Part 6

ADVANCED TECHNOLOGIES AND POWER INSTALLATIONS FOR THERMAL AND ELECTRIC ENERGY GENERATION

6.3. Heat and power supply units of low capacity

6.3.1. General characteristic of district heating in Russia and analysis of opportunities of using the small CHPPs instead of the heating boiler-houses

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Till now power sector of our country was developed due to commissioning of up-to-date steam turbine units having higher initial steam parameters and higher rated capacity. Increase in initial parameters yielded perfection of thermodynamic cycle and decrease in relative fuel consumption. Wide application of combined heat and power plants is also a substantial factor for efficiency increase.

Hereinafter the term “co-generation” means power supply based on the combined generation of heat and power. Thermodynamic basis of co-generation is beneficial use of exhaust steam after a steam turbine for heat supply to external consumers (in this case heat of phase transformation of steam into water is utilized).

The combined generation of heat and power make a basic difference of co-generation in comparison with a so-called separate method of power supply, when electric power is generated at condensing power plants and heat is produced in boiler-houses.

A special role of co-generation should be especially underlined for our country, situated in a zone of severe climatic conditions, where life-sustaining activity requires considerable power and heat consumptions. An average year temperature in Russia is –5,5°C. At the same time, for example, in Finland it is +1,5°C. In Sweden and Norway it’s even higher — +2 °C, they are the most northern European countries, located at latitude far to the north than the most part of the Russian territory. Such temperatures are explained by influence of the warm sea stream Gulfstream on the European climate. Therefore, climate zones in Europe are thus located that an average temperature changes, mainly, from west to east, but not from north to south, i.e. it’s getting colder with a distance from the seashore.

Co-generation in our country was developing by means of commissioning of steam turbine units T-110-130 or T-250/300-240. Development of co-generation yielded two times reduction of the specified fuel consumption for electric energy generation at combined heat power plants (CHPPs) within the last 50 years starting with b_{sp} = 590 to 264 grams of reference fuel kW/h. However, during the last 15 years a tendency of fuel reduction has almost stopped. It is connected with the fact that currently heat to almost all large heat consumers is supplied from large-capacity CHPPs with steam turbines of the following types: T-110-130, PT-80-130, T-175-130, T-250-240. Possible progress in thermodynamic efficiency of such units is settled. Construction of new CHPPs is also almost impossible because there are no large heat consumers.

At the same time Russia possesses wide possibilities to broaden construction of low-capacity CHPPs for heat supply. Nowadays 920 boiler units with productivity of 400 GJ/h each are in operation in Russia. According to the program of perspective development of the Russian power industry for the nearest 10 years, construction and expansion of about 70 boiler-houses with heat capacity of more than 800 GJ/h, including 36 with capacity of more than 1600 GJ/h and also 20 steam boilers with heat productivity of 200 t/h are planned. Such wide implementation of high-capacity boiler-houses leads to growth of separate generation of thermal and electric energy that means a decrease in efficiency of fuel heat energy utilization. Moreover, heat capacity of boiler-houses is insufficient for their substitution by CHPPs with steam turbines T-110-130 or turbines with higher capacity. In this case it is reasonable to apply small CHPPs, equipped with non-condensing steam turbines.

Application of small CHPPs has the following advantages:

- specific reference fuel consumption for electric energy generation at application of backpressure turbines is maintained about 160…170 g/kW·h, regardless of the unit capacity;
- operational staff remains minimal, it’s almost the same as for a common boiler-house;
- unit, supply from works of the main equipment considerably reduces time required for equipment mounting as well as commissioning period, compared to large CHPPs, thus reducing a period of “investments freezing” and construction payback period.

Wide application of small CHPPs in 40-50-ties, equipped with turbines with a unit capacity of 0,5…6 MW and steam pressure p_0 = 1,2…3,5 MPa showed their high reliability and efficiency.

In order to provide a high operational efficiency of small CHPPs, power generation as a whole should be accompanied with heat production. In this case installation of such turbines at completely purely heating CHPPs, i.e. without steam supply for industrial needs, requires full load of turbines within a whole season in order to keep a high efficiency of the turbine. This leads to decrease in combined heat power plant rate in a heat supply α_{chpp} to the load, correspondent to the load of hot water supply (or close to it) and auxiliary heat load. The rest required heat supply is covered by hot water boilers. α_{chpp} can be increased to the heat load, required in a heating season and, thus, consequently increase in the installed electric capacity of the boiler and power generation on heat supply. However, in this case full load of steam turbines within a whole year is not provided. In a non-heating season part of the steam turbines needs to be stopped due to lack of heat load. Operation of low-capacity steam units with condensers in a condensing mode during the heating season leads to considerable fuel over-consumption in a non-heating season due to low parameters of raw steam and imperfection of the thermodynamic cycle (low parameters of raw steam, absence of reheat and undeveloped regeneration system). For example, a turbine P-6-3,5/0,5-1 with initial parameters of steam p_0 = 3,5 MPa and t_0 = 435°C, operating in a condensing mode, at gas combustion, has a specific reference fuel consumption for power supply (net) b_{sp} = 490 g/(kW·h) and b_{sp} = 600…615 g/(kW·h) at coal combustion. Therefore, operation of such units in a condensing mode is inexpedient, because up to date native and foreign condensing steam turbine units have specific reference fuel consumption b_{sp} = 320 g/(kW·h). Thermodynamic features of some steam units in a non-condensing mode are provided in Tab. 6.10.

Instead of steam turbine units, combined cycle units can be also installed. In this case gas turbine exhaust is used for heat supply. Implementation of such technical options is mostly favorable for gas-fired boiler-houses.

A choice of the optimum option of CHPPs requires technical and economic calculations, based on the following principles of a choice of the optimum capacity of small CHPPs.

Table 6.10. **Thermal efficiency features of turbines, reasonable to apply at boiler houses**

Parameter	Turbine				
	R-5,2-2,2/0,3	R-4-2,1/0,3	R-2,5-3,4/0,3-1	R-2,5-2,1/0,3	PR-6-3,4/1,0/0,1-1
Manufacturer	Kharkov turbine works	Kharkov turbine works	Kaluga turbine works	Kaluga turbine works	Kaluga turbine works
Direct steam pressure, MPa	3,4	2,05	3,4	2,05	3,4
Direct steam temperature, °C	435	370	435	370	435
Turbine exhaust parameters:					
pressure, MPa	0,294	0,3	0,3	0,3	0,12
temperature, °C/dryness factor, kg/kg	184/—	175/—	194/—	184/—	136/—
Steam consumption in a rated mode, kg/s (t/h)	15,68 (54,6)	11,79 (42,43)	6,04 (21,7)	7,68 (27,63)	11,42 (41,1)
Power capacity at generator terminals, MW, at steam consumption, % of the nominal:					
100	5,19	4,0	2,5	2,5	6,0
75	3,45	2,65	1,71	1,68	4,21
50	1,75	1,39	0,98	0,87	2,54
Thermal capacity, supplied from a heating steam extraction, MW, at steam consumption, % of the nominal:					
100	35,59	26,59	13,85	17,43	26,35
75	27,16	20,31	10,56	13,31	20,07
50	18,68	13,94	7,23	9,12	13,66
Specific reference fuel consumption for power generation (kW·h), at steam consumption, % of the nominal:					
100	140	143	147	143	143
75	141	143	147	143	143
50	144	146	150	146	146
Specific fuel consumption for heat generation, kg/Gcal, at steam consumption, % of the nominal:					
100	155,2	155,3	156,8	155,2	156,8
75	155,3	155,3	157,9	155,2	156,8
50	158,6	158,7	160,1	158,7	160,2
Power generation at heat supply, %:					
100	14,61	15	18	14,3	22,77
75	12,7	13,04	16,19	12,62	20,98
50	9,37	9,97	13,55	9,54	18,59
Fuel heat utilization efficiency (brutto) at steam consumption, % of the nominal:					
100	91,42	91,15	89,84	91,28	90,09
75	91,45	91,22	89,90	91,33	90,13
50	89,66	89,45	88,27	89,48	88,30

Table 6.10 continuation

Parameter	Turbine				
	PR-12-3,4/0,6/0,1	PR-12-3,4/1,0/0,1	PR-6-3,4/0,5/0,1-1	PR-2,5-1,3/0,6/0,1	TG-0,6/0,4-K1,3
Manufacturer	Kaluga turbine works	Kaluga turbine works	Kaluga turbine works	Kaluga turbine works	Kaluga turbine works
Direct steam pressure, MPa	3,4	3,4	3,4	1,3	1,3
Direct steam temperature, °C	435	435	435	300	191
Turbine exhaust parameters:					
pressure, MPa	0,1	0,12	0,12	0,12	0,06
temperature, °C/dryness factor, kg/kg	99/—	105/1,0	145/1,0	113/1,0	85,9/0,992
Steam consumption in a rated mode, kg/s (t/h)	19,67 (70,8)	21,53 (77,5)	11,33 (40,8)	8,19 (29,5)	2,78 (10,0)
Power capacity at generator terminals, MW, at steam consumption, % of the nominal:					
100	12,0	12,0	6,0	2,5	0,6
75	8,46	8,42	4,21	1,67	0,41
50	5,14	5,08	2,54	0,95	0,24
Thermal capacity, supplied from a heating steam extraction, MW, at steam consumption, % of the nominal:					
100	44,41	48,33	26,36	18,49	6,07
75	33,87	36,89	20,06	14,12	4,60
50	23,09	25,19	13,65	9,59	3,11
Specific reference fuel consumption for power generation (kW·h), at steam consumption, % of the nominal:					
100	139	150	137	152	151
75	139	150	137	152	152
50	142	153	140	155	155
Specific fuel consumption for heat generation, kg/Gcal, at steam consumption, % of the nominal:					
100	156,7	156,8	156,8	155,0	158,4
75	156,7	156,7	156,8	155,1	158,2
50	160,1	160,2	160,1	158,6	161,51
Power generation at heat supply, %:					
100	27,02	24,83	22,76	13,52	9,9
75	24,98	22,82	20,98	11,83	8,9
50	22,26	20,17	18,61	9,9	7,72
Fuel heat utilization efficiency (brutto) at steam consumption, % of the nominal:					
100	90,54	89,10	90,79	90,67	89,29
75	90,61	89,26	90,81	90,76	89,46
50	88,71	87,52	88,94	88,99	87,74

Table 6.10 end

Parameter	Turbine				
	TG-0,6/0,4-K2,8	TG-1,2/0,4 P24/1,2	ТГ-0,75/0,4 Р13/2	ТГ-1,7/0,4 Р5/1,0	ТГ-2,5/6,3 Р7/1,0
Manufacturer	Kaluga turbine woks	Kaluga turbine woks	Kaluga turbine woks	Kaluga turbine woks	Kaluga turbine woks
Direct steam pressure, MPa	2,8	2,4	1,3	0,5	0,7
Direct steam temperature, °C	380	300	191	151	164
Turbine exhaust parameters					
pressure, MPa	0,06	0,12	0,2	0,105	0,105
temperature, °C/dryness factor, kg/kg	93/1,0	105/0,98	120,2/0,95	101/0,95	101/0,93
Steam consumption in a rated mode, kg/s (t/h)	1,28 (4,6)	3,47 (12,5)	4,44 (16)	10,56 (38)	11,11 (40)
Power capacity at generator terminals, MW, at steam consumption, % of the nominal:					
100	0,6	1,2	0,75	1,8	2,5
75	0,42	0,86	0,48	1,1	1,6
50	0,26	0,48	0,25	0,53	0,82
Thermal capacity, supplied from a heating steam extraction, MW, at steam consumption, % of the nominal:					
100	2,95	7,63	9,31	22,65	23,37
75	2,24	5,76	7,07	17,25	17,82
50	1,52	3,94	4,79	11,71	12,13
Specific reference fuel consumption for power generation (kW·h), at steam consumption, % of the nominal:					
100	149	145	148	140	140
75	150	145	148	140	140
50	153	148	151	143	143
Specific fuel consumption for heat generation, kg/Gcal, at steam consumption, % of the nominal:					
100	156,	155,2	155,3	155,0	155,1 1
75	157,	155,0	155,3	155,1	155,0
50	160,	158,4	158,6	158,3	158,5
Power generation at heat supply, %:					
100	20,33	15,72	8,06	7,95	10,7
75	18,75	14,93	6,79	6,37	8,98
50	17,1	12,18	5,22	4,53	6,76
Fuel heat utilization efficiency (brutto) at steam consumption, % of the nominal:					
100	89,70	91,00	91,24	91,78	91,65
75	89,15	91,14	91,35	91,82	91,74
50	87,84	89,33	89,59	90,04	89,84