NUMERICAL PREDICTION OF ENERGY DISSIPATION IN CONDENSING STEAM FLOW

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Summary In the presented work the analysis of energy dissipation in steam expansion flows is carried out. The adiabatic flow, with homogeneous and with heterogeneous condensation is considered. The influence of the condensation phenomenon and steam impurity on the losses is analyzed. For modelling of the steam properties the IAPWS-IF'97 formulation is implemented. The numerical computations are performed using an in-house multi-block code and commercial code TascFlow.

INTODUCTION

From the technical point of view in the fluid-flow machinery analysis and improvement is very important to localize the energy dissipation sources in the flow and reduce them. In the steam turbine an improvement in last stage efficiency can significantly impact the output of the total unit, considering the fact that the last stages produces a significant part of the total unit output. In the last stages of the steam turbine flow occurs condensation process and the flow is two-phase.

The aim of this research is to estimate the energy dissipation in the condensing steam flow. In the blade cascade flows exist the two types of losses, are aerodynamic losses (profile, secondary flow) and thermodynamic (caused by condensation phenomenon). Because the steam in power cycle includes always some impurities, the question connected with influence of steam impurities on the losses is considered. The comparison between the flow with homogeneous and heterogeneous condensation with respect to the losses is intended. The condensation produces thermodynamic losses in the flow and changes the flow parameters, which influences the aerodynamic losses. To date the estimations of the losses in the turbine flow are in the centre of interest for many researchers. However, the research on the influence of the condensation phenomenon on the losses is not often published. There are well known the works of Schnerr [1], Stastny [2] or White [3] dealing with the investigations of the 2-D cascade flow with condensation. This paper includes the complete analysis of the adiabatic steam flow and the steam flow with homogeneous and heterogeneous condensation with respect to the losses in the Laval nozzle and through the 3-D blade-to-blade channel. The numerical investigations presented in this paper are performed on a geometry of the low pressure part of the large steam turbine.

PHYSICAL AND NUMERICAL MODEL

The numerical simulation is based on the time dependent 3-D Reynolds averaged Navier-Stokes equations, which are coupled with a two-equation turbulence model (k-ω SST model) and additional mass conservation equations for the liquid phase (two for homogeneous and one for heterogeneous condensation). The set of governing equations is closed by means of a real gas equation of state [4]. The 'local' form of the real gas equation of state is used.

The condensation phenomena are modeled based on the classical nucleation theory of Volmer, Frenkel and Zeldovich, which is well suited for modeling technical flows [1,2,3]. The droplet growth equation of Gyarmathy is used. The system of governing equations is discretized on a multi-block structured grid using the finite-volume method and integrated in time using an explicit Runge-Kutta method. An upwind scheme proposed by Godunov, is used as the Riemann solver. The MUSCL technique is implemented to approach the TVD scheme with the van Albada flux limiter to avoid oscillations [5].

The commercial code TascFlow is a widely used code for the turbomachinery applications. TascFlow is based on the averaged Navier-Stokes equations employing the finite volume method (FVM) with an implicit, multi-block algorithm. The solution strategy is based on the Algebraic Multi-grid method. The steam properties are modelled using the virial equation of state with three virial coefficients. The flow is considered as an equilibrium dry/wet steam model without nucleation process.

RESULTS

The numerical calculations are carried out for the Laval nozzle and for the last and penultimate stages of the low-pressure part of steam turbine. The nozzle flow is the simplest test case for comparison with experiments and validation of the numerical codes. For nozzle flows different expansion processes are considered: adiabatic, diabatic with homogeneous and heterogeneous condensation. Expansion lines obtained for this cases are shown in h-s chart (Fig.1).

For the turbine stages different operating conditions are considered. The distributions of the flow parameters, distributions of the losses (Fig. 2), efficiency and power generated through the stage are investigated. Computational domain was discretized using the structural multi-block grid, in which the O-type grid near the blade is embedded within a C-type grid and in the inlet and outlet domain the H-type grid is used. The energy dissipation is described using loss coefficient.

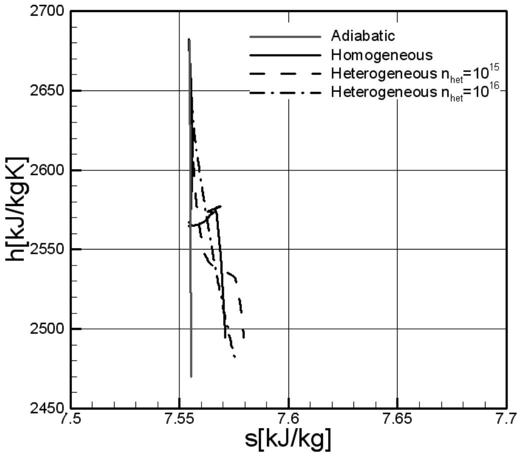

Fig.1.Expansion line in the Laval nozzle

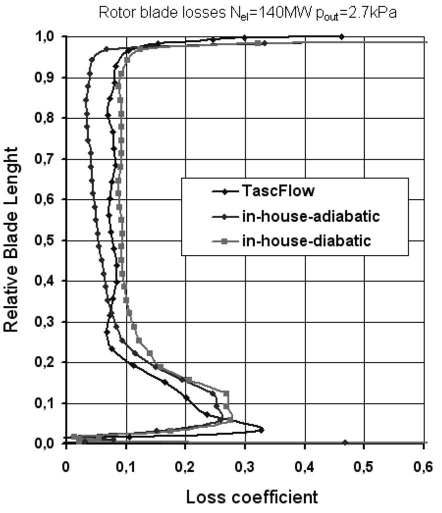

Fig.2.Loss coefficient distributions along the blade length

CONCLUSIONS

The analyses of the losses in the flow without condensation, with homogeneous and heterogeneous condensation are carried out. The influence of the impurities concentration on the losses is also investigated. The presented numerical results for the flow without condensation are performed on an in-house numerical code as well as commercial code CFX TascFlow. In the case of condensing flow the in-house code is used. The comparison of the results obtained by means of the in-house code and TascFlow code shows:

- very good agreement regarding the flow field parameters and energy dissipation distributions,
- very good agreement in the modelling of the steam (real gas) properties (The simplest equation of state used in the in-house code gives identical results like the virial equation of state with three virial coefficients applied in TascFlow).

For the 3-D flow through the LP steam turbine geometry the following conclusions can be drawn:

- for the flow with heterogeneous condensation the wetness is the highest,
- the worst with respect to efficiency and losses is the flow with homogeneous/ heterogeneous condensation,
- the condensation phenomenon can decrease or increase the power generated in the turbine stage, depends on the operating conditions,
- influence of the impurities (heterogeneous condensation) on the losses is not as significant, compared to the condensation itself,
- quality of the code and numerical grid influences the accurate solutions of aerodynamic as well thermodynamic losses.

References

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