P a r t 6

ADVANCED TECHNOLOGIES AND POWER INSTALLATIONS FOR THERMAL AND ELECTRIC ENERGY GENERATION

6.1. Improvement of the thermal cycle of traditional combined-cycle TPPs

6.1.4. Experience of using ultra supercritical steam parameters

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Presently in Russia and other countries power units with supercritical parameters are widely used with initial pressure p_0 = 23,57 MPa and temperature of direct steam t_0 = 540°C, with single intermediate superheating with parameters p_{is}=3,6 MPa and t_{is} = 540°C. These parameters allow achieving an efficiency of power unit of 41%. Since 1966 and to mid-70-ties an experimental unit SKR-100-300 with supercritical parameters of p_0 = 29,4 MPa, t_0 = 650°C was in operation at Kashirskaya SDPP. These researches enabled to establish a possibility of production of industrial equipment for supercritical parameters. The first industrial plant Eddistoun-1 for supercritical parameters p_0 = 35,9 MPa, t_0 = 648°C, with a double-shot intermediate superheating t_{is} = 565/565°C, was built in the U.S. in 1954.

Today there are dozens of units working at supercritical parameters worldwide, built mostly in the U.S., Germany, Denmark, Japan, characteristics of some of them are presented in Tab. 6.1.

Analysis of characteristics of TPPs, working at supercritical steam parameters, presented in Tab. 6.1, shows that commissioning of the first experimental units with parameters p_0 = 35 MPa, and t_0 = 650°C, with a double-shot intermediate superheating revealed the complexity of realization of such projects. At subsequent stages, especially it is visible on the example of plants, built in the 80-ties of the last century, it can be seen that the initial pressure and temperature increased slightly, p_0 = 25 ... 28 MPa, t_0 = 560 ... 580°C, while the parameters of intermediate superheating grew to t_{is} = 580 ... 600°C. This decision is justified, since reduction of parameters of the superheated steam allowed to use less expensive materials at simultaneous keeping safety and equipment mobility. Increase in the intermediate superheating temperature is not so critical, as the working pressure of metal in this case is much lower. However, an experience of equipment running showed that the use of a double-shot intermediate superheating at steam pressure up to 26 MPa is not reasonable from the economic point of view, since an increase in the overall efficiency by about 1% does not compensate a complication of the power unit thermal diagram, as well as a construction of the boiler and a turbine. Therefore, since 80-ties, power units with a single-shot intermediate superheating were mostly built. Only switching to the pressure of about p_0 = 30 MPa made application of the second intermediate steam superheating expedient again.

Growth of parameters was followed by improvement of thermal diagrams, increase in the feed water temperature, reaching t_{fw} = 300°C, introduction of low-pressure heaters of a mixing type, improvement of regenerating high-pressure heaters and their connection diagrams (Violen and Ricard-Nekolny diagrams).

At the same time a significant efficiency increase was achieved by reduction of the condenser pressure. Of particular note is the fact that pressure drop in the condenser was achieved not only by increasing the condenser area and perfection of the heat transfer processes in it, but also by maintaining a high vacuum in the operational process by preventing from deposits in the condenser pipe system and reduction of air inflow. Such a result was achieved by introducing continuous ball purification and the use of modern sealing materials. The result was a temperature drop in condensers from Δt = 6 ... 8°C to Δt = 3...4°C. The temperature reduction allowed to lower a pressure in the condenser by 1 kPa, resulting in the turbine capacity increase by 1...1,5% by average for equipment, designed for operation with supercritical steam, and by 2,5...4 % for power units of nuclear power plants.

An effect of increase in steam parameters is shown in dozens of papers. From Tab. 6.1 it can be seen that achievement of steam parameters p_0 = 29 MPa and t = 580/580/600°C enabled to obtain the power plant efficiency of 47%. By that, increase in the designed vacuum to $p_к$ = 2,35 kPa raised the power plant efficiency to 49%.

In connection with decrease in gas reserves, using steam with supercritical parameters at the coal-fired plants is very promising. At the same time it should be noted that growth of steam parameters to higher values is not as promising as going into p_0 = 30 MPa and t_0 = 600 °C. Increase in steam parameters to p_0 = 40 MPa and t_0 = 700...750 °C enables to improve the power plant efficiency to 51...52 %. At that, a cost of materials rises dramatically. Thus, increase in steam parameters for conventional steam-turbine equipment is close to achievement of its economical limit. Only appearance of entirely new materials with high strength properties will permit to increase the parameters even further.

Substantial fuel saving can now be achieved by the following:

- due to the combined (joint) generation of electrical and thermal energy;
- by building of steam-gas plants;
- due to modernization of the existing installations.

Table 6.1. **The main characteristics of power units, operating at supercritical steam parameters**

Country, TPP	Year of com-missi-oning	Fuel	Temperature of live steam and in-termediate super-heating steam $t_0/t_{is1}/t_{is2}$, °C	Initial pressure, MPa	Temperature of feed water, °C	Electric capacity, MW	Pressure in the condenser, kPa	Net efficiency of the power unit, %
U.S., Eddistoun-1	1954	Coal	648/565/565	35,9	—	325	—	—
Russia, Kashirskaya SDPP	1966	Coal	650/565	29,4	—	100	—	—
Japan, Wakamatsu	1968	Coal	593/593/593	31,0	—	50	—	—
Denmark, Strudstrup 3 and 4	1984—1985	Coal	540/540	25,0	261	350	2,1	41...42
Japan, Kavagoe-1	1989	Liquefied gas	566/566/566	30,5	310	700	4	41,9
Denmark, Funen 7	1991	Coal	540/540	25,0	280	350	2,7	43,5
Germany Shgaudinger 5	1992	Coal	545/562	26,2	270	550	3,8	43
Denmark, Esbjerg 3	1992	Coal	562/560	25,0	275	350	2,3	45,3
Germany, Lubeck	1995	Coal	580/560	27,5	—	400	—	45,7
Denmark, Skerbek 1 and 2 (Convoy)	1997	Gas	582/580/580	29,5	298	395	2,3	47
Denmark, Alborg	1997	Coal	580/580/600	28,5	300	400	2,35	49
Japan, Matsuura 2	1998	Coal	593/593/593	25,6	—	1000	—	45
Denmark, Nordzhilland	1998	Coal	582/580/580	29,5	—	385	—	49
Germany, Gessler	1998	Coal	580/600	27,5	301	740	3,6	45,4
Germany, Beksbah 2	—	Coal	575/595/—	25,0	290	750	—	46,3
Germany, Boxberg	2000	Lignite	545/581	26,6	—	907	—	42,7