

STUDY REGARDING SIMULATION AND MODELING OF STEAM CONDENSER

GRIGORE ROXANA, DRAGUSANU VASILE, LAZAROIU GHEORGHE, POPA SORIN

University of Bacau, S.C. CET S.A.BACAU, University POLITEHNICA Bucuresti

Abstract: The steam condenser is a major component of a power plant cycle. In the space of the condenser, the steam which exhaust from the turbine is forced to give up its latent heat of vaporization. The condenser generates a vacuum which increases the amount of energy extracted from the steam by the turbine. The stability of operation and the efficiency of the power plant depend on the efficiency of steam condenser operation. These things go to developing a dynamic model of steam condenser.

Keywords: steam condenser, governing equations, finite element method, method Petrov-Garlekin, mesh

1. STEAM CONDENSER OF THE BACAU POWER PLANT

The condenser plays two important roles [1]:

- It converts the used steam back into water for return to the steam generator as feedwater. This lowers the operational cost of the power plant because the clean and treated condensate is reused.
- It increases the cycle's efficiency.

The condenser of the steam turbine DSL 50-1 is water cooled- steam surface condenser with two-tubeside passes. The shell is fabricated from carbon steel and contains the heat exchanger tubes. At the bottom of the shell, where the condensate collects, an outlet is installed. A hotwell is provided. Condensate is pumped from the hotwell for reuse as feedwater for steam generator. The tube bundle and waterboxes are divided into two sections (figure 1).

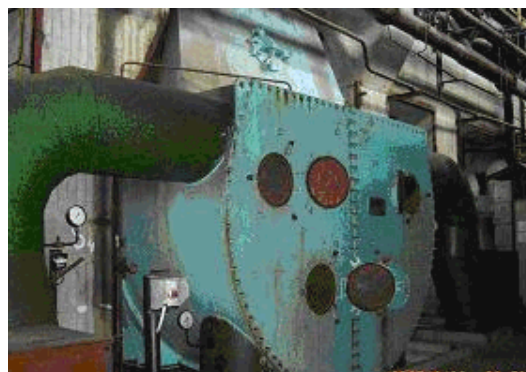


Fig. 1. View of steam condenser of Bacau Power Plant

The main heat transfer mechanism in a surface condenser is the condensing of saturated steam on the outside of the tubes and the heating of the circulating water inside the tubes. Thus for a given circulating water flow rate,

the water inlet temperature to the condenser determines the operating pressure of the condenser. . The condenser generates a vacuum which increases the amount of energy extracted from the steam by the turbine. The condenser also serves as a low-pressure collection point for various vent and drain streams within the plant. Technical dates regarding condenser of the steam turbine DSL 50-1 are in the table 1.

Table 1. Technical dates regarding condenser of the steam turbine DSL 50-1

	Name	U.M.	Value
In steam space	Fluid flow	t/h	127,4
	enthalpy	kJ/kg	2319,598
	Inlet static pressure	bar	0,054
	Cleanliness factor	%	0,85
	O ₂ maxim residual content	mg/kg	(14±2)*10 ⁻³
	Outlet temperature for steam-air mixture	°C	-
In cooling water space	Water quality	-	Filtrate untreated
	Inlet temperature	°C	20
	Fluid flow	m ³ /h	8000
	Velocity	m/s	1,7÷2
	Pressure drop	mH ₂ O	3,6
General	Minim difference between steam saturation temperature and outlet water temperature	°C	-
	Passes number	-	2
	Tubes number	-	5860
	Heat exchange surface	m ²	3000
	Hotwell capacity	m ³	1,4

The tubes are made from brass (70%Cu, 30%Ni). The shell's internal vacuum is supplied and maintained by an external steam jet ejector system.

2. THE ACHIEVEMENT OF MODELING OF STEAM CONDENSER

Modeling of a process or equipment involves the execution of the next steps[6]:

- Physical modeling;
- Mathematical modeling;
- Simulation (numerical modeling);
- Visualization;
- Validation.

Mathematical modeling includes assignation of governing equations. The partial differential equations governing fluid flow and heat transfer include the continuity equation, the Navier-Stokes equations and the energy equation. These equations are intimately coupled and non-linear making a general analytic solution impossible except for a limited number of special problems, where the equations can be reduced to yield analytic solutions. Because most practical problems of interest do not fall into this limited category, approximate methods are used to determine the solution to these equations. There are numerous methods available for doing so. In this paper is used the Cosmos/Flow program.

COSMOS/Flow solves the mathematical equations which represent heat and momentum transfer in a moving fluid. The finite element method is used to *discretize* the flow domain, thereby transforming the governing partial differential equations into a set of algebraic equations whose solution represents an approximation to the exact (and most often unattainable) analytical solution. The numerical formulation is derived from the SIMPLER solution scheme introduced by Patanker [3].

2.1. Governing equations

The governing equations for fluid flow and heat transfer are the Navier-Stokes or momentum equations and the First Law of Thermodynamics or energy equation. The governing pdes can be written as [2],[5]:

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z} = 0 \quad (1)$$

x-,y-,z-momentum equations:

$$\begin{aligned} \rho \frac{\partial u}{\partial t} + \rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} + \rho w \frac{\partial u}{\partial z} &= \rho g_x - \frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left[2\eta \frac{\partial u}{\partial x} \right] + \frac{\partial}{\partial y} \left[\eta \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right] + \frac{\partial}{\partial z} \left[\eta \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right) \right] + S_\omega + S_{DR} \\ \rho \frac{\partial v}{\partial t} + \rho u \frac{\partial v}{\partial x} + \rho v \frac{\partial v}{\partial y} + \rho w \frac{\partial v}{\partial z} &= \rho g_y - \frac{\partial p}{\partial y} + \frac{\partial}{\partial y} \left[2\eta \frac{\partial v}{\partial y} \right] + \frac{\partial}{\partial x} \left[\eta \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right] + \frac{\partial}{\partial z} \left[\eta \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right) \right] + S_\omega + S_{DR} \\ \rho \frac{\partial w}{\partial t} + \rho u \frac{\partial w}{\partial x} + \rho v \frac{\partial w}{\partial y} + \rho w \frac{\partial w}{\partial z} &= \rho g_z - \frac{\partial p}{\partial z} + \frac{\partial}{\partial z} \left[2\eta \frac{\partial w}{\partial z} \right] + \frac{\partial}{\partial x} \left[\eta \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right) \right] + \frac{\partial}{\partial y} \left[\eta \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right) \right] + S_\omega + S_{DR} \end{aligned} \quad (2)$$

The two source terms in the momentum equations are for distributed resistances and rotating coordinates, respectively. The distributed resistance term can be written in general as:

$$S_{DR} = - \left(K_i + \frac{f}{d} \right) \frac{\rho V_i^2}{2} - C \eta V_i \quad (3)$$

where i refer to the global coordinate direction (u, v, w momentum equation) and the other terms are described in the previous section. Note that the K-factor term can operate on a single momentum equation at a time because each direction has its own unique K-factor. The other two resistance types operate equally on each momentum equation.

The other source term is for rotating flow. This term can be written in general as:

$$S_\omega = -2\rho \omega_i \times V_i - \rho \omega_i \times \omega_i \times r_i \quad (4)$$

where i refer to the global coordinate direction ω is the rotational speed and r is the distance from the axis of rotation.

For incompressible and subsonic compressible flow, the energy equation is written in terms of static temperature:

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p u \frac{\partial T}{\partial x} + \rho c_p v \frac{\partial T}{\partial y} + \rho c_p w \frac{\partial T}{\partial z} = \frac{\partial}{\partial x} \left[k \frac{\partial T}{\partial x} \right] + \frac{\partial}{\partial y} \left[k \frac{\partial T}{\partial y} \right] + \frac{\partial}{\partial z} \left[k \frac{\partial T}{\partial z} \right] + q_v \quad (5)$$

The variables in these equations are defined in Table 2.

Table 2. Variables of the governing equations

Variable	Description
c_p	constant pressure specific heat
k	thermal conductivity
p	pressure
q_v	volumetric heat source
T	temperature
t	time
u	velocity component in x-direction
v	velocity component in y-direction
w	velocity component in z-direction
ρ	density

The continuity, momentum and energy equations represent 5 equations in the 5 unknowns: u , v , w , p , T or T_0 . They describe the fluid flow and heat transfer under steady-state conditions for Cartesian geometries.

For the turbulent flow, the solution of these equations would require a great deal of finite elements (on the order of 106 - 108) even for a simple geometry as well as near infinitesimal time steps. COSMOS/Flow solves the *time-averaged* governing equations.

The time-averaged equations are obtained by assuming that the dependent variables can be represented as a superposition of a mean value and a *fluctuating value*, where the fluctuation is about the mean.

2.2. Discretization method

In COSMOS/Flow, the finite element method is used to reduce the governing partial differential equations (pdes) to a set of algebraic equations. In this method, the dependent variables are represented by polynomial shape functions over a small area or volume (element). These representations are substituted into the governing pdes and then the weighted integral of these equations over the element is taken where the weight function is chosen to be the same as the shape function. The result is a set of algebraic equations for the dependent variable at discrete points or nodes on every element. One of the methods applied is method Petrov-Garlekin.

2.3. Boundary conditions and simplified hypothesis for modeling and simulation steam condenser

The physical model is realized in Solid Work. It is opening the file contains geometric modulation (Condensat_01c-0mm) and is defining the study of case, by specifying its name, analysis type, the disparagement mode (*shell*-for surface analysis). For this example, it defining thermal analysis (result type: permanent or transient, the iterative resolving technique: Newton-Raphson scheme, initial temperature and calculus tolerance). It defines material types (all, including shell, tube, fluids) for components. It defines loading and boundary condition. After those, it applied *mesh*, the disparagement mode, which is very important for the final results.

Simplified hypothesis:

- ✓ Mathematical description of steam flow in the porous media with negative source in cross – section of condenser;
- ✓ The steam is assumed like an homogenous condensate-steam mixture (biphasic);
- ✓ It is one inlet for the feedwater;
- ✓ The model doesn't consider the effect of noncondensable gases. It is ignorable velocity fall because of gases concentration increases;
- ✓ For the simplification of the model, it is modeled one tube for feedwater, The rest of the tubes are considered like distributed hydraulic resistances and with interior heat source.
- ✓ Is is applied symmetric condition.
- ✓ Water, steam and homogenous condensate-steam mixture are Newtonian fluids.

Boundary conditions

There are 5 types of boundaries for which conditions must be imposed on the governing equations: inlets, outlets, no-slip walls, symmetry lines, and slip walls.

Inlets

Table 3. Inlet data

No.	Fluid	Description	U.M.	Value
1	Cooling water	Temperature	°C	20
2		Velocity	m/s	1,844
3	Steam	Temperature	°C	34,2
4		Pressure	bar	0,0538
5		Scalar (steam title)	-	0,89

Internal heat sources: $14670/2=7335W$.

2.4. Results display

After the analysis was processed it can be visualized the results, under graphical form or numerical value(fig.3)[4].

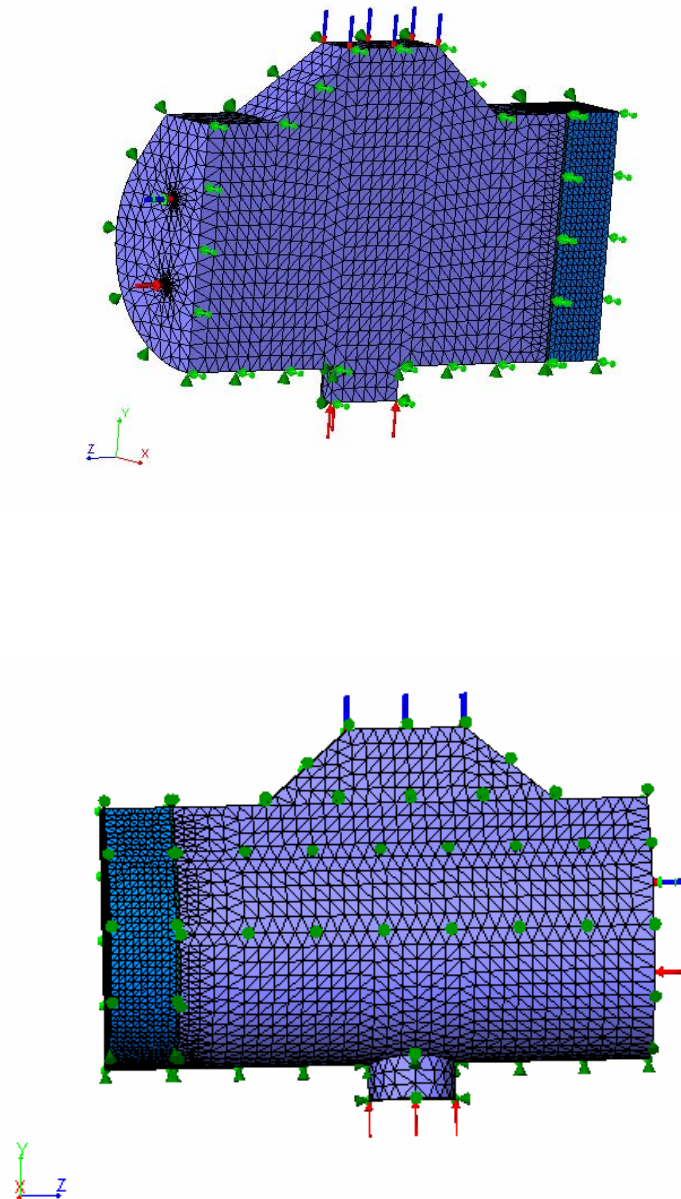


Fig. 2. Mesh

It is very important to realize the mesh with great accuracy. For the cooling water tube was allocated fine mesh, because the dimension was small (exterior diameter 25mm).

Analyze run for 50 iterations, in turbulence conditions. In the up side of the condenser take place an intensive heat transfer (values for heat transfer rate are bigger than in the down side of steam condenser).

The model is perfectible. However, it is difficult to realize a complete model because of the computer limits.

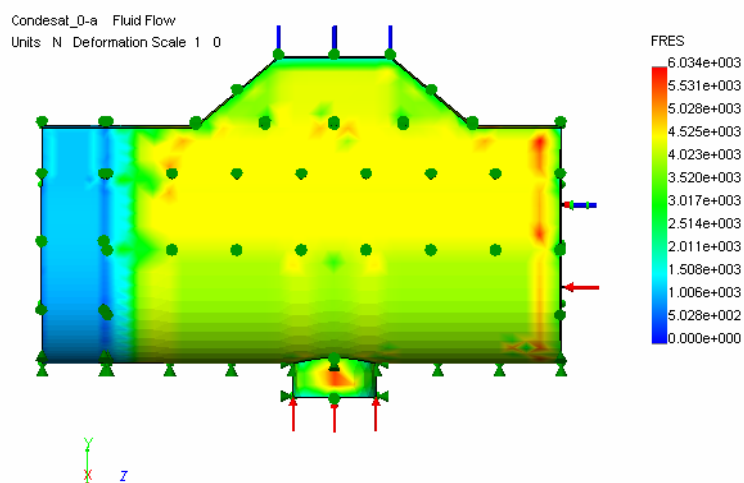
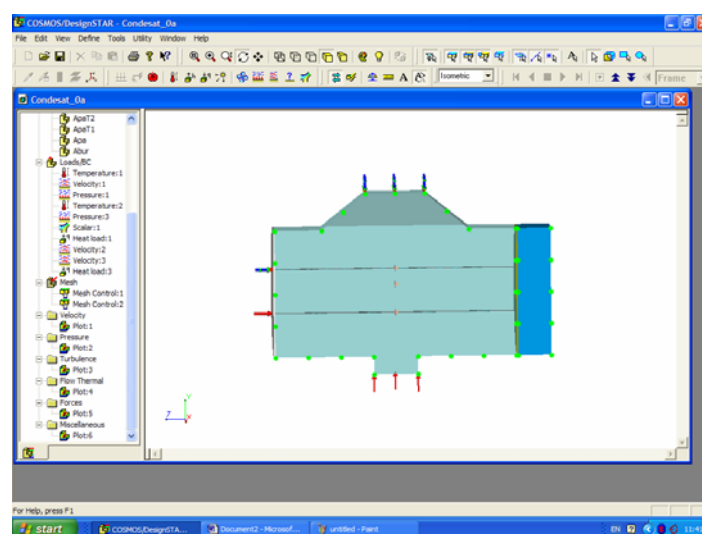


Fig. 3 Results

REFERENCES

- [1] Badea A., Necula H., Stan M., Ionescu L., Blaga P., Darie G., *Echipamente și instalații termice*, Editura Tehnică, București, 2003
- [2] *** COSMOS/Flow Technical Reference
- [3] Patanker, S.V., *Numerical Heat Transfer and Fluid Flow*, Hemisphere Publishing, New York, 1980
- [4] Grigore R., *Modelarea și simularea condensatorului turbinei de abur DSL 50-1*, referat de doctorat nr.3, Universitatea Politehnica București
- [5] Lăzăroiu Gh., *Sisteme de programare pentru modelare și simulare*, Editura POLITEHNICA PRESS, ISBN 973-8449-78-2, 490 pg., București, 2005.
- [6] Lăzăroiu Gh., *Modelarea și simularea funcționării dinamice a CTE*, seria *Exploatarea centralelor electrice*, Editura Printech, ISBN 973-98453-2-0, 203 pg., București 1998.