THREE DIMENSIONAL EFECTS IN SPONTANEOUS CONDENSATION IN THE WET STEAM FLOW

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In the present paper we have focused on the prediction of the spontaneous condensation in wet steam flow. The practical issue is to compare different tree dimensional ways of modelling of steam flow under low-pressure conditions by using an ideal gas assumption, and equilibrium and non-equilibrium models of condensation phase production. The basic tests including comparison with an experimental data have been performed using de Laval nozzle.

One of the most unwanted effect of turbine operation in low pressure conditions, is related to non-equilibrium condensation. As far as phase transitions are induced by the pressure drop, these do not always occur in the vicinity of the saturation line. According to the rate of pressure drop and the steam quality, these phase transitions can occur far from equilibrium conditions. In such situation the basic questions are focused on inception and growth of water droplets due to homogenous and heterogeneous condensation. Process of growth of individual droplet is governed by mass, momentum and energy transport mechanism between gas and liquid phases. Droplet growth can be described by an evolution of radius of droplet that moves in the wet steam field. Models are needed when nucleation start at some particles, dust, chemical compounds or corrosion products, that often happens before a Wilson line. Other sources of droplets are related to the mechanical action of steam flow and water film at surface of blades. [2,3].

If we want to model a liquid phase evolution, we should employ a mathematical model of condensed phase production that is analogous to governing equations of mass, momentum and energy, and can be discretized using the same numerical grid. We propose then a set of new transport equations [2]:

▪ balance of turbulent kinetic energy k :

$$\partial_t(\rho k) + \mathrm{div}(\rho k \mathbf{v}) = \mathrm{div}(\mathbf{J}_k) + \rho S_k \quad , \tag{1}$$

▪ balance of turbulent kinetic energy dissipation rate ε :

$$\partial_t(\rho \varepsilon) + \mathrm{div}(\rho \varepsilon \mathbf{v}) = \mathrm{div}(\mathbf{J}_\varepsilon) + \rho S_\varepsilon \quad , \tag{2}$$

▪ balance of dryness fraction x:

$$\partial_t(\rho x) + \mathrm{div}(\rho x \mathbf{v}) = \mathrm{div}(\mathbf{J}_x) + \rho S_x \quad , \tag{3}$$

▪ balance of droplet number a :

$$\partial_t(\rho a) + \mathrm{div}(\rho a \mathbf{v}) = \mathrm{div}(\mathbf{J}_a) + \rho S_a \quad , \tag{4}$$

where closures $\mathbf{J}_k$, $\mathbf{J}_\varepsilon$, $\mathbf{J}_x$, $\mathbf{J}_a$, S_k, S_ε, S_x, S_a have been eloborated in the paper [3].

The Fig. 1 shows an average in the section pressure *p*, enthalpy *h*, temperature *t* and wetness fraction *y=(1-x)* in de Laval nozzle. For comparison a 3D ideal gas, 3D equilibrium model and 3D non-equilibrium model of wet steam is presented in Fig.1. It should be underlined that until the condensation starts and the thermal blockage occurs an ideal gas assumption agree very well with wet-steam models and experimental data.

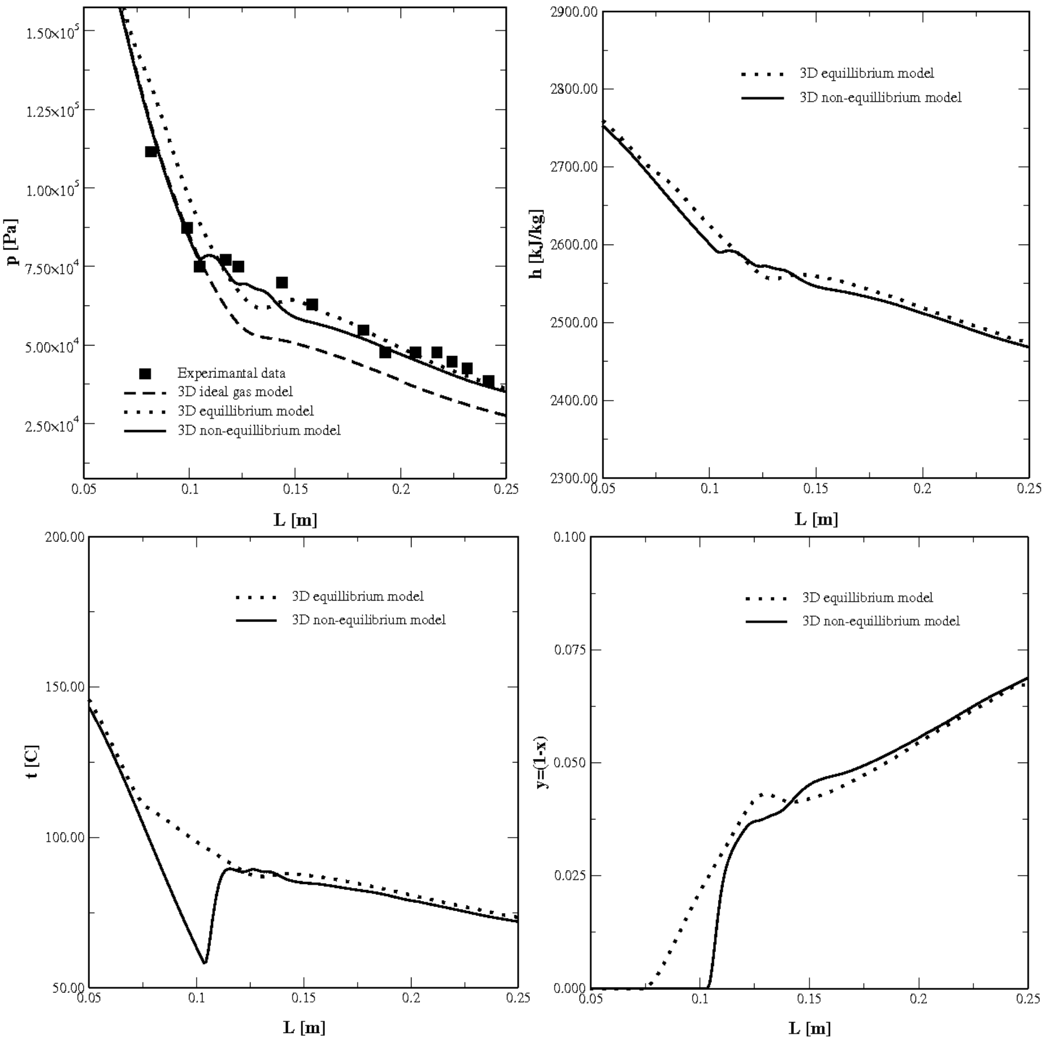

Fig.1. Pressure *p*, enthalpy *h*, temperature *t* and wetness fraction *y*=(1-*x*) changes in de Laval nozzle according to experimental data [1].

[1] R. Puzyrewski: Theoretical and experimental studies on formation and growth of water drops in LP steam turbines, *Transactions of IFFM* 42-44 (1969) 289-303.
[2] Z. Bilicki, J. Badur: A thermodynamically consistent relaxation model for a turbulent, binary mixture undergoing phase transition, *Journal of Non-Equilibrium Thermodynamics* **28** (2003) 145-172.
[3] M. Karcz, W. Zakrzewski, M. Lemański, J. Badur: *Zagadnienia modelowania 3D spontanicznej kondensacji w części niskoprężnej turbiny parowej 200MW,* Materiały konferencyjne X Międzynarodowej konferencji naukowo – technicznej Elektrownie Cieplne Eksploatacja – Modernizacje - Remonty, Słok 6-8 czerwca 2011.