.017636	0.023281
5.8146	0.3904 -3	0.2340 -2	0.16697	2.5060	0.009003	101.075	0.3527	40.322	5.748	5.839	0.017031	0.022925
5.8594	0.3710 -3	0.2254 -2	0.16471	2.5087	0.008693	104.806	0.3523	40.963	6.762	5.918	0.016439	0.022570
5.9052	0.3524 -3	0.2171 -2	0.16245	2.5115	0.008389	108.723	0.3518	41.621	6.776	6.000	0.015861	0.022217
5.9518	0.3345 -3	0.2089 -2	0.16020	2.5142	0.008091	112.840	0.3514	42.298	6.790	6.083	0.015296	0.021866
5.9995	0.3172 -3	0.2010 -2	0.15794	2.5169	0.007801	117.170	0.3510	42.993	6.804	6.169	0.014743	0.021516
6.0481	0.3007 -3	0.1933 -2	0.15569	2.5197	0.007517	121.727	0.3506	43.709	6.818	6.258	0.014204	0.021167
6.0977	0.2847 -3	0.1857 -2	0.15343	2.5224	0.007239	126.527	0.3501	44.446	6.832	6.349	0.013677	0.020820
6.1484	0.2695 -3	0.1784 -2	0.15117	2.5251	0.006969	131.585	0.3497	45.205	6.846	6.443	0.013162	0.020474
6.2002	0.2548 -3	0.1713 -2	0.14892	2.5278	0.006704	136.922	0.3493	45.987	6.860	6.540	0.012660	0.020129
6.2532	0.2408 -3	0.1643 -2	0.14666	2.5305	0.006445	142.554	0.3489	46.792	6.874	6.639	0.012171	0.019786
6.3073	0.2274 -3	0.1576 -2	0.14440	2.5332	0.006194	148.506	0.3485	47.623	6.888	6.742	0.011593	0.019444
6.3627	0.2145 -3	0.1510 -2	0.14215	2.5359	0.005949	154.799	0.3480	48.480	6.902	6.848	0.011227	0.019103
6.4194	0.2022 -3	0.1446 -2	0.13989	2.5386	0.005710	161.460	0.3476	49.365	6.916	6.957	0.010773	0.018764
6.4775	0.1904 -3	0.1384 -2	0.13764	2.5412	0.005476	168.516	0.3472	50.278	6.930	7.070	0.010331	0.018426
6.5369	0.1791 -3	0.1324 -2	0.13538	2.5439	0.005249	175.998	0.3468	51.222	6.944	7.186	0.009900	0.018090
6.5977	0.1683 -3	0.1255 -2	0.13312	2.5465	0.005028	183.939	0.3464	52.198	6.958	7.307	0.009481	0.017755
6.6601	0.1581 -3	0.1209 -2	0.13087	2.5492	0.004812	192.375	0.3460	53.207	6.972	7.431	0.009073	0.017421
6.7240	0.1483 -3	0.1154 -2	0.12861	2.5519	0.004603	201.347	0.3456	54.252	6.986	7.560	0.008676	0.017088
6.7896	0.1389 -3	0.1100 -2	0.12635	2.5545	0.004399	210.898	0.3452	55.334	7.001	7.694	0.008290	0.016757
6.8569	0.1300 -3	0.1048 -2	0.12410	2.5572	0.004200	221.078	0.3448	56.455	7.015	7.832	0.007915	0.016427
6.9260	0.1215 -3	0.9983 -3	0.12184	2.5598	0.004008	231.940	0.3444	57.617	7.029	7.975	0.007551	0.016098
6.9970	0.1135 -3	0.9498 -3	0.11958	2.5625	0.003821	243.544	0.3440	58.824	7.043	8.124	0.007197	0.015770
7.0700	0.1058 -3	0.9028 -3	0.11733	2.5651	0.003639	255.955	0.3435	60.077	7.058	8.278	0.006854	0.015444
7.1450	0.9859 -4	0.8574 -3	0.11507	2.5677	0.003463	269.247	0.3431	61.379	7.072	8.438	0.006521	0.015119
7.2223	0.9170 -4	0.8134 -3	0.11282	2.5733	0.003292	283.501	0.3427	62.733	7.086	8.605	0.006198	0.014795
7.3017	0.8518 -4	0.7710 -3	0.11056	2.5729	0.003127	298.807	0.3423	64.142	7.101	8.778	0.005885	0.014472
7.3836	0.7900 -4	0.7300 -3	0.10830	2.5756	0.002967	315.266	0.3419	65.610	7.115	8.959	0.005583	0.014151
7.4680	0.7316 -4	0.6904 -3	0.10605	2.5782	0.002812	332.995	0.3415	67.140	7.130	9.147	0.005290	0.013831
7.5551	0.6765 -4	0.6523 -3	0.10379	2.5808	0.002662	352.118	0.3411	68.737	7.145	9.343	0.005007	0.013511
7.6451	0.6245 -4	0.6155 -3	0.10153	2.5834	0.002517	372.780	0.3407	70.404	7.159	9.547	0.004733	0.013194
7.7380	0.5755 -4	0.5801 -3	0.09928	2.5859	0.002377	395.143	0.3403	72.148	7.174	9.761	0.004469	0.012877
7.8340	0.5293 -4	0.5460 -3	0.09702	2.5885	0.002241	419.391	0.3399	73.973	7.189	9.985	0.004214	0.012561
7.9334	0.4860 -4	0.5132 -3	0.09477	2.5911	0.002111	445.732	0.3395	75.884	7.204	10.219	0.003968	0.012247
8.0363	0.4453 -4	0.4817 -3	0.09251	2.5937	0.001985	474.401	0.3391	77.889	7.219	10.464	0.003732	0.011933
8.1430	0.4072 -4	0.4515 -3	0.09025	2.5963	0.001864	505.671	0.3387	79.994	7.234	10.722	0.003504	0.011621
8.2536	0.3715 -4	0.4225 -3	0.08800	2.5988	0.001748	539.848	0.3383	82.208	7.250	10.992	0.003285	0.011310

TABLE III.- NONDIMENSIONAL FLOW PROPERTIES FOR ISENTROPICALLY EXPANDED COMBUSTION PRODUCTS INCLUDING NORMAL-SHOCK PROPERTIES FOR SELECTED EQUIVALENCE RATIOS – Continued

(e) $R_{eq} = 0.525$

N_{Ma}	p/p_t	ρ/ρ_t	T/T_t	V/a_t	q/p_t	A/A^*	$N_{Ma,2}$	p_2/p_1	ρ_2/ρ_1	T_2/T_1	$p_{t,2}/p_{t,1}$	$p_1/p_{t,2}$
0.	1.0000	1.0000	1.00000	0.	0.	0.						
0.1428	0.9878	0.9899	0.99800	0.1427	0.012096	4.207						
0.3506	0.9292	0.9407	0.98802	0.3487	0.068666	1.811						
0.4758	0.8739	0.8940	0.97804	0.4712	0.119119	1.411						
0.5753	0.8219	0.8496	0.96806	0.5670	0.163953	1.234						
0.6607	0.7728	0.8073	0.95808	0.6483	0.203629	1.135						
0.7371	0.7265	0.7671	0.94810	0.7198	0.238573	1.076						
0.8071	0.6829	0.7289	0.93812	0.7844	0.269179	1.039						
0.8722	0.6418	0.6924	0.92814	0.8437	0.295807	1.017						
0.9335	0.6030	0.6577	0.91816	0.8986	0.318786	1.005						
0.9918	0.5664	0.6247	0.90818	0.9501	0.338418	1.001						
1.0475	0.5319	0.5932	0.89820	0.9985	0.354988	1.003	0.9617	1.100	1.081	1.017	0.999427	0.532214
1.1012	0.4994	0.5632	0.88822	1.0444	0.368754	1.010	0.9103	1.234	1.188	1.038	0.997589	0.500566
1.1532	0.4687	0.5347	0.87824	1.0881	0.379955	1.021	0.8691	1.366	1.291	1.057	0.994423	0.471282
1.2036	0.4397	0.5074	0.86826	1.1299	0.388813	1.036	0.8336	1.499	1.393	1.076	0.989592	0.444317
1.2528	0.4124	0.4815	0.85828	1.1699	0.395530	1.055	0.8025	1.635	1.494	1.093	0.982890	0.419554
1.3010	0.3866	0.4567	0.84830	1.2084	0.400294	1.077	0.7747	1.772	1.594	1.111	0.974480	0.396734
1.3481	0.3623	0.4331	0.83832	1.2455	0.403282	1.102	0.7499	1.912	1.693	1.128	0.964107	0.375794
1.3945	0.3394	0.4107	0.82834	1.2813	0.404656	1.129	0.7273	2.055	1.792	1.145	0.952109	0.356458
1.4402	0.3178	0.3892	0.81836	1.3160	0.404565	1.160	0.7068	2.200	1.890	1.163	0.938630	0.338555
1.4853	0.2974	0.3688	0.80838	1.3496	0.403146	1.194	0.6880	2.348	1.988	1.180	0.923530	0.322030
1.5300	0.2782	0.3493	0.79840	1.3822	0.400530	1.231	0.6707	2.500	2.085	1.197	0.906976	0.306734
1.5741	0.2601	0.3307	0.78842	1.4140	0.396836	1.271	0.6547	2.654	2.181	1.215	0.889338	0.292470
1.6180	0.2431	0.3130	0.77844	1.4448	0.392174	1.314	0.6399	2.812	2.277	1.233	0.870854	0.279101
1.6615	0.2270	0.2961	0.76846	1.4749	0.386649	1.361	0.6261	2.973	2.373	1.251	0.851310	0.266648
1.7048	0.2119	0.2801	0.75848	1.5043	0.380358	1.411	0.6131	3.137	2.468	1.269	0.830855	0.255021
1.7480	0.1977	0.2647	0.74850	1.5329	0.373390	1.464	0.6010	3.306	2.562	1.288	0.809632	0.244136
1.7910	0.1843	0.2502	0.73852	1.5609	0.365825	1.522	0.5896	3.478	2.657	1.307	0.787767	0.233923
1.8339	0.1717	0.2363	0.72854	1.5883	0.357742	1.584	0.5789	3.654	2.750	1.326	0.765381	0.224319
1.8768	0.1599	0.2230	0.71856	1.6151	0.349212	1.650	0.5688	3.835	2.843	1.346	0.742877	0.215186
1.9198	0.1487	0.2105	0.70858	1.6414	0.340302	1.720	0.5592	4.020	2.936	1.366	0.720178	0.206530
1.9628	0.1383	0.1985	0.69860	1.6671	0.331072	1.796	0.5501	4.210	3.028	1.387	0.697213	0.198353
2.0059	0.1285	0.1871	0.68862	1.6923	0.321578	1.877	0.5415	4.404	3.120	1.408	0.674072	0.190617
2.0491	0.1193	0.1762	0.67864	1.7171	0.311870	1.964	0.5333	4.604	3.211	1.430	0.650837	0.183284
2.0926	0.1107	0.1659	0.66866	1.7414	0.301998	2.057	0.5255	4.809	3.302	1.452	0.627584	0.176322
2.1363	0.1026	0.1561	0.65868	1.7653	0.292005	2.156	0.5181	5.020	3.393	1.475	0.604381	0.169703
2.1802	0.9498 -1	0.1468	0.64870	1.7887	0.281932	2.263	0.5109	5.236	3.483	1.498	0.581293	0.163402
2.2245	0.8789 -1	0.1380	0.63872	1.8118	0.271819	2.377	0.5041	5.459	3.573	1.522	0.558382	0.157393
2.2690	0.8124 -1	0.1296	0.62874	1.8345	0.261701	2.500	0.4976	5.688	3.662	1.547	0.535701	0.151658
2.3139	0.7503 -1	0.1216	0.61876	1.8568	0.251611	2.632	0.4913	5.923	3.751	1.573	0.513302	0.146178
2.3591	0.6923 -1	0.1140	0.60878	1.8788	0.241581	2.774	0.4852	6.166	3.839	1.599	0.491233	0.140936
2.4048	0.6382 -1	0.1069	0.59880	1.9004	0.231638	2.926	0.4794	6.416	3.928	1.626	0.469532	0.135916
2.4510	0.5876 -1	0.1001	0.58882	1.9217	0.221802	3.090	0.4738	6.674	4.015	1.655	0.448321	0.131076
2.4978	0.5405 -1	0.9363 -1	0.57884	1.9427	0.212092	3.267	0.4685	6.940	4.103	1.683	0.427665	0.126391
2.5451	0.4966 -1	0.8754 -1	0.56886	1.9634	0.202533	3.458	0.4633	7.215	4.189	1.713	0.407436	0.121894
2.5929	0.4558 -1	0.8177 -1	0.55888	1.9838	0.193143	3.663	0.4583	7.499	4.276	1.744	0.387667	0.117574
2.6414	0.4178 -1	0.7632 -1	0.54890	2.0038	0.183937	3.885	0.4534	7.792	4.362	1.776	0.368381	0.113420
2.6907	0.3825 -1	0.7117 -1	0.53892	2.0236	0.174929	4.126	0.4487	8.096	4.448	1.810	0.349596	0.109422
2.7406	0.3498 -1	0.6631 -1	0.52894	2.0432	0.166131	4.386	0.4442	8.410	4.533	1.844	0.331329	0.105570
2.7914	0.3194 -1	0.6171 -1	0.51896	2.0624	0.157553	4.669	0.4398	8.736	4.618	1.880	0.313592	0.101857
2.8430	0.2913 -1	0.5738 -1	0.50898	2.0814	0.149204	4.975	0.4356	9.074	4.702	1.916	0.296398	0.098273
2.8956	0.2652 -1	0.5330 -1	0.49900	2.1002	0.141094	5.309	0.4315	9.424	4.786	1.955	0.279755	0.094813
2.9490	0.2412 -1	0.4945 -1	0.48902	2.1187	0.133226	5.672	0.4275	9.788	4.870	1.995	0.263669	0.091468
3.0035	0.2190 -1	0.4583 -1	0.47904	2.1370	0.125608	6.068	0.4236	10.166	4.953	2.036	0.248146	0.088235
3.0589	0.1985 -1	0.4242 -1	0.46906	2.1550	0.118248	6.500	0.4198	10.559	5.036	2.079	0.233194	0.085106
3.1155	0.1796 -1	0.3923 -1	0.45908	2.1728	0.111146	6.972	0.4161	10.969	5.119	2.125	0.218813	0.082078
3.1732	0.1622 -1	0.3622 -1	0.44910	2.1904	0.104307	7.490	0.4125	11.395	5.201	2.172	0.205004	0.079143
3.2323	0.1463 -1	0.3341 -1	0.43912	2.2077	0.097731	8.057	0.4091	11.840	5.283	2.221	0.191763	0.076299
3.2927	0.1317 -1	0.3077 -1	0.42914	2.2248	0.091417	8.680	0.4057	12.305	5.364	2.272	0.179087	0.073539
3.3546	0.1183 -1	0.2830 -1	0.41916	2.2417	0.085366	9.366	0.4023	12.791	5.445	2.326	0.166971	0.070861
3.4179	0.1061 -1	0.2599 -1	0.40918	2.2584	0.079577	10.122	0.3991	13.299	5.525	2.382	0.155407	0.068260
3.4830	0.9491 -2	0.2384 -1	0.39920	2.2749	0.074047	10.957	0.3959	13.832	5.605	2.441	0.144389	0.065733
3.5500	0.8473 -2	0.2183 -1	0.38922	2.2912	0.068772	11.882	0.3929	14.390	5.685	2.503	0.133905	0.063276
3.6190	0.7546 -2	0.1995 -1	0.37924	2.3073	0.063746	12.909	0.3899	14.977	5.764	2.568	0.123941	0.060884
3.6898	0.6704 -2	0.1820 -1	0.36926	2.3232	0.058969	14.051	0.3869	15.594	5.843	2.636	0.114489	0.058557
3.7627	0.5941 -2	0.1658 -1	0.35928	2.3388	0.054436	15.324	0.3840	16.245	5.921	2.708	0.105540	0.056292
3.8380	0.5251 -2	0.1507 -1	0.34930	2.3543	0.050143	16.746	0.3812	16.931	5.999	2.785	0.097084	0.054085
3.9158	0.4628 -2	0.1367 -1	0.33932	2.3696	0.046085	18.339	0.3784	17.656	6.077	2.865	0.089106	0.051934
3.9962	0.4066 -2	0.1238 -1	0.32934	2.3847	0.042256	20.128	0.3757	18.423	6.154	2.951	0.081593	0.049836
4.0795	0.3562 -2	0.1118 -1	0.31936	2.3997	0.038651	22.143	0.3730	19.236	6.231	3.041	0.074533	0.047790
4.1660	0.3110 -2	0.1008 -1	0.30938	2.4144	0.035263	24.420	0.3704	20.101	6.308	3.137	0.067911	0.045793

TABLE III.- NONDIMENSIONAL FLOW PROPERTIES FOR ISENTROPICALLY EXPANDED COMBUSTION PRODUCTS INCLUDING NORMAL-SHOCK PROPERTIES FOR SELECTED EQUIVALENCE RATIOS – Concluded

(e) Concluded

N_{Ma}	p/p_t	ρ/ρ_t	T/T_t	V/a_t	q/p_t	A/A^*	$N_{Ma,2}$	p_2/p_1	ρ_2/ρ_1	T_2/T_1	$p_{t,2}/p_{t,1}$	$p_1/p_{t,2}$
4.2560	0.2706 -2	0.9061 -2	0.29940	2.4289	0.032085	27.000	0.3678	21.021	6.384	3.240	0.061712	0.043843
4.3498	0.2345 -2	0.8124 -2	0.28942	2.4433	0.029109	29.936	0.3653	22.002	6.460	3.350	0.055918	0.041938
4.4477	0.2024 -2	0.7264 -2	0.27944	2.4575	0.026330	33.289	0.3628	23.052	6.536	3.467	0.050516	0.040075
4.5501	0.1740 -2	0.6475 -2	0.26946	2.4715	0.023738	37.133	0.3603	24.178	6.611	3.592	0.045489	0.038254
4.6575	0.1489 -2	0.5753 -2	0.25948	2.4853	0.021329	41.559	0.3579	25.388	6.686	3.727	0.040822	0.036473
4.7703	0.1268 -2	0.5094 -2	0.24950	2.4989	0.019093	46.680	0.3555	26.693	6.761	3.873	0.036499	0.034729
4.8891	0.1073 -2	0.4494 -2	0.23952	2.5124	0.017024	52.636	0.3531	28.105	6.836	4.030	0.032506	0.033022
5.0145	0.9037 -3	0.3948 -2	0.22954	2.5257	0.015115	59.598	0.3508	29.637	6.911	4.201	0.028827	0.031350
5.1474	0.7561 -3	0.3453 -2	0.21956	2.5389	0.013359	67.785	0.3485	31.306	6.986	4.387	0.025458	0.029700
5.2889	0.6282 -3	0.3006 -2	0.20958	2.5518	0.011747	77.478	0.3462	33.131	7.061	4.591	0.022370	0.028083
5.4399	0.5180 -3	0.2602 -2	0.19960	2.5647	0.010273	89.038	0.3439	35.137	7.137	4.814	0.019549	0.026498
5.4714	0.4979 -3	0.2527 -2	0.19760	2.5672	0.009994	91.613	0.3433	35.562	7.152	4.861	0.019015	0.026187
5.5033	0.4785 -3	0.2453 -2	0.19561	2.5697	0.009721	94.286	0.3428	35.996	7.167	4.909	0.018491	0.025875
5.5357	0.4596 -3	0.2380 -2	0.19361	2.5723	0.009452	97.061	0.3424	36.438	7.182	4.959	0.017978	0.025564
5.5685	0.4413 -3	0.2309 -2	0.19162	2.5748	0.009188	99.944	0.3420	36.890	7.197	5.009	0.017474	0.025254
5.6018	0.4236 -3	0.2240 -2	0.18962	2.5773	0.008930	102.939	0.3415	37.351	7.212	5.060	0.016980	0.024946
5.6357	0.4064 -3	0.2172 -2	0.18762	2.5798	0.008676	106.052	0.3411	37.822	7.228	5.112	0.016495	0.024639
5.6700	0.3898 -3	0.2106 -2	0.18563	2.5823	0.008427	109.288	0.3406	38.303	7.243	5.166	0.016020	0.024333
5.7048	0.3737 -3	0.2041 -2	0.18363	2.5848	0.008183	112.655	0.3402	38.794	7.258	5.220	0.015554	0.024028
5.7402	0.3582 -3	0.1977 -2	0.18164	2.5873	0.007944	116.159	0.3397	39.296	7.273	5.276	0.015098	0.023724
5.7761	0.3431 -3	0.1915 -2	0.17964	2.5898	0.007710	119.807	0.3393	39.809	7.289	5.333	0.014650	0.023421
5.8126	0.3286 -3	0.1855 -2	0.17764	2.5923	0.007480	123.606	0.3389	40.334	7.304	5.391	0.014212	0.023120
5.8497	0.3145 -3	0.1795 -2	0.17565	2.5948	0.007255	127.564	0.3384	40.870	7.319	5.450	0.013782	0.022819
5.8873	0.3009 -3	0.1737 -2	0.17365	2.5973	0.007034	131.690	0.3380	41.418	7.335	5.511	0.013361	0.022520
5.9256	0.2878 -3	0.1681 -2	0.17166	2.5997	0.006818	135.992	0.3375	41.980	7.350	5.573	0.012949	0.022222
5.9645	0.2751 -3	0.1626 -2	0.16966	2.6022	0.006606	140.482	0.3371	42.554	7.366	5.637	0.012545	0.021925
6.0041	0.2628 -3	0.1572 -2	0.16766	2.6046	0.006399	145.167	0.3367	43.142	7.381	5.702	0.012150	0.021629
6.0442	0.2510 -3	0.1519 -2	0.16567	2.6071	0.006196	150.059	0.3362	43.744	7.397	5.768	0.011764	0.021334
6.0851	0.2396 -3	0.1468 -2	0.16367	2.6095	0.005998	155.171	0.3358	44.360	7.412	5.837	0.011385	0.021041
6.1267	0.2285 -3	0.1417 -2	0.16168	2.6120	0.005804	160.515	0.3353	44.992	7.428	5.906	0.011015	0.020748
6.1691	0.2179 -3	0.1368 -2	0.15968	2.6144	0.005614	166.103	0.3349	45.640	7.443	5.978	0.010653	0.020456
6.2123	0.2077 -3	0.1321 -2	0.15768	2.6168	0.005428	171.951	0.3345	46.303	7.459	6.051	0.010299	0.020166
6.2563	0.1978 -3	0.1274 -2	0.15569	2.6192	0.005246	178.074	0.3340	46.984	7.475	6.126	0.009953	0.019876
6.3010	0.1883 -3	0.1229 -2	0.15369	2.6216	0.005068	184.489	0.3336	47.682	7.491	6.203	0.009614	0.019588
6.3467	0.1792 -3	0.1184 -2	0.15170	2.6241	0.004894	191.214	0.3332	48.399	7.506	6.282	0.009284	0.019300
6.3932	0.1704 -3	0.1141 -2	0.14970	2.6265	0.004725	198.268	0.3327	49.134	7.522	6.363	0.008960	0.019014
6.4406	0.1619 -3	0.1099 -2	0.14770	2.6289	0.004559	205.670	0.3323	49.890	7.538	6.446	0.008645	0.018728
6.4889	0.1538 -3	0.1058 -2	0.14571	2.6312	0.004397	213.444	0.3319	50.666	7.554	6.532	0.008337	0.018444
6.5382	0.1459 -3	0.1018 -2	0.14371	2.6336	0.004238	221.614	0.3314	51.464	7.570	6.620	0.008036	0.018160
6.5885	0.1384 -3	0.9793 -3	0.14172	2.6360	0.004084	230.204	0.3310	52.284	7.587	6.710	0.007742	0.017878
6.6398	0.1312 -3	0.9414 -3	0.13972	2.6384	0.003933	239.244	0.3306	53.127	7.603	6.802	0.007455	0.017596
6.6922	0.1242 -3	0.9046 -3	0.13772	2.6408	0.003786	248.764	0.3301	53.995	7.619	6.898	0.007175	0.017316
6.7458	0.1176 -3	0.8687 -3	0.13573	2.6431	0.003643	258.795	0.3297	54.888	7.636	6.996	0.006903	0.017036
6.8005	0.1112 -3	0.8339 -3	0.13373	2.6455	0.003503	269.375	0.3293	55.808	7.652	7.096	0.006637	0.016758
6.8564	0.1051 -3	0.8000 -3	0.13174	2.6478	0.003366	280.541	0.3288	56.755	7.669	7.200	0.006378	0.016480
6.9135	0.9925 -4	0.7670 -3	0.12974	2.6502	0.003233	292.335	0.3284	57.732	7.685	7.307	0.006125	0.016203
6.9720	0.9364 -4	0.7350 -3	0.12774	2.6525	0.003104	304.803	0.3280	58.739	7.702	7.417	0.005879	0.015928
7.0318	0.8827 -4	0.7039 -3	0.12575	2.6549	0.002978	317.995	0.3275	59.779	7.719	7.531	0.005640	0.015653
7.0930	0.8314 -4	0.6737 -3	0.12375	2.6572	0.002855	331.964	0.3271	60.851	7.736	7.648	0.005406	0.015379
7.1557	0.7824 -4	0.6443 -3	0.12176	2.6595	0.002735	346.771	0.3267	61.959	7.753	7.769	0.005180	0.015106
7.2198	0.7356 -4	0.6159 -3	0.11976	2.6619	0.002619	362.482	0.3262	63.104	7.770	7.894	0.004959	0.014834
7.2856	0.6909 -4	0.5883 -3	0.11776	2.6642	0.002506	379.165	0.3258	64.288	7.787	8.022	0.004744	0.014563
7.3530	0.6483 -4	0.5615 -3	0.11577	2.6665	0.002396	396.899	0.3254	65.512	7.805	8.156	0.004536	0.014292
7.4221	0.6077 -4	0.5355 -3	0.11377	2.6688	0.002289	415.769	0.3249	66.779	7.822	8.293	0.004333	0.014023
7.4930	0.5690 -4	0.5104 -3	0.11178	2.6711	0.002186	435.872	0.3245	68.092	7.840	8.436	0.004137	0.013754
7.5657	0.5322 -4	0.4861 -3	0.10978	2.6734	0.002085	457.306	0.3240	69.453	7.858	8.584	0.003946	0.013487
7.6405	0.4972 -4	0.4625 -3	0.10778	2.6757	0.001987	480.191	0.3236	70.864	7.876	8.737	0.003761	0.013220
7.7173	0.4639 -4	0.4397 -3	0.10579	2.6780	0.001893	504.655	0.3232	72.328	7.894	8.895	0.003581	0.012954
7.7962	0.4323 -4	0.4177 -3	0.10379	2.6803	0.001801	530.833	0.3227	73.848	7.912	9.060	0.003407	0.012689
7.8774	0.4024 -4	0.3964 -3	0.10180	2.6826	0.001712	558.885	0.3223	75.429	7.931	9.230	0.003239	0.012425
7.9609	0.3740 -4	0.3758 -3	0.09980	2.6849	0.001626	588.984	0.3218	77.072	7.950	9.408	0.003075	0.012162
8.0468	0.3472 -4	0.3559 -3	0.09780	2.6872	0.001543	621.321	0.3213	78.783	7.969	9.592	0.002918	0.011899
8.1355	0.3218 -4	0.3368 -3	0.09581	2.6894	0.001462	656.117	0.3209	80.565	7.988	9.784	0.002765	0.011638
8.2269	0.2978 -4	0.3183 -3	0.09381	2.6917	0.001384	693.613	0.3204	82.423	8.007	9.984	0.002618	0.011377
8.3213	0.2752 -4	0.3005 -3	0.09182	2.6940	0.001309	734.082	0.3200	84.362	8.027	10.192	0.002475	0.011117
8.4187	0.2538 -4	0.2833 -3	0.08982	2.6962	0.001236	777.837	0.3195	86.388	8.046	10.409	0.002338	0.010858
8.5193	0.2337 -4	0.2669 -3	0.08782	2.6985	0.001166	825.220	0.3190	88.506	8.067	10.636	0.002205	0.010599
8.6234	0.2148 -4	0.2510 -3	0.08583	2.7007	0.001099	876.625	0.3186	90.722	8.087	10.873	0.002077	0.010342
8.7311	0.1971 -4	0.2358 -3	0.08383	2.7030	0.001034	932.500	0.3181	93.044	8.108	11.121	0.001954	0.010085
8.8427	0.1805 -4	0.2211 -3	0.08184	2.7052	0.000971	993.349	0.3176	95.480	8.129	11.381	0.001836	0.009829
8.9583	0.1649 -4	0.2071 -3	0.07984	2.7075	0.000911	1059.755	0.3171	98.038	8.150	11.653	0.001722	0.009574
9.0783	0.1504 -4	0.1937 -3	0.07784	2.7097	0.000853	1132.383	0.3166	100.727	8.171	11.939	0.001613	0.009320

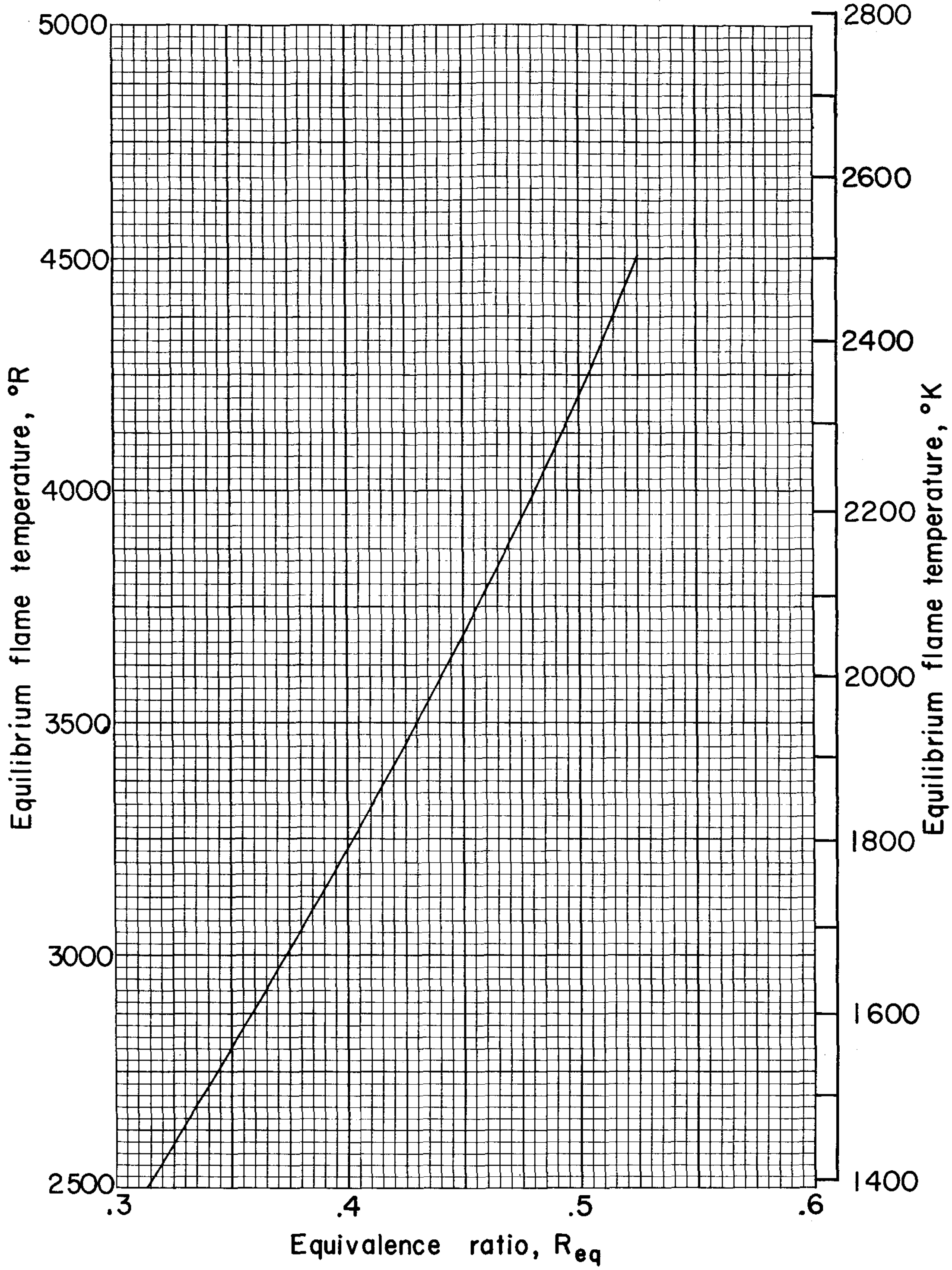
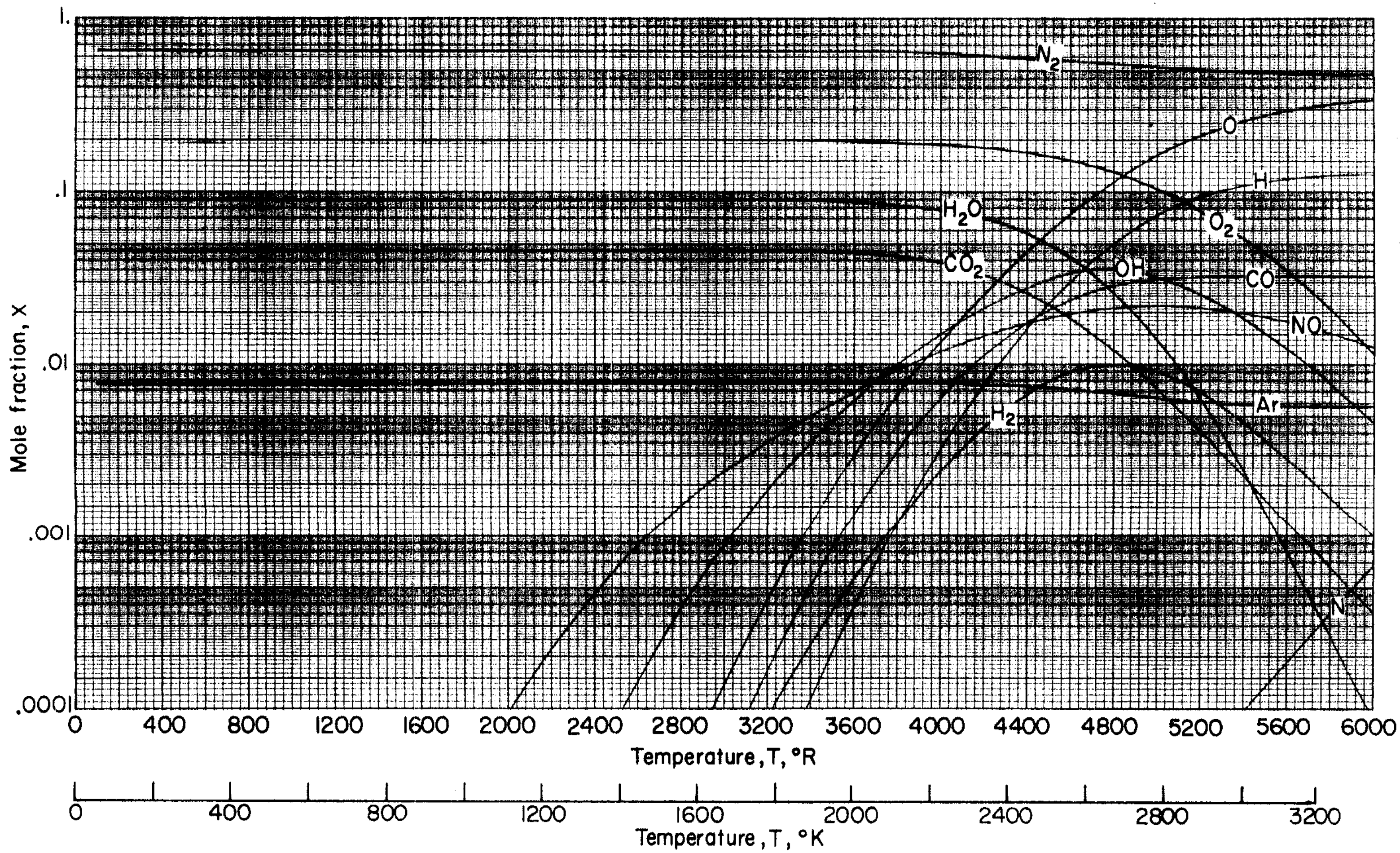
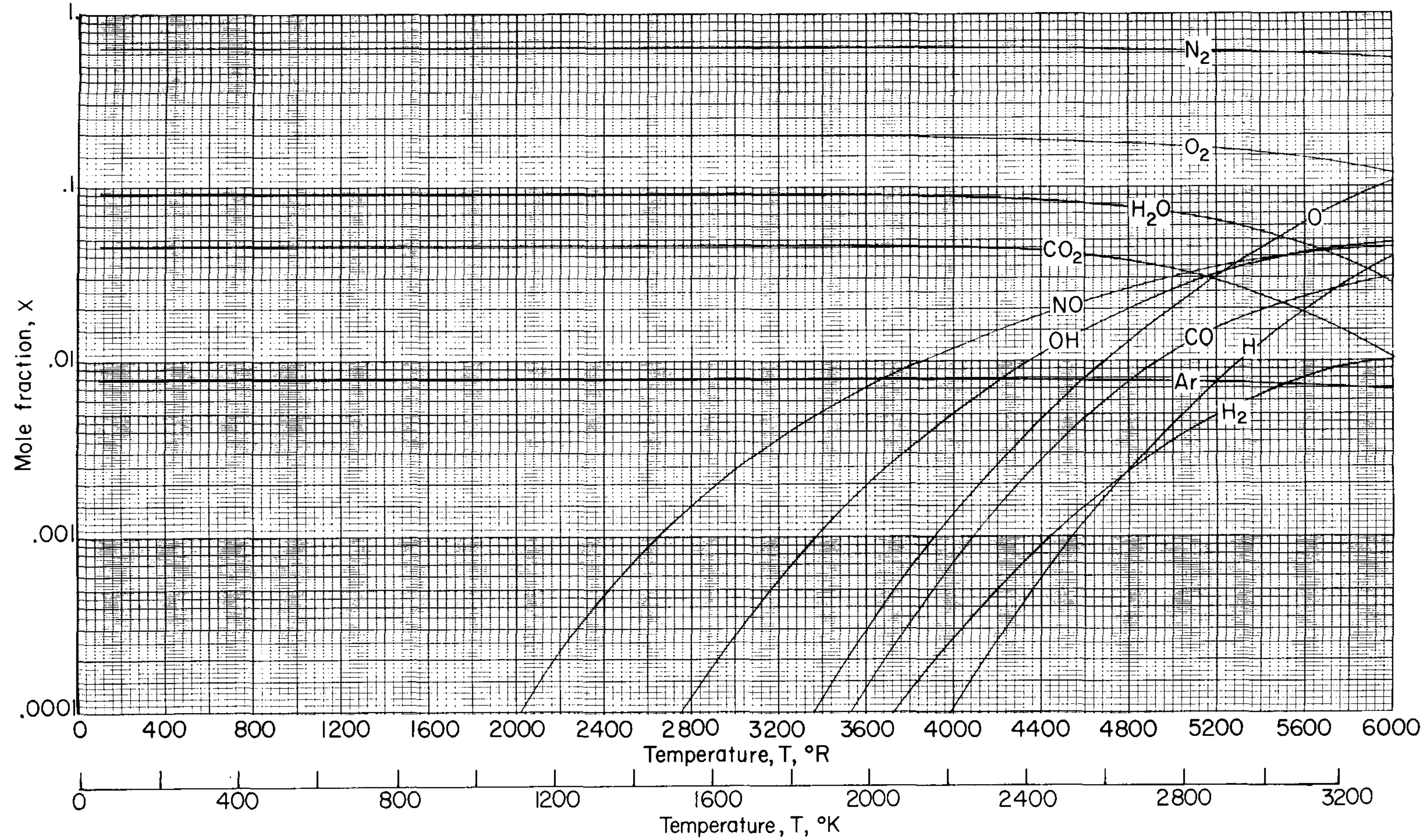


Figure 1.- Equilibrium flame temperature as a function of selected equivalence ratios for approximately 20-percent oxygen in the combustion products. $p > 10$ atm; initial T, 540° R (300° K).



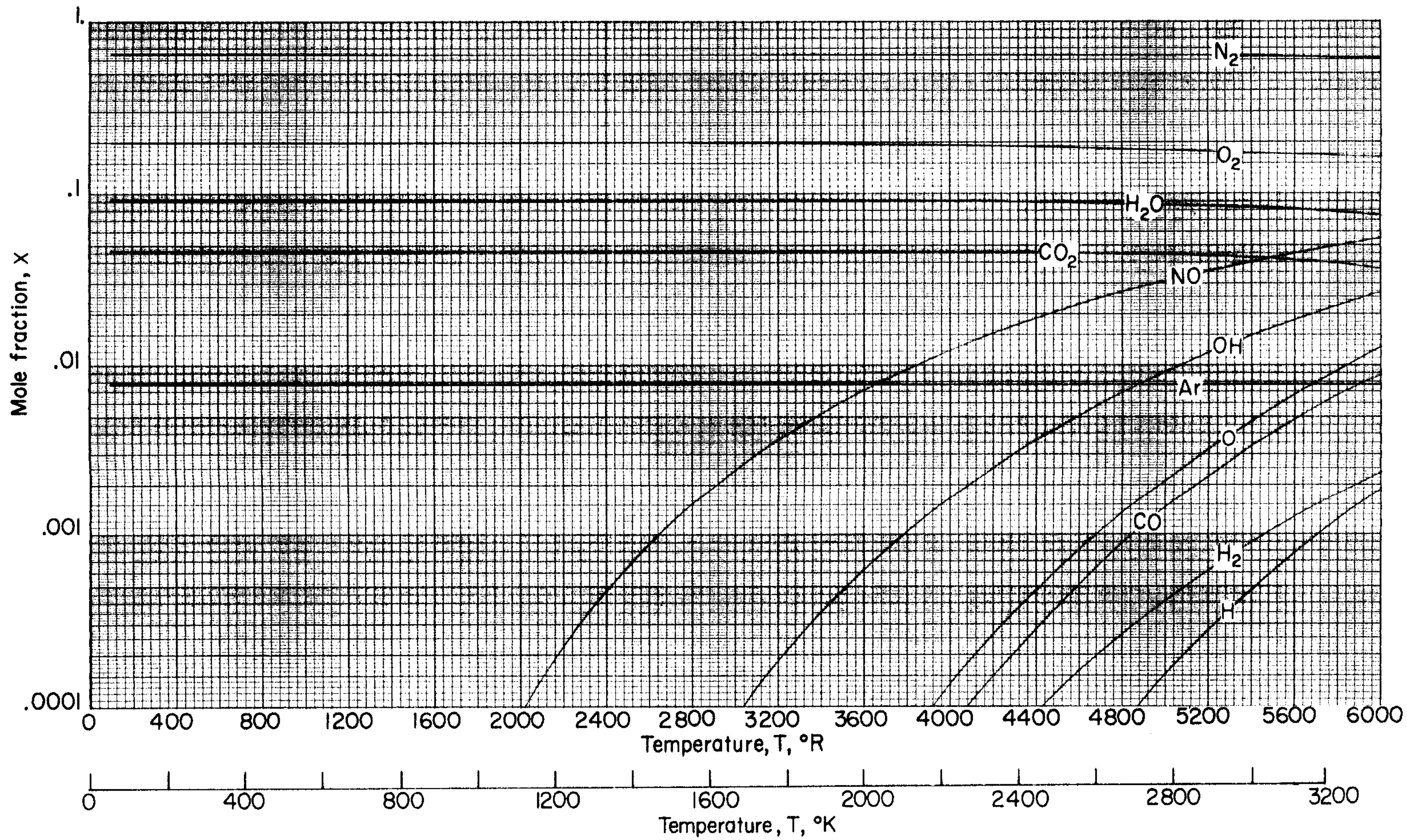
(a) p = 0.01 atmosphere.

Figure 2.- Equilibrium compositions of combustion products for selected pressures and R_{eq} = 0.315.



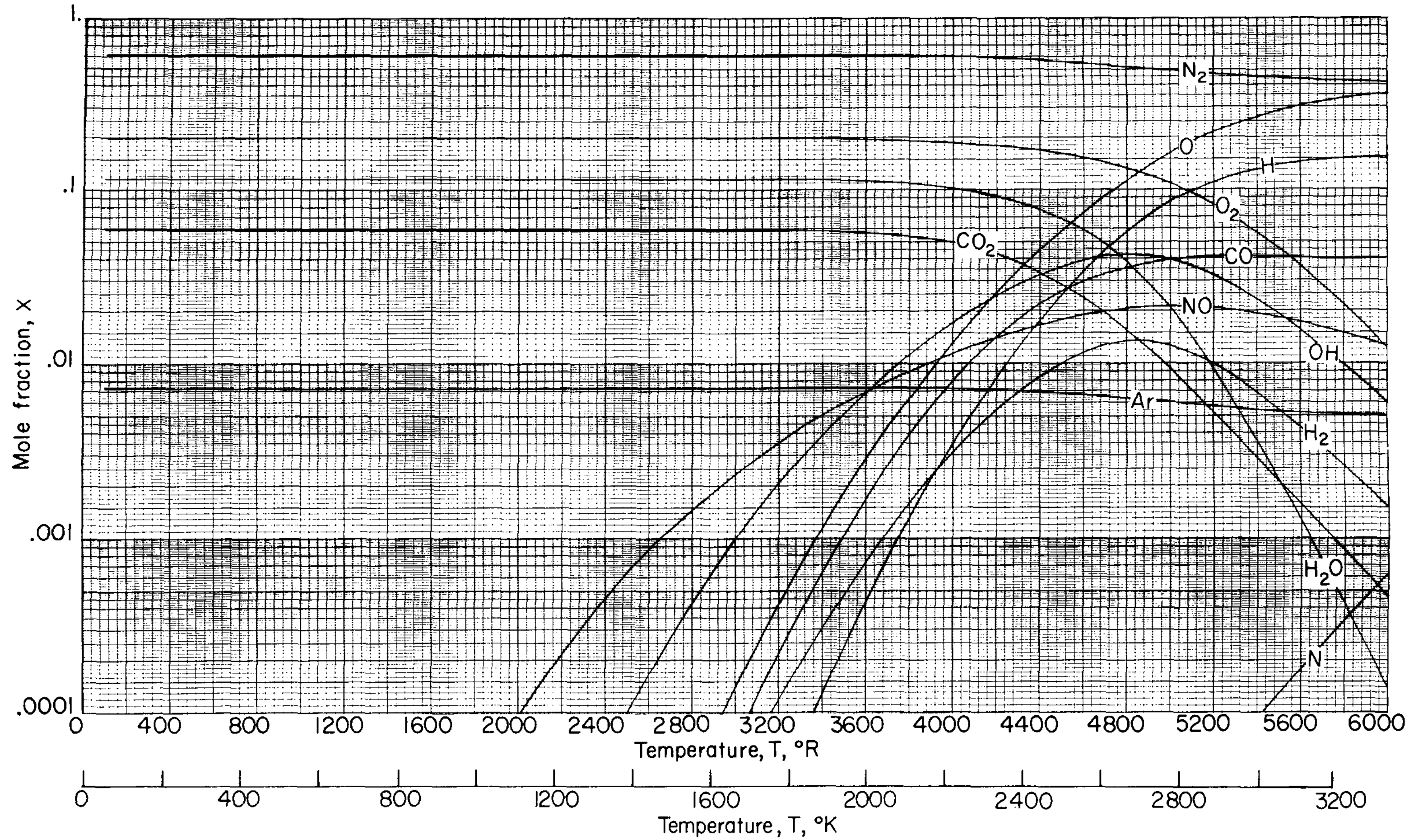
(b) p = 1.0 atmosphere.

Figure 2.- Continued.



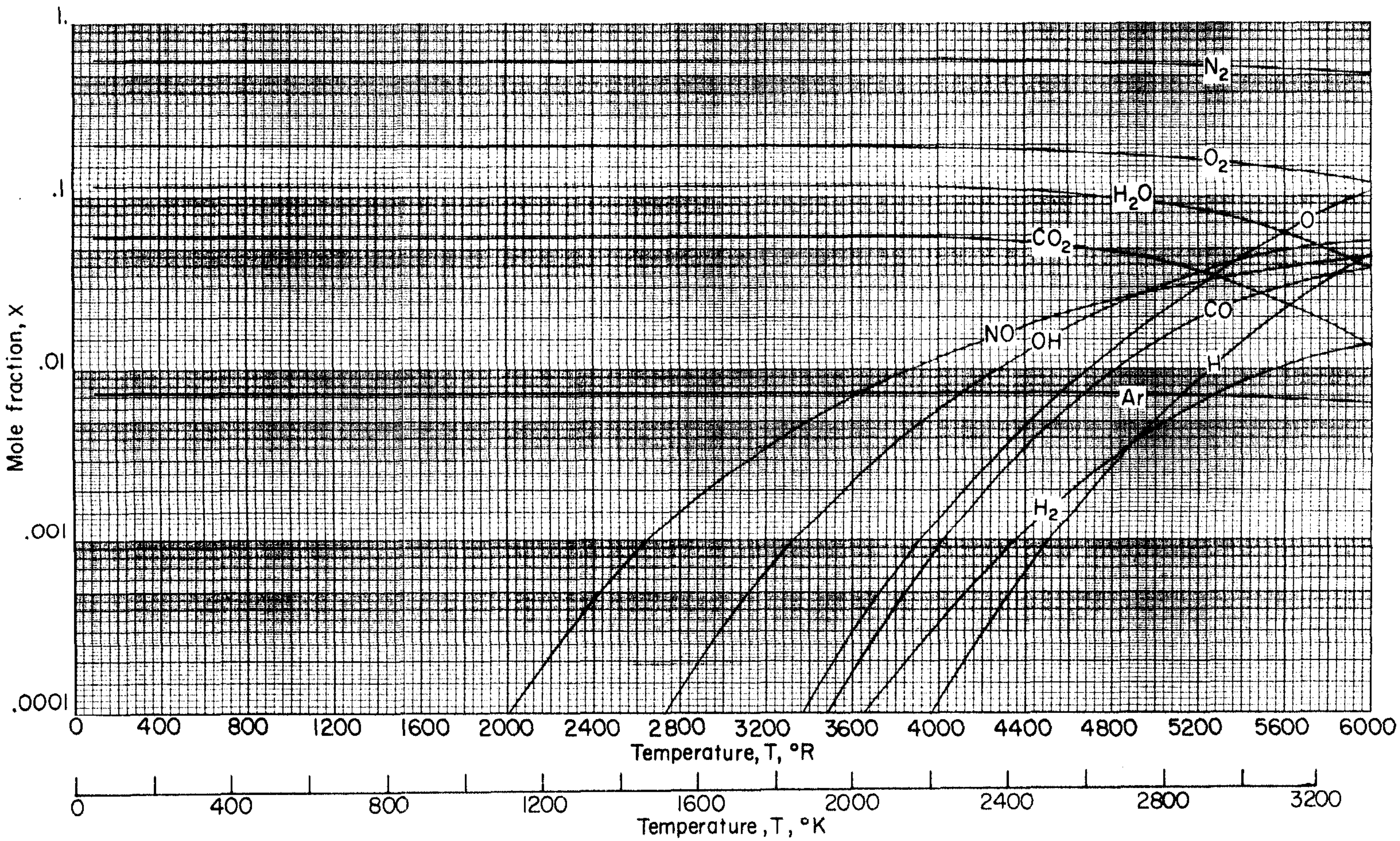
(c) p = 100 atmospheres.

Figure 2.- Concluded.



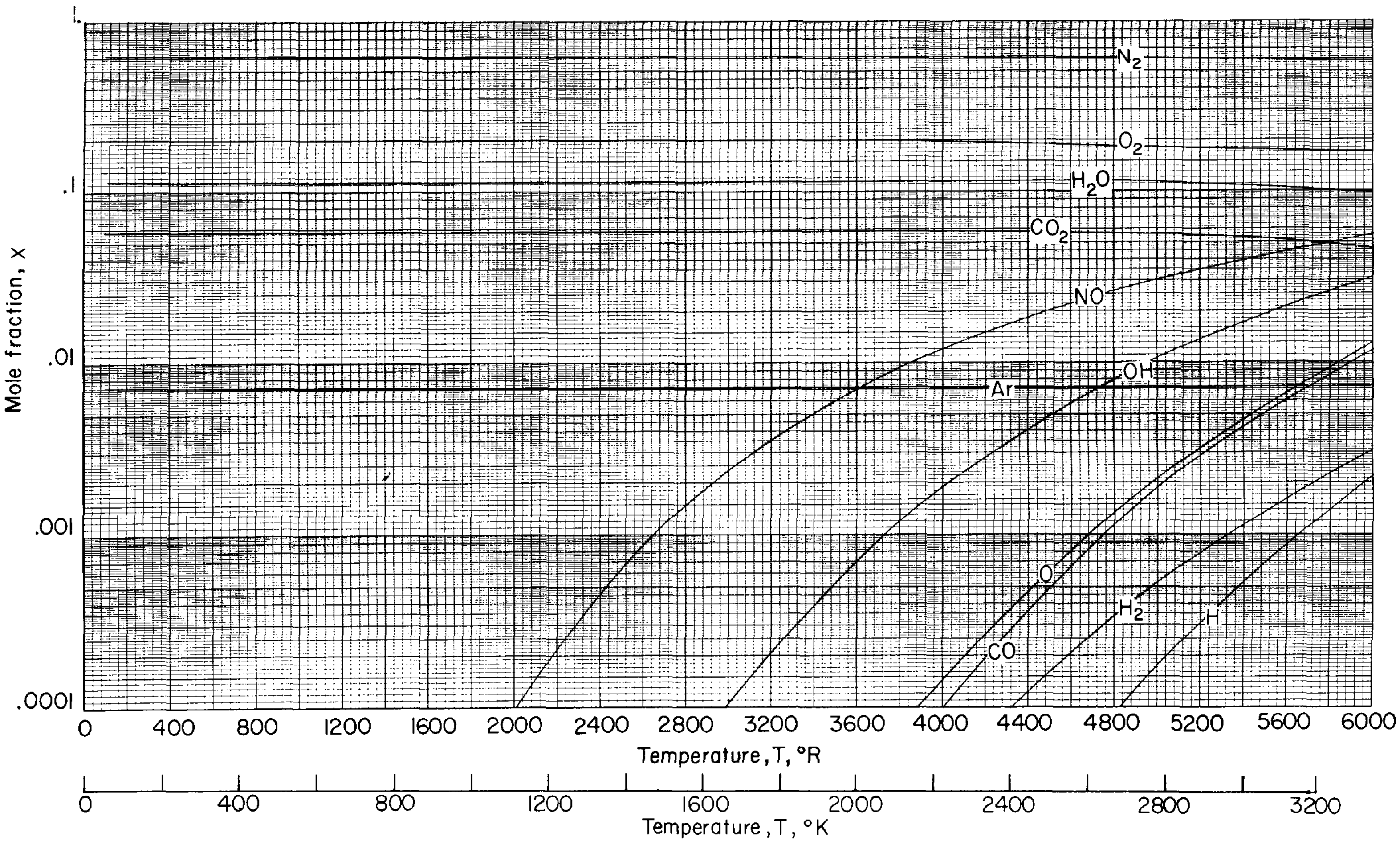
(a) p = 0.01 atmosphere.

Figure 3.- Equilibrium compositions of combustion products for selected pressures and R_{eq} = 0.370.



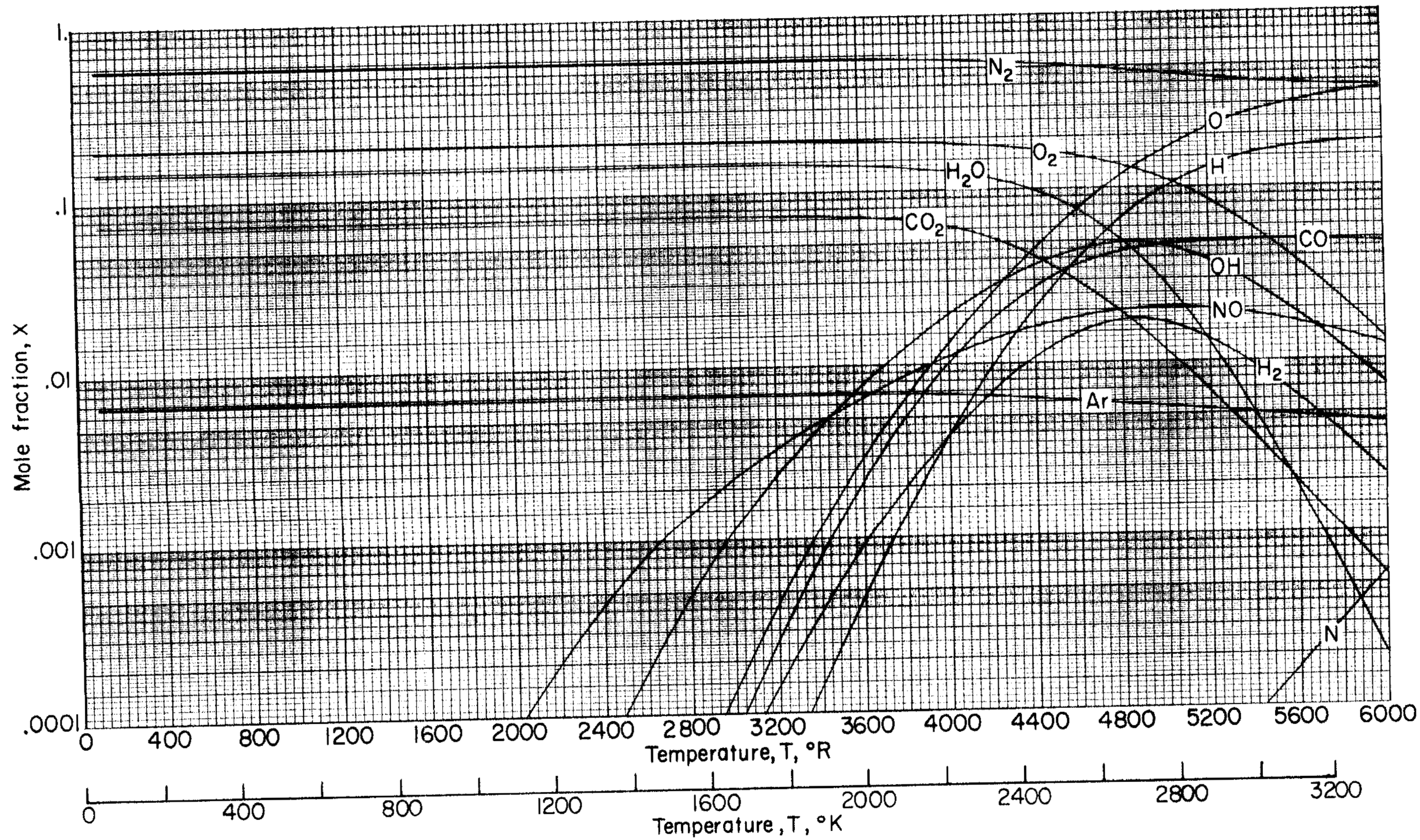
(b) p = 1.0 atmosphere.

Figure 3.- Continued.



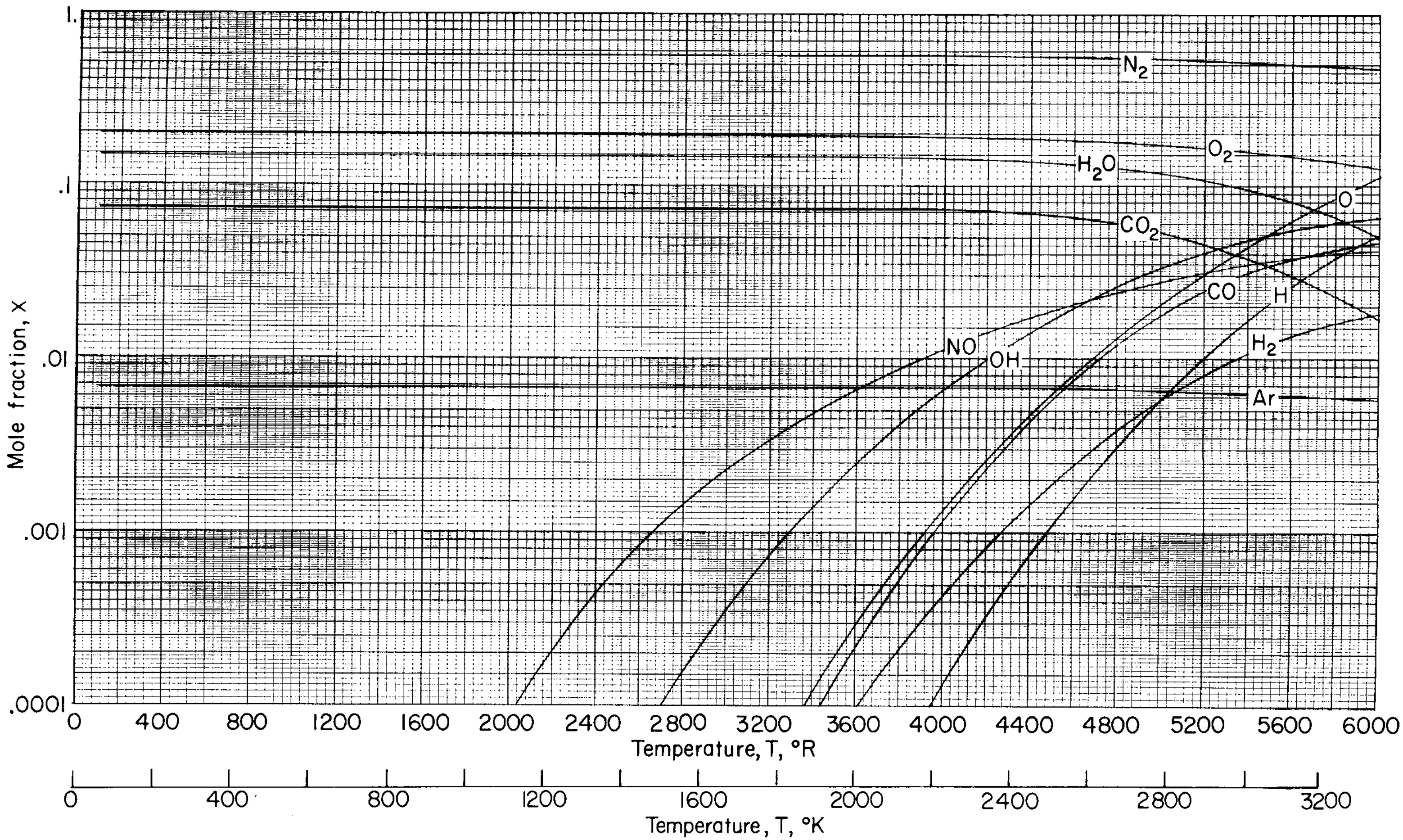
(c) $p = 100$ atmospheres.

Figure 3.- Concluded.



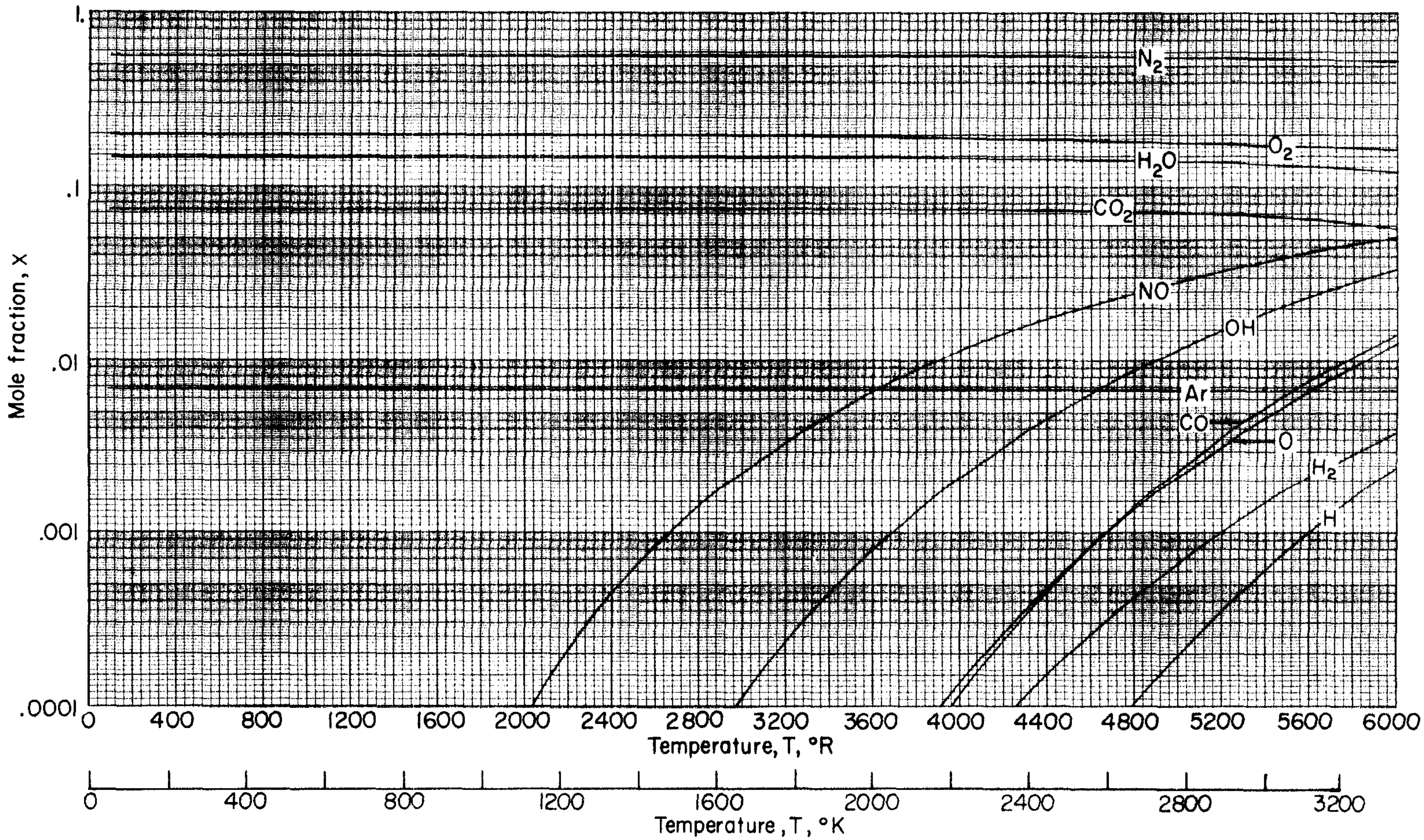
(a) p = 0.01 atmosphere.

Figure 4.- Equilibrium compositions of combustion products for selected pressures and $R_{eq} = 0.425$.



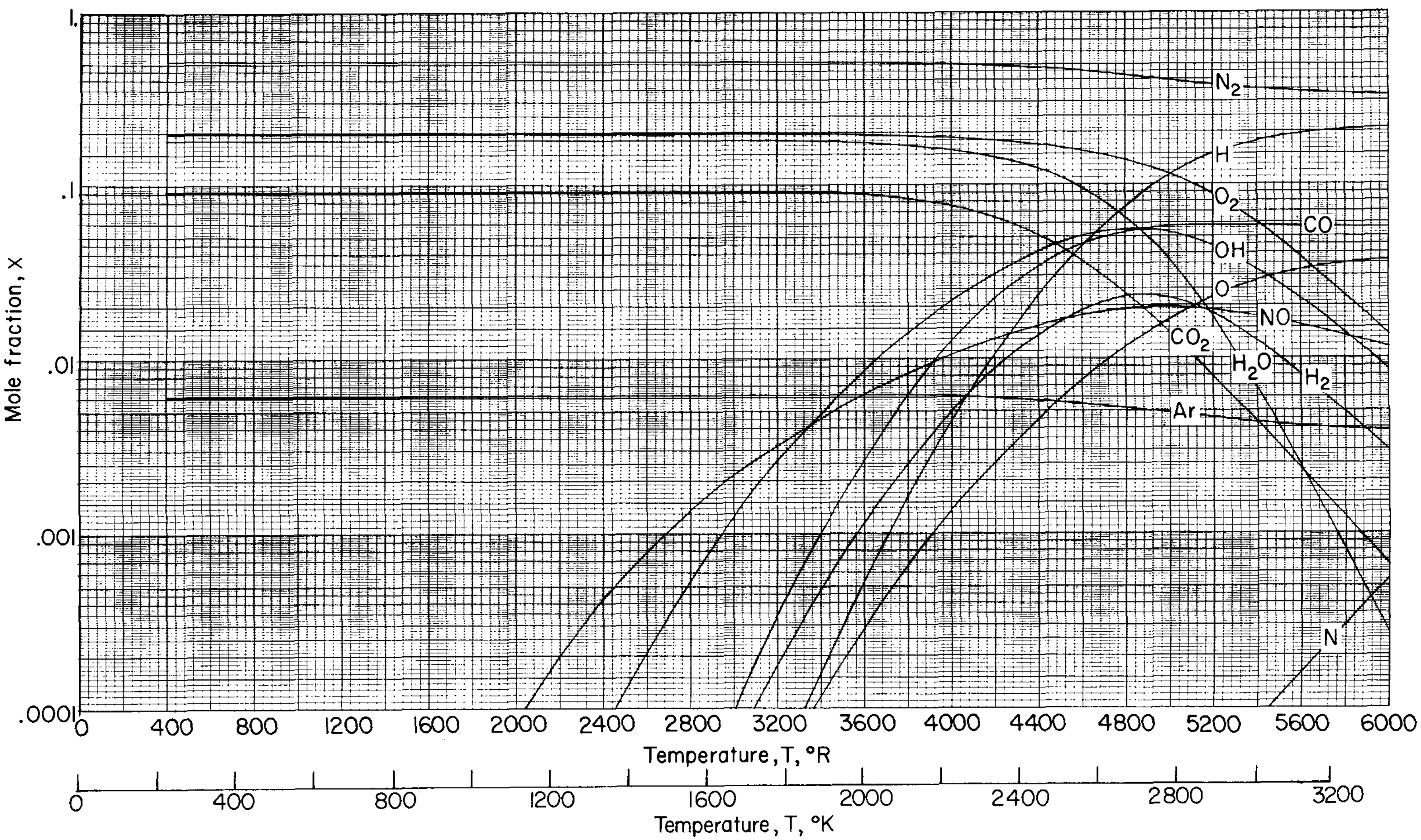
(b) p = 1.0 atmosphere.

Figure 4.- Continued.



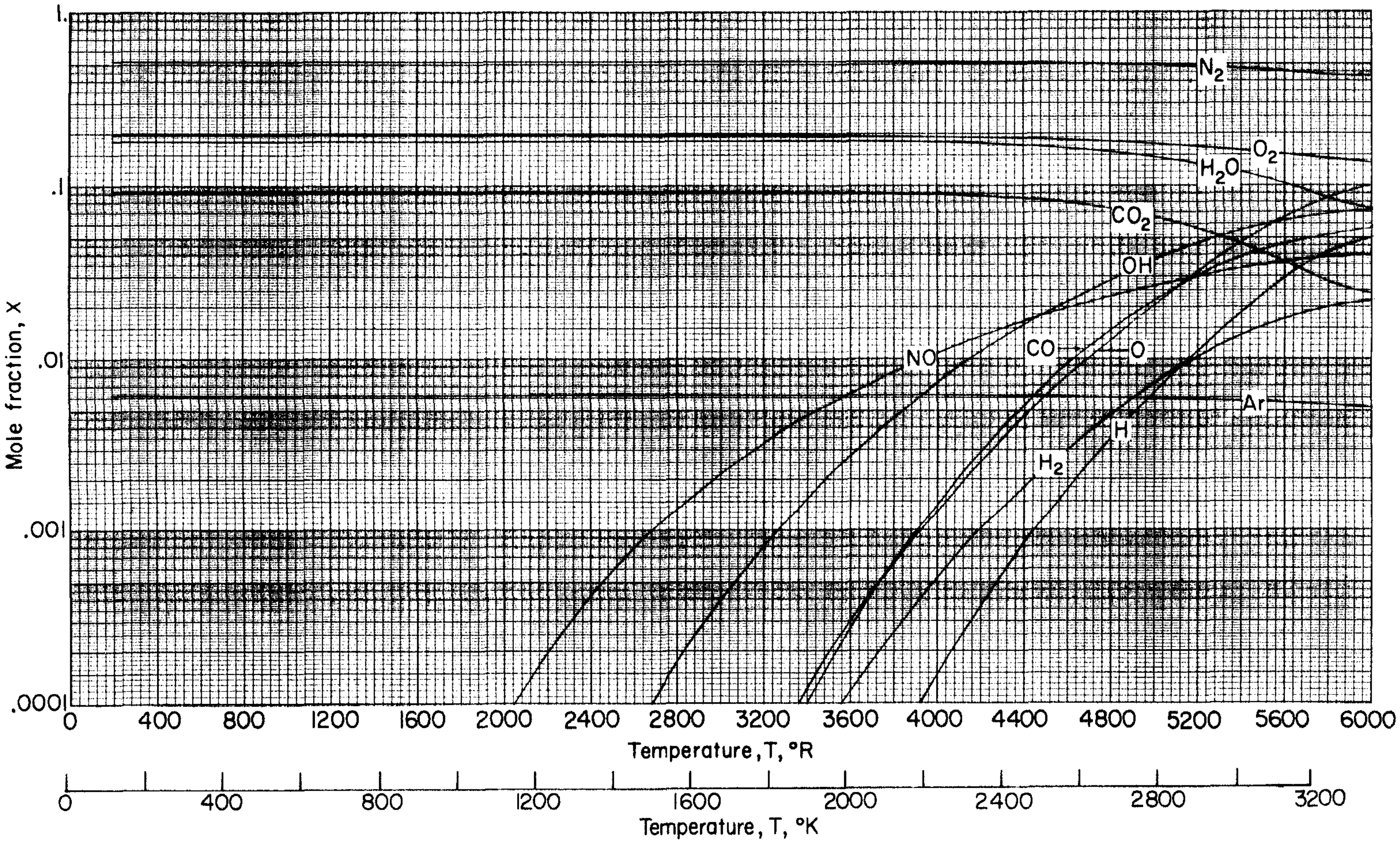
(c) p = 100 atmospheres.

Figure 4.- Concluded.



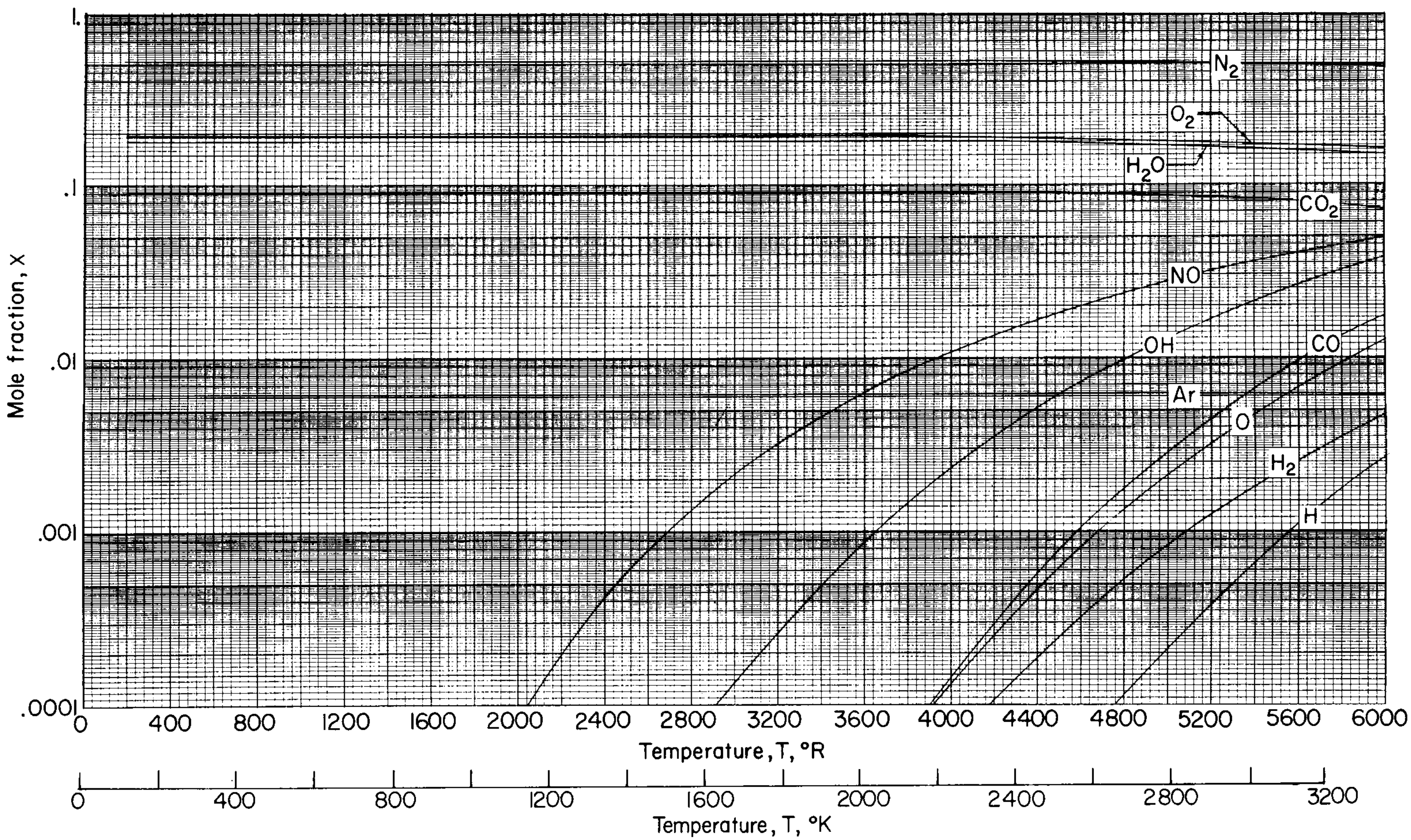
(a) p = 0.01 atmosphere.

Figure 5.- Equilibrium compositions of combustion products for selected pressures and R_{eq} = 0.480.



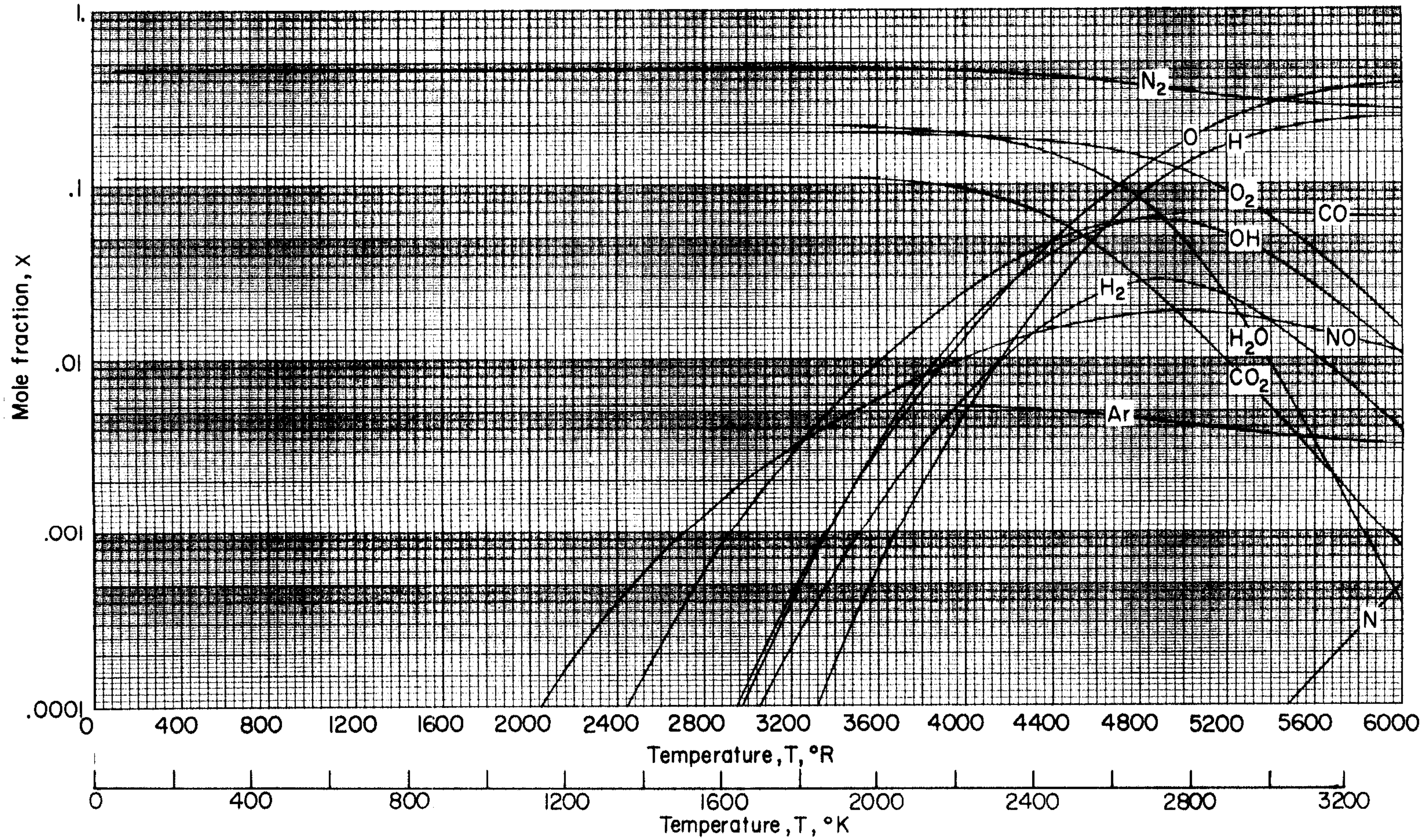
(b) p = 1.0 atmosphere.

Figure 5.- Continued.



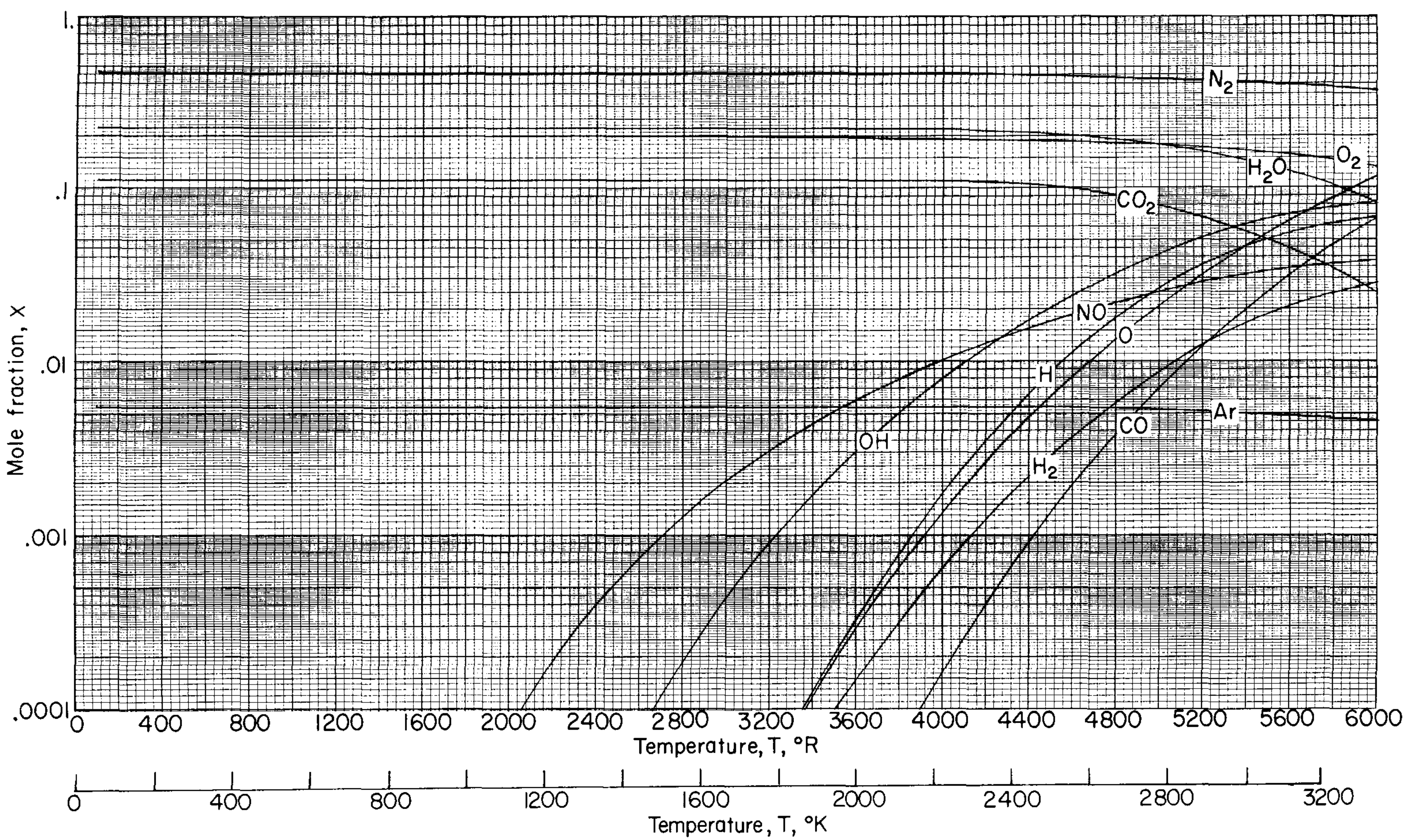
(c) p = 100 atmospheres.

Figure 5.- Concluded.



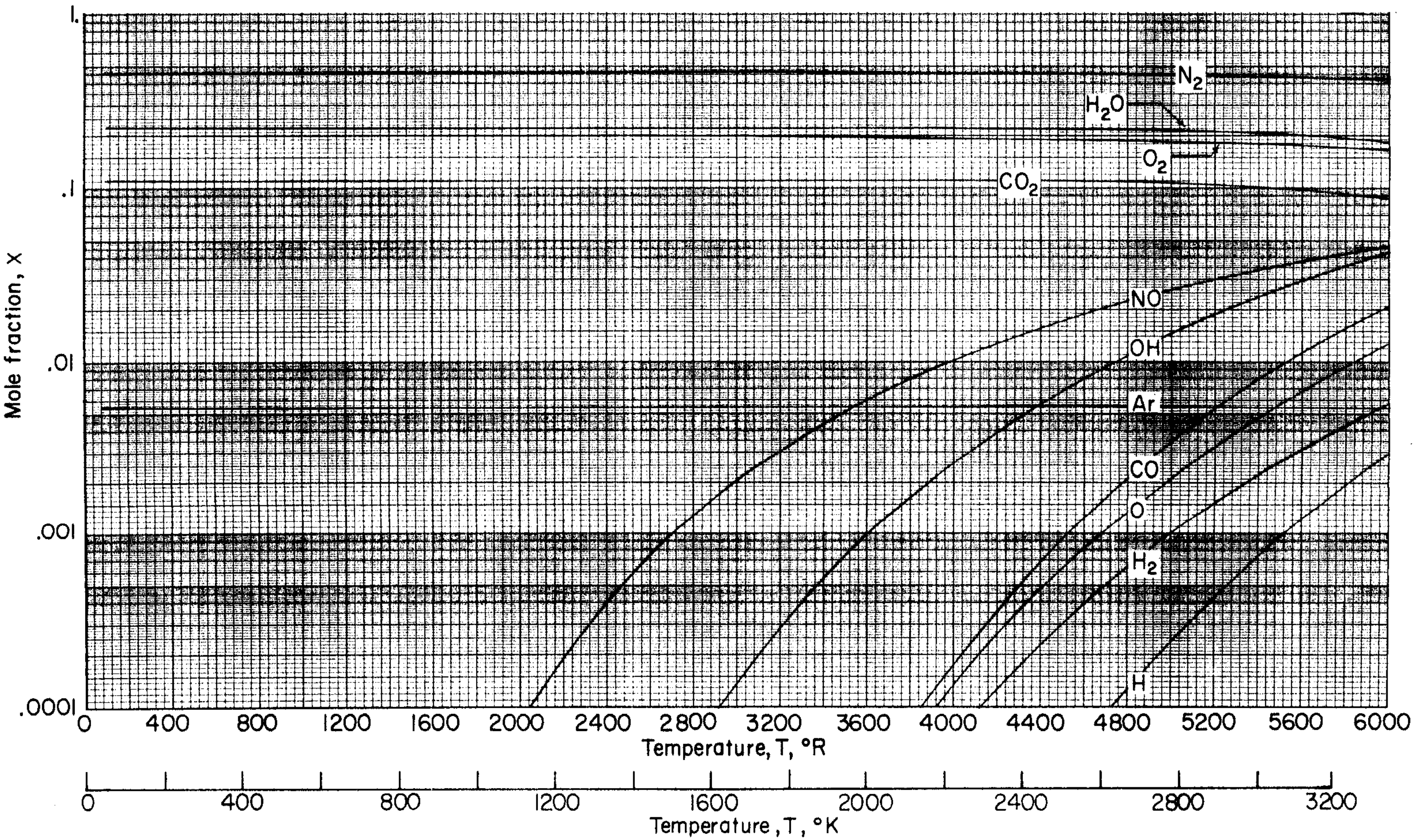
(a) p = 0.01 atmosphere.

Figure 6.- Equilibrium compositions of combustion products for selected pressures and R_{eq} = 0.525.



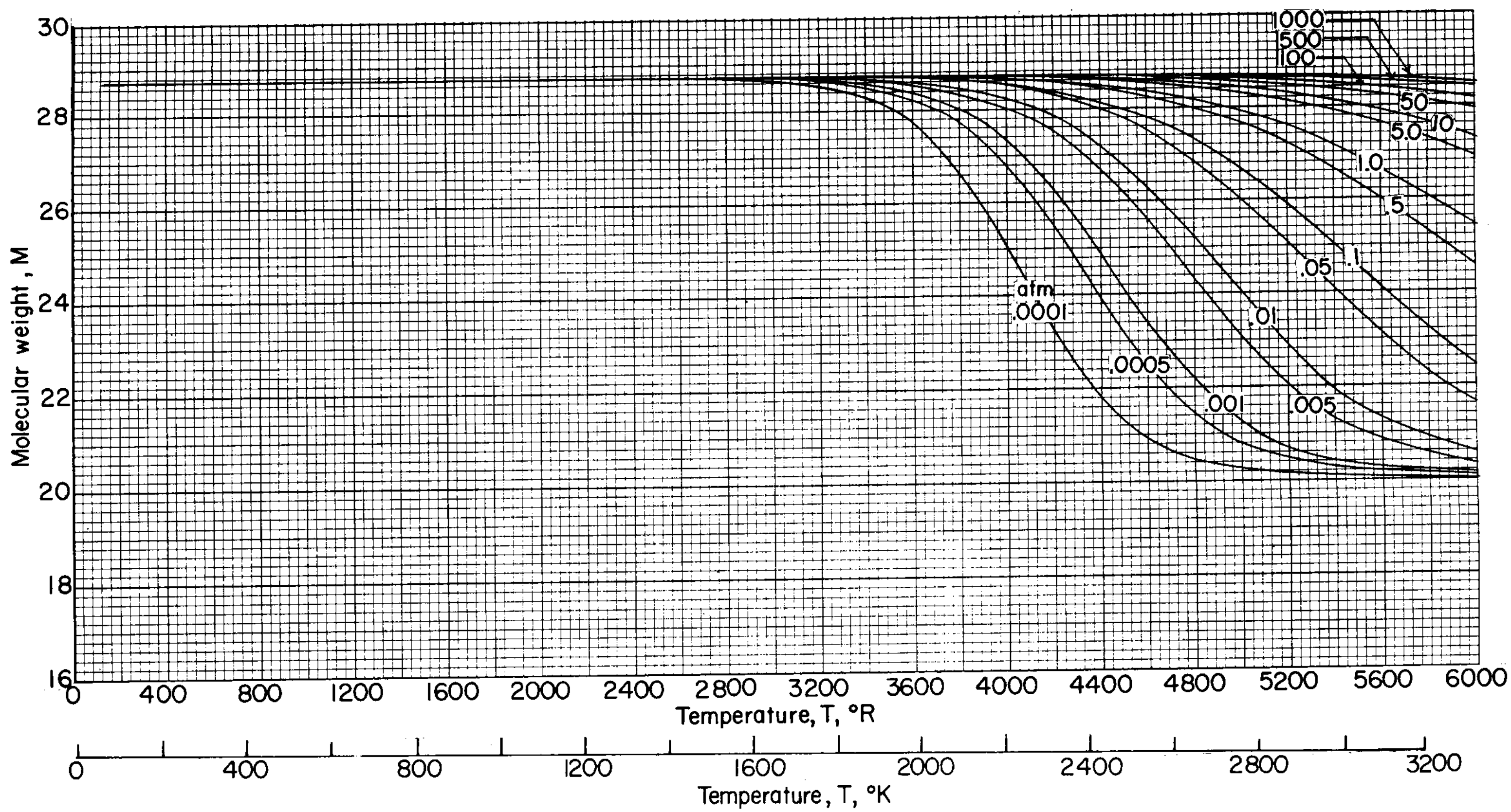
(b) p = 1.0 atmosphere.

Figure 6.- Continued.



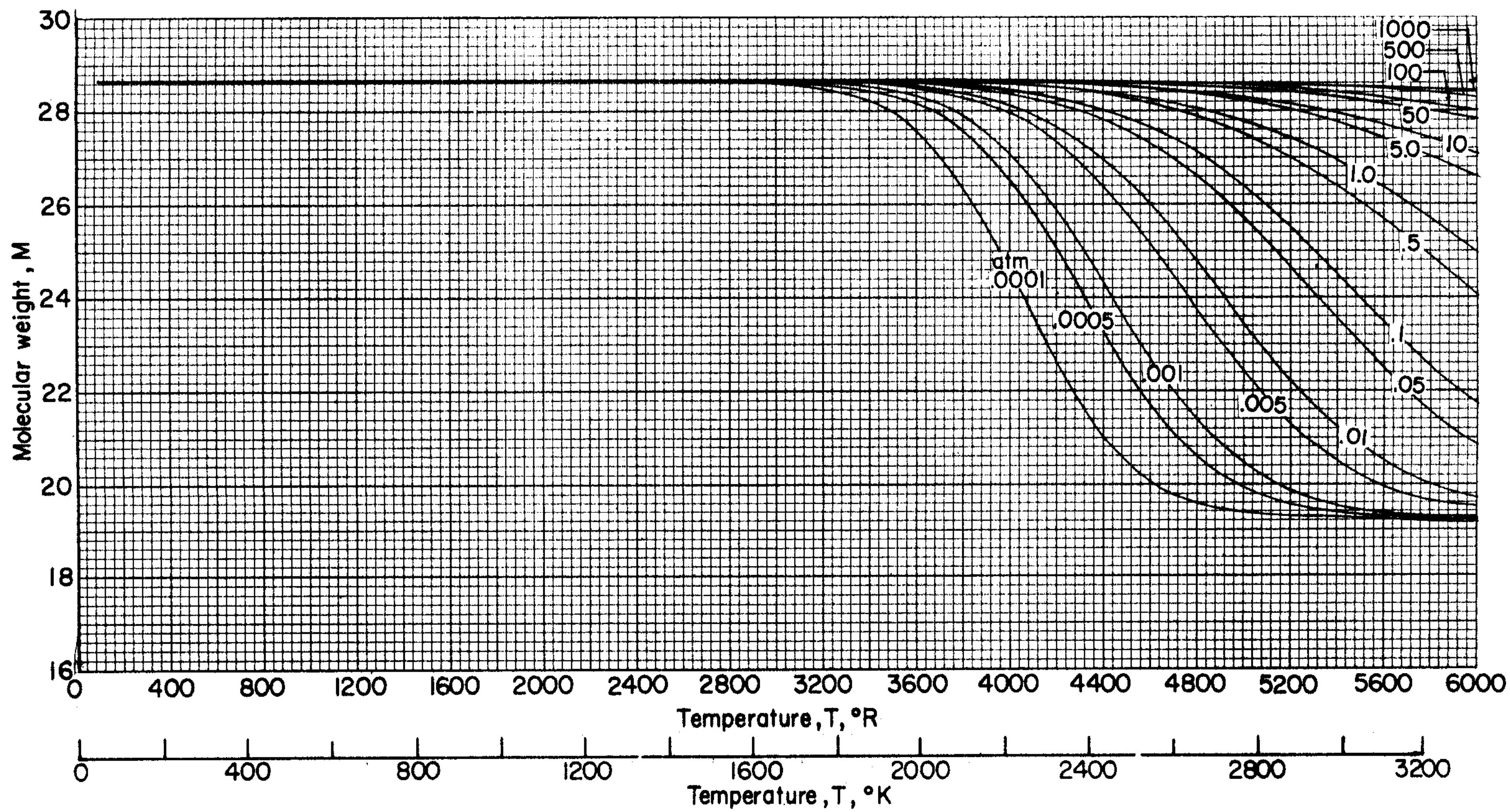
(c) p = 100 atmospheres.

Figure 6.- Concluded.



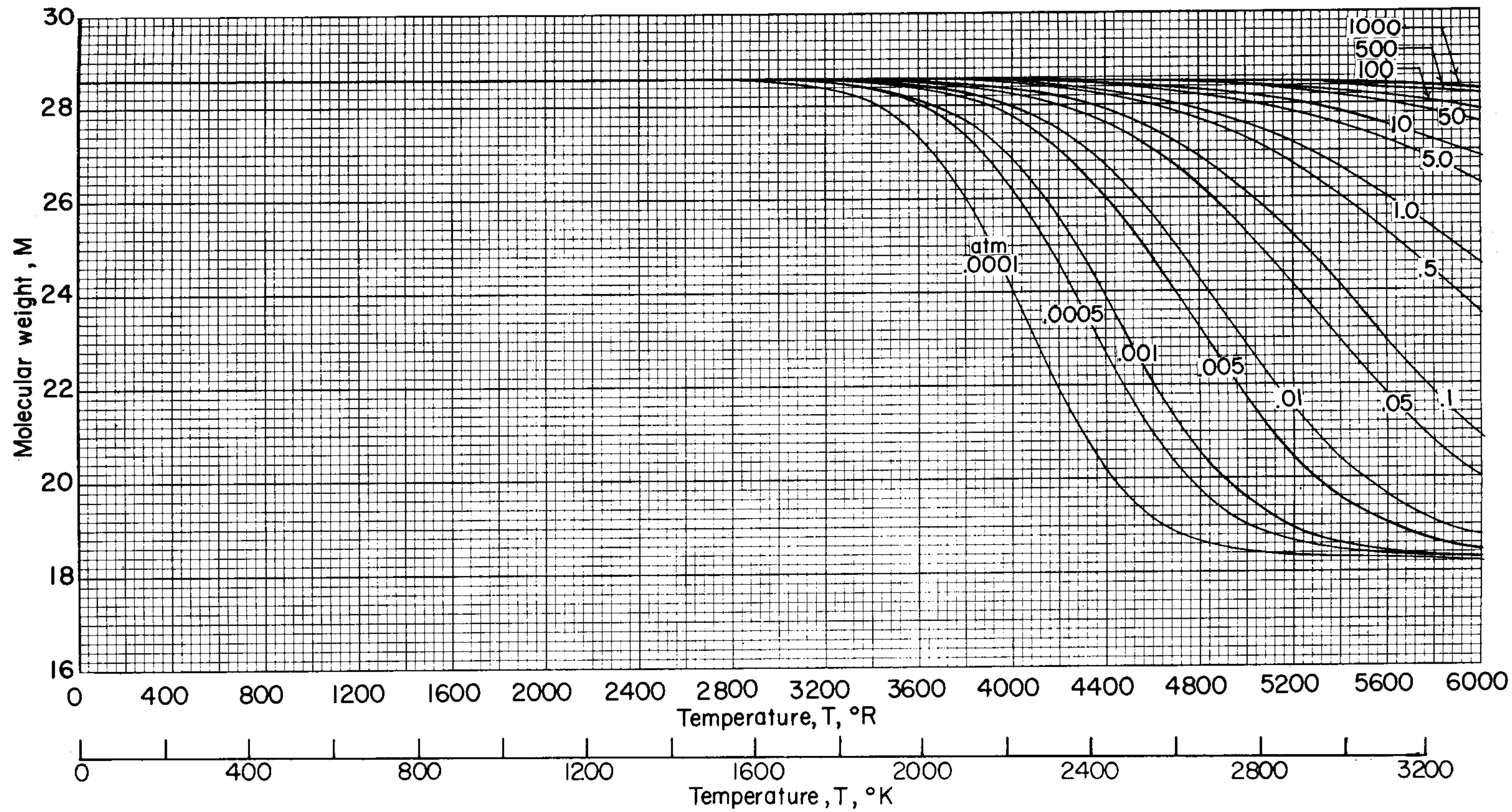
(a) $R_{eq} = 0.315$.

Figure 7.- Variation of molecular weight with temperature for selected pressures and equivalence ratios.



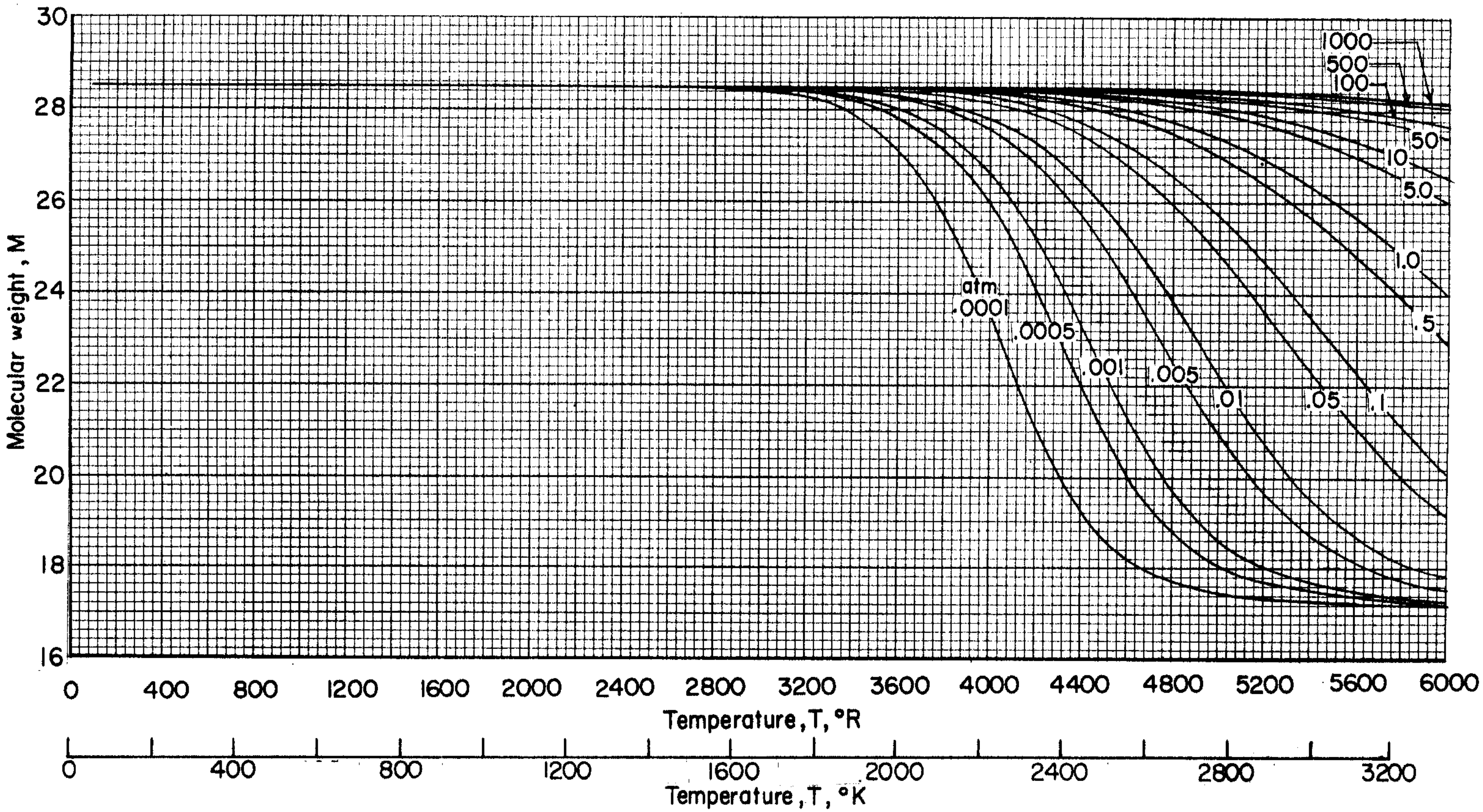
(b) $R_{eq} = 0.370$.

Figure 7.- Continued.



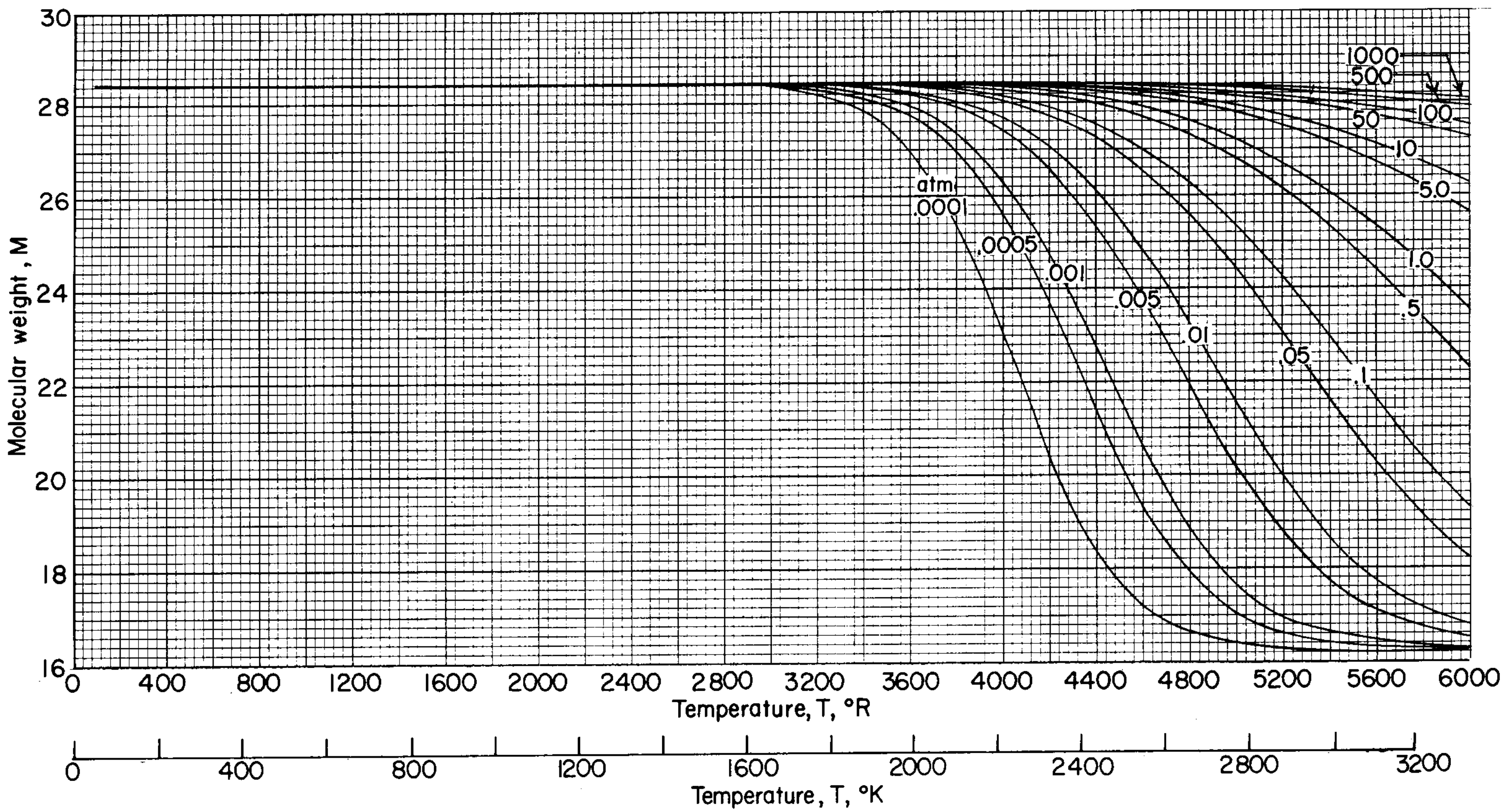
(c) $R_{eq} = 0.425$.

Figure 7.- Continued.



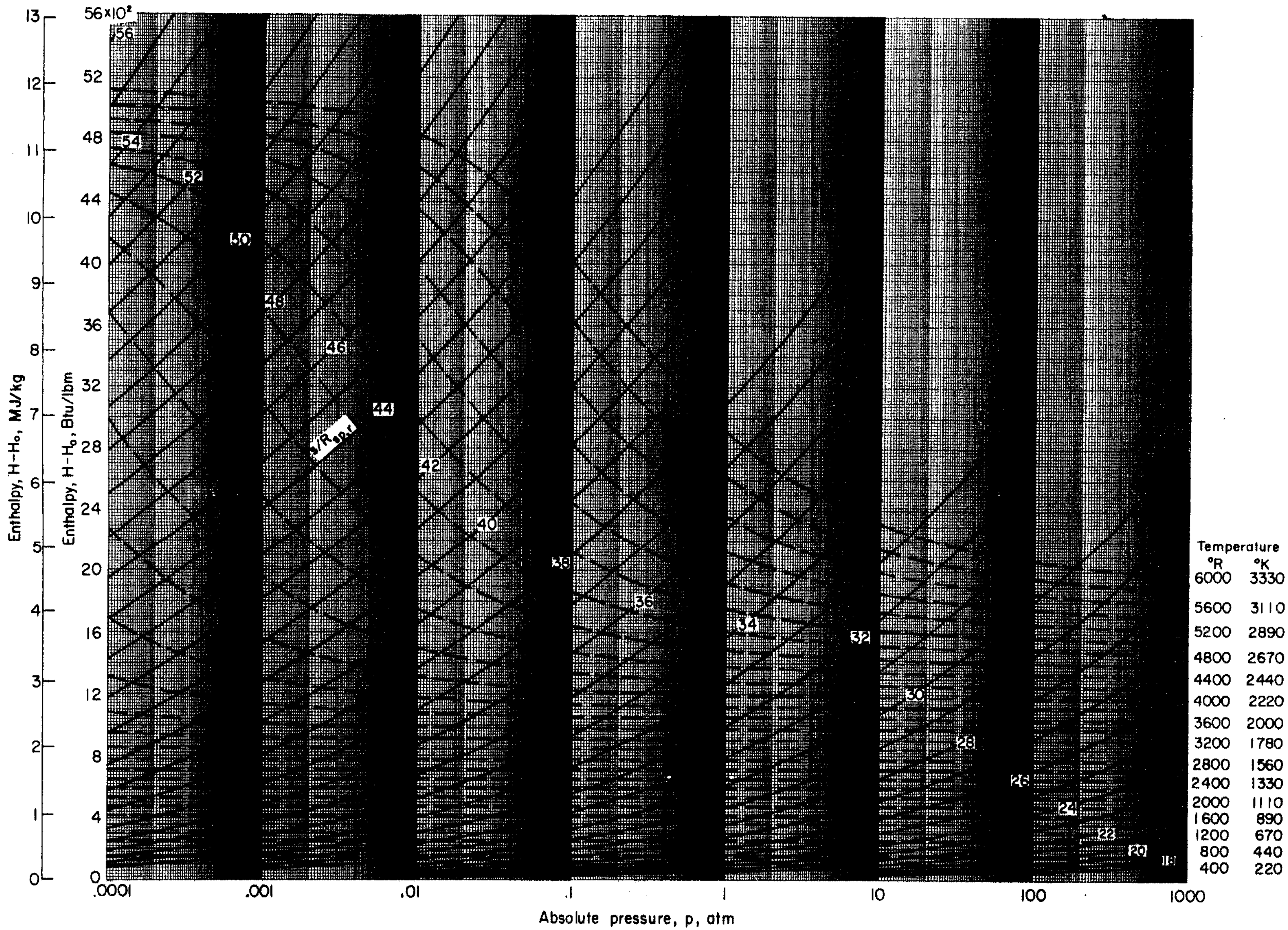
(d) $R_{eq} = 0.480$.

Figure 7.- Continued.



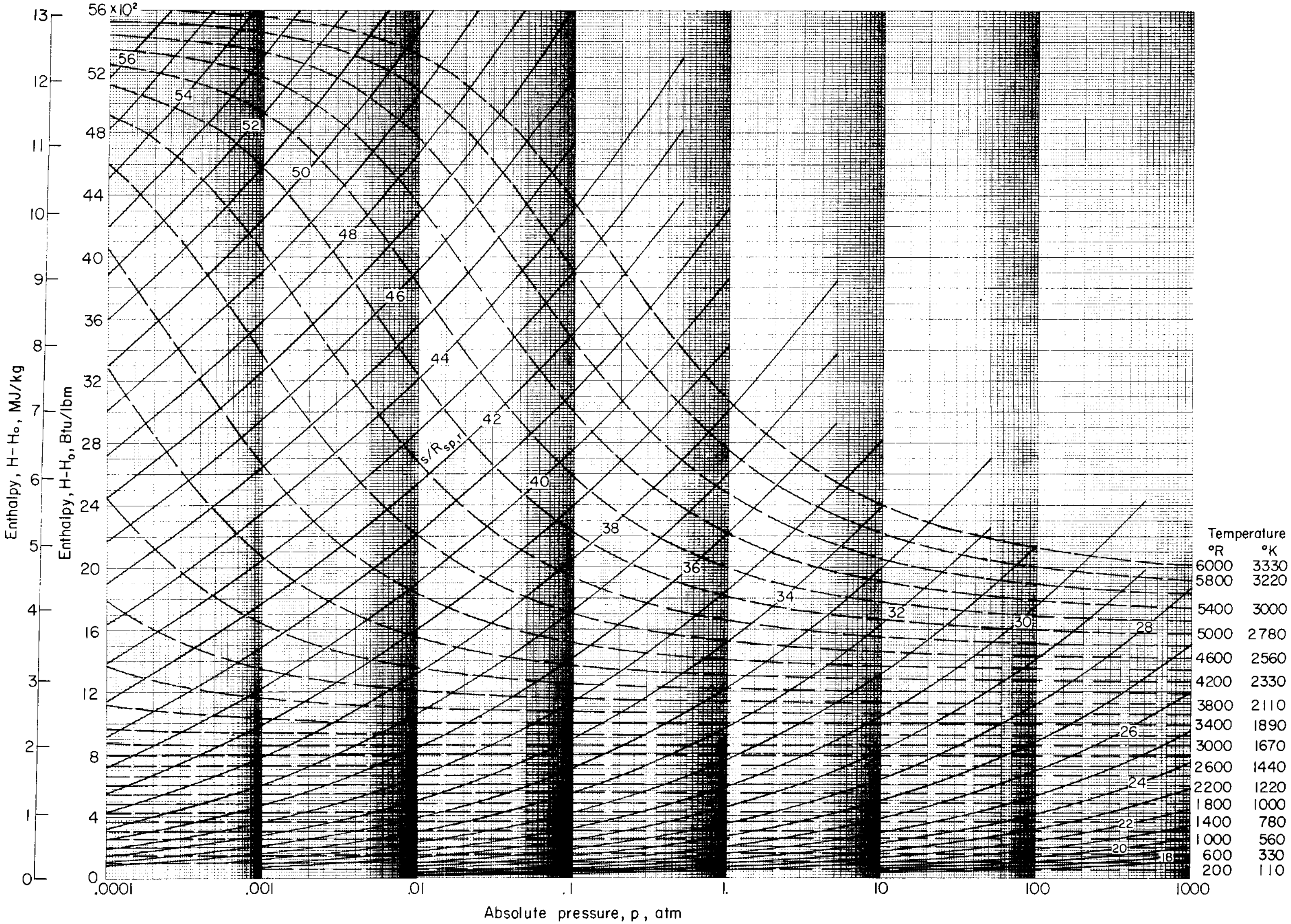
(e) $R_{eq} = 0.525$.

Figure 7.- Concluded.



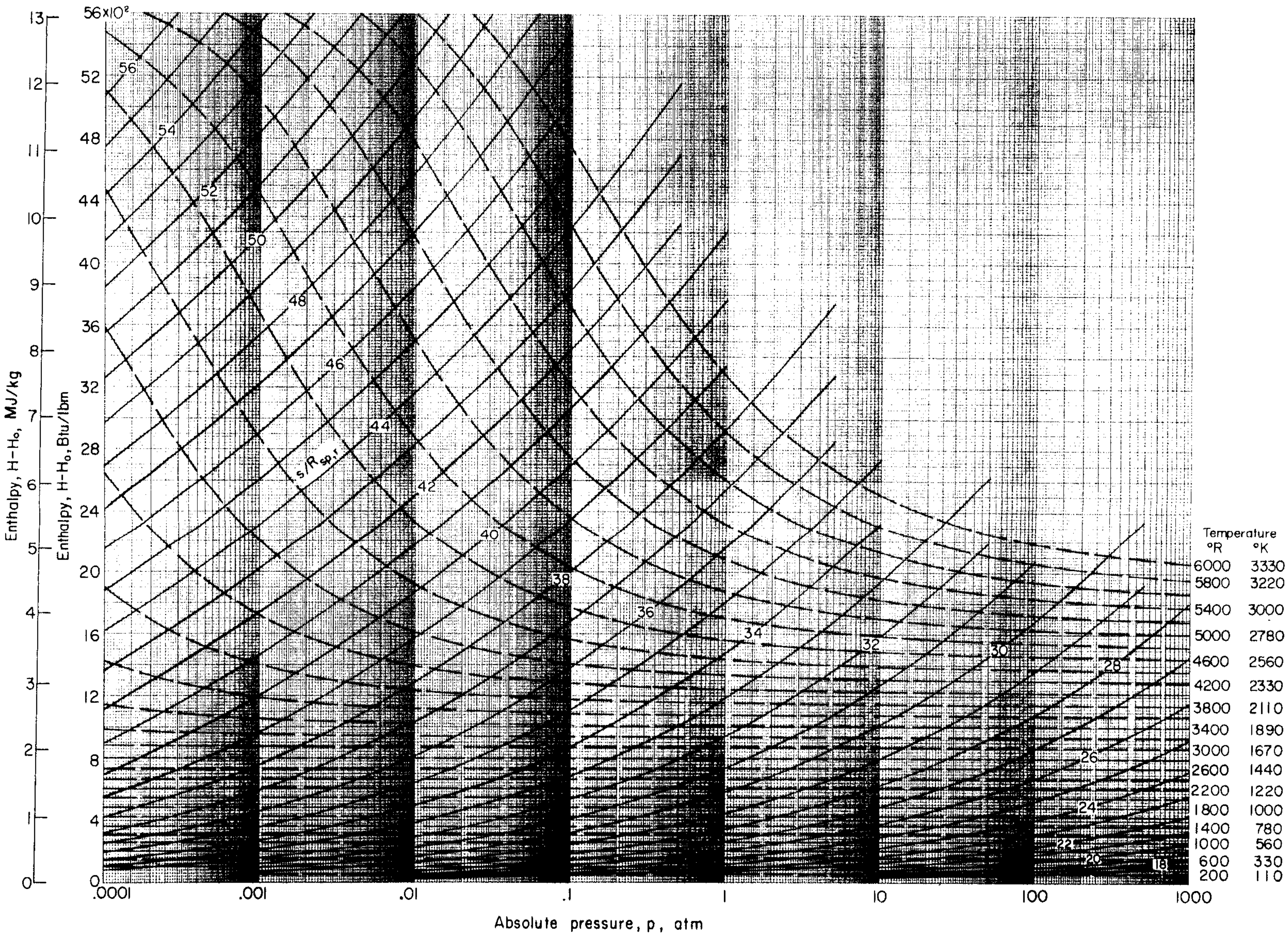
(a) $R_{eq} = 0.315$; $R_{sp,r} = 0.069138$ Btu/lbm-°R (289.466 J/kg-°K).

Figure 8.- Thermodynamic chart for combustion products.



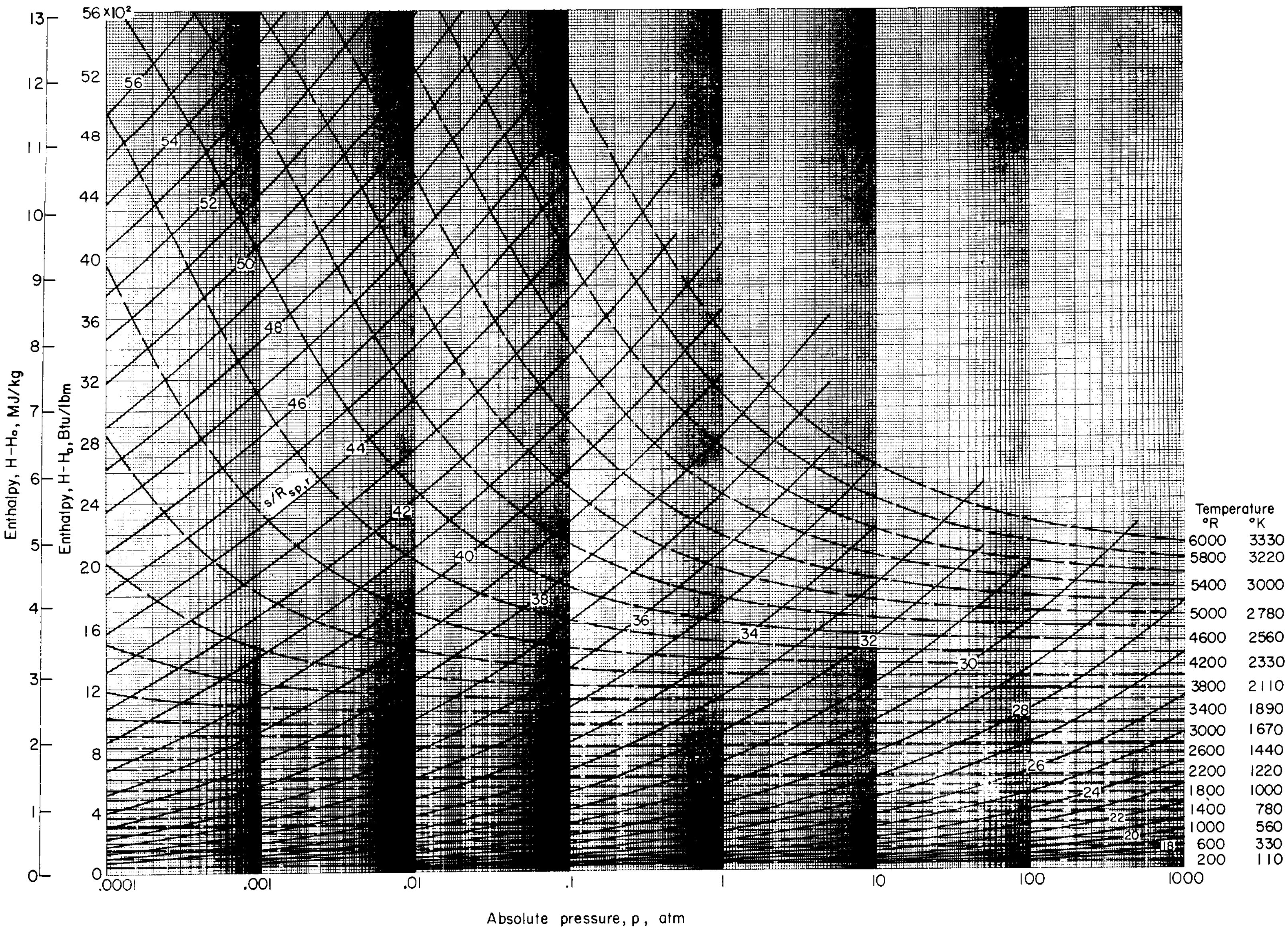
(b) $R_{eq} = 0.370$; $R_{sp,r} = 0.069271$ Btu/lbm-°R (290.022 J/kg-°K).

Figure 8.- Continued.



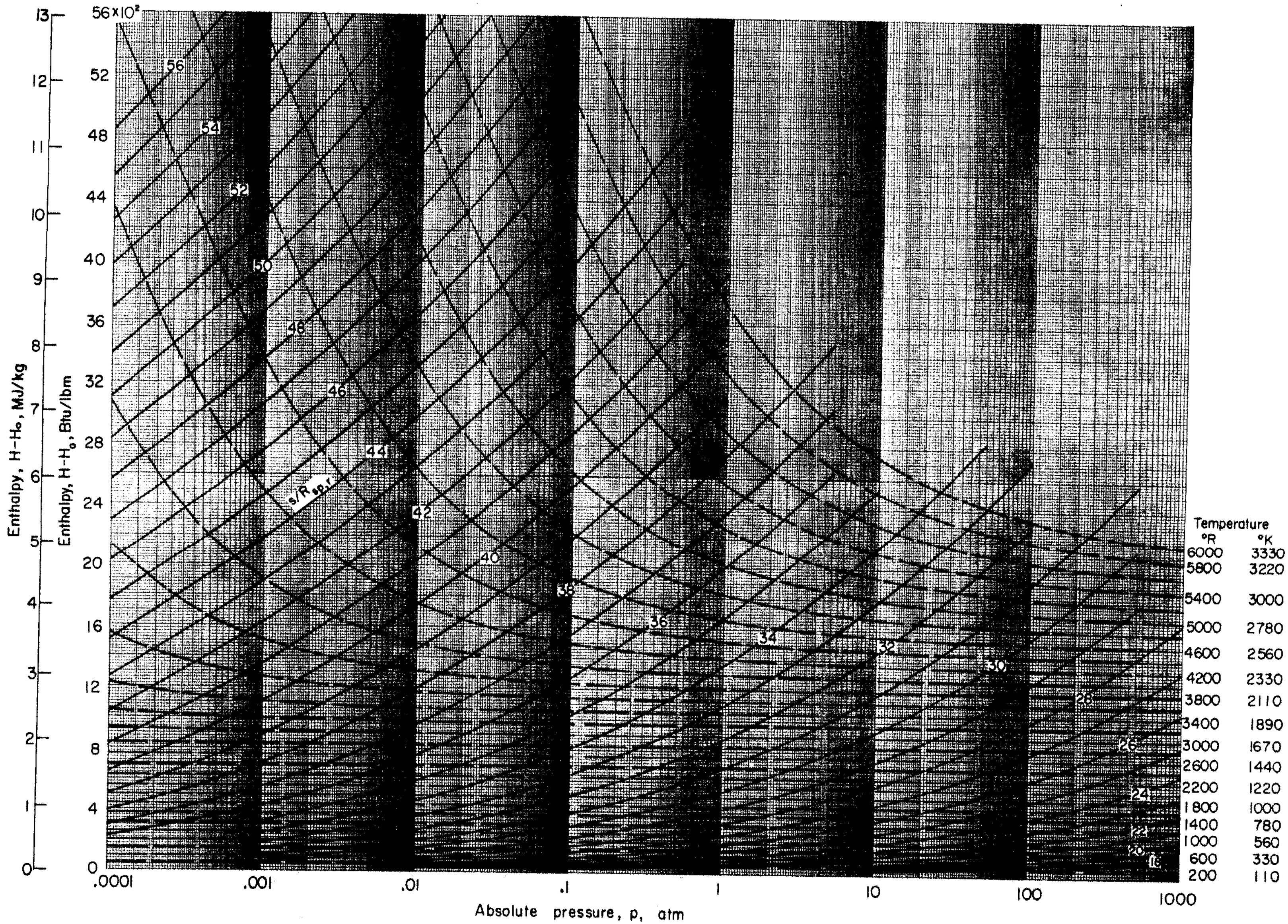
(c) $R_{eq} = 0.425$; $R_{sp,r} = 0.069509$ Btu/lbm-°R (291.018 J/kg-°K).

Figure 8.- Continued.



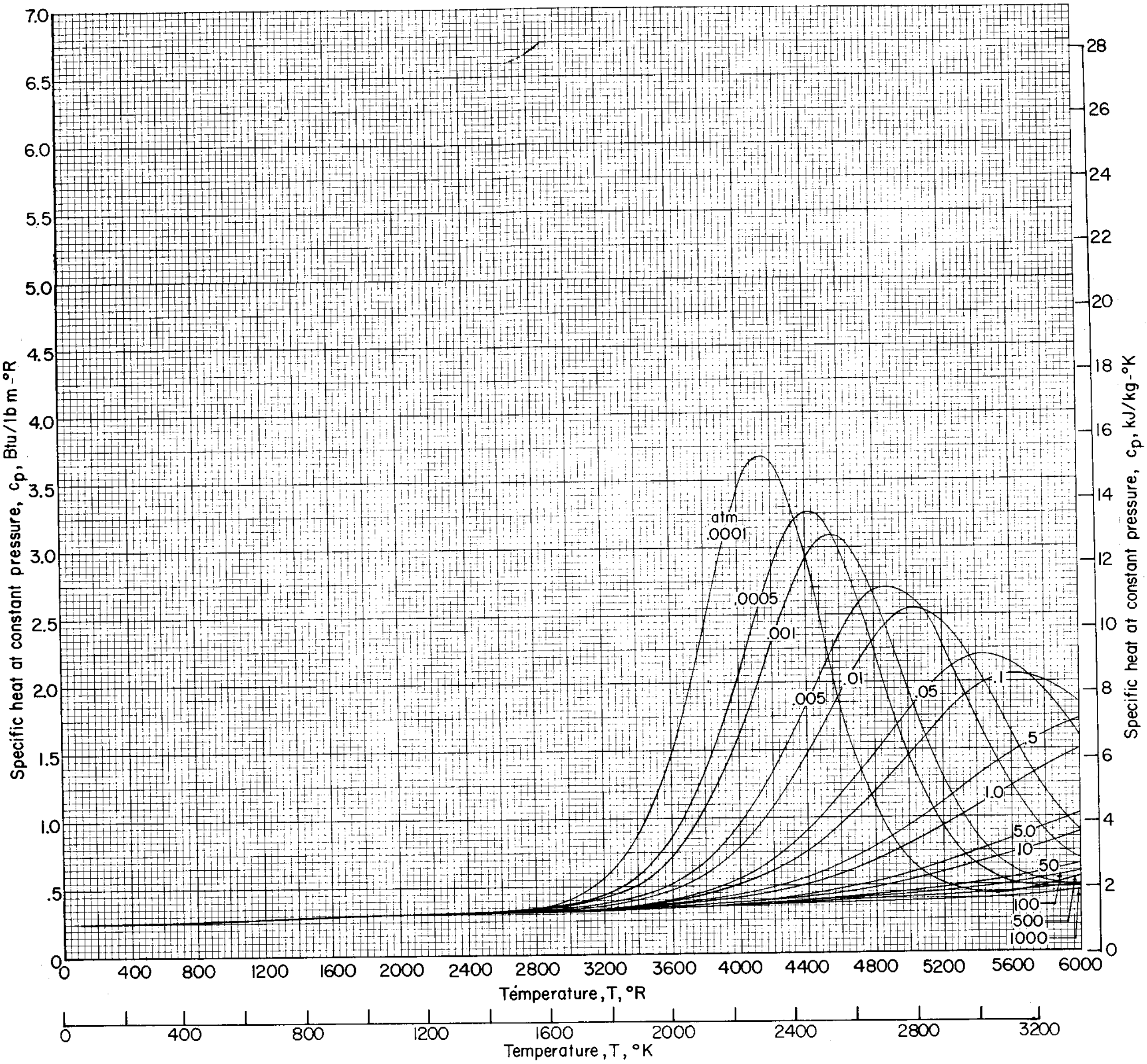
(d) $R_{eq} = 0.480$; $R_{sp,r} = 0.069644$ Btu/lbm-°R (291.335 J/kg-°K).

Figure 8.- Continued.



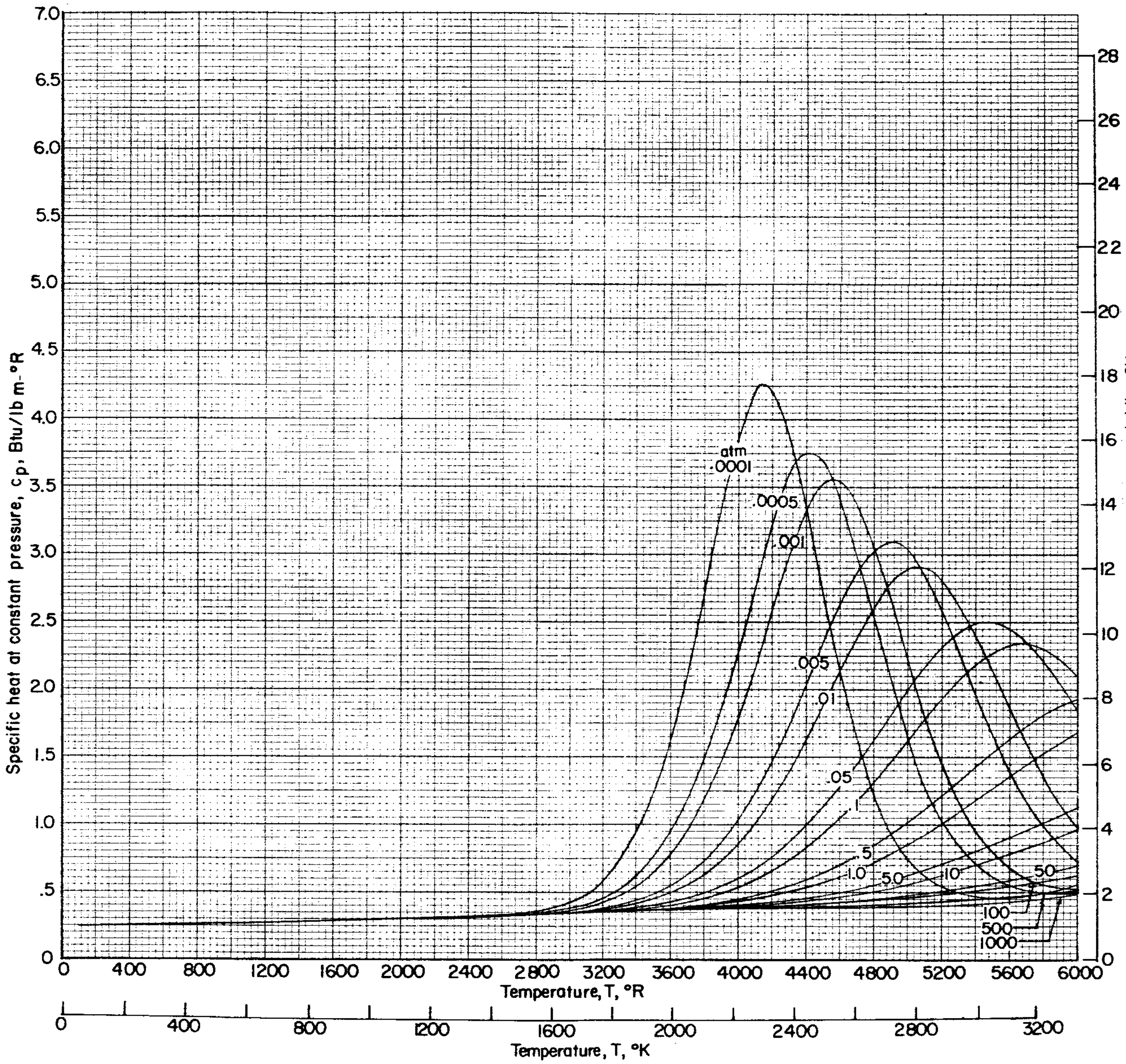
(e) $R_{eq} = 0.525$; $R_{sp,r} = 0.069828$ Btu/lbm-°R (292.357 J/kg-°K).

Figure 8.- Concluded.



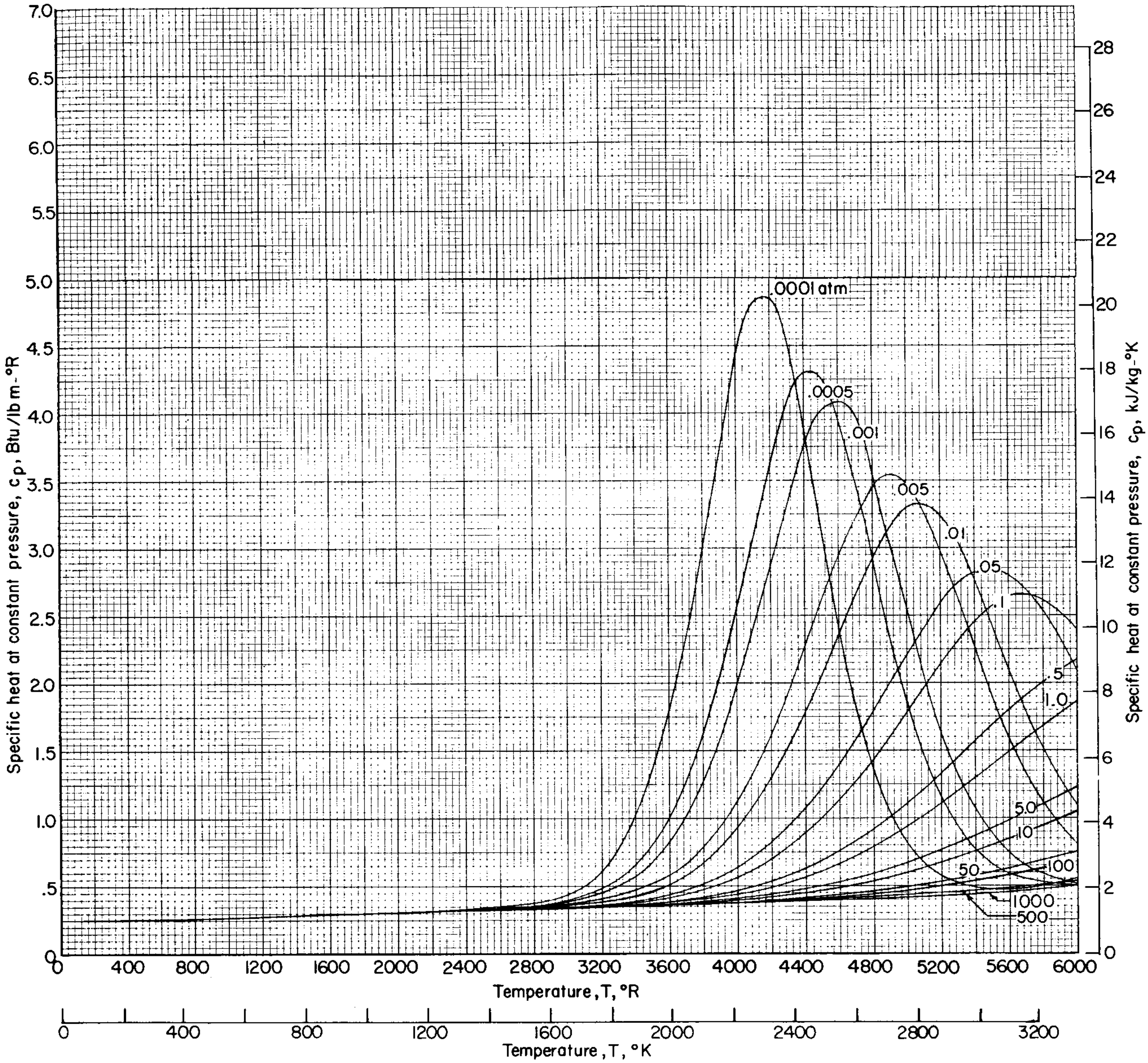
(a) R_{eq} = 0.315.

Figure 9.- Variation of specific heat with temperature for selected pressures and equivalence ratios.



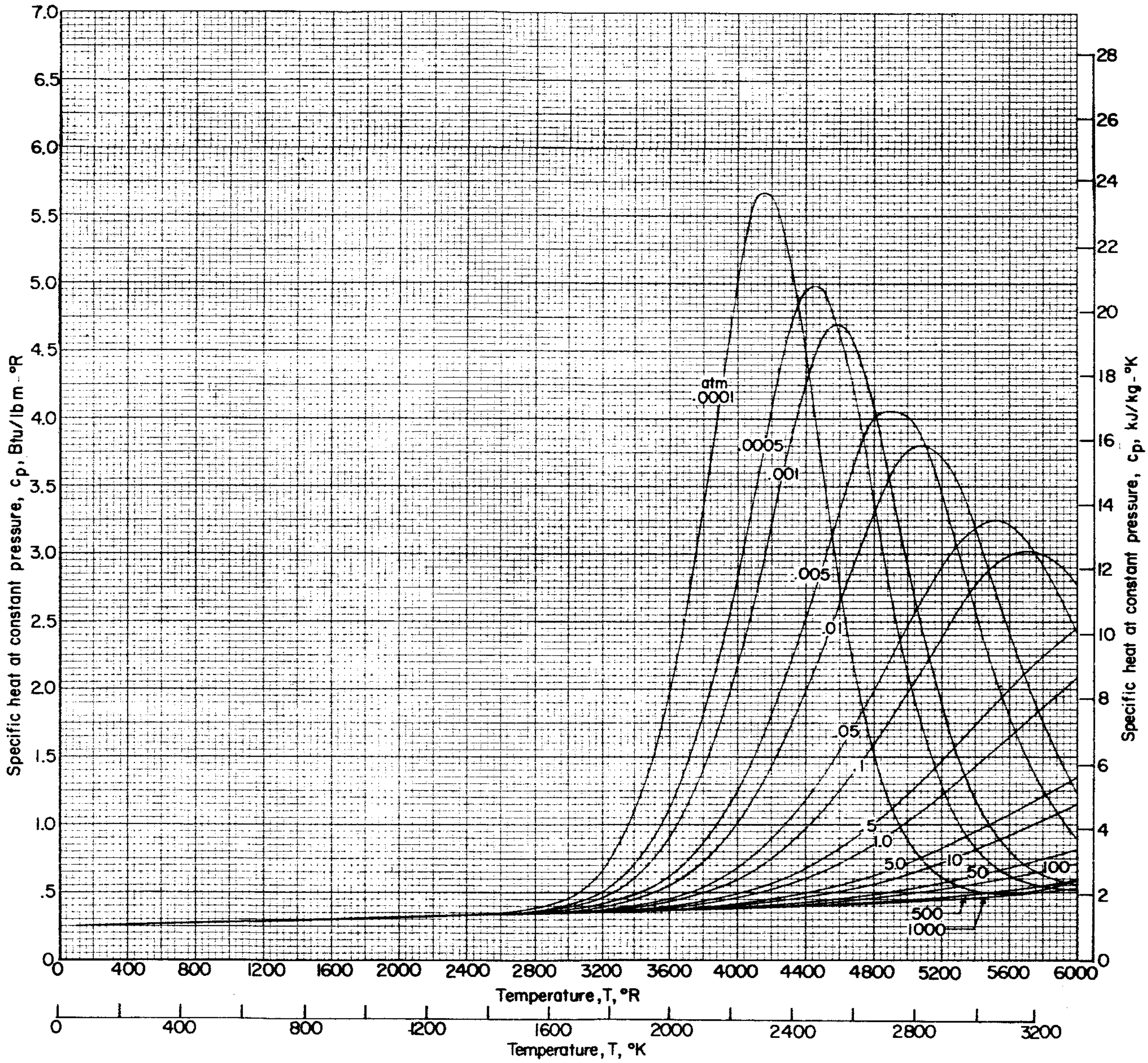
(b) $R_{eq} = 0.370$.

Figure 9.- Continued.



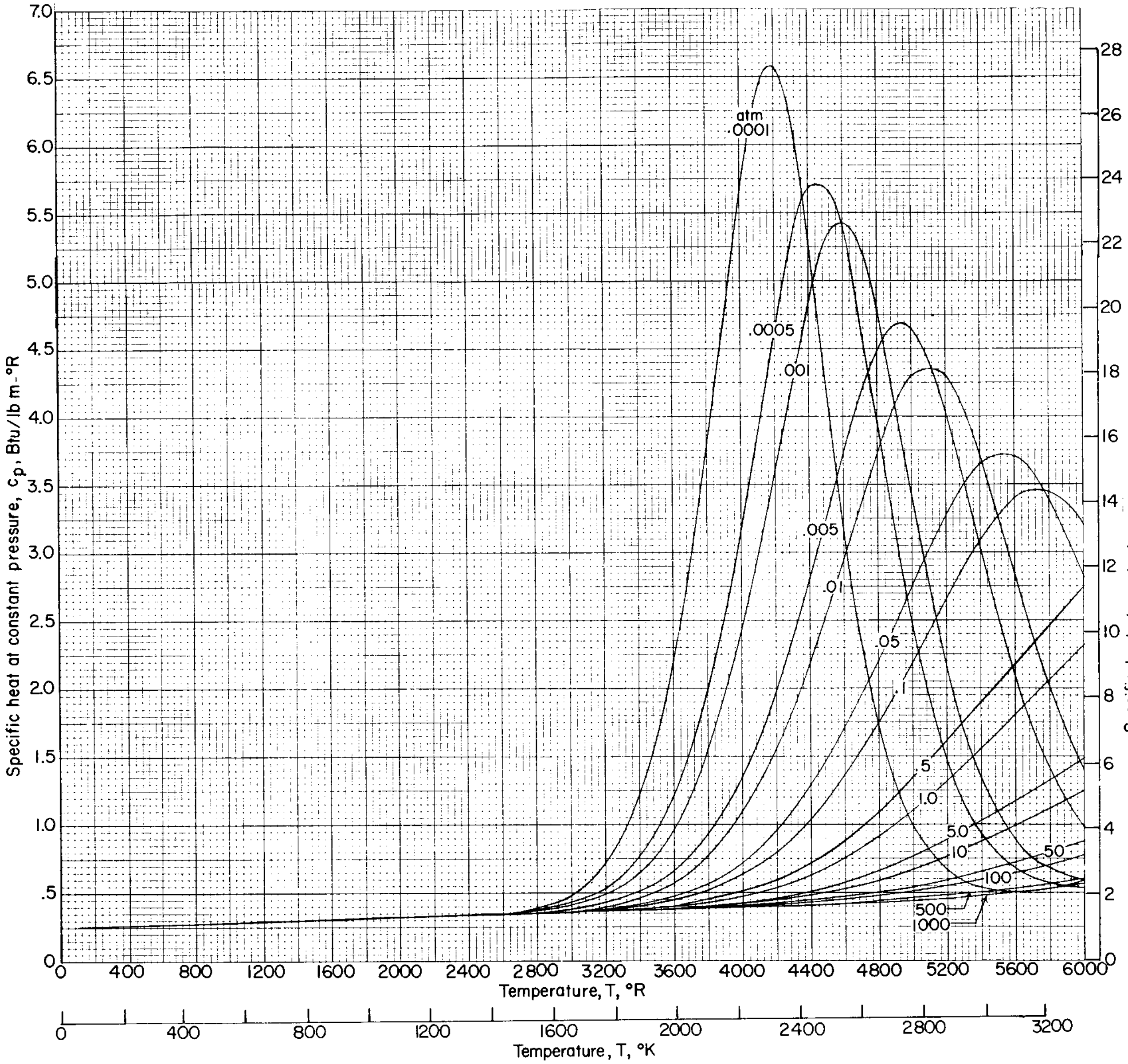
(c) $R_{eq} = 0.425$.

Figure 9.- Continued.



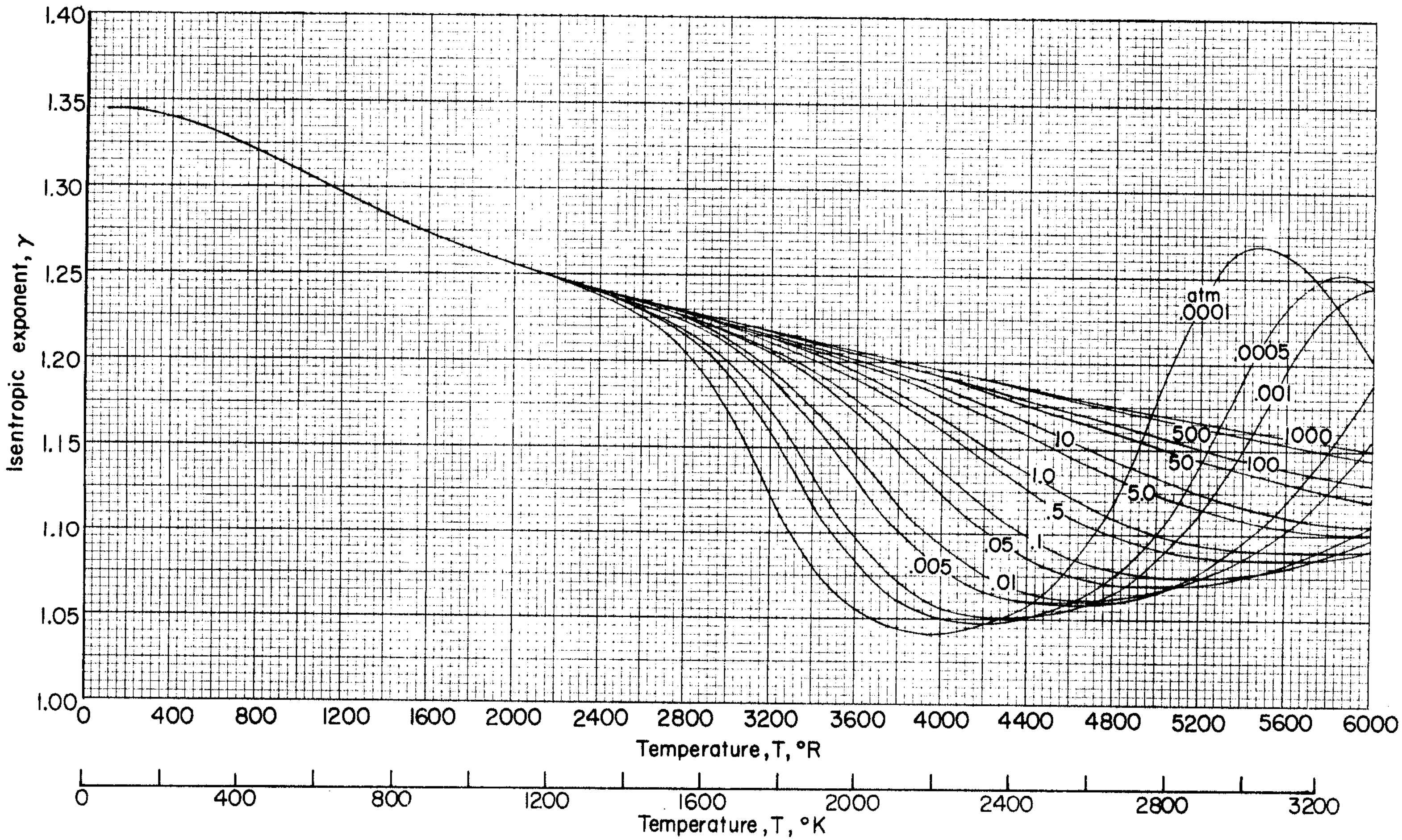
(d) $R_{eq} = 0.480$.

Figure 9.- Continued.



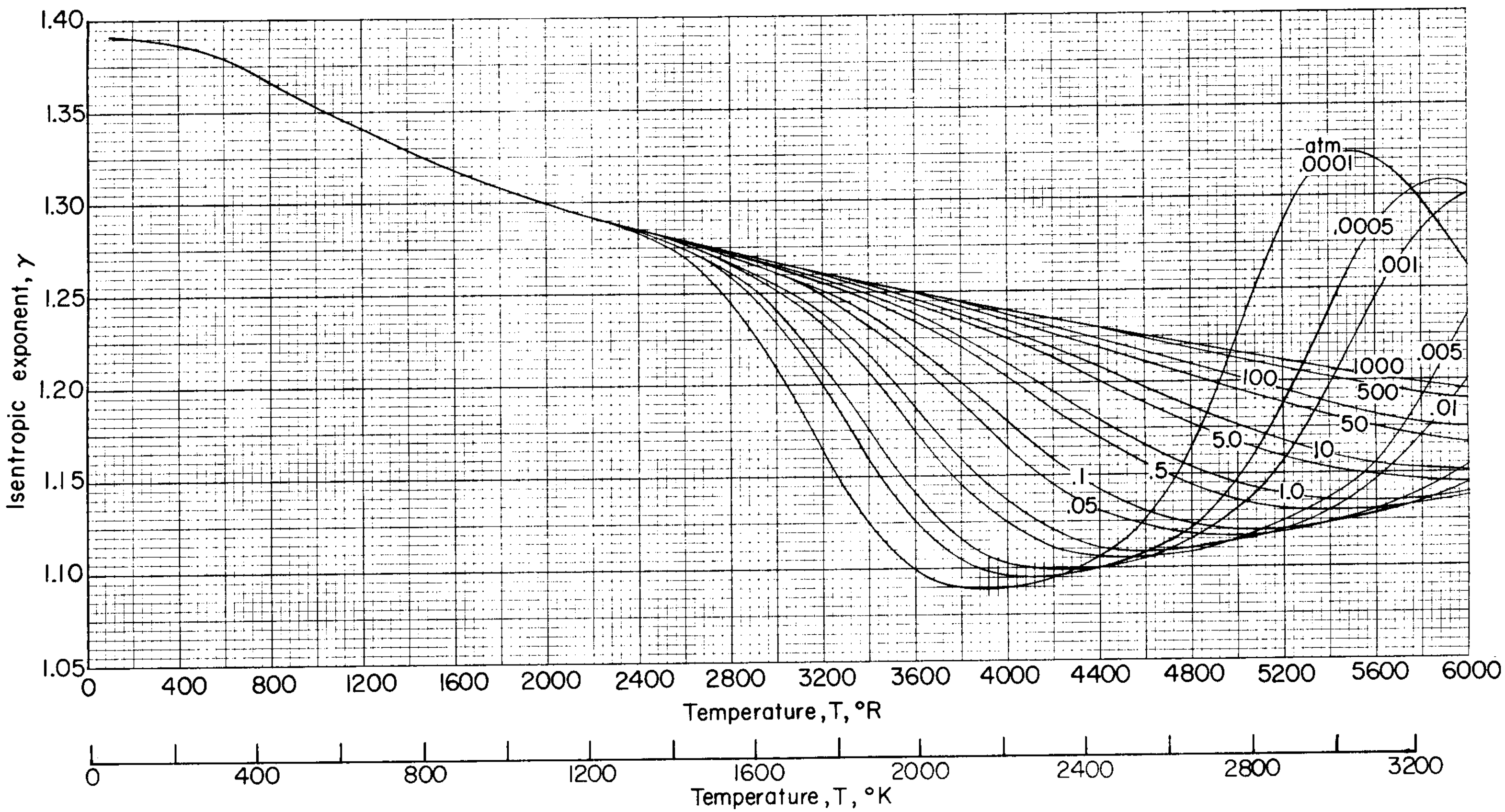
(e) $R_{eq} = 0.525$.

Figure 9.- Concluded.



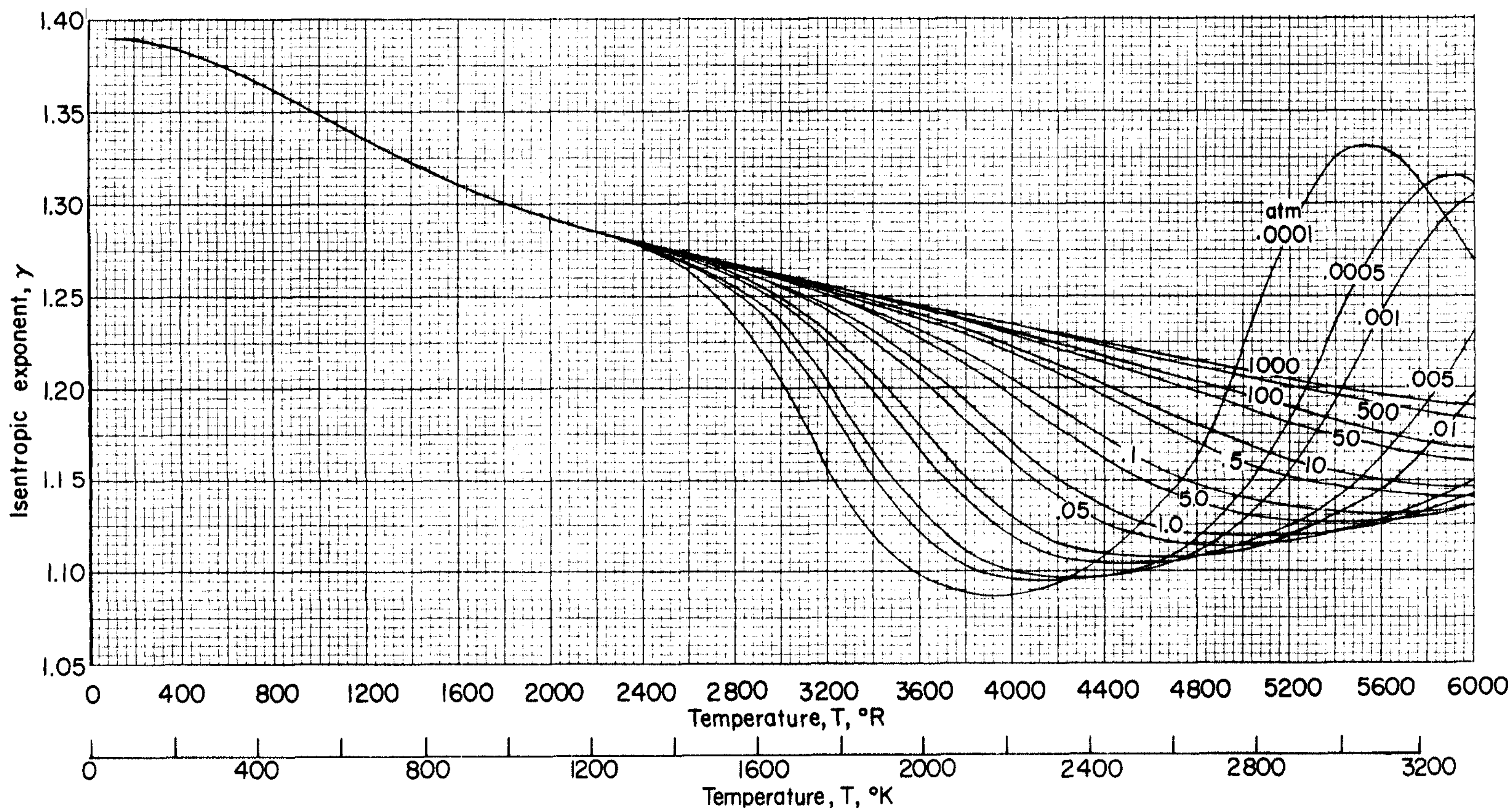
(a) $R_{eq} = 0.315$.

Figure 10.- Variation of isentropic exponent with temperature for selected pressures and equivalence ratios.



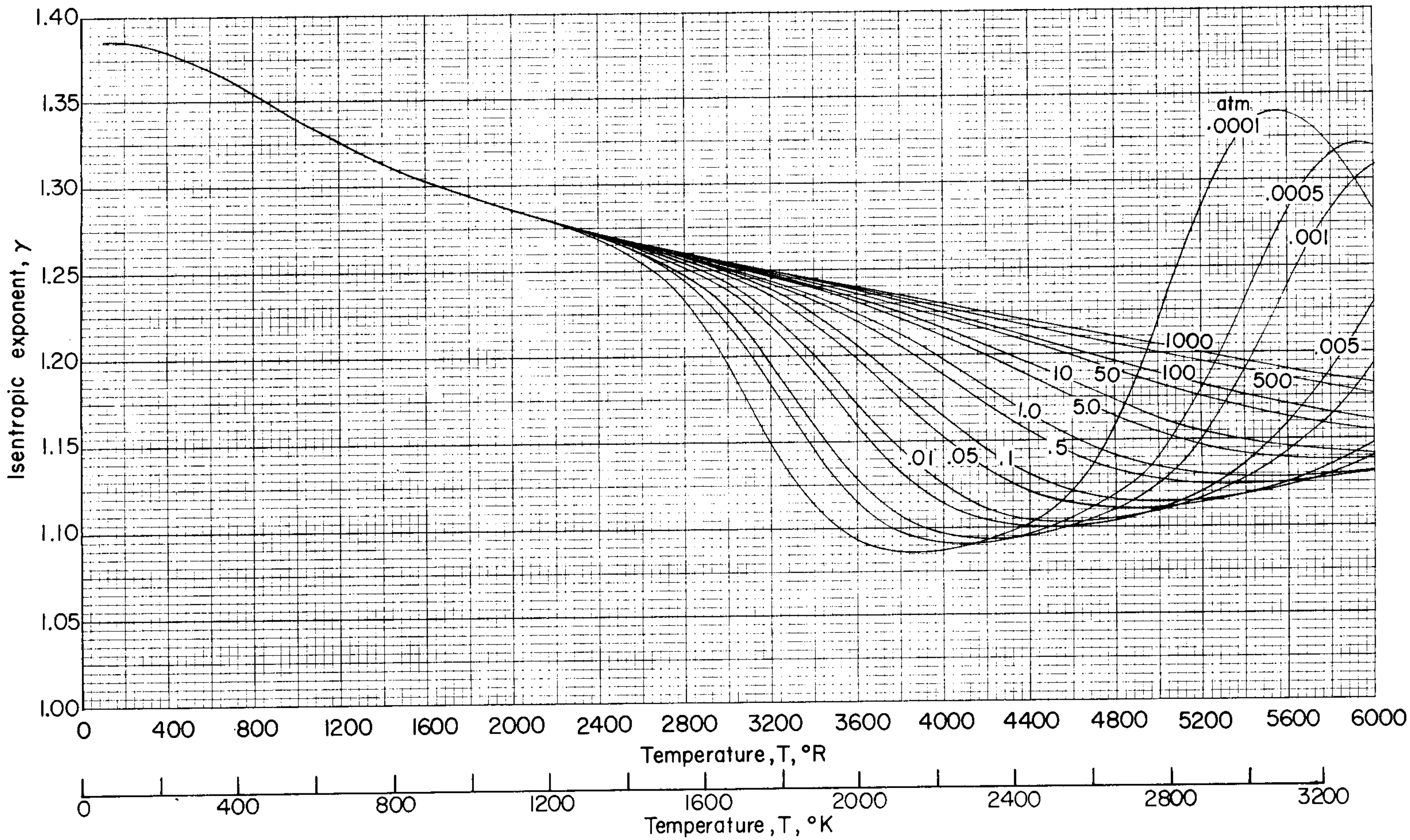
(b) $R_{eq} = 0.370$.

Figure 10.- Continued.



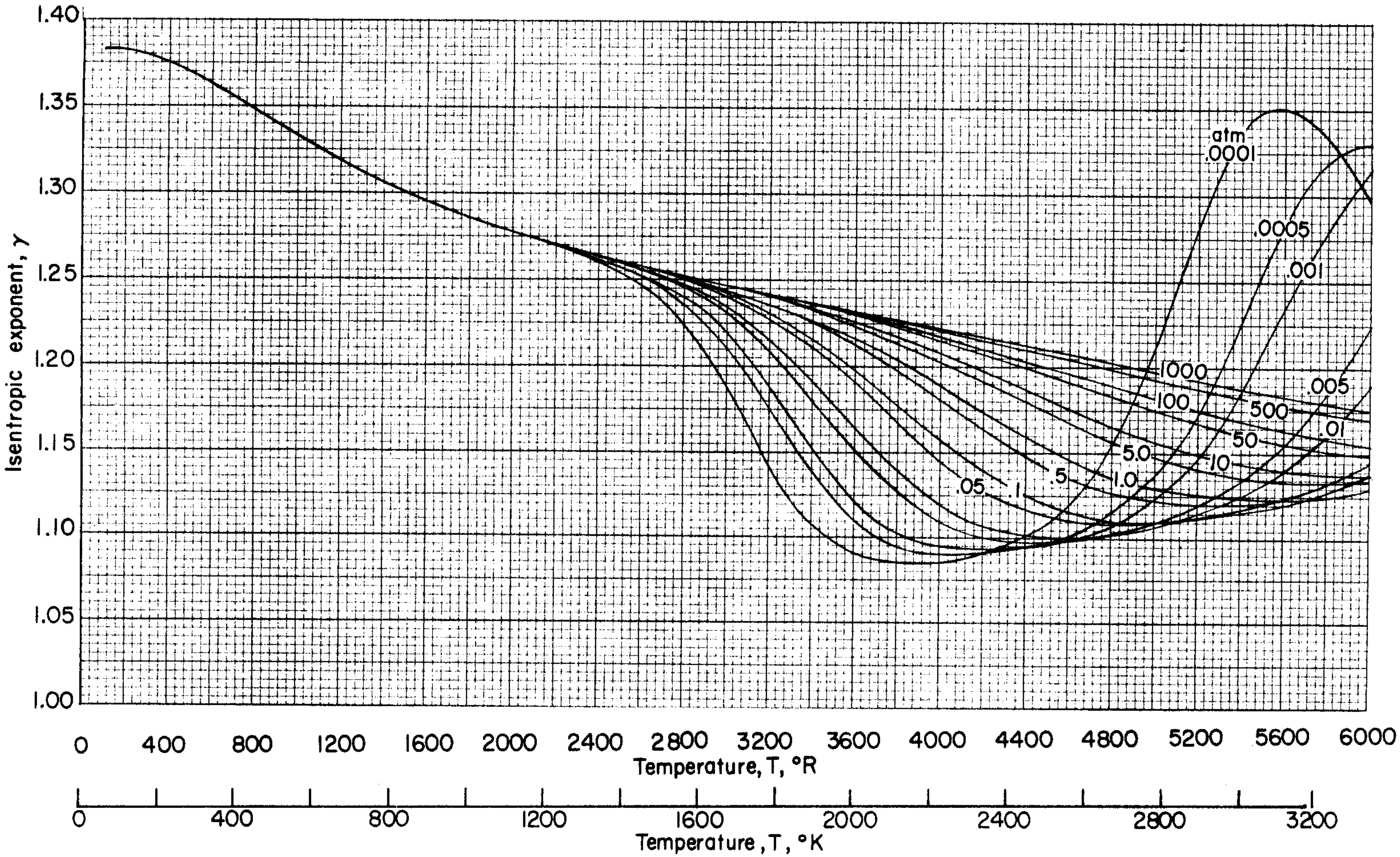
(c) $R_{eq} = 0.425$.

Figure 10.- Continued.



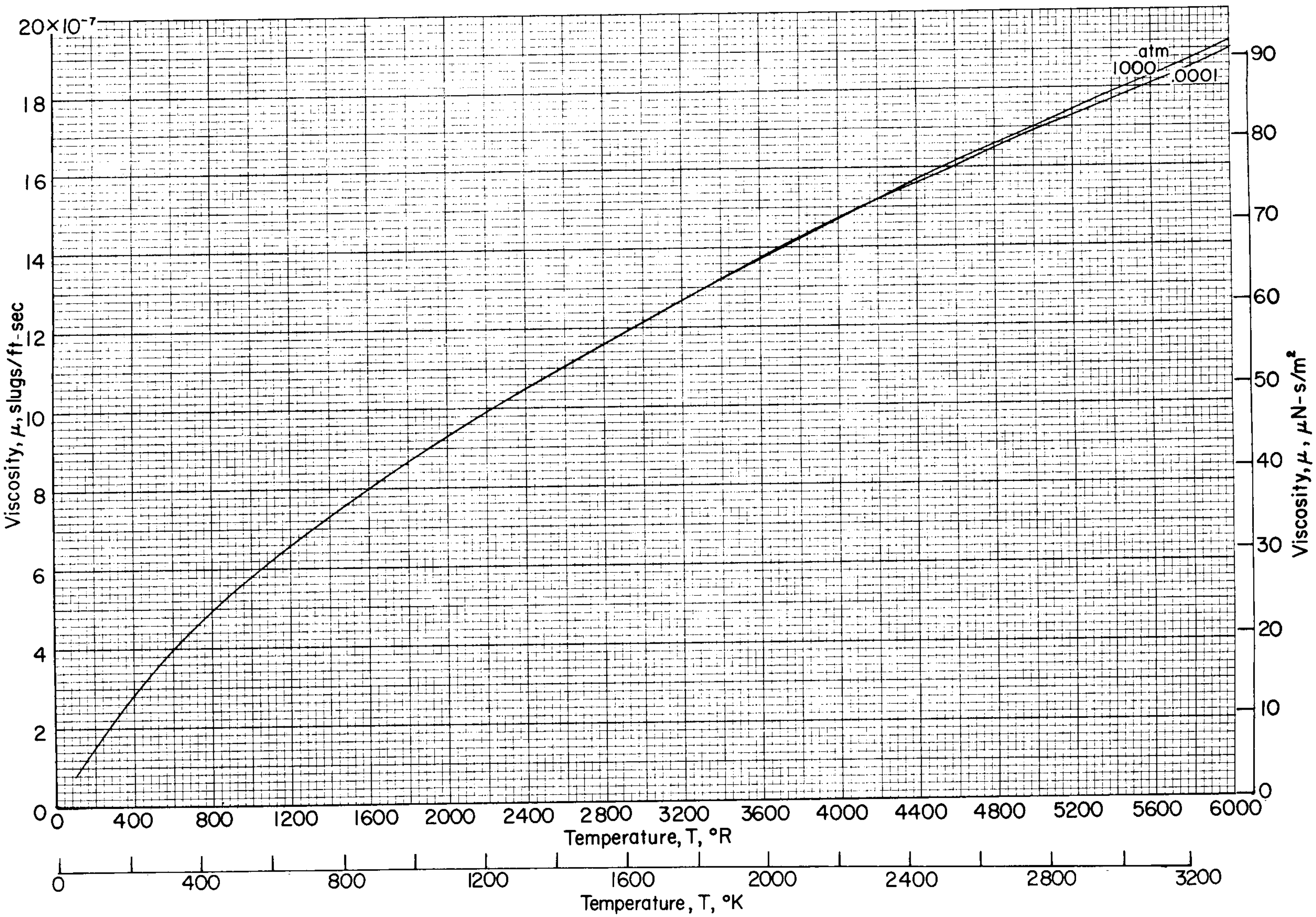
(d) $R_{eq} = 0.480$.

Figure 10.- Continued.



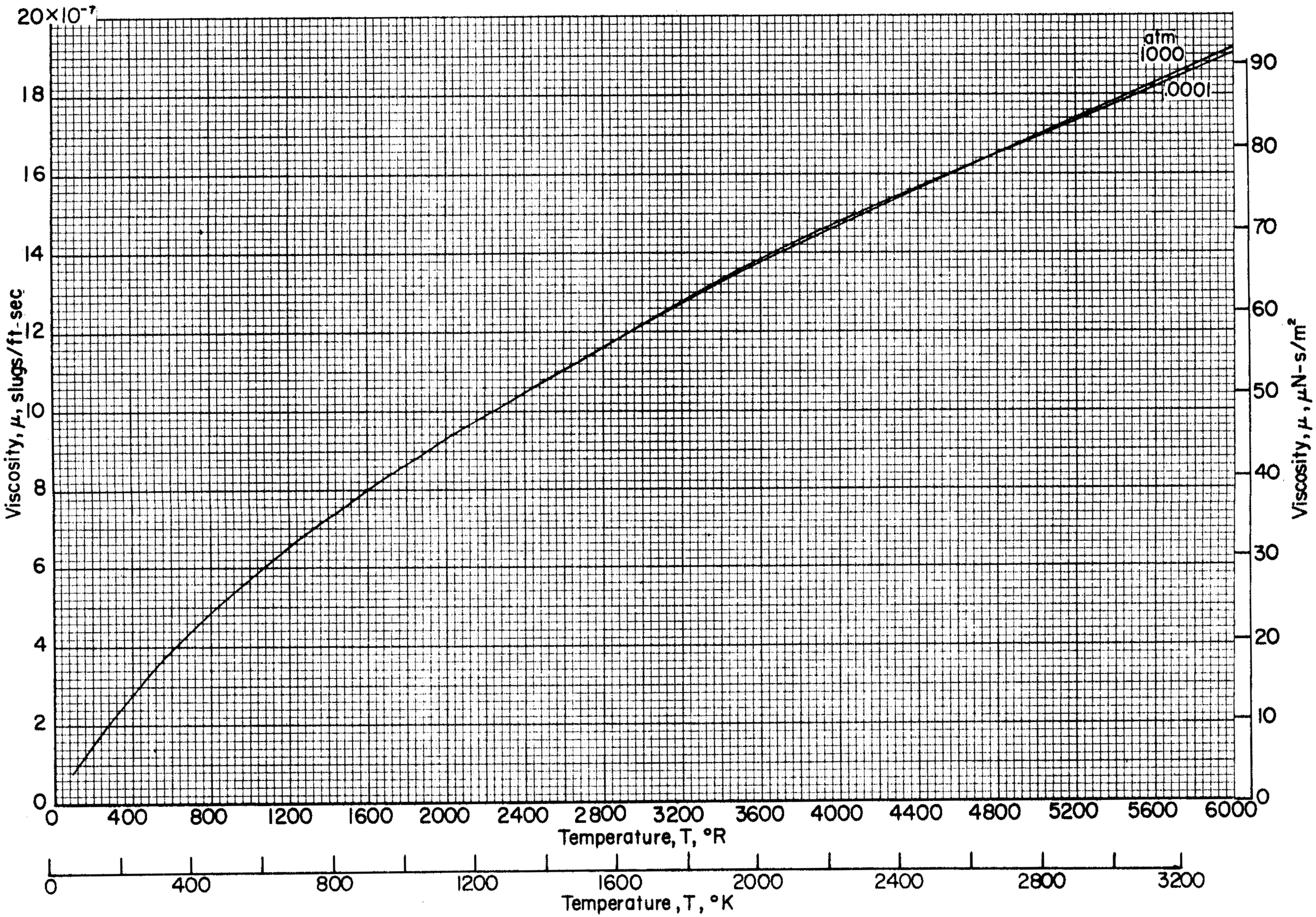
(e) $R_{eq} = 0.525$.

Figure 10.- Concluded.



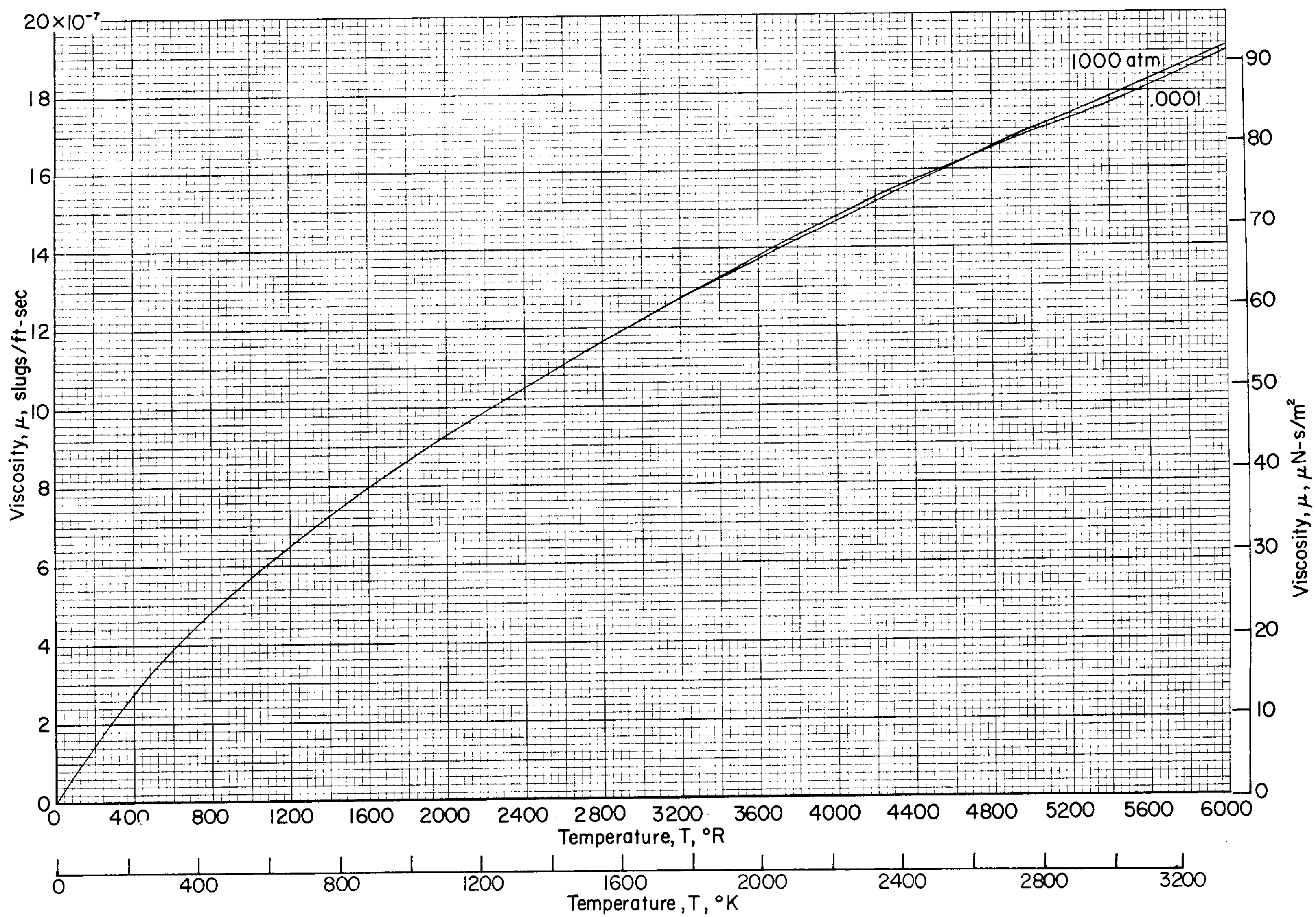
(a) $R_{eq} = 0.315$.

Figure 11.- Variation of viscosity with temperature for selected pressures and equivalence ratios.



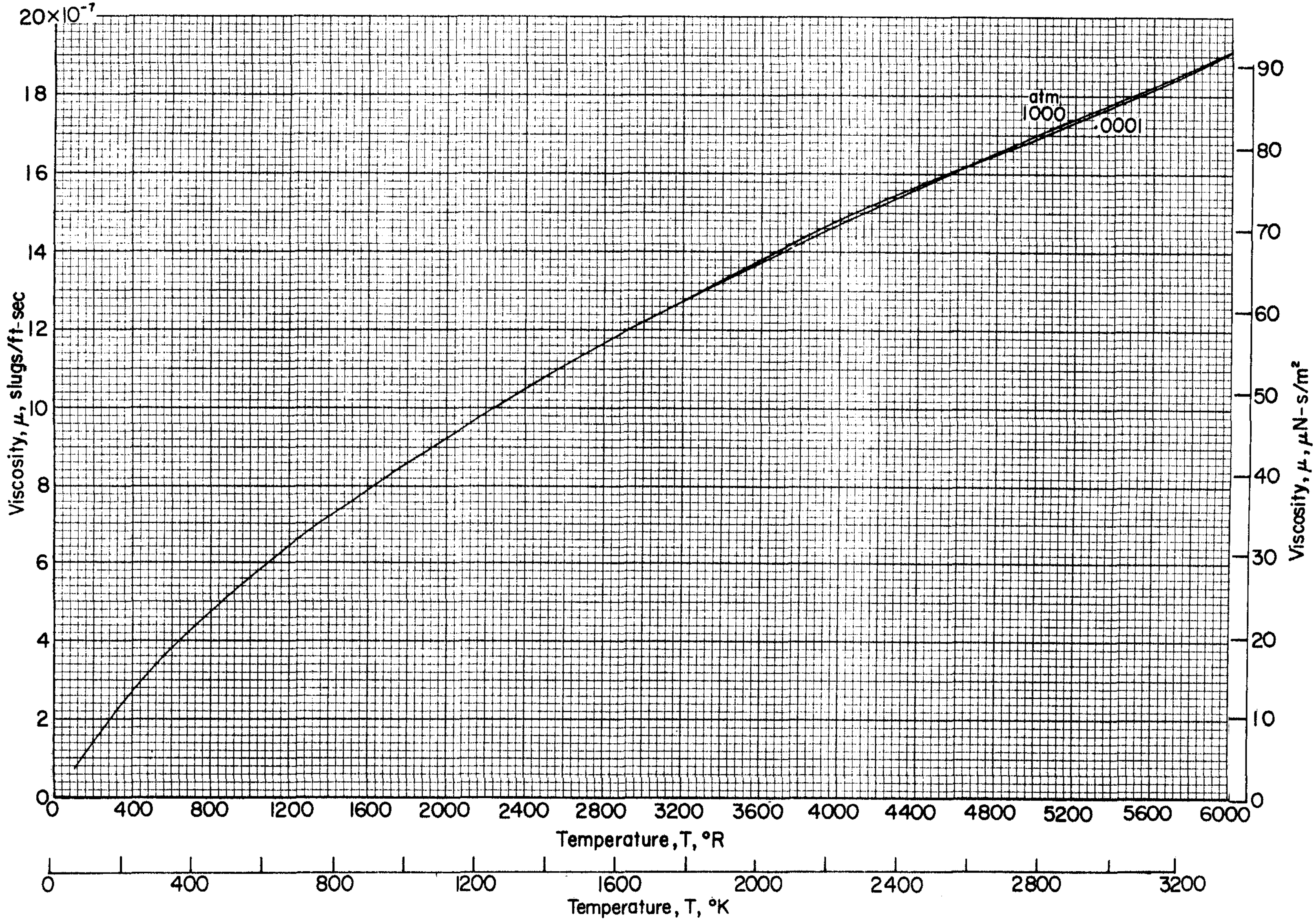
(b) $R_{eq} = 0.370$.

Figure 11.- Continued.



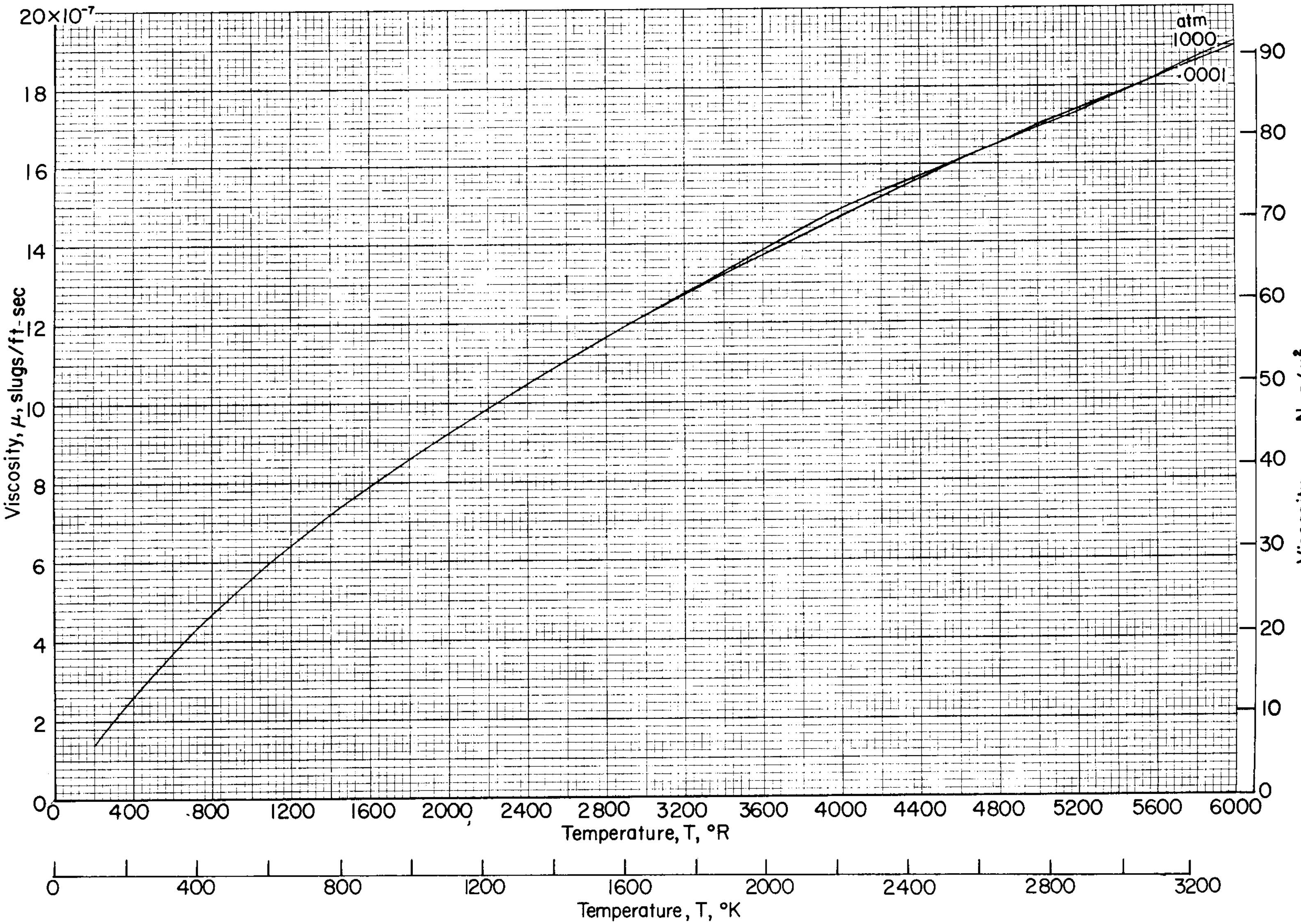
(c) $R_{eq} = 0.425$.

Figure 11.- Continued.



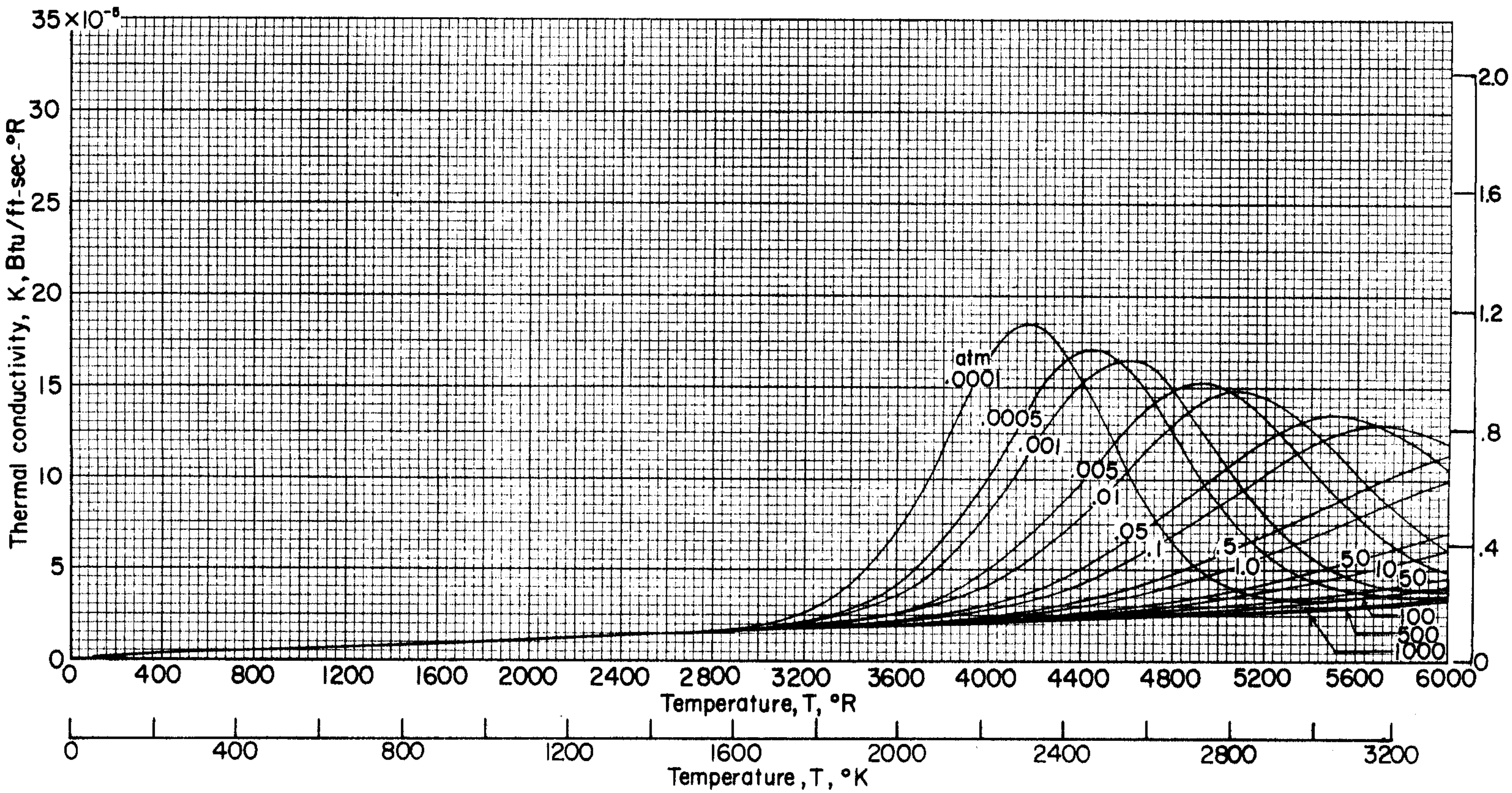
(d) $R_{eq} = 0.480$.

Figure 11.- Continued.



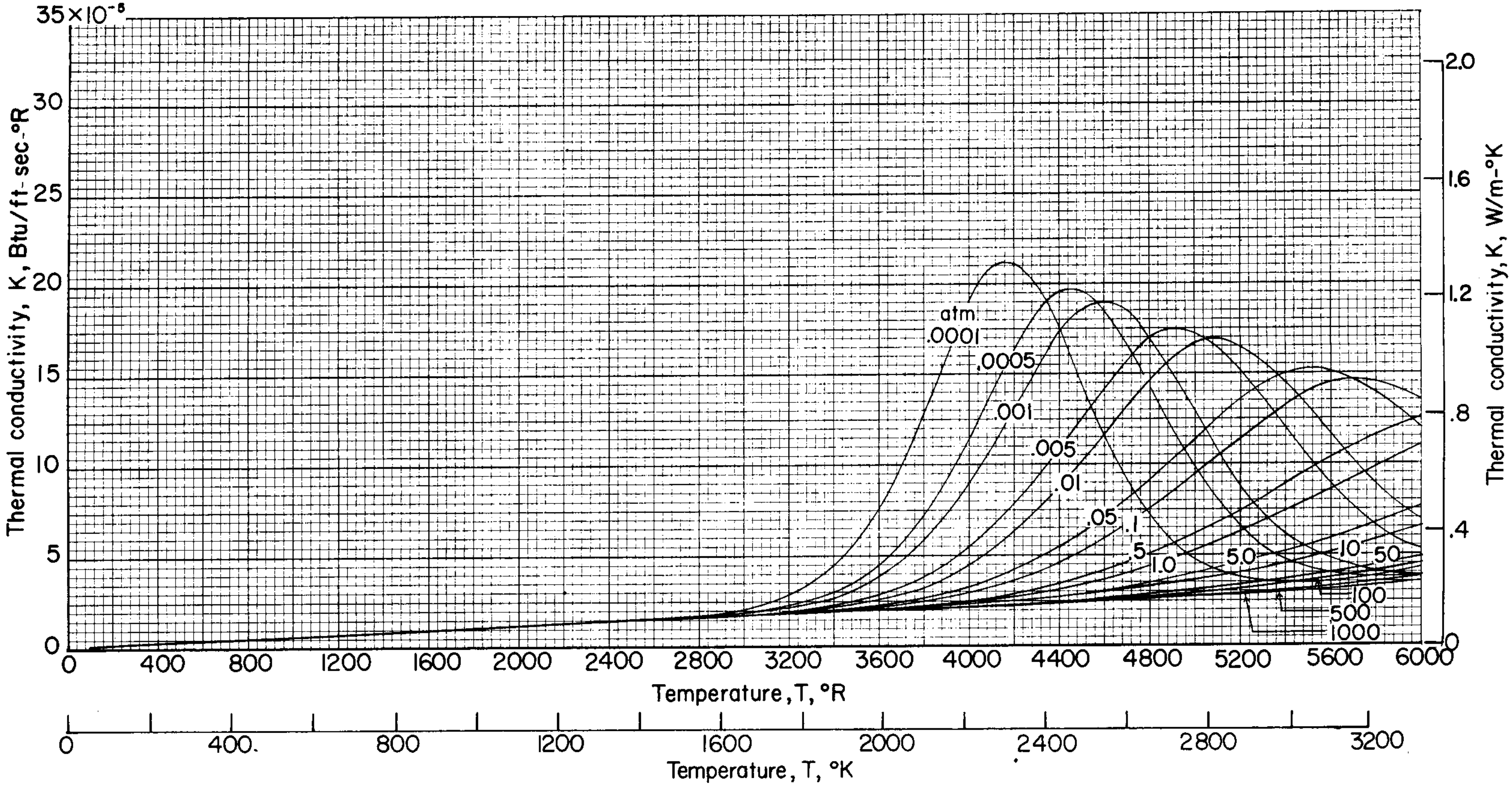
(e) $R_{eq} = 0.525$.

Figure 11.- Concluded.



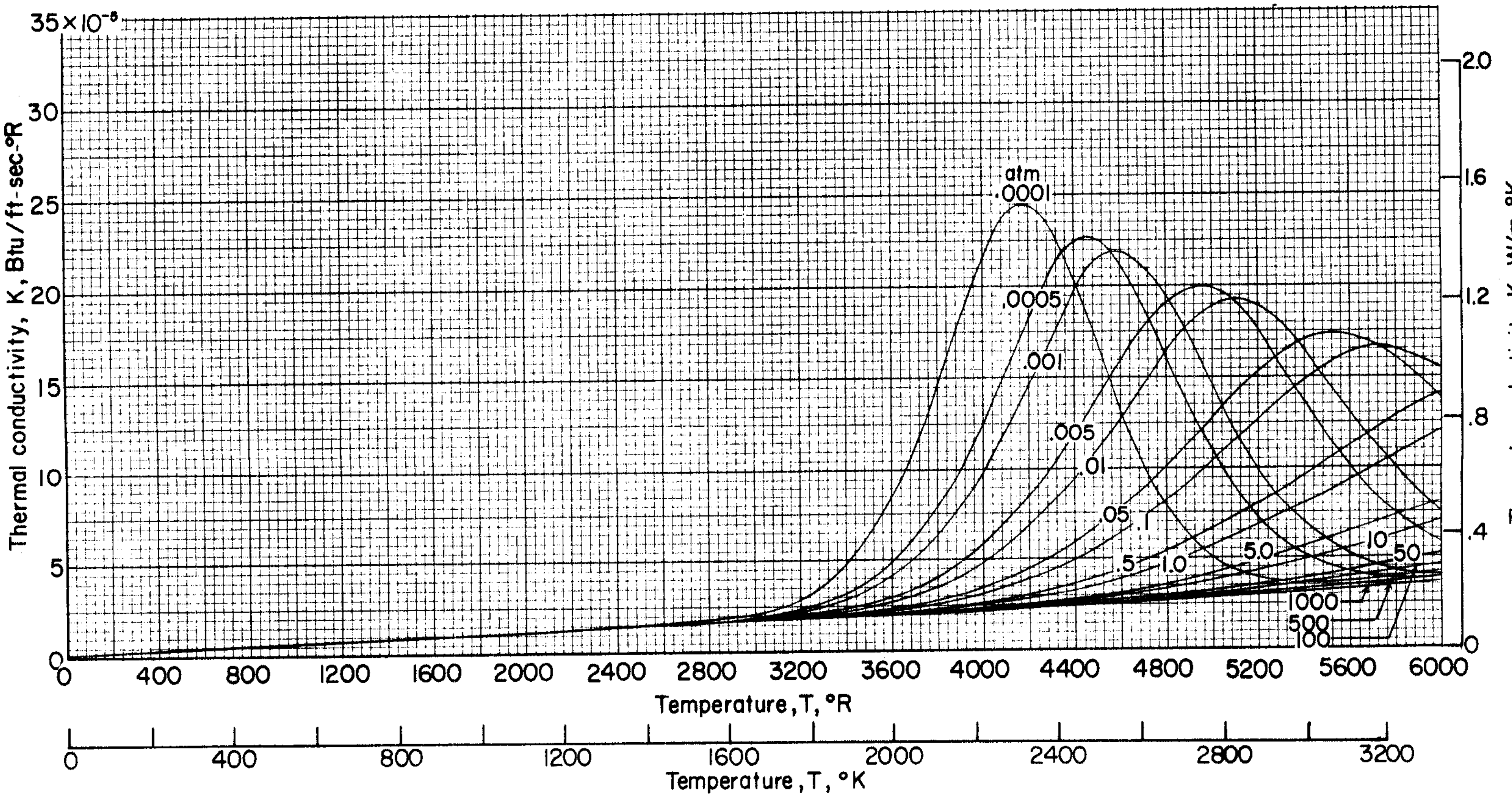
(a) $R_{eq} = 0.315$.

Figure 12.- Variation of thermal conductivity with temperature for selected pressures and equivalence ratios.



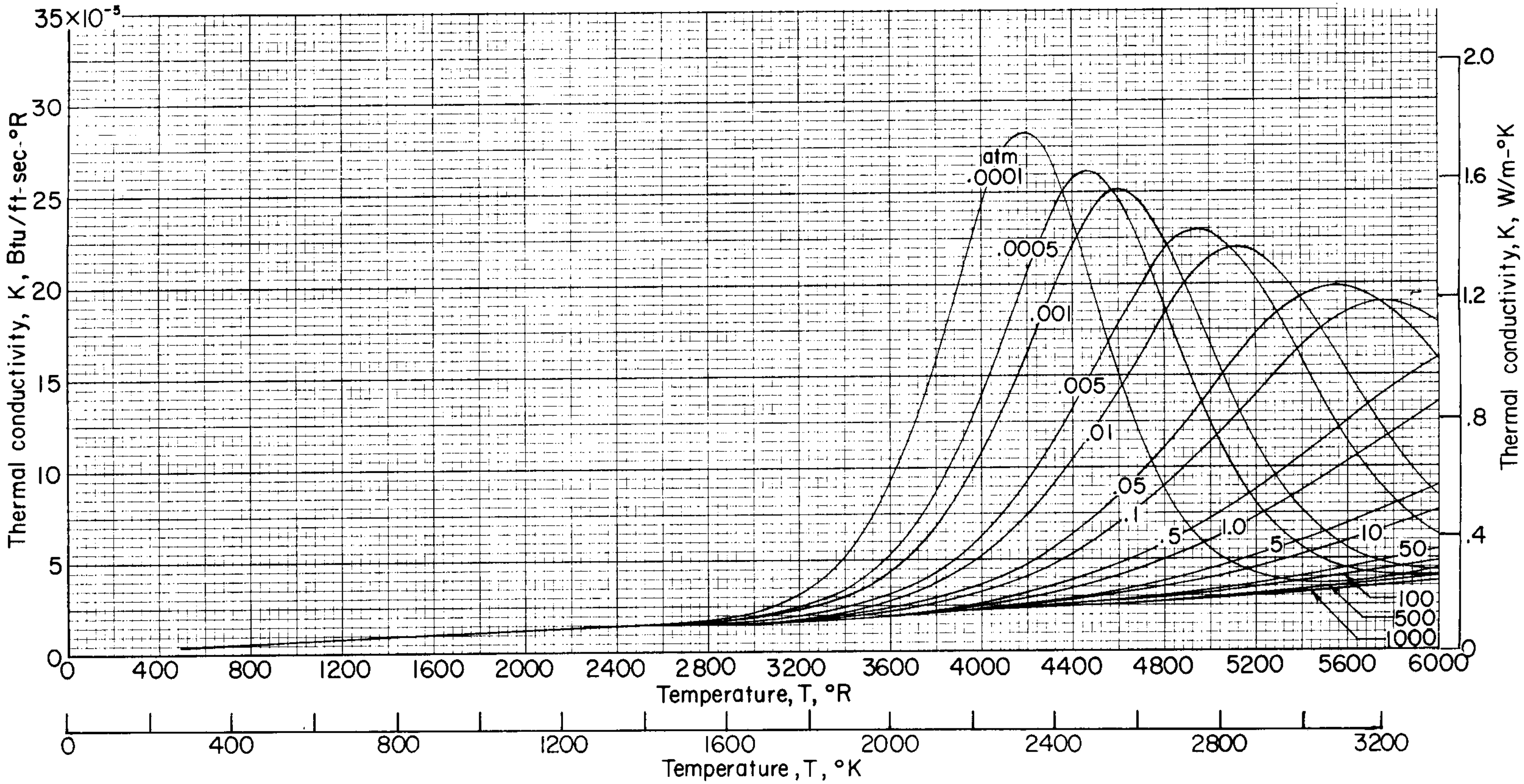
(b) $R_{eq} = 0.370$.

Figure 12.- Continued.



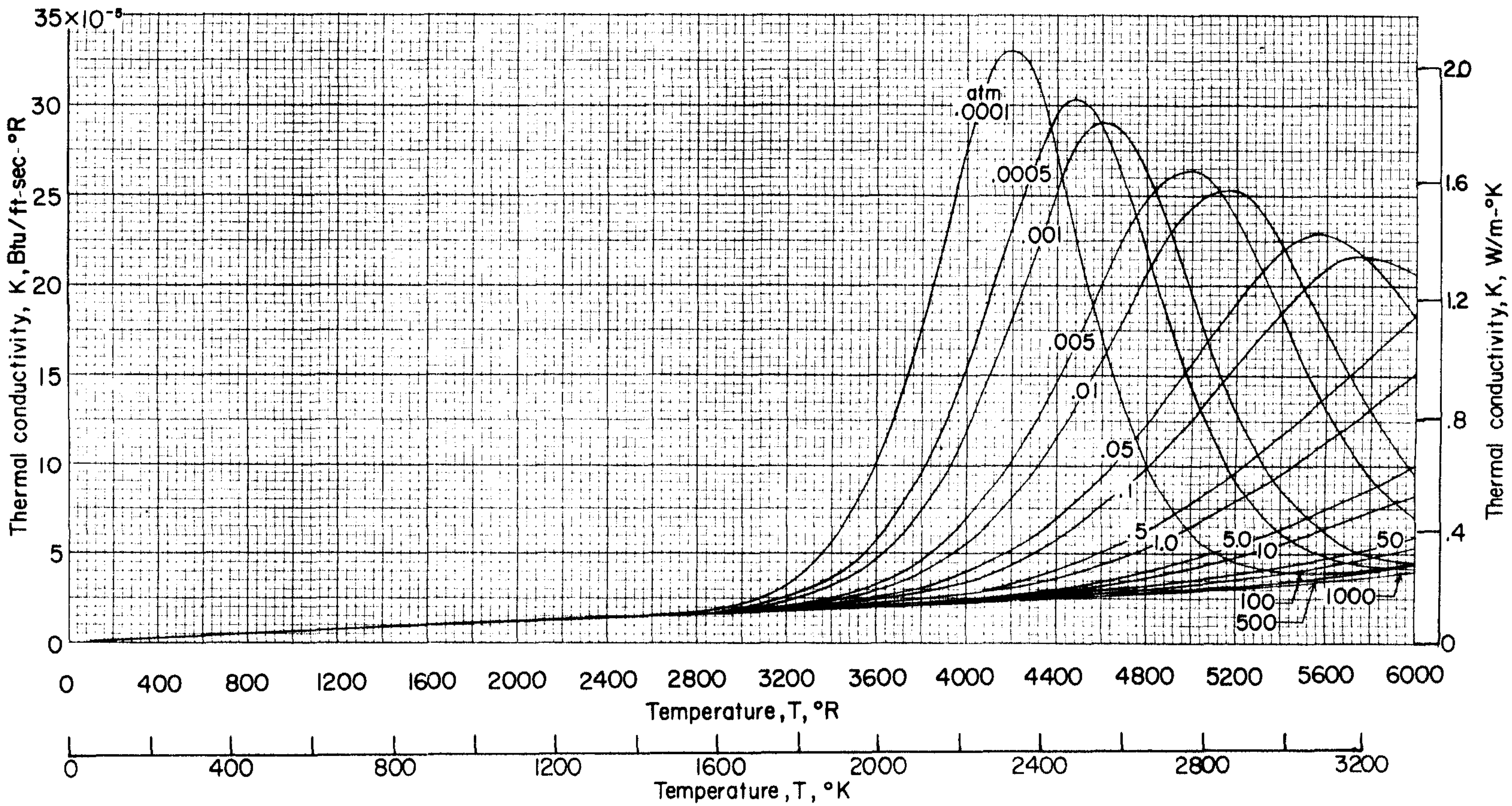
(c) $R_{eq} = 0.425$.

Figure 12.- Continued.



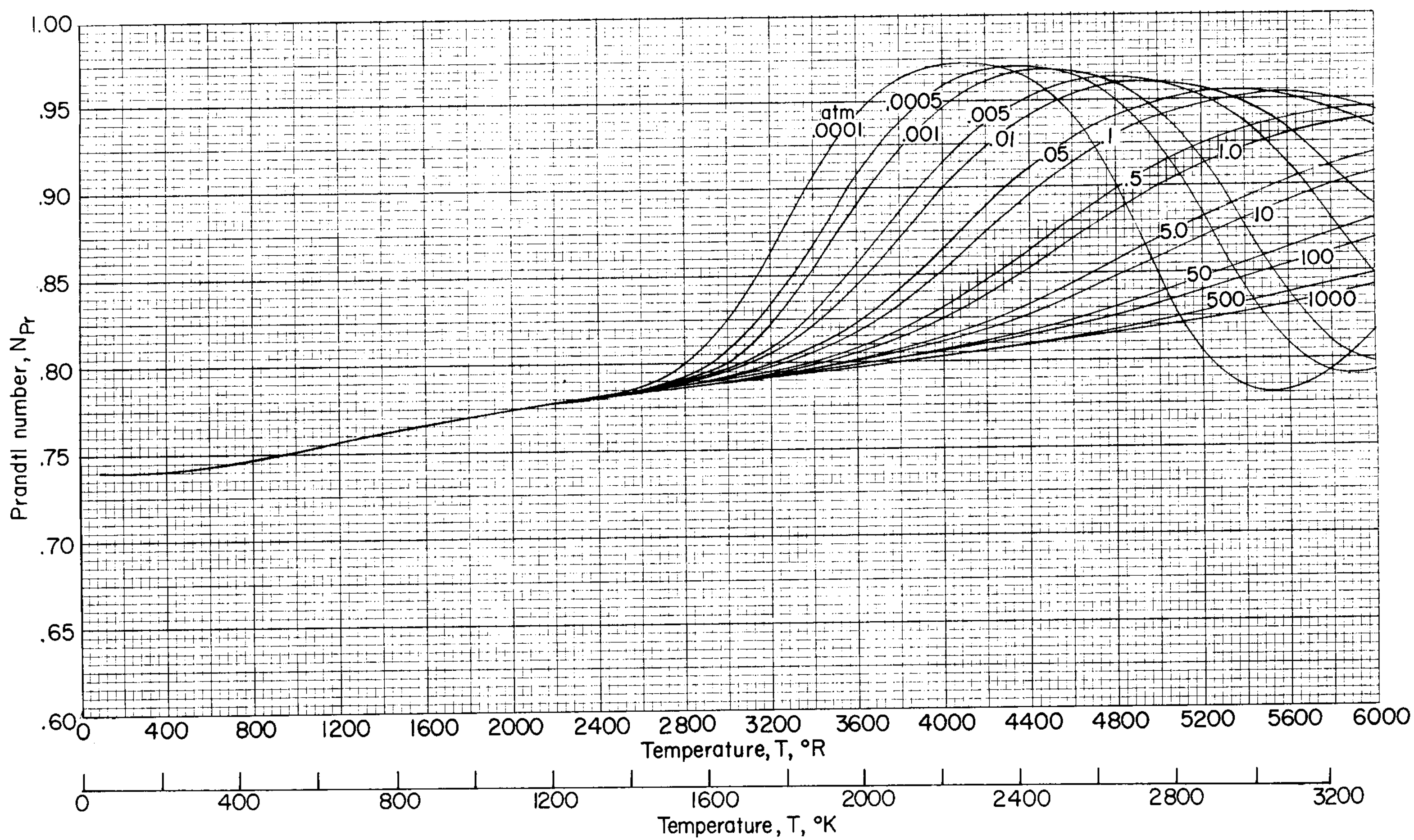
(d) R_{eq} = 0.480.

Figure 12.- Continued.



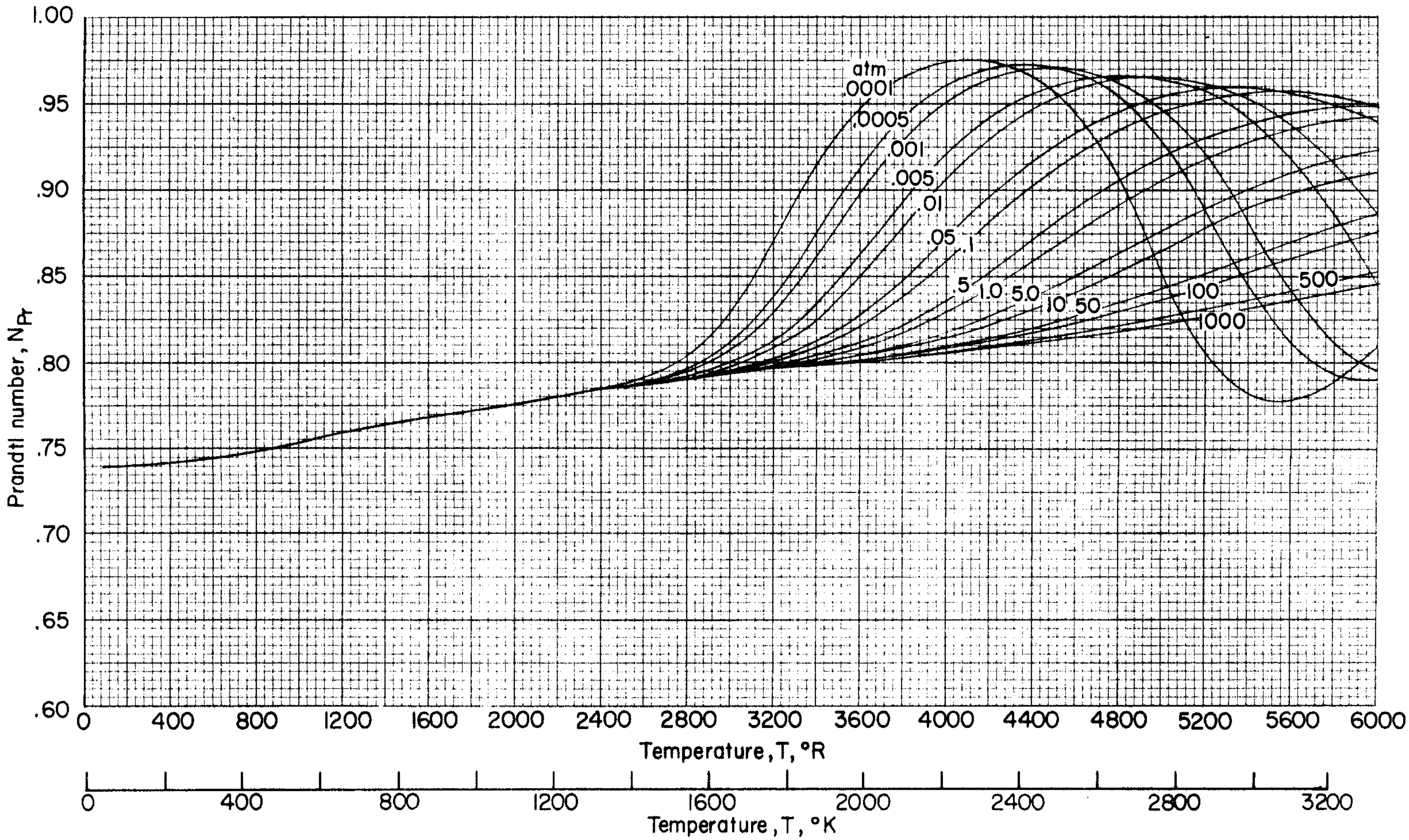
(e) $R_{eq} = 0.525$.

Figure 12.- Concluded.



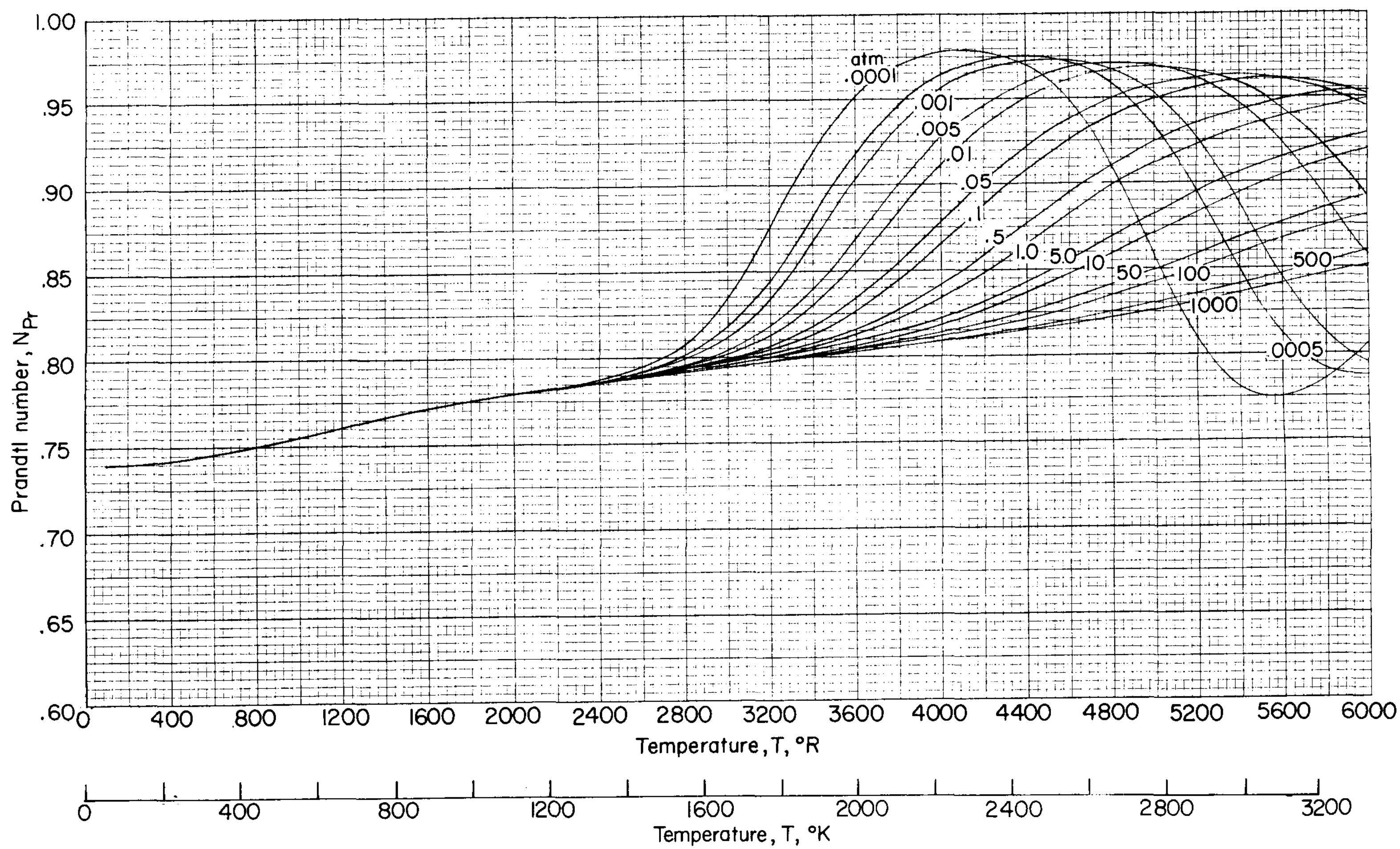
(a) $R_{eq} = 0.315$.

Figure 13.- Variation of Prandtl number with temperature for selected pressures and equivalence ratios.



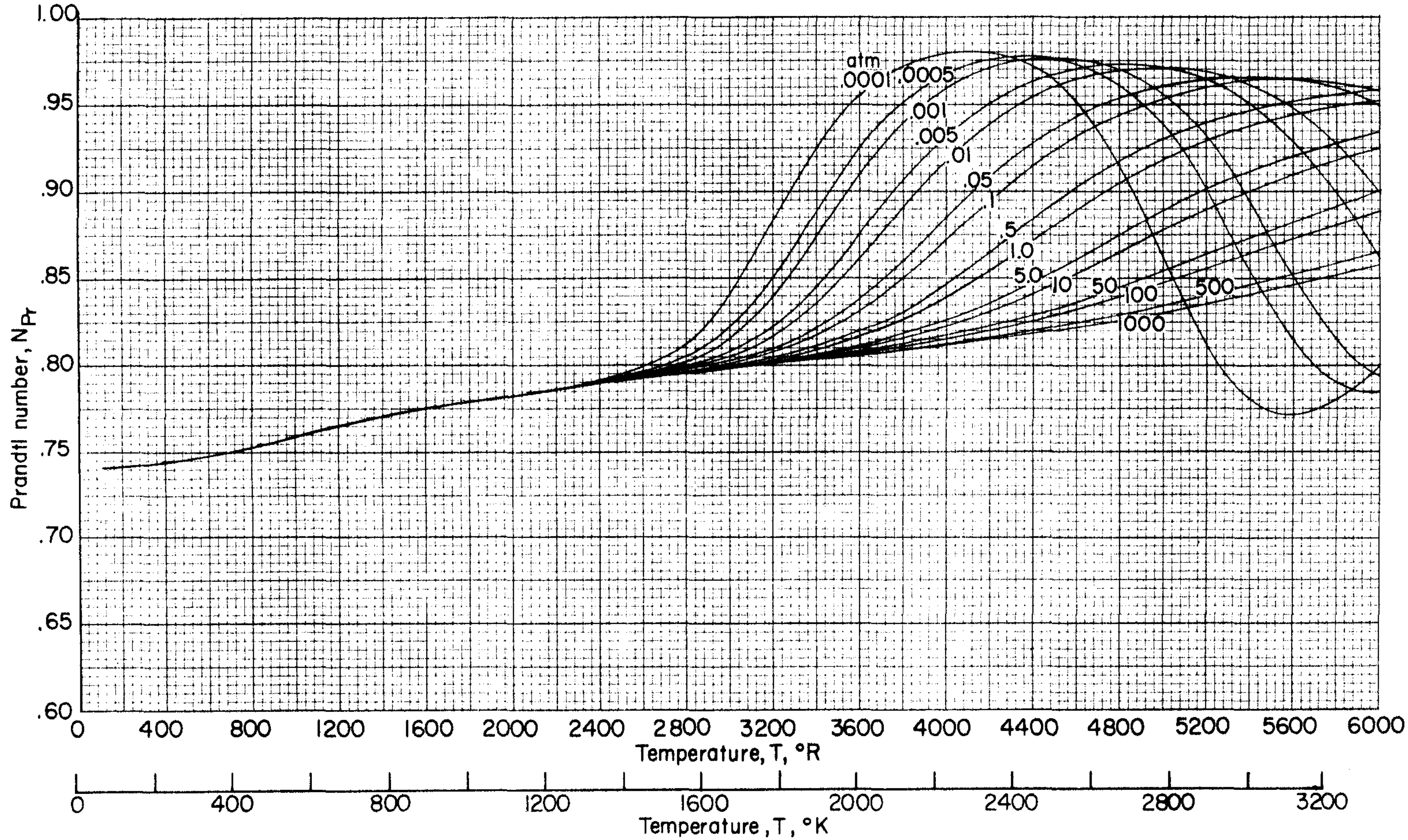
(b) $R_{eq} = 0.370.$

Figure 13.- Continued.



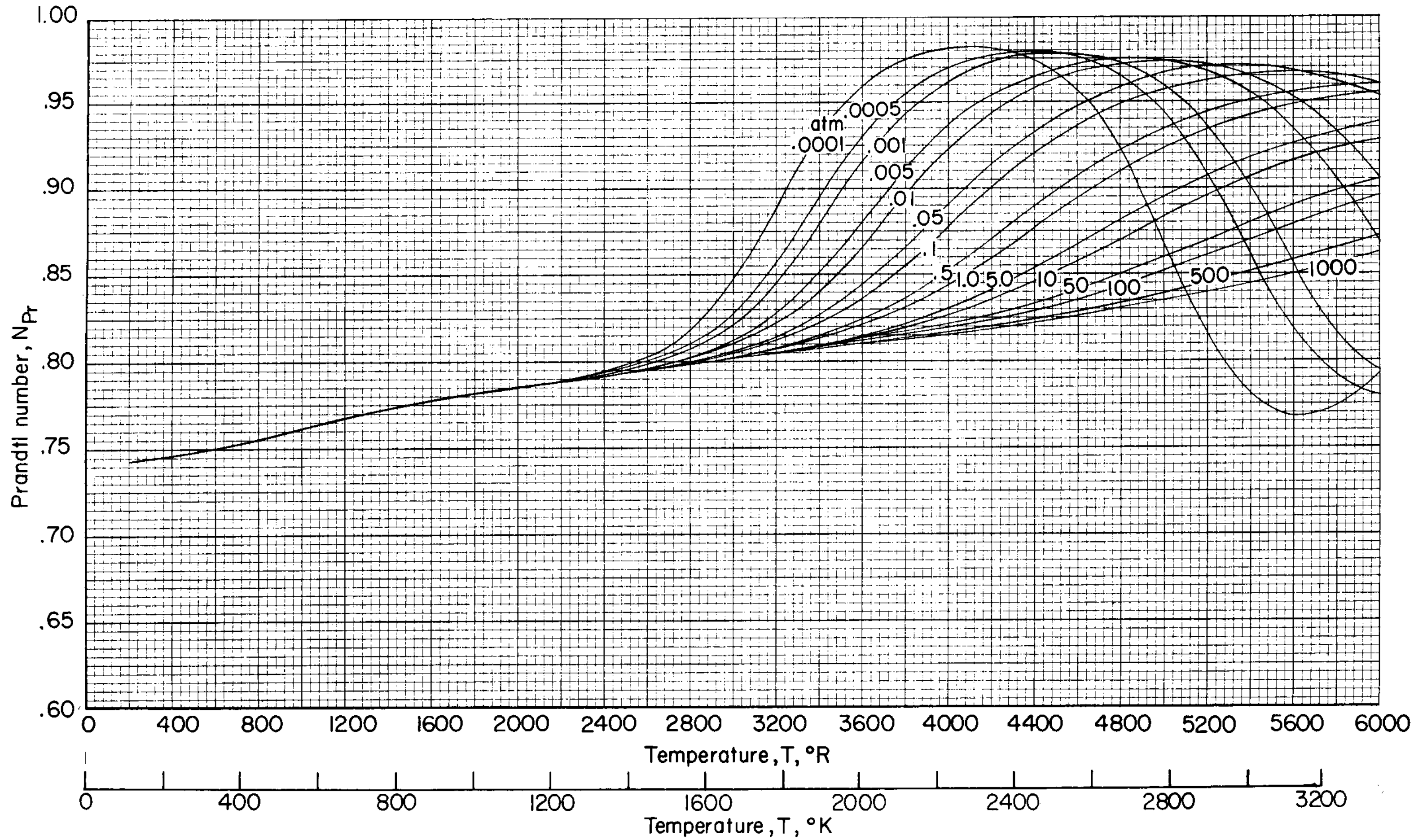
(c) R_{eq} = 0.425.

Figure 13.- Continued.



(d) R_{eq} = 0.480.

Figure 13.- Continued.



(e) $R_{eq} = 0.525$.

Figure 13.- Concluded.

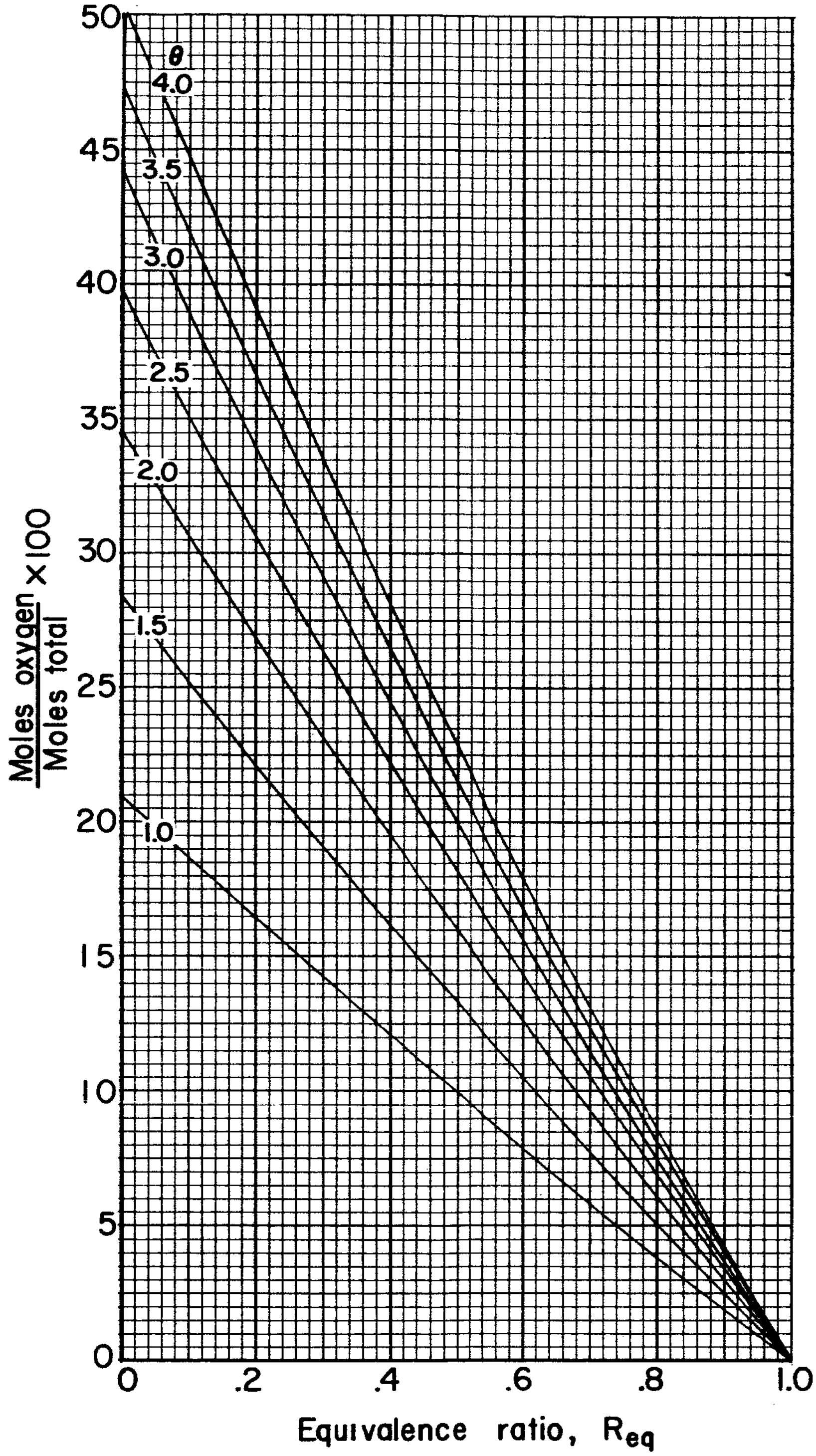


Figure 14.- Percent excess oxygen in combustion products as a function of equivalence ratio for selected values of θ.

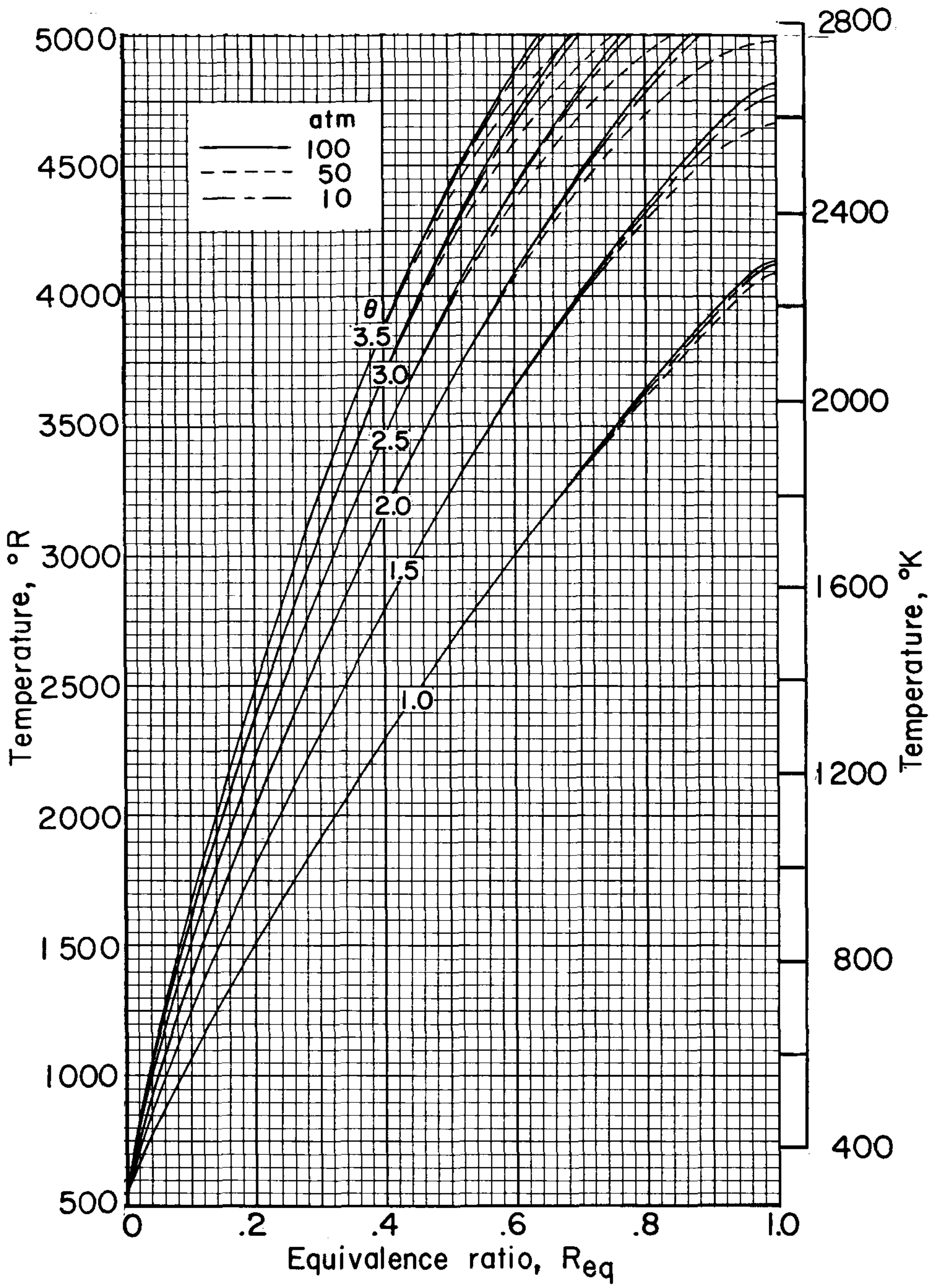


Figure 15.- Variation of equilibrium flame temperature with equivalence ratio for selected values of pressure and θ.

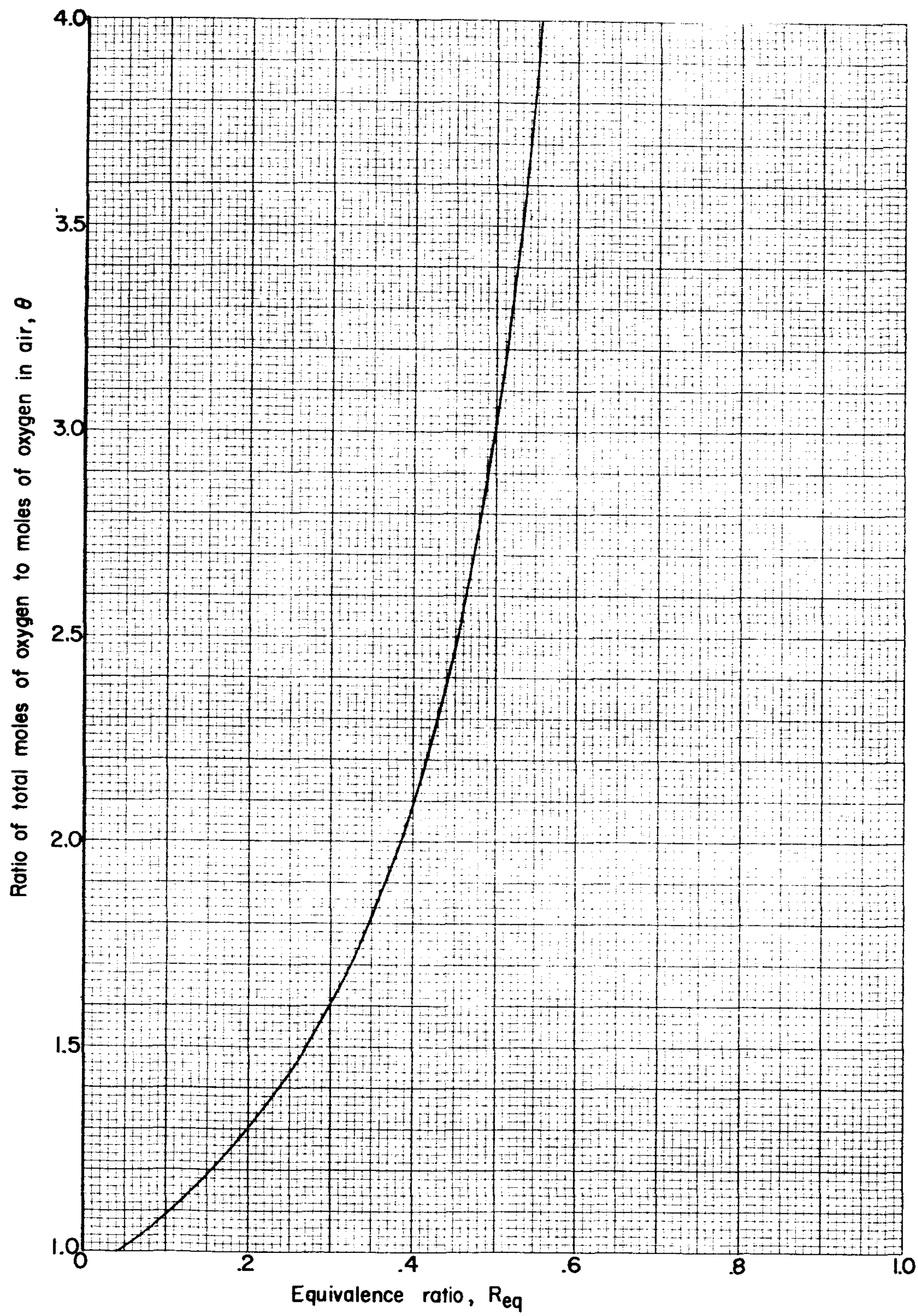


Figure 16.- θ required to maintain 20-percent oxygen in the combustion products as a function of R_{eq}.