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Properties of Humid Air for Calculating Power Cycles

Accurate calculation algorithms for the thermodynamic and transport properties of humid air are required for modeling compressed air energy-storage power cycles and designing their individual components. The development of such algorithms was part of the Advanced Adiabatic Compressed Air Energy Storage (AA-CAES) project, which had been supported by the European Commission. To obtain the statements of this paper, all available experimental data and new experimental data generated within the AA-CAES project were used as basis for comparisons between the different models for thermodynamic and transport properties. As a result, one model for calculating thermodynamic and one model for transport properties of humid air in AA-CAES cycle design and operation is recommended. Their application is possible for wide ranges of temperature from 243 K up to 2000 K, total pressure from 0.611 kPa up to 100 MPa, and water content up to 10% mass fraction with some restrictions concerning the calculation of viscosity η and thermal conductivity λ (up to 1000 K for both and up to 40 MPa for λ). These models have been implemented into a property library, which meets the requirements of programs for calculating compressed air energy-storage cycles. The developed property library can be used for the daily work of an engineer who calculates such cycles. The results summarized in this paper have been used for preparing Section 6, "Real Gas" of the ASME Report No. STP-TS-012, "Thermophysical Properties of Gases used in Working Gas Turbine Applications." [DOI: 10.1115/1.4000611]

1 Introduction

The objectives of the Advanced Adiabatic Compressed Air Energy Storage (AA-CAES) project of the European Union (EU) [1] were to investigate the technical and economical feasibilities of an energy-storage system using compressed humid air as a working fluid. The task of this project was based on the renewable energy target for Europe defined by the European Commission that predicts renewable energy sources to contribute between 12% and 20% of all energy sources to be used in 2020 [2,3]. The problem of the renewable energy sources is that they provide the energy independent of the demand of the energy market, e.g., electrical energy from wind mills or solar energy modules. Therefore, an effective system is needed to store electrical energy in the case of an excess supply. One promising process to store electrical energy consists in the compression of ambient air and storage in a cavern, and later, the use of the stored energy by expansion using a turbine. To obtain a high efficiency, a heat storage device is needed for the intermediate storage of the heat after the compression. Reliable models for calculating the thermophysical properties of humid air are necessary for the design of such processes.

Air and combustion gases are usually treated as ideal-gas mixtures in boiler and gas-turbine engineering, neglecting the residual contribution, to thermophysical properties which results from the real behavior. The situation is more complicated for AA-CAES plants because high pressures in combination with low temperatures occur, particularly in the heat storage device and in the cavern. Thus, residual effects exceed 10% in the case of the isobaric heat capacity. Such effects cannot be neglected either in process calculations or in system acceptance and performance tests.

Work Package 4 of the AA-CAES project [1] dealt with the generation of experimental data on thermodynamic and transport properties for dry air and humid air (density, speed of sound, saturated composition, viscosity, thermal conductivity), with the development of a property database for dry air and humid air, with the acquisition of all available data from literature, and with the test of suitable models describing these properties. The structure of the database is described in Sec. 5 and details are given in Ref. [4]. In addition, this paper gives an overview of the recommended models for calculating the thermodynamic properties and the transport properties of dry air and humid air. The algorithms, including the needed numerical information, are given in Ref. [4]. The recommendations were based on the results of comparative calculations for the different available models and on the comparison to experimental data.

In this paper, a survey of the calculation procedures for the thermodynamic and transport properties of humid air is presented. The comprehensive description of the algorithms can be found in the report [4].

This work has been the basis for the section "Thermodynamic Properties of Ideal Mixtures of Real Gases" of the ASME Report No. STP-TS-012, Thermophysical Properties of Working Gases used in Working Gas Turbine Applications [5].

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