BASIC PERFORMANCE INDICATORS OF THE PGU-450T STEAM-GAS UNIT DURING OPERATION IN THE DISTRICT HEATING AND ELECTRIC POWER MODE

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The basic performance indicators of the PGU-450T steam-gas unit during operation in the district heating and electric power generation mode are reported, based on tests at units of the North-west Heating and Electric Power Plant (TÉTs) and the TÉTs-27 Heating and Electric Power Plant of the firm JSC "Mosénergo."

Keywords: steam-gas unit, district heating and electric power mode, gas turbine, steam turbine, boiler-utilizer, engineering and economic indicators

Steam-gas units intended for operation with combined production of electric power and district heating are currently coming into widespread use in the Russian Federation. Operating PGU-450T units are being run in these modes at units 1 and 2 of the Kaliningrad TÉTs-2 (branch of JSC "INTER RAO EÉS"), units 1 and 2 of the Northwest TÉTs plant in St. Petersburg (branch of JSC "INTER RAO EÉS"), units 3 and 4 of TÉTs-27 and unit No. 11 of TÉTs-11 of JSC "Mosénergo," as well as at unit No. 4 of the Southern TÉTs, a "Nevskii" branch of JSC "TGK-1." In this article we report basic performance indicators for the PGU-450T steam-gas unit during operation with district heating, based on tests at units of the North-west Heating and Electric Power Plant (TÉTs) and TÉTs-27.

Brief description of the thermal configurations of the PGU-450T. The main power generating system in the PGU-450T at the Northwest TÉTs was designed for operation primarily in the district heating mode.[3]

After the heating loop was brought into operation in October 2006, the generator unit was run in a district heating mode with extraction of steam for mains heaters, so that the an experimental determination of the engineering and economic performance of the unit when it was operated with take-off for heating was of particular interest.

In the design it was assumed that when the outside air temperature was minimal, the system could be operated with a maximum amount of heat extraction with the mains water (380 Gcal/h) typical for operation of gas-turbine units in heating and electric power plants (without a steam turbine).

The district heating unit of the PGU-450T at the Northwest TÉTs (and the PGU-450T at the Kaliningrad TÉTs-2) consists of two horizontal mains water preheaters that are nondetachable from the steam (PSG-1 and PSG-2) and two vertical mains water preheaters (PSV-3 and PSV-4) connected in series with the mains water. PSG-1 and PSG-2 are supplied with steam from the discharge of the high and low pressure cylinders of the steam turbine, PSV-2 is fed from the low pressure steam supply after the 16th stage of the steam turbine (after the low pressure regulator valves), and PSV-4 is supplied with reduced steam from the high pressure loop.

The temperature of the direct mains water is maintained at the specified level by changing the position of the regulator deflection diaphragm for the steam turbine which is controlled by the steam pressure regulator in the district heating outtake.

Depending on the temperature regime for the heating grid, the mains water can be heated in the following cycles:

PSG-1 + PSG-2;

PSG-1 + PSG-2 + PSV-3;

PSG-1 + PSG-2+ PSV-3 + PSV-4.

When the unit is operated in district heating mode, drainage of condensate from the heating steam for the boilers can cause a rise in the condensate temperature at the inlet to the condensate gas preheater to 90 – 100°C or somewhat higher, which leads to an increase in the temperature of the effluent gases and a corresponding drop in the economic efficiency of the boiler-utilizer and the unit as a whole. In order to reduce the temperature of the primary condensate, additional boiler

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condensate coolers are included which use return mains water as a cooling medium.

One feature of the PGU-450T district heating systems at the Northwest and Kaliningrad plants is their ability to operate in a steam-gas unit-district heating and power plant mode. For this, the thermal configuration includes supply of high pressure steam reduced in a fast-acting reduction-cooling unit and of low pressure steam from a reduction unit for the high and low pressure loops of the boiler-utilizers. Unit No. 2 of the Northwest plant and the PGU-450T at the Kaliningrad plant include a special reduction-cooling unit for the district heating system which is intended for supply of reduced high pressure steam to the vertical preheaters PSV-3 and PSV-4.

Only horizontal preheaters PSG-1 and PSG-2 are installed in the PGU-450T at TÉTs-27 and TÉTs-21 of JSC "Mosénergo."

The excess heat in the primary condensate following the boiler-utilizer of the steam-gas unit can be utilized by switching in a water-water heat exchanger with the mains water with extraction of the heated water to the pipe for the primary mains water following PSG-2. Use of the water-water heat exchanger makes it possible to reduce the temperature of the effluent gases from the boiler-utilizer and, thereby, to increase the economic efficiency of the cycle through distribution of up to 20 Gcal/h of heat from the mains water (from the two boiler-utilizers).

Major characteristics of the equipment in the district heating unit. The block district heating system (BTU) for the unit at the Northwest plant was designed for a mains water feed of 7500 tons/h, but is operated with a reduced feed of 4500 – 5000 tons/h. At the time the district heating unit No. 1 was brought into operation in October 2006, only PSG-1 and PSG-2 were running. The steam to these preheaters arrives from steam turbine takeoffs and makes it possible to obtain a mains water temperature of 113 – 115°C after PSG-1 and 118 – 121°C after PSG-2, with a return mains water temperature of 70°C. The amount of heating in PSG-2 is small because of insufficient steam pressure in the second district heating takeoff from the steam turbine.

The settings for protection from overpressure in the upper district heating takeoff from the steam turbine were low by 0.1 MPa relative to the manufacturer's specifications. This limitation made it impossible to shift the unit to running with the regulating deflection diaphragm of the steam turbine fully closed (minimum position of the deflection diaphragm is 9 mm according to the position indicator).

Because heat from the hot condensate in the condensate gas preheater is used in the district heating unit loop, additional heat on the order of 17 – 20 Gcal/h can be obtained in the water-water heat exchanger.

Thus, at the PGU-450T unit at the Northwest plant with two-step preheating of the mains water and preheating of the mains water in two water-water heat exchangers, it can transfer a total of about 200 Gcal/h of heat with a mains water temperature at the outlet of the unit district heating system of about 115°C.

Connecting the PSV-3 preheater for steam with parameters $p = 0.44$ MPa and $t = 205$°C through the reducer in the low pressure loop from the two boiler-utilizers in tests with the feed rate of mains water reduced to 2500 tons/h made it possible to raise the temperature of the direct mains water to 135°C and with a thermal load of about 42 – 50 Gcal/h.

There is no need to connect the PSV-4 preheater under the conditions of the actual temperature operating regime.

The operating efficiency of the PGU-450T at the Northwest plant was estimated by comparing the supplier's design data with the actual data (Table 1) for an outside air temperature of –2.2°C.

The discrepancy is caused by the presence in the factory configuration of an inbuilt bundle in the condenser and a higher feed rate of mains water to the unit and by the power of the steam turbine. After correction for the power and the mains water feed, the results are close to the manufacturer-designer's data.

Figure 1 is a plot of the variation in the nominal fuel supply for electric power generation and heat production obtained with proportional separation.

The maximum thermal load for the block district heating system of unit No. 1 at the Northwest plant over almost 6 years of operation was 213 Gcal/h, and with a heat of 17 kcal/h obtained from the two water-water heat exchangers, the total thermal load reached 240 Gcal/h for a return mains water temperature of 50 – 68°C.

During the heating season the maximum opening of the deflection diaphragm was no more than 22 – 35%. This made it possible to maintain the required pressure in the outtake from the mains preheater PSG-2.

The gross efficiency of the unit when the entire heat output of the fuel was shifted to electrical load was 46%.

When the unit was operated with combined electrical power and heat, the design configuration for the district heating installation at unit No. 1 yielded up to 300 Gcal/h of

TABLE 1. Estimated Efficiency of the PGU-450T Unit at the Northwest District Heating and Electric Power Plant

Parameter	Based on test data	Design data from LMZ
Mains water feed rate G_{mw}, tons/h	4558	7500
Steam turbine power, N_{st}, MW	114	128.5
Thermal load, Gcal/h:		
Q_{psg1}	114.5	144.12
Q_{psg2}	88.3	152.80
Q_{psg3}	17.1	21.07
Q_{Σ}	219.9*	317.99/198.0*
Mains water temperature,°C:		
return t_{mwret}	59.4	50.3
direct t_{mwdir}	103	90

* Including corrections for power and mains water feed rate.

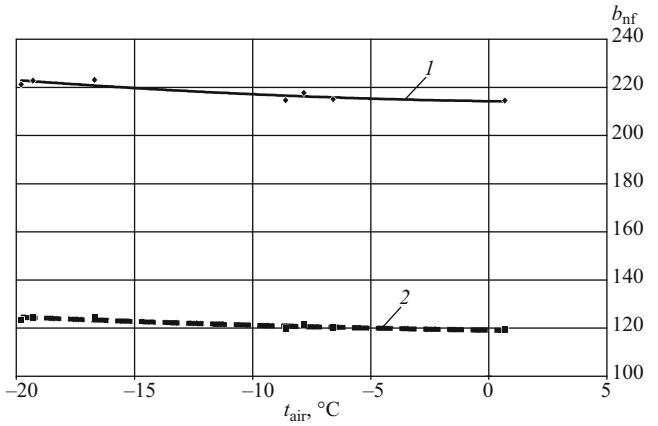

Fig. 1. The specific feed rate of nominal fuel for production of electrical energy (*1*) and heat (*2*) as a function of outside air temperature: *1*, b_{nf}^{e}; g/(kW · h); *2*, b_{nf}^{h}, kg/Gcal.

thermal energy when the two-step system for heating the mains water was used.

PGU-450T units No. 3 and 4 at the TÉTs-27 district heating and electric power plant of JSC "Mosénergo." The PGU-450T power generator units No. 3 and 4 at the TÉTs-27 plant were brought into operation in December 2007 and 2007, respectively, with the complete system including the block district heating system.

TABLE 2. Design Characteristics of the T-125/150-7,4 Steam Turbine in the District Heating Mode

Indicator	Outside air temperature, °C	
	–20	–2.5
Mass flow rate of steam, tons/h:		
high pressure loop	444.2	460.2
low pressure loop	107.6	110.4
Steam pressure, kgf/cm^2 (MPa):		
high pressure loop	71.90 (7.05)	74.75 (7.33)
low pressure loop	5.29 (0.519)	5.36 (0.526)
Steam temperature, °C:		
high pressure loop	496.5	499.6
low pressure loop	203.9	204.4
Power to generator terminals, MW	111.4	125.12
Mains water temperature, °C:		
at inlet to PSG-1	60.0	43.3
at outlet from PSG-2	98.4	83.4
Mains water feed rate, tons/h	7500	7500
Steam pressure at takeoffs, kgf/cm^2 (MPa)		
at PSG-1	0.743 (0.073)	0.280 (0.0275)
at PSG-2	1.230 (0.121)	0.709 (0.070)
Mass flow rate of steam to condenser, tons/h	11.1	9.4
Mass flow rate of collected steam, tons/h:		
at PSG-1	314.5	214.6
at PSG-2	201.1	325.2
Heat load, Gcal/h (MW):		
mains preheaters	277.4 (322.56)	293.5 (341.28)
condensate cooler	10.4 (12.09)	6.9 (8.02)
total	287.8 (334.65)	300.4 (349.30)

The block heating system for units 3 and 4 includes the following:

— two horizontal mains water preheaters PSG-1 and PSG-2 connected in series along the mains water;

— three condensate boiler pumps KNB-A, -B, and -V;

— a boiler condensate cooler; and,

— three mains pumps in the first riser.

The mains water preheaters are supplied with steam from outtakes at the discharge from the high and low pressure cylinders of the T-125/150-7,4 steam turbine and are not disengaged by steam. The pressure in the discharge to PSG-1 is regulated by a deflection diaphragm.

The mains water passes successively through PSG-1 and PSG-2, with possible bypassing of PSG-2 and of the group PSG-1, PSG-2.

PSG-1 and PSG-2 are steam-water pipe heat exchangers with housing of welded sheet carbon steel. The heat exchangers for PSG-1 and PSG-2 are designed to be two-way.

The boiler condensate cooler, a T-20-MFG plate type from the "Alfa Laval" company is intended for cooling the condensate of the warming steam with counterflow of the heating and heated streams.

Three horizontal mains water preheater condensate pumps with a regulator valve on the pipe head intended for maintaining the specified level in PSG-1 are mounted in the heating steam condensate discharge.

In order to prevent backflow of the steam produced during boiling of the condensate in the condensate drains of the preheaters during load surges on the steam turbine, a device is provided which consists of no-return valves installed in the piping joining the preheater housing with the condensate collector.

The condensate of the heating steam from PSG-2 drains into PSG-1 through an 11 m hydraulic seal and, when the steam feed to the preheaters is low and during emergencies, on to the condenser. For high steam feeds to the horizontal mains water preheaters, the heating steam condensate is pumped out by the preheater discharge pumps through the boiler condensate cooler into the main condensate line.

Depending on the operating conditions, the heating steam condensate either is discharged in cascade into the condenser or is fed through the boiler condensate cooler to the discharge pump in the main condensate line.

Part of the return mains water from the head collector of the first riser pumps is collected at the boiler condensate cooler, where it is preheated by the heating steam condensate, and at the two water-water heat exchangers on the bypass for the condensate gas preheaters of the boiler-utilizers.

The water-water heat exchanger, a T-20-MFG plate type from the "Alfa Laval" company, is intended for cooling the condensate after the gas condensate preheater. The heating and heated flows are in opposite directions (counterflow).

The major design characteristics of the T-125/150-7,4 steam turbine with a district heating unit are listed in Table 2 for outside air temperatures of –20 and –2.5°C.

Engineering and economic performance of the PGU-450T district heating system. Table 3 lists the economic indicators for the PGU-450T units at the TÉTs-27 plant in the district heating and condensation modes obtained during the tests described here and Fig. 2 is a comparison of the specific indicators for operation of the PGU-450T unit with steam power and district heating units at powers of 80 – 250 MW.

As an example, Table 4 lists the results of measurements made during tests at the PGU-450T unit at the TÉTs-27 plant of Mosénergo.

A comparison of Tables 2 and 4 shows that the power in the takeoffs for an outside air temperature of -16°C is lower than the design value by about 7 Gcal/h, because of the lower steam capacity of the boiler-utilizers for high pressure steam. From the two boiler-utilizers is should be on the order of 460 tons/h for the high pressure steam and 110 tons/h for the low pressure steam. In fact, the steam capacity for the high pressure steam is 420 tons/h and for the low pressure steam, 96 tons/h.

A similar situation was also observed for an outside air temperature of –4°C, where the difference in the thermal power from the design value was about 9 Gcal/h according to the test data.

The thermal capacity of the water-water heat exchangers of the boiler-utilizers is 7.1 and 9.8 Gcal/h for outside air temperatures of –4 and –16°C, respectively.

These tests and other inspections revealed the presence of unsealed channels in the gas duct of the boiler-utilizer. After these were eliminated, the total thermal load on the PGU-450T power generator units was 290 Gcal/h, in agreement with the design thermal load.

The operation of the PGU-450T unit with a single mains water preheater should be examined separately. Operation in these modes is possible in the summer with reduced thermal loads and lower mains water feeds when the required amount of heat from the mains water is 50 – 60 Gcal/h.

Mains water bypasses for the PSG-1 and PSG-2 preheaters are provided for the thermal configuration of the unit; these can be used to heat the mains water in only a single

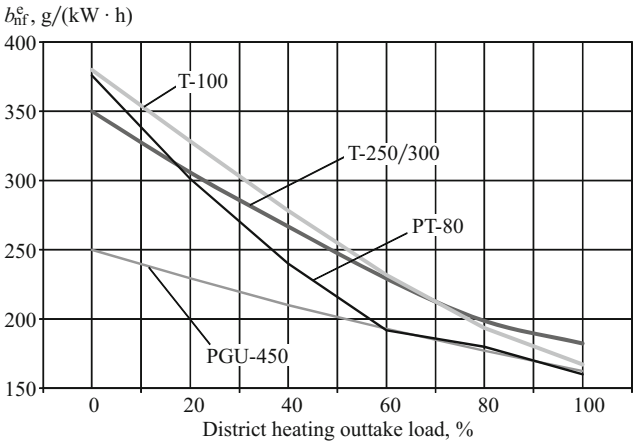

Fig. 2. Specific feed rate of nominal fuel for generating electrical energy as a function of relative load to district heating take-offs for power generation units with steam turbine powers of 80 – 250 MW and for the PGU-450T.

preheater. However, in these operating modes a second preheater which is disconnected from the mains water operates with lower feed rates compared to the design value (about 2000 tons/h to provide scheduled heat to consumers).

When the power generating unit operates with a nominal electrical load, it is best to switch the district heating system with two-step mains water preheating to single-step operation in the following cases:

— when the mains water feed rate through the PSG (horizontal mains water preheater) piping system falls below 2500 tons/h;

— when it is necessary to maintain the mains water temperature at the outlet from the BTU (block district heating system) below 80°C; and,

— when the total district heating load on the power generating unit falls below 130 Gcal/h (spring-summer operation).

Table 5 lists the parameters that characterize the operation of the district heating system of the PGU-450T power generating unit at the TÉTs-27 plant of JSC "Mosénergo" with single-step preheating of the mains water.

Experience with running the mains water preheater at the TÉTs-27 plant during 2008 – 2010 in these modes shows

TABLE 3. Engineering and Economic Indicators for the PGU-450T District Heating Unit

Indicator	Condensation mode	District heating mode
Steam gas unit (PGU) electric power N, MW	450.8/479	426.3/450
Amount of heat produced Q, Gcal	–/–	284/295
Specific feed rate of fuel for:		
electric power generation b^{e}_{nf}, g/(kW · h)	251.2/244.4	208.3/198.0
heat production, b^{h}_{nf}, kg/Gcal	–/–	145/145
Efficiency gross, %	49/50.2	45/47
The coefficient of fuel (CF), %	–/–	75/78

Note. The numerator gives the actual value and the denominator, the design value.

TABLE 4. Results of Tests on the District Heating System at Unit No. 3 of TÉTs-27

t_{air}, °C	p_{hp}, MPa	t_{hp}, °C	G_{hp}, MPa	p_{lp}, MPa	t_{lp}, °C	G_{lp}, MPa	G_{st31}, m³/h	G_{st32}, m³/h	N_{st31}, MW	N_{st32}, MW	N_{st}, MW	N_{PGU}, MW	G_{mw}, tons/h	UP_{pd}, %	Q_{psg}, Gcal/h	t_{mw}^{dir}, °C	t_{mw}^{ret}, °C
–4.4	7.3	503	426.0	0.56	232	97.0	50,740	50,832	154.1	154.3	115.4	423.8	7435	0	284.0	84	47
–4.2	7.3	503	427.0	0.56	232	96.7	51,269	51,321	156.0	154.4	115.9	426.3	7430	0	284.0	84	47
–3.9	7.3	503	427.0	0.56	232	97.0	49,861	50,003	152.3	152.7	115.9	420.9	7518	0	284.0	84	46
–3.3	6.5	507	380.5	0.49	226	80.0	41,897	41,313	125.0	125.1	111.6	361.8	7388	0	277.0	82	46
–4.0	6.5	507	378.7	0.53	226	81.6	41,334	41,263	123.2	122.9	96.1	342.2	7449	0	237.0	77	46
–5	7.3	502	427.8	0.55	232	96.3	51,032	51,147	154.3	154.4	108.9	417.6	5096	0	270.0	101	48
–9	6.4	504	376.0	0.51	230	75.0	42,135	42,153	124.6	124.7	99.6	348.9	7595	0	235.5	81	50
–9	7.2	502	422.0	0.55	232	94.0	51,270	51,281	155.8	155.6	109.4	420.8	7605	0	258.6	90	56
–9	7.2	503	422.0	0.55	232	97.0	50,734	50,787	155.6	155.6	99.4	410.6	5255	0	168.2	90	58
–16	6.4	503	375.0	0.55	233	74.0	41,838	41,737	125.2	125.7	98.9	349.8	7937	0	230.2	82	53
–16	7.1	502	419.0	0.56	233	96.0	50,534	50,657	155.7	155.4	107.2	418.3	7947	0	270.2	93	59
–16	7.1	502	419.0	0.56	232	96.0	50,725	50,644	155.0	154.7	106.2	415.9	7947	0	270.2	95	61

TABLE 5. Operating Indicators for a District Heating System with a PGU-450T Unit with Single-Stage Preheating of Mains Water

N_{st}, MW	UP_{pd}, %	Q_{BTU}, Gcal/h	G_{mw} through PSG-1, tons/h	t_{mw}^{ret}, °C	t_{mw}^{dir}, °C
139	100	67.7	1997	41	78
110	85	120.6	2448	40	70
101	55	128.0	3900	39	75

that, with constant monitoring of the state of the piping systems and keeping the mains water feed rates at a level of 2000 – 2500 tons/h, there were no disruptions in its operation. Constant monitoring of the efficiency of the horizontal mains water preheaters (PSG) based on the thermal balance of the preheater and a fixed level of mains water quality confirms that there were no deposits in the piping of the horizontal mains water preheaters.

CONCLUSIONS

1. Operating the PGU-450T units with combined electrical and thermal energy production using the heat from take-offs on the T-125/150-7,4 district heating steam turbine provides the consumer with heat in amounts up to 290 Gcal/h while maintaining an output power of at least 410 MW from the unit.

2. The inclusion of additional mains preheaters PSV-3 and, later, PSV-4, in the loop for the district heating systems at the Northwest TÉTs and the Kaliningrad TÉTs-2 plants has been validated for the temperature schedule of the heating grid with a direct mains water temperatures above 125 – 150°C.

3. Water-water heat exchangers provide a hot water supply for the station when the mains preheaters are disconnected during the summer season and add up to 19 Gcal/h when the unit is run in the district heating mode, thereby reducing the temperature of the effluent gases from the boiler-utilizers with a minimal reduction in the power of the steam turbine. Another way of solving this problem is to use just one mains water preheated, PSG-1.

4. Type PGU-450T units operated with two-step mains water preheating have a thermal efficiency similar to that of the T-125/150-7,4 steam turbine when it is operated with heat release to the take-offs.

5. Installing the additional preheaters PSV-3 and PSV-4 in the thermal circuits of the PGU-450T units at the Northwest TÉTs and the Kaliningrad TÉTs-2 plants makes it easier to follow the thermal schedule by using them to reduce the load on the steam turbine.