STP-TS-012-1

THERMOPHYSICAL PROPERTIES OF WORKING GASES USED IN WORKING GAS TURBINE APPLICATIONS

ASME STANDARDS TECHNOLOGY, LLC

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Air Properties Committee

ASME STANDARDS TECHNOLOGY, LLC

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Summary of Changes

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The following changes have been made to the first revision of STP-TS-012.

Rev. 1 Page	*Location*	*Change*
iv-viii	Table of Contents	Updated to reflect changes
14	Table 18, row 3	Corrected from “1.50” to “-1.50”
14	Table 18, row 4	Corrected from “1.25” to “-1.25”
14	Table 18, row 5	Corrected from “0.75” to “-0.75”
14	Table 18, row 6	Corrected from “0.50” to “-0.50”
14	Table 18, row 7	Corrected from “0.25” to “-0.25”
79	Annex F	Inserted NASA Tables Referenced to 77F

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FOREWORD

This document describes a collection of ideal gas and real gas data for 14 chemical species and air, in temperature and pressures ranges typically of interest to the gas turbine performance community. The ideal gas data (heat capacity, enthalpy, entropy and enthalpy of formation) for these species is readily available in the literature. For each species, the relevant data has been documented, evaluated and recommended values presented in at least three published sources. The committee has adopted equation representations, as published by NASA and VDI, which are based on one of these recommended sets, although any of the three sets could have been used to derive an equation representation. The committee is certainly aware that new experimental measurements could suggest a modified set of recommended data. Any comments from the readers would help contribute to a decision as to whether the data presented in this report is out of date and should be updated.

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ABSTRACT

This document presents a consensus of the Air Properties Committee of the latest formulations for ideal gas thermodynamic and viscosity (pure fluids only) for working fluids most typically used by the gas turbine performance community. Real gas properties are considered where necessary.

The investigation on ideal gas properties has shown that there are two sets of formulations available (NASA and VDI), which represent the current knowledge on properties of the relevant gases equally well. The results of both formulations agree with each other to far within the uncertainty of the best available data. Since both formulations have advantages and disadvantages regarding simplicity and range of validity, the Air Properties Committee decided to include both sets as alternative means for property calculations. The correlation equations given are based on the NASA/TP-2002-211556 "NASA Glenn Coefficients for Calculating Thermodynamic of Individual Species" and the NASA "Thermobuild" website and on the VDI guideline 4670.

Where necessary, real gas properties for the most relevant components of humid air and combustion gases are calculated using internationally accepted reference equations of state, as they are used, e.g., in the NIST Reference data base for Fluid Thermodynamic and Transport Properties "REFPROP," Version 8.1 [3] software. In the absence of an appropriate mixture model covering all working gases relevant for gas turbine applications, a model based on a quasi-ideal mixture of real gases (herein after abbreviated as "ideal mixture of real gases") is presented. An advanced model is given to accurately calculate the gas-phase partial-pressure of water at saturation for humid air at high pressures, as it is required, e.g., in humidified gas-turbine or compressed air energy storage applications.

This document explicitly presents the relatively simple equations required for calculating the ideal gas property data. The much more comprehensive reference equations for the real fluid behavior are available from cited publications.

The following table summarizes the properties addressed in this document:

Species	Ideal Gas Coefficients and Tables NASA	Ideal Gas Coefficients VDI	Real Gas Properties
O_2	X	X	X
N_2	X	X	X
H_2	X		
H_2O	X	X	X
CO	X	X	
CO_2	X	X	X
NH_3	X		
CH_3OH	X		
Ar	X	X	X
Air	X		X
O	X		
H	X		
N	X		
OH	X		
NO	X		
Ne		X	
SO_2		X	

1 OBJECTIVE

The objective of this document is to provide working gas properties for the entire gas turbine establishment.

2 SCOPE

This document presents recommended thermodynamic and transport property data, as derived from a critical evaluation of experimental and theoretical data. Citations as to the origin of this evaluation are given. Ideal and real gas property tables are presented. In addition, two (quantitatively very similar) alternative sets of polynomial equations for ideal gas properties are included. References are given for the more complex reference equations describing the real gas behavior. Real gas property tables are presented to enable an assessment of the impact of real gas effects without programming the corresponding equations or without purchasing corresponding software.

This document covers ideal gas properties up to 6000 K (in some cases even up to 20000 K) and real gas properties up to the highest temperatures and pressures for which validation is feasible, typically 50 MPa. Fourteen species, plus air, have been included in this document since they represent the most commonly encountered species in gas turbine analysis. Real gas properties are not included for minor, unstable or radical gaseous species (H, N, O and OH).

3 NOMENCLATURE

3.1 Symbols

A_r	relative atomic mass
a_i	coefficients for ideal gas equations
b_i	integration constants for ideal gas equations
C_p	isobaric heat capacity
C_v	isochoric heat capacity
H	enthalpy
M	molar mass
m	mass
n	amount of substance
M_r	relative molecular mass
R	molar gas constant
S	entropy
w	speed of sound
T	thermodynamic temperature
$\Delta_f H^o$	enthalpy of formation