A 3D METHOD TO EVALUATE MOISTURE LOSSES IN A LOW PRESSURE STEAM TURBINE

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ABSTRACT

This project presents a physically consistent 3D method to evaluate moisture losses and it is further employed to estimate the moisture losses in the last stage of a 1000 MW fossil-fired steam turbine. The 3D method is based on the information of the flow-field and droplets deposition. An inhomogeneous multi-phase flow model is adopted to simulate the condensing flow in the last stage. Massive computations of droplets deposition by both inertial and turbulent mechanisms on the stationary blade and moving blade have been conducted for different droplet diameters at the inlet of the last stage. In our work, the moisture losses are divided into six categories namely thermodynamic loss, drag loss of fog droplets, drag loss of coarse droplets, impact loss, capturing loss and centrifuging loss. The effect of the fog droplet size at the inlet of the last stage on the moisture losses has been analyzed and the results indicate that the overall moisture losses rise and the relative fractions of each category of the moisture losses vary against the increase of the fog droplet diameter. By consider the above factors an attempt to e made to work for simulation modelling for better optimization using soft wares CATIA and ANSYS.

INTRODUCTION

The steam in low-pressure steam turbines of thermal power plants is generally expanded across saturation line and the rear stages operate in wet-steam conditions. The droplet nucleation process and the subsequent droplet laden flow in steam turbine cause additional energy dissipations which are collectively referred to as moisture losses. A full understanding of the moisture loss mechanisms is necessary for an accurate prediction of turbine performance. The moisture losses in steam turbine have been examined by many researchers. Baumann firstly attempted to quantify the moisture losses and proposed a simple empirical correlation which suggested that a 1% reduction in dry isentropic efficiency for each 1% mean wet ness fraction. However, the empirical approach offers no insight into the moisture loss mechanism. Needless to say, the physically based predict ion of the moisture losses in steam turbine requires the knowledge of the condensing flow-field and droplets deposition. A theoretical, physic ally consistent one-dimensional (1D) approach to evaluate moisture losses in steam turbine was proposed firstly by Gyarmathy. Since then, similar treatments were presented by Laali and Moore. These approaches did not consider the highly three-dimensional (3D) flow in low pressure stages, e.g. for large power steam turbines. In recent years, the advances in computer hardware and CFD technology have made it possible for a 3D calculation of condensing flow-field in steam turbine and thus a 3D analysis of the moisture losses. Starzmann et al. made a tentative prediction of the moisture losses in a three-stage model low pressure steam turbine by a 3D two-phase CFD modeling, but only thermodynamic loss, kinematic and braking losses were considered. Petr and Kolovratnik employed a statistical two-dimensional (2D) evaluation method to compute the moisture losses based on the 3D computational flow-field in a 1000 MW nuclear and a 210 MW fossil-fired low pressure steam turbine.

The moisture losses are related to the distribution of fog and coarse droplets in steam turbine. The coarse droplets originate from the fog drop lets deposition. Therefore, an understanding of the droplet deposition process is necessary for the prediction of the moisture losses. In general, the mechanisms of fog droplet deposition onto the turbine blades can be divided into the inertial impaction and turbulent diffusion. The deposition of small particles in turbulent pipe flow has been the subject of a large number of investigations but a few papers focused on fog droplets deposition in steam turbine, for example the work by Gyarmathy, Crane , Yau, Young and Starzmann. Yau and Young extended the theories of diffusional deposition proposed by Wood to predict the diffusional deposition of fog droplets on the steam turbine blades and employed a quasi-3D Lagrangian particle track method to determine the inertial deposition. Starzmann implemented the diffusional theory of Yau and Young into a full 3D multi-momentum two phase model to calculate the diffusional deposition of fog droplets on the stationary blades of the last stage of a model low-pressure steam turbine. In this work, the deposition of liquid droplets by the turbulent diffusion and inertial impact on the stationary and moving blades of the last stage of a 1000 MW fossil-fired steam turbine are calculated by the method of Yau and Young and a number of full-3D Euler–Lagrangian computations. Based on the results of droplets deposition and the 3D multi-phase flow solutions, a physically consistent 3D method to evaluate the moisture losses is presented and six categories of the moisture losses are determined for the last stage. In addition, the effect of fog droplets size at the inlet of the last stage on the magnitude and relative fractions of each category of the moisture losses is analyzed.

In general, steam turbines are complex machines in which a wide range of multidisciplinary mechanisms interact. The fundamental working principle of steam turbines is comprised in the expansion of the incoming steam, as it is through this expansion and using impulse to generate shaft power that the energy conversion from heat to electricity occurs. In addition, other relevant thermal processes within a steam turbine are those of gland steam sealing and losses due to friction and fanning. Future scenarios of the primary energy mix for 2050 expect that fossil fuels will remain a dominant source but that growth rates will be highest for renewable energy sources with increases in the global share of 5-10%.

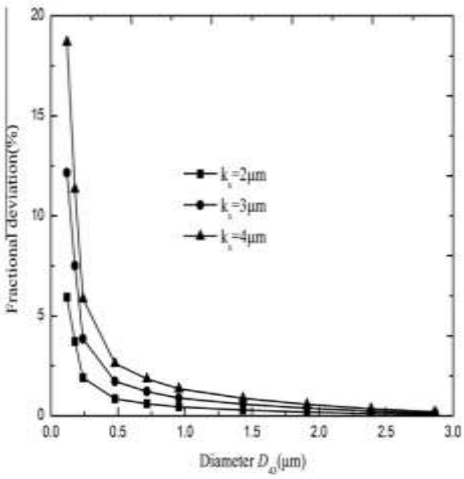
The increased penetration of renewables in the grid implies that the operation of steam turbines is required to be more flexible. The requirements are mainly related to fast cycling capabilities for frequency control as well as flexibility for start-up and shut-down. Furthermore, the deployment of renewable technologies based on steam cycles also poses higher requirements on steam turbine flexibility during start-up. An example of this is the operation of steam turbines in concentrating solar power plants (CSPPs). Due to the fluctuating nature of the solar supply, the number of start-up cycles endured by solar steam turbines is greater than those in base load plants, with multiple starts possible during a 24h period. The aforementioned requirements on steam turbine operation are related to flexibility during transient operation, especially during startup. A key aspect sought of such flexibility is the capability for fast starts. There are two main types of operating conditions a turbine can be subject to: steady state and transient. The latter occurs when the conditions under which the turbine is operating are variable.

MATHEMATICAL MODELS

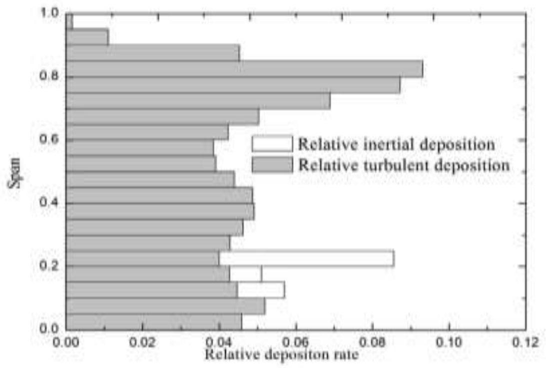
The condensing two-phase flow calculations are carried out with the commercial implicit solver ANSYS CFX 12.1. The solver uses an Euler–Euler method to predict the condensing steam flow. The coupling between conservation equations of mass, momentum and energy for the vapour phase and liquid phase is realized via a source term formulation. An advantage of the multi phase model is the possibility to realize a ''source specific'' droplet representation. Users are allowed to define several liquid phases and activate or deactivate each liquid phase to nucleate for the calculated domains separately. For the last stage considered in the current work, three liquid phases are defined to model the inlet droplets, droplets nucleated in the stationary blade domain and droplets nucleated in the moving blade domain respectively. The standard shear stress transport (SST) model is employed to model the turbulence and mixing planes are used between the stationary and rotating parts to perform steady flow simulations

Inhomogeneous multi-fluid model

The similar trends and magnitudes of the total deposition rate for the three results indicate that the Lagrangian particle track model employed in the current work and in the work of Young and Yau to calculate the inertial deposition can obtain equivalent results as the method based on the inhomogeneous multi-fluid model utilized by Starzmann. The three results show that, when the droplet size is small, the diffusional deposition dominates. With the increase of droplet diameter, the deposition by the inertial effect becomes significant.



However, there are also some differences among the three results. The main reason for the differences may be attributed to the different blades designs studied which affect the magnitudes and distributions of droplets sizes and the flow conditions at the inlet of the blade passage. The methods to calculate the inertial deposition of droplets are also different. For the Lagrangian method employed in this work, the growth of droplets is neglected which may underestimate the inertial deposition rate. But according to Young and Yau, the Lagrangian method can obtain the consistent results as measurements. The method to calculate the inertial deposition employed by Starzmann et al. is based on the inhomogeneous multi-fluid model in which the particle–wall interaction is neglected. The resulting high droplet concentration near the blades due to the accumulation of droplets may overestimate the inertial deposition rate. In addition, the different considered span heights among the three results may also bring some differences.



D×4

Relative deposition rate on the stationary blade over span height for different inlet droplets diameters.

The fog droplets deposited on the stationary blade coagulate into films and rivulets and are drawn toward the trailing edges of blades. Detachment of these films and rivulets at the trailing edge forms coarse water droplets consisting of larger droplets in the 10–100 lm size range. The evaluation of droplets deposition on the moving blade should take these coarse droplets into account. For this purpose, additional computations are conducted for the domain downstream of the trailing edge of the stationary blade together with the moving blade domain as shown in Fig. These additional computations include the simulations by the Euler–Euler multiphase model and the Lagrangian particle track model for different droplet sizes at the inlet of the last stage. In Fig., the coarse water inlet corresponds to the location of the trailing edge of stationary blade. The span-wise distributions of mass fraction of coarse droplets are given based on the results of fog droplet deposition on the stationary blade shown in Fig. The size of coarse droplets can be roughly evaluated from the critical Weber number which relates to the forces acting on a droplet to the surface forces.

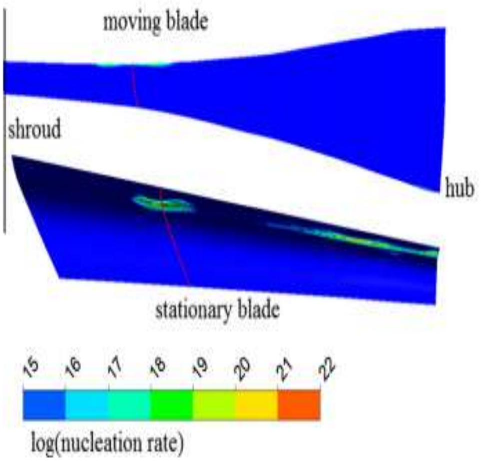
RESULTS OF MOISTURE LOSS CALCULATIONS

In this part, a physically consistent 3D method to evaluate the moisture losses is presented. The method is based on the 3D inhomogeneous multi-phase flow simulations and the results of droplets deposition on the stationary blade and moving blade. Six categories of loss mechanisms are considered and presented in detail in the following sections.

Thermodynamic loss

Thermodynamic loss is produced due to the heat and mass transfer between the vapor phase and liquid droplets at a different temperature during the droplet nucleation and growth processes. A principle to determine the entropy production rate is employed to estimate the thermodynamic loss.

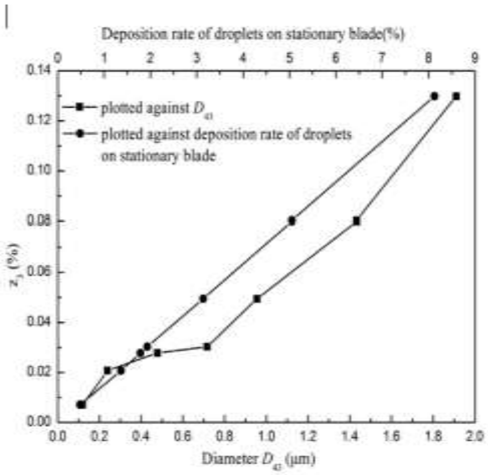
The computed thermodynamic loss of the last stage with different inlet diameters is shown in Fig. For small inlet fog droplets, a fast increase of thermodynamic loss is predicted while for large droplets, the loss coefficient remains approximately constant at about 4.6%. Fig. shows the nucleation rate for the case D * 4 in the last stage. The nucleation mainly occurs around span height 70% in the stator and rotor and near the hub in the stator. Compared to Fig. 1, the secondary nucleation rate for the case D*4 is much higher than that for the case D *1. It can be concluded that larger droplets have strengthened the secondary nucleation in the last stage, causing the temperature of droplets much higher than that of the surrounding steam. The resulting temperature difference is responsible for the increase of thermodynamic loss.



The surfaces for the contour plot are obtained by offsetting 2 mm from the suction surfaces of blades. The red line denotes the position of span height 70%. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

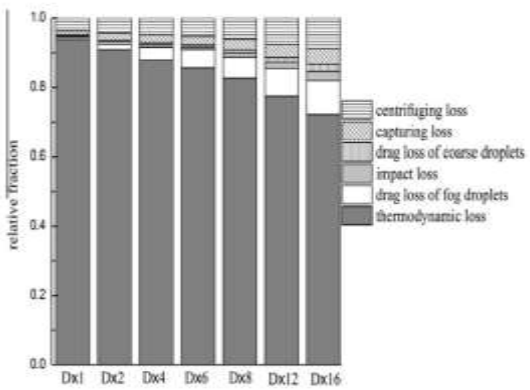
Impact loss

The coarse droplets re-entrained into the flow with much lower velocity than that of the steam and impinged on the leading edge of the moving blade. The impinging of coarse droplets on the moving blade causes a reduction of blade work, which is usually called impact loss. The impact loss can be determined from the momentum acting on the blade surfaces.



(b) Drag loss of coarse droplets

The drag losses of fog and coarse droplets for different fog droplets diameters at the inlet of the stage



Relative fractions of the six categories of the moisture losses for different fog droplet diameters at the inlet of the last stage.

METHODOLOGY OF MODELLING AND SIMULATION

With the advances in computer technology and cad system, complex programs can be modeled with relative ease. Several alternative configurations can be tried out on a computer before the first prototype is built .of the various design packages available in the market ,Pro-Engineer is a parametric feature based package which is very flexible and versatile and hence is widely used .also it has an additional advantage of direct interface with a CNC machine.

Finite Element Modeling Analysis

It is very difficult for human brain to examine critically the behavior of a complex structure subjected to different conditions. To overcome this, scientists started to divide the complex structure into individual components, whose behavior can be understood intuitively. This individual component is then assembled to study the behavior of the entire structure. This method of discretizing a complex structure and then making analysis on it is termed as Finite Element Method.

Need for Finite Element Analysis:

The tendency of structure or a component in a machine to fail increased with the complexity of structure. This necessitated the analysis of the machine during design, a building before and after construction, to ensure proper functioning and reduce production losses. The analysis becomes difficult and time consuming as the complexity of the model increases. This dictated the need for an efficient method that gives a reasonably good result and require less time. Finite element methods give plausible solutions to such problems and are much widely in use because the techniques can be adapted to digital computers.

In many situations, an adequate model is obtained by dividing it into a finite number of well-defined components called elements. Such problems are termed discrete. Whereas in some cases the discretization is finite and can only be defined by fictional mathematics equations. Such problems are termed continuous. It becomes difficult to solve such equations even by fast digital computers. This imposed the need for finite element methods, which uses equations that can be solved easily by the computers.

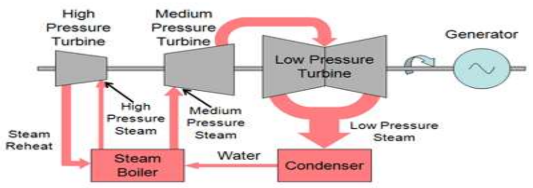
All these factors called for a need for Finite Element Methods

Advantages of Finite Element Methods

There are certain advantages of Finite Element Methods, which made it a widely used method. They are as follows:

1. With the advent of digital computers the analysis became cheaper, easier and faster.
2. Finite Element Analysis makes it possible to evaluate a detailed and complex structure in a computer during the planning stage itself. The demonstration in computer of the adequate strength of the structure and the possibility of improving the design during the planning stage justify the cost of analysis.
3. In the absence of Finite Element Analysis (or any numerical methods), designing and analysis of structures are based on hand calculations. Certain assumptions have to be made to reduce the complexity of calculations. This reduces the accuracy of solution. FEA makes effective use of numerical techniques, and even though some assumptions are made, the desired degree of accuracy can be achieved.

MODELING



Multi Stage Steam Turbine Generator

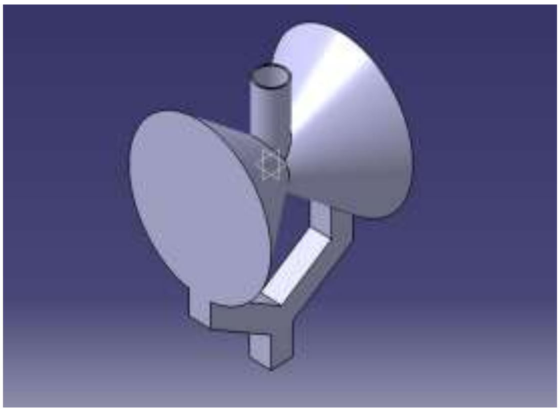


Figure: shows the objective modeling of low pressure steam turbine

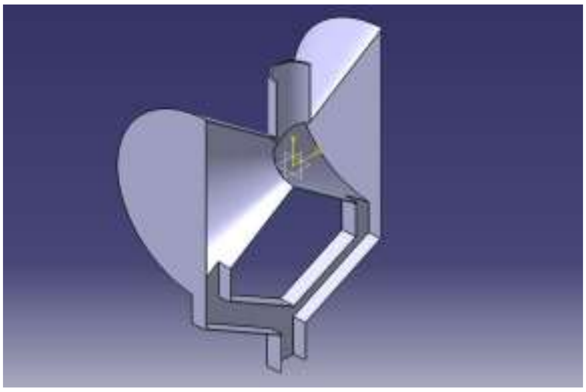


Figure: shows the sectional phenomenon of application

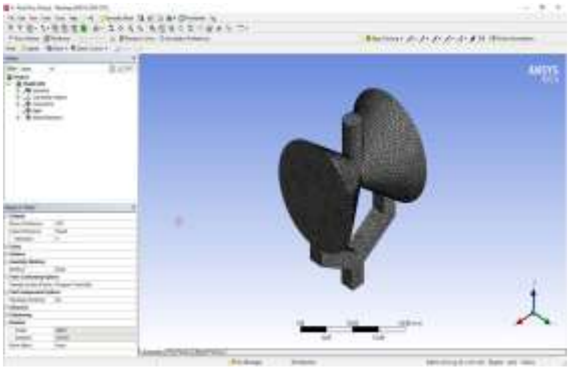


Figure: shows Fine mesh of steam turbine

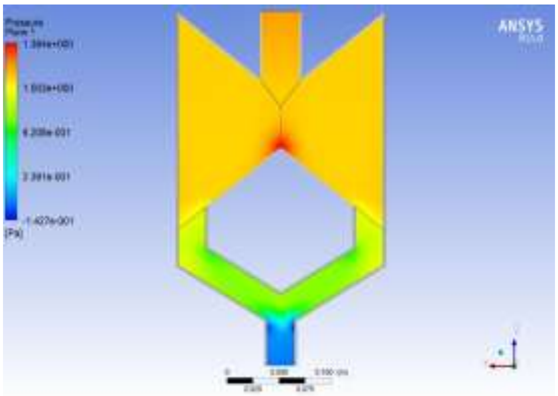


Figure: shows pressure inlet

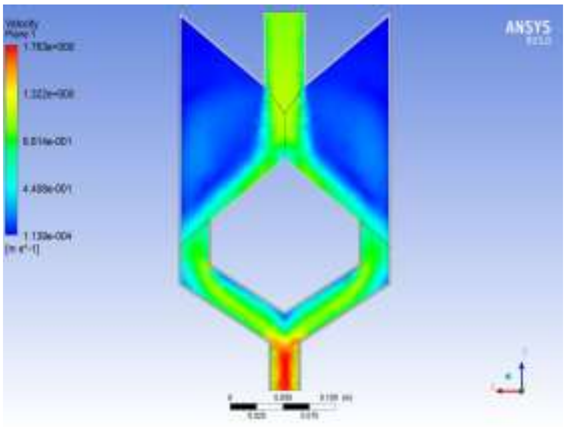


Figure: shows velocity inlet

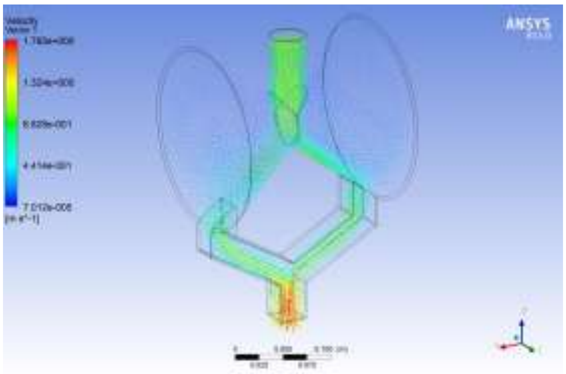


Figure: shows velocity vector contours

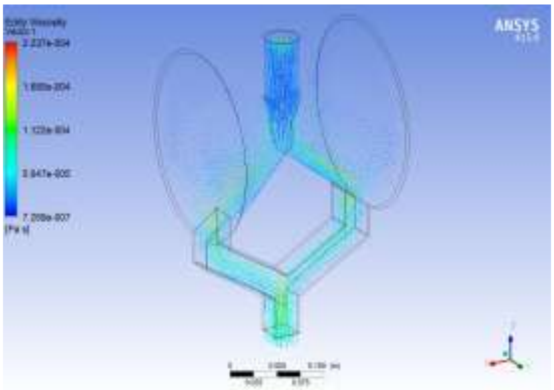


Figure: shows the velocity distribution

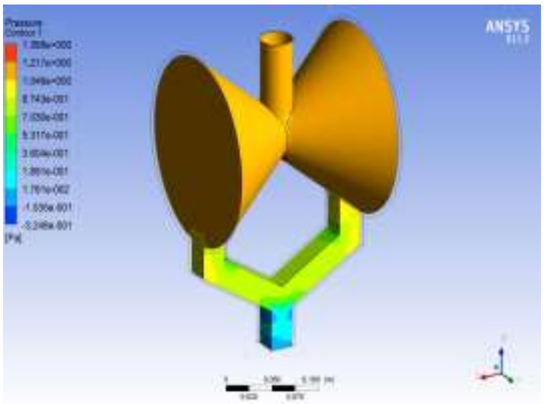


Figure: shows the pressure contour areas

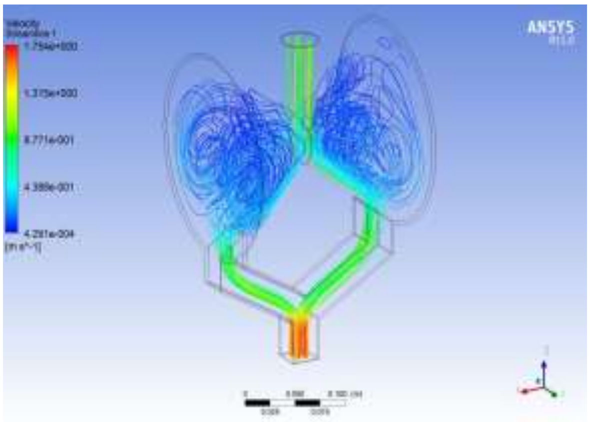


Figure: sows the velocity distributions

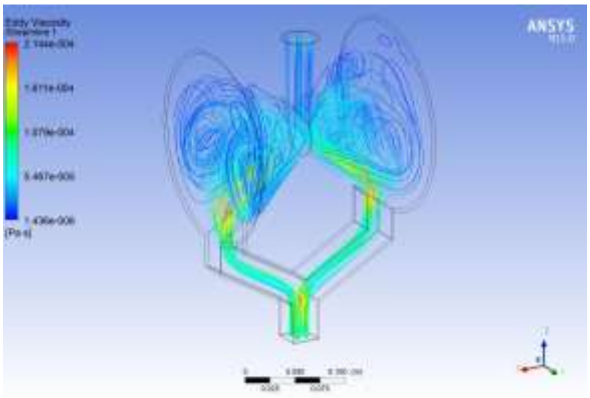


Figure: shows maximum velocity vectors at edges.

CONCLUSIONS

In the current work, a prediction of the diffusional and inertial deposition of droplets on the stationary blade and moving blade for different fog droplet diameters at the inlet of the last stage of a 1000 MW fossil-fired steam turbine has been realized. A Lagrangian particle track model was used to predict the inertial deposition and the span-wise distributions of droplet diameter and mass fraction were considered by settings of injection regions. For the determination of the droplets deposition on the moving blade, separate calculations were conducted on the domain downstream the trailing edge of the stationary blade together with the moving blade domain.

In the context of 3D multi-phase flow solutions and the droplets deposition predictions on the blades, a physically consistent 3D method to evaluate the moisture losses has been presented. Within the method, the moisture losses are divided into six different categories namely thermodynamic loss, drag loss of fog droplets, drag loss of coarse droplets, impact loss, capturing loss and centrifuging loss. All six categories as well as the total moisture losses in the last stage are determined for different fog droplet diameters at the inlet of the last stage. Results demonstrate that inlet droplet diameter has significant effect on the moisture losses and larger inlet droplets results in higher moisture losses. In addition, for all cases considered, the thermodynamic loss dominates. With the increase of fog droplet diameter, the relative fraction of thermodynamic loss decreases and the relative fractions of other five categories of the moisture losses rise.

For the current work, the analysis is based on the steady calculations. As indicated by the wake chopping effects due to the inherent unsteadiness in turbine may have impact on the nucleation process and droplet sizes. It is the ambition of the authors to consider the unsteadiness effect when estimating moisture losses in the future.

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