A deaerator model

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Abstract: - The modelling of the different components of a power plant represents an useful tool in activities like design, verification of the control system, optimum operation of the power plant, training and analyses of behaviour. The deaerator is one of the important equipments in a power plant, because of its degassing and preheating role, but also because of the cavitation and chocking problems that may appear due to faulty operation. The use of a deaerator simulation model represents a simple and efficient way to study its behaviour.

The paper presents a mathematical model of the deaerator, based on the physical laws of mass and energy conservation. Differential equations are used to analyze the parameters variation over time. The results obtained during the turbine shut-down are presented as an example.

Key-Words: - deaerator, power plant, model, conservation laws

1 Introduction

The study of the dynamic behavior of the various equipments of the power plants is of interest in different fields, starting from research and design, to the assistance of operation, decision-taking, optimization, training and failure analysis.

The deaerator is an important component of the feed-water preheating circuit of a power plant. Its main role is to discharge the oxygen and to preheat the make-up water.

Besides accomplishing its scope, the proper operation of the deaerator is important during the transitory regimes of uploading or downloading a power plant. The problems that may appear during these periods [1] include:

- cavitation in the suction area of the feed-water pumps
- chocking in the deaerator.

The paper presents a dynamic simulation model of the deaerator. The mathematical background of the model consists of the physical laws of mass and energy conservation. They are completed with the other relations that link the different physical parameters [2].

Some results obtained for the turbine shutdown regime are presented as an example.

2 The deaerator – functionality and role in a power plant

The main function of the deaerator is to eliminate the gases (primarily the oxygen) from the feed water before it enters the boiler, in order to avoid corrosion of the power plant installation..

The elimination of gases is based on their decrease of solubility when the temperature increases. In the deaerator, the temperature is raised by the addition of steam into the make-up water.

The construction of the deaerator (fig. 1) consists of two sections [3]:

- the degassing section, in the upper side
- the storage water tank, in the lower side

From a functional point of view, the deaerator is a direct contact (mixing) heat exchanger for the feed water. The saturation temperature of water is maintained so that gases are separated and eliminated at the upper side of the deaerator. To do this, in the degassing section water is dropped in counter-current with the ascending steam. At saturation, the quantity of gases dissolved in water tends to zero.

ISBN: 978-960-474-318-6

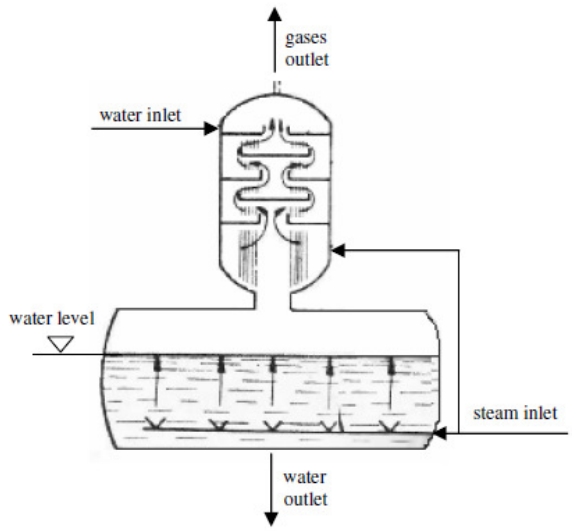

Figure 1. The deaerator functional scheme

To keep the saturation temperature in the whole degassing system, bubble steam is introduced bellow, in the storage water tank. Due to the presence of the water tank, the deaerator represents also a preheated water storage reserve for the main circuit of the power plant.

The model of the deaerator considers the of following physical processes [4, 5]:

- at the saturation phase, vapours and liquid water are at equillibrum
- there is the same pressure in the degassing section and in the water tank
- the degassification process is determined exclusively by the process of water heating
- there is a variation of the level in the water tank, as an effect of the input/output flows and of the processes within the equipment.

The physical processes that are neglected and implicitly not considered in the model include:

- the effects of non-condensable gases
- the variation of the concentration of gases in steam
- the heat loss in walls.

3 The deaerator model

The model developed is based on the law of conservation of mass and energy written in unidirectional geometry and with concentrated parameters [6].

The change of any parameter generates a transient process by which the system is evolving towards a new steady-state regime.

The independent variable in the differential equations is the time.

3.1 Boundary parameters

From a functional point of view, the fluids that pass at the border of the deaerator are: the input steam, the input make-up water, the output preheated water (at saturation).

For these fluids, some of their parameters represent known input parameters and others represent unknown output parameters for the model. This is why the input parameters of the model may differ from the functional input parameters in the real equipment. As an example, the enthalpy of the input make-up water (which enters the deaerator) is an output parameter for the model, as it is calculated within it. Similar, the water flow leaving the deaerator represents an input parameter for the model, as it is an imposed, given value.

From the model's point of view, the input (known) parameters are:

- for the steam entering the deaerator:
  - D_s - flow [kg/s]
  - p_s - pressure [Pa]
  - t_s - temperature [°C]
- for the water entering the deaerator:
  - D_w - flow [kg/s]
  - p_w - pressure [Pa]
  - t_w - temperature [°C]
- for the water coming out of the deaerator:
  - D_o - flow of output, saturated water [kg/s].

The output parameters of the deaerator model are:

- for the steam entering the deaerator:
  - h_s - enthalpy [J/kg]
  - p_s - pressure [Pa]
  - t_s - temperature [°C]
- for the water entering the deaerator:
  - h_w - enthalpy [J/kg]
  - p_w - pressure [Pa]
  - t_w - temperature [°C]
- for the water coming out of the deaerator:
  - h_o - enthalpy [J/kg]
  - p_o - pressure [Pa]
  - t_o - temperature [°C]
  - ρ_o – density [kg/m^3].
- parameters from inside the deaerator:
  - p_s - pressure [Pa]
  - y – level of water in the tank [m].

The boundary parameters of the model are schematised in fig. 2. Thick arrows show the input

ISBN: 978-960-474-318-6

(known) parameters and thin arrows show the output (unknown) parameters.

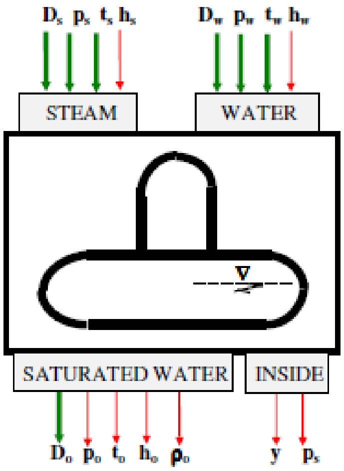

Figure 2. Boundary parameters for the deaerator model

3.2 The equations of conservation

The core of the model is given by the equations of mass and energy conservation, written for the deaerator. Differential equations are used to analyze the parameters variation over time [7].

In the model, the following equations of conservation are used:

- The equation of mass conservation:

$$\frac{d\rho}{d\tau} = \frac{1}{V}\left[D_s + D_w - D_o\right] \tag{1}$$

where:

ρ – density [kg/m^3]
V – volume [m^3]
τ – time [sec]

- The equation of energy conservation:

$$\frac{du}{d\tau} = \frac{D_w \cdot h_w + D_s \cdot h_s - D_o \cdot h_o - V \cdot u \cdot \frac{d\rho}{d\tau}}{\rho \cdot V} \tag{2}$$

where:

u – internal energy [J/kg]
D - flow [kg/s]
h - enthalpy [J/kg]
ρ – density [kg/m^3]

indices: w- water
s- steam
o- output water

The density is calculated from the mass conservation equation (1) and the internal energy from the energy conservation equation (2).

The pressure within the deaerator is:

$$p_s = f(\rho, u) \tag{3}$$

Similar, the other parameters of the fluids are obtained from the water-steam properties [2, 8]:

$$t_s = f(\rho, u) \tag{4}$$

$$h', \rho' = f(p, t) \tag{5}$$

$$h'', \rho'' = f(p, t) \tag{6}$$

where:

t_s – temperature at saturation [°C]
ρ', ρ'' – water/steam density at saturation [kg/m^3]
h', h'' – water/steam enthalpy at saturation [J/kg]

The pressure at the base of the deaerator (the outlet water pressure) is given by :

$$p_0 = p_s + \rho \cdot g \cdot y \tag{7}$$

where:

g – acceleration of gravity [m/s^2]
y – level of water in the tank [m]

The water level in the deaerator of the tank is given by considering the volumes of the two phases (steam and water). Making the assumption that the variation of the level is linear with the variation of the volume of the condensate, the level is given by:

$$y = h_r \cdot \frac{\rho - \rho''}{\rho' - \rho''} \tag{8}$$

where:

h_r – height of the storage water tank [m]

Fig. 3 describes the structure of the modelling algorithm for the deaerator.

The input and output parameters of the model are the boundary parameters listed in chapter 2.1.

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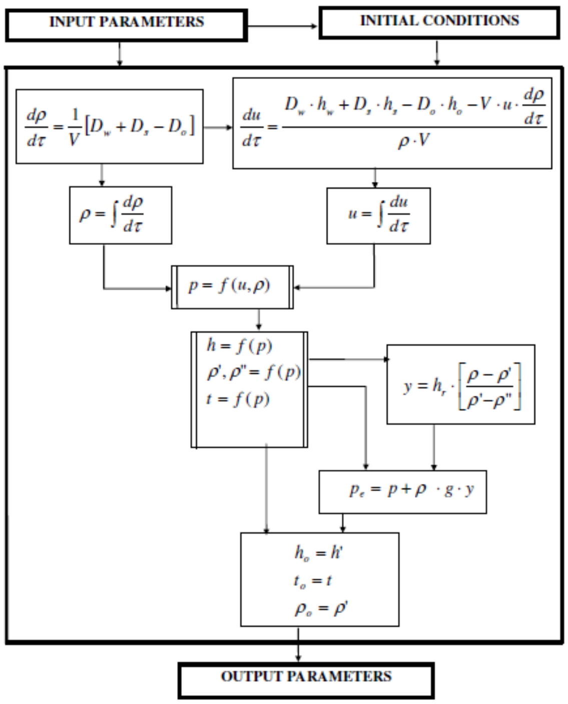


Figure 3. Modelling algorithm for the deaerator

The initial conditions of the model contain the geometrical dimensions of the deaerator, the initial values of the physical parameters and other constants.

To control the level in the storage water tank, a control model is used [9]. Such a model is not the subject of this paper.

The mathematical model was written using the Advanced Continuous Simulation language (ACSL), developed by Mitchell and Gauthier Associates [10].

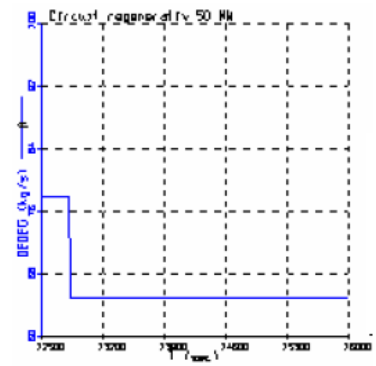
4 Simulation example

The model was used to simulate the deaerator from the primary circuit of the cogeneration 50 MW power plant [11].

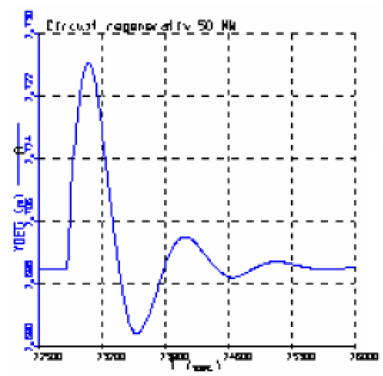
To check the dynamic behaviour of the model, transitory operation regimes are studied, especially during the turbine loading and shut-down.

To control the water level inside the water storage tank, an automation model was added to the deaerator model (not described in the paper) [6]. The control model opens or closes the supplementary feed-water valve to bring and maintain the level of water in the storage tank at the prescribed value.

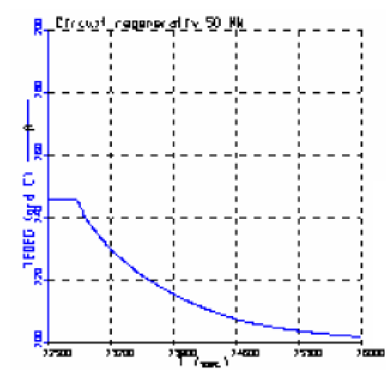
Fig. 4 contains the results of the transitory regime during the turbine shut-down.



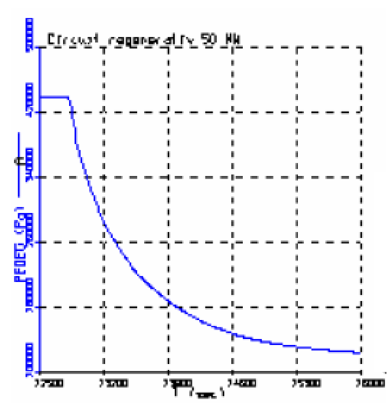
(a) outlet water flow



(b) water level



(c) outlet water temperature



(d) outlet water pressure

Figure 4. Simulation results

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At the turbine shut-down regime, the steam supply to all the heat-exchangers is interrupted, except to the deaerator. The latter is supplied with a lower steam flow.

The main effects of the turbine shut-down over the preheating circuit are:

- a lower feed water flow in the circuit, which was imposed to the model by a step change in the water flow that leaves the deaerator. This flow is an input value for the simulation model (fig. 4-a)
- the variation of the level in the deaerator (fig. 4-b). Through a damped oscillations process, the level is brought back to the reference point. This effect is made possible by the intervention of the control system over the regulating valve of the supplementary water in the circuit.
- the decrease of the thermo-physical properties of the fluids in the deaerator (fig.4-c,d), as a consequence of the reduction of the steam and water flows and of their parameters (pressure, temperature).

As showed in fig. 4, the variation of the parameters evolves towards a new stationary regime when the input values stop changing.

5 Conclusion

The development of the simulation models for the thermal processes in power plants is a very useful tool for activities like design of power plants, control systems and monitoring systems, assistance for the operation and the management staff, failure analyses and training.

The deaerator is a delicate equipment of the power plant's preheating circuit, especially during the transitory regimes of the power plant start and shut-down. By using a model, its behavior during operation can be easily studied and different malfunctions can be avoided.

The model presented in the paper is based on the physical conservation laws, completed with other relations that describe the fluids properties. To follow the dynamic behavior, differential equations are used, written in concentrated parameters. The independent parameter of these equations is time.

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