AIR PROTECTION FROM POWER INDUSTRY EMISSIONS

1.5. Technologies of organic fuel combustion at TPPs with the lowered level of harmful emissions into atmosphere

1.5.2. Solid fuel gasification

1.5.2.1. Gasification basis and technologies

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Gasification is performed by chemical transformation of carbon, containing in coal, as well as of water steam at high temperatures with formation of a mixture of combustion gases (CO, H_2, CH_4). Heat, required for the reaction, is released due to combustion of a part of coal (there are also known and studied the processes with heat supply from the outside). Sulfur, containing in the coal, is converted into hydrogen sulfide, which is removed from the generator gas by industrially mastered and economically effective processes. As a result of gasification, pure combustion gas and heat are obtained from the coal. The heat can be converted into work.

Principle flow diagrams of combined-cycle plants (CCPs) with coal gasification are shown in Fig. 1.62. Oxygen or compressed air and steam are supplied into reactor (gas generator, gasifier), in which preliminary treated coal is also fed. In the gasifier coal is partly oxidized with generation of combustion gas (generator, synthetic), containing, mainly, CO and H_2, and also (depending on a technology) N_2, CO_2 and H_2O as well as ash, removed through the sluice. Generator gas is purified from the ash residues and sulfur compounds, and then is burnt in combustion chamber of the Gas-turbine plant (GTP). The GTP exhaust gas heat as well as heat, removed in process of gasification and generator gas cooling, are used for steam generation and its superheating, supplied into the steam turbine and for gasification.

Pure generator gas, burned in GTP combustion chamber, creates favorable conditions for operation of the wheel space of the gas turbine: sulfur emissions into atmosphere are almost absent. Combustion heat of the generator gas is enough to maintain the required gas temperature before the turbine, which at GTP development can be raised and achieves the peak values relevant to stoichiometric combustion.

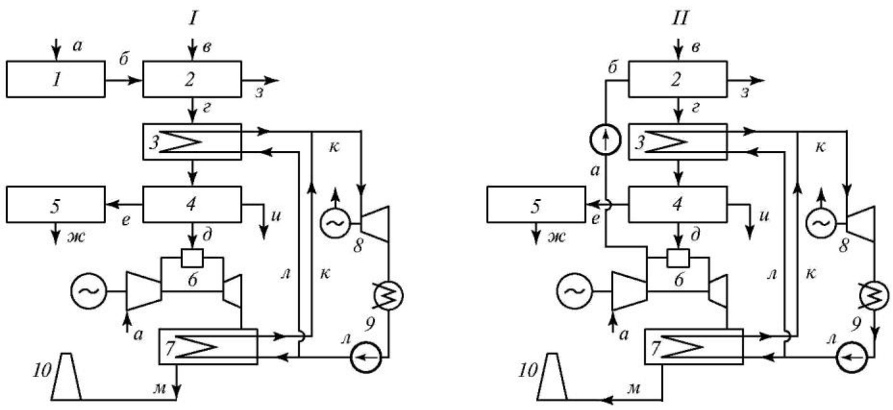

Fig. 1.62. GTP flow diagram:
I — oxygen blow; *II* — air blast; basic circuit elements: *1* — oxygen plant; *2* — gasification; *3* – raw gas cooling; *4* — gas purification; *5* — sulfur release; *6* — GTP; *7* — exhaust-heat boiler; *8* — combined-cycle turbine; *9* - condenser; *10* - chimney; *II* — supercharger, increasing the air pressure; material flows: *а* — air; *б* - oxygen; *в* — coal; *г* — raw gas; *д* - purified gas; *е* — sorbent; *ж* —sulfur; *з* — ash; *и* — dust; *к* — steam; *л* — water; *м* - flue gases

Systems of coal gasification and generator gas purification complicate the power plant scheme and raise its price. The processes in the systems are connected with loss of function and significantly reduce in CCP efficiency even at the almost complete conversion of coal chemical energy into chemical energy of the generator gas as well as heat, and utilization of the released heat with minimum thermodynamic losses.

Important advantages of the most advanced gasification systems are: the ability of processing different types of coal with different sintering ability, ash content, volatile matter content and different particle size; simple construction; the great efficiency; the high rate of readiness to work; the ability of quick load change; simple start-up and shutdown; no sewages and hydrocarbons, condensing in the generator gas.

The most studied coal gasification technologies are: gasification in the filling bed, FB, in the flow (Fig. 1.63.). At gasification in the filling bed, coal is filled into apparatus, and oxidant like air or oxygen together with water steam is supplied from the bottom and passes through the coal bed. Gasification occurs at a counterflow of coal and gases; gas temperature at the bed outlet is decreased so, that in the generator gas undecomposed condensing hydrocarbons, resins and oils can contain. The gasifier with the filling bed requires using of coal of a certain particle size, which should not stick together to provide a gas permeability of the bed. Since at the modern coal mining methods there is about 50% of small particles in coals, and in process of transportation and transfer their content becomes even greater, for gasifiers of this type pelletizing and briquetting of small particles is needed.

FB gasification should be realized at a temperature, lower than a temperature of ash softening point. It requires the increase in particle residence time in the reaction zone and the greater volume of the apparatus.

Coal reactivity and ash sintering ability are the most significant characteristics of fuel, used in FB gasifiers. They influence the oxygen consumption, carbon transformation, fly ash recirculation as well as capacity. A high degree of gasification at the moderate operating temperature is the most easily gained, using high reactivity coal. At regulation of FB gasifier load, the blowing speed should be more than a minimum speed of fluidization.

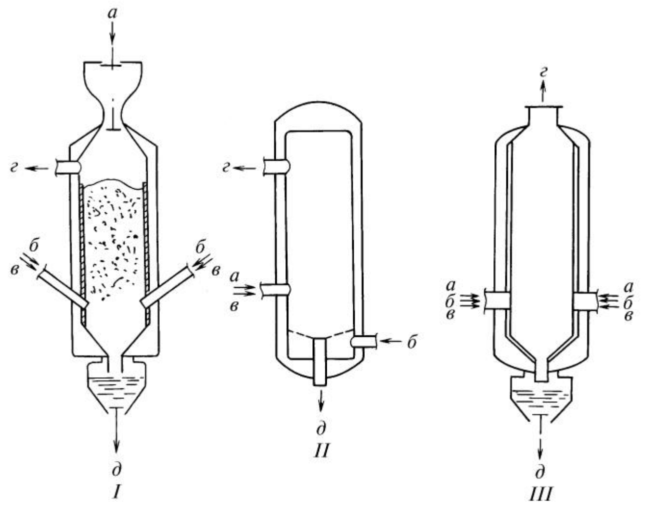

Fig. 1.63. Principal flow diagrams of the gasifier: *I and II* — filling and fluidizing bed, accordingly; *III* —gasification in the flow; *а* —coal; *б* — air or oxygen; *в* — steam; *г* — generator gas; *д* — ash or liquid slag

At gasification of coal dust in the oxidant flow there are no specific requirements for the coal quality. It occurs at a high temperature and heat loads on the working chamber walls. As on oxidant, oxygen is usually used, which provides at the short residence time of coal in the apparatus, the necessary temperature, required for complete carbon gasification and a rather high combustion heat of the generator gas. Owing to a high gas temperature at the gasifier outlet, it is free from resins and other condensing compounds.

Coal can be gasified at air blast and oxygen blow. Technologically oxygen using gives obvious advantages, because it allows intensifying processes, raising the carbon transformation degree, and gaining medium-calorie gas (10…12 MJ/m^3), which contains the minimum ballast (N_2, CO_2, H_2O) and allows making its purification easy. Together with it a presence of the oxygen plant complicates and raises the price of gasification system, and the costs for oxygen obtaining reduce power plant efficiency.

Raw generator synthetic gas consists of such substances that can pollute the environment and disturb the gas turbine operation, therefore, it is necessary to purify it from dust, sulfur compounds (H_2S, COS, CS_2), nitrogen (HCN, NH_3), alkali elements, chlorine, and fluorine. Purification technology makes a significant influence on the cost and heat efficiency of power plants.

For implementation of industrially mastered present technologies of gas purification from hydrogen sulfide, its cooling to the temperature of about 40^0C is needed. The cooling process is connected with pressure drop and loss of function; when using the released heat for steam generation it is transformed into work with efficiency of the steam cycle, but not of the whole combination set. Costs of the cooling system and the generator gas purification system is about 15… 20% of the total TPP cost.

According to the estimations, application of wet gas purification reduces CCP efficiency by 1%.

One of reasons of efficiency reduction at the generator gas wet purification is water steam condensation (significant amount of which is in the raw gas) at temperatures lower than 200^0C and connected with this losses of heat and function, and also absorption of not only H_2S_4, but also CO_2 from water steam and correspondent decrease in the mass flow rate through the gas turbine.

Generation gas cooling from 1400^0C to 800^0C leads to CCP efficiency reduction by 1% due to cooled gas recirculation.

High temperature technologies of generator gas purification are more and more developed. These technologies result in cutting the price and simplifying the system operation, as well as reducing losses, connected with the purification. It is possible in FB gasifiers to add sorbent into the bed and bind more than 90% of coal sulfur in the gasification processes, as well as absorb dust particles and compounds of alkali elements at temperatures of 540…600^0C in the same equipment. Additional cleaning of generator gas from sulfur and its supply into GTP at the same temperatures, and in the prospect after improvement of pipeline materials, at temperatures of 650 - 760^0C, are possible in case it's required. Temperature effect on CCP efficiency, at which dry gas cleaning is realized, is rather small. At temperature increase from 250…300 to 900…1100^0C CCP efficiency increases by 0,3…0,4%.

Characteristic features of three basic gasification methods for coal are mentioned in Tab. 1.30.

Though, in essence, all coal types – from lignite to anthracite – can be gasified, the present industrial experience is referred, mainly, to coal. Parameters, which can be achieved in different gasification systems at coal and brown coal using, are mentioned in Tab. 1.31.

Independently from gasification technology about the same part of energy (high combustion heat) - from 94,4 to 95,8%, is transformed into combustion gas and heat (Tab. 1.31). Increases in the process temperature at gasification in the flow raises a specific load of gasification section and reduces hydrocarbon content in the raw gas that simplifies its cleaning. Together with the temperature increase, complete oxidizing and burning of the main part of coal, supplied to gasifier, are necessary. Owing to it, a part of its chemical energy, transformed into combustion gas, reduces, and a part of energy, released as heat, increases. A maximum degree of transformation of coal chemical energy into generator gas combustion heat is achieved in the gasifier with filling bed and a low gas temperature at the outlet. So, for each gasification technology, a specific fuel utilization factor in the combustion cycle, influencing a structure and parameters of CCP, is characteristic.

Table 1.30 **Characteristic features of coal gasification processes**

Characteristics	Gasifier type					
	With the fixed bed		With the fluidized bed		With the dust-coal flow	
	Manufacturer					
	“Lurgi”	“British Gas-Lurgi” (BGL)	“Rein-brown”	KRV	“Texaco”, “Destek”	“Shell”
A state of the removed ash	Dry	Liquid	Dry	Agglomerated	Liquid	Liquid
A state of the filled coal	Lumped		Crushed		WCS*	Dust
Oxygen demand	Small		Absent or moderate		High	
Gas temperature at the outlet, °C	430... 540		870... 980		1260...1480	
Process features	Generator gases contains liquid hydrocarbons, resins, oils		Fly ash recirculation is needed because of high content of combustibles in ash		A great amount of chemical energy of coal is converted into heat	

* WCS— water-coal suspension.

Table 1.31. **Indicators of different coal gasification systems**

Indicator	Gasification technology and manufacturers						
	In the flow		With the fluidized bed		With the filling bed	In the flow	With the fluidized bed
	“Texaco”	“Shell”	“Vestinhaus” (KRV)		BGL	“Shell”	“Vestinhaus” (KRV)
Coal type	Coal, Illinois№ 6					Lignite	
Type of blow	Oxygen			Air	Oxygen	Oxygen	
Raw gas temperature, °C	1260... 1480	1400...1530	870... 980	870... 980	430... 540	1400...1530	950
Pressure in the gasifier, MPa	4,2	2,8	3,1	2,3	2,3	2,7	3,1
Typical content of generator gas % (by volume):							
CH_4	0,07	0,04	7,45	2,77	6,27*	—	6,51
H_2	37,65	30,93	34,1	15,85	31,5	28,46	28,16
CO	49,08	62,82	45,4	27,89	57,2	60,50	47,80
CO_2	11,13	1,5	11,42	3,27	2,20	5,37	15,70
inert	2,04	4,91	1,62	50	2,27	5,67	1,83
High combustion heat, kJ/m^3	10 434	11 180	12 297	6148	14 346	10 806	11 551
Gas release, m^3/kg of coal	2,1	2,08	1,97	4,11	2,00	1,77	1,65
Oxygen consumption, kg/kg of coal	0,86	0,6	0,61	0,68	0,53	0,73	0,62
Steam consumption, kg/kg of coal	—	0,029	0,0647	0,261	0,328	—	0,24
Water consumption, kg/kg of coal	0,5	0,063	0,053	0,064	0,053	0,10	0,18
Carbon conversion degree, %	99	99	95	92	99	99	97,5
A part of coal combustion heat used, %:							
chemical energy of gas	75,93	79,58	80,84	79,01	89,36	78,06	78,76
physical heat of gas	18,45	14,94	13,73	15,4	5,70	16,71	17,0
total	94,38	94,53	94,57	94,41	95,05	94,77	95,76

* Beside CH_4, the gas contains 0,53 % of C_nH_m