TABLES

**Table 1**

**NOx Specific Emission Norms for Boilers to be Installed at TPS before 01.01.2001**

| Boiler thermal output,MW | Fuel fired | Units of measurement | | |
|---|---|---|---|---|
| | | g/MJ | kg/tfe | mg/m³ of dry gas ( = 1.4) |
| 100-299 | Gas | 0.05 | 1.46 | 150 |
| | Fuel oil | 0.10 | 2.93 | 290 |
| | Brown coal: | | | |
| | dry-bottom | 0.12 | 3.50 | 320 |
| | wet-bottom | 0.13 | 3.81 | 350 |
| | Bituminous coal: | | | |
| | dry-bottom | 0.17 | 4.98 | 470 |
| | wet-bottom | 0.23 | 6.75 | 640 |
| >300 | Gas | 0.05 | 1.46 | 150 |
| | Fuel oil | 0.103 | 3.03 | 300 |
| | Brown coal | 0.14 | 3.95 | 370 |
| | Bituminous coal: | | | |
| | dry-bottom | 0.2 | 5.86 | 540 |
| | wet-bottom | 0.25 | 7.33 | 700 |

**NOx Specific Emission Norms for Boilers to be Installed at TPS since 01.01.2001**

| Boiler thermal output, MWFuel fired | Units of measurement | | | |
|---|---|---|---|---|
| | | g/MJ | kg/tfe | mg/m³ of dry gas ( = 1.4) |
| 100-299 | Gas | 0.043 | 1.26 | 125 |
| | Fuel oil | 0.086 | 2.52 | 250 |
| | Brown coal | 0.11 | 3.2 | 300 |
| | Bituminous coal: | | | |
| | dry-bottom | 0.17 | 4.98 | 470 |
| | wet-bottom | 0.23 | 6.75 | 640 |
| >300 | Gas | 00.043 | 1.26 | 125 |
| | Fuel oil | 0.086 | 2.52 | 250 |
| | Brown coal | 0.11 | 2.52 | 250 |
| | Bituminous coal: | | | |
| | dry-bottom | 0.13 | 3.81 | 350 |
| | wet-bottom | 0.21 | 5.97 | 570 |

**SOx Emission Norms for Boilers to be Installed before 01.01.2001**

| Boiler thermal output, MW | Unit of measurement | g/MJ | | kg/tfe | | mg/$m^3$ ( = 1.4) | |
|---|---|---|---|---|---|---|---|
| | Fuel | Normatired S content, % kg/MJ | | | | | |
| | | $S_n$0.045 | $S_n$ >0.045 | $S_n$ 0.045 | $S_n$ >0.045 | $S_n$ 0.045 | $S_n$ >0.045 |
| 100-299 | All solid and oil fuels | 0.875 | 1.5 | 25.7 | 44.0 | 2000 | 3400 |
| 300 | All solid and oil fuels | 0.875 | 1.5 | 25.7 | 38.0 | 2000 | 3000 |

**SOx Emission Norms for Boilers to be Installed since 01.01.2001**

| Boiler thermal output, MW | Unit of measurement | g/MJ | | kg//tfe | | mg/$m^3$ ( = 1.4) | |
|---|---|---|---|---|---|---|---|
| | Fuel | Normatired S content, % kg/MJ | | | | | |
| | | Sn 0.054 | Sn>0.045 | Sn0.045 | Sn>0.045 | Sn0.045 | Sn>0.045 |
| 100-199 | All solid and oil fuels | 0.5 | 0.6 | 14.77 | 17.6 | 1200 | 1400 |
| 200-249 | | 0.4 | 0.45 | 11.7 | 13.1 | 950 | 1050 |
| 250-299 | | 0.3 | 0.3 | 8.8 | 8.8 | 700 | 700 |
| 300 | | 0.3 | | 8.8 | | 700 | |

### Table 3

**Particular Matter Specific Emission Norms for Boilers to be Installed before 01.01.2001**

| Boiler thermal output, MW | Unit of measurement | g/MJ | | | kg/tfe | | | mg/$m^3$ ( = 1.4) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Fuel | Normatired ash content, % kg/MJ | | | | | | | | |
| | | below 0.6 | 0.6-2.5 | above 2.5 | below 0.6 | 0.6-2.5 | above 2.5 | below 0.6 | 0.6-2.5 | above 2.5 |
| 100-299 | All solid fuels | 0.06 | 0.06-0.2 | 0.2 | 0.176 | 1.76-5.85 | 5.86 | 150 | 150-500 | 500 |
| 300 | All solid fuels | 0.04 | 0.04-0.16 | 0.16 | 1.175 | 1.175-4.7 | 4.7 | 100 | 100-400 | 400 |

**Particulate Matter Specific Emission Norms for Boilers to be Installed since 01.01.2001**

| Boiler thermal output, MW | Units of measurement | g/MJ | | | kg/tfe | | | mg/$m^3$ ( = 1.4) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Fuel | Normatired ash content, % kg/MJ | | | | | | | | |
| | | below 0.6 | 0.6-2.5 | above 2.5 | below 0.6 | 0.6-2.5 | above 2.5 | below 0.6 | 0.6-2.5 | above 2.5 |
| 100-299 | All solid fuels | 0.6 | 0.06-0.1 | 0.1 | 1.76 | 1.76-2.93 | 2.93 | 150 | 50-250 | 250 |
| 300 | All solid fuels | 0.02 | 0.02-0.06 | 0.06 | 0.586 | 0.586-1.76 | 1.76 | 50 | 50-150 | 150 |

Table 4

**Some Data on Steam Turbine Units of Russia**

| Quantity | Unit rating, MW | | | | | |
|---|---|---|---|---|---|---|
| | 150 | 200 | 300 | 500 | 800 | 1200 |
| Total number of units | 37 | 89 | 101 | 7 | 14 | 1 |
| Including coal-fired units | 27 | 47 | 31 | 7 | 2(5) | |
| Number of monoblock | 14 | 57 | 50 | 6 | 14 | 1 |
| Number of two-boilers single-turbine units | 23 | 32 | 51 | 1 | | |
| Number of TKZ boilers | 22 | 58 | 91 | | 12 | 1 |
| Number of ZIO boilers | 38 | 56 | 65 | 8 | 2 | |
| Number of BKZ boilers | | 9 | | | | |
| Number of LMZ turbines | 4 | 89 | 53 | | 14 | 1 |
| Number of KhTZ turbines | 33 | | 26 | 7 | | |
| Number of TMZ turbines | | | 22 | | | |
| Number of EAS alternators | 37 | 31 | 71 | | 14 | 1 |
| Number of ETM alternators | | 58 | 26 | 5 | | |
| Number of SETM alternators | | | 4 | 2 | | |
| Live steam pressure, MPa | 14.0 | 14.0 | 25.5 | 25.5 | 25.5 | 25.5 |
| Live and reheat steam temperature, C | 545 | 545 | 545 | 545 | 545 | 545 |
| Steam Flow, t/h | 500 | 640-670 | 950-1000 | 1650 | 2650 | 3950 |
| kg/s | 139 | 178-186 | 264-278 | 458 | 736 | 1097 |
| Nom.gas flow, thou.$m^3$/h | 500 | 660 | 1060 | 1700 | 2700 | 4000 |
| kg/s | 172 | 227 | 364.5 | 585 | 929 | 1376 |

**Table 5**

**Data on some pulverized coal boilers**

| Name | Type and Manufacturers of Boilers | | | | | | |
|---|---|---|---|---|---|---|---|
| | E-500 BKZ | TPE-214A TKZ | TPE-216 TKZ | TPP-312A TKZ | P-57R ZIO | TPP-804 TKZ | P-67 ZIO |
| Delivery of first boiler | 1981 | 1988 | 1984 | 1976 | 1986 | 1982 | 1983 |
| Grade of Coal | Brown | Bitumin. | Brown | Bitumin. | Bitumin. | Bitumin. | Brown |
| Coal Field | Berezovo | Kuznetsk | Berezovo Kharanor | Donbas | Ekibastuz | Kuznetsk | Berezovo |
| Steam capacity, t/h | 500 | 670 | 670 | 1000 | 1650 | 2650 | 2650 |
| kg/s | 139 | 186 | 186 | 278 | 458 | 736 | 736 |
| Live steam pressure, MPa | 14.0 | 14.0 | 14.0 | 25.5 | 25.5 | 25.5 | 25.5 |
| temperature, C | 545 | 545 | 545 | 545 | 545 | 545 | 545 |
| Reheat temperature, C | – | 545 | 545 | 545 | 542 | 542 | 542 |
| Furnace section (depth width), m | 10.311.3 | 12.513.5 | 13.512.5 | 8.717.4 | 9.821.8 | 15.530.9 | 23.123.1 |
| Heat release rate: | | | | | | | |
| volume, MW/$m^3$ | 0.1 | 0.072 | 0.084 | 0.135 | 0.134 | 0.075 | 0.061 |
| section. MW/$m^2$ | 3.22 | 3.38 | 3.39 | 5.33 | 6.04 | 4.29 | 3.95 |
| Boiler efficiency, % | 90.0 | 92.0 | 90.5 | 89.5 | 90.5 | 92.4 | 92.6 |
| Exhaust gas temperature, C | 167 | 131 | 158 | 165 | 157 | 132 | 140 |

Table 6

**Basic Parameters of Large Steam Turbines Operating in Russia**

| Parameters | Turbine type and manufacturer | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | LMZ | | | | | KhTZ | | TMZ | | |
| | K-1200-240 | K-800-240 | K-300-240 | K-210-130 | PT-80/100-130/13 | K-500-240 | K-160-130 | T-250-240 | T-185-130 | T-100-130 |
| 1. Nominal capacity, MW | 1200 | 800 | 300 | 210 | 80 | 500 | 160 | 250 | 185 | 100 |
| 2. Max.output, MW | 1400 | 870 | 330 | 215 | 100 | 535 | 165 | 300 | 220 | 120 |
| 3. Live steam pressure, MPa | 23.5 | 23.5 | 23.5 | 12.8 | 12.8 | 23.5 | 12.8 | 23.5 | 12.8 | 12.8 |
| 4. Live steam temperature, C | 540 | 540 | 565* | 565* | 555 | 540 | 565 | 540 | 555 | 555 |
| 5. Reheat pressure, MPa | 3.5 | 3.24 | 3.53 | 2.31 | | 3.65 | 2.8 | 3.68 | | |
| 6. Reheat temperature, C | 540 | 540 | 565* | 565* | | 540 | 565 | 540 | | |
| 7. HP cylinder max. steam flow: t/h | 3950 | 2650 | 930 | 670 | 470 | 1650 | 516 | 980 | 760 | 485 |
| kg/s | 1097.2 | 736.1 | 258.3 | 186.1 | 130.6 | 458.3 | 143.3 | 272.5 | 225 | 135 |
| 8. Condenser pressure, kPa | 3.58 | 3.43 | 3.43 | 3.45 | | 3.5 | 3.43 | 5.8 | 5.0 | 5.6 |
| 9. Cooling water temperature, C | 12 | 12 | 12 | 10 | 20 | 12 | 12 | 20 | 20 | 20 |
| 10. Cooling water flow, thou.m$^3$/h | 103 | 73 | 33.5 | 25.0 | 8.0 | 53.5 | 20.8 | 28.0 | 24.8 | 16.0 |
| 11. Number of steam extraction for regeneration9 | 8 | 8 | 7 | 7 | 9 | 7 | 8 | 7 | 7 | |
| 12. Feedwater temperature, C | 274 | 274 | 265 | 240 | 249 | 265 | 229 | 263 | 232 | 232 |
| 13. Designed specific heat consumption, kJ/kW.h | 7660 | 7720 | 7720 | 8065 | 9610 | 7720 | 8260 | 8170 | 8760 | 9080 |
| 14. Same at present, kJ/kW.h | 7616 | 7683 | 7704 | | | 7640 | | 8145 | | |
| 15. Number of cylinders | 5 | 5 | 3 | 3 | 2 | 4 | 2 | 4 | 3 | 3 |
| 16. Number of stages, including | 21 | 26 | 29 | 27 | 30 | 26 | 21 | 31 | 25 | 25 |
| HP** | 8 | 1R+11 | 1R+11 | 1R+11 | 1R+16 | 16+9 | 7 | 1R+11 | 1R+12 | 2R+8 |
| IP** | 28 | 29 | 12 | 11 | 1R+8 | 11 | 8 | 10+26 | 9 | 14 |
| LP** | 25 | 25 | 25 | 24 | 1R+3 | 45 | 26 | 23 | 2(1R+2) | 2(1R+1) |
| 17. Number of exhausts | 6 | 6 | 3 | 2x1.5 | 1 | 4 | 2 | 2 | 2 | 2 |
| 18. Last stage average dia, mm | 3000 | 2480 | 2480 | 2100 | 2000 | 2550 | 2125 | 2390 | 2280 | 1915 |
| 19. Last stage blade length, mm | 1200 | 960 | 960 | 765 | 665 | 1030 | 1030 | 940 | 830 | 550 |

* — operated at 540 C; ** — 1R, 2R - single and twin control stage.

**Table 7**

**Parameters of heavy-duty GT units**

| Name | Type, manufacturer and purpose | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | TMZ | | NZL | KhTZ | Mashproject | LMZ | | |
| | GTN-16 | GTN-25 | GTN-25 | GTE-45 | GTG-110 | GTE-150 | GTE-150 | GTE-200 |
| | mechanical drive | | | utility | | | | |
| 1. Output, MW | 16.8 | 25.5 | 30.0 | 54.0 | 110.0 | 131.0 | 161.0 | 190.0 |
| 2. Efficiency, % | 29.5 | 32.3 | 29.0 | 28.0 | 36.0 | 31.0 | 31.5 | 33.1 |
| 3. Number of shafts | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 |
| 4. Turbine inlet gas temperature, C | 920 | 1060 | 900 | 900 | 1210 | 950 | 1100 | 1250 |
| 5. Turbine outlet gas temperature, Ñ | 430 | 460 | 400 | 475 | 517 | 423 | 530 | 545 |
| 6. Pressure ratio | 11.5 | 13.0 | 12.5 | 7.8 | 14.7 | 13.0 | 13.0 | 15.6 |
| 7. Air flow, kg/s | 89 | 103 | 170 | 271 | 357 | 636 | 630 | 630 |
| 8. Possible heating load, MJ/s | 28.5 | 37.9 | 51.1 | 98.8 | 157 | 220 | 296.5 | 302 |
| 9. Turbine unit weight, t | 60 | 60 | 97 | 180 | 50 | 320 | 320 | 320 |

Table 8

**Parameters of CIS marine and aeroderivative GT units**

| Name | Manufacturer, type, year of production | | | | | |
|---|---|---|---|---|---|---|
| | Mashproject | | YuTZ | Tushino | "Saturn" | "Trud" |
| | GT-15 | GT-16 | GT-25 | RD29-300 | AL-31STE | NK-37 |
| | 1990 | 1993 | 1994 | 1996 | 1996 | 1994 |
| 1. GT output, MW | 15.8 | 17.0 | 25.7 | 20.0 | 20.0 | 25.0 |
| 2. GT efficiency, % | 30.0 | 35.5 | 36.8 | 30.0 | 35.5 | 36.4 |
| 3. Pressure ratio | 12.8 | 20.0 | 21.8 | 10.7 | 21.0 | 23.4 |
| 4. Turbine inlet gas temperature, C | | | | 957 | 1252 | 1147 |
| 5. Gas flow, kg/s | 98.5 | 71.0 | 85.0 | 98.0 | 62.0 | 101.0 |
| 6. Turbine outlet gas temperature, C | 365 | 420 | 497 | 457 | 518 | 425 |
| 7. Possible heating load, MW | 23.4 | 22.6 | 33.3 | 34.4 | 25.9 | 23.1 |

Table 9

**Parameters of Domestic CCPs**

| Designation | CCP-450T | CCP-325 | CCP-80 |
|---|---|---|---|
| 1. GT type/manufacturer | V94.2, Siemens-LMZ | GTG-110, Mashproject | NK-37, TRUD |
| 2. Number of GTs | 2 | 2 | 2 |
| 3. Heat recovery boiler (HRSG) manufacturer | ZIO | ZIO | BZEM |
| 4. ST manufacturer | LMZ | LMZ | KTZ |
| 5. GT gross output, MW | 143.6 | 110.0 | 24.2 |
| 6. ST gross output, MW162.8 | 115.0 | 19.8 | |
| 7. CCP gross output, MW | 450.0 | 325.0 | 68.2 |
| 8. Auxiliary consumption, MW | 13.5 | 8.1 | 3.4 |
| 9. CCP net output, MW | 436.5 | 316.9 | 64.8 |
| 10. CCP efficiency, % | 50.0 | 52.5 | 45.5 |
| 11. Gas flow, kg/s | 499.4 | 358.5 | 104.2 |
| 12. Gas turbine outlet temperature, C | 545 | 524 | 429 |
| 13. Exhaust gas temperature, C | 110 | 100 | 130 |
| HP Circuit | | | |
| 14. Steam flow, t/h | 472 | 305 | 71 |
| 15. Steam pressure past HRSG/before ST, MPa | 8.0/7.6 | 7.0/6.5 | 40.8/37.0 |
| 16. Steam temperature past HRSG/before ST, C | 515/510 | 495/490 | 430/427 |
| LP Circuit | | | |
| 17. Steam flow, t/h | 114.0 | 75.0 | 18.5 |
| 18. Steam pressure past HRSG/before ST, MPa | 0.65/0.6 | 0.65/0.6 | 0.765/0.6 |
| 19. Steam temperature past HRBG/before ST, C | 200/195 | 210/205 | 205/203 |

## Table 10

### Gas Turbine Blade Alloy characteristics

| Name | Deformed alloys | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EI607A | EI893 | EI765 | TsD-1 | TsJ-24 | EP783 | EP800 | EI-929 | EP-220 | EP-957 |
| 1. Ultimate strength, MPa | 930 | 1050 | 1100 | 1050 | 1150 | 1100 | 1150 | 1150 | 1165 | 1260 |
| 2. Yield point, MPa | 485 | 560 | 620 | 630 | 660 | 710 | 750 | 730 | 845 | 940 |
| 3. Relative elongation, % | 39 | 30 | 25 | 25 | 20 | 15 | 10 | 15 | 15 | 8 |
| 4. Impact viscosity, kJ/m² | 1350 | 500 | 400 | 400 | 350 | 200 | 200 | 200 | 230 | 110 |
| 5. Stress rupture, MPa: 650C | 275 | 390 | 390 | 430 | 480 | | | | | 650 |
| 750C | | 180 | 180 | 190 | 210 | 275 | 280 | 300 | | 350 |
| 850C | | | | | | | 95 | 110 | 130 | 135 |
| 6. Corrosion loss, mg/cm² | 9 | 10 | | | | 11 | 320 | 320 | 660 | |

| Name | Casting alloys | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EI893L | EP539LMU | TsL-2 | TsL-4 (ZMI-4U) | TsL5(7) | ZMI-3 | TsNK-7RS | TsNK-7NK | JSBK-RS | JSBK-NK |
| 1. Ultimate strength, MPa | 700 | 750 | 740 | 750 | 700 | 800 | 800 | 750 | 950 | 750 |
| | 750 | 850 | 800 | 850 | 850 | 860 | 900 | 1100 | 1000 | 1100 |
| 2. Yield point, MPa | 440 | 650 | 600 | 600 | 500 | 700 | 700 | 700 | 850 | 700 |
| | 480 | 700 | 700 | 650 | 600 | 750 | 770 | 1050 | 900 | 1100 |
| 3. Relative elongation, % | 10-25 | 2-4 | 2.2-3.6 | 2.5-6.0 | 2.5-5.0 | 2.5-5.0 | 2.5-7.0 | 1.5-2.5 | 1-3 | 1-20 |
| 4. Stress rupture, MPa: 650C | | 580 | | | | 615 | 645 | 665 | | |
| 750C | 180 | 320 | | | | 335 | 360 | 380 | | |
| 850C | | 120 | 120 | 115 | 120 | 125 | 145 | 155 | 170 | 190 |
| 5. Corrosion loss, mg/cm² | 10 | 8 | 30 | | 6 | 13 | 6 | 6 | 650 | 650 |

## Table 11

### Forecast of Electric Energy Generation in Regions of Russia

| Parameter | Calendar year | Main regions | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Center | N-W | Middle Volga | N.Caucasus | Urals, Tumen | Siberia | Far East | Total |
| Electricity production, bln kWh | 1990 | 305.9 | 77.0 | 111.1 | 58.8 | 260.4 | 199.6 | 44.6 | 1057.0 |
| | 2010 | 457.8 | 131.4 | 162.0 | 112.0 | 401.6 | 344.0 | 102.1 | 1711.0 |
| Heat consumption, bln GJ | 1990 | 3.546 | 0.754 | 1.242 | 0.502 | 2.140 | 2.001 | 0.175 | 10.363 |
| | 2010 | 4.112 | 0.892 | 1.708 | 0.586 | 2.483 | 3.538 | 0.837 | 14.156 |
| Installed capacity, GW | 1990 | 55.3 | 14.5 | 22.5 | 10.8 | 41.2 | 45.2 | 11.1 | 200.7 |
| | 2010 | 84.3 | 24.7 | 34.5 | 25.3 | 71.6 | 73.2 | 26.5 | 340. |
| including TPS, GW | 1990 | 39.2 | 6.0 | 13.2 | 8.6 | 38.8 | 22.0 | 8.3 | 136.2 |
| | 2010 | 59.3 | 14.9 | 23.9 | 17.7 | 69.8 | 43.3 | 15.7 | 244.6 |
| Max.Load, GW | 1990 | 47.8 | 11.8 | 16.7 | 11.3 | 38.4 | 31.8 | 7.9 | 165.7 |
| | 2010 | 74.0 | 19.0 | 22.6 | 18.6 | 59.8 | 47.0 | 18.6 | 259.6 |
| Fuel demand, mln. tfe | 1990 | 106.7 | 17.2 | 44.2 | 21.5 | 103.8 | 57.8 | 17.9 | 351.2 |
| | 2010 | 150.0 | 35.0 | 64.5 | 45.4 | 174.0 | 114.0 | 40.3 | 582 |
| Including coal, mln. tfe | 1990 | 13.8 | 1.9 | 1.0 | 3.7 | 21.9 | 55.0 | 12.3 | 97.3 |
| 2010 | 27.2 | 6.0 | 9.8 | 10.4 | 67.2 | 99.0 | 27.7 | 219.6 | |

**Table 12**

**NOx Control Technologies**

| Data \ Project, Technology Develope, Sponsor, p.p. of CCTDF | The Babcock & Wilcox coal-reburning system Babcock & Wilcox Company 7-40 | ABB CE LNCFS with AOFA Southern Co Services, Inc. 7-48 | Foster Wheeler's LNB with AOFA Southern Co Servisec, Inc. 7-46 | The Babcock & Wilcox Low-$NO_x$ Cell burner system The Babcock & Wilcox Company 7-42 | EERC's gas-reburning and Low-$NO_x$ burner system (GR-LNB) Energy & Envir.Res. Corp. 7-44 | Fuller's micronized coal reburning technology Tennessee Valley Authority 7-52 | SCR Technology for the Control of NOx Emission Southern Co Serv. Inc. 7-50 |
|---|---|---|---|---|---|---|---|
| 1. Power Unit Output, MW | 100 — 300 | 200 — 800 | 50 — 800 | 300 — 800 | 50 — 800 | 50 — 800 | 200 — 800 |
| 2. Status (development stage): | commercial | commercial | commercial | commercial | commercial | demo | pilot |
| . Pilot, demo, commercial. | | | | | | | |
| Date of commercial implementation | 1995 | 1995 | 1995 | 1995 | 1995 | 1998 | 1998 |
| 3. Reasonable operating time, ths.hrs/yr | > 6 | > 4 | > 4 | > 4 | > 4 | > 4 | > 4 |
| 4. Emissions reduction, % | 50 | 40 | 65 | 55 | 70 | 50 — 60 | >80 |
| 5. Construction period, years | 1.0 | 0.5 | 0.2 | 0.2 | 1.0 | 0.5 | 0.92 |
| 6. Availability, % | — | — | — | 90,0 | — | — | — |
| 7. Kinds of fuel** À, Bit, Lign | Bit, Lign | Bit | Bit | Bit | Bit | Bit | |
| 8. Reagents: type | — | — | — | — | natural gas | — | ammonia |
| comsumption, g/MJ | — | — | — | — | < 20% | — | — |
| 9. Capital investment, doll/kW | 40 — 65 | 30 — 40 | 30 — 40 | 5.5 — 8.0 | 17 — 42 | 32 | 80 — 90 |
| 10. Maintenance costs, cents/kW.h | 0.21 — 0.29 | 0.067 — 0.17 | 0.067 — 0.17 | 0.03 — 0.04 | 0.2 — 0.7 | 0.1 | 0.4 — 0.5 |
| 11. Cost of 1 t of $NO_x$ removed, $ | 260 | 420 — 1590 | 420 — 1590 | 160 — 450 | 400 — 2000 | — | 700 — 5000 |
| 12. Reference Unit Capacity, MW | 200 | 500 | 500 | 500 | 300 | 300 | 300 |

* — Clean Coal Technology Demonstration Program; Program Update 1993

** — A (anthracite), Bit (bituminous coals), Lign (Lignites)
Service life is about 20 years

Table 13

**$SO_2$ Control Technologies**

| Data \ Project / Technology Developer / Sponsor / p.p. of CCTDP* | (CT-121) advanced FGD process (wet)<br>South.Co Serv., Inc. 7-62 | AFGD-process (wet)<br>Pure Air on the Lake, L.P. 7-60 | FLS miljo a/s's (GSA) system for FGD (semidry)<br>AirPol, Inc. 7-54 | Bechtel Corp.'s (CZD/FGD) process (semidry)<br>Bechtel Corp. 7-56 | LIFAC's sorbent injection process (semidry)<br>LIFAC-North America 7-58 |
|---|---|---|---|---|---|
| 1. Power Unit Output, MW | 100 | 200 — 800 | 50 — 300 | 50 — 800 | 50 — 300 |
| 2. Status (development stage): pilot, demo, commercial. | demo | commercial | pilot | demo | commercial |
| Date of commercial implementation | 1995 | 1995 | 2000 | 1995 | 1995 |
| 3. Reasonable operating time, ths.hrs/yr | > 6 | > 6 | > 4 | > 4 | > 4 |
| 4. Emission reduction, % | | | | | |
| - of $SO_2$ | 95 | 95 | 90 | 50 | 80 |
| - of NOx | ~20 | — | — | — | — |
| - of particulate matter | ~50 | — | — | — | — |
| 5. Construction period, years | 2.0 | 2.5 | 0.4 | 0.3 | 1.1 |
| 6. Availability, % | — | 99.9 | — | — | — |
| 7. Kinds of fuel** | Bit; S > 2%<br>Lign; S > 1.5% | Bit; S > 2%<br>Lign; S > 1.5% | Bit; 1 < S < 2%<br>Lign; 0.6 < S < 1.5% | Bit; S < 0.4%<br>Lign; S < 0.3% | Bit; S < 1%<br>Lign; S < 0.6% |
| 8. Water requirement, 1/MJ | — | 0.1 | — | — | — |
| 9. Reagents: type | $CaCO_3$ | $CaCO_3$ | $Ca(OH)_2$, $Mg(OH)_2$ | $Ca(OH)_2$ | $CaCO_3$ |
| Ca/S ratio | ~1 | ~1 | ~1.0 — 1.5 | ~2 | ~2 |
| consumption, g/MJ | < 5 | < 5 | < 2.8 | 0.7 | <2.5 |
| 10. Wastewater, ml/MJ | — | 5.0*** | — | — | — |
| 11. By-Products type | $CaSO_4$ | $CaSO_4$ | $CaSO_4$, $CaSO_3$, $CaCO_3$ | $CaSO_4$, $CaSO_3$ $MgSO_4$, $MgSO_3$ | $CaCO_3$ |
| yield, g/MJ | < 6.5 | < 6.5 | < 5 + fly ash | < 1 + fly ash | < 3 + fly ash |
| application | sale | sale | ash disposal | ash disposal | ash disposal |
| 12. Capital investment, doll/kW | 180 — 250 | | (160) | 30 — 60 | 50 — 60 |
| 13. Maintenance costs, cents/kW.h | 0.5 — 1.3 | | (0.551) | — | — |
| 14. Cost of sulfur removed, doll/t | 470 — 630 | | 420 — 680 | 500 — 650 | 650 |
| 15. Reference Unit Capacity, MW | 100 | 500 | 300 | 200 | — |

* — CCTDP - Clean Coal Technology Demonstration Program; Program Update 1993

** — Bit (bituminious coals), Lign (lignites)

*** — Wastewater Dissolved Solids: pH = 8–9; content of chloride - 4560 ppm; sulphate - < 2500 ppm; fluoride - 19 ppm; tot al dissolved solids - 1.41 $g/m^3$
Service life is about 20 years.

## Table 14

## Combined SO2/NOx Control Technologies

| Data / Project / Technology Developer / Sponsor / p.p. of CCTDP* | SNOX Flue Gas Cleaning Technology<br>ABB Environ. System<br>7-64 | SNRB Flue Gas Cleaning Technology<br>The Babcock & Wilcox Co<br>7-68 | NOXSO $SO_2/NO_x$ Flue Gas Cleanup System<br>NOXSO Corp.<br>7-74 | Integrated Dry $NO_x/SO_2$ Emission Control System<br>B&W Technology Public Service Co of Colorado<br>7-76 | Millicen Clean Coal Technology Demonstrat. Project<br>New York State E & G Corp<br>7-72 | Technology: LIMB<br>B&W<br>Babcock & Wilcox Co<br>7-66 | Technology: Coolside<br>Consolid. Coal Co | E & E Research Corp.'s Gas Reburning and sorbent injection process<br>Energy & Envir. Research Corp.<br>7-70 | TWR-technology Healy Clean Coal Project<br>Alaska Industr.<br>7-32 |
|---|---|---|---|---|---|---|---|---|---|
| 1. Power Unit Output, MW | 200 – 800 | 50 – 200 | 100 – 300 | 50 – 250 | 300 | 50 – 500 | 50 – 250 | 50 – 500 | 50 – 300 |
| 2. Status (development stage): Pilot, demo, commercial | commercial | pilot | demo (no results) | demo | demo (no results) | commercial | commercial | commercial | pilot |
| Date of commercial implementation | 1998 | 2000 | after 2000 | 1998 | after 2000 | 1995 | 1995 | 1995 | after 2000 |
| 3. Reasonable operating time, ths. hrs/yr | > 6 | > 6 | > 6 | > 4 | > 6 | > 4 | > 6 | > 5 | > 6 |
| 4. Emission reduction, % | | | | | | | | | |
| - of $SO_x$ | 95 | 80 | 97 | 70 | 98 | 20 – 30 | 70 | > 50 | > 90 |
| - of $NO_x$ | 90 | 90 | 70 | 70 | 50 | 40 – 50 | | > 60 | 80 |
| - particulate matter | > 99 | 99.8 | - | - | 20 | - | - | - | 99.9 |
| 5. Construction period, years | 1.0 | 0.8 | 1.0 | 1.3 | 1.1 | 2 | 2 | 2.3 | 2.3 |
| 6. Kinds of fuel** | Bit; S > 2%<br>Lign; S > 1.5% | Bit; S < 1%<br>Lign; S < 0.6% | Bit; S > 2%<br>Lign; S > 1.5% | Bit; S < 0.7%<br>Lign; S < 0.4% | Bit; S > 2%<br>Lign; S > 1.5% | Bit; S < 0.3%<br>Lign; S < 0.2% | S < 0.7%<br>S < 0.4% | Bit; S < 0.4<br>Lign; S < 0.3 | Bit; 1 < S < 2%<br>Lign; 0.7 < S < 1.5 |
| 7. Reagents, type | $NH_3$, catalysis | $Ca(OH)_2 + NH_3$<br>$NaHCO_3 + NH_3$ | sorbent<br>natural gas | Ña + Na + urea | $CaCO_3$<br>urea | $CaCO_3$ | $Ca(OH)_2$ | $CaCO_3$, $Ca(OH)_2$ | $CaCO_3$ |
| Ca/S ratio | - | 1.5 - 2.0 (Ca/S)<br>1.0 - 1.5 ($Na_2/S$) | - | - | ~1 | 2 | 2*** | 1.7 | |
| $NH_3/NO_x$ ratio | 0.9 | 0.9 | | | - | - | - | - | - |
| consumption, g/MJ | $NH_3$ – 0.2 | $Ca(OH)_2$ – 1.4<br>$NH_3$ – 0.2 | - | - | $CaCO_3$ < 5 | Ñ$aCO_3$ < 5 | - | 0.65 | - |
| 8. Wastewater | | | | | neutralized | | | | |
| 9. By-Products, type | $H_2SO_4$, $Na_2CO_3$<br>$NaNO_3$, NaCl | $CaSO_4$, $CaSO_3$, $CaCO_3$, $CaCl_2$, CaO, $Na_2SO_4$, $Na_2SO_3$ | sulfur | $CaSO_4$, $CaSO_3$<br>$Na_2SO_4$, $Na_2SO_3$<br>fly ash | $CaSO_4$, $CaCl_2$ | $CaSO_4$, $CaSO_3$, $CaCO_3$ | $Na_2SO_4$ | $CaSO_4$, $CaSO_3$, $CaCO_3$ | slag, $CaSO_4$<br>$CaCO_4$, fly ash |
| yield, g/MJ | < 4.7 | 1.4 + fly ash | < 1.5 | - | < 6.5 | - | 1.9 + fly ash | 0.9 + fly ash | - |
| application | sale | ash disposal | sale | ash disposal | sale | ash disposal | | ash disposal | ash disposal |
| 10. Capital investment, doll/kW | - | 260 | 250 | - | 180 | 31–102 | 69 – 160 | 40 | - |
| 11. Maintenance costs, cents/kW.h | - | 1.5 | 0.4 | - | - | 0.54 | - | - | - |
| 12. Cost of sulfur removed, doll/t | - | 510 | 210 | - | 450 | 370 – 620 | - | - | - |
| $NO_x$ removed, doll/t | - | 510 | 800 | - | - | - | - | - | - |
| 13. Reference Unit Capacity, MW | 300 | 200 | 200 | 100 | 300 | 200 | | 300 | 200 |

* – CCTDP - Clean Coal Technology Demonstration Program. Program Update 1993
** – Bit (bituminous coals), Lign (Lignites)
*** – With addition NaOH or $Na_2CO_3$ of Na/Ca = 0.2 ratio
Service life is about 20 years

## Table 15

### Basic Characteristics of Coal TPS Emission Reduction Technologies

| Contaminant | Technology | | Coal grade and combustion technology | Maximum cleaning efficiency % | Enlarged specific heat consumption Btu/kW.h (%)*** | Specific cost, $/kW | | Enlarged costs for repair and service c/kW.h | Enlarged electricity cost, c/kW.h | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | new plants | modified plants | | new plants | modified plants |
| Sulfur Dioxide | FGD | Wet Limestone/ Forced Oxidation | High Sulfur Coals | 95 - 98 | 120 (1.34) | 130 - 300 | 150 - 250 | 0.28 | 0.48 - 0.61 | 0.53 - 0.66 |
| | | Lime Slurry Wet/Dry | Low Sulfur Coals | 80 - 90 | 60 (0.67) | 100 - 150 | 130 - 200 | 0.16 | 0.35 - 0.40 | 0.37 - 0.48 |
| | | Simplified Wet/Dry | Low Sulfur Coals | 60 - 70 | 54 (0.6) | 30 | 70 | 0.15 | 0.30 | 0.35 |
| | | Dry | Low Sulfur Coals | 30 - 50 | 9 (0.1) | 30 | 40 | 0.10 | 0.10 | 0.10 |
| Nitrogen Oxides | Low-$NO_x$ burners + overfire air supply | | reconstruction of dry-bottom boilers | 40 | 20 (0.22) | <10 | 10 - 20 | 0.01 | <0.03 | 0.03 - 0.04 |
| | reburning and additional measures (burners. etc.) | | FBC, PC and cyclon boilers | 50 - 70 | 22(0.25) | | | 0.10 | 0.04 | 0.05 |
| | SCR on hot side at high dust content | | rigid standards for PC, FBC and cyclon boilers | 60 - 80 | 75 (0.84) | 70 - 90 | 80 - 100 | 0.26 | 0.40 - 0.43 | 0.41 - 0.45 |
| | SNCR with ammonia or urea injection | | rigid standards for PC,CFB,FBC | 40 - 80 | 0 | 5-10 | 10 - 20 | 0.10 | 0.11 - 0.12 | 0.12 - 0.13 |
| Fly ash | ESP | | High Sulfur Coals | 4.3-8.6* 11 - 22** | 5 - 20 (0.06 - 0.22) | 85 | 85 | 0.15 | 0.25 | 0.20 |
| | baghouses | reverse air cleaning | All grades of coals | 4.3*/11** | <10 (<0.11) | 70 | 90 | 0.17 | 0.28 | 0.31 |
| | | pulse jet cleaning | All grades of coals | 4.3*/11** | 20 (0.22) | 50 | 60 | 0.20 | 0.28 | 0.30 |

* mg/MJ;
** mg/m³ at SR =1.4;
*** at $b_e$ = 8980 BTu/kW.h, which corresponds to =38%

## Table 16

## Advanced Electric Power Generation Projects

| Data / Project, Technology Develo, Sponsor, p.p. of CCTDF* | Pressurized Fluidized-bed Combustion (PFBC) Systems | | | | Atmospheric circulating FB Combustion Systems | | Integrated Gasification Combined Cycle (IGCC) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tidd PFBC<br>The Ohio Power Co<br>7-14 | The Appalachian Power Co PFBC<br>7-8 | DMEC-1 Limited Partnership<br>PYROFLOW PCFB<br>7-10 | Four Rivers Energy Partners PCFB<br>7-12 | ACFB York County Energy Partners<br>7-18 | ACFB Nucla Tri-State Generation & Trasmis.<br>7-16 | ABB CE Inc.<br>7-20 | Texaco's technology<br>Tampa Electric Co<br>7-28 | Tampella U-GAS system<br>TAMCO Partn.Co<br>7-26 | Pinon Pine Sierra Pacific Power Co<br>KRW<br>7-24 | Wabash River Coal Gasific Repowering Project JV<br>Destec<br>7-30 | Duke Energy Corp.<br>BGL<br>7-22 | Centerior Energy Corp.<br>COREX<br>7-96 |
| 1.Power Unit Output, MW | 80 | 300 – 500 | 50 – 200 | 300-500 | 100 – 300 | 50 – 200 | 200 – 400 | 200 – 600 | 200 – 600 | 200 – 600 | 200 – 600 | 200 – 600 | 200 – 400 |
| 2.Status (development stage): Pilot, demo, commercial | commercial | demo | demo | pilot | demo | commercial | demo | demo | demo | demo | demo | demo | demo |
| Date of commercial implementation | 1998 | 2000 | after 2000 | after 2000 | 2000 | 1995 | after 2000 | 1998 | 2000 | 2000 | 1998 | 2000 | after 2000 |
| 3.Reasonable operating time, ths.hrs/yr | >6 | >6 | >6 | >6 | >4 | >4 | >4 | >6 | >6 | >6 | >6 | >6 | >6 |
| 4.Emissions reduction, % | | | | | | | | | | | | | |
| of $SO_2$ | 90 | 95 | 90 | 95 | 90 | 70 – 95 | 99 | 96 | 99 | 98 – 99 | 98 | 99 | 90 |
| of $NO_x$ | 80 | 80 | 70 | 70 | 60(80) | 60 | 90 | 90 | 90 | 94 | 80 | 90 | 97 |
| 5.Construction period, yrs | 3.0 | 3.2 | 2.0 | – | 1.5 | | – | 2.7 | – | 2.2 | – | – | – |
| 6.Kinds of fuel** | Bit;1<S<2.5% | Bit;S >2% | Bit;1<S<2% | Bit; S >2% | Bit; S <2% | Bit;S <1.5% | Bit; S <3% | Bit; S >3% | Bit;S >3% | Bit;S >3% | Bit;S >3% | Bit;S >3% | Bit;1<S <2% |
| | Lig;0.6<S<2 % | Lig;S>1.5% | Lig;0.6<S<1.5% | | Lig;S <1.5% | Lig;S <1.0% | Lig; S >2% | Lig; S >2% | Lig;S >2% | | | | Lig;0.6<S<1. 5% |
| 7.Water requirement, | no | no | no | no | no | no | no | yes | no | no | yes | yes | yes |
| 8.Reagents type | $CaCO_3$ | $CaCO_3$ | $CaCO_3$ | $CaCO_3$ | $CaCO_3$ | $CaCO_3$ | regenerated | | $CaCO_3$ | $CaCO_3$ | regenerated | | $CaCO_3$ |
| Ca/S ratio | – | – | – | – | – | 1.5/4.0 | – | – | – | – | – | – | – |
| 9.By-products type | M | M | M | M | M | M | slag | $H_2SO_4$, slag | M | M | sulfur, slag | sulfur, sl. | M |
| application | ash disposal | ash dispos | ash disposal | ash dispos. | ash dispos. | ash dispos. | sale | sale | ash disposal | | sale | sale | – |
| 10. Reference Unit Capacity, MW | 80 | 340 | 100 | 300 | 250 | 150 | 200 | 250 | 300 | 300 | 300 | 300 | 200 |
| 11. Reference Unit Efficiency,% | 40.0 | 42.2 | 40.0 | 47.0 | 39.5 | – | 45.0 | 42.0 | 46.2 | 45.9 | 40.0 | 44.6 | 47.2 |
| 12. Emissions Particulate matter, mg/MJ | – | – | – | – | – | – | – | – | – | 4.3 | – | – | – |
| $SO_2$, mg/MJ | – | – | – | – | 100 | – | 45 | 90 | 25 | 20 | 85 | 45 | 100 |
| $NO_x$, mg/MJ | – | – | 130 | 130 | – | 80 | 45 | 115 | 40 | 30 | 45 | 65 | 50 |
| mg/m³ | 165 – 200 | 110 | 330 | 330 | – | 200 | 115 | 300 | 100 | 75 | 85 | 105 | 130 |
| 13. Year of Unit Start-up – | 2002 | 1997 | – | 1997 | – | 1998 | 1996 | 1998 | 1997 | 1995 | 1998 | 1999 | |
| 14. Cleaning | – | – | – | – | – | – | dry clean. | wet clean. | dry clean. | dry clean. | wet clean. | wet clean. | wet cleaning |
| 15. Oxdizer | – | – | – | – | – | – | air | oxygen | air | air | oxygen | oxygen | oxygen |

* CCTDP - Clean Coal Technology Demonstration Program, Program Update 1993

** Bit(bituminous coals); Lig(Lignites)

M mixture of utilized ($CaSO_4$, $CaSO_3$) and nonutilized ($CaCO_3$) sorbent with fly ash

Service life is about 20 years

Table 17

**IGCC Demo Projects developed in USA in accordance with CCTP**

| Name | Location | | | | | | |
|---|---|---|---|---|---|---|---|
| | Wabash River | Springfield | Pinon Pine | Cleveland | Camden | Tampa | Tom Creek |
| 1. Gasification technology | EF | EF | FB | FB | MB | EF | FB |
| 2. Developer | DCh | CE | KRW | VA | BGL | Texaco | T |
| 3. Gasifier output, t/h | 95 | 23 | 30 | 111 | 435 | 72 | 16.5 |
| 4. Coal grade | bituminous | | | | | | |
| 5. CCP output, MW | 269 | 60 | 100 | 150 | 480 | 260 | 55 |
| 6. Type of GT, MW | M7F | M6B | M6FA | – | M7F | M7F | M6B |
| 7. GT output, MW | 191 | 40 | 61 | – | 2192 | 192 | – |
| 8. ST output, MW | 111 | 25 | 46 | – | – | (124) | – |
| 9. CCP efficiency, % | 39.0 | – | – | – | – | 40.6 | 39.1 |
| 10. Blown by | O | A | A | O | O | O | A |
| 11. Ash removal in gasifier | L | S | S | – | L | L | S |
| 12. Clean up of particulates | H | H | H | – | – | H | H |
| 13. Desulfurisation of gas | C | H | H | – | C | H | H |
| 14. New (n)/retrofit (r) | r | r | r | n | n | n | n |
| 15. Start of tests | 1995 | 1996 | 1997 | – | – | 1996 | 1998 |
| 16. Completion of tests | 1998 | 2001 | 2000 | – | – | 1997 | 2000 |
| 17. Project cost, mln.USD | 398 | 271 | 270 | 825 | 780 | 241 | 197 |
| 18. DOE share, % | 50 | 48 | 50 | 18 | 25 | 50 | 47 |

EF - entrained-flow; FB - in fluidized bed; MB - in moving (fixed) bed; DCh - Dow Chemical;
CE - Combustion Engineering; VA - Voest Alpine; BGL - British- Gas-Lurgi; KRW - Kellog;
T - Tampella & Gas Research Institute; O - oxygen; A - air; L - liquid; S -solid; H - hot; C - cold.

## Table 18

### Test Results of Direct Coal Combustion for GT

| Name | Company | | | | |
|---|---|---|---|---|---|
| | Solar | Allison | | Westinghouse | |
| 1. GT capacity, MW | 4.0 | 4.6 | | 104 | |
| 2. Fuel supplied | CWS | CWS | | dust | CWS |
| 3. Max. particle size, mm | 75 | 15 | | 200 | 110 |
| 4. Mean particle size, mm | 11 | 5 | | 44 | 40 |
| 5. Ash content (dry), % | 3.0 | 0.8 | | 6.5 | |
| 6. S (dry), % | 0.6 | 0.7 | | 1.0 | |
| 7. Gas outlet temperature, C | 1054 | 1127 | | 1054 | 1010 |
| 8. Combuster pressure, MPa | 0.55 | 1.07 | | 0.59 | 0.60 |
| 9. Air flow, kg/s | 1.60 | 1.86 | 15.0 | 3.18 | |
| 10. Carbon burnout, % | 99.9 | 99.6 | 94 – 99 | 99 | |
| 11. Type of slag removal liquid | dry | liquid | | | |
| 12. Type of precipitator | inertial + filter | | | inertial | |
| 13. Ash slag removal, % | 98 | – | 89 | 90 | 89 |
| 14. Emissions of $NO_x$, ppm | 29 | 25 | 25 | 90 | 80 |
| 15. Capture of $SO_2$, % | 55 | 50 | - | 40 | 22 |
| 16. Type of sorbent | dolomite | | | limestone | |
| 17. Ca/S molar ratio | 1.2 – 1.6 | 3.7 | – | 2 – 4 | 3 |

CWS coal-water-slurry

Table 19

**Quality of Russian Coals Fired at TPS in 1993**

| Coal Field/Type | Used at TPS, mln.t | Content as per working mass | | | | | | Volatiles |
|---|---|---|---|---|---|---|---|---|
| | | W, % | A, % | LHV, MJ/kg | C, % | S, % | N, % | V, % |
| Kuznetsk, bit. | 22.3 | 10.7 | 20.4 | 21.8 | 40.5 - 66.0 | 0.4 | 1.3 - 1.8 | 12 - 41 |
| Kansk-Achinsk, br. | 27.5 | 33.1 | 6.8 | 15.4 | 37.4 - 44.3 | 0.3 | 0.5 | 48.0 |
| Eastern Donbas, AC | 5.8 | 8.2 | 25.1 | 21.5 | 62.5 | 1.7 | 0.5 | 5.0 |
| Pechora.,bit. (Inta) | 2.2 | 11.6 | 29.1 | 17.0 | 43.9 | 2.4 | 1.5 | 40.0 |
| Neryungrinsk, bit.(Yakutia) | 4.2 | 8.3 | 15.8 | 24.85 | 64.8 | 0.2 | 0.7 | 20.0 |
| Chelyabinsk, br. (Urals) | 6.4 | 15.2 | 37.2 | 12.6 | 33.8 | 0.8 | 0.9 | 44.0 |
| Near-Moscow, br. | 6.0 | 29.6 | 36.2 | 7.9 | 22.2 | 2.35 | 0.4 | 48.0 |
| Azeisk,.br. (East) | 8.0 | 23.5 | 17.4 | 16.3 | 43.1 | 0.5 | 0.9 | 48.0 |
| Kharanorsk, br. (East) | 8.2 | 38.6 | 13.6 | 11.8 | 34.3 | 0.3 | 0.5 | 44.0 |
| Bikinsk, br. (Far East) | 5.5 | 38.0 | 28.8 | 7.0 | 22.0 | 0.3 | 0.6 | 53.0 |
| Ekibastuz, subbitum. (Kazakhstan) | 25.6 | 6.1 | 39.9 | 16.4 | 41.9 | 0.7 | 0.8 | 25.0 |
| Gusinoozersk, br. (Buryatia) | 2.5 | 24.7 | 21.3 | 13.1 | 38.3 | 0.4 | 0.6 | 43.0 |

Bit bituminous; br. brown; AC anthracite culm.

Table 20

**Some Characteristics of Kuznetsk Coals and their Ash**

| Name | Coal Grade | | | | | |
|---|---|---|---|---|---|---|
| | LF | G | WS1 | WS2 | L&A | Wastes |
| Moisture content, W,.% | 11.5 – 13(18) | 8.5 – 11(19) | 9 – 12(21) | 8.5 – 12(19) | 710(13) | 6 – 25 |
| Ash content, $A^d$ ,% | 18(25) | 18.5 – 25 | 20 – 30 | 18 – 30 | 20 – 25 | 13 – 45 |
| Volatiles, $V^{daf}$ ,% | 40.5 | 39.5 | 31 | 20 | 12.5 | 16 – 41.5 |
| Sulfur content, $S^{daf}$, % | 0.4 | 0.5 | 0.5 | 0.4 | 0.5 | 0.3 – 0.9 |
| LHV, Q, MJ/kg | 21.9( 18 – 23) | 23.6 (16 – 27) | 23.4 (17 – 25) | 25.3 (16 – 26) | 25.1(27.7) | 17.4 – 22.3 |
| Fixed nitrogen, $N^{daf}$, % | 2.6 | 2.7 | 2.1 | 2.1 | 2.2 | 1.7 – 3.1 |
| $SO_2$ concentration in combustion gases: mg/MJ | 365 | 425 | 430 | 315 | 400 | 345 – 810 |
| mg/m³* | 935 | 1080 | 1090 | 810 | 1020 | 880 – 2060 |
| Ash composition, %: $SiO_2$ | 59.5 | 55.7 | 56.0 | 59.7 | 55.4 | 41.4 – 64.2 |
| $Al_2O_3$ | 20.6 | 21.6 | 23.6 | 22.4 | 25.4 | 17.4 – 26.8 |
| $Fe_2O_3$ | 6.7 | 7.8 | 10.1 | 8.5 | 77.2 | 4.1 – 10.8 |
| CaO | 3.9 | 6.0 | 4.0 | 2.7 | 4.6 | 2.4 – 7.6 |
| MgO | 2.7 | 2.8 | 1.8 | 1.6 | 1.9 | 1.4 – 3.4 |
| $K_2O$ | 3.0 | 2.3 | 2.0 | 2.6 | 1.9 | 0.8 – 3.9 |
| $Na_2O$ | 2.0 | 2.0 | 0.7 | 0.9 | 0.7 | 0.4 – 3.7 |
| $TiO_2$ | 0.9 | 0.8 | 1.0 | 0.9 | 0.8 | 0.8 – 1.2 |
| $P_2O_5$ | 0.5 | 0.8 | 0.5 | 0.5 | 1.6 | 0.2 – 1.6 |
| MnO | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 |
| Temperature of normal liquid slag removal, C | 1600 | 1500 | 1550 | 1700 | – | 1430 – 1580 |

* Here and hereinbelow, the emissions are related to m³ in standard conditions with excess air of 1.4 or $O_2$ = 6%.
The bracketed values are limiting for open-cast produced coals.

Table 21

**Some Characteristics of Bituminous Coals and their Ash**

| Name | Field/Coal Grade | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Pechora | | East Donbass | | S.-Yakutia. Neryungri | Ekibastuz | | |
| | Inta | Vorkuta | | | | | | |
| | LF | G | L | AC | WS | group 1 | group 2 | middle |
| Moisture content, W, % | 11.5 | 8.0 | 6.0 | 9.0 | 10.0 | 6.0 | 5.0 | 6.0 |
| Ash content, $A^d$,% | 32.5 | 32.0 | 34.0 | 35.0 | 22.0 | 43.0 | 48.0 | 45.0 |
| Volatiles, $V^{daf}$, % | 40.0 | 33.0 | 12.0 | 4.0 | 20.0 | 25.0 | 25.0 | 25.0 |
| Sulfur content, $S^{daf}$, % | 3.2 | 1.1 | 2.7 | 1.9 | 0.2 | 0.6 | 0.6 | 0.6 |
| LHV, Q, MJ/kg | 16.9 | 20.8 | 20.6 | 19.1 | 22.5 | 16.1 | 14.6 | 15.5 |
| Fixed nitrogen, $N^{daf}$, % | 2.6 | 2.4 | 0.8 | 0.8 | 0.8 | 1.7 | 1.7 | 1.7 |
| $SO_2$ concentration in combustion gases, mg/MJ | 3790 | 1060 | 2620 | 1990 | 180 | | | 770 |
| mg/$m^3$ | 9680 | 2700 | 6700 | 5080 | 460 | | | 1970 |
| Ash composition, %: $SiO_2$ | 54.6 | 62.6 | 49.9 | 54.1 | 53.6 | 62.6 | 59.2 | 60.6 |
| $Al_2O_3$ | 18.6 | 19.4 | 22.3 | 23.9 | 27.5 | 28.2 | 29.6 | 28.6 |
| $Fe_2O_3$ | 14.1 | 8.6 | 17.5 | 11.1 | 8.0 | 5.0 | 6.0 | 5.4 |
| CaO | 6.9 | 3.0 | 4.0 | 2.9 | 4.9 | 1.0 | 1.6 | |
| MgO | 2.3 | 2.3 | 1.6 | 1.7 | 2.4 | 0.7 | 0.6 | |
| $K_2O$ | 1.3 | 2.1 | 2.8 | 3.5 | 0.7 | 0.6 | 0.5 | |
| $Na_2O$ | 1.4 | 1.0 | 1.2 | 1.5 | 0.7 | 0.2 | 0.2 | 0.2 |
| $TiO_2$ | 0.8 | 1.0 | 0.7 | 1.3 | 1.2 | 1.1 | 1.3 | |
| $P_2O_5$ | | | | | 0.8 | 0.6 | 0.7 | |
| MnO | | | | | 0.2 | 0.1 | 0.2 | |
| Temperature of normal liquid slag removal, C | 1450 | 1550 | 1400 | 1550 | 1600 | 1650 | 1580 | 1600 |

Table 22

**Brown Coal Ash Chemical Composition and Fusibility**

| Field | Ash Chemical Composition, % | | | | | | | | Ash Fusibility, C | | | Tnj, C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | Ta | Tb | Tc | |
| 1. Kansk-Achinsk coals: | | | | | | | | | | | | |
| Irsha-Borodinsk 46.8 | 0.6 | 12.9 | 7.9 | 25.8 | 5.0 | 0.5 | 0.5 | 1180 | 1210 | 1230 | 1300 | |
| Nazarovo | 30.5 | 0.6 | 10.0 | 19.0 | 35.0 | 4.0 | 0.4 | 0.4 | 1200 | 1220 | 1240 | 1300 |
| Berezovo | 30.0 | – | 11.0 | 9.0 | 42.0 | 6.0 | 1.2 | 0.8 | 1270 | 1290 | 1310 | 1400 |
| 2. Azeisk | 52.8 | 0.4 | 28.8 | 7.2 | 7.9 | 2.1 | 0.6 | 0.2 | 1200 | 1340 | 1420 | 1550 |
| 3. Gusinioozersk | 51.5 | 1.3 | 23.6 | 12.1 | 5.6 | 2.8 | 1.9 | 1.2 | 1150 | 1260 | 1330 | 1460 |
| 4. Kharanorsk | 57.9 | 0.7 | 23.3 | 5.5 | 7.4 | 2.8 | 1.6 | 0.8 | 1170 | 1270 | 1360 | 1450 |
| 5. Raichikhinsk | 55.7 | 0.8 | 25.5 | 7.8 | 7.0 | 1.4 | 1.2 | 0.6 | 1150 | 1240 | 1340 | 1400 |
| 6. Bikinsk | 58.2 | 0.7 | 26.8 | 5.3 | 3.5 | 2.3 | 1.7 | 1.5 | 1240 | 1450 | 1500 | – |
| 7. Near-Moscow | 47.5 | 0.5 | 38.5 | 8.5 | 3.5 | 0.5 | 0.7 | 0.3 | 1350 | 1500 | 1500 | 1750 |

Ta, Tb, Tc, C typical temperatures of ash softening;

Tnj, C temperature of beginning of normal liquid slag removal.

Table 23

**Base-Case Options of Russian Advanced Coal TPS**

| Parameters | Supercritical Pulverized Coal Units | | | IGCC Plant | | Supercritical Pulverized Coal Units | | | Supercritical Pulverized Coal Units | | CFB Unit | Subcritical Pulverized Coal Units | IGCC Plant | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | existing | De-$SO_x$-De-$NO_x$ systems | Ecologically clean | oxygen blowing | air blowing | existing | with De-$SO_x$-De-$NO_x$ systems LD | HD | existing | with De-SOx-De-NOx clean | | | | |
| TPS capacity, MW | 6400 | | | 6000 | | 4000 | | | 2400 | | | 360 | 500 | 640 |
| Utilization period, h/yr | 6500 | | | 6500 | | 6190 | | | 4000 | | | 6000 | | |
| Unit capacity, MW | 800 | | | 650 | | 500 | | | 300 | | | 180 | 250 | 320 |
| Fuel characteristics: | | | | | | | | | | | | | | |
| Coal field | KANSK-ACHINSK | | | | | EKIBASTUZ | | | DONETSK | | | KUZNETSK | | |
| Coal grade | BROWN COAL | | | | | BITUMINOUS | | | AC | | | BITUMINOUS | | |
| Heat value, MJ/kg | 15.07 | | | | | 14.45 | | | 17.25 | | | 22.25 | | |
| Ash content, % | 7.00 | | | | | 45.60 | | | 36.00 | | | 21.60 | | |
| Moisture content, % | 38 (33 – 38) | | | | | 5.00 | | | 10.00 | | | 10(12 – 20) | | |
| Sulfur content, % | 0.3 (0.2 – 0.5) | | | | | 0.60 | | | 1.40 | | | 0.4 | | |
| Nitrogen content, % 0.3 | 0.80 | | | | | | 0.50 | | 1.50 | | | | | |
| Efficiency in nominal output, % | 38.50 | 37.60 | 38.70 | 42.50 | 43.50 | 38.15 | 35.90 | 37.20 | 37.60 | 36.80 | 37.30 | 36.30 | 38.50 | 41.90 |
| Relative specific investment cost | 1.227 | 1.483 | 1.193 | 1.326 | 1.358 | 1.000 | 1.577 | 1.470 | 1.043 | 1.673 | 1.071 | 1.375 | 1.534 | 1.399 |
| Specific emissions | | | | | | | | | | | | | | |
| $NO_x$, mg/m³ | 600 | 200 | 200 | 40* | 30* | 900 | 200 | 200 | 800–1200 | 200 | 200 | 900 | 80* | 80* |
| mg/MJ | 220 | 75 | 75 | 30 | 25 | 320 | 70 | 70 | 280–420 | 70 | 70 | 320 | 65 | 65 |
| $SO_x$, mg/m³ | 600 | 300 | 300 | 3.5 | 10 | 2100 | 200 | 200 | 2800 | 200 | 200 | 1000 | 60* | 60* |
| mg/MJ | 220 | 110 | 110 | 2.5 | 8 | 750 | 70 | 70 | 1000 | 70 | 70 | 350 | 48 | 48 |
| Particulate matter, mg/m³ | 150 | 50 | 50 | 0.7 | 0.7 | 500 | 100 | 100 | 500 | 50 | 50 | 250 | 2* | 2* |
| mg/MJ | 55 | 18 | 18 | 0.6 | 0.6 | 180 | 35 | 35 | 180 | 18 | 18 | 90 | 1.6 | 1.6 |

* For IGCC Plants the emissions are related to m³ in standard conditions with excess air of 3.0 or $O_2$ = 15%

Table 24

Technical Characteristics of modular type FRO-12000 fabric filter

| | |
|---|---|
| Filtering surface area, $m^2$ | 1200 |
| Specific gas loading at filtering surface, $m^3/(m^2 min)$ | not more than 47 |
| Number of sections | 24 |
| Number of filtering bags per section | 54 |
| Total number of filtering bags | 1296 |
| Bag length, mm | 10000 |
| Bag diameter, mm | 300 |
| Temperature of gases to be cleaned, C | not more than 180 |
| Rarefaction in the filter, Pa | not more than 8000 |
| Pressure drop, Pa | not more than 2000 |
| Dimensions, mm: length | 40200 |
| width | 9810 |
| height | 19000 |
| Filter weight, kg | 420000 |

Table 25

**Characteristics of catalysts for different De-$NO_x$ locations**

| Name | De-$NO_x$ location | |
|---|---|---|
| | before air heater | past De-$SO_x$ |
| Flue gases dust content, g/$m^3$ | 70 – 100 | not more than 0.15 |
| $SO_2$ concentration, mg/$m^3$ | 2000-2200 | 200 – 300 |
| Temperature, Ñ | 300 – 320 | 320 – 350 |
| Catalyst: | | |
| channel size, mm | 6.1 – 6.3 | 3.4 – 3.6 |
| surface, $m^2/m^3$ | 430 – 470 | 750 |
| relative activity | 1.0 | 1.0 – 1.2 |
| relative volume | 1.0 | 0.4 – 0.5 |
| service life, thou.h | 12 – 15 | 24 |
| Relative pressure drop | 1.0 | 1.0 – 2.5 |

## Table 26

### Some Data of Limestone $DeSO_x$ Plant

| | |
|---|---|
| Cleaned gas flow, $m^3/h$ | $2.1\,10^{6}$ |
| Gas temperature: before $DeSO_x$ plant, C | 100 |
| past absorber, C | 50 |
| past $DeSO_x$ plant, C | 55 |
| $SO_2$ Concentration: before $DeSO_x$ plant, $mg/m^3$ | 2100 |
| past $DeSO_x$ plant, $mg/m^3$ | 300 |
| $SO_2$ discharge after cleaning, g/s | 175 |
| Pressure drop, kPa | 3.5 |
| Limestone consumption (95% of calcite), kg/h | 6860 |
| Amount of gypsum produced, kg/h | 10860 |
| Service water consumption, $m^3/h$ | 60 |
| Gas dust content: before $DeSO_x$ plant, $mg/m^3$ | 150 |
| past $DeSO_x$ plant, $mg/m^3$ | 100 |

Table 27

**Performance of 500 MW Unit with differ De-$NO_x$ Plant Location**

| Parameter | 500 MW Unit | | |
|---|---|---|---|
| | | Ecologicaly clean TPS | |
| | Ekibastuz TPS-2 | $DeNO_x$ past $DeSO_x$ | in-build $DeNO_x$ |
| Additional capacity*, MW | 0 | 4.8 | 1.1 |
| Heating surface, thou.$m^2$ | | | |
| air heater | 163 | 252 | 252 |
| economizer | 12.4 | 12.4 | 17.3 |
| heat exchangers: air-water | – | 3.42 | 6.12 |
| in-build air-water | – | 23.10 | 7.50 |
| gas-gas | – | 230.00 | – |
| Design power of draft machines. MW | 10.22 | 20.48 | 13.70 |
| ESP power, MW | 2.05 | 3.80 | 3.80 |
| Power consumed for $DeSO_x$ plant, MW | – | 5.53 | 5.68 |
| Increased auxiliary power, MW | – | 17.54 | 13.15 |
| Total fuel consumption, t/h | 327.3 | 339.0 | 327.2 |
| Boiler efficiency, % | 91.09 | 94.37 | 94.07 |
| Exhaust gas temperature, C | 159 | 99 | 100 |
| Annual specific fuel consumption, g/kW.h | 322.4 | 342.7 | 330.3 |
| Annual efficiency, % | 38.15 | 35.89 | 37.20 |
| Relative specific investment cost | 1.0 | 1.58 | 1.50 |

* Power, produced by steam which was not used for feedwater preheating

Table 28

**Design Characteristics of CFB Boiler for 300 MW Units**

| | |
|---|---|
| **FURNACE** | |
| Number per boilers | 2 |
| Plan dimensions, mm | 108008600 |
| Outer diameter and wall thickness of waterwall tubes, mm | 326 |
| Heat absorption surface of furnace waterwalls, m² | 1144 |
| **CYCLONES** | |
| Number per boiler | 4 |
| Inner diameter, mm | 10000 |
| Inlet port size, mm | 25005715 |
| Letdown inner diameter, mm | 1500 |
| Total height, mm | 25000 |
| **EXTERNAL HEAT EXCHANGERS** | |
| Number per boiler | 4 |
| Number of main superheater sections | 2 |
| Number of reheater sections | 1 |
| Outer diameter and wall thickness of tube, mm | 386 |
| Heat transfer surface, m² | 1250+480 |
| Exchanger dimensions, mm: length14200 | |
| width | 6000 |
| height | 6000 |
| **CONVECTIVE SECTION** | |
| Superheater: number of banks | 1 |
| tube dia, mm | 32 ŏ 6 |
| heat transfer surface, m² | 2750 |
| Reheater: number of banks | 2 |
| tube dia, mm | 424 |
| heat transfer surface, m² | 6230 |
| Economiser: number of banks | 2 |
| tube dia., mm | 383 |
| heat transfer surface, m² | 8200 |
| Air heater: number of banks | 3 |
| number of passes | 4 |
| tube dia, mm | 401.5 |
| heat transfer surface, m² | 67500 |
| Boiler dimensions, m: width | 39.0 |
| depth | 43.5 |
| height | 52.5 |

Table 29

**Some Data of CFB 300 MW AC-fired Boilers**

| | |
|---|---|
| Boiler capacity, t/h | 1000 |
| Flow of reheated steam, t/h | 800 |
| Temperature of superheated steam, C | 545 |
| Temperature of reheated steam, C | 545 |
| Pressure of live steam, MPa | 25.0 |
| Pressure of reheated steam, MPa | 3.8 |
| Feedwater temperature, C | 270 |
| Boiler efficiency, % | 86.4 |
| Heat losses, %: exhaust gases | 5.5 |
| unburned gases (CO,CH, etc.) | 0 |
| carbon loss | 6.0 |
| external | 0.2 |
| slag | 0.4 |
| limestone decomposition | 1.5 |
| Total fuel consumption, t/h | 176.6 |
| Limestone consumption, t/h | 16.8 |
| Exhaust gas temperature, C | 140 (100) |
| Furnace thermal characteristics: | |
| outlet temperature, C | 900 |
| mean gas velocity, m/s | 6.4 |
| volume heat release rate, $kW/m^3$ | 169.3 |
| Furnace ash balance: | |
| flue gas fly ash concentration at furnace outlet, $kg/m^3$ | 10.4 |
| fly ash circulation ratio | 180 |
| ash fed to furnace, t/h | 5300 |
| Air distribution: | |
| furnace air excess | 1.02 |
| same,past air heater | 1.28 |
| share of primary air of total air flow, % | 50 |
| share of secondary air, % | 50 |
| share of recirculation air past air heater,% | 9.5 |
| Temperature, Ñ: | |
| economizer inlet water | 270 |
| furnace chamber wall outlet steam | 394 |
| convective superheater outlet steam | 402 |
| external heat exchanger superheater outlet steam | 545 |
| convective reheater inlet steam | 287 |
| same, outlet steam | 446 |
| external heat exchanger reheater outlet steam | 545 |
| cold air | 30 |
| air heater inlet | 50 |
| air heater outlet | 300 |
| Convective section gas velocity, m/s: | |
| superheater | 10.0 |
| reheater | 10.0 |
| economizer | 6.5 |
| air heater | 13.3 |
| Air heater air velocity, m/s | 6.9 |

Table 30

**IGCC Plant Performance**

| Name | Types of gasifiers | | | | | | | | Natural gas CCP | |
|---|---|---|---|---|---|---|---|---|---|---|
| | moving bed | | | | entrained flow | | | | | |
| | oxygen blast | | air blast | | oxygen blast | | air blast | | | |
| Ambient temperature, C | -5 | +15 | -5 | +15 | -5 | +15 | -5 | +15 | -5 | +15 |
| HP live steam flow to ST, t/h | 472 | 454 | 577 | 532 | 607 | 574 | 585 | 551 | 495 | 480 |
| LP steam flow past boiler, t/h | 228 | 185 | 268 | 209 | 244 | 190 | 232 | 184 | 244 | 195 |
| Steam consumed for drying, t/h | 99 | 86 | 129 | 112 | 124 | 106 | 111 | 97 | 0 | 0 |
| Superheated steam temperature, C | 515 | 535 | 520 | 540 | 520 | 540 | 520 | 540 | 505 | 525 |
| Reheat temperature, C | 460 | 470 | 455 | 465 | 460 | 475 | 465 | 475 | 455 | 460 |
| LP steam temperature, C | 240 | 232 | 256 | 243 | 248 | 236 | 247 | 234 | 248 | 237 |
| Reheat steam pressure past boiler, MPa | 2.25 | 2.16 | 2.30 | 2.16 | 2.30 | 2.16 | 2.30 | 2.16 | 2.20 | 2.16 |
| GT output, MW | 509 | 418 | 500 | 413 | 510 | 414 | 445 | 372 | 487 | 405 |
| ST output, MW | 196 | 188 | 240 | 220 | 246 | 233 | 242 | 227 | 222 | 210 |
| CCP gross output, MW | 705 | .606 | 740 | 633 | 756 | 647 | 687 | 600 | 709 | 615 |
| Auxiliary power, MW | 74 | 68 | 38 | 32 | 110 | 94 | 36 | 31 | 13 | 11 |
| IGCC net efficiency (on coal basis), % | 43.6 | 43.4 | 44.9 | 44.2 | 43.9 | 43.8 | 44.8 | 44.1 | 52.1 | 52.0 |
| Fuel saving as compared with p.c. | | | | | | | | | | |
| 800 MW unit (39% efficiency), % | 10.6 | 10.1 | 13.1 | 11.8 | 11.2 | 11.0 | 12.9 | 11.6 | 25.1 | 25.0 |

## Table 31

### Coal characteristics adopted in CCP design

| Parameter | Coal grade | | | |
|---|---|---|---|---|
| | Berezovo | | Kuznetsk WS2 | |
| | raw | dried | raw | dried |
| Heat value, Q, MJ/kg | 15.66 | 21.97 | 20.51 | |
| Ash content, % | 4.70 | 6.60 | 24.00 | |
| Moisture, % | 33.00 | 6.00 | 11.50 | |
| Sulfur content, % | 0.20 | 0.28 | 0.40 | |
| Elementary composition on fired basis, %: C | 44.63 | 62.62 | 56.80 | 63.20 |
| H | 3.06 | 4.29 | 3.01 | 3.35 |
| N | 0.61 | 0.86 | 1.38 | 1.53 |
| O | 13.8 | 19.35 | 3.01 | 3.35 |
| Volatiles per combustibles, % | 48.00 | | 20.00 | |

**Table 32**

**Composition and properties of coal-derived gas**

| Parameters | Gasification technology and type of blast | | | |
|---|---|---|---|---|
| | moving-bed | | entrained-flow | |
| | air | | oxygen (95%) | |
| | raw | cleaned | raw | cleaned |
| Gas composition, % | | | | |
| including: CO | 19.52 | 19.53 | 54.60 | 54.70 |
| $CO_2$ | 5.92 | 5.93 | 9.70 | 9.72 |
| $H_2$ | 10.17 | 10.18 | 20.40 | 20.44 |
| $H_2S$ | 0.06 | | 0.175 | |
| $CH_4$ | 1.39 | 1.39 | | |
| $H_2O$ | 14.96 | 14.97 | 14.10 | 14.10 |
| $N_2$ | 47.98 | 48.00 | 1.00 | 1.00 |
| Density, kg/m$^3$ | 1.120 | 1.001 | 1.005 | |
| Low heat value, MJ/m$^3$ | 4.07 | 4.06 | 9.09 | 9.07 |
| Consumption per 1 kg of dried coal, kg | | | | |
| oxydant | | 2.69 | 0.74 | |
| steam | | 0.40 | | |
| Combustible gas yield, kg/kg | | 4.454 | 1.590 | |
| Raw gas temperature at reaction zone outlet, C | 1280 | | 1530 | |

With entrained-flow oxygen-blown gasification of Kuznetsk coal featuring lower ash melt temperature, the gasifier outlet temperature is adopted at 1300C. The raw syngas contains 65% CO, 2.7% $CO_2$, 29.7% $H_2$; its LHV = 11.43 MJ/m$^3$, density 0.925 kg/m$^3$.

Table 33

**Characteristics of fluidized bed gasification system**

| | |
|---|---|
| Reaction chamber pressure, MPa | 2.0 - 2.1 |
| Fluidized bed area, $m^2$ | 8.7 |
| Fluidized bed height, m | 3.0 |
| Combustible gas LHV, MJ/kg | 4.07 |
| Flows for one gasifier, t/h (kg/s): | |
| coal | 60 (16.7) |
| steam and air | 230 (63.9) |
| ash from bed | 8 (2.2) |
| Consumption of oxydizers per kg of coal, kg: | |
| air | 3.15 |
| steam | 0.67 |
| Gas yield, kg/kg of coal | 4.3 |
| Temperature, C: | |
| in reaction volume | 1100 |
| steam-air | 450 |
| gas past reactor | 950 |
| gas before cleaning | 210 |
| gas past cleaning | 160 |
| gas before expansion turbine | 310 |
| Coal characteristics: LHV, MJ/kg | 23.65 |
| Moisture, % | 10 - 12 |
| Ash content, % | 13 - 21.5 |
| Sulfur content, % | 0.35 - 0.40 |

# FIGURES

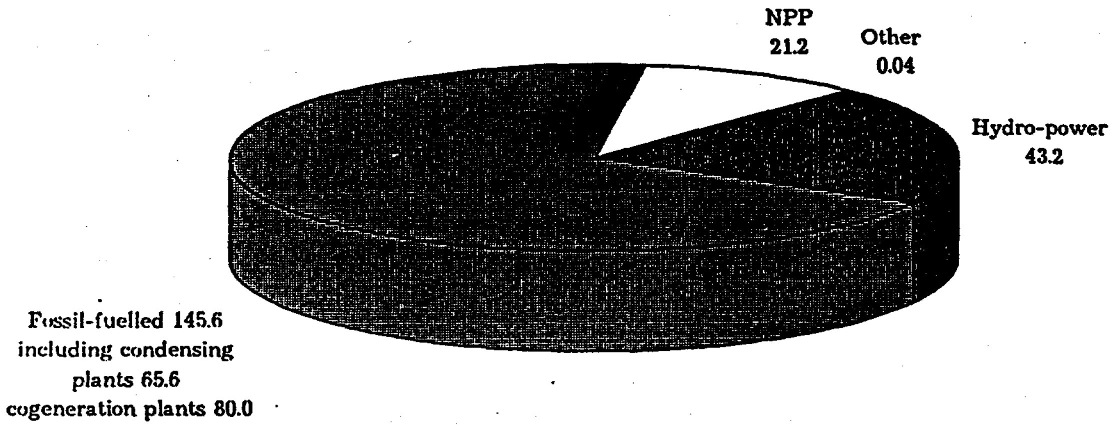



Fig.1. Russian electric power generation mix, GW

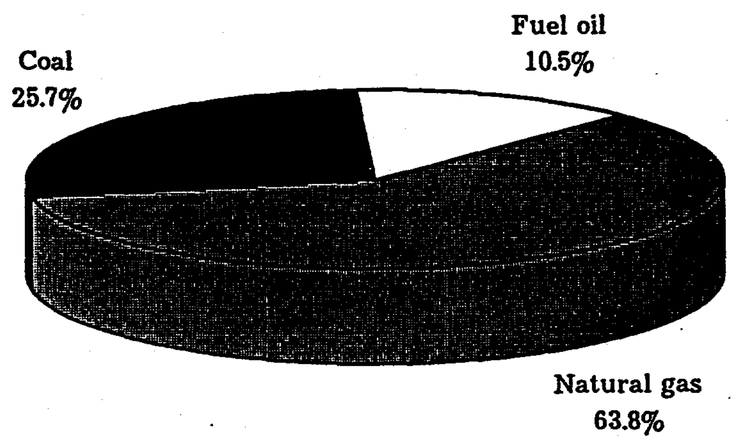



Fig. 2. Russian fuel mix for fossil power plants

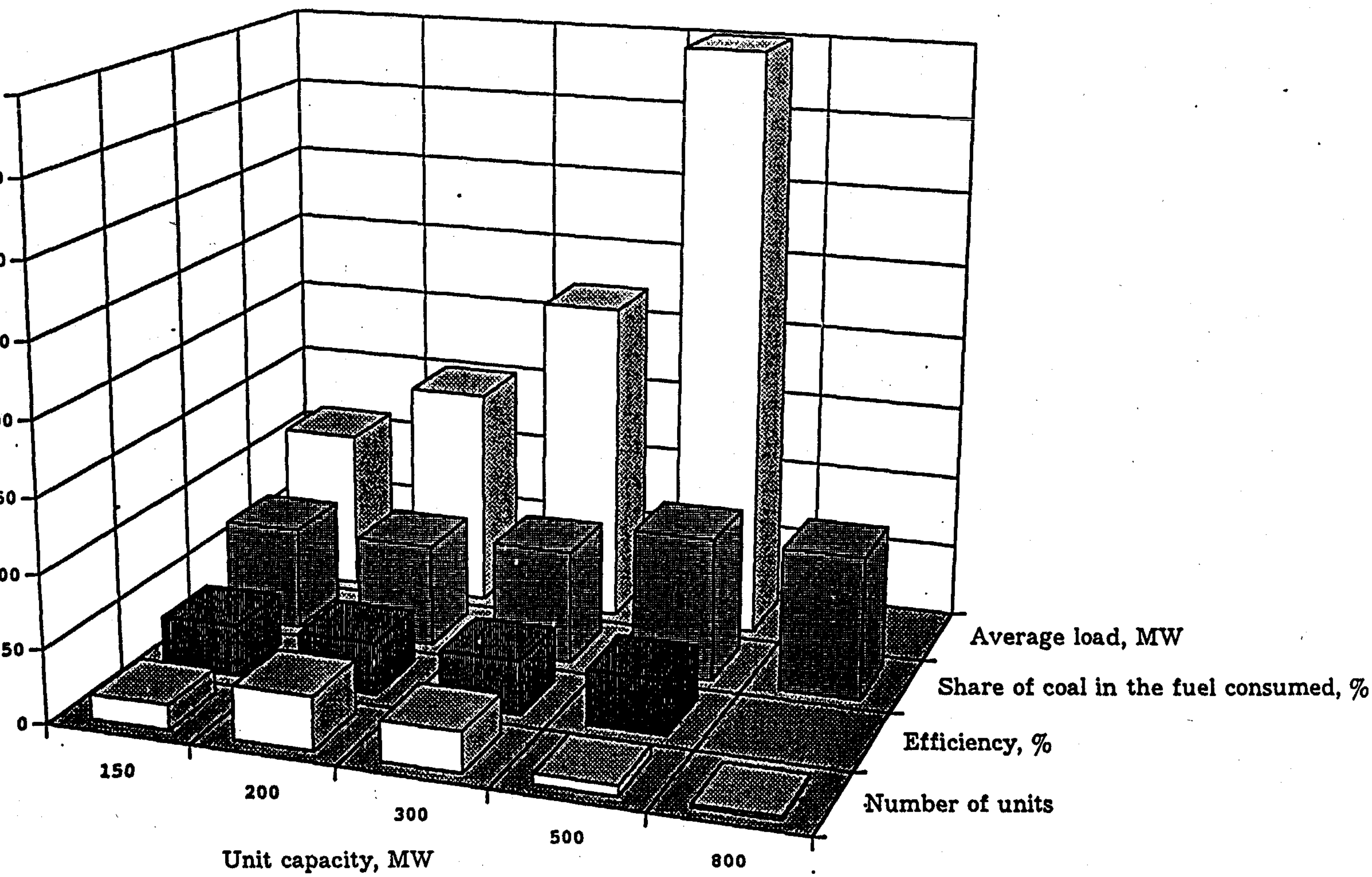



Fig.3. Some data on coal condensing power units (TPS)

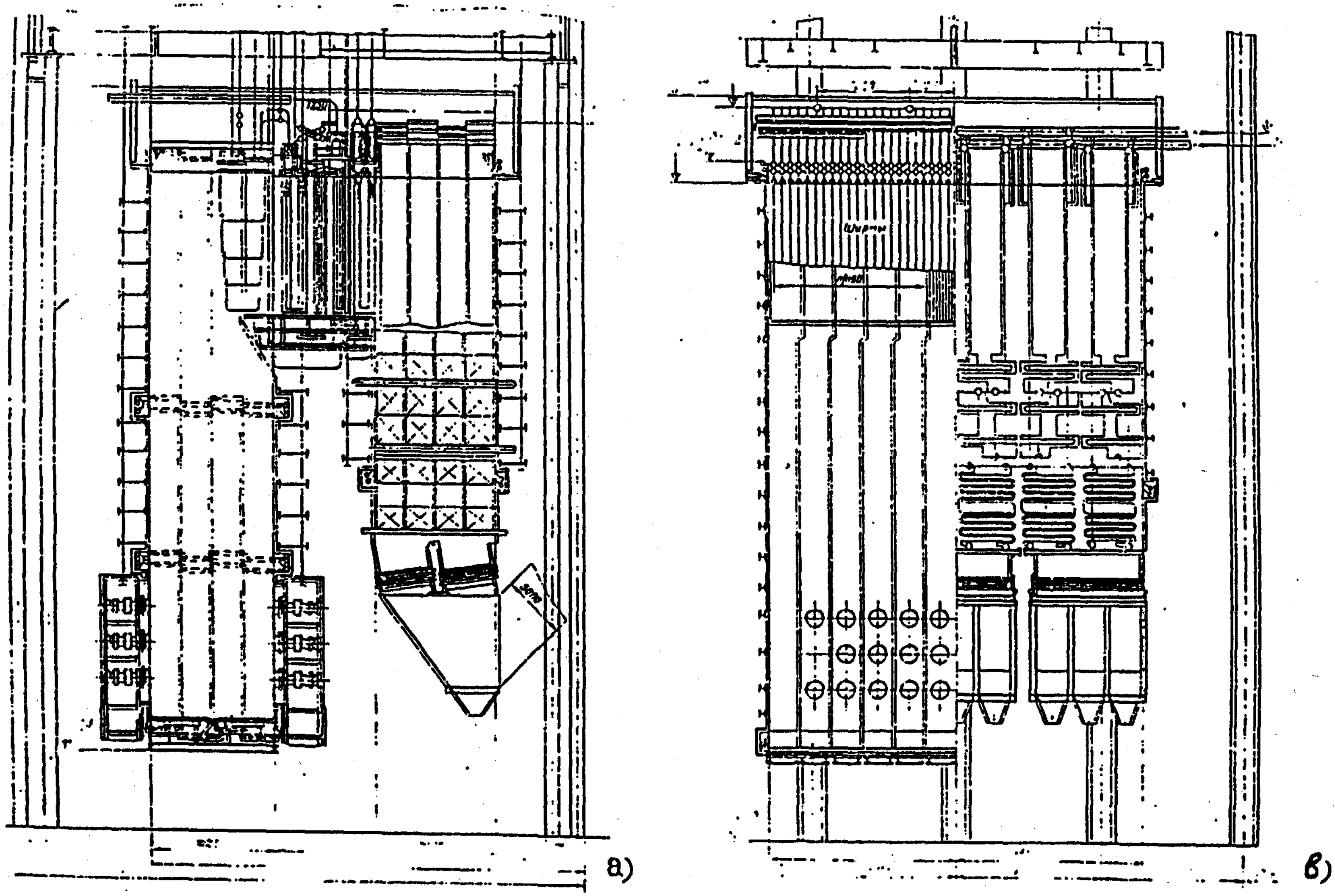



Fig. 4. Pp-3950-25-545/542 GMN (TGMP-1202) Boiler: a,b) - longitudinal and cross sections respectively

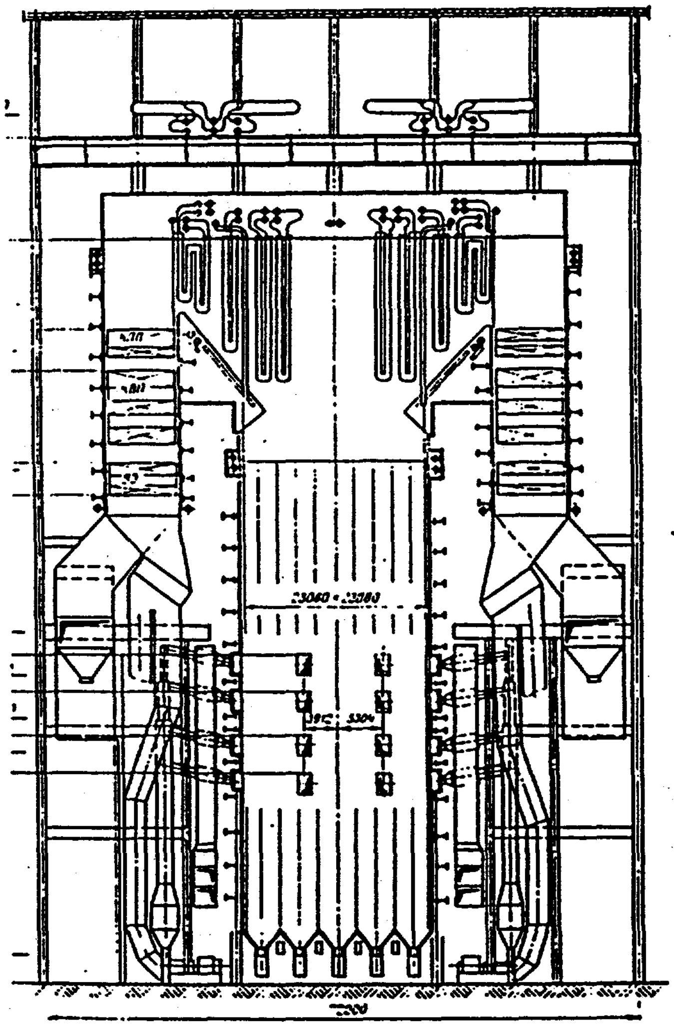


Fig. 5. Pp - 2650-255 (P-67) Boiler
(cross-section)

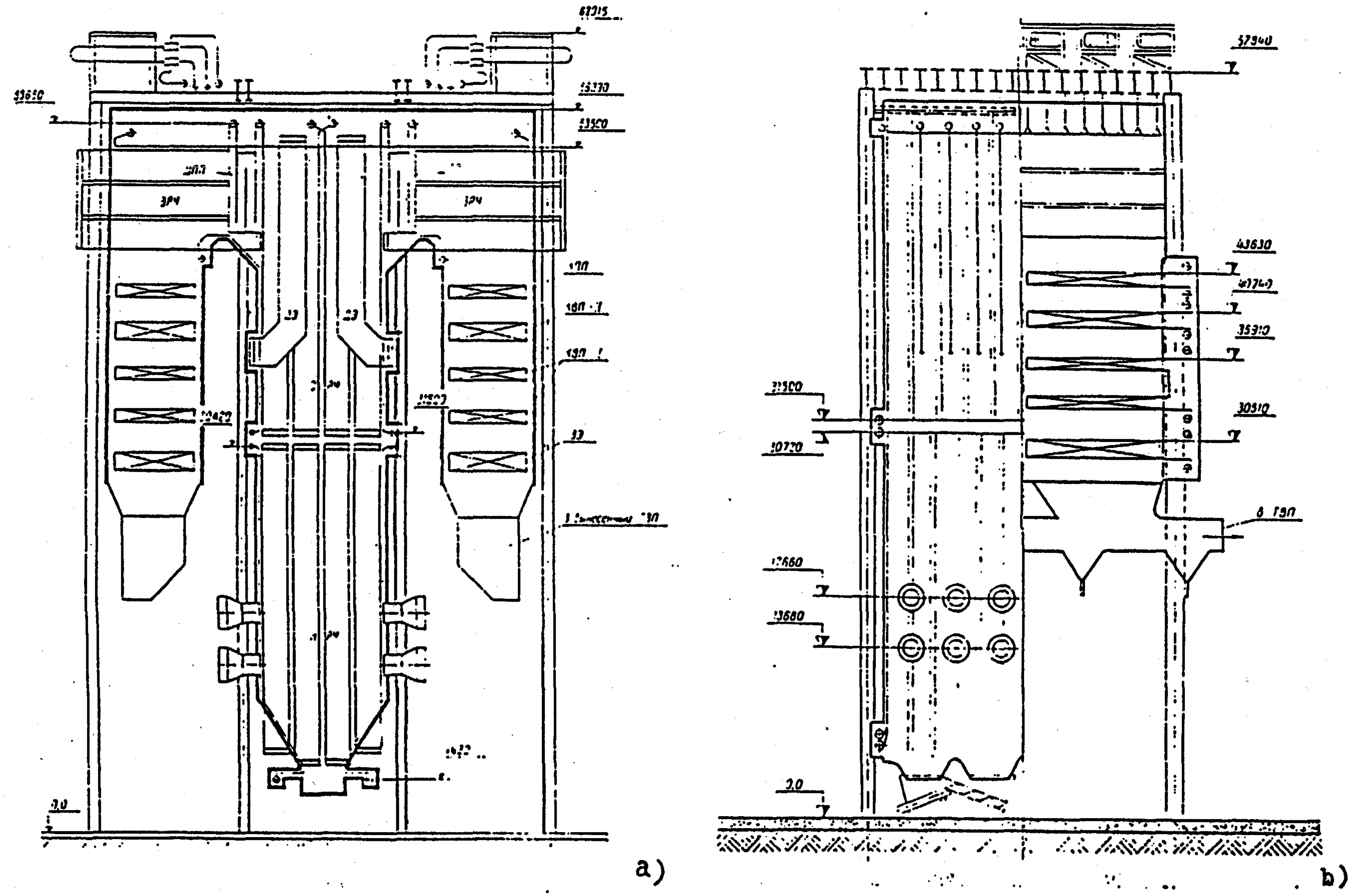



Fig.6. Boiler P-1650-255 (P-57R);

a - longitudinal section miew

b - cross section view

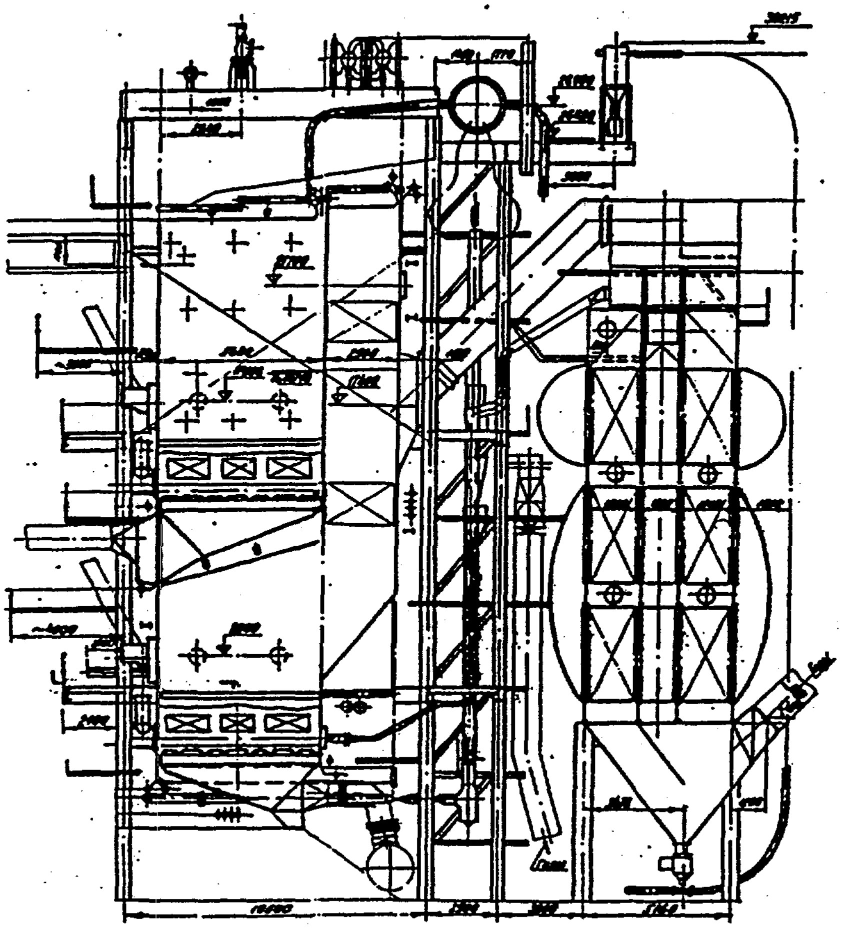


Fig. 7. The 420 t/h bubbling fluidized bed boiler (E-420-140 KS); steam pressure 13,8 MPa, temperature 560°C

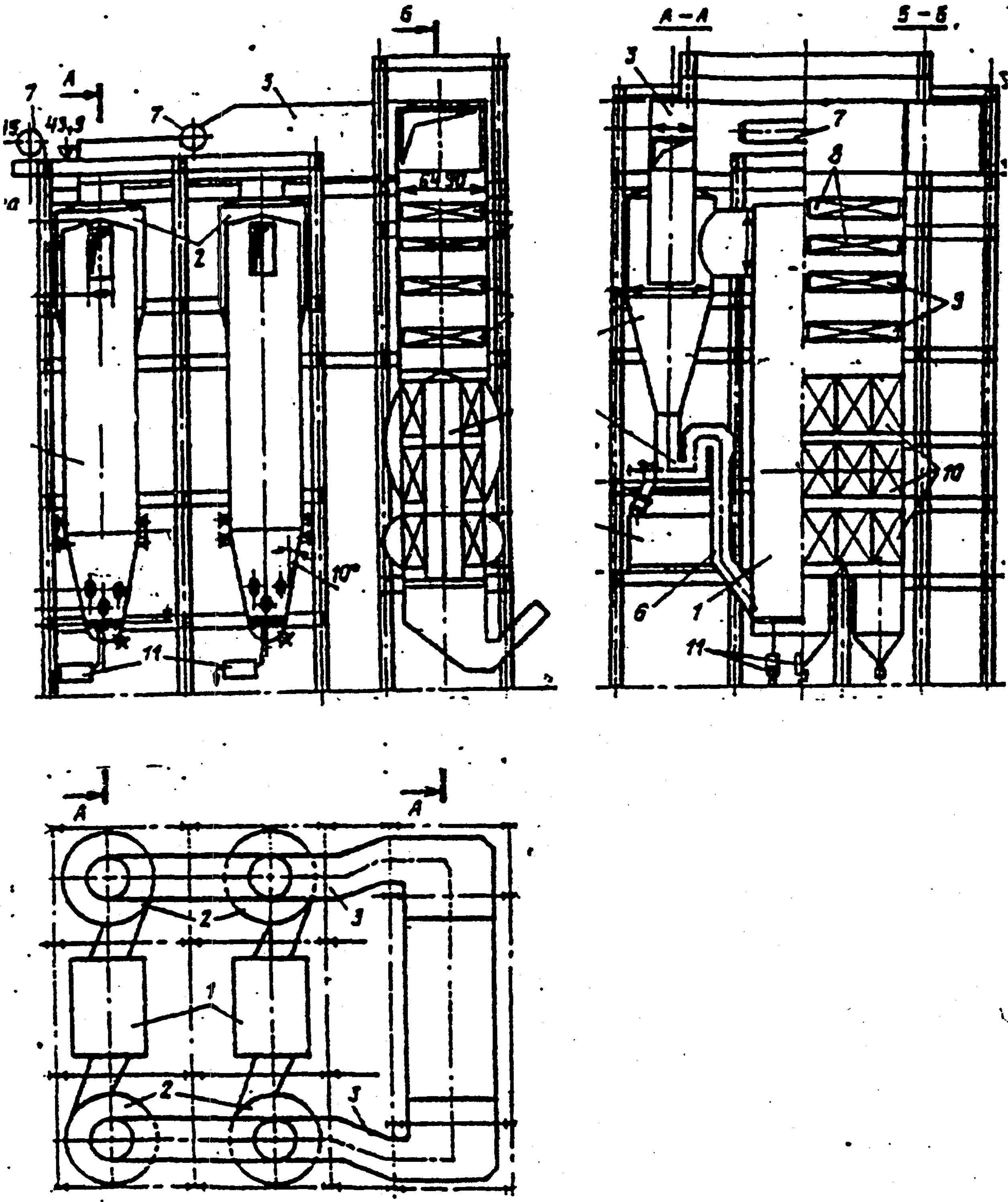



Fig. 8. Demo 500 t/h CFB boiler

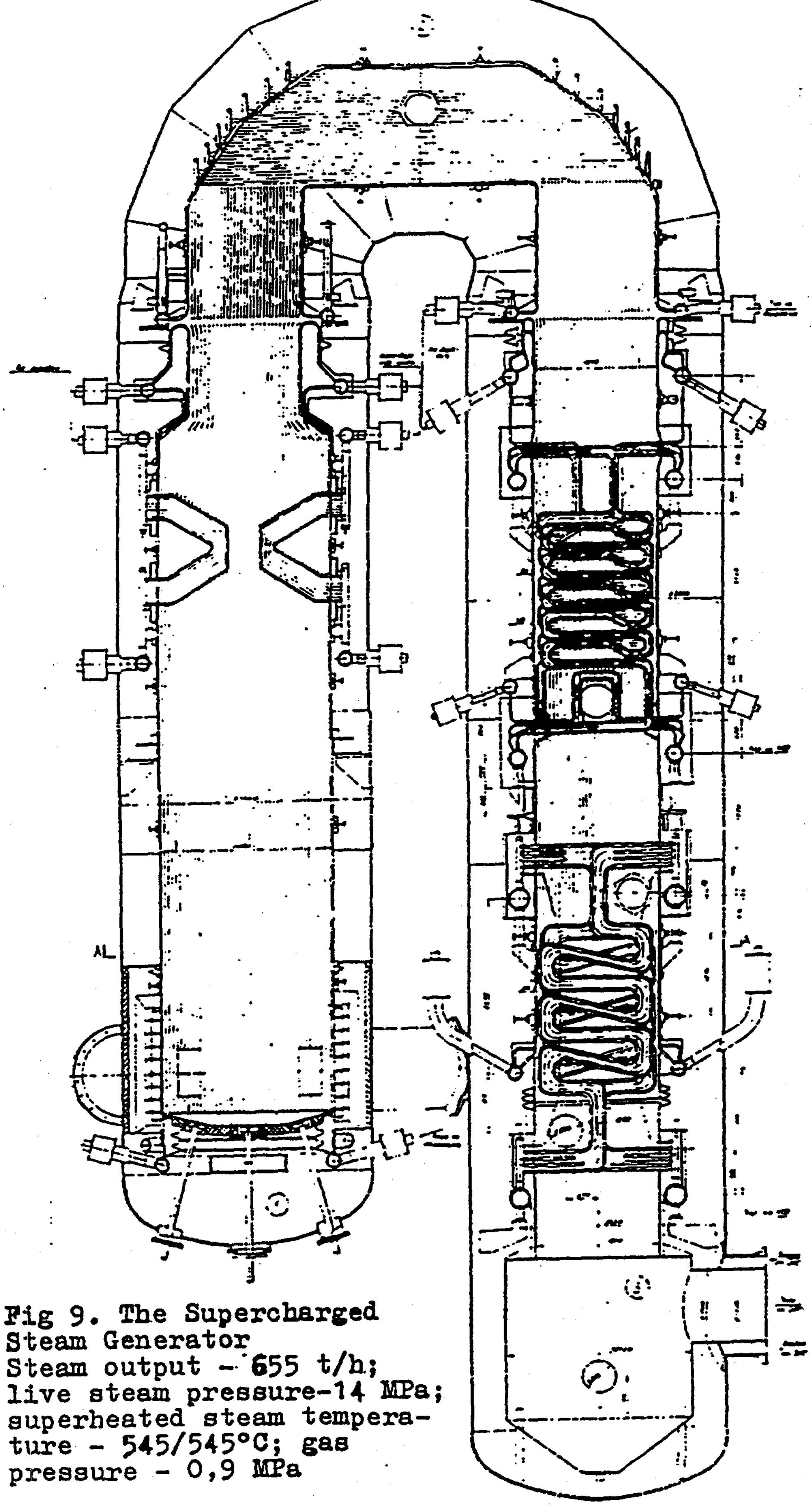


Fig 9. The Supercharged Steam Generator
Steam output - 655 t/h; live steam pressure-14 MPa; superheated steam temperature - 545/545°C; gas pressure - 0,9 MPa

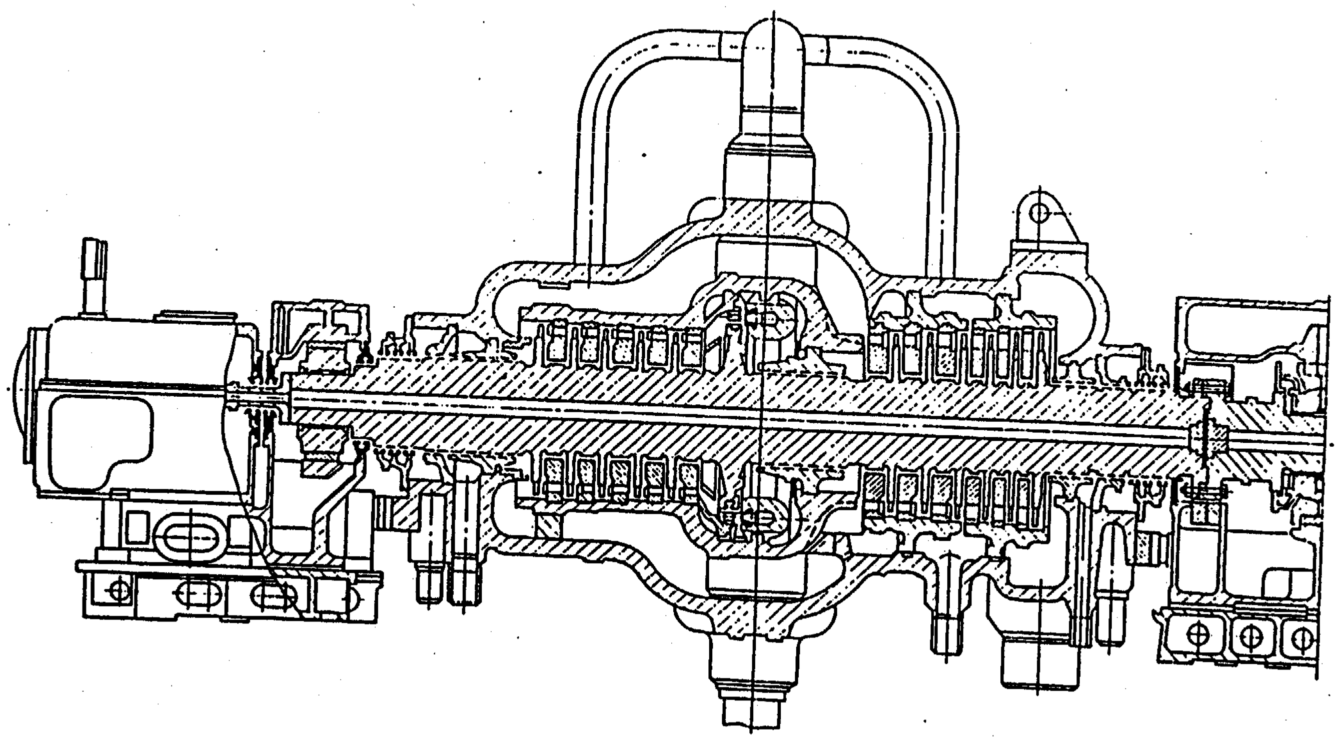


Fig. 10. The typical design of HP cylinder with loop steam flow

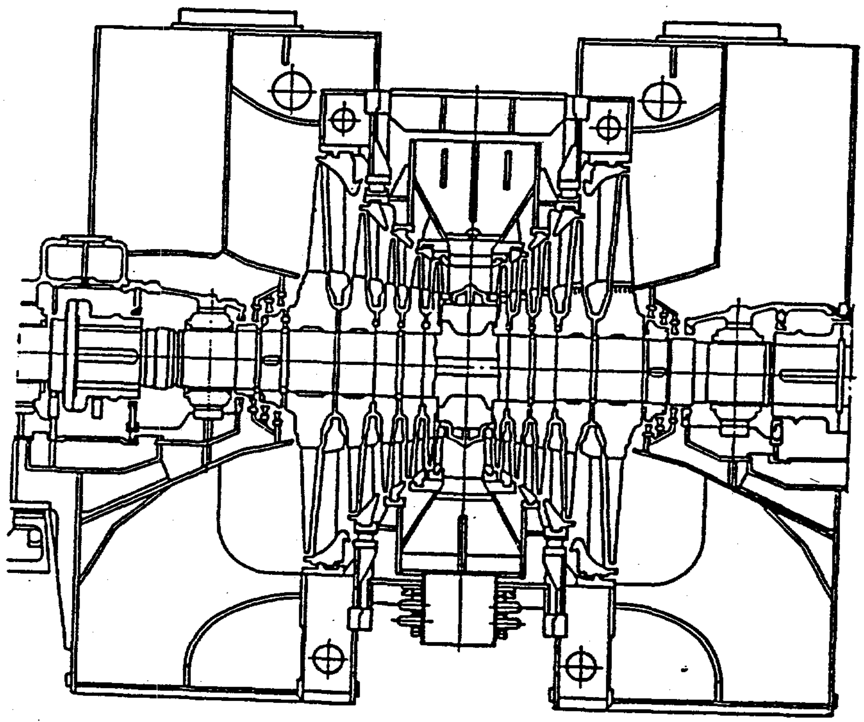


Fig. 11. The typical LP cylinder

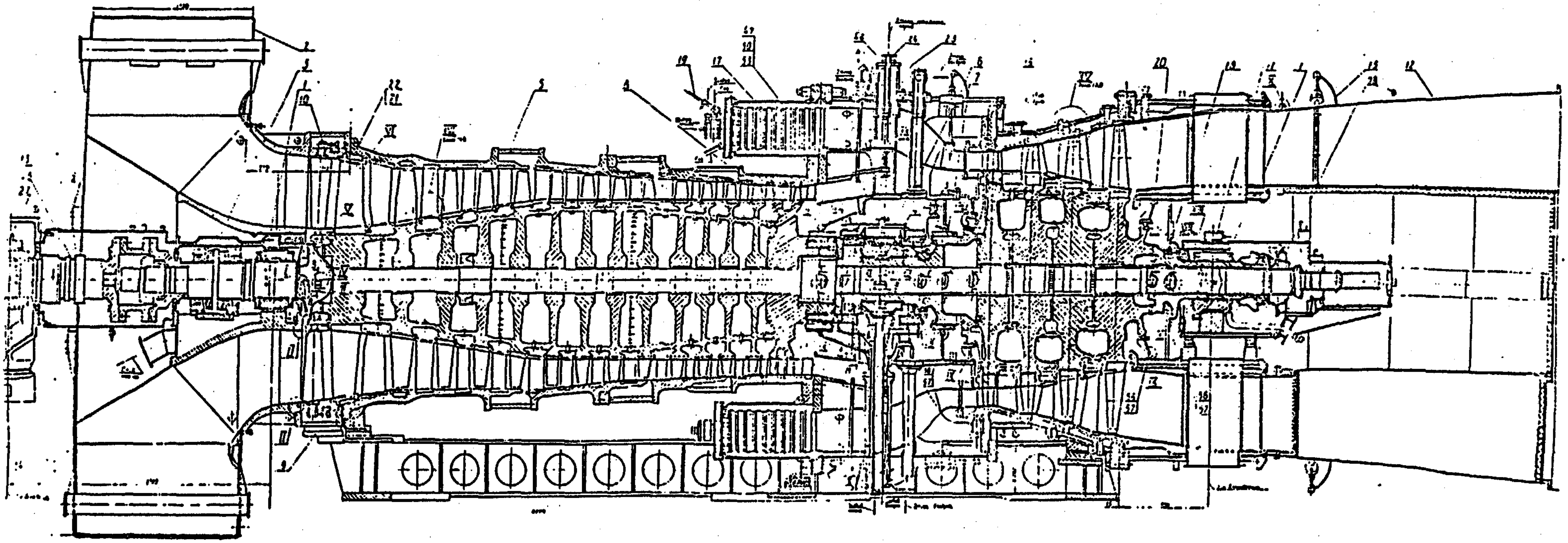


Fig. 12. Longitudinal section through GTE-150 unit

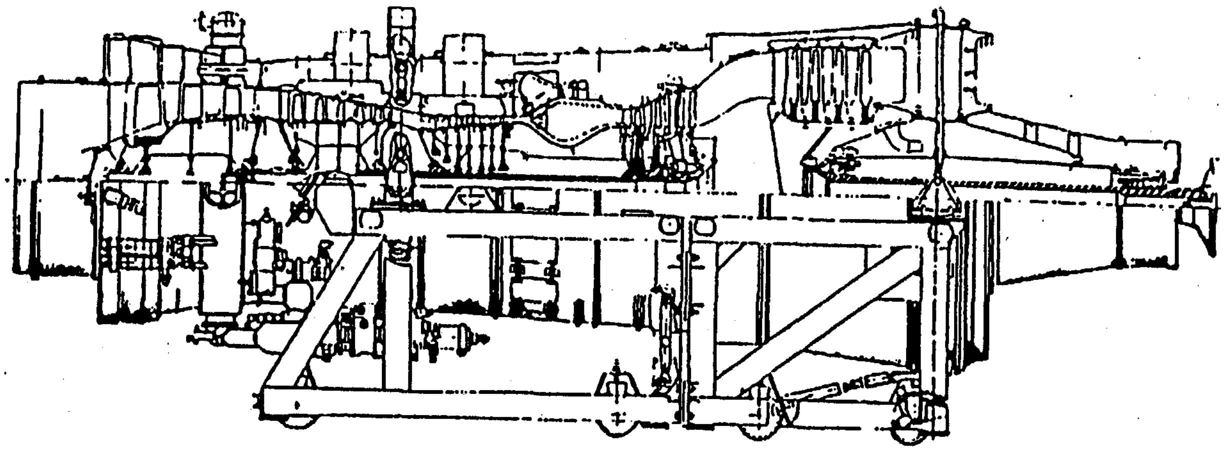


Fig. 13. Longitudinal section through NK-37 unit

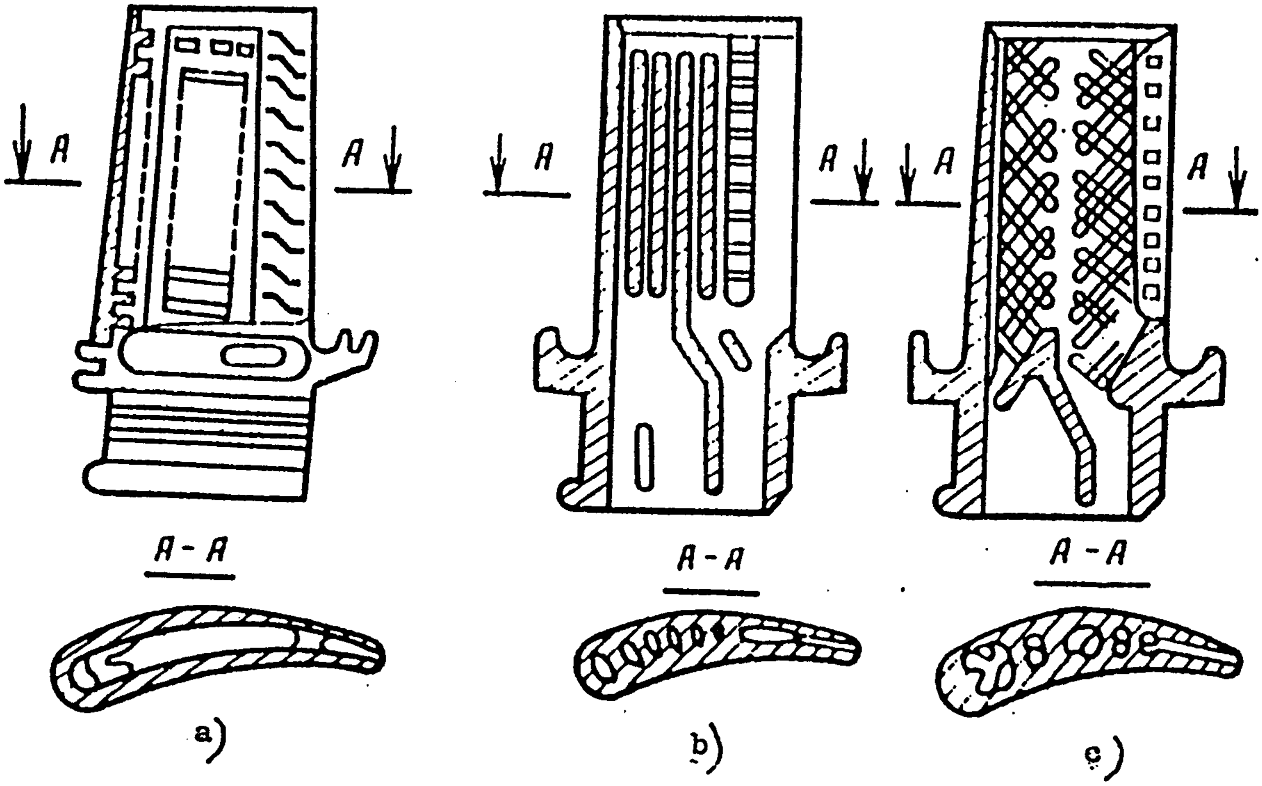



Fig. 14. The first stage buckets with various internal cooling

a - air deflector  b - serpentine  c - vortex

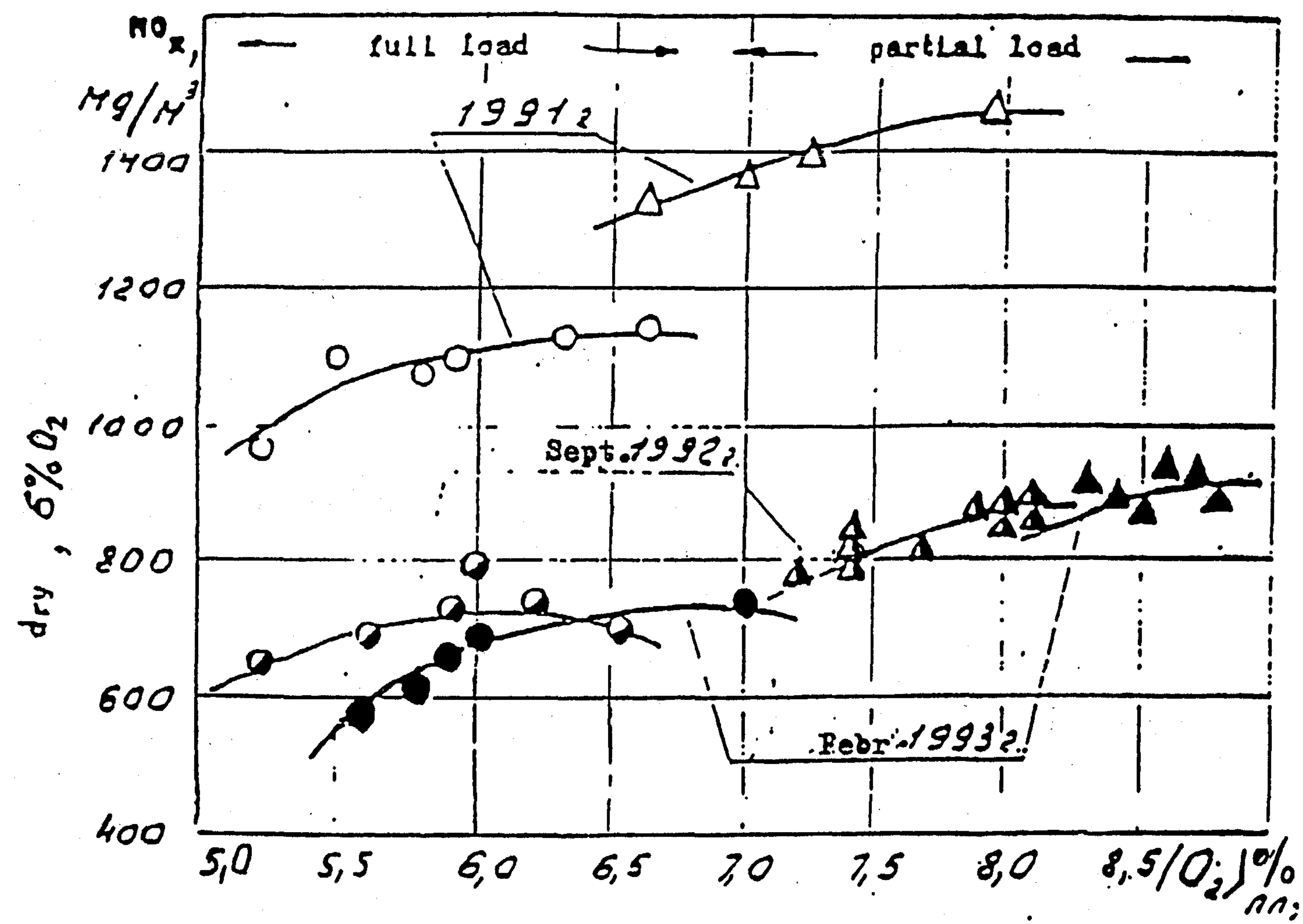



Fig. 15. NOx emission versus $O_2$ after superheater before (1991) and after (1992-93) reconstruction. Boiler 420 t/h; brown coal

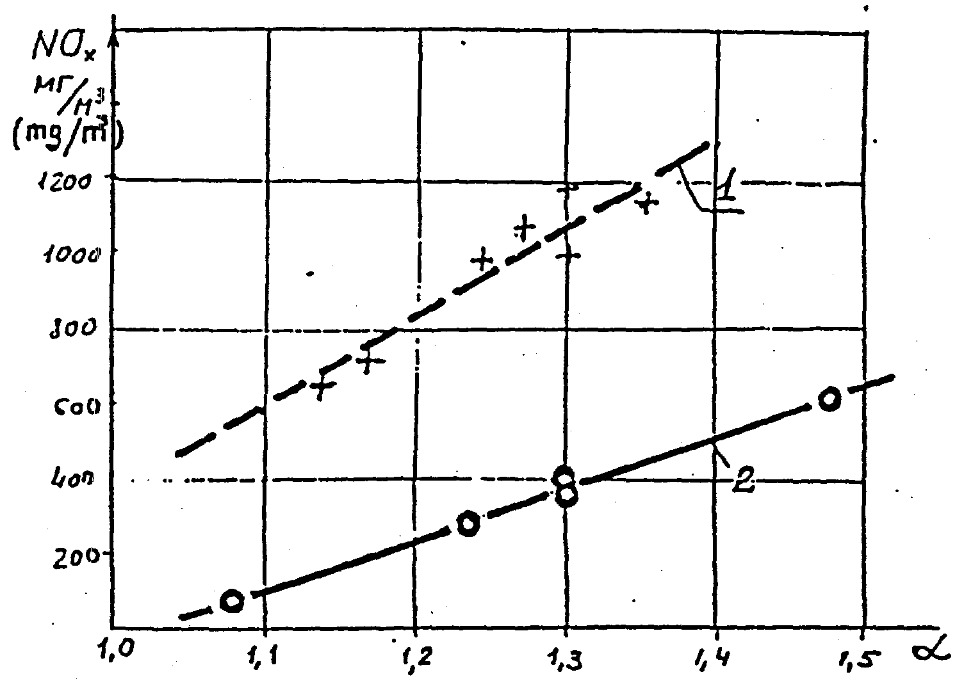



Fig. 16. NOx emissions when high concentrated pulverized coal mixture is fired

1 - coal entrance before burner;
2 - coal entrance in burner throat; α — furnace outlet excess air coefficient

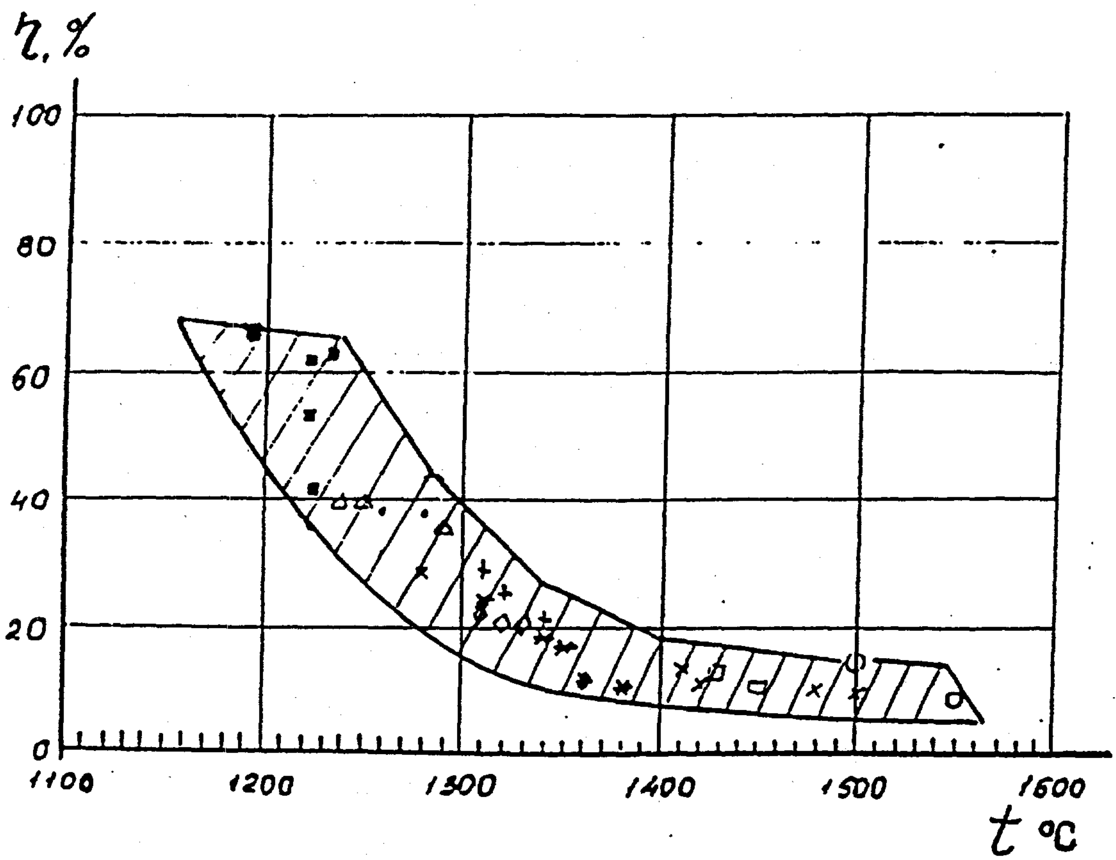



Fig.I7.Sulfur fixation by fly ash in
boilers firing K-A coals

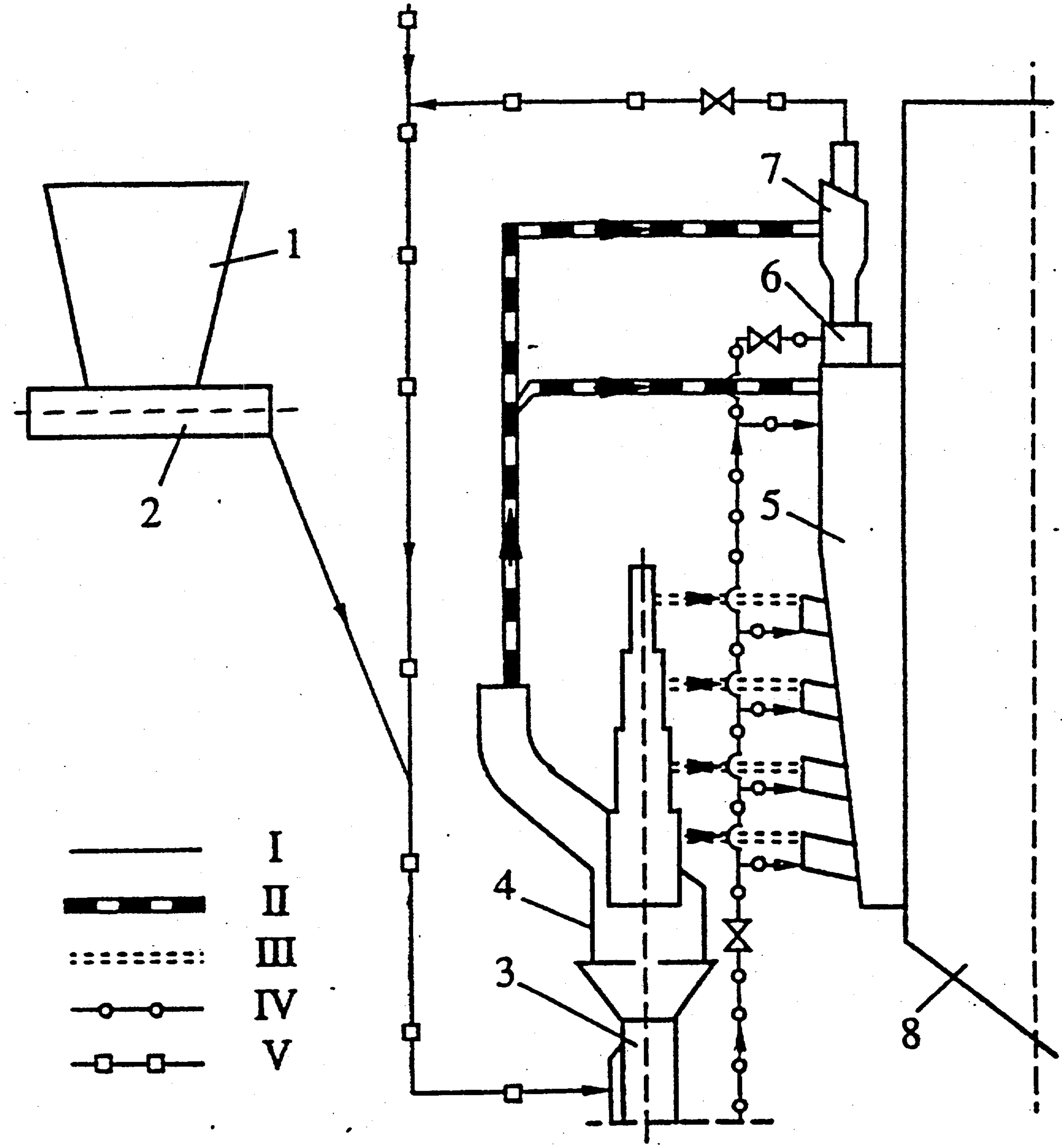



Fig. 18. The coal pulverizing system with an installation for high-temperature powder heating (for a P-67 boiler). (1) Raw coal hopper; (2) raw coal feeder; (3) MV 3400 fan-pulverizer; (4) coal-powder concentrator; (5) coal-powder heater; (6) muffle burner; (7) cyclone; (8) furnace; (I) fuel; (II) coal-powder-air mixture (concentrated stream); (III) coal-powder-air mixture (low-powdery stream); (IV) hot air; (V) flue gases

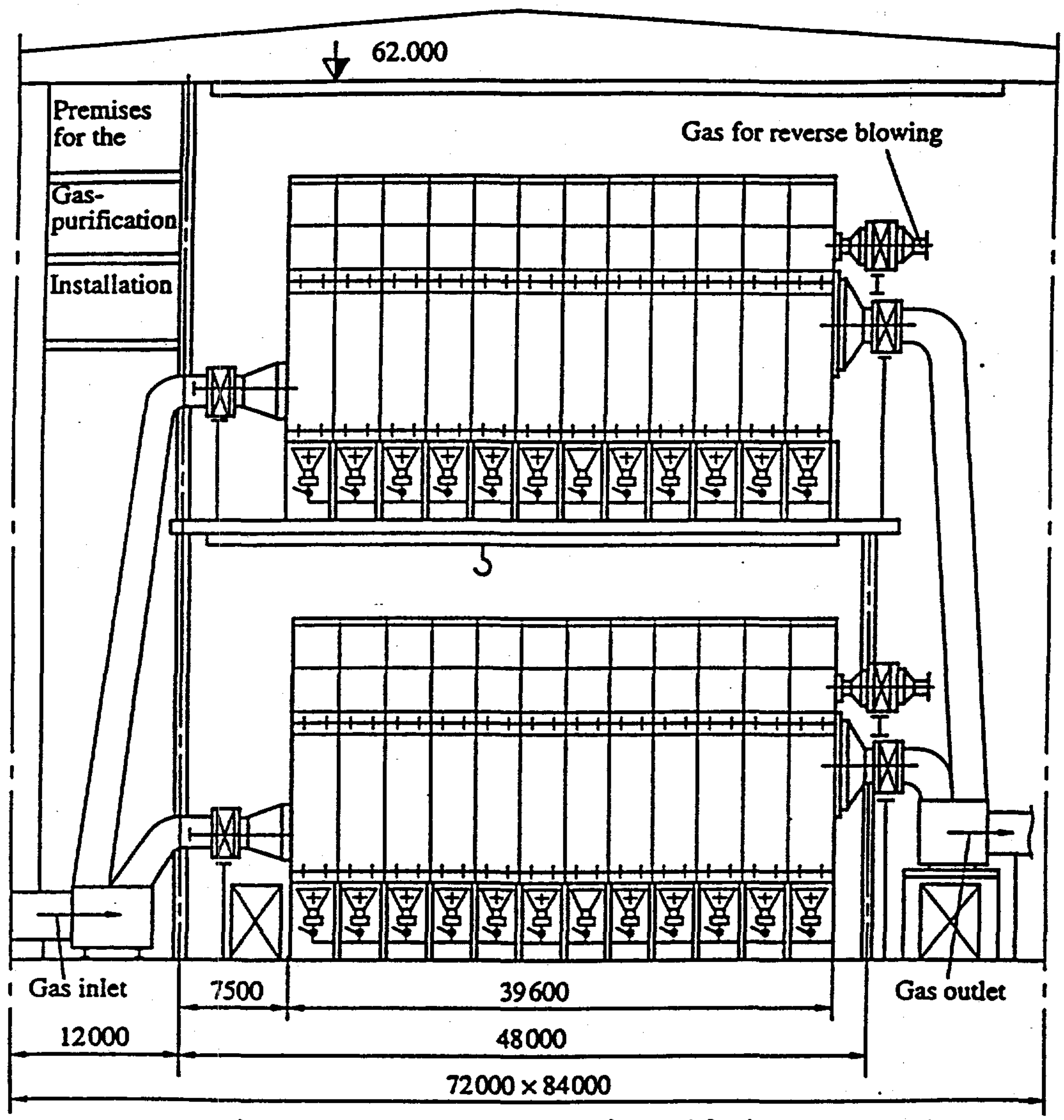



Fig. 19. Two-storey baghouse with FRO-12000 filter

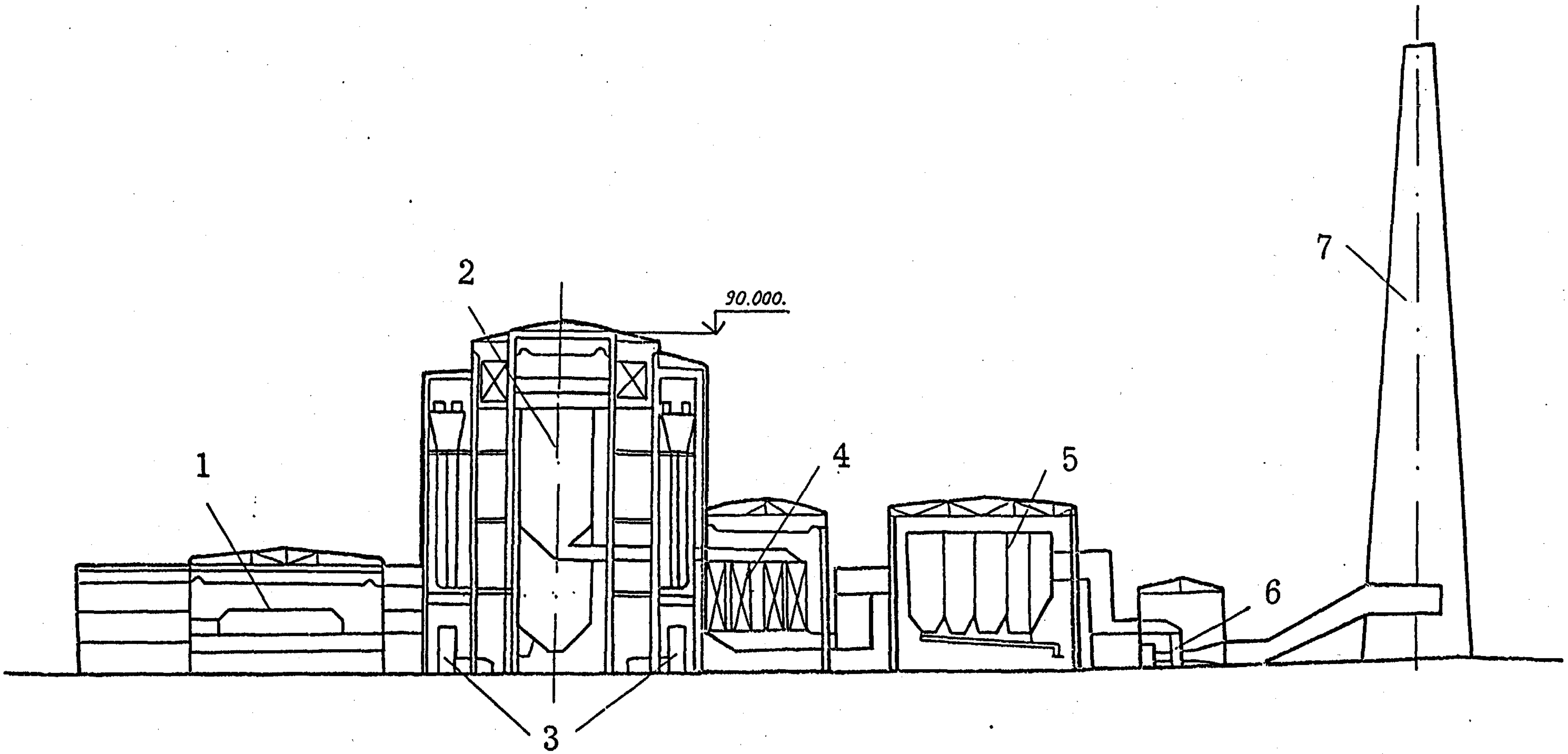



Fig. 20. Cross-section of 800 MW Unit

1-ST; 2-boiler; 3-mills; 4-air heater; 5-baghouse;

6-induced draught fan; 7-stack

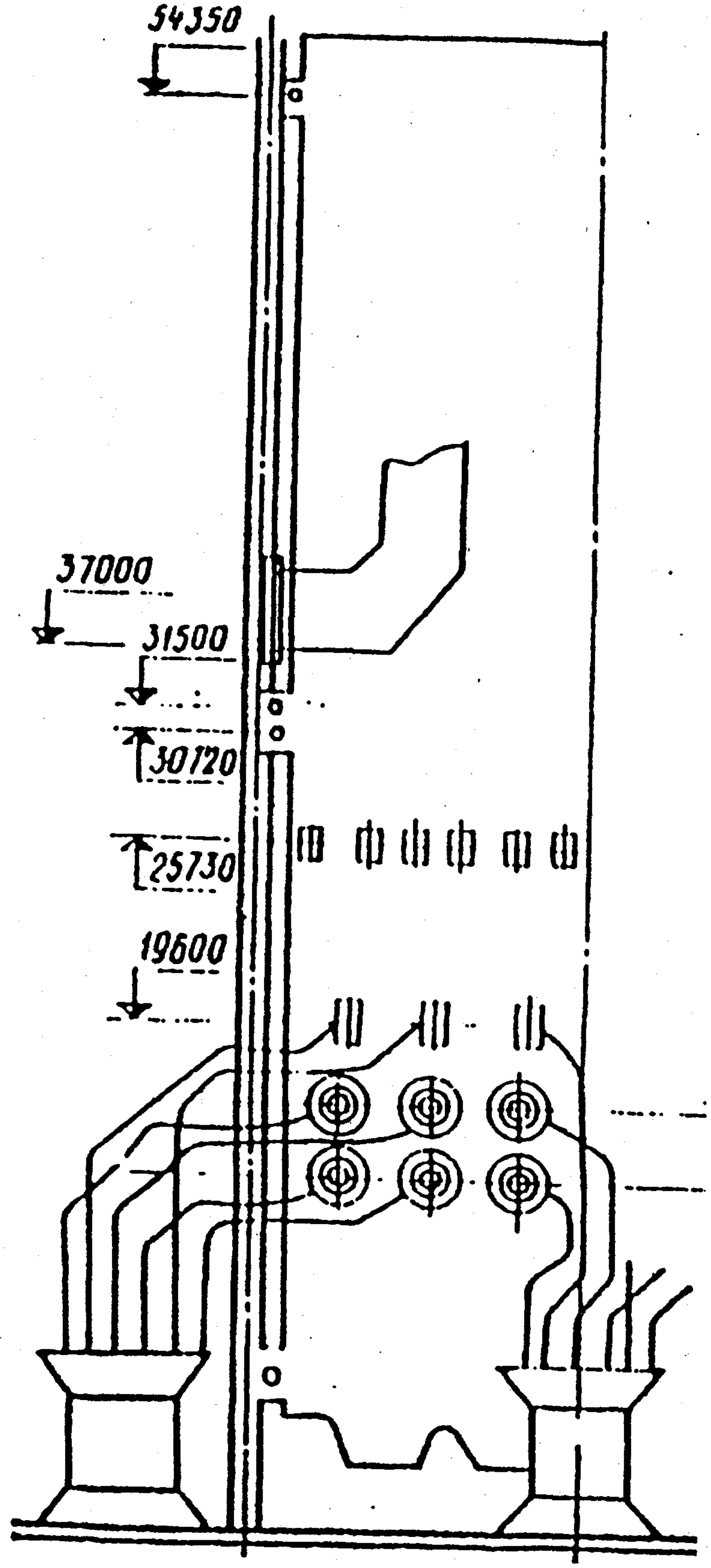



Fig. 21. The layout of the furnace with in-wall vortex burners

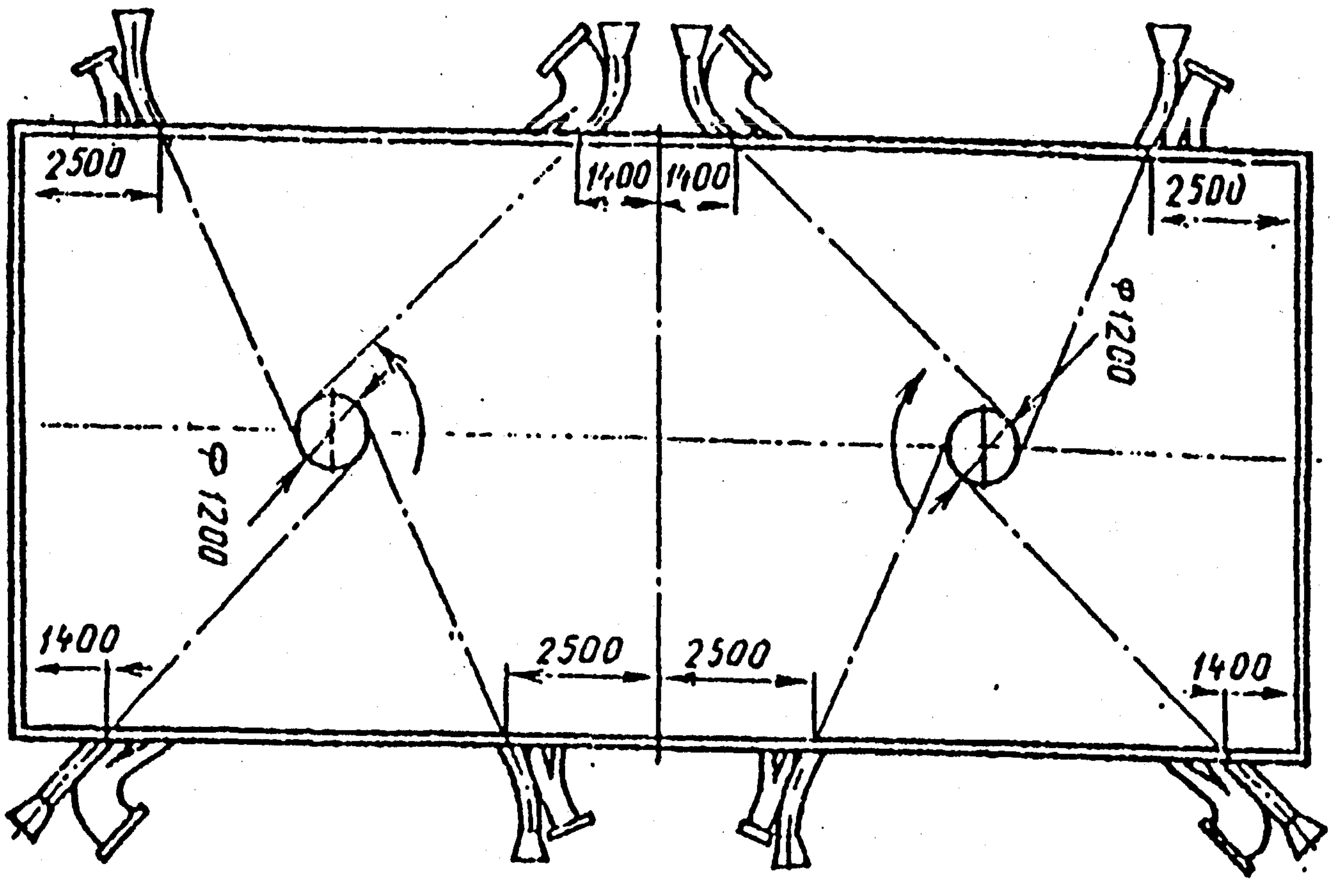



Fig. 22. The furnace with tangential scheme of fuel combustion

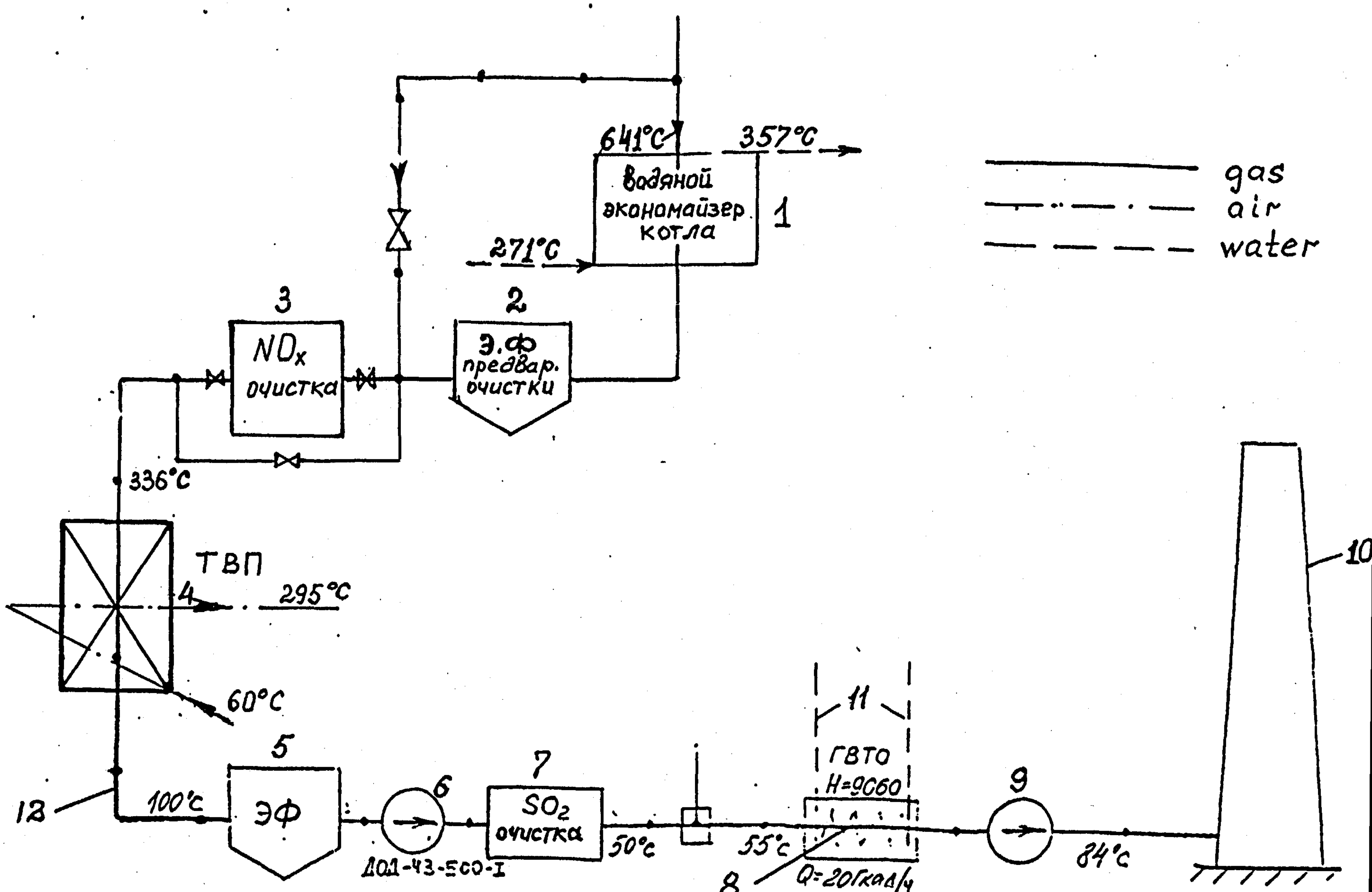



Fig. 23. Low Temperature 500 MW Unit's Boiler Path with High Dust DeNOx

1-economiser; 2-hot ESP; 3-DeNOx; 4-air heater; 5-main ESP; 6-main induced draught fan; 7-DeSOx; 8-gas heater; 9-auxiliary induced draught fan; 10-stack; 11-hot water for gas heating; 12-flue gases

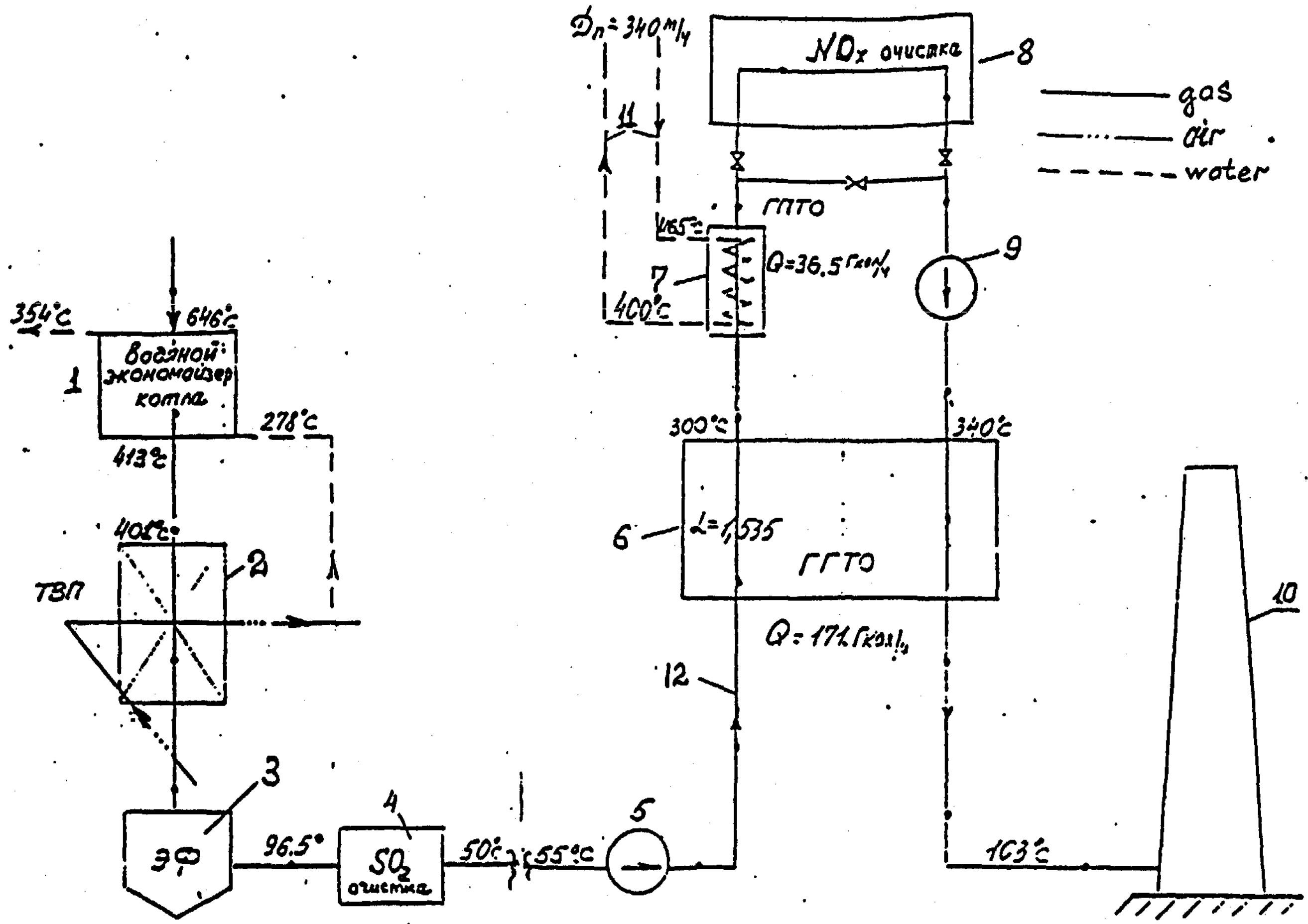



Fig. 24. Low Temperature 500 MW Unit's Boiler Path with Low Dust DeNOx

1-economiser; 2-air heater; 3-main ESP; 4-DeSOx system; 5-main induced draught fan; 6-convective gas heater-cooler; 7-high temperature gas heater; 8-DeNOx; 9-auxiliary induced draught fan; 10-stack; 11-superheated steam for gas heating; 12-flue gases

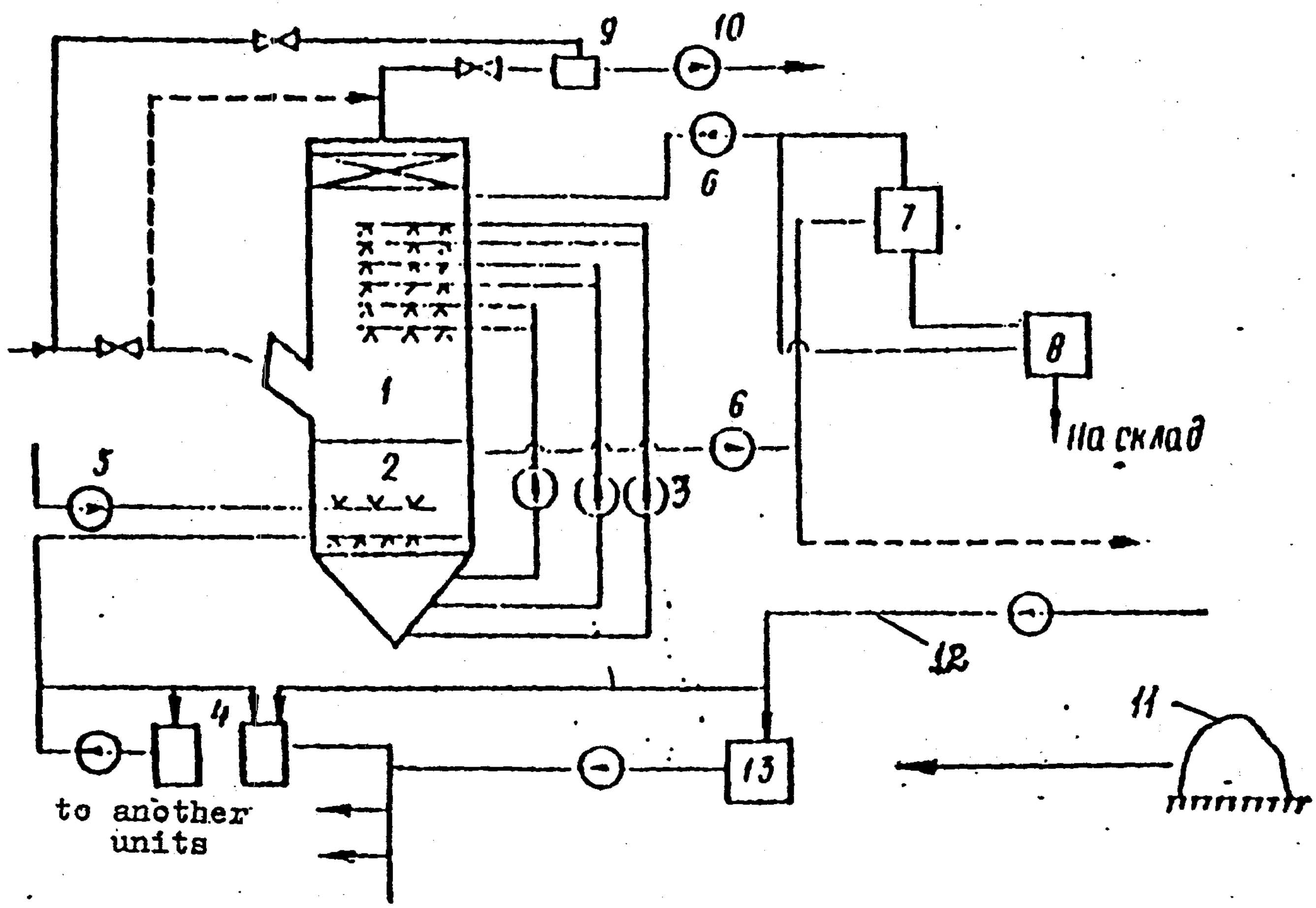



Fig. 25. Wet DeSOx System

1 - scrubber; 2 - water collected part; 3 - slurry recirculating pump; 4 - slurry tanks; 5 - oxydizing air blower; 6 - waste slurry and sludge pump; 7 - hydrocyclone; 8 - centrifuge; 9 - gas heater; 10 - induced-draught fan; 11 - limestone; 12 - water; 13 - slurry preparation

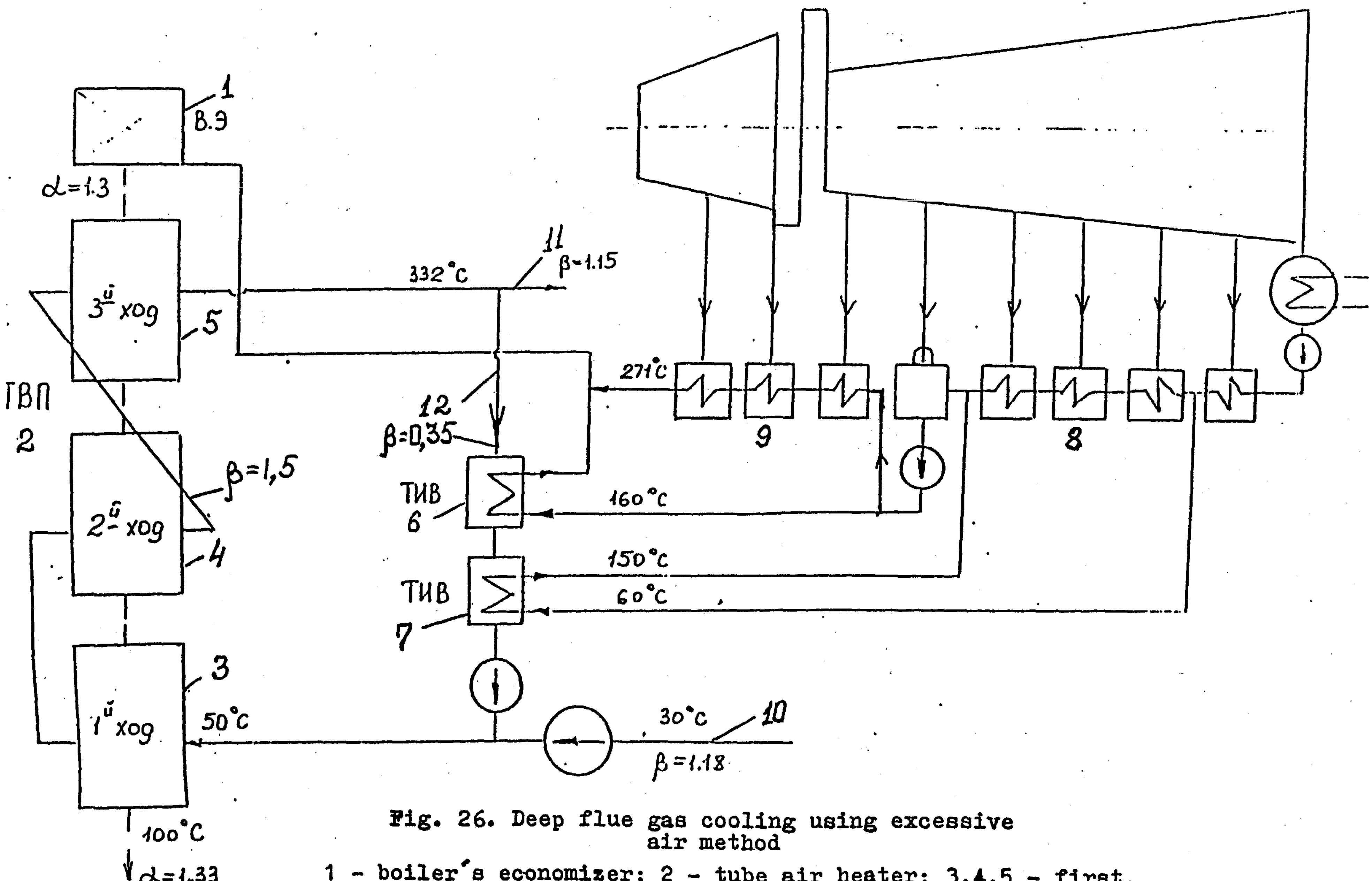



Fig. 26. Deep flue gas cooling using excessive air method

1 - boiler's economizer; 2 - tube air heater; 3,4,5 - first, second and third stage; 6 - feedwater heater; 7 - condencate heater; 8 - LP preheaters; 9 - HP preheaters; 10 - ambient air; 11 - to-furnace air; 12 - recirculated air

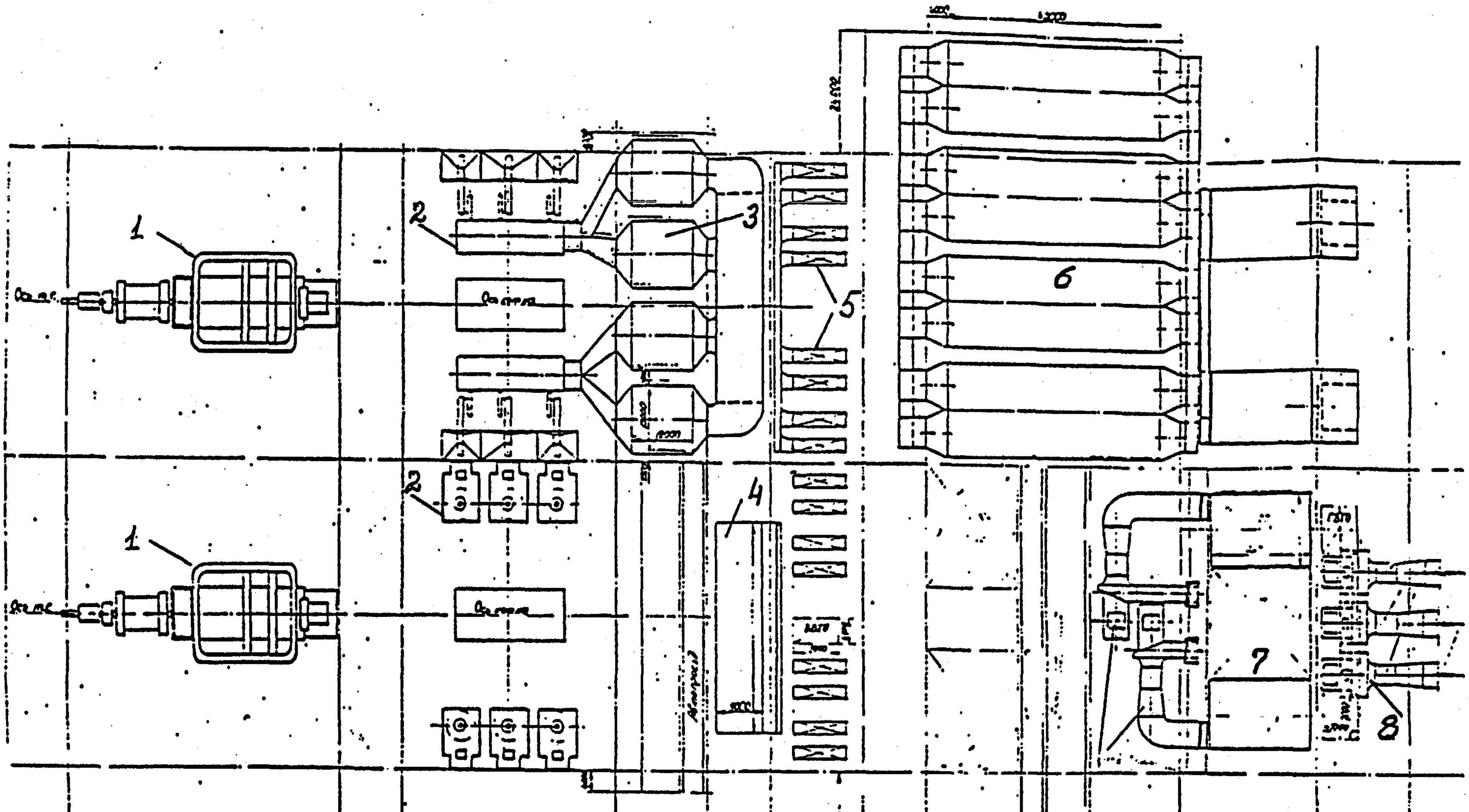



Fig. 27. Layout of p.c.500 MW Unit

1 - ST; 2 - boiler; 3 - hot ESP; 4 - DeNOx system; 5 - air heater;
6 - main ESP; 7 - DeSOx system; 8 - induced draught fan

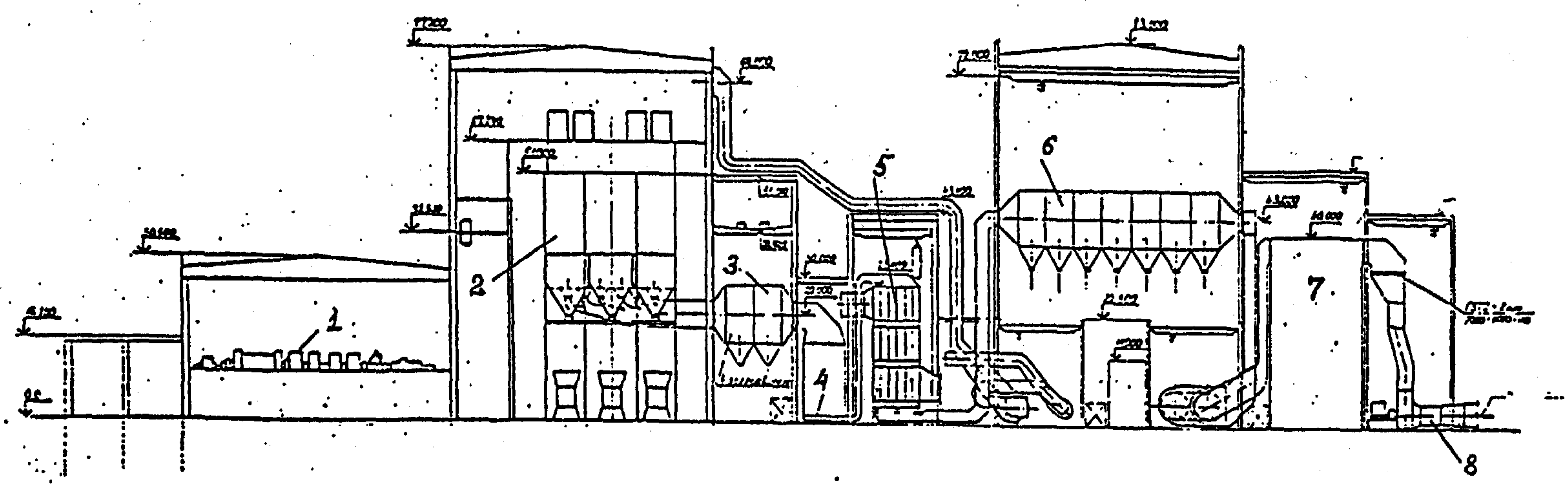
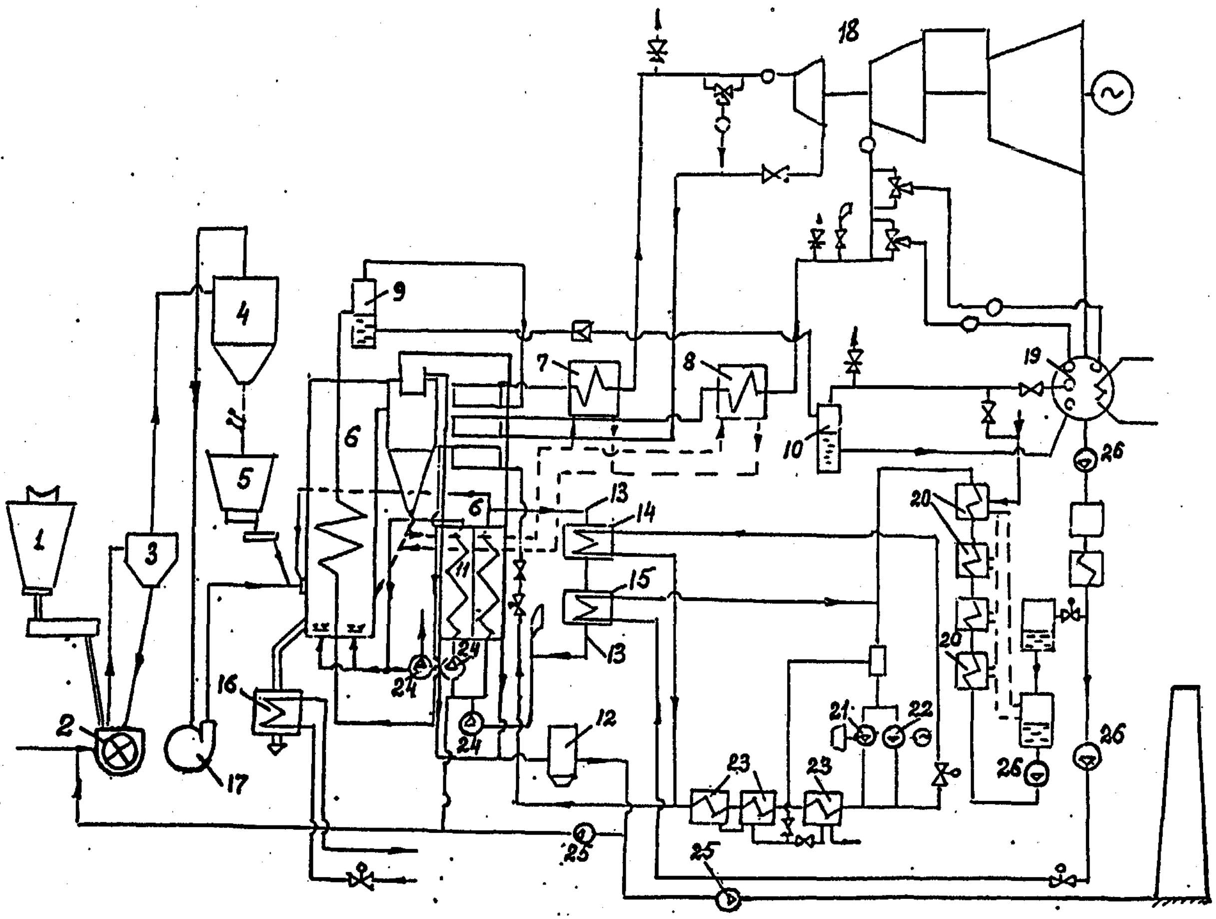



Fig. 28. Cross-section of p.c.500 MW Unit

1 - ST; 2 - boiler; 3 - hot ESP; 4 - DeNOx system; 5 - air heater; 6 - main ESP; 7 - DeSOx system; 8 - induced draught fan




1. raw coal hopper
2. hammer mill
3. separator
4. cyclon
5. day hopper
6. furnace and gas path
7. live steam-ash heat exchanger
8. reheat steam-ash heat exchanger
9. full flow separator
10. starting separator
11. air preheater
12. ESP
13. overflow air
14. HP air-water heater
15. LP air-water heater
16. discharged bed ash cooler
17. for mill air fan
18. steam turbine
19. condenser
20. LP steam-water preheaters
21. feed water turbo pump
22. feed water electrical pump
23. HP steam-water preheaters
24. forced draft fans
25. induced draft fans
26. condensate pumps

Fig. 29. Schematic of a CFB boiler with K-300-240 Turbine

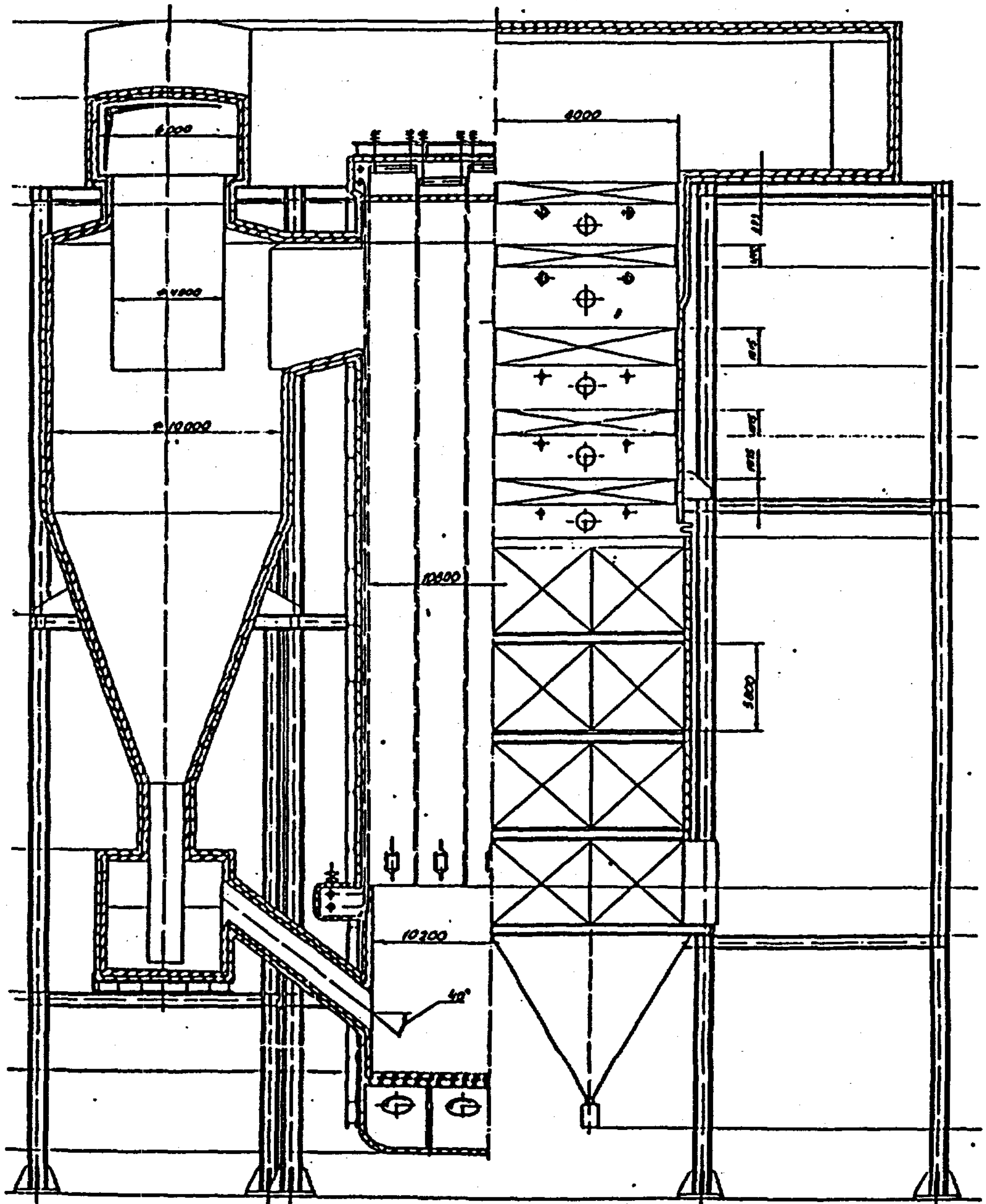



Fig. 30. Cross-section of the 1000 t/h CFB boiler

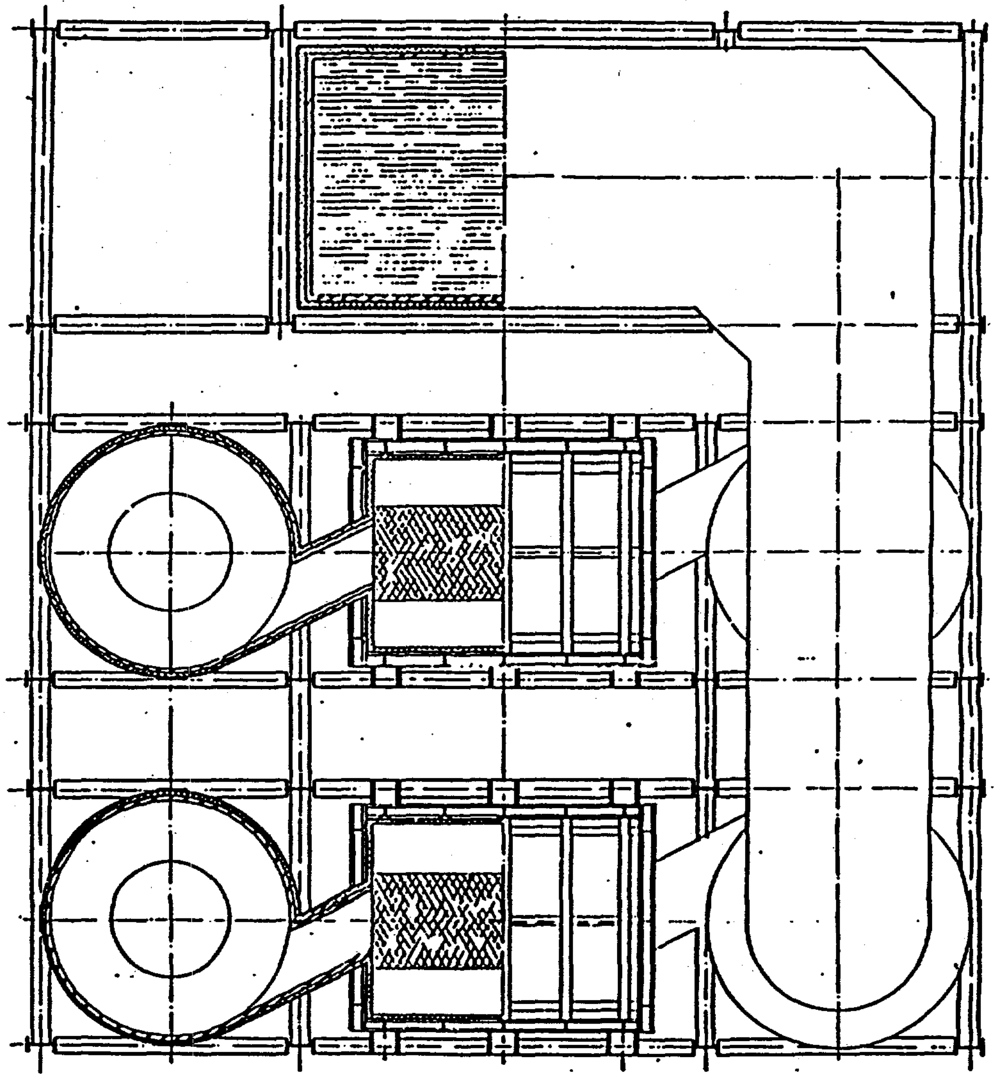


Fig. 31 . The layout of the 1000 t/h CFB boiler

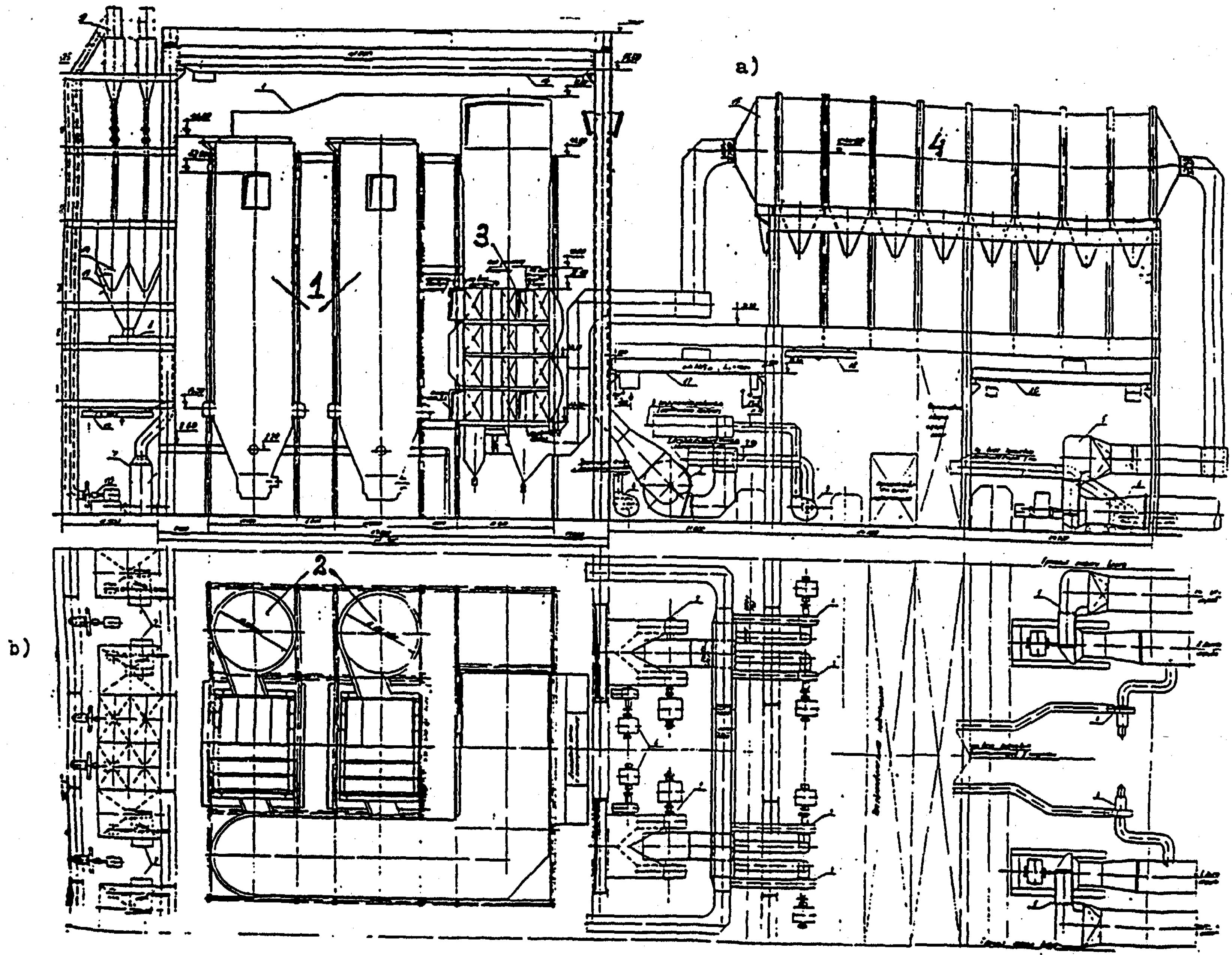



Fig. 32. CFB boiler installation: a) cross-section, b) layout
1 - furnace; 2 - hot cyclones; 3 - air heater; 4 - ESP

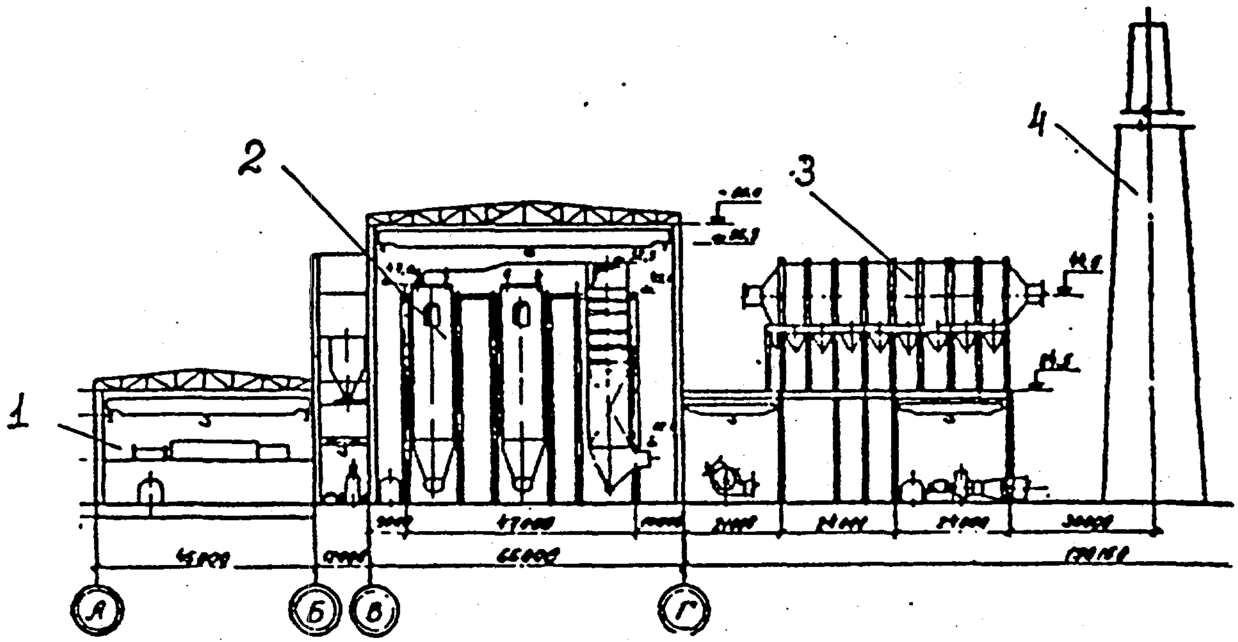



Fig. 33. Cross-section of 300 MW CFB unit
1 - ST; 2 - CFB boiler; 3 - ESP;
4 - stack

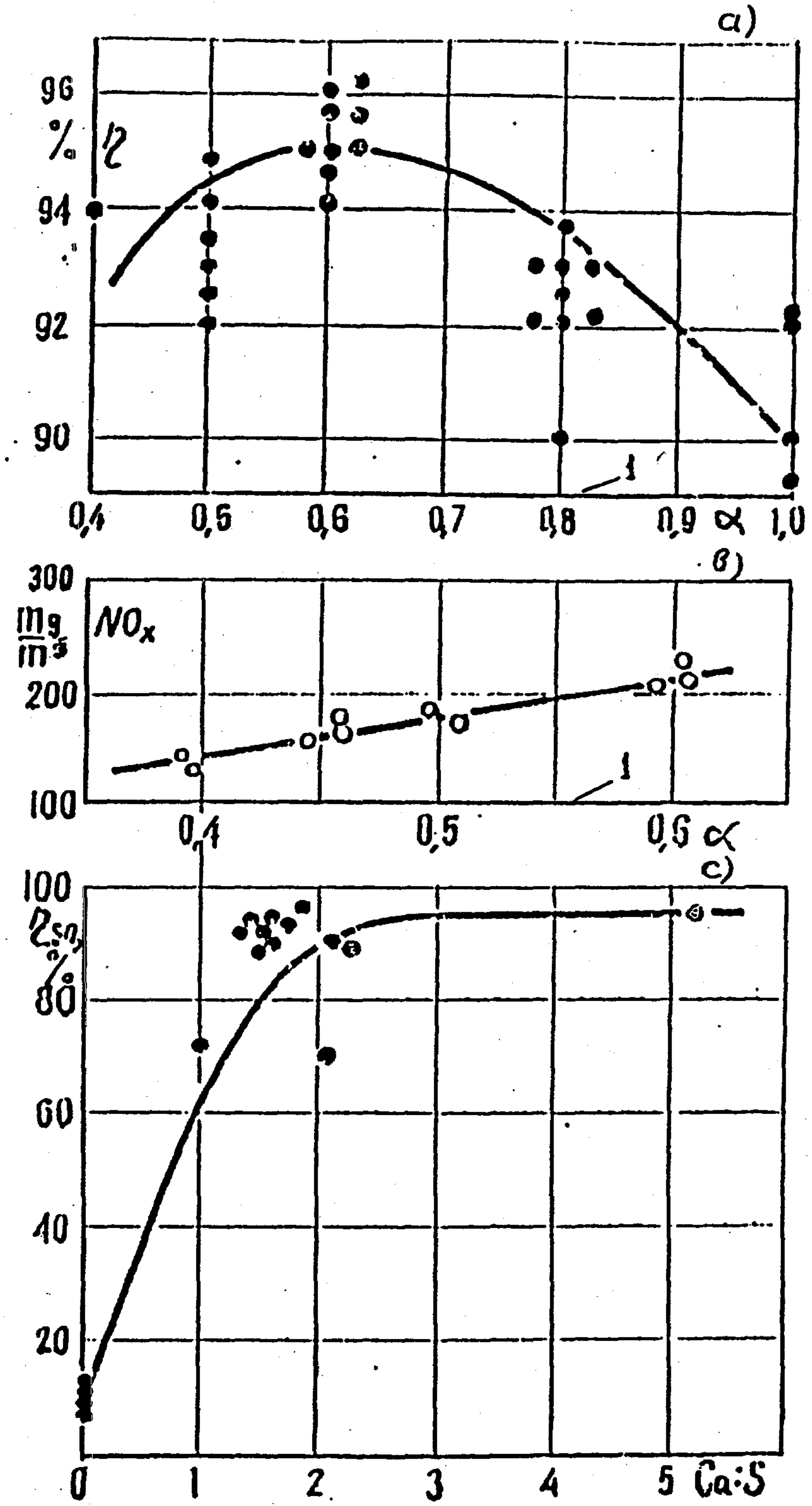



Fig. 34. Anthracite culm firing efficiency with CFB

(a) anthracite culm conversion; (b) NOx formation (Ca/S=2.5 - 4.0, t = 860-900°C, α = 1.15-1.25); (c) $SO_2$ fixation. 1- primary air to fuel stoichiometry

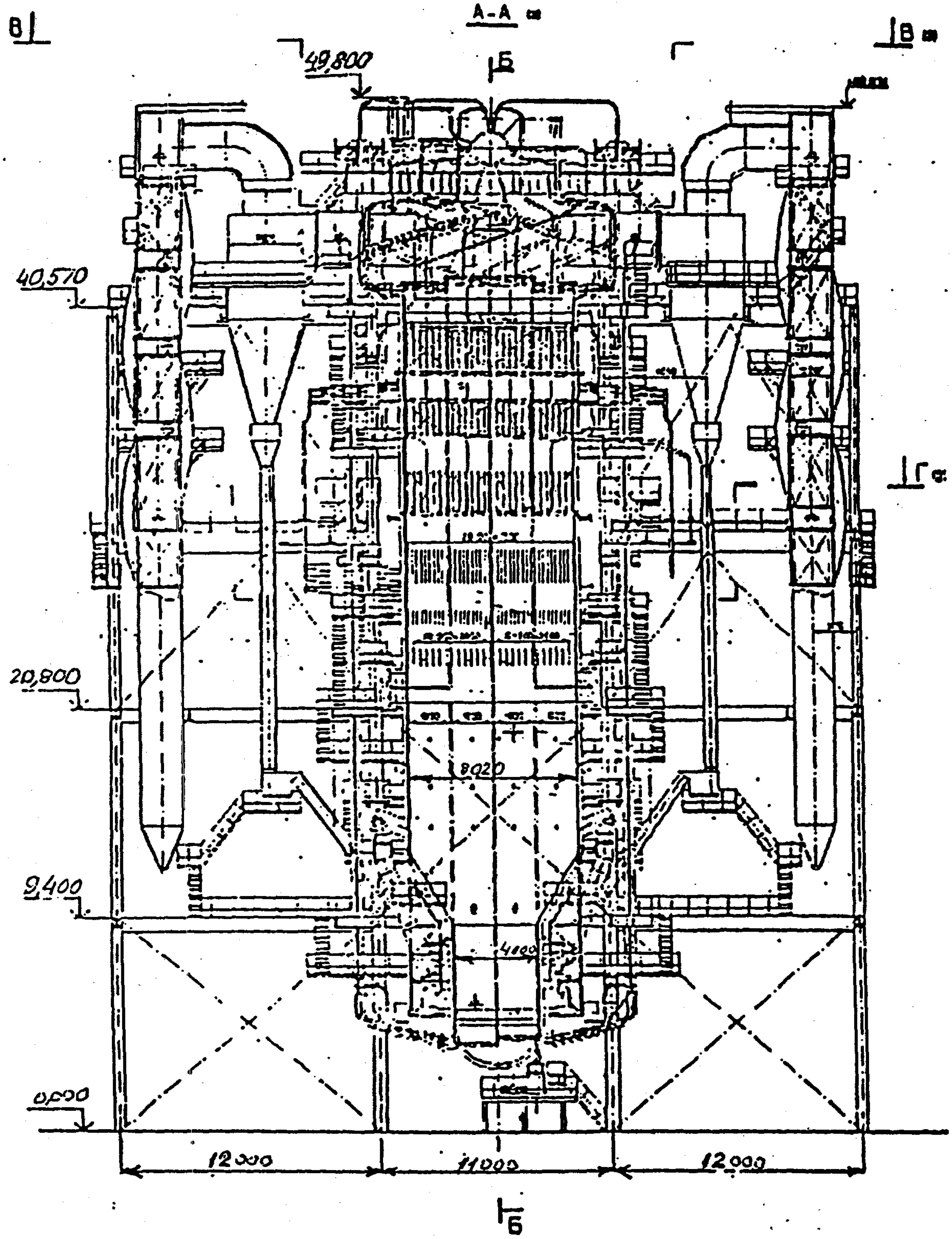
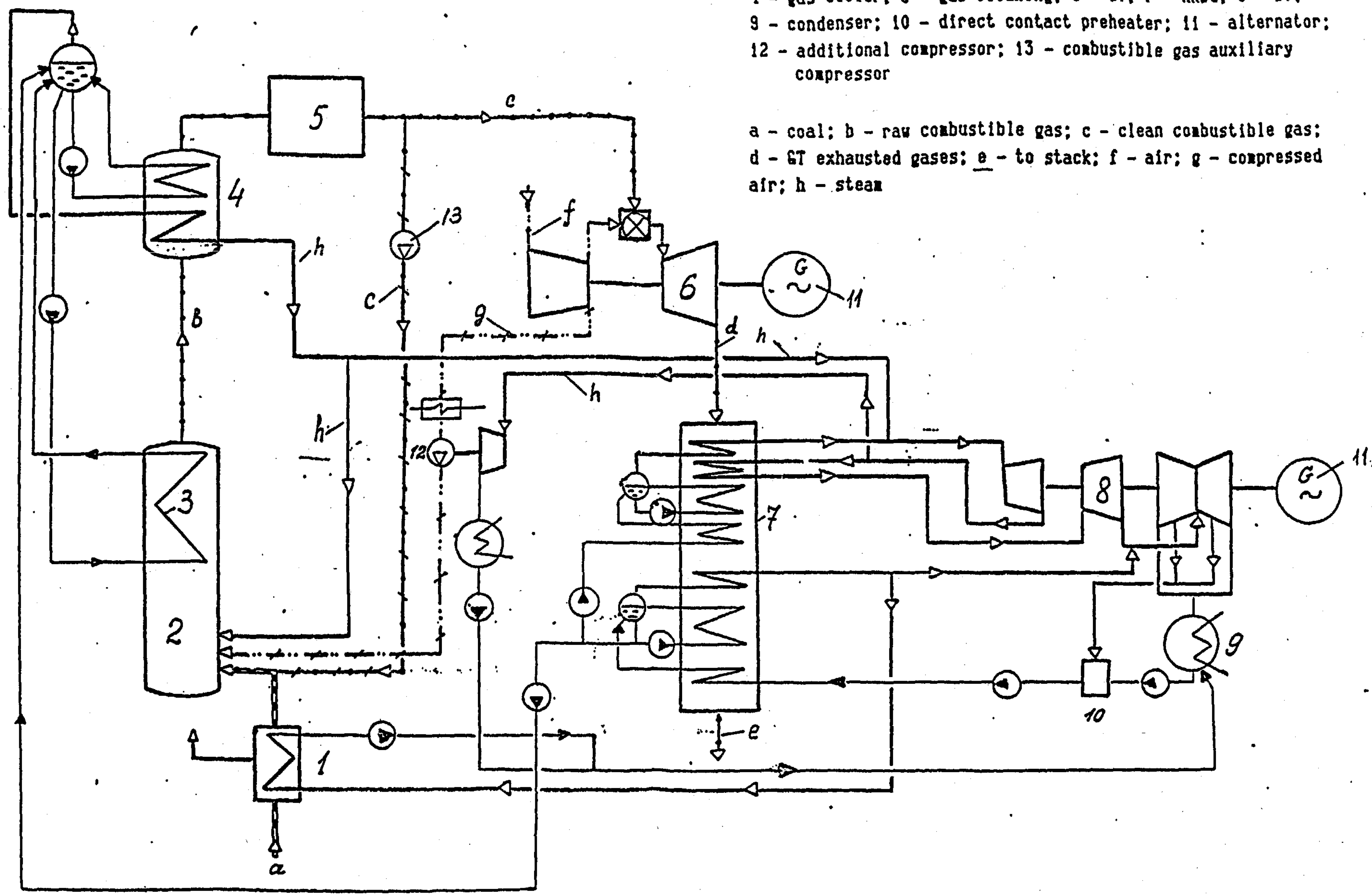



Fig.35.Demo 500t/h CFB boiler with "cold" cyclones.



1 - coal treatment; 2 - gasifier; 3 - waterwall cooling system;
4 - gas cooler; 5 - gas cleaning; 6 - GT; 7 - HRSG; 8 - ST;
9 - condenser; 10 - direct contact preheater; 11 - alternator;
12 - additional compressor; 13 - combustible gas auxiliary compressor

a - coal; b - raw combustible gas; c - clean combustible gas;
d - GT exhausted gases; e - to stack; f - air; g - compressed air; h - steam

Fig. 36. Flow Sheet of Air Blown IGCC-600

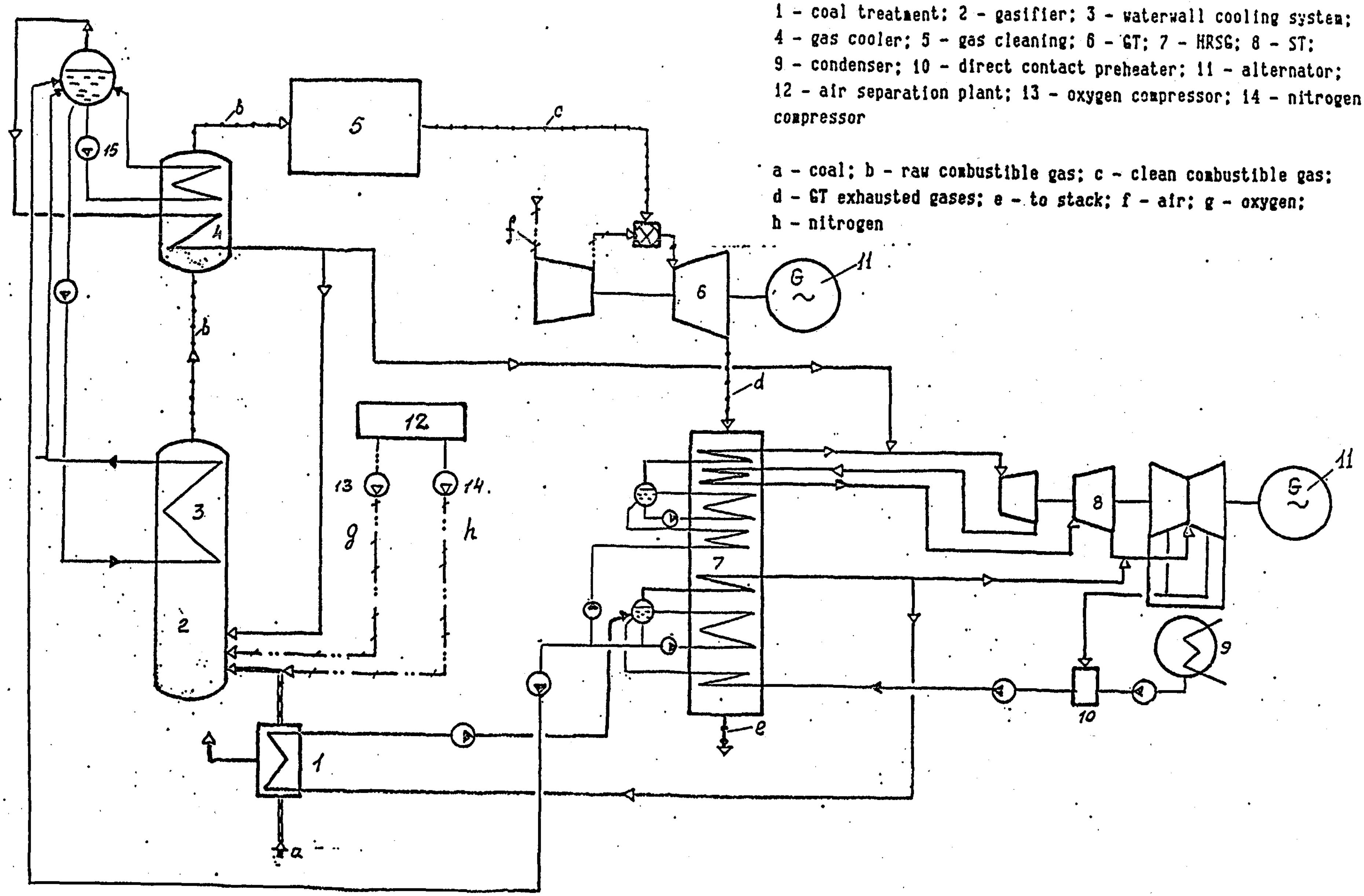



Fig. 37. Flow Sheet of Oxygen Blown IGCC-600

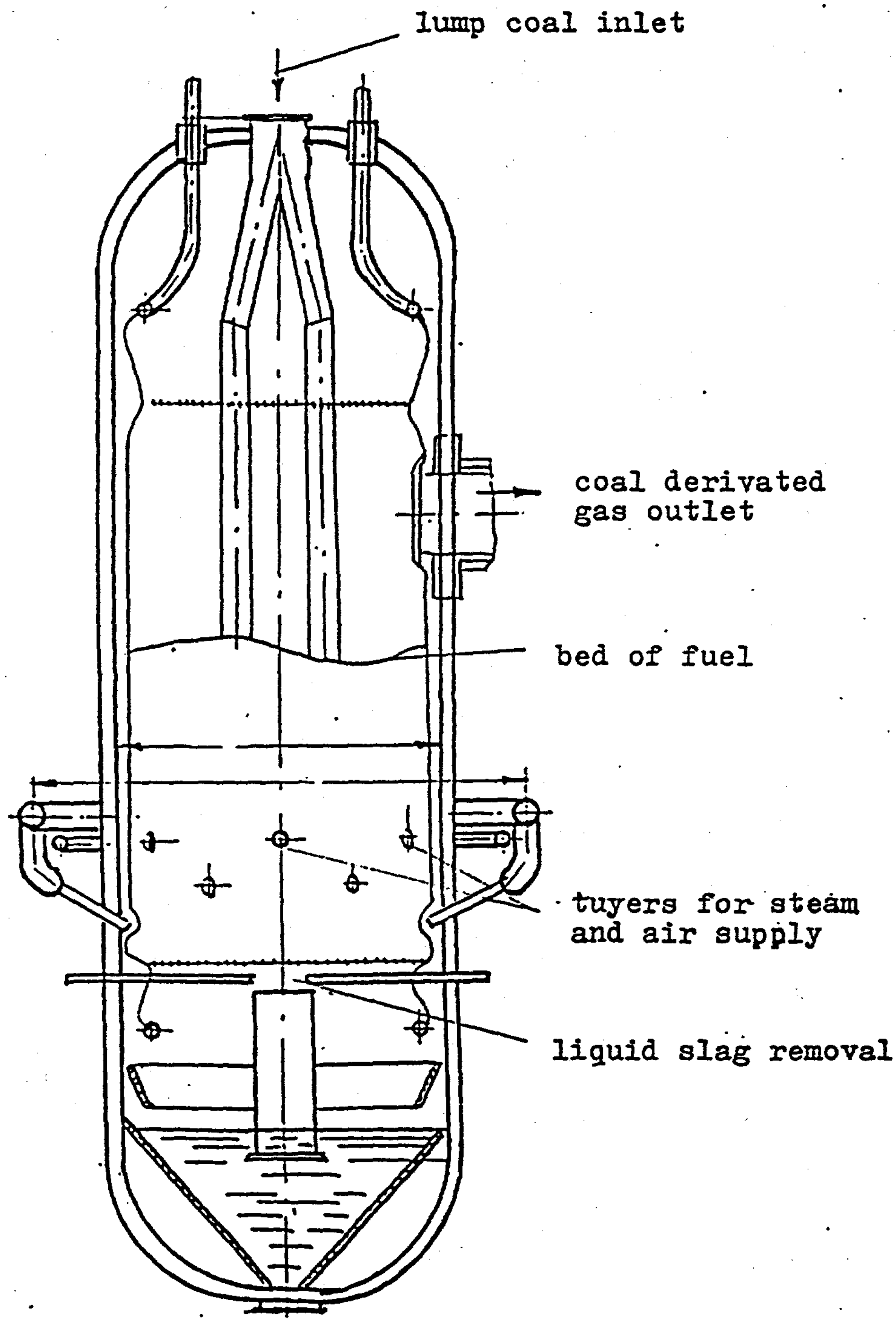



Fig. 38. Moving-bed gasifier

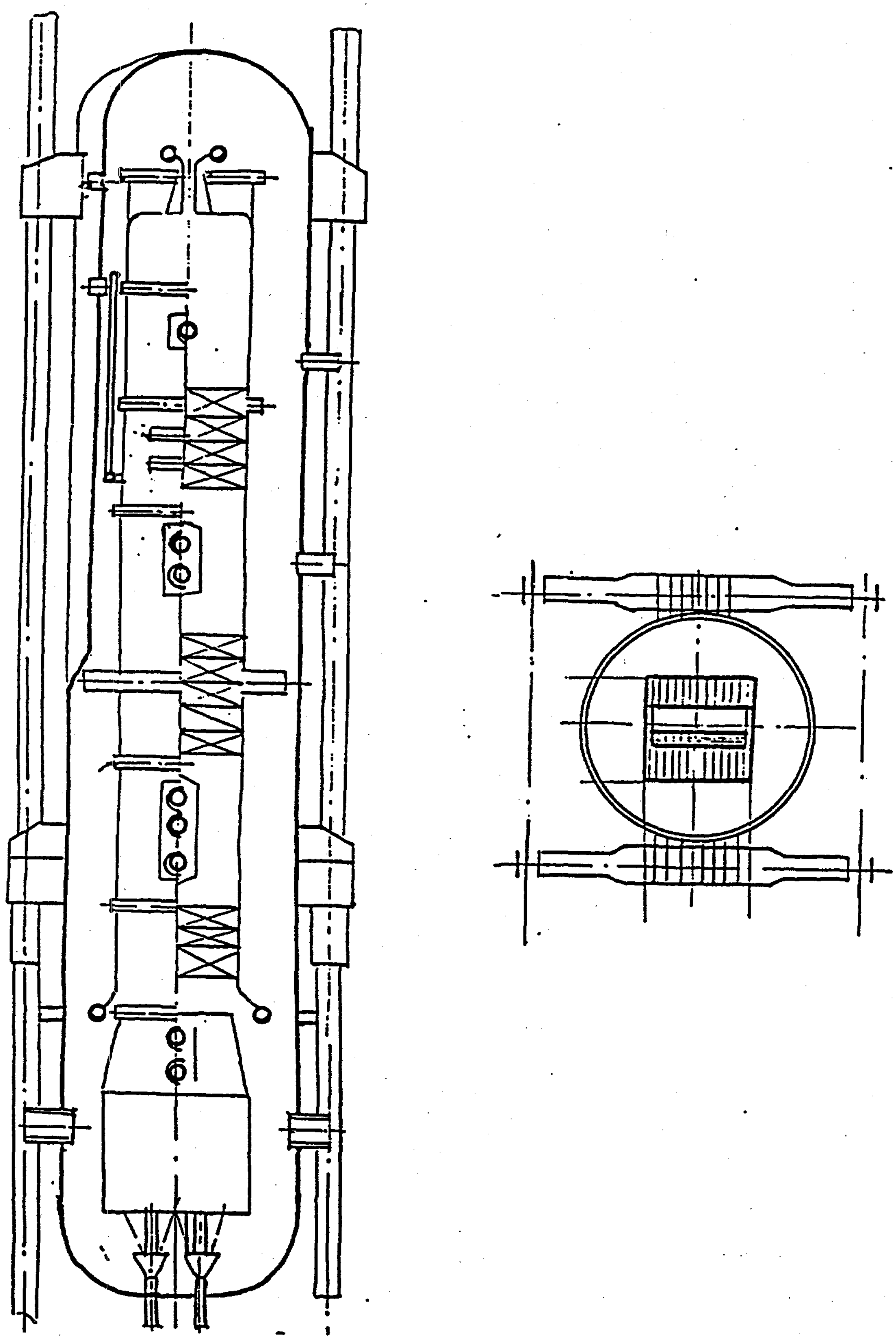


Fig. 39. Convective gas cooler for moving-bed gasifier

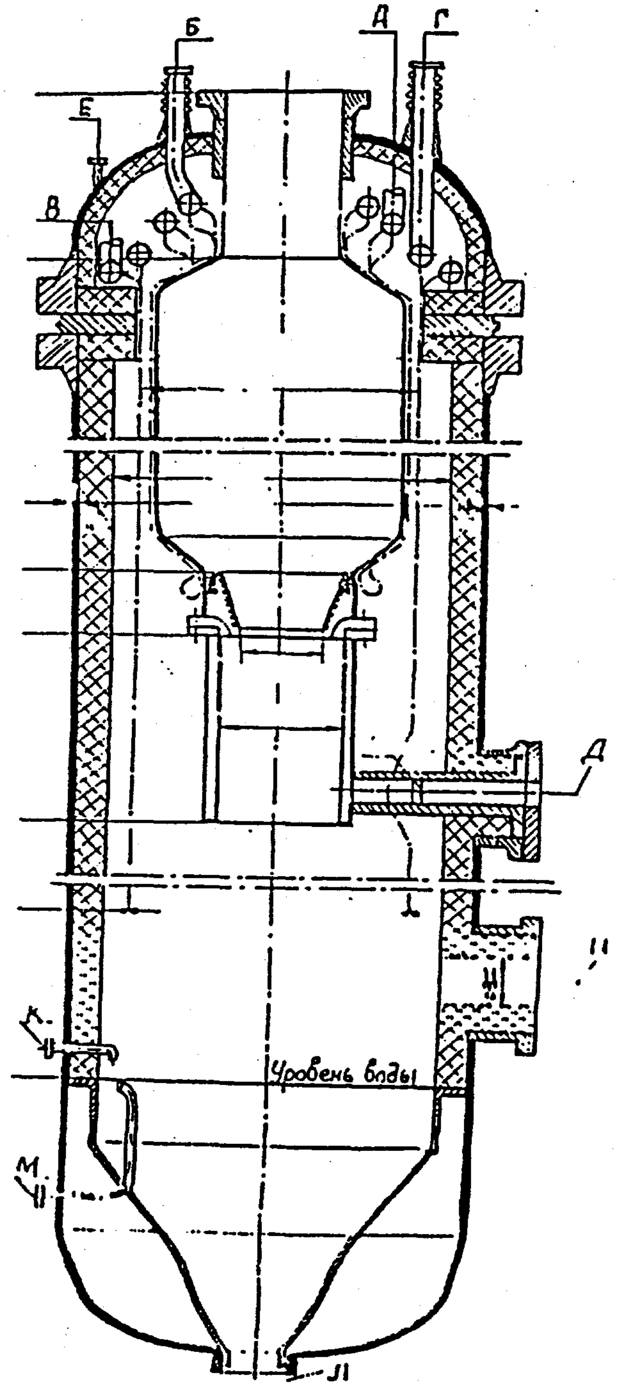



Fig. 40. Entrained-flow oxygen blown gasifier

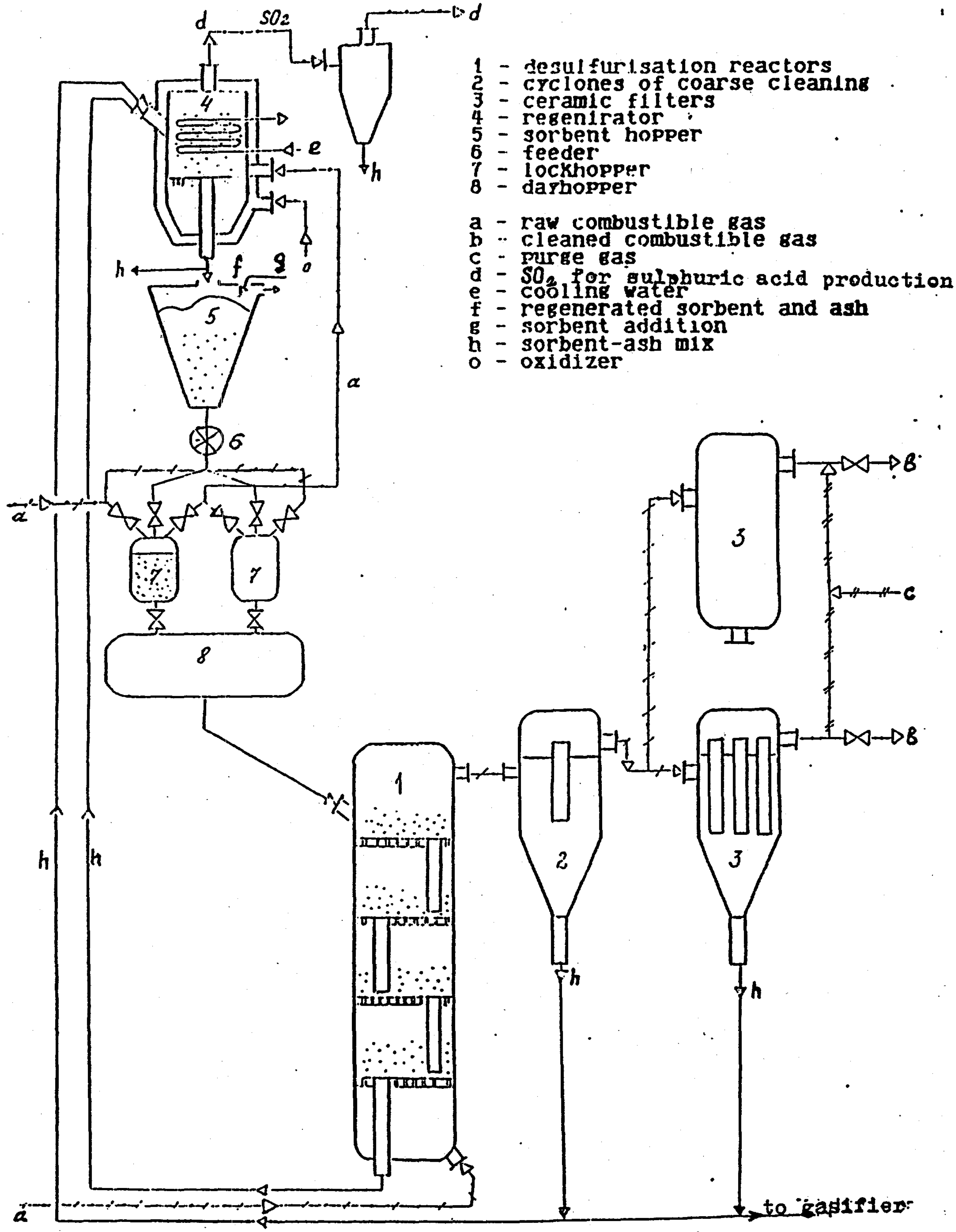
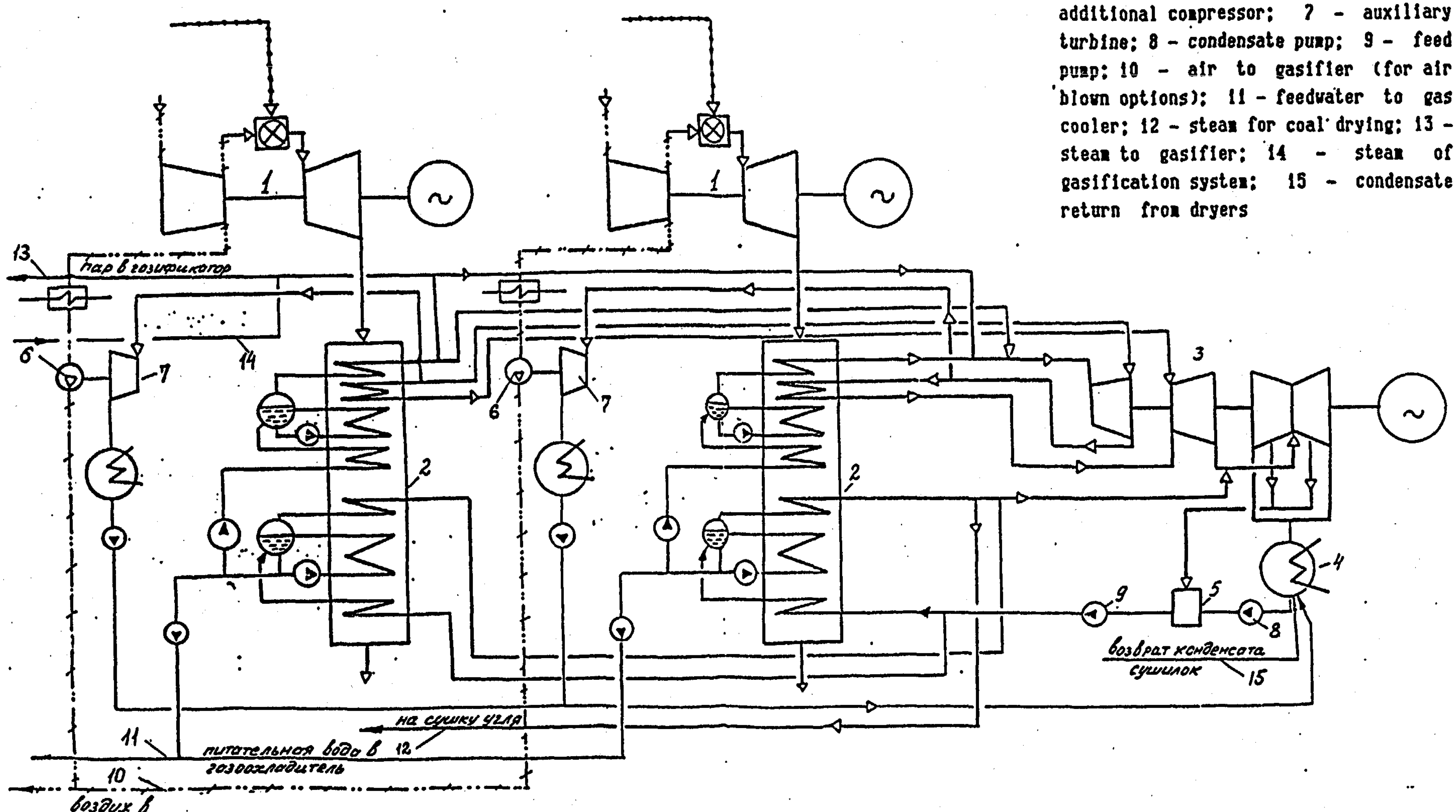



Fig.41. The cleaning system of raw coal derivative gases




1 - GT; 2 - HRSG; 3 - ST; 4 - condenser; 5 - direct contact preheater; 6 - additional compressor; 7 - auxiliary turbine; 8 - condensate pump; 9 - feed pump; 10 - air to gasifier (for air blown options); 11 - feedwater to gas cooler; 12 - steam for coal drying; 13 - steam to gasifier; 14 - steam of gasification system; 15 - condensate return from dryers

Fig. 42. Flow Sheet of Power Part IGCC-600

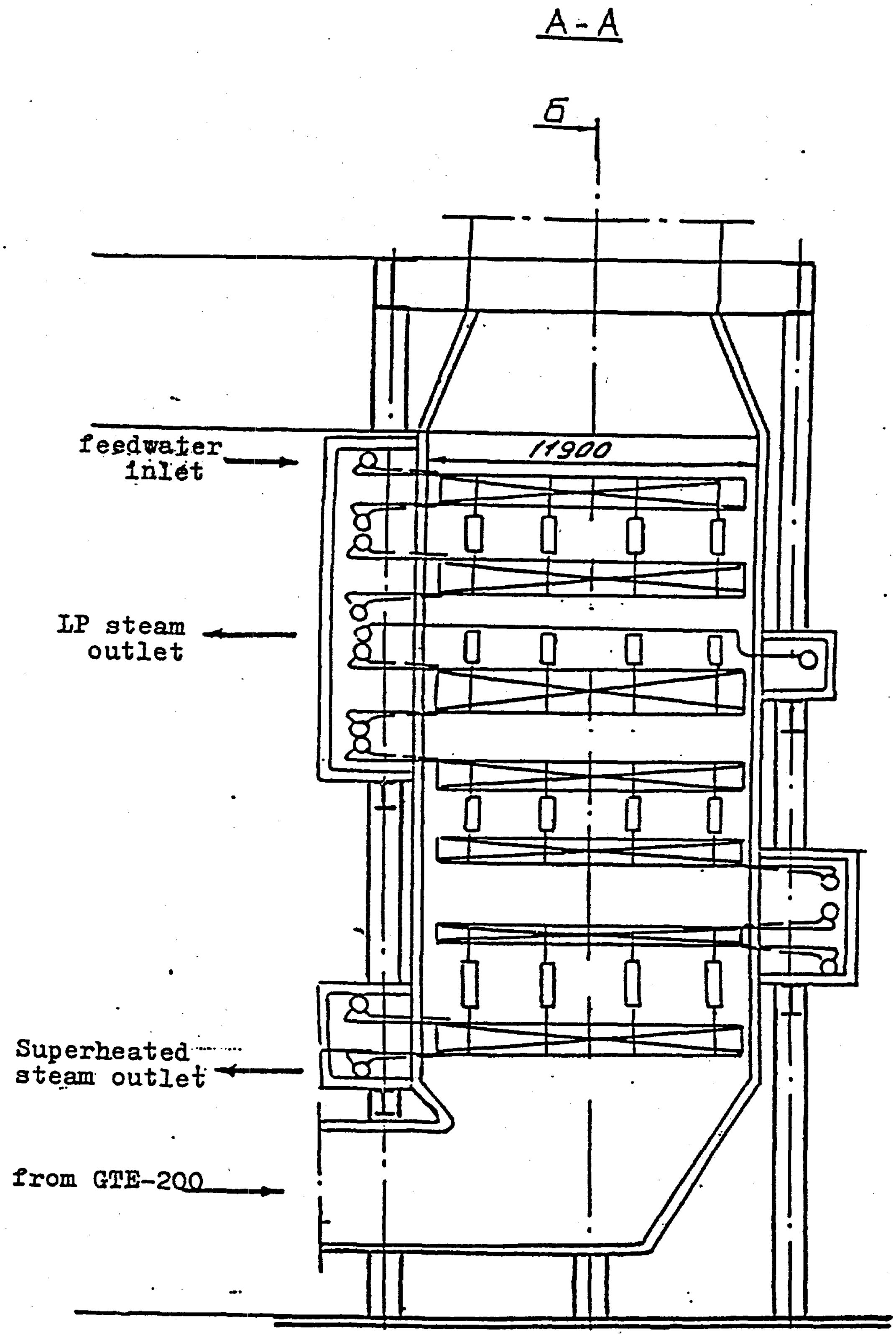



Fig. 43. Heat-Recovery Boiler

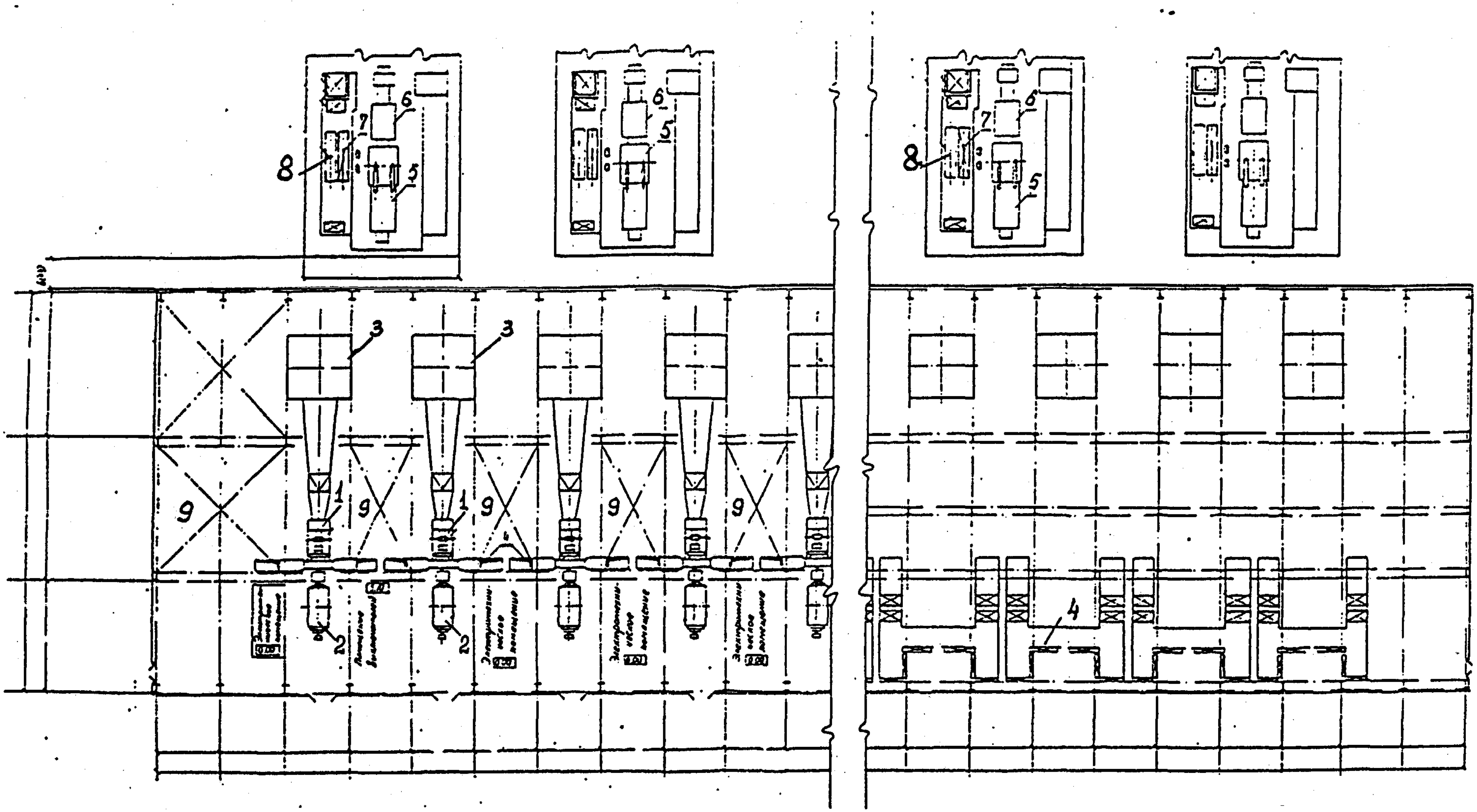


Fig. 44. Layout of the Main Building for Power Part of IGCC Plant

1 - GT; 2 - alternator; 3 - HRSG; 4 - air suction; 5 - ST;
6 - ST alternator; 7 - electrical *drived* feed pump; 8 - stand
by feed pump; 9 - place for maintenance

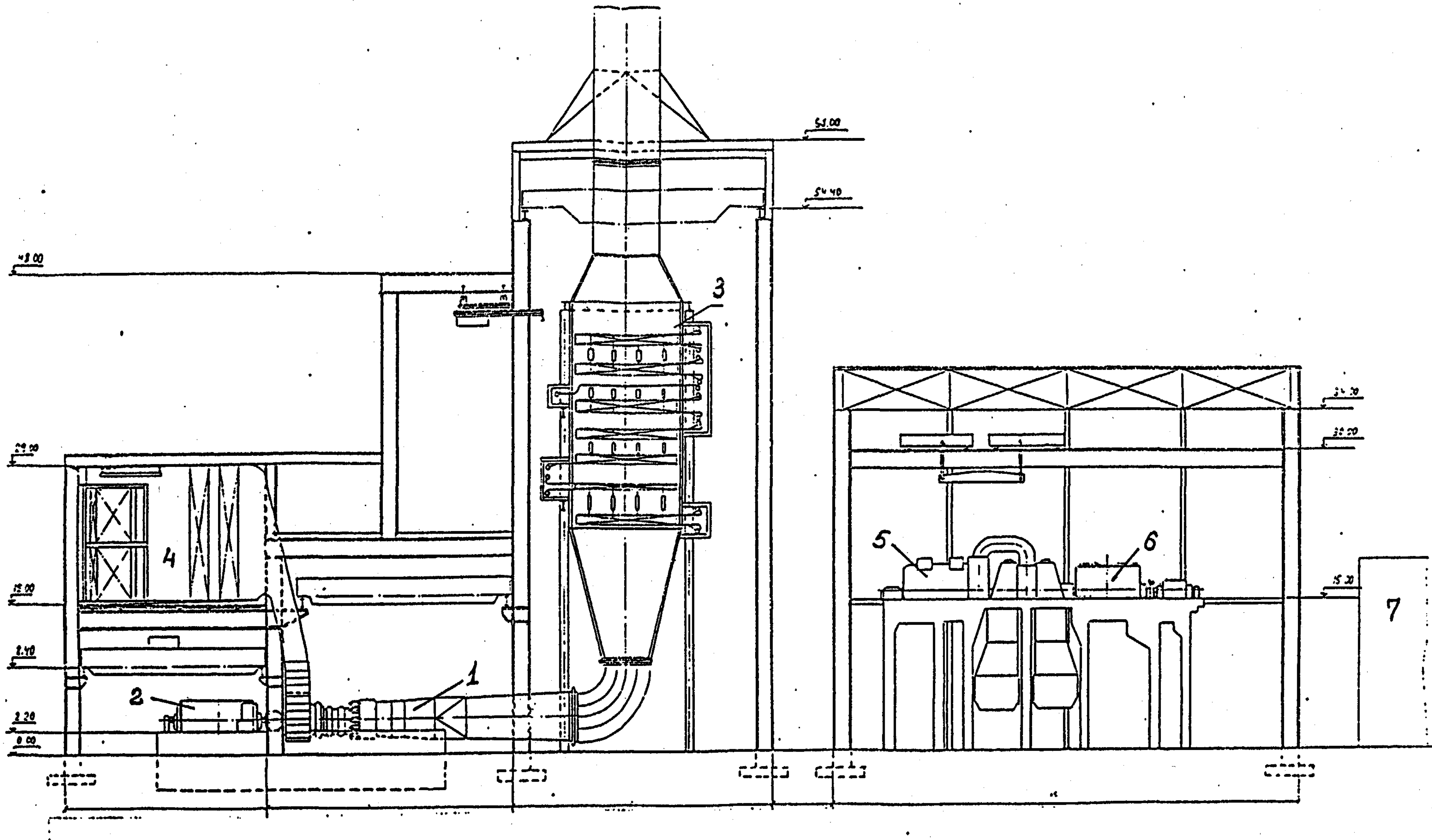



Fig. 45. Cross-section of the Main Building for Power Part of IGCC Plant

1 - GT; 2 - alternator; 3 - HRSG; 4 - air suction;5 - ST; 6 - ST alternator; 7 - main control room

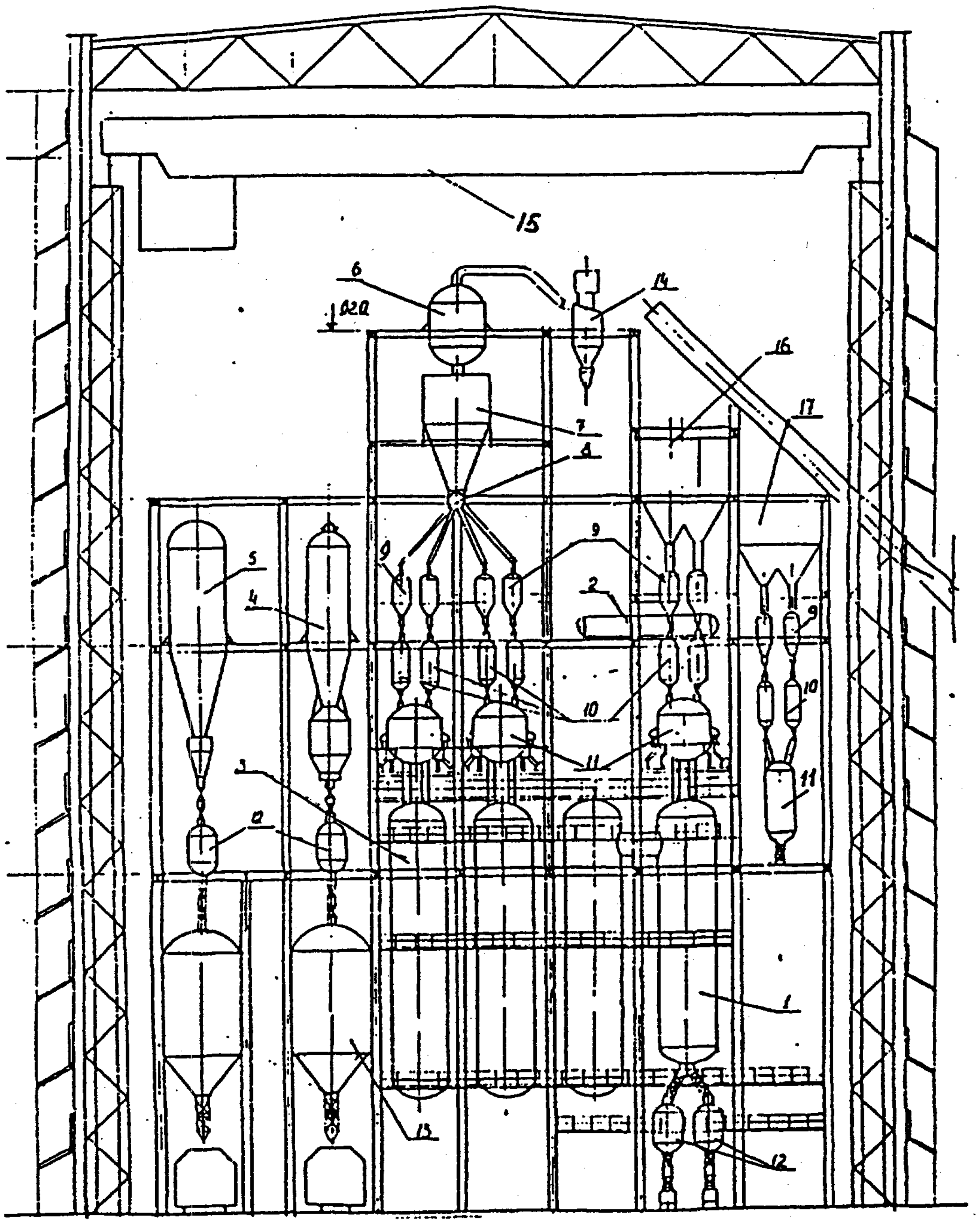



Fig. 46. Cross-section of gasification system using air blown moving-bed gasifier

1 - gasifier; 2 - steam drum of gasifier cooling; 3 - reactor of desulfurisation system; 4 - cyclone of coarse cleaning; 5 - ceramic filters; 6 - regenerator; 7 - sorbent hopper; 8 - feeder; 9-10 - lockhopper system; 11 - day hopper; 12 - slag removing lockhopper; 13 - hopper; 14 - cyclone; 15 - bridge crane; 16 - lump coal hopper; 17 - fines hopper; 18 - convective gas cooler

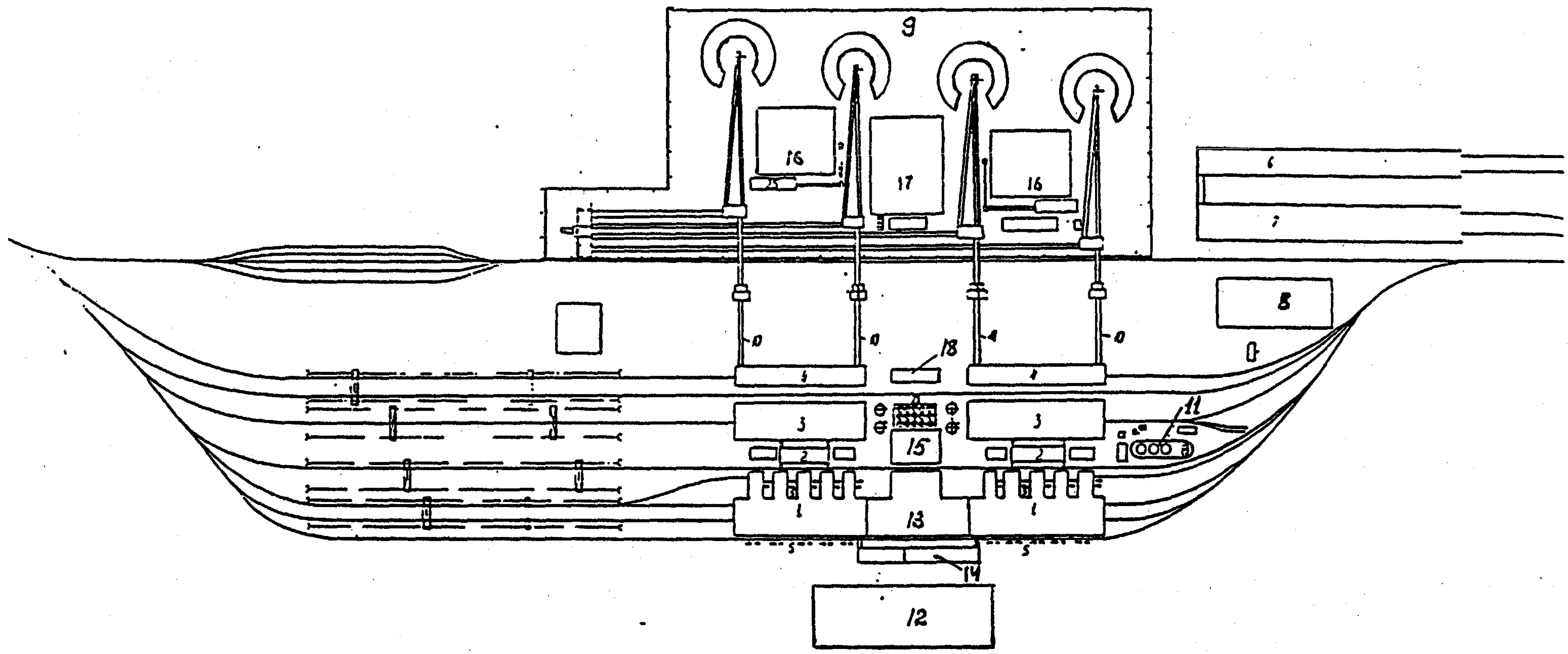



Fig. 47. The Layout of TPS with 10|IGCC 600 MW Units

1 - main building; 2 - main control room; 3 - gasification systems; 4 - fuel treatment; 5 - transformers; 6 - air separation plant (ASP); 7 - ASP compressor's building; 8 - sulphuric acid plant; 9 - coal yard; 10 - conveyors galeries; 11 - fuel oil tank; 12 - open switchgear; 13 - auxiliary building; 14 - officies; 15 - water treatment; 16 - ash disposal place; 17 - sladge pond; 18 - auxiliary boilerhouse

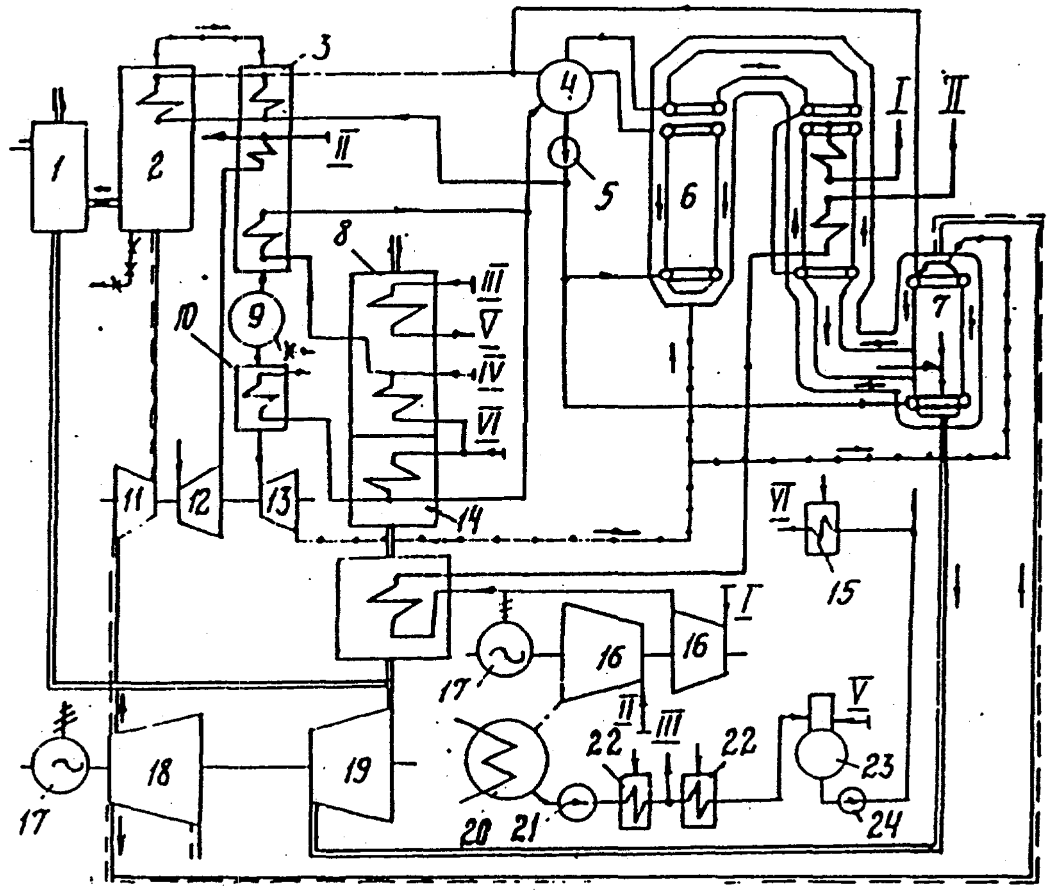


Fig. 48. Flow Sheet of IGCC Unit rated 250 MW

1 - coal drying; 2 - fluidized-bed gasifier; 3 - gas cooler; 4 - drum of SSG; 5 - internal circulating pump SSG; 6 - furnace of SSG; 7 - top combuster; 8 - gas-water heater (GWH); 9 - scrubber; 10 - gas heater; 11 - additional compressor; 12 - auxiliary steam turbine; 13 - turboexpander; 14 - economizer; 15 - HP preheaters; 16 - main steam turbine; 17 - alternators; 18 - GT compressor; 19 - GT turbine; 20 - steam condenser; 21 -condencate pump; 22 - LP preheaters; 23 - deaerator; 24 - feed pump; I,II - steam to HP and LP sections of ST; III - condencate to GWH; IV - feedwater to GWH; V - condencate to deaerator; VI - feedwater to economizer

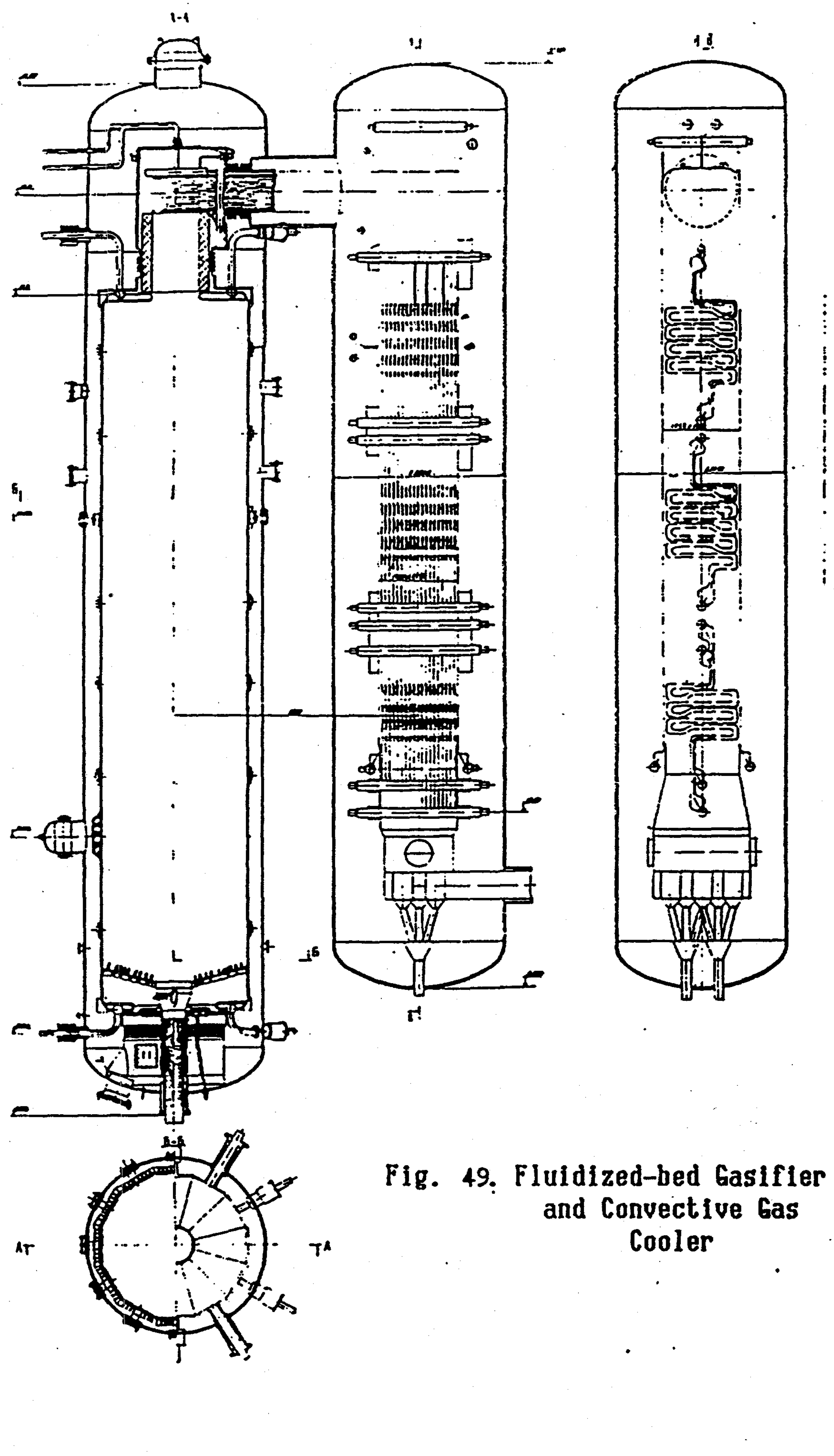


Fig. 49. Fluidized-bed Gasifier and Convective Gas Cooler

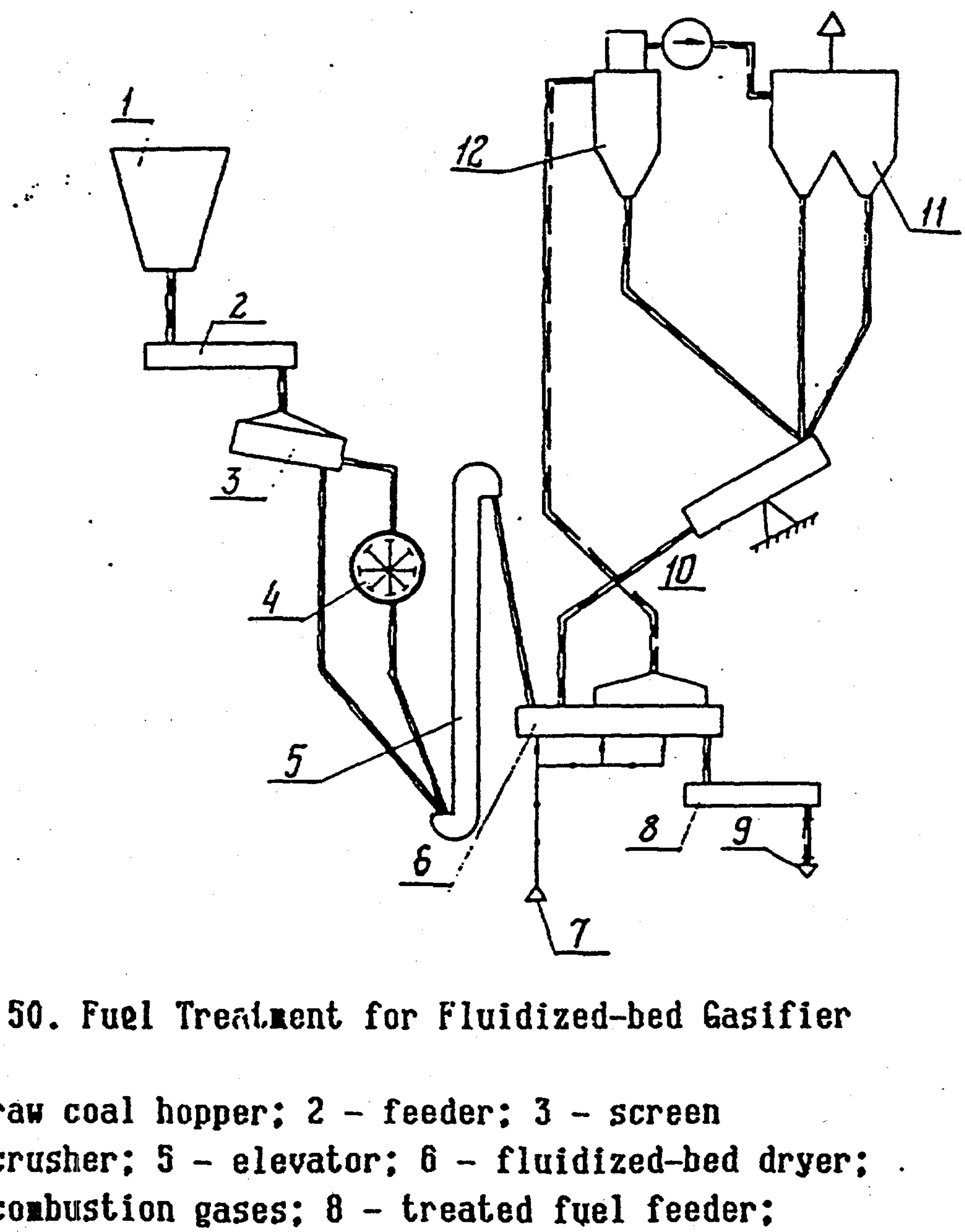



Fig. 50. Fuel Treatment for Fluidized-bed Gasifier

1 - raw coal hopper; 2 - feeder; 3 - screen
4 - crusher; 5 - elevator; 6 - fluidized-bed dryer;
7 - combustion gases; 8 - treated fuel feeder;
9 - to lockhopper; 10 - dust granulator; 11 - ESP;
12 - cyclone

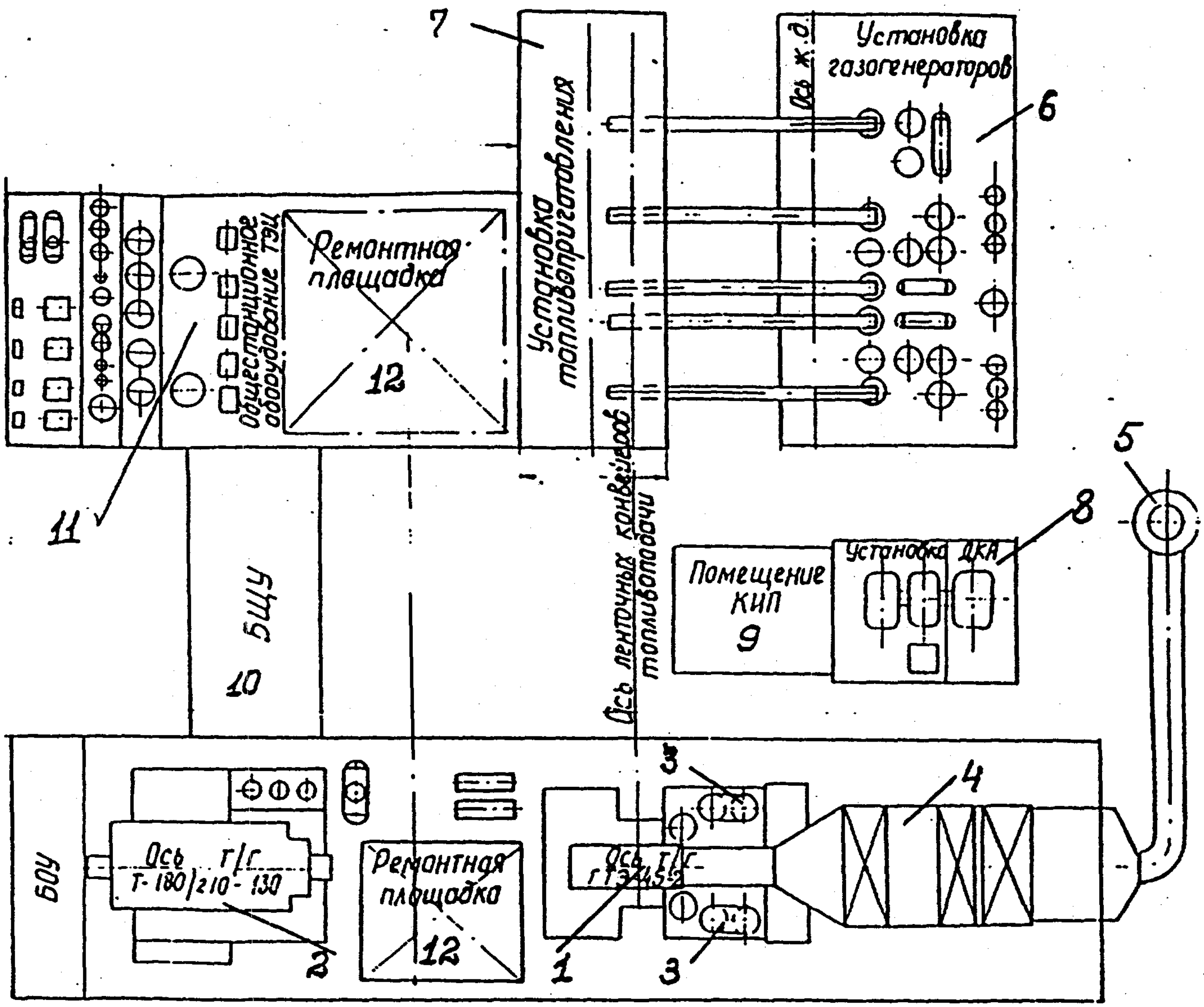



Fig. 51. The Layout of IGCC Plant rated 250 MW

1 - GT; 2 - ST; 3 - supercharged boiler; 4 - gas- water heat exchanger; 5 - stack; 6 - gasifier's building; 7 - fuel treatment; 8 - auxiliary compressor-turbo-detander; 9 - I&C room; 10 - main control room; 11 - balance of plant equipment; 12 - place for maintenance