

# Cooling Circuit Model for Computer Simulator

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## Abstract

**Background/Objectives:** The cooling circuit model of parallel connected equipment units for the computer simulator is described. **Methods/Statistical Analysis:** For simulation of the cooling circuit with specified configuration of the pipeline system the loop flow method based on generalized Kirchhoff's law was used: balance of the flow for each pipeline branching point and equation of each circuit cycle. **Findings:** The results of the model operational performance in case of emergency situations at water flow rate change in standard and emergency operation modes of the cooling circuit are presented. Technological pipelines network as the scheme of parallel-connected lines and applying to it the described method, it is possible to determine the values of cooling water rates at any moment of time. The calculated water rates serve as input signals for the equipment units cooling system model. The required parameters of the model for simulating emergency situations in the cooling circuit were found experimentally. The graphs presented in the article illustrate function testing of the cooling model operational performance when emergency characteristics change. **Applications/Improvements:** The developed model allows simulating standard and emergency situations in the cooling circuit.

**Keywords:** Computer Simulator, Cooling Circuit Model, Matlab, Technological Pipelines Network

## 1. Introduction

To develop computer simulator of any chemical process the process cooling model development is often required. If several equipment units usually connected with the unified head source in parallel by the pipeline system are used in the chemical process (for example, in fluorine production)<sup>1</sup>, it is necessary to develop equipment units cooling circuit. Consequently, for developing cooling circuit model it is required to analyze it, to calculate cooling circuit elements and standard and emergency situations should be simulated.

### 1.1 Purpose

To develop the model of fluorine production cooling circuit, which calculates water rate and takes into account possible emergency situations for its application in the computer simulator.

### 1.2 Objectives

To determine model parameters and requirements to cooling circuit calculation; to choose mathematical

simulation methods of water rate in the system; to hypothesize; to take into consideration possible faults in the cooling circuit; to develop the model using Matlab; to test the developed model operational performance; to set experimentally the required model parameters for simulating emergency situations in the cooling circuit.

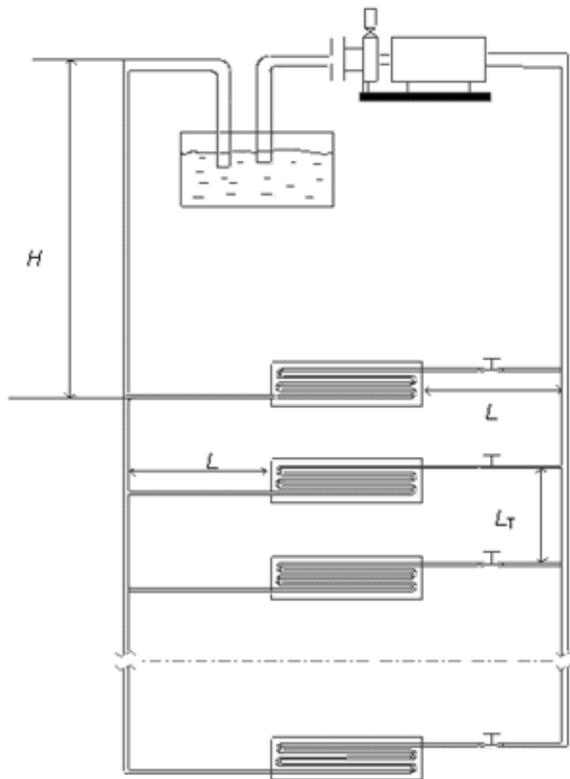
## 2. Description of the Simulation for Equipment Units Cooling Circuit Calculation

Water is supplied by the pump to the common collector and flows through separate pipelines to each equipment unit. Then water flows through the control valve and serpentine tube-sheet, withdrawing heat released by the equipment unit. Cooled water is dumped from the tube-sheets into common unloading manifold. Water rate for cooling each equipment unit is controlled by the shutoff and regulating valve (pipeline valve by the processing media direction flow and membrane double beat valve by the regulating unit design). Such type of the valve provides specified characteristic regulation, gate seal,

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high sliding joint hermeticity and corrosion resistance of membrane materials.

The equipment units cooling circuit is presented in Figure 1. It includes the pump, pipelines, valves and cooling coil of 4 units (from 20 simulated equipment units).



**Figure 1.** Scheme of equipment units cooling circuit.

To calculate resistance of the circuit elements according to designations used in Figure 1 the following parameters were used:  $H$  - distance from the head source, 30 m;  $L$  - length of the pipe to the equipment unit, 3 m;  $LT$  - distance between the pipes, 3 m.

### 3. Requirements and Methods for Equipment Units Cooling Circuit Simulation

The use of the model of water rate distribution in the pipeline system in the computer simulator imposes the following requirements to the mathematical model method: dynamic analysis of point discharge in the pipeline system; fast response; pipeline system technological peculiarities recording; guaranteed precision provision of

the control valves at any variations of their conditions; the method should obey the laws of physics and chemistry.

For simulation of the cooling circuit with specified configuration of the pipeline system the loop flow method based on generalized Kirchhoff's law was used: balance of the flow for each pipeline branching point and equation of each circuit cycle. Pipeline

Pipeline system of the cooling circuit presented in Figure 1 is divided into independent circuits the number of which is equal to the number of pipelines with cooling pipes. The media impulse change equal to the sum of forces applied to it is recorded<sup>2</sup>.

## 4. Assumptions

All elements in use and equipment units cooling circuit configuration allow making the following assumptions in the simulation: the cross section of all cooling circuit pipelines  $S_w$  is equal; the height difference  $h_w$  for cooling circuit is zero due to pipelines connection configuration and position of water treating container and equipment units, that is the heights of water rise and water dump are equal; the valve characteristic is linear; input pressure in the common collector is specified by the head-flow characteristic equation and corresponds to the linear section of the differences maintained by the change of the rotor wheel shaft speed; the pump faults are not considered.

## 5. Consideration of the Faults in the Cooling Circuit Model

To provide simulation possibility of the faults (reduction of water rate per equipment unit to 0.0003 kg/s, which results in emergency situation in a short period of time; and to 0.0005 kg/s in a long period of time) caused by emergency operation of the valves, pipelines lockage or leakage, emergency characteristics were added into the ratio for calculating pipeline system units resistance: emergency characteristic in the general line section  $KwLz$  changes in the range from 0 to 2, is equal to 1 in standard operational mode, is more than 1 when the line is locked, is less than 1 at pipeline leakage, is close to 0 at significant flow leakage; emergency characteristic in the line  $Kwz$  changes in the range from 0 to 2, equal to 1 in standard operational mode, is more than 1 when the valve is locked, is less than 1 when there is leakage in the line of

equipment unit  $z$ , is closer to 0 at significant flow leakage, is equal to  $\infty$  at equipment unit bypassing; pressure drop across resistance is proportional to the square of the media mass flow across this resistance<sup>2</sup>.

## 6. Cooling Circuit Simulation

Changes of the flow in each  $z$  line are calculated from the following system of equations written on the basis of the method described above taking into consideration the assumptions:

$$\frac{dG_{wz}}{dt} = \begin{cases} \left[ \frac{S_w}{l_w} \cdot \left[ \begin{array}{l} P_{wH} - P_w - (2 \cdot K_{wLz} \cdot R_{wLz} + K_{wz} \cdot R_{wz}) \cdot G_{wz}^2 \\ -2 \cdot K_{wLz} \cdot R_{wLz} \cdot \left( \sum_{i=z+1}^n G_{wi} \right)^2 \end{array} \right] \right], & z=1 \\ \left[ \frac{S_w}{l_w} \cdot \left[ \begin{array}{l} P_{wH} - P_w - (2 \cdot K_{wLz} \cdot R_{wLz} + K_{wz} \cdot R_{wz}) \cdot G_{wz}^2 \\ -2 \cdot K_{wLz} \cdot R_{wLz} \cdot \left( \sum_{i=z+1}^n G_{wi} \right)^2 - 2 \cdot \sum_{j=z-1}^1 \left( R_{wLj} \cdot \left( \sum_{i=j}^n G_{wi} \right)^2 \right) \end{array} \right] \right], & z>1 \end{cases}$$

where  $=1, \dots, n; n = 20, R_{wz} = R_{wEz} + R_{wKz}, P_{wH}, P_w$  – starting pressure created by the pump equipment, pressure at the end of the common pipeline,  $Pa; R_{wz}, R_{wLz}, R_{wKz}, R_{wEz}$  – resistance of the lines, pipelines between equipment units, valves and tube-sheet of equipment units cooling,  $1\text{kg}\cdot\text{m}; G_{wi}$  – mass flow in the lines,  $\text{kg/s}$ .

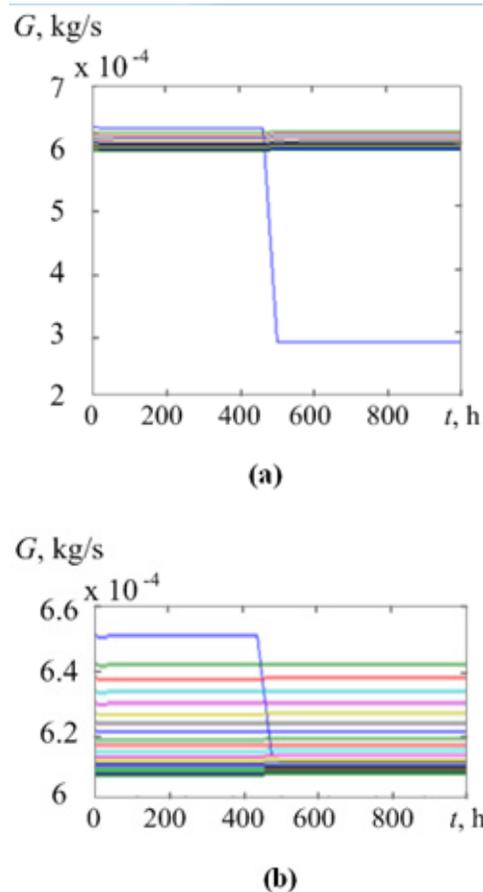
## 7. Developed Model Operational Performance Testing

Simulating the faults characteristics the following initial conditions were specified: Euler method was used for numerical calculation; initial step for stable model solution was 0.01s; the number of equipment units was equal to 20; simulation time was 1000 s; in standard mode the initial values of the pump fault characteristics in the general line and on the valve are equal to 1.

The model solution time should be much less than the process establishment time at production (when only the media temperature is measured in equipment units, for example, at fluorine production<sup>1</sup>, this time can be up to 5 min).

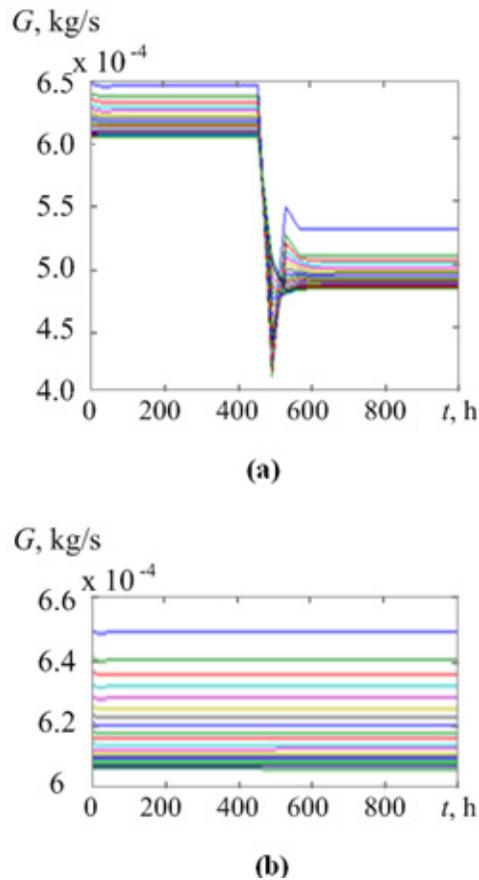
Let us consider the change of the cooling water flow depending on the emergency characteristic value on valve  $K_{wz}$ . At the time moment  $t > 500$  s, the emergency

characteristic on the valve takes the value of 0.2. In Figure 2 (a) the simulation results at the flow changes on the 1 valve are shown. The simulation results at the flow changes on the 1 valve at the time moment of  $t > 500$  s are presented in Figure 2 (b), emergency characteristic on the valve takes the value of 0.9.



**Figure 2.** Cooling water flow change at  $K_{wz} = 0.2$  (a). At  $K_{wz} = 0.9$  and (b) on the 1 valve.

Let us also consider the cooling water flow change depending on the value of the emergency characteristic on the general line  $K_{wLz}$ . The simulation results at the flow changes on the 1 line at the time moment of  $t > 500$ s are presented in Figure 3<sup>3</sup>, emergency characteristic in the general line takes the value of 0.2. Figure 3 (b) shows the simulation results at flow changes in the 20 line at the time moment of  $t > 500$ s, emergency characteristic in the general line takes the value of 0.1.



**Figure 3.** Cooling water rate change at  $KwLz = 0.2$  in the 1 line (a) at  $KwLz = 0.1$  in the 20 line (b).

It was experimentally found that when emergency features are equal to 0.2, the minimal required water rate for emergency simulation in the computer simulator is set. Also it was found that the model solution time is

much less than the time of the process establishment at production, which makes it possible to implement real and speeding up time modes in the computer simulator.

## 8. Conclusions

Thus, presenting technological pipelines network as the scheme of parallel-connected lines and applying to it the described method, it is possible to determine the values of cooling water rates at any moment of time. The calculated water rates serve as input signals for the equipment units cooling system model<sup>1</sup>. The required parameters of the model for simulating emergency situations in the cooling circuit were found experimentally. The graphs presented in the article illustrate function testing of the cooling model operational performance when emergency characteristics change. The developed model allows simulating standard and emergency situations in the cooling circuit.

## 9. References

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