METHODOLOGY OF THERMALHYDRAULIC TESTS OF FUEL ASSSEMBLIES FOR WWER-1000

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Keywords: Thermalhydraulic, prequalification test, fuel assembly, WWER-1000

INTRODUCTION

At present 11 units with WWER-1000 are in operation in Ukraine. The NPPs are provided with nuclear fuel from Russia. The fuel assemblies are fabricated and delivered to Ukrainian NPPs from Russia. However the contemporary tendencies of nuclear energy development in the world assume a diversification of nuclear fuel vendors. Therefore the creation of the own nuclear fuel cycle of Ukraine is in mind in the strategy of nuclear energy development of Ukraine. As a part of the fuel assemblies fabrication process complex of the thermalhydraulic tests should be carried out to confirm design characteristics of the fuel assemblies before they are loaded in the reactor facility. The experimental basis and scientific infrastructure for the thermalhydraulic tests arrangement and realization of the programs and procedures for the core equipment examination are under consideration.

Nuclear energy of Ukraine was developed as a part of the nuclear energy complex of the former Soviet Union. Some scientific support centers with experimental facilities for nuclear energy studies were created in some places of Ukraine. A number of experimental thermalhydraulic facilities were erected for the study of accidental and transient regimes. But the powerful experimental rigs for thermalhydraulic tests of the core elements were mainly concentrated in Russia.

There has been for many years experience of thermalhydraulic research in Ukraine. A lot of experiments carried out on different in scale experimental facilities gave an opportunity to collect a large quantity of experimental data on the main phenomena occurring in the primary and the secondary circuits and in the reactor vessel as well.

Typical operating integral thermalhydraulic facility for research of the steady and unsteady processes events is situated in the Institute of Engineering Thermal Physics Academy of Sciences of Ukraine. It has the following parameters:

Pressure of water	- up to 20 MPa
Electrical power	- up to 2 MW
Flow rate	- up to 2 T/h
Experimental section length	- 1 m

Wide scope of the phenomena and processes research, such as heat exchange crisis in boiling conditions, hydrodynamic resistance behavior in channels, hydrodynamic stability in parallel operating channels etc., were carried out using the facility.

Similar experimental multipurpose facilities with close to the mentioned parameters and power capacities were constructed in Kiev National Technical University, Sevastopol Nuclear Energy and Industry Institute, Odessa Polytechnical University and others (1993). Special attention will be drawn to Zuev Experimental Thermal Station (Donetsk region) where the experimental basis for in-depth investigations of the main problems of nuclear energy have been created in the 70-ties. Some large scale (up to 1:50) thermalhydraulic facilities modeling WWER-440 and WWER-1000 loops and elements were designed and constructed. The site is provided with sufficient places and has the necessary energy supply (water, steam, electricity). More details can be seen elsewhere (1991). The available experimental basis requires certain modernization for the fuel assemblies testing application. Moreover some experimental facilities should be constructed to carry out the whole scope of fabricated fuel assemblies examination.

METHODOLOGY OF PREQUALIFICATION THERMALHYDRAULIC TESTS OF FUEL ASSEMBLIES FOR WWER-1000

Thermalhydraulic tests of the core elements inside the reactor during start-up and adjustment works and operation on power are the final stage of the fuel assemblies fabrication. The test procedures are regulated by some methodological programs (1983A). The following tasks are performed by the thermalhydraulic tests:

- Definition and confirmation of the real thermalhydraulic characteristics of the fuel assembly and its conformity to the designed values;
- Checking and confirmation of the calculation-experimental justification of the core thermalhydraulic characteristics;
- Comparison of obtained data with the similar ones for other WWER-1000 units;
- Checking and registration of phenomena and processes that are not considered in the design;

Thermalhydraulic tests of the core elements are considered as completed if they are carried out in a whole scope according to the programs and if the tests results correspond to the designed characteristics pointed in the Technical Conditions for WWER-1000 (1983A, 1983B). The main parameters controlled during the tests are shown in Table 1.

PARAMETER	VALUE
Coolant flow rate through the cassette, m^3/h	515±55
Maximal power of the cassette, MW	27
Temperature at the reactor entrance, °C	289,7
Temperature at the exit of the reactor, °C	320
Temperature at the exit of the cassette with maximal thermal loading, °C	334
Coolant flow rate irregularity through cassettes	± 5 %
Bypass flow rates	± 3 %
Hydraulic resistance of the core, MPa	0, 142±0,024

Table 1. Main thermalhydraulic characteristics controlled during the tests

The thermalhydraulic tests consist of – prequalification tests carried out on special experimental facilities and qualification tests carried out at the start-up and adjustment stage and at operation at nominal power. The latter ones are out of the scope of the paper.

The prequalification tests consist of two cycles - testing of fuel assembly of new construction (or known construction for extension of the design parameters) and testing of commercial assemblies.

The first cycle includes a wide spectrum of problems such as fuel rods shell tests on thermalhydraulic rigs with its heating (by steam or by electricity) simulation and a series of tests on research reactors with fuel rods loaded with the nuclear fuel. Experimental thermalhydraulic tests include study of hydraulic resistance, heat transfer, inter channel mixing, distribution of thermalhydraulic parameters (enthalpy and mass flow rate) through the fuel assemblies cross section and between paralleled operating fuel assemblies, boiling onset, heat transfer crisis during boiling, over crisis heat transfer regimes, hydraulic instability and so on. Such scope of the tests should be implemented by means of many special engineering research institutes efforts.

The tests are carried out in combination with strength and vibration ones, resources tests etc. for sampled part of the assemblies (approximately 1-3 % of the total quantity).

THE MAIN SERIES OF THERMALHYDRAULIC TESTS

The thermalhydraulic tests of single fuel element, single fuel assembly, group of fuel assemblies are carried out.

Thermalhydraulic tests of a single fuel element are carried out on special thermalhydraulic rigs. The working section - annular channel of 3,5 m length and central rod diameter of 9,1 mm - allows to install tested element loaded (or not) by the fuel. Firstly cold washing of the working section at atmospheric pressure during 10-15 min is carried out. Then in the case of leak tightness the pressure is increased at the rate of 1-2 MPa per minute up to 20 MPa. Gradual coolant heating of the coolant from outer sources at the rate of 10-20°C per min up to final temperature 340°C is realized at a pressure of 20 MPa. The main tests are conducted in the following range of the coolant regime parameters:

Pressure - 15,7 MPa
Temperature - 20-340°C
Mass flow rate - 1000-2992 kg/m^2.s

During the tests the parameters take the following fixed values as shown in Table 2:

Parameter	Parameter value				
Pressure, MPa	15,7				
Temperature, °C	20	100	200	305	340
Mass flow rate, kg/m^2.s	1000	2000	3000		

Table 2 Parameters reached during the single fuel rod tests

At each steady thermal and hydrodynamic regime the following parameters are recorded:

- pressure, flow rate, working section inlet and outlet temperatures,
- pressure difference through the channel and through one of the spacers,
- vibration characteristics.

The results of thermalhydraulic resistance measurements are compared to the calculated, but vibration characteristics – with permissible ones. Then unsteady regime tests and resources ones are carried out as well.

During unsteady regimes tests the repeated heating of coolant from cold state to temperature - 340°C with the rate of 10-30°C per min at 15,7 MPa pressure and cooling at the same rate are performed. The number of cycles is not less than 300. After the unsteady tests completion the tests at the nominal regime are carried out. The values of thermalhydraulic resistance should be unchanged.

Resource tests are carried out at the nominal regime (pressure - 15,7 MPa, temperature - 305°C, mass flow rate - 2992 kg/m^2.s and are kept during not less than 10000 h. After the resource tests the checking tests of the channel are carried out. The values of thermalhydraulic resistance should be unchanged or a 5 % increase is permissible due to the corrosion deposits on the rod surface.

Thermalhydraulic tests of single fuel assembly are carried out on special thermalhydraulic rigs. The working section has hexagonal shape and consists of 312 fuel rods. It may be either pilot assembly or commercial one with or without the fuel. The methodology for the fuel assembly thermalhydraulic tests is similar to the one for single fuel rod tests with some changes and supplements.

Under the main series of the tests fulfillment regimes parameters take the following fixed values:

Parameter	Parameter value		
Pressure, MPa	15,7		
Temperature, °C	20	200	340
Flow rate, m^3/h	100	300	570

Table 3 Parameters reached during the single fuel assembly tests

Resource tests are carried out at: nominal regime pressure -15,7 MPa, temperature - 305°C, coolant flow rate - 515 m^3/h during not less than 1000 h.

The most powerful rigs are required for the group of fuel assemblies testing. The tests are carried out on 7 pilot or commercial fuel assemblies for WWER-1000. The simulator of the fuel assembly which is similar to the fuel assembly in construction and used for the measurements of the coolant flow rate through separate cassette can be installed. The pretest works are identical to the ones for a single rod or a single fuel assembly. The alterations are related to the regime parameters. Range of the parameters is the following: pressure -15,7 MPa, temperature – 20-340°C, coolant flow rate - 700-3400 m^3/h during not less than 1000 h. The regime parameters take the fixed values pointed in Table 4.

Parameter	Parameter value		
Pressure, MPa	15,7		
Temperature, °C	20	200	340
Flow rate, m^3/h	100	300	570

Table 4 Parameters reached during the tests of fuel assemblies group

The tests are carried out on the group which consists of 7 pilot or commercial fuel assemblies for WWER-1000.

After the tests cycle completion successively the simulator of the fuel assembly is installed in place of central fuel assembly or one of the circumferential ones. The tests are carried out at nominal regime at pressure -15,7 MPa, temperature -305°C, coolant flow rate - 700-3400 m^3/h. Ununiformity of the flow rate through the assemblies should be not more than 5 %.

REQUIREMENTS TO THE TEST FACILITIES FOR THERMALHYDRAULIC TESTS

The experimental basis for examination of fuel rods and fuel assemblies should include a complex of rigs and facilities. Let us consider one version of the minimal needed set of facilities for the prequalification tests.

First of all one or more rigs for thermalhydraulic tests of single fuel rod facilities are required. Such facilities could work either on close or open scheme but anyway it should allow to install the fuel rod in the annular channel (length of 3,5 m and diameter of 9,1 mm) and allow to reach pressure - 20 MPa and flow rate - 2 m^3/h. The coolant must be chemically purified water.

The rig should be equipped with the control instrumentation providing measurement and registration of the coolant parameters in steady and unsteady regimes such as coolant temperature, pressure, flow rate through the working section, pressure difference on the full height and separate parts of the channel.
So the rig must include hydraulic circuit with flow rate of more than 2 m^3/h, circulation pump, adjusting throttle device at the working section entrance, pressurizer, water heating devices with power > 300 kW, filters, heat exchangers, control measurement devices etc. The instrumentation should include sensors and devices for measurements of:

- Temperature (accuracy < 1,0)
- Pressure (accuracy <0,5)
- Pressure difference (accuracy < 1,0)
- Flow rate (accuracy < 1,0)

The measurement complex have to include acquisition and processing system and proper instrumentation for resource tests. These requirements are related to every test facility.

A powerful test rig is required for the examination of commercial fuel assemblies consisting of 312 fuel rods. The rig construction should permit to simulate of the neighbor fuel assemblies and the working section conditions should correspond to the real ones. The main dimensional sizes of the assembly are the following:

- Cassette height - 4570 mm
- Cassette size - 234 mm
- Cassette shape - hexagonal without the case

Technological parameters of the rig should be not lower than:

- Pressure ~20 MPa (16 MPa – possible)
- Flow rate - appr. 600 m^3/h
- Temperature - 340°C
- Height of working section - not less than 5 m

The rig should include hydraulic circuit, circulation pumps, pressurizer, outer heating sources (steam, electricity), filters, coolers. To reduce installed capacity of the rig it is desirable to use a close circulation circuit.

The facility for hot testing of pilot and commercial fuel assemblies and control drivers of WWER-1000 is shown in Fig.1.

The important element of testing procedures is the high pressure rig for thermalhydraulic and resource tests of seven pilot or commercial fuel assemblies for WWER-1000. The rig parameters should be not less than:

- Pressure ~ 20 MPa
- Flow rate - appr. 4200 m^3/h

- Temperature - 340°C.
- Height of working section - not less than 6 m

The working section should provide simulation of the 7 tested cassettes surroundings by the neighbor ones. Instead of separate fuel assemblies it is necessary to expect installation of cassettes mock-ups, used for flow rate measurements through separate cassette. The main requirements to the rig are similar to the above facility for one assembly testing. OKB "Hydropress" high pressure rig for resource testing of pilot cassettes and control rods drivers is shown on Fig.2. The rig consists of column for 7 cassette with internals, main circulation pipelines having two symmetrical loops.

The low pressure hydrodynamic rig for seven cassettes testing is shown on Fig.3. It was designed for complex studies of hydraulic and vibration characteristics of WWER-1000 fuel assemblies of various modifications. It consists of 7 cassettes column with internals, main circulation pipelines of 400 mm diameter disposed in the shape of two symmetrical loops. Circulation is realized by means of four pumps.

Creation and keeping of required temperature regimes in the column are provided by the heat released from the pumps. The temperature is regulated by two heat exchangers disposed on the loops bypasses. There is a steam mixer with a flow rate up to 5-8 m^3/h for high temperature water supply to the entrance of one of the cassettes. Technical specification characteristics of the rig are the following:

- Circulation circuit pressure - up to 1 MPa
- Operation temperature - up to 80°C
- Coolant flow rate through the column - up to 420 m^3/h

The scope of the works fulfilled on the rig includes:

- Hydraulic and vibration testing of WWER-1000 cassettes for various modifications,
- Research of turbulent mixing between cassettes on the core height,
- Examination of new construction equipment.

The proposed set of the test facilities for the thermalhydraulic tests of fuel rods and fuel assemblies is sufficient for comprehensive thermalhydraulic prequalification tests fulfillment.

CONCLUSIONS

1. The main technical requirements for test rigs designed for thermalhydraulic tests of fuel assemblies are defined.
2. The methodological approaches to the thermalhydraulic tests of the fuel assemblies are shown.
3. The available experimental basis is reviewed. It would be applied for the tests implementation only after some modernizations.
4. The minimal set of facilities for the core elements thermalhydraulic tests is proposed.

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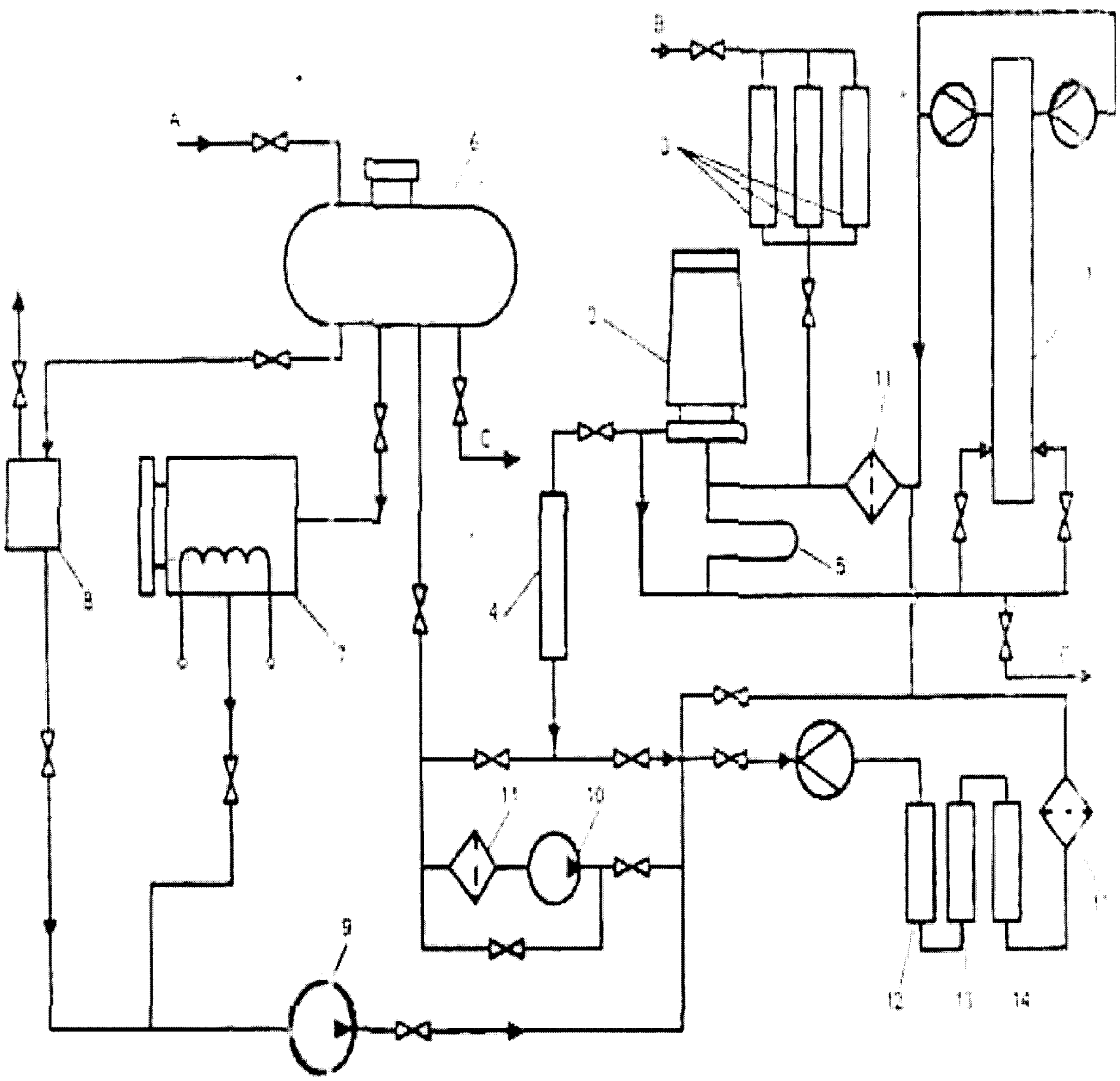

Fig.1

1-column; 2-circulation pump; 3-pressurizer; 4-cooler; 5-electric heater; 6-feed tank; 7-boric acid tank; 8-tank for chemical reagents; 9-acid proof tank; 10-feed pump; 11-mechanical filter; 12-cationic filter; 13-anionic filter; 14-cellulose filter

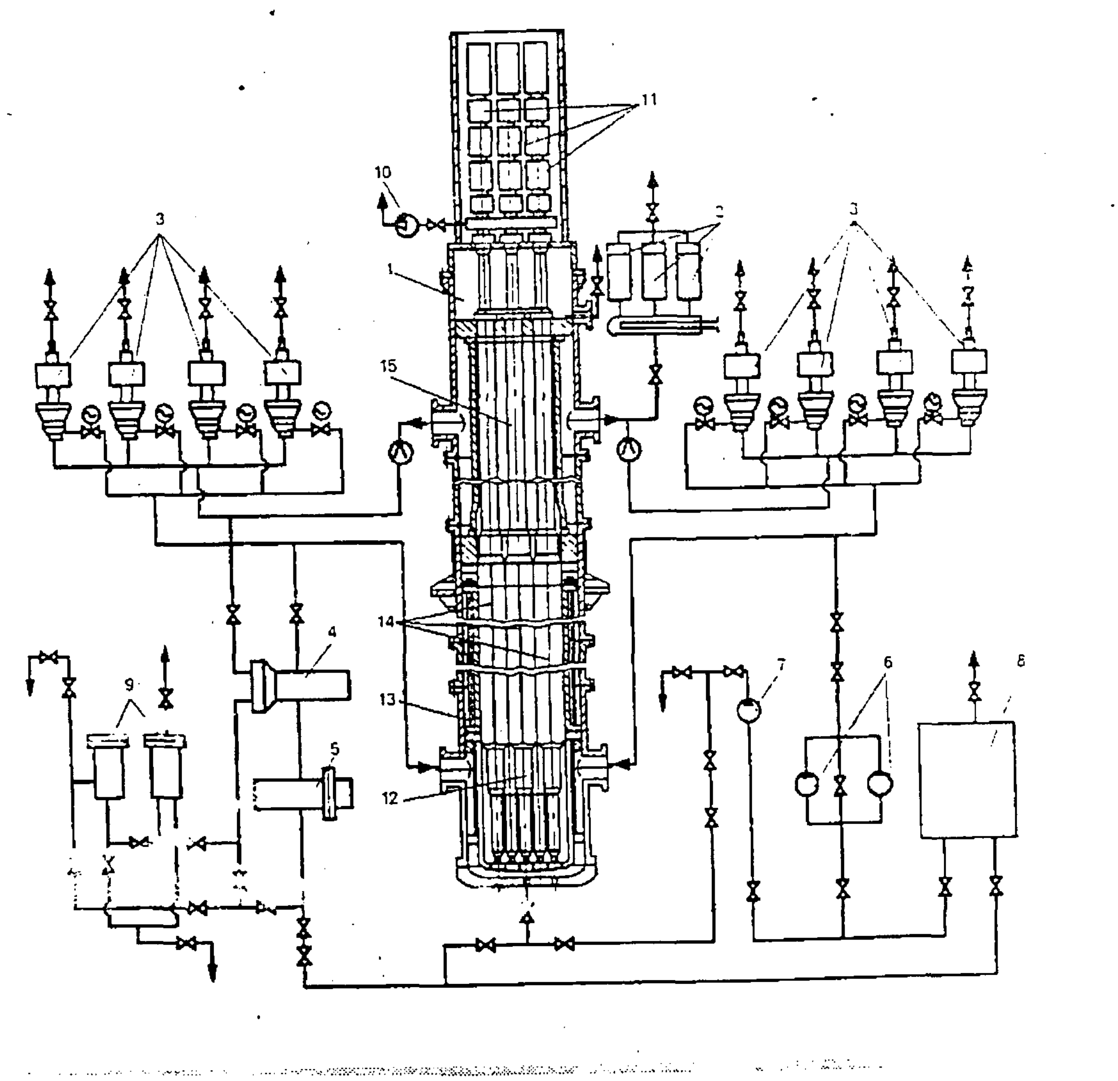

Fig.2

1-column; 2-pressurizer; 3-RCP; 4-heat exchanger; 6-feed water pump; 7-make-up pump; 8-feedwater tank; 9-chemical water purification filters; 10-fan; 11-control rod driver; 12-support cylinder; 13-core screen; 14-fuel assembly; 15-protective tube unit

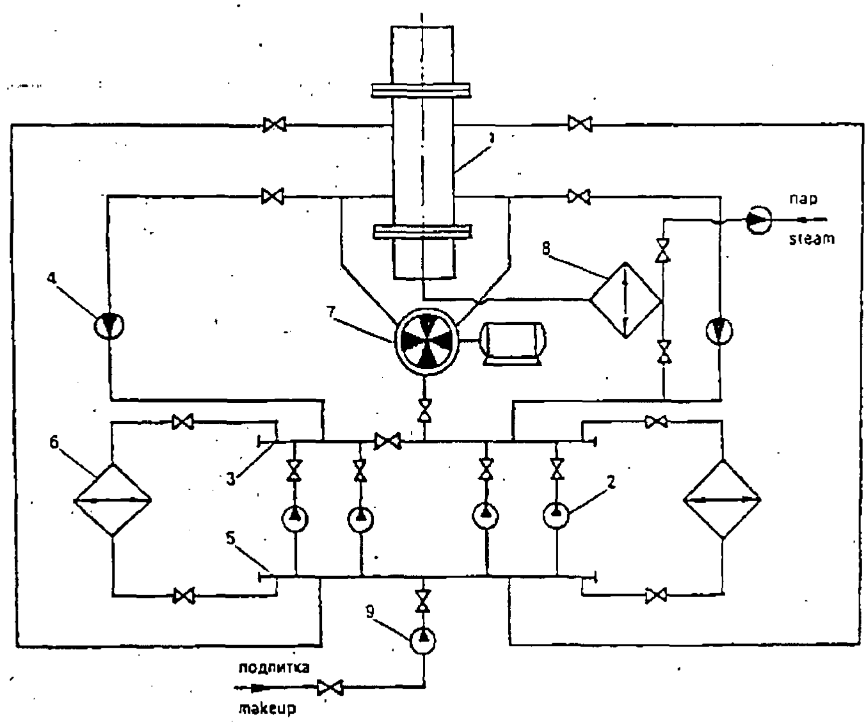

Fig.3
1-seven-assembly column; 2-circulation pump; 3-distributing header; 4-flowmeter orifice; 5-collecting header; 6-heat exchanger; 7-pressure pulser; 8-steam mixer; 9-make-up pump