P a r t 6

ADVANCED TECHNOLOGIES AND POWER INSTALLATIONS FOR THERMAL AND ELECTRIC ENERGY GENERATION

6.2. Gas turbine and combined-cycle units

6.2.3. Coal-fired combined-cycle units

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Coal-fired combined-cycle units with coal gasification under pressure [7—9]. Technology of coal gasification under air blow pressure in a gas-dust flow was developed is the State Institute of Nitric Industry and Fuel Institute in Freiberg (Germany). Design of a test-industrial CC unit, using this technology, was developed by VTI in Russia within the federal scientific and technical program "Environmentally clean energy".

Fuel for a domestic CCU is berezovsky brown coal with moisture limit of 38 %, ash content of 7,0 % and calorific value of 14,3 MJ/kg on the working mass. The sulfur content in coal makes 0,2 %. The coal dust with a moisture content of 10 % is gasified. The output of fuel gas from coal makes 1,79 m^3/kg, its calorific value — 9,05 MJ/m^3 on the working mass. Fuel gas contains the following components, % on volume: CO = 50,4; H_2 = 18,18; CO_2 = 7,91; H_2O = 19,54; N_2 = 3,87; H_2S = 0,013. Density of fuel gas — 1,0062 kg/m^3.

Functionally a CC unit consists of a power plant and an integrated gasification plant (Fig. 6.11).

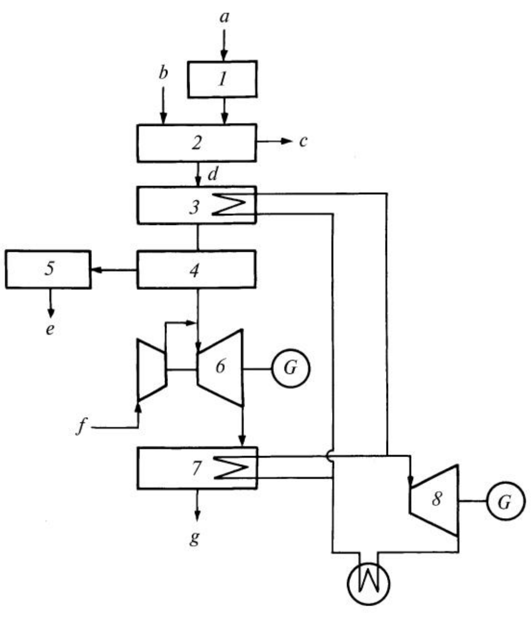

Fig. 6.11. Schematic diagram of CC with coal gasification:
1 — coal preparation system; *2* — gasifier; *3* — raw fuel gas cooling system; *4* — system of raw fuel gas cleaning from solids and gases; *5* — hydrogen sulphide recycling unit; 6— GT; *7* — HRSG; *8* — steam turbine; *9* — electric generator; *a* — coal; *b* — oxygen; *c* —slag; *d* — raw fuel gas; *e* — sulfur; *f*— air; *g* — flue gases

The power plant core is a binary CC, including two gas turbines GTE-200 with initial temperature of 1250°C, two heat recovery steam generators (HRSGs) and one steam turbine (ST) with a capacity of about 330 MW. Steam for the ST is generated in a gasifier and HRSGs, installed after gas turbines.

Each HRSG consists of a high-pressure circuit (path), a low-pressure path and a reheat.

Gasification plant includes a fuel treatment unit, a reactor with fuel dust intake, ash and slag removal, radiation and convective gas coolers and a system of fly ash recirculation to the gasifier, systems of "dry" ash- and sulfur cleaning.

Oxygen for gasification is provided by means of low temperature rectification of liquid air in an air separation installation. Each gas turbine is equipped with one gasifier with capacity of 160 t/h of coal dust.

Gasifier for an industrial CC consists of two parts: the reactor with burners, located above and the radiation gas cooler. Coal dust is gasified in the reactor in a descending dust/gas flare. In a radiation gas cooler generator gas is cooled to 700 … 900°C. The granulated slag after gas cooling drops out into a water bath, located at the bottom of a gasifier, from which through the lock system it is directed to the sediment tank, after which it is fractionized and shipped to consumers. Chemical analyses of slag, performed by VTI on test installations, has shown its complete hazardousness. It can be used as a concrete filler at road construction and in building industry.

Raw dusty fuel gas with a temperature of about 800°C enters the cyclones, where it is separated from large particles, and then it's supplied to convective gas coolers, where its temperature goes down to 500°C. At this temperature the gas passes dry fine clearing from dust in metal hose or ceramic filters. The "fly" ash, collected in a cyclone and fine filters, returns back to the gasifier and the cleaned gas enters a system of "dry" high-temperature desulfurization unit based on hemosorption of hydrogen sulfide, for example, by means of ferrous oxide or zinc ferrite at a temperature of 450 … 550°C.

The gas turbine unit represents a modification of 200 MW GT, manufactured in Russia, with initial temperature of 1250°C at natural gas combustion.

The CCU with coal gasification requires modification of combustion chambers and a turbine nozzle area, taking into consideration air selection for gasification.

The design of a HRSG has some peculiarities, connected with a gasification unit - HRSG and a gasifier have interconnection by steam and feed water.

Raw steam with an average pressure after the boiler of 14 MPa and temperature of 545°C enters the cylinder of high pressure of the steam turbine, after which the secondary steam with a pressure of 2,4 MPa returns to the boiler for reheat. In a boiler superheater the secondary steam is heated up from about 325 to 525°C.

To ensure the necessary steam flow at fluctuations of the ambient temperature, operation of the turbine in a sliding pressure mode with completely open steam regulating valves is provided. In a range of ambient temperatures of –30 to + 30°C a pressure of high-pressure steam changes in a range of 13,8 … 12,1 MPa.

The CC unit with coal gasification in flow under pressure, designed with two gas turbines and HRSG, provides both a wide range of electric capacity regulation during the day, and also possibility to stop the whole CC unit for weekends. Decrease in load is provided by reducing the gasifier productivity by corresponding reduction in fuel, oxygen and steam supply. At shutting down the unit, fuel, oxygen and steam isn't supplied to the gasifier and the whole energy part of the CCU stops.

Commissioning of the gasifier from a hot state takes 30 … 40 mines, from a cold one — 3 … 4 hours. Fuel gas is used as a starting fuel. Starting gas is taken from a collector in which it is delivered from the operating power units. The collector is equipped with receivers for accumulation of synthetic gas.

The CC unit has the following technical and economic characteristics at various ambient temperatures, °C:

Ambient temperature °C	+30	+5	-15	-24
Coal consumption, t/h	2x178,3	2x202,9	2x222,2	2x232,0
GT capacity (gross), MW	2x151,9	2x184	2x212,6	2x226,4
Steam turbine capacity, MW	327,7	339,1	348,1	353,1
Auxiliary needs, MW	33,2	26,6	40,2	41,5
Capacity of the unit (net), MW	618,1	694,3	759,1	791,8
CC efficiency (net), %	45,9	45,6	45,2	45,2

High environmental parameters are characteristic for the CCU with coal gasification under pressure. Concentration of solid particles in combustion products, discharged through stacks is less than 3 mg/m^3.

Special design of a GT combustion chamber and injection of steam into it, when necessary, provides nitrogen oxide concentration less than 100 mg/m^3 with 6% of oxygen in flue gases.

Though flue gases are almost free from sulfur dioxide, it's contained in gases, emitted from Klaus installation. Total emissions of sulfur dioxide will not exceed 80 mg/m^3 (at 6 % O_2) under conservative estimations.

High efficiency of the CCU with coal gasification yields reduction of carbon dioxide emissions by 10 … 15 %.

As capacity of the steam turbine makes about 50 % of the total capacity of the unit, cooling water consumption decreases by 1,5 times, compared to a steam turbine unit of the similar capacity.

Despite of the complicity of the technology, implemented in the described gasification unit, it does not discharge harmful wastewaters. All water using systems are water deficit.

The CC unit with coal combustion under pressure [10]**.**

Coal combustion in the fluidized bed yields it complete burning out, regardless of the coal quality. The achieved by that high heat transfer factors yield small heat exchange surfaces, and low combustion temperatures (about 900°C) provide nitrogen oxide emissions less than 200 mg/m^3 (less than 100 mg/MJ). Possibility to add sorbents (dolomite or limestone) to the bed yields connection of 90 … 95 % of sulfur, contained in coal.

Coal combustion in the fluidized bed under pressure (FBP), keeping advantages, characteristic for coal burning in the fluidized bed, results in essential increase in the boiler unit capacity and reduction of its overall sizes as well as in availability of combustion products after their purification from solid particles, being suitable for GT operation. A scheme of such CCU is shown in Fig. 6.12.

Combustion air is fed to the bed by a GTU compressor under pressure of 1 … 1,5 MPa; combustion products after purification from ash are supplied to the gas turbine, where useful work is performed. After the GT combustion products are cooled in the heat exchangers, included into a steam turbine cycle. Heat, accepted from FBP, is used for generation of steam, directed to the steam turbine.

Crashed coal and sorbent are supplied to the furnace in a dry state through a lock system or pumped as a water coal paste. Ash, containing sulfur compounds, is removed through the lock system after cooling in a heat exchanger. Flue gases are cleaned from fly ash in cyclones, purification efficiency makes 97 … 99 %.

Technical, economic and environmental characteristics of the unit with capacity of 270 M,W based on a steam turbine К-220-12,75 (under $t_{amb\ air}$ = +15 °C) are below:

Coal consumption, kg/s 36,7
Dolomite consumption, kg/s 3
Combustion temperature, °C 900
Steam pressure at a turbine exhaust, MPa 13,7
Steam consumption, kg/s 175
Reheater pressure, MPa. 2,57
Reheater temperature, °C ……………………..545
Gas pressure in the boiler, MPa 1
Flue gas consumption, kg/s 290
Electric capacity (net), MW………………......270
Steam turbine capacity (net), MW……………. 225
Gas turbine capacity (net), MW………………..45
Estimated efficiency (net), % 42,6
Coal composition, %:
Moisture 11
Ash 36
Flue gases .... …4
Low coal calorific value, MJ/kg 17,26
Sulfur content, % 1,4
Nitrogen content, % .... …0,9
Hazardous emissions, mg/m^3:
Sulfur oxides .... …200
Nitrogen oxides .... less than 200
Solid particles .... less than 10

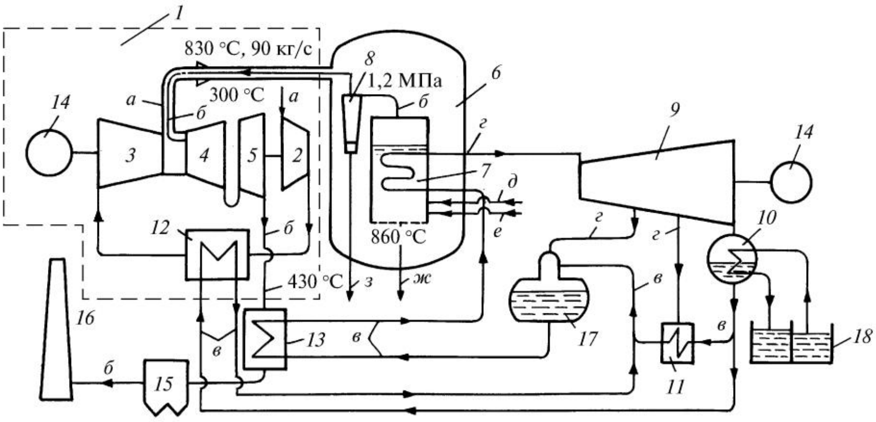

Fig. 6.12. Principal diagram of CCU with coal burning in the fluidized bed under pressure:
1 — GTU; *2* — low-pressure compressor; *3* — high-pressure compressor; *4* — HPT; *5* — LPT; *6* — generator; 7 — furnace with the fluidized bed; *8* — cyclone; 9 — steam turbine; *10* — condenser; *11* — low-pressure heater; *12* — intermediate air cooler; *13* — economizer; *14* — electric generator; *15* — electric filter; *16* — stack; *17* — deaerator; *18* — cooling pond; *a* — air; *б* —combustion products; *в* — water; *г* — steam; *д* — coal; *e* — sorbent; *жс* — ash removal from the bed; *з* — ash removal from the cyclone; МПа – MPa; кг/с – kg/s